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Dynamic Simulation of Shipboard Electric Power Systems

by
Timothy J. McCoy

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Timothy J. McCoy

Submitted to the Department of Ocean Engineering and the Department of Electrical Engineering and Computer Science on May 7, 1993 in partial fulfillment of the requirements for the Degrees of Naval Engineer and Master of Science in Electrical Engineering and Computer Science

Abstract

It is the aim of the proposed research to develop digital computer simulation models for a typical shipboard electric propulsion system, conduct dynamic analyses and determine viable control schemes for such a system. Electric propulsion for shipboard use is being considered as an attractive alternative to the geared diesel and gas turbine mechanical drives currently being used in most naval ships. Prior to building an electric propulsion drive system, the dynamic behavior must be understood and methods for controlling the system have to be determined.

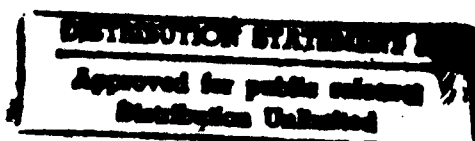
A shipboard electrical system is small in size and has fewer components than a typical commercial power distribution system. A typical combatant ship may have three or four generators with a combined capacity of 80-100 megawatts. Most of this capacity is used by the propulsion motors, which for a two shaft ship will be rated in the range of 35-40 megawatts each. These loads, which are large with respect to the generating capacity, make the analysis of shipboard electrical systems more difficult than typical commercial power systems. Many of the simplifying assumptions used in the analysis of commercial power systems are not valid with shipboard systems. This complication requires a detailed model of the entire system including the relevant dynamics of each component.

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Chapter 1: Introduction

Electric drive systems have been used in naval ships for over 80 years. In the past, they have been characterized by higher initial cost, lower efficiency and greater space and weight requirements than mechanical drive systems. Their primary advantage over mechanical systems has been the high degree of control over the propeller and the degree of flexibility afforded to the naval architect in locating the propulsion equipment within the ship [1].

The advent of modern power electronics for implementing variable speed motor drives using synchronous or induction motors has made electric propulsion much more attractive. In recent years various types of electric drive propulsion systems have been proposed to reduce or alleviate some of the historical drawbacks of the electrical propulsion system, especially in the area of system efficiency.

The U.S. Navy has indicated its desire to develop and produce a modern electric propulsion system for its ships. However, the dynamic behavior of electrical networks required for such propulsion systems is not well understood. This research develops tools which can be used to investigate the dynamic behavior of typical electric drive systems under various operating conditions. It also attempts to determine a viable means for controlling such an electric drive system.

1.1 Shipboard Propulsion Systems

The current state of the art for naval surface ship propulsion systems consists of two diesel or gas turbine engines coupled to the propeller shaft through clutches and a mechanical transmission. This type of propulsion system allows the use of either one or both engines to drive the propeller. Above a certain ship speed, the ship's speed is controlled by varying the engine speed. When it is desired to move slower than the idle speed of the engine or to apply reverse power, the mechanical means provided to accomplish this comes in the form of a variable geometry propeller or a fluid coupling with reversing capability.

This configuration provides redundancy of main engines in case of battle damage and for conducting underway maintenance. It also allows for disconnecting both engines from one shaft, letting the shaft "trail," and driving the ship with its other shaft to improve fuel economy for certain ship speeds.

In mechanical systems of this type it is difficult to combine engines of different types on the same propeller shaft. They also do not allow for cross-connecting both propellers to one engine as is possible with older steam powered ships. Mechanical drives also require separate prime movers to generate electricity for ship's service loads. Another major disadvantage of mechanical propulsion systems is the necessity of providing mechanical alignment between the main engines and the propeller. This requires the engines to be located low in the ship. However, the light weight and large air intake and

exhaust requirements of modern gas turbine engines makes it highly desirable from an arrangement standpoint to locate them relatively high in the ship. This more efficient arrangement of engines is only possible with an electric drive ship.

Historically, there have been primarily two types of electric ship propulsion: ac synchronous and direct current. In standard practice, ac synchronous systems are essentially a synchronous generator or generators directly connected to a synchronous propulsion motor. The speed ratio between the generators and motor is a constant determined by the ratio of poles in the machines. In ac synchronous systems control of the ship's speed is accomplished by varying the speed of the generator prime mover. For reverse operation, the phase sequence to the motor is reversed. During maneuvering situations when synchronism cannot be maintained, the motor is operated as an induction motor. This results in a low power factor that reduces efficiency. Ac systems tend to be more reliable, efficient and lighter in weight than dc systems of the same power rating. They are also available in larger power ratings than dc systems [1].

Standard dc systems consist of multiple dc generators connected directly to dc motors. Commutation requirements limit both the system voltage and generator speed. Power handling equipment such as circuit breakers limit the current. These restrictions confine the power of dc systems to around 10,000 horsepower per shaft. This power level makes dc systems infeasible for most naval ship applications [1].

Despite their historical drawbacks, modern electric drives have numerous advantages over mechanical systems. Electric propulsion systems are able to be

cross-connected and power any one or both propellers from any prime mover. It is also possible to parallel diesel and gas turbine generators to drive the same shaft. Electric power cables are flexible and easily routed as compared to steel propulsion shafting, allowing the naval architect to place engines almost anywhere within the ship. The paralleling ability of electric propulsion systems allows the use of an odd number of engines, since the power of an engine may be split electrically between two propulsion shafts. As naval gas turbines only come in discrete sizes, this allows the generating capacity to be more closely matched to the load requirements. Propulsion derived ship's service electric power (PDSS) allows the elimination of separate prime movers for ship's service power generation. Electric propulsion systems provide more redundancy of key components for surviving battle damage and for maintenance. All of these features of electric propulsion systems make them very attractive at a time when fiscal constraints make cost and efficiency a prime consideration in warship design.

1.2 Analysis of Shipboard Electric Systems

Previous research into shipboard electric power systems, references [2],[3] and [4] has focused on developing algorithms for numerically solving the systems of equations which describe the shipboard electrical system and determining the stability of various components within the system. As of yet, there has been no research into the stability, performance and control of complete shipboard electric drive systems.

The analysis of shipboard electric distribution and propulsion systems is significantly different from commercial power systems analysis. The assumption of constant frequency is not valid for shipboard systems. During large transients the frequency will vary by a significant amount from its nominal value. Electrical, mechanical and control dynamics all exhibit similar time constants, therefore the technique of time scale separation will not work with shipboard systems. In a shipboard system, some of the loads are of a similar order of magnitude as the generators, thus the dynamics of that load must be considered. Additionally, the concepts of an "infinite bus" and a "slack bus" are not applicable to shipboard power systems. These difficulties require utilizing a dynamic model for each major component of the system. Each of these dynamic component models must be connected together in such a way as to properly simulate the electric power system.

The systems to be considered are quite simple from a power systems standpoint (i.e., one to three generators driving one or two motors either through frequency converters or directly). By using dynamic models of each component, accurate predictions of system performance can be obtained. However, the complexity of the overall system using full order component models does not lend itself to analytical solution. Therefore, digital computer simulations will be employed in the conduct of this research, and reduced order models will be used where appropriate.

The full order model of the power system constitutes a system of nonlinear differential equations which are subject to algebraic constraints. The algebraic constraints

arise as a result of Kirchoff's voltage and current laws. The differential equations come from the dynamic models of the various components. The resulting system of differential/algebraic equations (DAE's) poses a difficult numerical problem which many numerical simulation programs cannot handle. Various modeling techniques will be used in order to avoid the algebraic loops inherent in DAE systems.

1.3 Computer Simulation Tools

A survey was conducted of various software packages to determine their acceptability for conducting computer simulations of shipboard power systems. Some of the programs are:

PSPICE: Simulation Program with Integrated Circuit Emphasis (SPICE) is a program intended for circuit analysis [5]. PSPICE is a pc-based version of the original. This program is unacceptable for the proposed research because it cannot handle nonlinear implicit components.

SIMULAB: Simulab is a graphical interfaced general purpose program for simulating dynamic systems [6]. It can accept Matlab M-files or C-language coded components and can handle nonlinear implicit loops. Simulab contains several numerical integration algorithms, however it does not include a method for solving differential/algebraic equations. This algorithm could be hand coded into the program as a function if necessary.

WAVESIM: This program was developed specifically to simulate shipboard electric distribution systems [3]. The unique feature of this program is that it treats the state variables as continuous waveforms. However, the current implementation of WAVESIM depends on the software package MATLAB to perform its calculations, resulting in a very slowly running program. However, several of the component models are already in existence and have been thoroughly validated.

ACSL: Advanced Continuous Simulation Language, (ACSL) is a general purpose interactive simulation program which uses a language very similar to FORTRAN [7]. It has the ability to handle implicit nonlinear systems where it uses the Newton-Raphson method for solution of the algebraic constraint equations. However, it slows down appreciably when these systems are modeled.

After review of the capabilities and limitations of the above simulation programs, ACSL was selected as the tool to perform the required simulations as it appears to be best suited to handling the systems under consideration, and there are several component models already written and available for use.

1.4 Control of Shipboard Propulsion Systems

The control systems for current mechanical drive ships consist of a digitally implemented control algorithm which adjusts propeller pitch with constant propeller speed up to a certain speed. The propeller speed is then varied by adjusting fuel flow into the engines in an open loop fashion. The commanded speed is input with a single lever either from the ship's bridge (primary) or from the Engineering Central Control Station (CCS) (secondary). There is also an ability to control manually each prime mover's speed and propeller pitch separately from the engine room. This manual control is intended only for emergency operation.

Electric drive ships are more complicated than mechanical drive ships from a control standpoint. In addition to controlling the power output of the prime mover, there are several other system inputs which must be controlled. Specifically, the generator and

motor excitation, system frequency and the electronic motor drive must all be correctly controlled for the system to work properly.

Excitation of the generator will determine its power factor and maximum electrical power output. This must be matched (after losses) by the power input from the prime mover. These two variables determine the electrical power available to the system. However, motor excitation determines the maximum torque which can be produced by the motor. This requirement will vary depending on the speed and maneuvering requirements of the ship [8].

In past electric drive ships, the frequency of the propulsion bus was varied to change the ship's speed. In the modern systems which are proposed, the propulsion bus frequency will be held constant (probably at 60 Hz.), and the motor drive will convert this constant frequency power to whatever frequency is needed to drive the propulsion motor at the correct speed. This conversion is accomplished through the timing of the thyristers in an inverter circuit [9]. The advantage of this arrangement is that the fuel efficiency of the prime mover is improved by operating it at a constant speed. This type of design also allows the ship's service electrical load to be supplied off the propulsion bus which eliminates the need for separate generators.

For ease of operation and commonality with existing ships, it is desired to retain a "single-stick" control for electric drive ships. However, the additional inputs of the electric drive require a more sophisticated control system than is presently installed on mechanical drive ships. A closed loop system will be required to maintain the constant

propulsion bus frequency. Similarly, the motor drive electronics will need a closed loop controller.

1.5. Research Approach

This research studies the dynamic behavior of likely configurations of an integrated electric drive ship under both normal and abnormal operating conditions as well as fault conditions. Possible control schemes for these systems are also investigated for their suitability.

The ship which will be studied is the next generation amphibious ship, known as the LX. All major components of the propulsion electric bus will be modeled. These include the synchronous generators and their associated prime movers, propulsion motors, frequency converters and the propeller load on the motors. The propulsion derived ship's service load will be modeled as a single lumped parameter constant power load (see figure 1-1). This research is divided into four major tasks. These tasks are:

- I. Identify system configurations to be studied.
- II. Develop computer models for system components.
- III. Integrate component models into system models.
- IV. Conduct simulations and evaluate results.

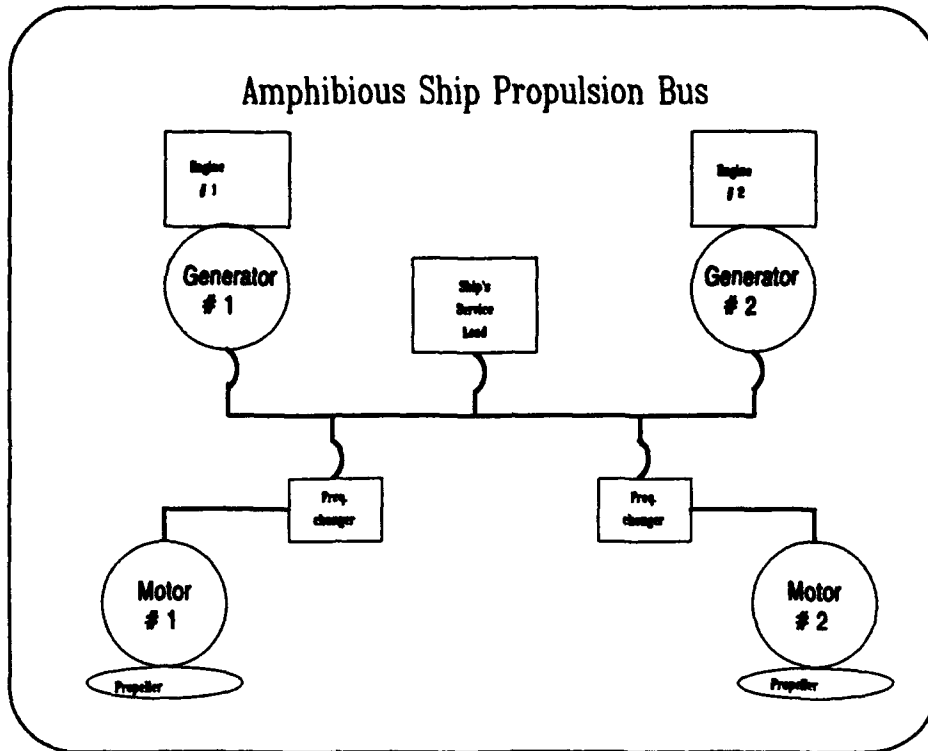


Figure 1-1

Chapter 2: Component Models

In order to conduct simulations of an entire shipboard electrical system, it is necessary to derive models of the various components which make up the system. This chapter describes the various component models which make up the system under consideration. The ACSL code for the following models is located in Appendix A.

2.1 Synchronous Machine

The synchronous machine model used in this study is based on the derivation in [10]. This model assumes linear magnetics and sinusoidal winding distribution. There are three windings on the stator and three on the rotor. The stator windings are the three phase windings. The rotor windings are the field winding and the direct and quadrature axis damper windings, which are lumped-parameter representations for various distributed paths of current flow in the rotor. In order to generate a tractable model it is necessary to transform the stator variables into a reference frame which is rigidly attached to the rotor of the machine. The transformation which accomplishes this is the well known Park's transformation, which is given by:

$$T = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin \theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (2.1)$$

and the inverse transformation is:

$$T^{-1} = \begin{bmatrix} \cos \theta & -\sin \theta & 1 \\ \cos \left(\theta - \frac{2\pi}{3} \right) & -\sin \left(\theta - \frac{2\pi}{3} \right) & 1 \\ \cos \left(\theta + \frac{2\pi}{3} \right) & -\sin \left(\theta + \frac{2\pi}{3} \right) & 1 \end{bmatrix} \quad (2.2)$$

$$\text{where, } \underline{F}_{dq} = \begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = T \cdot \underline{F}_{abc}$$

$$\text{and, } \underline{F}_{abc} = \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = T^{-1} \cdot \underline{F}_{dq}$$

Note that $\underline{F}$ is a vector place holder which represents voltage, current or any other quantity to be transformed. This version of the Park transformation will be used throughout this research.

The d and q subscripts correspond to the direct and quadrature axes, respectively. The direct axis is aligned with the field, and the quadrature axis leads the field by 90 degrees. The zero-sequence variables are not used unless unbalanced conditions are considered. Only balanced conditions will be considered in this research.

The synchronous machine model is given by the following set of equations from [10]:

$$\frac{d\psi_d}{dt} = -\frac{\psi_d}{T_{ad}} + \frac{e_q''}{T_{ad}} + \omega \cdot \psi_q + \omega_o \cdot v_d \quad (2.3)$$

$$\frac{d\psi_q}{dt} = -\omega \cdot \psi_d - \frac{\psi_q}{T_{aq}} - \frac{e_d''}{T_{aq}} + \omega_o \cdot v_q \quad (2.4)$$

$$\frac{de_q''}{dt} = -\frac{x_d'}{x_d''} \cdot \frac{e_q''}{T_{do}} + \frac{e_q'}{T_{do}} + \left(\frac{x_d' - x_d''}{x_d''} \right) \cdot \frac{\psi_d}{T_{do}} \quad (2.5)$$

$$\frac{de_d''}{dt} = -\frac{x_q}{x_q''} \cdot \frac{e_d''}{T_{qo}} - \left(\frac{x_q - x_q''}{x_q''} \right) \cdot \frac{\psi_q}{T_{qo}} \quad (2.6)$$

$$\frac{de_q'}{dt} = -\alpha \cdot \frac{e_q'}{T_{do}} + (\alpha - 1) \cdot \frac{e_q'}{T_{do}} + \frac{e_{af}}{T_{do}} \quad (2.7)$$

$$\frac{d\delta}{dt} = \omega - \omega_o \quad (2.8)$$

$$\frac{d\omega}{dt} = \frac{\omega_o}{2H} \left[T_m + \frac{\psi_d \cdot e_d''}{x_q''} + \frac{\psi_q \cdot e_q''}{x_d''} + \psi_d \cdot \psi_q \cdot \left(\frac{1}{x_q''} - \frac{1}{x_d''} \right) \right] \quad (2.9)$$

where the following definitions have been made:

$$T_{ad} = \frac{x_d''}{\omega_o \cdot r_s} = \text{Direct axis armature time constant}$$

$$T_{aq} = \frac{x_q''}{\omega_o \cdot r_s} = \text{Quadrature axis armature time constant}$$

$$T_{do}'' = \frac{x_{kd}}{\alpha \cdot \omega_o \cdot r_{kd}} = \text{D-axis open circuit sub-transient time constant}$$

$$T_{qo}'' = \frac{x_{kq}}{\omega_o \cdot r_{kq}} = \text{Q-axis open circuit sub-transient time constant}$$

$$T_{do}' = \frac{x_f}{\omega_o \cdot r_f} = \text{D-axis open circuit transient time constant}$$

$$\alpha = \frac{x_d - x_d''}{x_d' - x_d''}$$

$$e_q' = \frac{x_{ad}}{x_f} \cdot \psi_f = \text{Voltage behind transient reactance}$$

$$e_q'' = \frac{x_{ad}}{x_{kd}} \cdot \psi_{kd} = \text{Voltage behind sub-transient reactance}$$

$$e_d'' = -\frac{x_{aq}}{x_{kq}} \cdot \psi_{kq} = \text{Voltage behind sub-transient reactance}$$

Stator currents in the following model are given in generator coordinates by:

$$\psi_d = e_q'' - x_d'' \cdot i_d, \text{ and } \psi_q = -e_d'' - x_q'' \cdot i_q \quad (2.10)$$

The transients of interest are electromechanical ones with time constants in the range of 0.1 seconds to 10 seconds or longer. The stator equations (2.3) and (2.4), have eigenvalues on the order of 0.0026 seconds ($1/\omega_o$). Since integration routines used for computer simulation typically require time steps smaller than the smallest eigenvalue in the system, including the stator transients and resistance requires a high overhead in simulation time. Neglecting stator transients requires making the following assumptions: $\omega \gg \frac{d}{dt}, \frac{1}{T_{ad}}, \frac{1}{T_{aq}}$. These assumptions are valid under balanced conditions for all times and frequencies which will be studied herein. These simplifications are common practice when simulating electrical networks [11]. After making these approximations, equations (2.3) and (2.4) reduce to:

$$v_q = \frac{\omega}{\omega_o} \cdot \psi_d, \text{ and } v_d = -\frac{\omega}{\omega_o} \cdot \psi_q \quad (2.11)$$

Substitution of (2.10) into (2.5), (2.7), (2.9) and (2.11) yields the following model:

$$v_d = (e_d'' + x_q'' \cdot i_q) \cdot \frac{\omega}{\omega_o} \quad (2.12)$$

$$v_q = (e_q'' - x_d'' \cdot i_d) \cdot \frac{\omega}{\omega_o} \quad (2.13)$$

$$\frac{de_q''}{dt} = -\frac{e_q''}{T_{do}} + \frac{e_q'}{T_{do}} - \frac{(x_d' - x_d'')}{T_{do}} \cdot i_d \quad (2.14)$$

$$\frac{de_d''}{dt} = -\frac{e_d''}{T_{\phi''}} + \frac{(x_q - x_q'')}{T_{\phi''}} \cdot i_q \quad (2.15)$$

$$\frac{de_q'}{dt} = -\alpha \cdot \frac{e_q'}{T_{d0}} + (\alpha - 1) \cdot \frac{e_q''}{T_{d0}} + \frac{e_{af}}{T_{d0}} \quad (2.16)$$

$$\frac{d\delta}{dt} = \omega - \omega_0 \quad (2.17)$$

$$\frac{d\omega}{dt} = \frac{\omega_0}{2H} \left[T_m - e_d'' \cdot i_d - e_q'' \cdot i_q + i_d \cdot i_q \cdot (x_d'' - x_q'') \right] \quad (2.18)$$

For the generators which operate near rated frequency, the additional assumption of $\omega \approx \omega_0$ can be made. This modifies the above motor model by eliminating the factor of $\frac{\omega}{\omega_0}$ from equations (2.12) and (2.13). By using the D and Q-axis currents as inputs, this form of the model is most useful for system studies.

2.2 Frequency Changer

A solid-state frequency changer is used to supply variable frequency AC power to the synchronous propulsion motor while the bus frequency is held constant. The particular frequency changer used in this study is a DC-link load commutated controlled rectifier-inverter. The derivation which follows is similar to those found in references [9] and [12]. Figure 2-1 shows the circuit configuration of this device. Notice that the converter is symmetric about the DC-link, thus only the inverter side need be analyzed. The equations of the rectifier are identical with appropriate substitution of variables. If the DC-side voltage and current are considered constant and instantaneous commutation is assumed, then the AC-side waveforms are as shown in figure 2-2. The two thirds cycle

pulse wave current waveform shown is somewhat idealized. The actual current wave pulses will exhibit a finite rise and decay time which is associated with the inductive elements in the AC side of the converter. This is known as commutation overlap. In the interest of creating a more tractable model for system studies, the commutation overlap effect will be neglected, which is consistent with other models for system level studies [12]. The currents can then be represented by their Fourier series:

$$i_a = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin(\omega t - \beta_i) - \frac{1}{5} \sin 5(\omega t - \beta_i) - \frac{1}{7} \sin 7(\omega t - \beta_i) \dots \right]$$

$$i_b = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin\left(\omega t - \frac{2\pi}{3} - \beta_i\right) - \frac{1}{5} \sin 5\left(\omega t - \frac{2\pi}{3} - \beta_i\right) - \frac{1}{7} \sin 7\left(\omega t - \frac{2\pi}{3} - \beta_i\right) \dots \right]$$

$$i_c = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin\left(\omega t + \frac{2\pi}{3} - \beta_i\right) - \frac{1}{5} \sin 5\left(\omega t + \frac{2\pi}{3} - \beta_i\right) - \frac{1}{7} \sin 7\left(\omega t + \frac{2\pi}{3} - \beta_i\right) \dots \right]$$

Transforming these currents into the rotating reference frame of the motor using eq. (2.1) gives:

$$i_d = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \sin \beta_i \quad (2.19)$$

$$i_q = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \cos \beta_i \quad (2.20)$$

with harmonic components neglected.

DC Link Frequency Converter

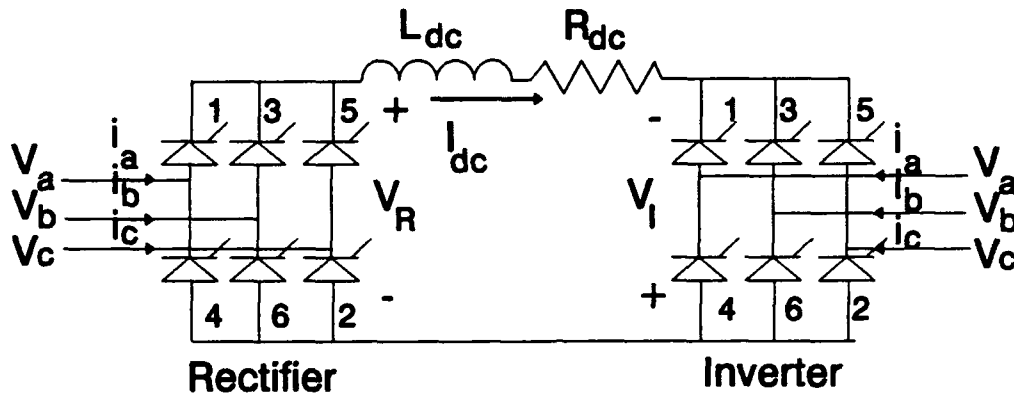


Figure 2-1

Voltage and Current Waveforms

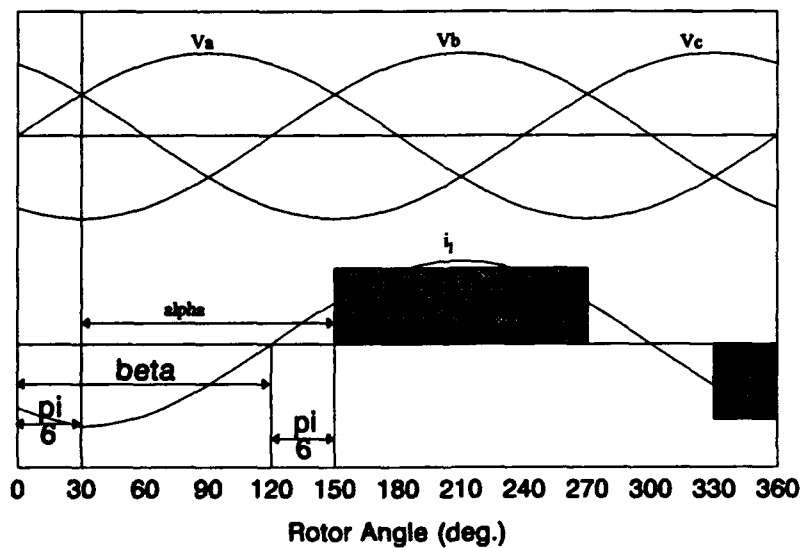


Figure 2-2

The voltages across the bridge may be related using the average value voltage equation [11]:

$$V_i = \frac{3\sqrt{3}}{\pi} E_{pi} \cdot \cos \alpha_i \quad (2.21)$$

$$\text{where: } E_{pi} = \sqrt{v_{di}^2 + v_{qi}^2} \quad (2.22)$$

$$\alpha_i = \beta_i \quad (2.23)$$

A similar analysis on the rectifier yields:

$$i_{dr} = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \cos \beta_r \quad (2.24)$$

$$i_{qr} = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \sin \beta_i \quad (2.25)$$

$$V_r = \frac{3\sqrt{3}}{\pi} E_{pr} \cdot \cos \alpha_r \quad (2.26)$$

$$E_{pr} = \sqrt{v_{dr}^2 + v_{qr}^2} \quad (2.27)$$

$$\alpha_r = \beta_r \quad (2.28)$$

Writing KVL around the DC link and solving for the time derivative results in the one state equation contained in the frequency changer model:

$$\frac{dI_{dc}}{dt} = \frac{1}{L_{dc}} [V_r + V_i - R_{dc} \cdot I_{dc}] \quad (2.29)$$

Equations (2.19) - (2.29) constitute the rotating reference frame model of the dc-link frequency changer used throughout this analysis. This model inputs ac side voltages and

outputs ac side currents. The rectifier and inverter firing angles, which control the converter are also inputs to this model.

2.3 Voltage Regulator

The voltage regulator model is a standard PI type controller which varies the field excitation of the generator in response to changes in terminal voltage. The terminal voltage is calculated from the d and q-axis voltages as:

$$V_T = \sqrt{V_d^2 + V_q^2}$$

The regulator dynamics are given by:

$$\frac{E_{af}}{V_{ref} - V_T} = \frac{K}{\tau s + 1} \quad (2.30)$$

Where: V_{ref} = Reference terminal voltage
 E_{af} = Generator field excitation
 K = Voltage regulator gain
 τ = Voltage regulator time constant

Satisfactory values of K and τ have been determined to be 100 and 0.1, respectively. This model also includes a limiting function on the value of E_{af} . The inputs to this model are the D-axis, Q-axis and reference terminal voltages. Its output is the field excitation.

2.4 Induction Motor

The vast majority of the ship's service electrical load on any ship consists of induction motors which power various pumps, fans and other equipment. In order to simulate the effect of a large transient in the ship's service load an induction motor model was developed from the derivation contained in [11]. The equations describing the induction motor in the synchronously rotating reference frame are given by:

$$\frac{d\psi_{ds}}{dt} = \omega_o \cdot (v_d - r_s \cdot i_{ds} + \psi_{qs}) \quad (2.31)$$

$$\frac{d\psi_{qs}}{dt} = \omega_o \cdot (v_q - r_s \cdot i_{qs} - \psi_{ds}) \quad (2.32)$$

$$\frac{d\psi_{dr}}{dt} = (\omega_o - \omega_m) \cdot \psi_{qr} + \frac{\omega_o \cdot r_r}{X_{lr}} \cdot (\psi_{md} - \psi_{dr}) \quad (2.33)$$

$$\frac{d\psi_{qr}}{dt} = -(\omega_o - \omega_m) \cdot \psi_{dr} + \frac{\omega_o \cdot r_r}{X_{lr}} \cdot (\psi_{mq} - \psi_{qr}) \quad (2.34)$$

$$\frac{d\omega_m}{dt} = \frac{\omega_o}{2H} (T_e + T_m) \quad (2.35)$$

$$\psi_{md} = X_{ad} \left(\frac{\psi_{ds}}{X_{ls}} + \frac{\psi_{dr}}{X_{lr}} \right) \quad (2.36)$$

$$\psi_{mq} = X_{aq} \left(\frac{\psi_{qs}}{X_{ls}} + \frac{\psi_{qr}}{X_{lr}} \right) \quad (2.37)$$

$$i_{ds} = \frac{1}{X_{ls}} (\psi_{ds} - \psi_{md}) \quad (2.38)$$

$$i_{qs} = \frac{1}{X_{ls}} (\psi_{qs} - \psi_{mq}) \quad (2.39)$$

$$T_e = (\psi_{ds} \cdot i_{qs} - \psi_{qs} \cdot i_{ds}) \quad (2.40)$$

where: ψ_{ds} = D-axis stator flux linkage
 ψ_{qs} = Q-axis stator flux linkage
 ψ_{dr} = D-axis rotor flux linkage

$$\begin{aligned}\psi_q &= \text{Q-axis rotor flux linkage} \\ \psi_{md} &= \text{D-axis mutual coupling flux linkage} \\ \psi_{mq} &= \text{Q-axis mutual coupling flux linkage}\end{aligned}$$

The inputs to this model are the terminal voltages and mechanical torque, the outputs are the terminal currents and rotor speed. Stator transients are included in this model to eliminate algebraic loops. Primarily, the dynamics of interest are the rotor transients.

2.5 Ship's Service Load

Since one of the objectives of this research is to simulate an integrated electric drive ship, it was considered necessary to include the ship's service load. This was developed as a constant power load using the concept of complex power [12]. In complex form, the power in the rotating reference frame is given by:

$$P + jQ = \hat{V} \cdot \hat{I}^* = (v_d + jv_q) \cdot (i_d - ji_q) = (v_d i_d + v_q i_q) + j(v_q i_d - v_d i_q) \quad (2.41)$$

Solving for i_d and i_q yields:

$$i_d = \frac{v_d P + v_q Q}{v_d^2 + v_q^2} \quad \text{and,} \quad i_q = \frac{v_q P - v_d Q}{v_d^2 + v_q^2} \quad (2.42)$$

This results in a model with voltages as inputs and currents as outputs. P and Q are input parameters which are set to desired constants. For a more realistic loading which varies randomly about a mean, P and Q can be made random variables instead of constants.

2.6 Diesel Engine

Typical models of diesel engines for engine analysis found in the literature include the dynamics of the combustion process, as well as the thermodynamic and heat transfer aspects to the engine. This type of model is much more complex than is necessary for the present purposes. Towards that end, an empirical model was developed which models the torque output of the engine as a function of the fuel rack position, engine speed and load.

The model which was developed is based on similar ones by Woodward [14], Hendrics [15] and Fowler [16]. It consists primarily of an engine map (fig. 2-3) which determines the relationship between speed, torque and fuel rack position and the appropriate time delays. The time delays considered in this model are the fuel injection delay and the turbocharger lag.

If the engine receives a step change in its fuel rack position, the fuel injection delay arises because the change in fuel entering the cylinders does not occur until two complete revolutions of the crankshaft (for a four stroke engine) have occurred. According to Woodward [14], if the speed is not varied over a wide range this delay may be approximated as:

$$\tau_f = \frac{30}{N} + \frac{120}{Q \cdot N}, \text{ seconds} \quad (2.43)$$

where, N = Engine speed (RPM)
 Q = Number of cylinders

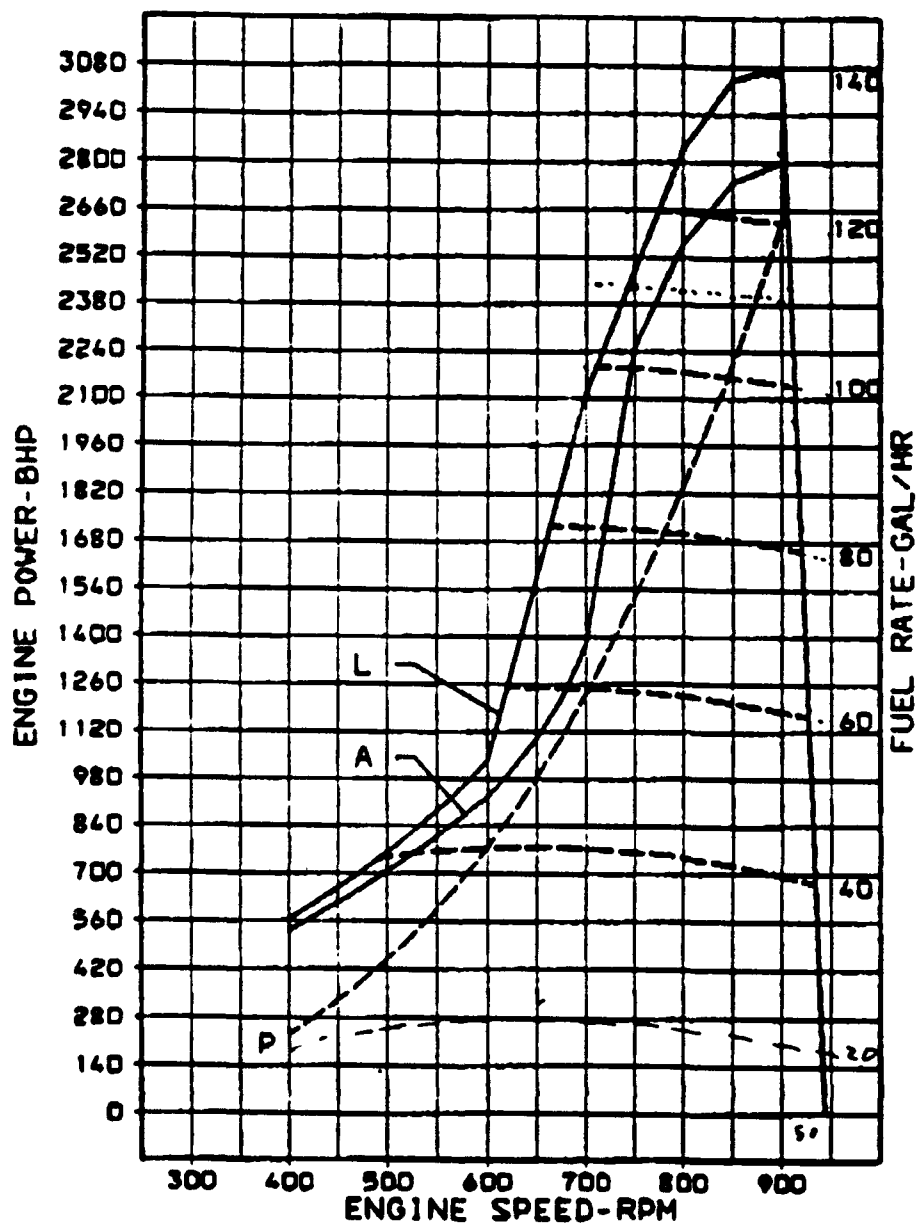


Figure 2-3

Since this engine model is to be used as a generator set, it will not see a wide range of speed variation and this type of delay can be considered adequate.

It would be desirable to use a "compressor map" which represents the pressure ratio and efficiency of the turbocharger compressor as a function of mass flow rate and turbocharger speed for modeling the turbocharger dynamics. However, this information was not available from the manufacturer. Instead a first order lag time constant was developed which resulted in the proper time scale behavior of the engine. This is similar to that used by Fowler [16]. Taylor [17] indicates that the time lag of a turbocharger is inversely proportional to the power output of the engine. The turbocharger lag is given by:

$$\tau_T = \frac{K_T}{(T_m + 1)} \quad (2.44)$$

where, K_T = Empirical Constant
 T_m = Engine output torque

These two time delays are then summed together to produce the total time lag in output torque exhibited by the engine. The resulting dynamics resemble a first order lag with a variable time constant. Unfortunately, dynamometer test data was not available for this particular engine, so a quantitative evaluation of the model was not made. However, the speed and torque response characteristics of this model compared favorably with those of [25] and [26] on a qualitative basis.

2.7 Diesel Engine Governor

In order to use the diesel engine as a generator prime mover, a speed regulating governor was developed. The diesel engine model described above uses the fuel rack setting as its control input. The governor which was developed is a PID type controller which acts on an error signal created by comparing the actual shaft speed with the desired speed of the engine. Its output is the fuel rack position. The governor can be represented as:

$$\frac{u}{e} = \frac{ks}{\tau s + 1} \quad (2.45)$$

where: u = fuel rack position
 e = speed error signal
 k = controller gain
 τ = controller time constant
 s = Laplace operator

The PID controller was chosen over a PI controller due to the slow response of the diesel engine which can be attributable primarily to the turbocharger dynamics. When tuned to the particular engine being used, the gain and time constant values were determined to be 2 and 0.2 respectively. This model also includes a limiting function which only allows the fuel rack position to vary from zero to one as would be the case in a real engine.

2.8 Gas Turbine Engine

The gas turbine engine model that was used has been provided to the author by code 2753 of the Naval Surface Warfare Center (NSWC) detachment Annapolis, MD. It

is based on a detailed thermodynamic model of the General Electric LM-2500 marine engine which was developed using manufacturer's test bed data. This model consists of four parts:

- 1) The gas generator and power turbine module characterizes the two rotating shafts in the engine. When the compressor inlet temperature, pressure and fuel flow rate are input, this model calculates the torque and speed of both the free turbine which drives the compressor and the power turbine which drives the output shaft.
- 2) The main fuel control module simulates the dynamics of the fuel system on the engine. It calculates the fuel flow rate as a function of compressor inlet temperature, discharge pressure, speed and power level angle (PLA) actuator.
- 3) The free standing electronics enclosure (FSEE) module models the dynamics of the controller which is supplied as part of the engine installation. It determines the PLA as a function of throttle input command, power turbine shaft speed and inlet pressure and compressor inlet temperature and pressure.
- 4) For use as a generator, a limited PI type controller is used to maintain the power turbine shaft speed at a constant 3600 rpm.

With the exception of the speed controller, all of the modules use lookup tables to relate the input and output variables. The lookup tables are based on manufacturer's performance data from a real engine. Configuration and operational details of this engine can be found in reference [18]. Although this model is more detailed than actually

required for the control studies conducted herein, it is a proven accurate model of the most common gas turbine engine found in U.S. Navy ships. In order to eliminate duplication of effort, this model was used without changes.

2.9 Mechanical Load

A simple polynomial type mechanical load was used during the software testing phase to apply a load to the various prime movers and electric motors. This load is represented as:

$$T = a \cdot \omega^2 + b \cdot \omega + c \quad (2.46)$$

where: T = load torque
 ω = per unit rotational speed
 a = coefficient of speed squared term
 b = coefficient of linear term
 c = constant term

The coefficients are varied as necessary to exercise the model. This was written primarily as a convenience to allow running various loading conditions without recompiling the computer model being tested. The speed squared term allows the simulation of ship propulsion or fan loading on electric motors.

2.10 Ship Seaway dynamics

The ship seaway dynamics model was also provided to the author by code 2753 of NSWC Annapolis. This program models the propeller and hydrodynamic characteristics for a ship hull moving through the water in one degree of freedom. The hull resistance,

the propeller torque, and the propeller thrust characteristics have been per unitized. The characteristics, torque and thrust are represented as functions of per unit ship speed and per unit propeller shaft speed. The ship hull resistance function is characterized using a 10th order polynomial to fit the actual ship's data. This model also includes the friction torque function for the propeller shafts associated with the ship hull. The inputs are shaft speed in RPM on both shafts and the outputs are the shaft torque values. This model also allows the inclusion of a seaway loading on the propeller. This is a very important feature since the time varying torque on the propulsion motors significantly complicates the control problem. This will be discussed more thoroughly later. This model has also been validated so it is used without change.

Chapter 3: Interconnections

To simulate a complete electric propulsion system, it is necessary to connect the various component models together so that the simulation model resembles the actual system. Assembly of the computer model requires adherence to both the physical laws which describe the system as well as constraints imposed by the numerical implementation of the models on the computer. Since the physical system's electrical components are interconnected by transmission lines and switchboards, it is first necessary to develop a model for the transmission line. Switchboards are treated in the simulations as lossless switches and any losses that may be associated with the switchboards are lumped into the transmission line models.

3.1 Transmission Line Model

The transmission line model used in all analyses is simply a balanced three phase series R-L element as shown in figure 3-1. The voltage drop across the transmission line is:

$$\underline{V}_1 - \underline{V}_2 = L \cdot \frac{d\underline{I}}{dt} + R \cdot \underline{I} \quad (3.1)$$

Where:

$$\underline{V}_1 = \begin{bmatrix} v_{a1} \\ v_{b1} \\ v_{c1} \end{bmatrix}, \quad \underline{V}_2 = \begin{bmatrix} v_{a2} \\ v_{b2} \\ v_{c2} \end{bmatrix}, \quad \underline{I} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\text{and, } L = \begin{bmatrix} l & m & m \\ m & l & m \\ m & m & l \end{bmatrix}, \quad R = \begin{bmatrix} r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & r \end{bmatrix}.$$

The off-diagonal terms in the inductance matrix represent the mutual coupling between the phases. Transforming this into the rotating reference frame using equation (2.1) yields:

$$V_{1d} - V_{2d} = \frac{x}{\omega_o} \cdot \frac{di_d}{dt} - \frac{\omega}{\omega_o} \cdot x \cdot i_q + r \cdot i_d \quad (3.2)$$

$$V_{1q} - V_{2q} = \frac{x}{\omega_o} \cdot \frac{di_q}{dt} + \frac{\omega}{\omega_o} \cdot x \cdot i_d + r \cdot i_q \quad (3.3)$$

Where: $x = \omega_o \cdot (l - m)$

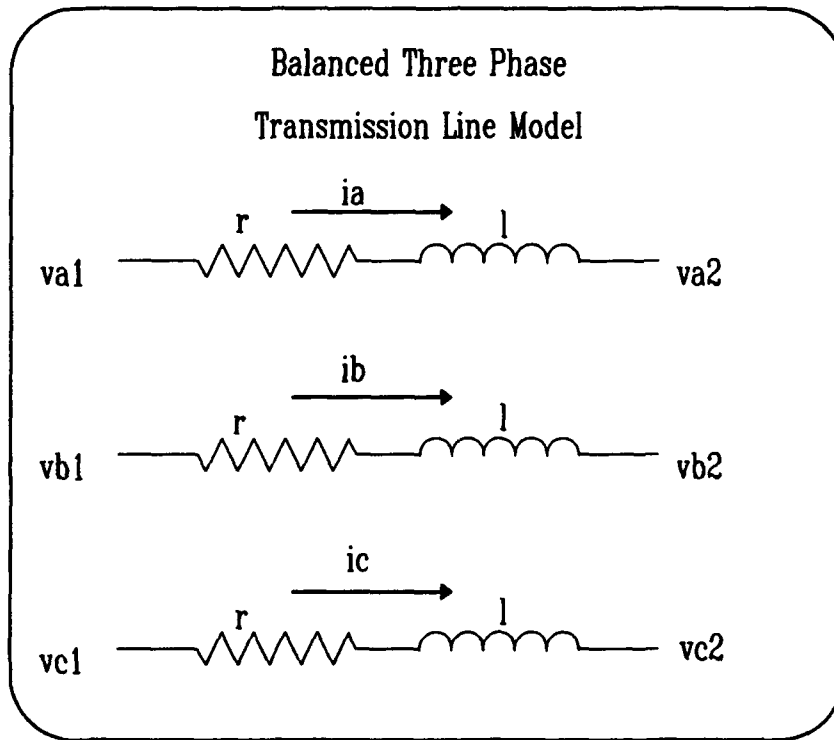


Figure 3-1

Shipboard transmission lines tend to have very small resistance values in comparison to commercial distribution systems, primarily due to their shorter length. For this reason the resistance terms in equations (3.2) and (3.3) can be neglected without loss

of accuracy. Similarly, since x is small and $\frac{d}{dt} \ll \omega, \omega_o$ for the time scale of interest, the transformer voltage terms may also be ignored leaving only the speed voltage terms. For the transmission lines that operate at bus frequency, we can further assume that $\omega \approx \omega_o$, which is the approach taken in [12]. The reduced order transmission line model then becomes:

$$V_{1d} - V_{2d} = -x \cdot i_q \quad (3.4)$$

$$V_{1q} - V_{2q} = x \cdot i_d \quad (3.5)$$

This model is used to interconnect generators and loads via the main propulsion bus.

3.2 Physical and Numerical Considerations

The electrical component models must be interconnected such that Kirchoff's voltage and current laws (KCL and KVL) are obeyed. As mentioned previously, this leads to algebraic constraint equations in addition to the state equations contained in the various component models.

Besides these physical constraints, when modeling the system on the computer all variables must be explicitly calculated as a function of other variables somewhere within the simulation. Put more simply, every variable must appear on the left hand side of the equals sign exactly once in the simulation. As a result of this constraint, each component model has certain inputs and outputs. When connecting two models together, this input/output relationship must be taken into account, in addition to satisfying KCL and KVL.

In the case of two components connected electrically, it is very straightforward to satisfy the numerical and physical constraints simultaneously. If one component uses voltage as its input and calculates its required current from that voltage, and the other component uses current as its input and calculates a terminal voltage from its terminal current; then by setting the terminal currents and voltages of the two components equal to each other all constraints are satisfied. This assumes that the terminal variables of at least one of the components are related through one or more state variables. This is the case when the frequency changer model is connected to the synchronous motor model. The motor inputs currents and outputs voltages, whereas the frequency changer inputs voltages and outputs currents. Furthermore, the frequency changer's AC side current output is a function of the DC-link current (a state variable) and the thyristor firing angle. The problem becomes more difficult when three or more components are to be interconnected.

With multiple components connected to the same bus, the difficulty of the problem depends on what the input and output variables of each component are. In general, for a bus KCL can be written as: (d-axis, q-axis is similar)

$$i_{dg1} + i_{dg2} + \dots + i_{dgn} = i_{dl1} + i_{dl2} + \dots + i_{dlm} \quad (3.6)$$

where there are n generators and m loads attached to the bus. This can be solved for any one of the currents if all the other currents are known (i.e., outputs of their respective component models). Equations (3.4) and (3.5) can be used to relate the terminal voltage of each component to the bus voltage. This represents a set of $2*(n+m+1)$ equations with

$2*(n+m+1)$ unknowns. The easy solution to this problem is when there is exactly one component attached to the bus which inputs current and outputs voltage. In this case equation (3.6) can be solved for that component's currents, and its corresponding transmission line voltage equations can be solved for the bus voltages. Once the bus voltage is known, the terminal voltages of all other components can be calculated directly. This is exactly the case that occurs in the systems simulated with one generator operating.

In the case of multiple generator operations, the bus configuration has numerous components (the generators) which require currents as inputs. All load models have been configured with voltages as inputs. Equation (3.6) can no longer be explicitly solved since it has several unknown quantities, so another method for determining the bus voltage and generator currents must be found.

One approach is to modify the transmission line equations for all generators except one. This is accomplished by solving equations (3.2) and (3.3) for the time derivatives, making the currents state variables. Although this method can be made to work, it introduces a set of very fast eigenvalues that control the time step size of the simulation. It also is very sensitive to the transmission line impedance value and tends to introduce numerical instabilities into the system. Because of these difficulties, this method was not chosen to conduct two generator simulations.

Another approach is to use equations (2.12)–(2.18) with currents as inputs for one of the generators, and equations (2.3)–(2.10) with voltages as inputs for the other generators. This reintroduces the stator transients into the system for all the generators

except one, and is similar to the above method. While the stator transients are fast eigenvalues, they are not nearly as fast as those introduced by the transformer voltages in the transmission line. However, this method also seems to suffer from numerical stability problems of unknown origin. This method was not used for conducting two generator simulations.

A third approach is simply to solve the set of transmission line and stator voltage equations implicitly along with the current equations. ACSL has a built-in function to solve this type of implicit loop based on the Newton-Raphson method for solving simultaneous equations. Although the Newton-Raphson method in general is not always convergent [19], in this case the set of equations which must be solved is linear and no convergence problems were encountered. This method of solving the algebraic loop is preferred, and was used for all two generator simulations.

Since the system of equations is linear, it would also be possible to explicitly solve the system by collecting the equations together into a single vector equation and inverting the coefficient matrix. Although the matrix inversion would probably be faster than the implicit solution, ACSL doesn't handle matrix operations very eloquently. The result of this approach is that the object oriented structure of the simulation models would be compromised.

A fourth method for breaking the algebraic loop is simply to leave the loop in the simulation. This allows the computer to calculate the variables algebraically in the sequence in which they occur in the simulation. For example, given:

$$v_{g1} = f(i_{g1}) \text{ and } i_{g1} = f(v_{g1}),$$

the simulation calculates these variables at each time step as:

$$v_{gl}^{n+1} = f(i_{gl}^n) \text{ and } i_{gl}^{n+1} = f(v_{gl}^{n+1}).$$

This is effectively a first order Euler integration of v and i . According to Crandall [20], the error of this method is on the order of h (the step size), which is kept below .01 seconds in the simulations. If the variables v and i are on the order of one, then this method is considered accurate enough for the purpose at hand. The ship's service load model described in chapter 2 uses this method to calculate its required current from its terminal voltage. The ship dynamics model also uses this method for calculating ship speed when a seaway is invoked.

3.3 Per-unitization

All the electrical models described in chapter 2 have been per-unitized. The choice of base values for per-unitization is arbitrary, but is usually selected to be the rated voltage and power when working with a single component. When several components of different ratings are connected in a system, one common base must be used throughout the system. For this research, this common base was chosen to be the rated values for the propulsion motor.

In the actual system, the voltage must be the same throughout or transformers must be supplied to connect components which operate at different voltages. If the base voltages are chosen in the same ratio as the transformer turns ratio for two components connected through a transformer, then the ideal transformer can be eliminated from the per

unit model of the system [21]. However, since the currents are related across a transformer by the inverse of the turns ratio, the currents in the per unit system must be converted from one base to another. The per unit base conversions are given by:

$$VA_{pu,2} = VA_{pu,1} \cdot \frac{VA_{base,1}}{VA_{base,2}} \quad (3.7)$$

$$V_{pu,2} = V_{pu,1} \cdot \frac{V_{base,1}}{V_{base,2}} \quad (3.8)$$

$$I_{pu,2} = I_{pu,1} \cdot \frac{V_{base,2}}{V_{base,1}} \cdot \frac{VA_{base,1}}{VA_{base,2}} \quad (3.9)$$

$$Z_{pu,2} = Z_{pu,1} \cdot \left(\frac{V_{base,1}}{V_{base,2}} \right)^2 \cdot \frac{VA_{base,2}}{VA_{base,1}} \quad (3.10)$$

Equation (3.9) is used to convert the terminal currents of the generators to the propulsion motor base in all simulations.

3.4 System Configurations

There are two configurations which have been considered during this research. They are both based on the system outlined in figure 1-1. The first system, known as "system 1" uses only one generator to provide electrical power. It is represented schematically in figure 3-2. The interconnection equations for this system are:

$$i_{dg1} = \frac{2 \cdot i_{d1} + i_{d2}}{ki_{g1m1}} \quad (3.11)$$

$$i_{qg1} = \frac{2 \cdot i_{q1} + i_{q2}}{ki_{g1m1}} \quad (3.12)$$

$$V_{d\text{bus}} = V_{d\text{g1}} + i_{q\text{r1}} \cdot X_{\text{g1}} \quad (3.13)$$

$$V_{q\text{bus}} = V_{q\text{g1}} - i_{d\text{r1}} \cdot X_{\text{g1}} \quad (3.14)$$

$$V_{d\text{r1}} = V_{d\text{bus}} + i_{q\text{r1}} \cdot X_{\text{r1}} \quad (3.15)$$

$$V_{q\text{r1}} = V_{q\text{bus}} - i_{d\text{r1}} \cdot X_{\text{r1}} \quad (3.16)$$

Where: $k_{i_{\text{g1m1}}}$ = per unit base conversion factor for generator #1.

Note that the value of x_{t2} has been taken as zero since the reactance of this transmission line can be accounted for in the power factor of the ship's service load.

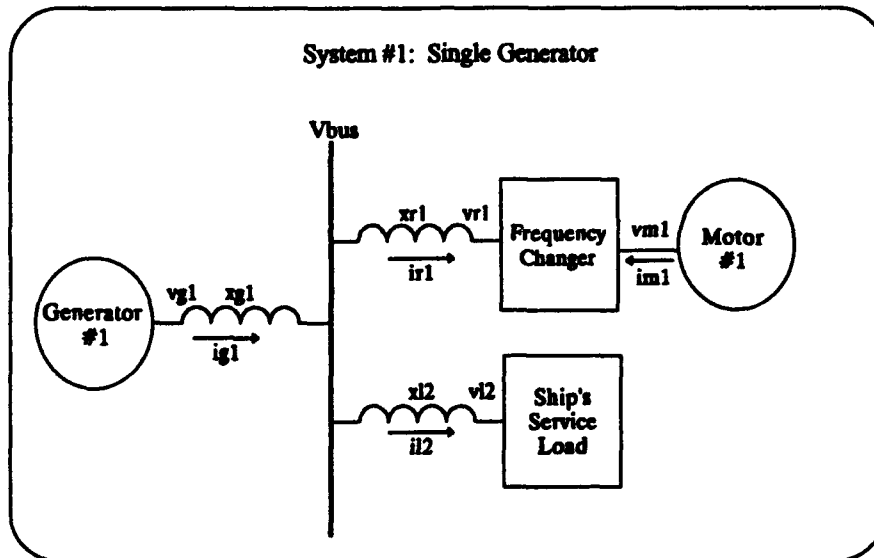


Figure 3-2

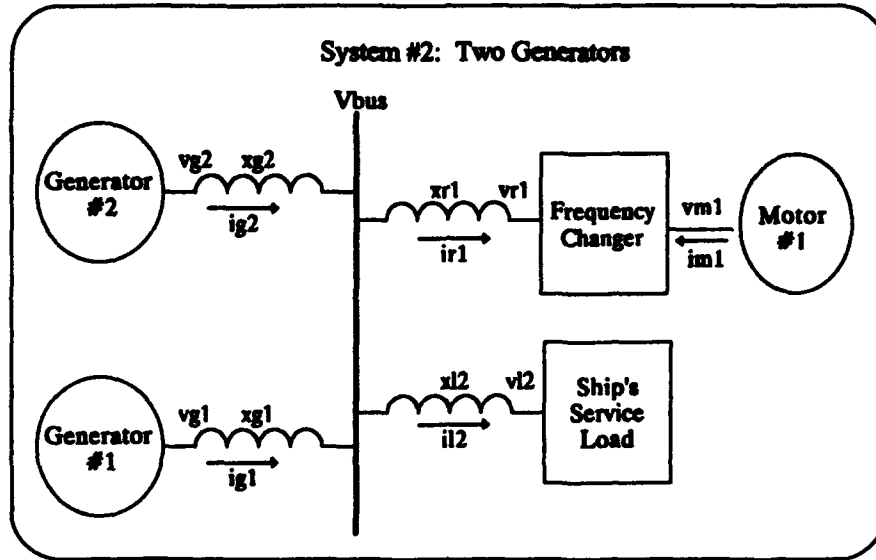


Figure 3-3

The second system, or "system 2" uses two generators and is pictured in figure 3-3. One of the generators is driven by a gas turbine and the other is driven by a diesel engine. The interconnection equations of this system are given by:

$$V_{bus} = V_{dg1} + i_{qg1} \cdot X_{g1} \quad (3.17)$$

$$V_{qbus} = V_{qg1} - i_{dg1} \cdot X_{g1} \quad (3.18)$$

$$i_{qg1} = \frac{(V_{dg2} - V_{bus})}{X_{g2} \cdot k_{ig1m1}} \quad (3.19)$$

$$i_{dg1} = \frac{(V_{qg2} - V_{qbus})}{X_{g2} \cdot k_{ig1m1}} \quad (3.20)$$

$$V_{dr1} = V_{bus1} + i_{qr1} \cdot X_{r1} \quad (3.21)$$

$$V_{qr1} = V_{qbus} - i_{dr1} \cdot X_{r1} \quad (3.22)$$

$$i_{dg1} = \frac{(2 \cdot i_{dr1} + i_{d2} - i_{d2} \cdot k_{ig2m1})}{k_{ig1m1}} \quad (3.23)$$

$$i_{q1} = \frac{(2 \cdot i_{q1} + i_{q2} - i_{q2} \cdot k_{i2m1})}{k_{i1m1}} \quad (3.24)$$

Where: k_{i2m1} = per unit base conversion factor for generator #2.

Both of the systems simulated for control studies use only one propulsion motor / frequency converter combination. This simplification was made to reduce computing time as all simulations were carried out on a personal computer. To properly simulate the load on the generators, the rectifier currents have been multiplied by a factor of two in equations (3.11), (3.12), (3.24) and (3.25) above. The only constraint placed on the system by this simplification is that maneuvering situations where each shaft is turning at different speeds (or directions) cannot be simulated. It is not necessary to simulate such situations for the present studies, however it is a simple programming change to add the second propulsion motor if such studies are undertaken at a later date. To verify this capability, some simulations were run with two propulsion motors attached to the bus with no problems encountered. The results of these simulations are presented in appendix C.

Chapter 4: Control Studies

With system modeling completed , it becomes possible to study the dynamic behavior of an integrated shipboard electrical drive and power distribution system. The aim of conducting control studies is to determine in general what type of controls are necessary to stabilize the system and provide adequate performance from an operational standpoint.

4.1 Inputs and Outputs

As mentioned in the introduction, there are several control inputs to the system.

The primary controls are:

- Generator prime mover fuel rate.
- Generator field excitation.
- Motor field excitation.
- Rectifier and Inverter thyristor firing angles.

In addition to these controls there are other inputs which affect the system such as sensor noise and plant disturbances. The most significant form of plant disturbance is sea state induced variation in ship speed. This is the only disturbance which will be treated in this preliminary study. Sensor noise will not be addressed herein.

Additionally, there are several observable outputs of the system. The outputs which we are interested in controlling are:

- Bus voltage.
- Bus frequency.
- Motor torque.
- Motor speed.
- Ship Speed.

4.2 Voltage and Frequency Control

The prime mover fuel rate is used to control system frequency. This is accomplished by the speed governor. The voltage regulator uses the generator field excitation to control the bus voltage. Both of these variables are controlled in closed-loop fashion by the simple P-I type controllers described in chapter 2. The objective for controlling bus frequency and voltage is to maintain both at their constant set point values. For U.S. Navy ships, the requirements for electric power generation are found in MIL-STD-1399. Table 4-1 summarizes the voltage and frequency requirements contained therein.

	Frequency	Voltage
Nominal	60 Hz	440/115 Volts
Steady State Tolerance	$\pm 3\%$	$\pm 5\%$
Transient Tolerance	$\pm 4\%$	$\pm 16\%$
Worst Case Excursion	$\pm 5.5\%$	$\pm 20\%$

Table 4-1

4.3 Control of Inverter fed Motor

The propulsion motor speed and torque, and consequently the ship's speed are controlled by the rectifier and inverter firing angles and the motor field excitation. The following sections describe various schemes for controlling the propulsion motor / frequency changer combination.

4.3.1 Open Loop Volts/Hertz Control

This method of control is the one method true synchronous operation with an inverter-fed synchronous motor. In this method of control, the inverter frequency is a control input which uniquely determines the machine speed. As the load torque changes, the electromagnetic torque is developed by changes in the load angle δ . This is analogous to the operation of a synchronous motor attached to a conventional constant frequency supply. This type of control is used in voltage-fed inverters where the terminal voltage of the motor can be controlled in proportion to the supply frequency. By maintaining a constant volts/hertz ratio at the motor terminals, the airgap flux of the machine remains constant and maximum torque is developed at all speeds.

The main advantage of this method is that accurate control of machine speed can be achieved at all speeds. This control method is commonly used with permanent magnet and variable reluctance machines. Open loop control is not suitable for applications with high dynamic performance requirements, and consequently is not considered for ship propulsion applications [9].

4.3.2 Self-Controlled Synchronous Motors

This type of motor is also known as an electronically commutated motor (ECM), or a brushless dc motor because the torque-speed characteristics of the motor are similar to that of a mechanically commutated dc motor. The inverter bridge replaces the mechanical commutator, making the terminal characteristics at the dc side of the inverter identical to that of a mechanically commutated motor.

The self control method is a closed-loop scheme where the inverter frequency is slaved to the rotational speed of the motor. This is accomplished by the use of a position sensor on the motor to generate the inverter firing pulses. Some systems have replaced the position sensor with algorithms which determine the rotor position from the terminal voltages of the motor [22]. By using the rotor position to trigger the inverter firing, the motor can't fall out of step with the supply. This type of control is applicable to voltage or current-fed inverters as well as cycloconverters. Permanent magnet, variable reluctance or conventional wound rotor synchronous motors may be controlled in this manner.

In high power applications such as ship propulsion, this method is most commonly used with the LCI-fed synchronous motor. The electromagnetic torque of the motor is directly proportional to the dc-link current in this configuration. The motor speed is determined by the balance between the electromechanical and load torques. Consequently, the control system usually consists of a two-loop arrangement with the inner torque control loop controlling the dc-link current and the outer loop controlling the speed of the motor.

The rectifier firing angle is the control variable which is used to control the dc-link current. The field excitation of the motor is controlled to maintain a constant airgap flux, providing constant torque output for a given current level. This arrangement is pictured schematically in figure 4-1.

The load commutated inverter is most commonly found on high power applications since it is simpler in construction and exhibits lower power losses than forced commutated inverters [23]. It is limited by the fact that it requires the motor to operate at

a leading power factor to ensure thyristor commutation. Additionally, at low speeds (below about 10% of rated) the back EMF generated by the motor is insufficient to ensure thyristor commutation and some method of forced commutation must be employed. The simplest method of accomplishing this without introducing additional circuit elements is to pulse the dc-link current on and off. This does produce large pulsating torques, but in ship propulsion applications, that is not considered to be a serious drawback.

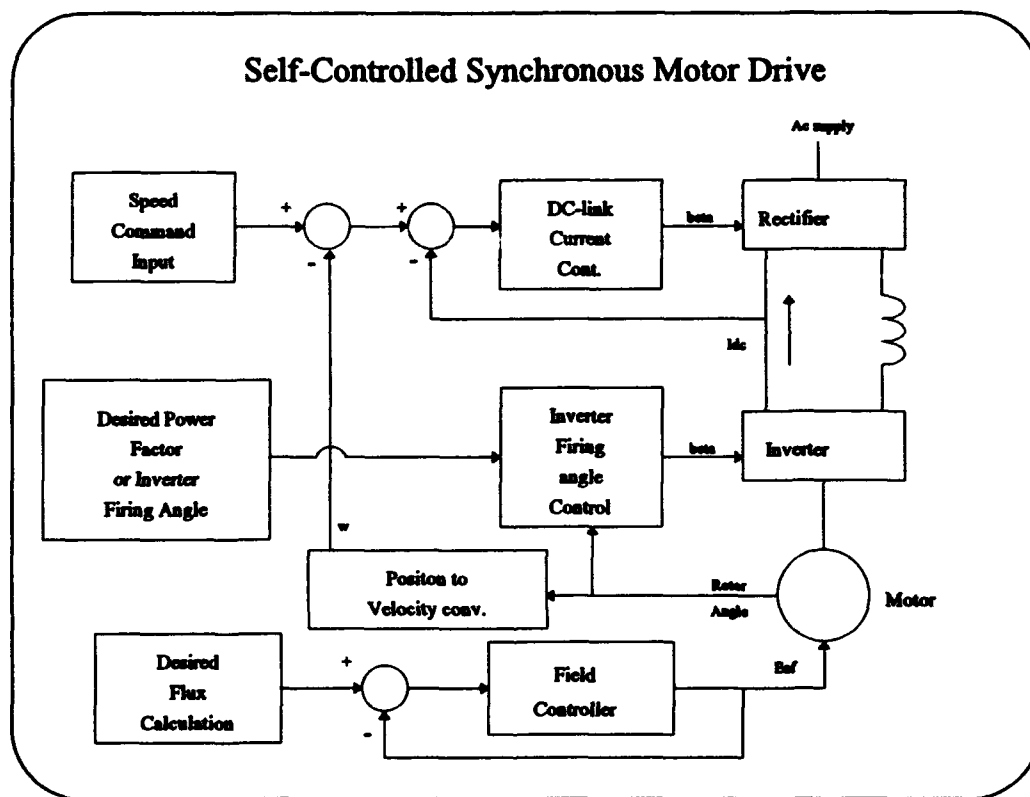


Figure 4-1

While the rectifier firing angle is used to control the motor torque, the inverter firing angle can be used to control the position of the stator current waveform relative to the stator voltage, thus controlling the power factor. This is known as constant margin

angle control and is one of two control schemes used in the simulations for control of the inverter firing angle. The other is simply to keep the inverter firing angle constant.

Obviously, the constant firing angle control is easier to realize, however the constant margin angle control offers several advantages. With constant margin angle control, the inverter firing angle and field excitation are controlled in unison to maintain the stator flux at a constant value as shown in figure 4-2. By maintaining the flux relationship shown in this phasor diagram, the leading power factor required for load commutation is ensured under all load conditions. This is not the case with constant firing angle control. Also, with constant firing angle control the power factor angle becomes quite large in the lightly loaded condition. This causes excessive VAR loading on the inverter [9].

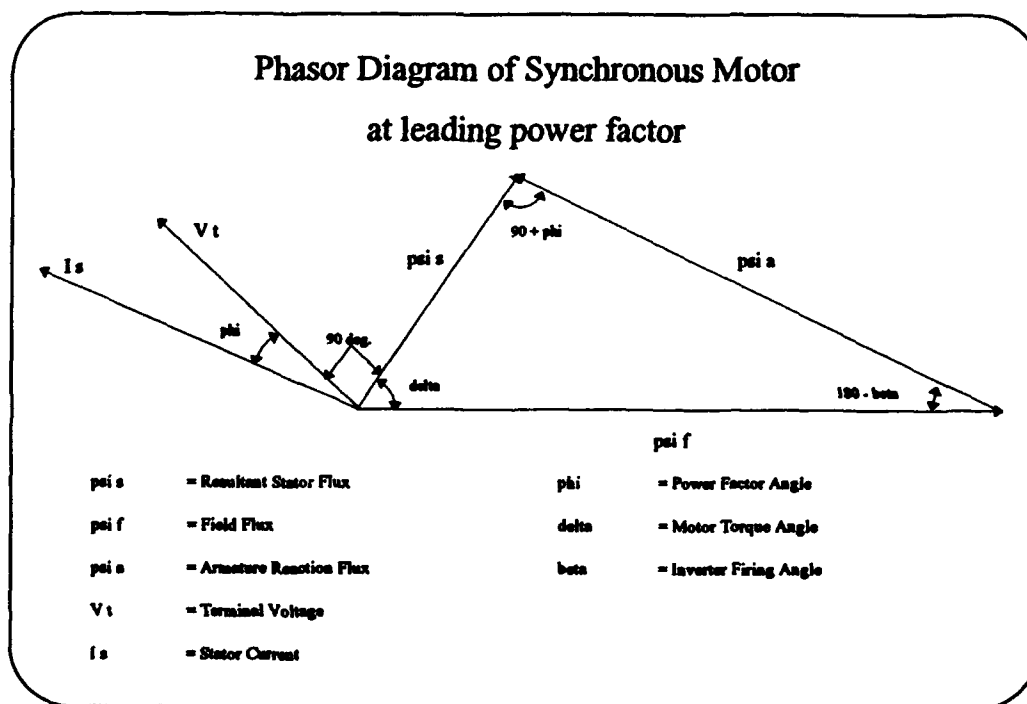


Figure 4-2

4.3.3 Vector Controlled Synchronous Motors

This type of control is also known as field oriented control. Vector control de-couples the field current from the torque component of stator current as is the case in mechanically commutated dc machines. This can be accomplished on an electronically commutated machine by operating at unity power factor. Since the LCI drive requires a leading power factor to ensure thyristor commutation, vector control is not possible with the LCI drive [23].

The primary purpose of using vector control over a self-controlled machine is to provide faster time response. For ship propulsion applications, the improved response is not needed because the ship dynamics are slower than the electrical dynamics and are the controlling factor in determining the motor's speed response. For these reasons, this type of control was not considered for use in the present simulations.

4.3.4 Motor Control for Ship Propulsion

All of the control schemes outlined above have been developed for applications where precise speed control of the motor is required. Precise speed control of the propulsion motor is not required or even desired in shipboard applications. This is due to the nature of the loading on the motor. The motor sees a load torque which is a quadratic function of speed in the steady state, but varies about its mean value as the ship encounters waves. This variation in loading is caused by the ship motions in the seaway and can become very significant in heavy sea states.

One approximation for this loading is used in the ship dynamics model described in chapter 2. This approximation assumes a single frequency sea induced sinusoidal variation

of the ship's speed. While this is a crude approximation at best, it does manage simulate the major influence the seaway has on the propulsion system, that of the time varying nature of the ship's speed as it traverses over large ground swells. This approximation does not account for any propeller racing which sometimes occurs as a result of the ship's pitching and rolling in a heavy sea state. It also does not account for the random nature and many frequencies of waves which make up a seaway.

Figure 4-3 shows a simulation run with a standard self-controlled synchronous motor drive system. The outer speed control loop uses a P-I type controller to maintain the motor speed. Note that the sinusoidal variation in ship speed shows up in the trace of motor torque. This variation propagates back through the electrical system causing a similar variation in the generator loading. Another simulation run with a different wave frequency was able to excite one of the natural modes of the gas turbine engine and cause a frequency oscillation as well. With this type of loading on the propulsion motor, it would be difficult if not impossible to maintain the power requirements in table 4-1 even in the steady state.

One solution to this problem would be to adjust the gain and time constant on the speed controller so that the sea induced load variation is faster than the response of the controller and would be attenuated as noise. The problem with this approach is that this requires a time constant on the order of 30+ seconds which would result in a very sluggish response to changes in the commanded speed input from the ship's bridge. On supertankers or Navy re-supply ships this type of response may be tolerated, however it is expected that combatant ships be able to stop and change speeds quickly.

To solve this problem of conflicting requirements, a two mode controller was developed which has a sluggish low gain band in the vicinity of zero speed error and a fast high gain response outside of this band. The low gain region allows the motor speed to vary in response to the sea induced loading variations while minimizing its effect on the main electrical bus and generators. The high gain region ensures a quick response to operator input. Figure 4-4 shows a block diagram representation of the two mode motor control used in the simulations. Figure 4-5 shows the response of the two mode controller to the same loading condition as that of figure 4-3. The two mode controller was used for all subsequent simulations.

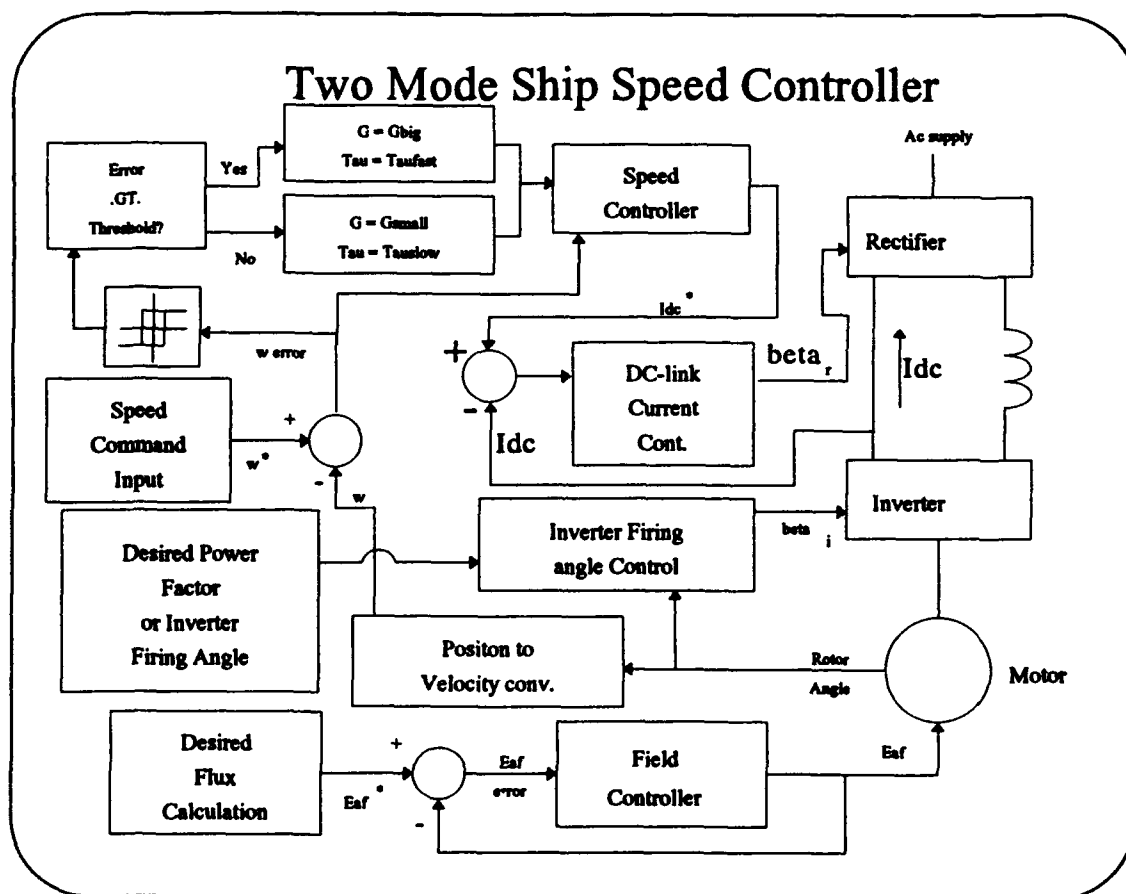


Figure 4-4

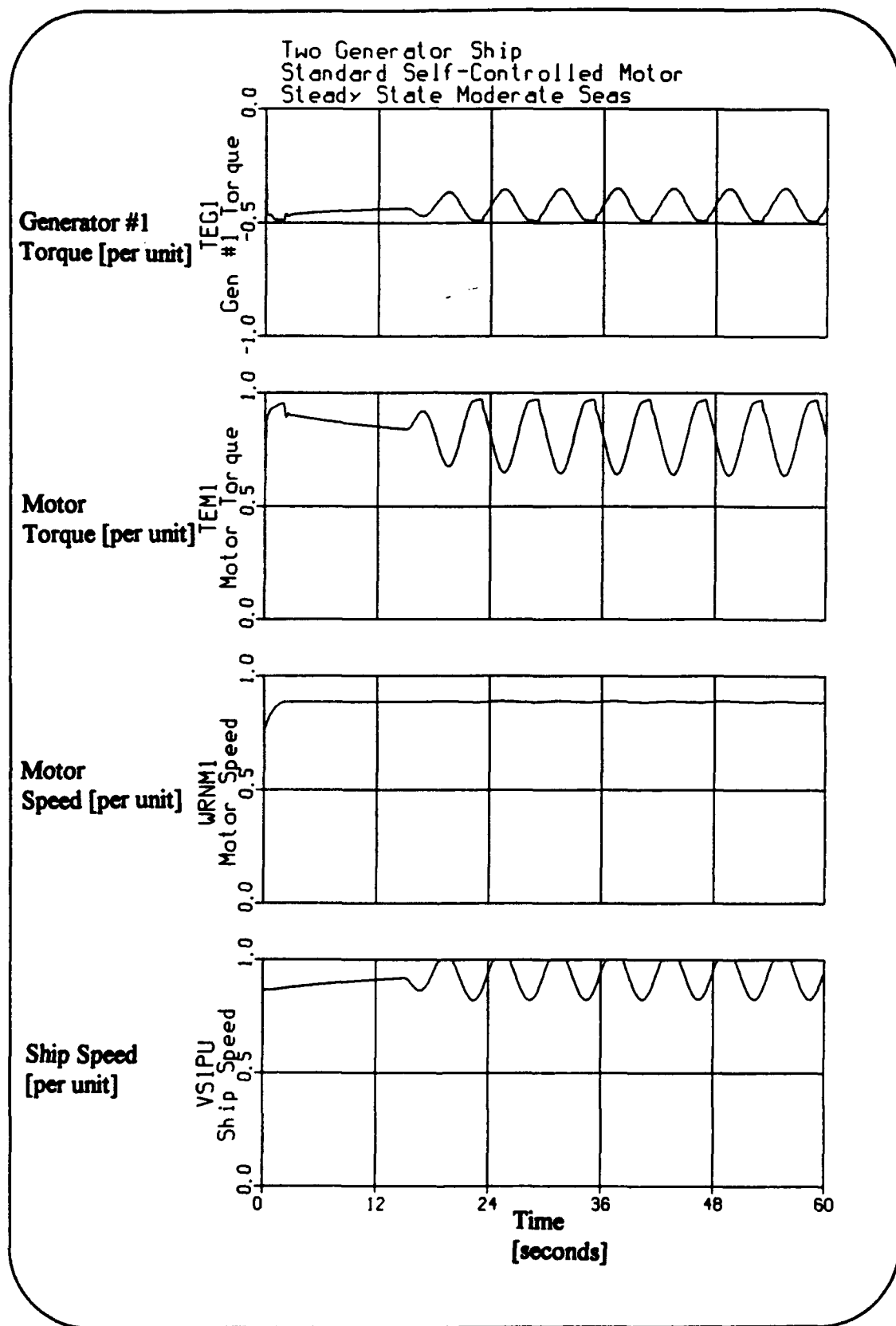


Figure 4-3

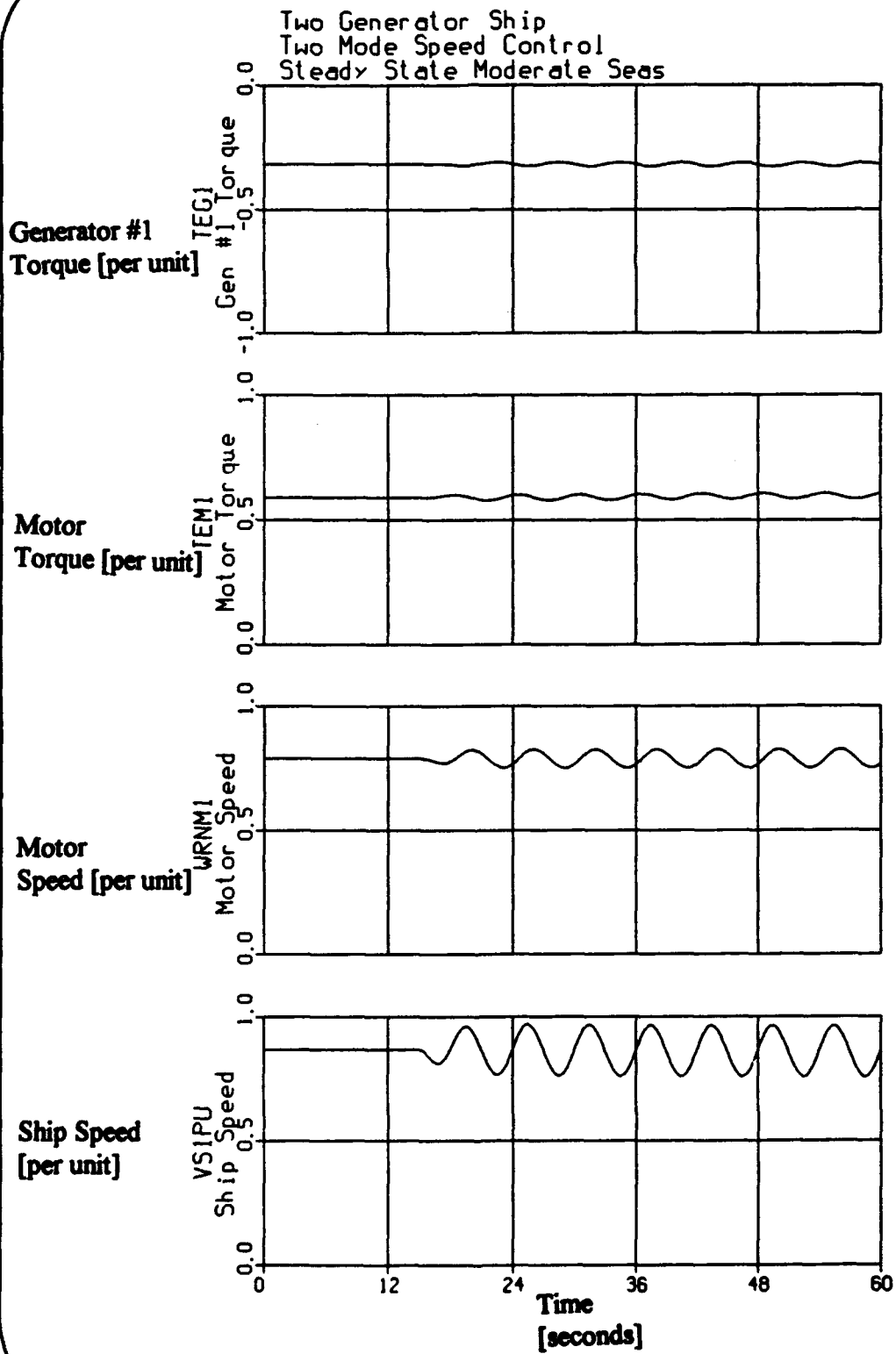


Figure 4-5

Chapter 5: Results and Conclusions

5.1 Simulation Results

Numerous simulations were conducted to verify the operation of the computer models and to evaluate the proposed control schemes. Both of the two systems outlined in chapter 3 were evaluated with similar results. The following sections describe some of the specific simulation runs. Complete graphical results are located in appendix D.

5.1.1 Two Generator Ship: Acceleration From Rest

In this run, the ship is simply accelerated from rest to a speed of 0.9 per unit. After running the simulation for 15 seconds to settle out the gas turbine speed, the shaft speed input setting is changed from 0.05 per unit to 0.9 per unit. This change in desired speed setting causes the dc-link current to increase to its maximum value, followed by the motor terminal currents. The motor speed rises to about 0.5 per unit in 4-5 seconds, then it accelerates at the same rate as the ship speed increases as shown in figure 5-1. Similarly, the motor terminal voltage builds up with the motor speed. This is what would be expected given the form of the motor and ship dynamics models. The two mode control switches into the "fast mode" when the input command is given. It switches back to the slow mode when the motor speed error is reduced to the threshold value of 0.1 per unit. There is no seaway invoked for this simulation.

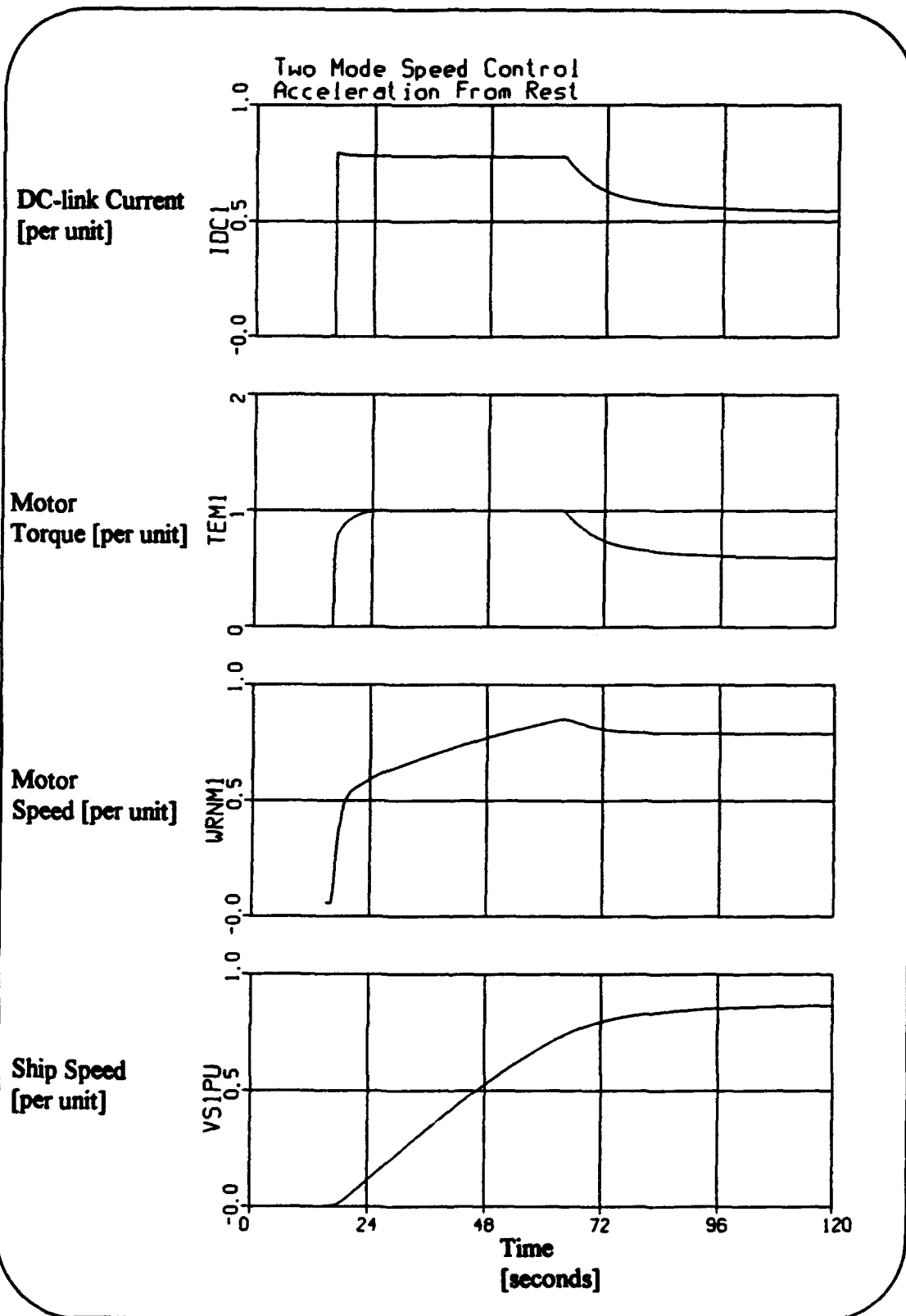


Figure 5-1

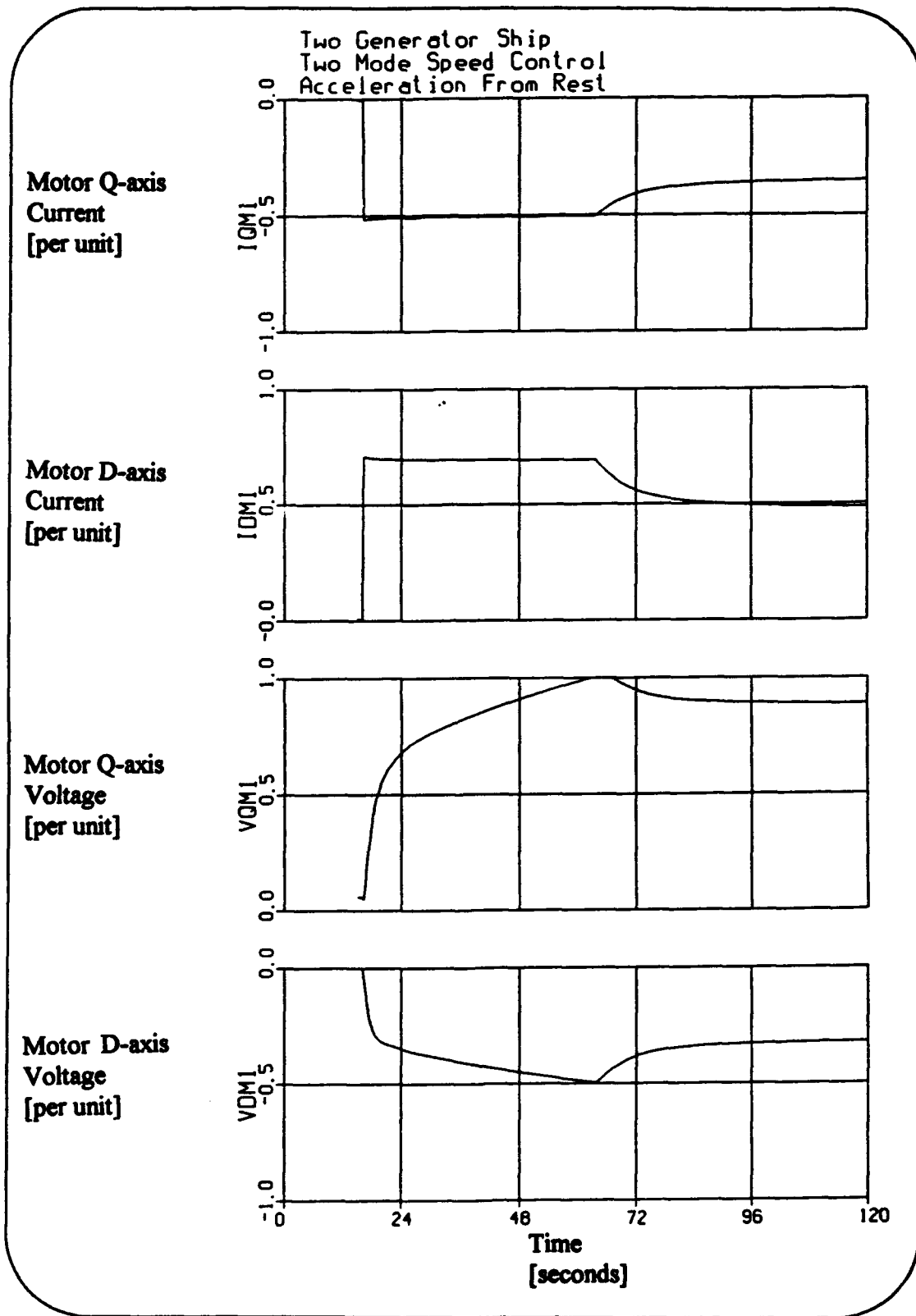


Figure 5-1 (continued)

5.1.2 Two Generator Ship: Moderate Sea State

This simulation was described in chapter 4. Currently, the threshold value for the switch from "fast mode" to "slow mode" has been optimized for the moderate sea state conditions in the ship dynamics model. In actuality, this threshold would be made somewhat larger to allow the ship to operate at steady state in any sea without the control system switching into the "fast mode".

The threshold value is now simply a constant value of speed error. Because of the low gain in the "slow mode", the system has a large steady state error which at lower speed settings becomes quite significant. A different technique would be to make the threshold value a constant fraction of the current desired speed setting. The above simulation was repeated after making this modification. The results at low speed settings showed improved steady state error, however at higher speed settings the system would switch back and forth between the fast and slow modes. With a little fine tuning of the constants, it is believed that this technique would work quite well.

5.1.3 Two Generator Ship: Crashback

"Crashback" is the name given to the event that occurs when the ship is traveling ahead at a high rate of speed and reverse speed is ordered. This is the equivalent of slamming on the brakes in an automobile, and is an important measure of the maneuvering performance of the ship. It is also the harshest transient on any drive system, mechanical or electric. This was the most difficult simulation to run since it involved making a sequence of events occur in logical steps with the only input being the change of the speed input command.

This simulation begins with the ship operating at a steady speed of 0.9 per unit. At $T=115$ seconds, the speed setting is changed from 0.9 to -0.5 per unit. First, the rectifier firing angle is set to 90 degrees which causes the dc-link current to decay rapidly to zero. When it reaches zero, the inverter firing angle is also set to 90 degrees. This is done to keep the terminal voltage of the motor from reversing the dc-link current. These actions effectively isolate the motor from the propulsion bus.

Next, a braking resistor is applied across the terminals of the propulsion motor. This is initially set to a conductance value of 1.5 per unit. In figure 5-2 this can be identified by the first peak in motor torque and current. The motor rapidly slows to about 0.2 per unit speed, then decays slowly. When the terminal voltage decays to 0.3 per unit, the conductance is changed to 5.0 per unit causing the second torque peak and speed drop. This configuration is held until the motor speed drops to 0.04 per unit.

At this time the phase sequence of the inverter is reversed and the rectifier and inverter firing angles are returned to their normal controlled values. This action causes the third torque spike which stops the motor and causes it to reverse directions. As the motor continues rotating in reverse, the ship eventually stops and reverses direction also. This is also evidenced in figure 5-2.

This simulation run illustrates very well the difficult requirement of controlling this type of system such that the operator only has to give a single input to achieve the desired result. The controls demonstrated here are still quite rudimentary, however. The torque trace in figure 5-2 shows that the motor is over-torqued when the braking resistor is engaged and when its value is changed. A better method would be to use several steps of

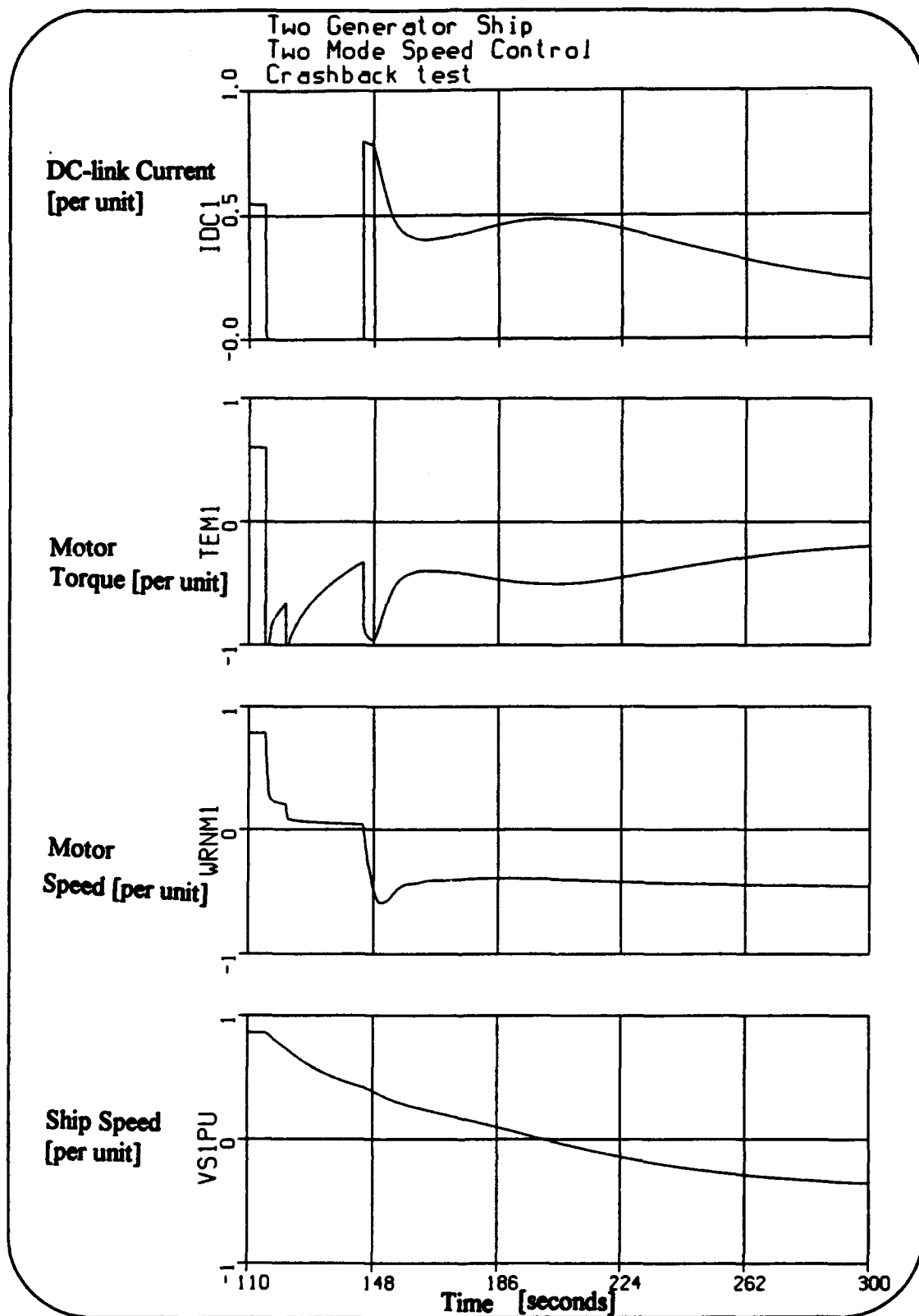


Figure 5-2

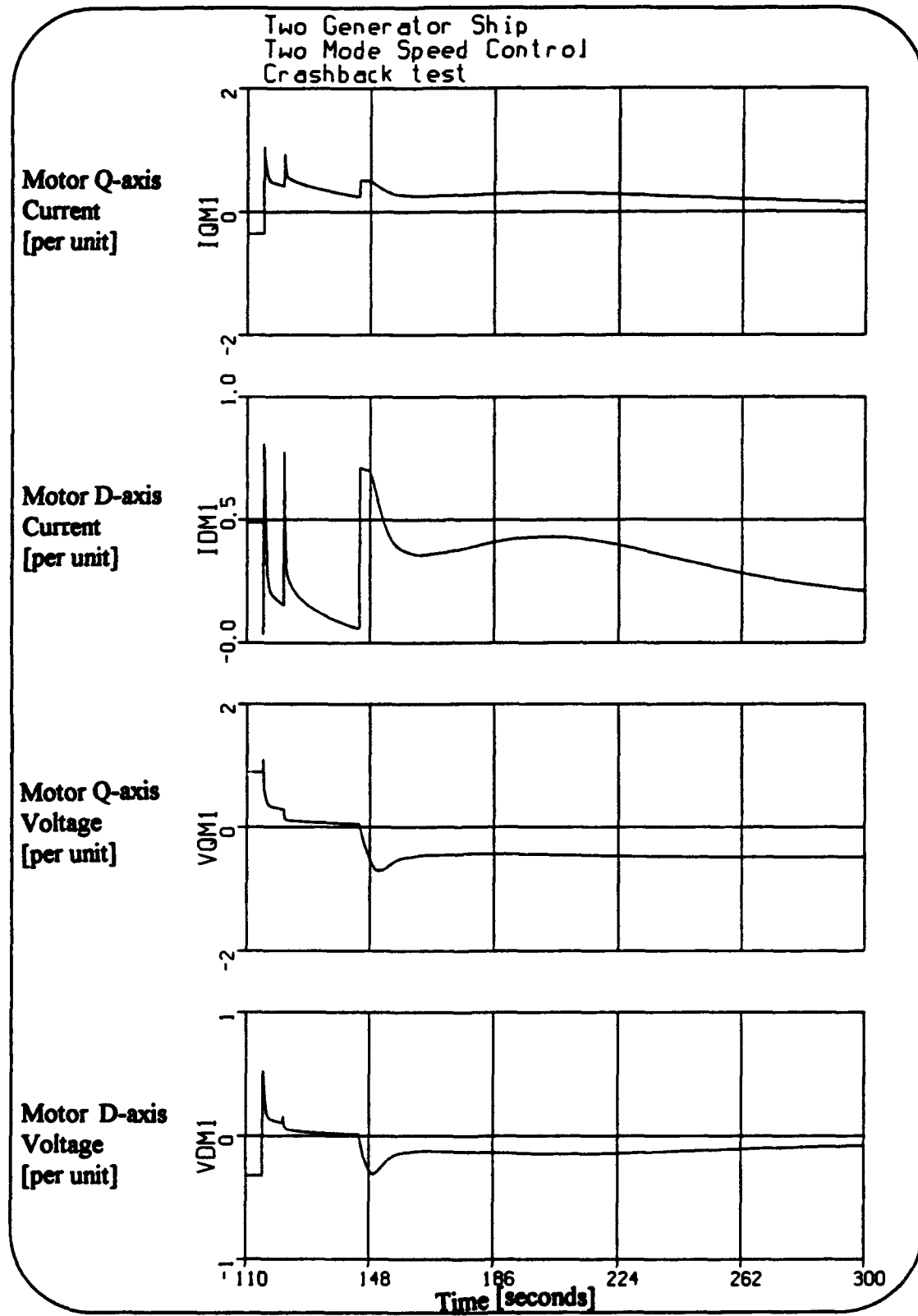


Figure 5-2 (continued)

resistor values to prevent this over-torque problem. A more sophisticated system would use the power generated in slowing the propulsion motor to supply the ship's service load by feeding it back to the bus through the frequency changer. This has been discussed at the concept level in conjunction with pulsed power weapons. The current simulation models are capable of simulating this mode of operation given the proper control system. Another feature which has not been looked into is limiting the rate at which the motor load is removed from the bus. Currently it is removed instantaneously which can cause a generator over-speed shutdown if the generator is highly loaded [24].

5.1.4 Two Generator Ship: Generator Failure

As the name implies this run simulates the results when one of the two generators is tripped off-line. Actually, this consists of two different runs. The reason for this is that the results are quite different for the two situations. In both cases generator #2 is disconnected from the bus, causing generator #1 (the gas turbine generator) to pick up the entire propulsion and ship service load.

In the first run, the speed input is set to 0.5 per unit. At $T=15$ seconds the generator #2 breaker is tripped, causing generator #1 to take the entire load. In this case, the combined propulsion and ship's service load is less than the capacity of generator #1, which successfully picks up the entire load as generator #2 shuts down. Notice in figure 5-3 that the motor variables are effectively constant during the entire period of transition from two to one generator.

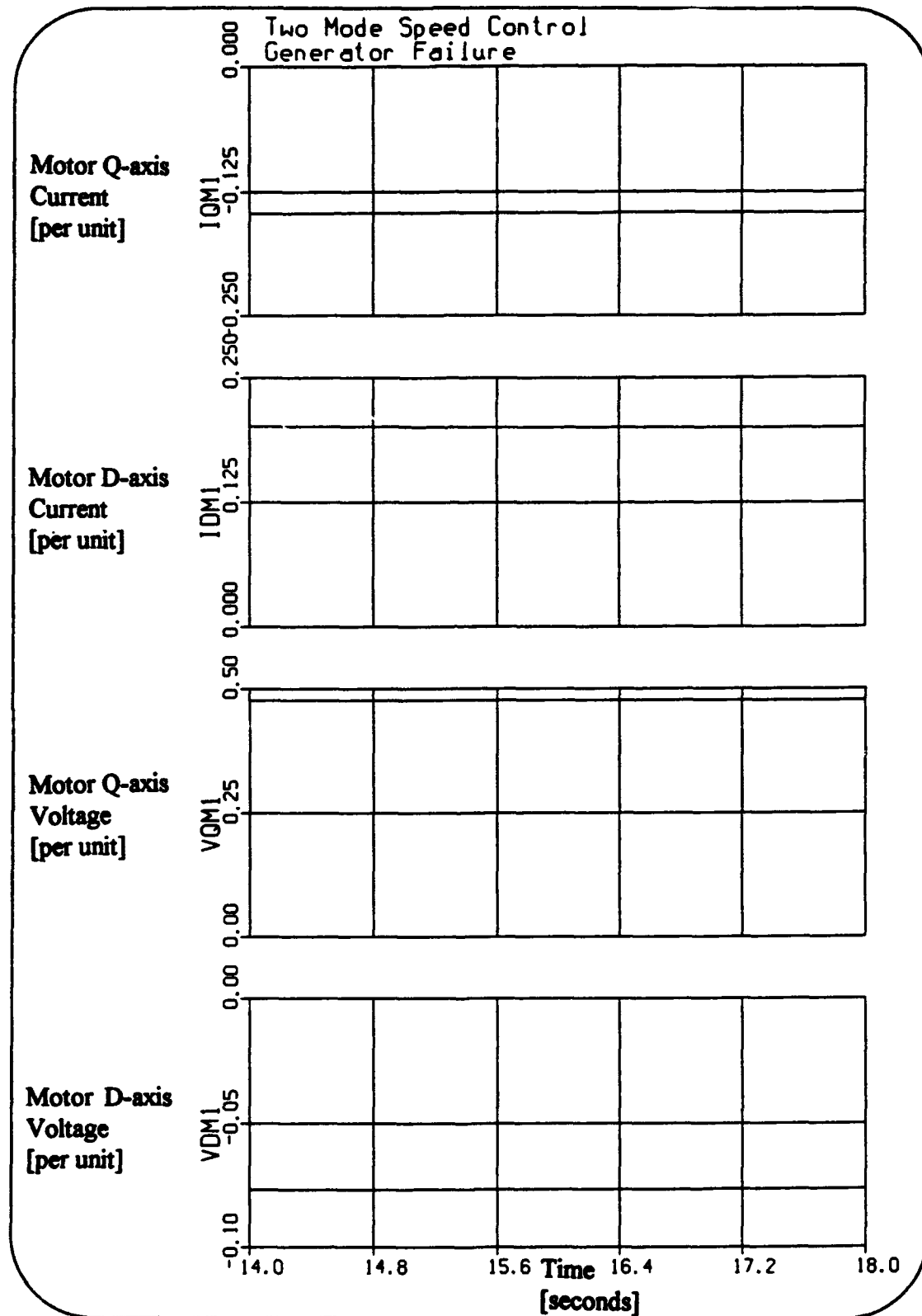


Figure 5-3

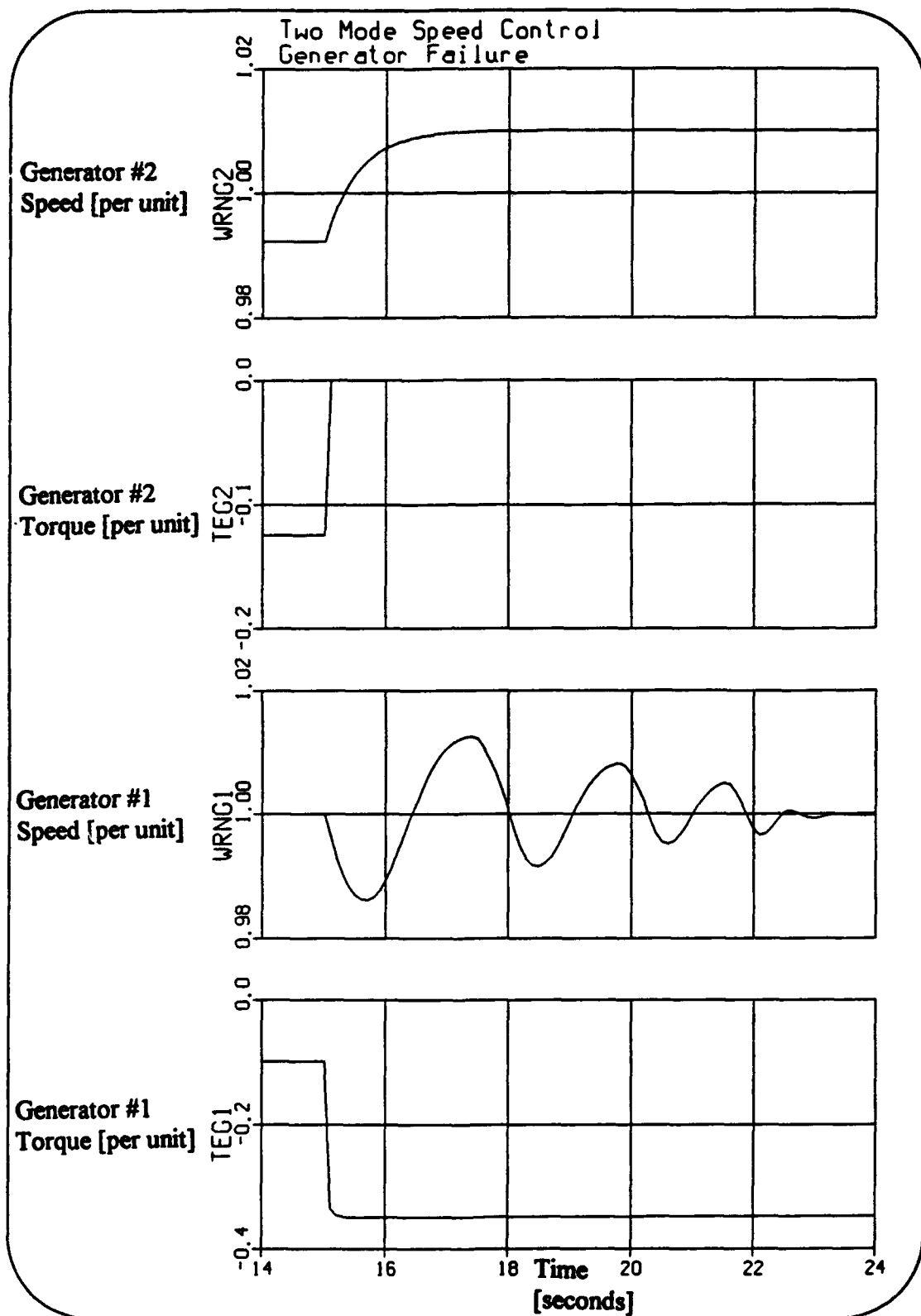


Figure 5-3 (continued)

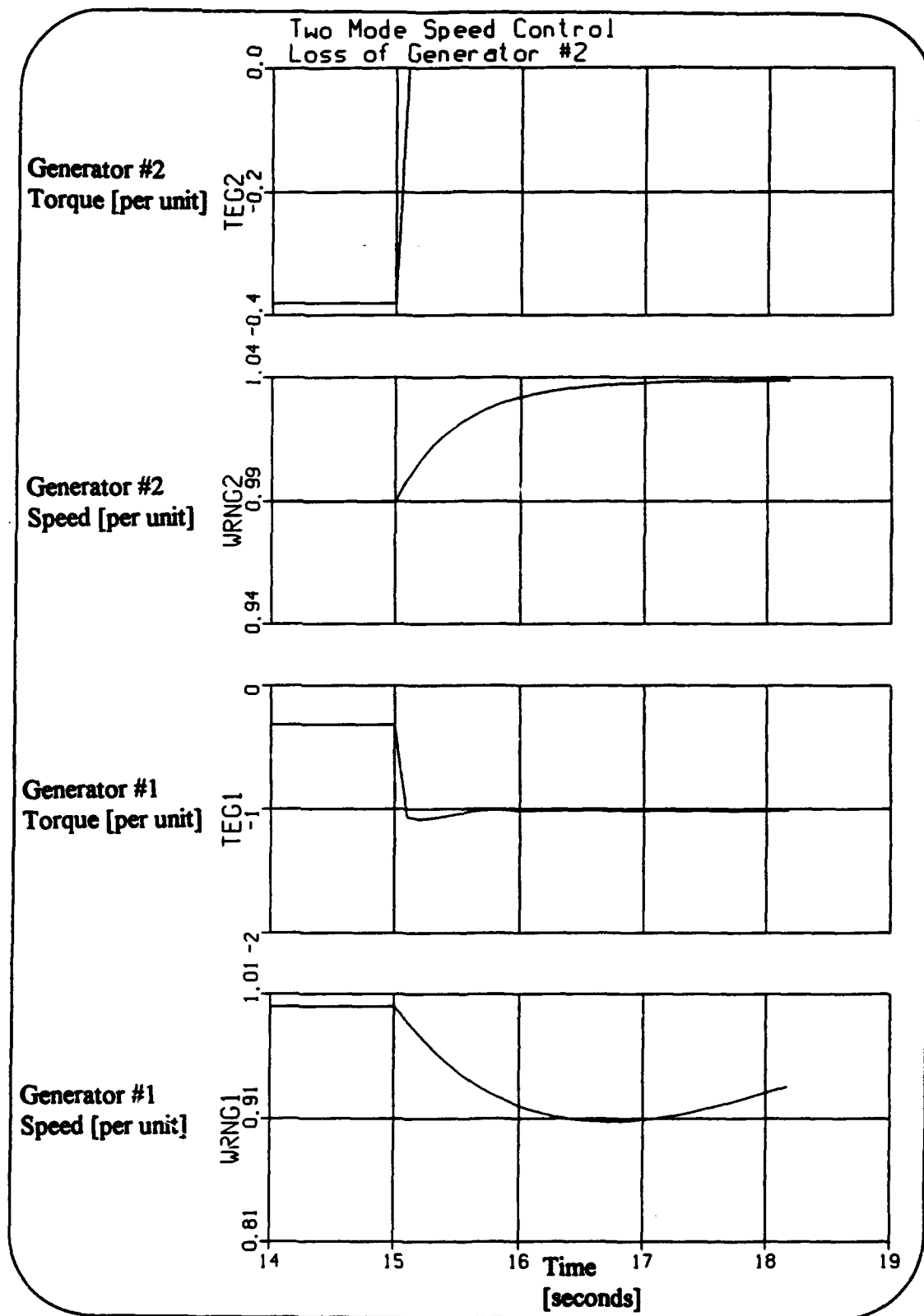


Figure 5-4

In the second run the speed is set to 0.9 per unit. Again, generator #2 is tripped off-line at $T=15$ seconds. In this case, the power demanded by the propulsion motor and ship's service load is greater than the capacity of generator #1. The torque trace in figure 5-4 shows the over-torque condition which results on generator #1. This over-torque condition causes a power turbine over-temperature shutdown of the gas turbine 3.18 seconds after the first generator failure. In this load condition, a one generator failure degrades into a two generator failure causing the entire ship to lose electrical power. This is obviously not an acceptable result. What is required to eliminate this problem is a supervisory control system which will monitor the on-line generating capacity and limit the maximum power demand of the propulsion motor to that which is available at any given instant in time. This will allow the ship to keep operating, albeit in a reduced capacity, when a generator failure occurs.

5.2 Features and Limitations of Simulation Models

There are several useful features to the simulation models developed in this research. First, they are highly portable. The only required hardware is a PC or a workstation. The software requirements are the ACSL program and a FORTRAN compiler. The ACSL translator writes FORTRAN-77 code which will compile on virtually any compiler. It should be noted that these systems do take a few hours to run on even the fastest PC's currently available. It is recommended that any future simulations done with these models be done on a workstation.

The models have been written in a modular object oriented fashion. This makes them quite flexible. Each physical component is written as a separate ACSL macro which allows the generation of unique variable names for each instance of a particular object. The control components are also in separate macros which readily allows evaluation of various control schemes without changing the basic configuration of the model.

Similarly, the interconnection equations have been solved to allow easy modification of the system. Any number of generators or loads can be added to the main bus by simply algebraically adding its current to equations (3.23) & (3.24) and writing its transmission line equations, ((3.19) & (3.20) for generators or (3.21) & (3.22) for loads). Consequently, it is very easy to change the configuration of the simulation model. Only a knowledge of Kirchoff's laws and a minimal understanding of ACSL syntax is required to modify the system to suit the users needs.

There are also some limitations to the current models. The frequency changer model doesn't have a discontinuous current mode of operation. As mentioned previously, when the motor speed drops below about 10% of rated, the back EMF isn't sufficient to cause commutation of the inverter thyristers. This has been ignored in the current model. One method of simulating discontinuous conduction in an average value model presented by Branson [12] makes the dc-link current follow a rectified sine wave.

Another limitation to the current models is the diesel engine. It has not been properly verified against test data for the actual engine. Despite numerous efforts, the author has been unable to obtain dynamometer data for the particular engine which has been modeled. The computer model has been qualitatively compared to actual data of

other engines, but a quantitative comparison can only be made against the engine on which the engine map is based.

The ship load dynamic model could be improved. It is only a one dimensional model, whereas ship motions have six degrees of freedom. The model allows two propeller shaft inputs, but since it is one dimensional, operating the two shafts at different speeds only results in an averaged speed output. This can be seen in the outputs of the two motor simulations in appendix C. In an actual ship, this type of operation would generate a yawing moment causing the ship to turn left or right. The seaway feature of this model could also be improved upon. A real seaway is random in nature, containing many harmonic components. Many of these components will not excite the propulsion system, however some sort of random distribution of wave frequency would be an improvement on the current model.

5.3 Suggestions for Future Research

Quantitatively verify the diesel engine model. This may require switching the model to a different engine. The particular engine chosen for this study was selected because it is a Navy qualified diesel generator set currently in use aboard ships. Perhaps a manufacturer who is not yet Navy qualified would be more forthcoming with their test data.

Add a discontinuous conduction mode to the frequency changer model. Similarly, including the effects of AC-side reactance which were ignored in the development of the current model would be more realistic. AC-side reactance is always present when

connected to a motor load. Bose [9] presents this concept, but does not utilize it in the development of average value converter models for control studies.

The controls which have developed to date are rather rudimentary. More sophisticated controls incorporating the supervisory features discussed above should be developed. The concepts of graceful degradation and damage tolerant controls should also be investigated.

5.4 Conclusions

This research has developed and demonstrated useful tools for the design of controls for shipboard electrical systems. By taking an object oriented approach, the resulting tools are very flexible and can be used to simulate any conceivable shipboard configuration with only minor alterations. As a result the "learning curve" for an engineer not familiar with the specifics of ACSL or the various devices is greatly reduced.

The current model parameters are based on the U.S. Navy's "Baseline 2" electric drive system which utilizes wound rotor synchronous machine technology. The flexibility of these simulation models allows other technologies such as permanent magnet or superconducting machines to be simulated with *minimal* changes to the model.

This research has also conducted a preliminary control analysis of the required control systems. It has pointed out areas where more sophisticated controls are required and areas where existing controls may be adequate. The controls engineer interested in this specific problem now has a flexible tool which may be used to evaluate many sorts of control systems, only some of which have been discussed herein.

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Appendix A: ACSL Code

A.1 System #1

```
=====
|
|      system 1: single generator
|      with ship dynamics and ship service loads
|
|      Copyright 1993 by Timothy J. McCoy
|
|*****
|      NOTE:  this model requires the following compiler
|              command line options:  "/AH /B1 fl1.exe"
|*****
|
|      NOTE:  The gas turbine and ship dynamics models require
|              the following function lookup subroutines:
|              fcq.for,func.for,qlapsf.for,qlavsf.for,
|              qlavr.for,tlavsf.for,tlavr.for
|
|      These subroutines are property of the U.S. Navy and
|      can be obtained by qualified users from code 2753 of
|      NSWC Annapolis Detachment (Formerly DTRC-Annapolis).
|
|=====
|
|      RECORD OF CHANGES
|
|      NO.  DATE      BY      SUMMARY
|      ---  -
|      0    4-10-93  tjm      Model Written.
|=====
PROGRAM system1
|=====
|      MACRO DEFINITIONS
|=====
INCLUDE 'c:\acsl\synmac\syntaxr4.mac'
INCLUDE 'c:\acsl\synmac\syntaxr4b.mac'
INCLUDE 'c:\acsl\freqchg\freqchg2.mac'
INCLUDE 'c:\acsl\synmac\vreg2.mac'
INCLUDE 'c:\acsl\synmac\contmrtr.mac'
INCLUDE 'c:\acsl\synmac\spdcon3.mac'
INCLUDE 'c:\acsl\misc\constant.inc'
INCLUDE 'c:\acsl\lm2500\turbine.mac'
INCLUDE 'c:\acsl\ship\ship.mac'
INCLUDE 'c:\acsl\loads\shipserv.mac'
INCLUDE 'c:\acsl\misc\baseconv.mac'
|=====
|      INITIAL SECTION
|=====
INITIAL
    SORT
```

```

!---Set base frequency & bus parameters
CONSTANT wo      = 377.0 !---[rad/sec]
CONSTANT xgl      = 0.1, &
          xll      = 0.1, &
          xml      = 0.1

!---Set parameters for dynamic brake
LOGICAL lbrake
  lbrake = .false.
  kbrake = 1.0
  gml    = 1.5

!---Set frequency changer parameters
LOGICAL lfwdl
  lfwdl = .true.

!---Set synchronous motor parameters (20,000 HP 150 RPM motor)
!---24 poles
CONSTANT &
  xqml      = 1.157,&
  xdm1      = 1.76 ,&
  xqppm1    = 0.494,&
  xdppm1    = 0.542,&
  xdpml     = 0.608,&
  xlm1      = 0.337,&
  tdopml    = 2.10 ,&
  tdoppm1   = 0.039,&
  tqoppm1   = 0.193,&
  basemml   = 150 ,&
  basevml   = 5000 ,&
  basekwml  = 14914.0

  hml       = 0.773 + hhps !---hhps is propeller/shaft inertia
  baseqml   = 1000*basekwml/(basemml/rparad)

  xdmxqml   = xdm1 - xqml
!---Initialize the synchronous motors
mtr4ic(ml)

!---Set synchronous generator parameters (18 MVA w h20 cooled stator)
!---values provided by NSWC
CONSTANT &
  xqgl      = 1.64 ,&
  xdgl      = 1.77 ,&
  xqppgl    = 0.15 ,&
  xdppgl    = 0.15 ,&
  xdpgl     = 0.18 ,&
  xlg1      = 0.13 ,&
  tdopgl    = 3.19 ,&
  tdoppgl   = 0.04 ,&
  tqoppgl   = 0.09 ,&
  hgl       = 0.924,&
  basengl   = 3600.,&
  basevgl   = 4160.,&

```

```

basekwgl = 16200.0

!---conversion factors for generator and motor bases
baseconv(kvglml,kkwglml,kiglm1,kzglm1 = &
        basevgl,basevml,basekwgl,basekwml)

!---Initialize synchronous generators
mtr4bic(gl)

!---Initialize gas turbine engine
LOGICAL lpwrd1      !---true for power demand mode
CONSTANT lpwrd1 = .FALSE. !---false for speed demand mode
CONSTANT wrnlord = 1.0 !---ordered speed [per unit]
CONSTANT wrnlordic = 1.0 !---ordered speed ic [per unit]
CONSTANT teglic = 0.0 !---electrical torque ic [per unit]
CONSTANT wrnglic = 1.0 !---generator speed ic [per unit]

!---set desired motor speed
CONSTANT spdrefl = 1.0

END !---of initial
!=====
!
! DYNAMIC SECTION
!=====
DYNAMIC

CINTERVAL CINT = .05 ! Communication interval
NSTEPS nstp = 10
MAXTERVAL MAXT = .1 ! Maximum integration step
MINTERVAL MINT = 1.0E-8 ! Minimum integration step
ALGORITHM IALG = 1 ! Integration algorithm
CONSTANT tstop = 0.0 ! stop time

!---stop on reaching maximum time
TERMT(t.GE.(tstop-CINT/2.0),'====> STOP on time limit <====')

!=====
!
! DERIVATIVE SECTION
!=====
DERIVATIVE
!---Invoke synchronous generator macros
synmtr4b(tagl,vqgl,vdgl = eafgl,iqgl,idgl,wrngl,gl)

!---Invoke voltage regulator macros
vreg2(eafgl = vdgl,vqgl,gl)

!---Invoke Gas Turbine engine macro
turbine(1,lpwrd1,wrnlord,wrnlordic,tagl,teglic,wrnglic,wrngl,qptlpu)
wmgl = wrngl*wo

!---Invoke synchronous motor macro
synmtr4 (teml,vqml,vdml,wrml = eafml,iqml,idml,ttml,ml)

!---Invoke motor controller macro
contmtr(eafml,betail = idml,iqml,vdml,vqml,edppml,eqppml,&

```

```

        xdppm1,xdmxxm1,xqm1,lbrake,m1)

!---Invoke frequency changer macro
freqchg (iqrl,idr1,iqil,idil = &
        vqrl,vdr1,vqil,vdil,icr1,betail,lfd1,lbrake,1)

!---Invoke speed controller macro
speedcon (icr1,lfd1,lbrake = spdref1,wrnm1,idc1,1)

!---Invoke ship load macro
wrnm2 = wrnm1
ship(tmm1,tmm2 = wrnm1,wrnm2,basenm1)

!---Invoke ship service load macro
shipserv(idl2,iql2 = vdbus,vqbus,1)

!---Transmission line equations
idgl   = (idr1 + idl2)/kiglml
iqgl   = (iqrl + iql2)/kiglml
vdbus  = vdgl + iqrl*xgl
vqbus  = vqgl - idrl*xgl
vdr1   = vdbus + iqrl*xl1
vqrl   = vqbus - idrl*xl1
vdil   = vdm1 + iqm1*xm1
vqil   = vqm1 - idm1*xm1

!---This procedural places a braking resistor across motor terminals
!---when lbrake = .true.
PROCEDURAL (idm1,iqm1 = idil,iqil,gm1,lbrake)
    IF(lbrake)THEN
        IF(vtm1.LT.0.3) gm1 = 5.0
        idbm1 = vdm1*gm1
        iqbm1 = vqm1*gm1
        idm1  = idil + idbm1
        iqm1  = iqil + iqbm1
    ELSE
        gm1    = 1.5
        idbm1  = 0.0
        iqbm1  = 0.0
        idm1   = idil
        iqm1   = iqil
    ENDIF
END !---of procedural

END !---of derivative

END !---of dynamic
!=====
!                                     TERMINAL SECTION
!=====
TERMINAL

END !---of terminal

END !---of program

```

A.2 System #2

```
=====
|
|               System 2a: two generators in parallel
|             with ship dynamics and ship service loads
|
|             Copyright 1993 by Timothy J. McCoy
|
|*****
|      NOTE:   this model requires the following compiler
|             command line options:  "/AH /BI fl1.exe"
|*****
|
|      NOTE:   The gas turbine and ship dynamics models require
|             the following function lookup subroutines:
|             fcq.for,func.for,qlapsf.for,qlavsf.for,
|             qlavsr.for,tlavsf.for,tlavsr.for
|
|             These subroutines are property of the U.S. Navy and
|             can be obtained by qualified users from code 2753 of
|             NSWC Annapolis Detachment (Formerly DTRC-Annapolis).
|
|=====
|
|               RECORD OF CHANGES
|
|
|      NO.  DATE      BY      SUMMARY
|      ---  -
|      0   4-10-93   tjm      Model Written.
|      1   4-10-93   tjm      Changed generator #1 to 2.5 MW kato unit.
|      2   4-10-93   tjm      Added gas turbine on generator #2.
|      3   4-10-93   tjm      Removed coordinate transformation.
|      4   4-10-93   tjm      Added diesel engine to generator #1.
|      5   4-11-93   tjm      Acceleration run made. Changed name
|                             to 'system 2'
|      6   4-15-93   tjm      Switched speed control to 'spdcon2.mac'.
|      7   4-17-93   tjm      Added circuit breaker and breaking resistor
|                             to motor. Changed name to "system2a"
|      8   4-18-93   tjm      Changed motor controller to "conmtr2".
|      9   4-19-93   tjm      Changed motor controller to "conmtr".
|     10   4-20-93   tjm      Successful crashback run. Changed TERMT
|                             statements to IF statements for applying
|                             dynamic brake resistor in 'spdcon3'.
|     11   4-20-93   tjm      Added circuit breaker to generator #2,
|                             switched generator prime movers.
|=====
PROGRAM system2a
|=====
|               MACRO DEFINITIONS
|=====
INCLUDE 'c:\acsl\synmac\synmtr4.mac'
INCLUDE 'c:\acsl\synmac\synmtr4b.mac'
INCLUDE 'c:\acsl\freqchg\freqchg2.mac'
```

```

INCLUDE 'c:\acsl\synmac\vreg2.mac'
INCLUDE 'c:\acsl\synmac\contntr.mac'
INCLUDE 'c:\acsl\synmac\spdcon3.mac'
INCLUDE 'c:\acsl\misc\constant.inc'
INCLUDE 'c:\acsl\lm2500\turbine.mac'
INCLUDE 'c:\acsl\diesel\diesel.mac'
INCLUDE 'c:\acsl\diesel\governor.mac'
INCLUDE 'c:\acsl\ship\ship.mac'
INCLUDE 'c:\acsl\loads\shipserv.mac'
INCLUDE 'c:\acsl\misc\baseconv.mac'
INCLUDE 'c:\acsl\misc\cb.mac'
!-----
!
!                               INITIAL SECTION
!-----
INITIAL
    SORT

!---Set base frequency & bus parameters
CONSTANT wo      = 377.0 !---[rad/sec]
CONSTANT xg1     = 0.1, &
           xg2     = 0.1, &
           xl1     = 0.1, &
           xm1     = 0.1

!---Set parameters for dynamic brake
LOGICAL lbrake
    lbrake = .false.
    kbrake = 1.0
    gml    = 1.5

!---Set frequency changer parameters
LOGICAL lfwd1
    lfwd1 = .true.

!---Set circuit breaker parameter
LOGICAL lcbg2
    CONSTANT lcbg2 = .true. !---Initially close cbg2

!---Set synchronous motor parameters (20,000 HP 150 RPM motor)
!---24 poles
CONSTANT &
    xqm1      = 1.157,&
    xdm1      = 1.76 ,&
    xqppm1    = 0.494,&
    xdppm1    = 0.542,&
    xdpm1     = 0.608,&
    xlm1      = 0.337,&
    tdopm1    = 2.10 ,&
    tdoppm1   = 0.039,&
    tqoppm1   = 0.193,&
    basem1    = 150 ,&
    basevm1   = 5000 ,&
    basekvm1  = 14914.0

    hm1       = 0.773 + hhps !---hhps is propeller/shaft inertia

```

```

baseqnl = 1000*basekwnl/(basenml/rpmrad)

xdmxqnl = xdm1 - xqnl
!---Initialize the synchronous motors
mtr4ic(m1)

!---Set synchronous generator parameters (18 MVA w h20 cooled stator)
!---values provided by NSW
CONSTANT &
  xqg1      = 1.64 ,&
  xdgl      = 1.77 ,&
  xqppg1    = 0.15 ,&
  xdppg1    = 0.15 ,&
  xdp1      = 0.18 ,&
  xlg1      = 0.13 ,&
  tdopg1    = 3.19 ,&
  tdopp1    = 0.04 ,&
  tqopp1    = 0.09 ,&
  hg1       = 0.924,&
  baseng1   = 3600.,&
  basevg1   = 4160.,&
  basekwg1  = 16200.0

!---Set synchronous generator parameters (kato 2.5 MW generator)
CONSTANT &
  xqg2      = 1.01 ,&
  xdgl      = 1.63 ,&
  xqppg2    = 0.28 ,&
  xdppg2    = 0.18 ,&
  xdp2      = 0.25 ,&
  xlg2      = 0.075,&
  tdopg2    = 3.79 ,&
  tdopp2    = 0.38 ,&
  tqopp2    = 0.19 ,&
  hg2       = 1.91 ,&
  baseng2   = 900.0,&
  basevg2   = 450.0,&
  basekwg2  = 2500.0

!---conversion factors for generator and motor bases
baseconv(kvg1ml,kkwg1ml,kig1ml,kzg1ml = &
          basevg1,basevml,basekwg1,basekwnl)
baseconv(kvg2ml,kkwg2ml,kig2ml,kzg2ml = &
          basevg2,basevml,basekwg2,basekwnl)

!---Initialize synchronous generators
mtr4bic(g1)
mtr4bic(g2)

!---Initialize gas turbine engine
LOGICAL lpwrd1      !---true for power demand mode
CONSTANT lpwrd1 = .FALSE. !---false for speed demand mode
CONSTANT wrnlord = 1.0 !---ordered speed [per unit]
CONSTANT wrnlordic = 1.0 !---ordered speed ic [per unit]
CONSTANT teglic = 0.0 !---electrical torque ic [per unit]

```

```

        CONSTANT wrnglic = 1.0      !---generator speed ic [per unit]

!---Initialize diesel engine
        CONSTANT cyl2      = 8      !---number of cylinders
        CONSTANT tmech2ic= 0.0      !---mechanical torque ic
        CONSTANT nmin2     = 400     !---min engine speed [rpm]
        CONSTANT nmax2     = 950     !---max engine speed [rpm]
        CONSTANT kturbo2   = 0.5     !---turbo constant [sec]
        CONSTANT wmg2ic    = 377.0   !---generator speed ic [rad/sec]

!---set desired motor speed
        CONSTANT spdref1 = 1.0

END !---of initial
!=====
!                                     DYNAMIC SECTION
!=====
DYNAMIC

        CINTERVAL    CINT  = .05      ! Communication interval
        NSTEPS        nstp  = 10
        MAXTERVAL     MAXT  = .1       ! Maximum integration step
        MININTERVAL   MINT  = 1.0E-8   ! Minimum integration step
        ALGORITHM      IALG  = 1       ! Integration algorithm
        CONSTANT      tstop = 0.0      ! stop time

!---stop on reaching maximum time
        TERMT(t.GE.(tstop-CINT/2.0),'====> STOP on time limit <====')

!=====
!                                     DERIVATIVE SECTION
!=====
DERIVATIVE
!---Invoke synchronous generator macros
synmtr4b(teg1,vqg1,vdg1 = eafg1,iqg1,idg1,wrng1,g1)
synmtr4b(teg2,vqg2,vdg2 = eafg2,iqg2,idg2,wrng2,g2)

!---Invoke voltage regulator macros
vreg2(eafg1 = vdg1,vqg1,g1)
vreg2(eafg2 = vdg2,vqg2,g2)

!---Invoke Diesel governor macro
governor(fuel2,n2 = wmg2,teg2,2)

!---Invoke Diesel engine macro
diesel(tmg2 = fuel2,n2,2)
wmg2d = (teg2 + tmg2)*wo/(2*hg2)
wmg2  = INTEG(wmg2d,wmg2ic)
wrng2 = wmg2/wo

!---Invoke Gas Turbine engine macro
turbine(1,lpwrd1,wrnlord,wrnlordic,teg1,teglic,wrnglic,wrng1,qpt1pu)
wmg1 = wrng1*wo

```

```

!---Invoke synchronous motor macro
synmtr4 (tem1,vqm1,vdm1,wrnm1 = eafm1,iqm1,idm1,tmm1,m1)

!---Invoke motor controller macro
contmtr(eafm1,beta11 = idm1,iqm1,vdm1,vqm1,edppm1,eqppm1,&
        xdppm1,xchaxqm1,xqm1,lbrake,m1)

!---Invoke frequency changer macro
freqchg (iqr1,idr1,iqil,idil = &
        vqr1,vdr1,vqil,vdil,idcr1,beta11,lfwd1,lbrake,1)

!---Invoke speed controller macro
speedcon (idcr1,lfwd1,lbrake = spdref1,wrnm1,idc1,1)

!---Invoke ship load macro
wrnm2 = wrnm1
ship(tmm1,tmm2 = wrnm1,wrnm2,basenm1)

!---Invoke ship service load macro
shipserv(idl2,iql2 = vdbus,vqbus,1)

!---Transmission line equations
CONSTANT vdbic = 0.0, vqbic = 1.0, errbound = 0.0001,maxit = 10, &
        delv = 0.0001
IMPL(vdbus = vdbic,errbound,maxit,vderr,vdgl + iqq1m1*xg1,delv)
IMPL(vqbus = vqbic,errbound,maxit,vqerr,vqgl - idg1m1*xg1,delv)
IMPL(iqq2m1 = iqq2ic,errbound,maxit,iqq2err,-(vdg2 - vdcbg2)/xg2,delv)
IMPL(idg2m1 = idg2ic,errbound,maxit,idg2err,(vqg2 - vqcbg2)/xg2,delv)

!---Invoke circuit breaker macro for gen #2
cb(vdcbg2,vqcbg2,idcbg2,iqcbg2 = &
    lcbg2,vdbus,vqbus,vdg2,vqg2,idg2m1,iqq2m1)

idg2 = idg2m1/kig2m1
iqg2 = iqq2m1/kig2m1
CONSTANT kir = 2.0
idg1m1 = (kir*idr1 + idl2 - idcbg2)
iqg1m1 = (kir*iqr1 + iql2 - iqcbg2)
idg1 = idg1m1/kig1m1
iqg1 = iqq1m1/kig1m1
vdr1 = vdbus + iqr1*xl1
vqr1 = vqbus - idr1*xl1
vdil = vdm1 + idm1*xm1
vqil = vqm1 - idm1*xm1

!---This procedural places a braking resistor across motor terminals
!---when lbrake = .true.
PROCEDURAL (idm1,iqm1 = idil,iqil,gm1,lbrake)
    IF(lbrake)THEN
        IF(vtmm1.LT.0.3) gm1 = 5.0
        idbm1 = vdm1*gm1
        iqbm1 = vqm1*gm1
        idm1 = idil + idbm1
        iqm1 = iqil + iqbm1
    ELSE

```

```

        gml      = 1.5
        idbm1    = 0.0
        iqbm1    = 0.0
        idm1     = idi1
        igm1     = iqil
    ENDIF
END !---of procedural

END !---of derivative

END !---of dynamic
!-----
!                                     TERMINAL SECTION
!-----
TERMINAL

END !---of terminal

END !---of program

```

A.3 Diesel Engine

```

!-----
!
!                                     Diesel Engine Model
!
!                                     Copyright 1992 by Timothy J. McCoy
!
!-----
!                                     Record of Changes
!
!  No.   Date    By      Summary
!  ---   -
!  0    12-20-92 tjm     Model written.
!  1    12-24-92 tjm     Changed input speed from rad/sec to rpm.
!-----
!  macro:      diesel
!  function:    Models four stroke turbocharged diesel engine.
!
!                                     CONCATENATION
!
!      z      = synchronous machine identifier
!
!                                     INPUTS
!
!      fr      = fuel rate [per unit]
!      n      = engine speed [rpm]
!
!                                     OUTPUTS
!
!      tm      = mechanical torque [per unit]
!
!                                     CONSTANTS
!-----
!----- (must be defined in the calling program) -----
!      tmech&z&ic = mechanical torque ic [per unit]
!      cyl&z&#    = number of cylinders [per unit]
!      nmin&z&#   = minimum operating speed of engine [rpm]
!      nmax&z&#   = maximum operating speed of engine [rpm]

```

```

!   kturbo&z&   = empirical turbo time constant [sec*p.u.torque]
!
!               INTERNAL (STATE OR STATE RELATED)
!   fuelag&z&   = delay due to fuel rack and engine dynamics [sec]
!   turbolag&z& = delay due to turbocharger [sec]
!   delay&z&    = time constant of engine [sec]
!   Tmap        = lookup table of torque vs speed and fuel rate
!
!               INTERNAL (NOT STATE RELATED)
!   NONE
!
!=====
!---include engine torque-speed look-up table
INCLUDE 'c:\acsl\diesel\cat3608.map'

MACRO diesel (tm , fr,n,z)
!=====
!               Begin Derivative Section
!=====

!---stop if engine is outside of performance limits
TERMT((n .LT. nmin&z&),'====> STOP Diesel engine underspeed <====')
TERMT((n .GT. nmax&z&),'====> STOP Diesel engine overspeed <====')

!---Calculate delay due to fuel injection and engine dynamics
fuelag&z&   = 30/n + 120/(cyl&z&*n)
!---Calculate delay due to turbo lag
turbolag&z& = kturbo&z&/(tm + 1)

!---Sum delays
delay&z&    = fuelag&z& + turbolag&z&

!---Calculate torque from performance map lookup table
torq&z& = Tmap(fr,n)

!---Delay output of revised torque to account for engine dynamics
tm      = REALPL(delay&z&,torq&z&,tmech&z&ic)

!=====
!               End of Derivative Section
!=====
MACRO END : of diesel

```

A.4 Diesel Engine Governor

```

!-----
!
!               GOVERNOR MODEL
!
!               Copyright 1992 by Timothy J. McCoy
!
!=====
!               Record of Changes
!

```

```

| No.   Date   By      Summary
| ----  -
| 0    12-22-92 tjm    Model written.
| 1    12-24-92 tjm    Added load torque compensation to the set
|                        speed. Gain and time constant adjusted to
|                        their final values.
| 2    12-26-92 tjm    Added PID type control.
| 3    12-27-92 tjm    Added load compensation from generator voltages
|                        and currents.
| 4    12-28-92 tjm    Changed load compensation back to load torque
|                        as input. Added wm as input and changed n to
|                        output for better modularity.
| 5    12-28-92 tjm    Revised constants for synchronous operation.
|                        Model verified.
|=====
| macro: governor.mac
| function: Limited PI type governor for a diesel engine
|
|                        CONCATENATION
|      z          = Engine identifier
|
|                        INPUTS
|      wm         = engine speed [rad/sec]
|      tl         = Load torque [per unit]
|
|                        OUTPUTS
|      fuel       = fuel rate [per unit]
|      n          = engine speed [rpm]
|
|                        CONSTANTS
|      kgov&z&    = governor gain
|      taugov&z&  = governor time constant
|      nset&z&    = desired engine speed [rpm]
|      fuelmin&z& = minimum fuel rack setting [per unit]
|      fuelmax&z& = maximum fuel rack setting [per unit]
|      k2gov&z&   = governor load factor gain
|
|=====
|===== (must be defined in the calling program) =====
|
|                        INTERNAL (STATE OR STATE RELATED)
|
|                        INTERNAL (NOT STATE RELATED)
|
|      NONE
|
|=====
| MACRO governor (fuel,n,wm,tl,z)
|=====
|                        Begin Derivative section
|=====
|---parameters
|      CONSTANT kgov&z&    = 0.2
|      CONSTANT nset&z&    = 900.0
|      CONSTANT taugov&z&  = 2.0
|      CONSTANT fuel&min   = 0.0
|      CONSTANT fuel&max   = 1.0

```

```

        CONSTANT fuel&ic      = 0.0

!---Convert speed to rpm for diesel use
        n = wm*2.38732 !---60/(2*pi*pole pairs)

!---Error signal
        spderr&z = nset&z - n

!---P-I type controller
!---fuel&d = (-fuel + pfac&z& + kgov&z&*(spderr&z&))/taugov&z
!---fuel      = BOUND(fuel&min,fuel&max,LIMINT(fuel&d,&
!---            fuel&ic,fuel&min,fuel&max))

fuel = BOUND(fuel&min,fuel&max,kgov&z&*spderr&z& + &
            LIMINT(spderr&z&*kgov&z&/taugov&z&,fuel&ic,fuel&min,fuel&max))
!---P-I-D type controller
!---fuel      = BOUND(fuel&min,fuel&max,(kgov&z&*spderr&z &
!---            - LIMINT(fuel,fuel&ic,fuel&min,fuel&max))/taugov&z)
MACRO END !---of governor

```

A.5 Diesel Engine Map

```

!---Caterpillar 3608 performance map
!---Values are in per unit torque
!---Base torque is 17,973 ft-lbf.
!---speed is in RPM, Fuel rate is in per unit
!---Base fuel rate is 140 gal/hr.
TABLE Tmap, 2, 8,12/0.0,.1428,.2857,.4286,.5714,.7143,.8571,1.0,&
400.,450.,500.,550.,600.,650.,700.,750.,800.,850.,900.,950.,&
0.0, 0.1242, 0.1 , 0.04 , 0.053 , 0.014 , 0.017 , 0.003 , &
0.0, 0.1364, 0.2 , 0.08 , 0.105 , 0.029 , 0.035 , 0.007 , &
0.0, 0.1373, 0.3960, 0.16 , 0.21 , 0.058 , 0.069 , 0.015 , &
0.0, 0.1426, 0.4012, 0.31 , 0.42 , 0.115 , 0.139 , 0.031 , &
0.0, 0.1339, 0.3726, 0.6137, 0.8426, 0.23 , 0.278 , 0.062 , &
0.0, 0.1259, 0.3461, 0.5665, 0.7869, 0.46 , 0.555 , 0.125 , &
0.0, 0.1169, 0.3215, 0.5239, 0.7264, 0.9143, 1.1105, 0.25 , &
0.0, 0.1013, 0.2922, 0.4851, 0.6702, 0.8533, 1.0364, 0.5 , &
0.0, 0.0877, 0.2703, 0.4474, 0.6209, 0.7962, 0.9716, 1.0883, &
0.0, 0.0722, 0.2475, 0.4160, 0.5776, 0.7426, 0.9110, 1.0469, &
0.0, 0.0617, 0.2273, 0.3863, 0.5439, 0.6981, 0.8474, 1.0000, &
0.0, 0.0492, 0.2030, 0.3491, 0.4876, 0.6460, 0.7967, 0.9228/

```

A.6 Frequency Changer

```

!=====
!           Three phase frequency Changer model
!
!           Copyright 1993
!           by
!           Timothy J. McCoy
!
!   Portions of this model are based on the models developed by
!   M. Branson et. al. of Purdue University for The U.S. Navy
!   DTRC code: 2753. Used with permission.
!=====

```

```

|      NOTES: 1.) This model assumes instantaneous commutation
|              2.) all quantities are in per unit
|=====
|
|              RECORD OF CHANGES
|
|      No.   Date   By   Summary
|      ---   -
|      0    2-9-93   tjm   Model written
|      1    2-11-93  tjm   Removed one-phase portion of model
|      2    3-22-93  tjm   Added betai to input list for controller use
|=====
|      macro:      freqchg
|      function:    models a three phase dc-link frequency converter
|
|              CONCATENATION
|      z          =   frequency changer identifier
|
|              INPUTS
|      vqr        =   the machine-side, q-axis voltage of rectifier
|      vdr        =   the machine-side, d-axis voltage of rectifier
|      vqi        =   the machine-side, q-axis voltage of inverter
|      vdi        =   the machine-side, d-axis voltage of inverter
|      idcr       =   commanded value of dc link current
|      betai      =   inverter firing angle [rad]
|      lfwd       =   logical variable to determine direction of
|                      desired torque
|
|              OUTPUTS
|      iqr        =   the machine-side, q-axis current of rectifier
|      idr        =   the machine-side, d-axis current of rectifier
|      iqi        =   the machine-side, q-axis current of inverter
|      idi        =   the machine-side, d-axis current of inverter
|
|              CONSTANTS
|                      Defined in 'constant.inc'
|      k3rt3opi   =   1.65398669 = 3*sqrt(3)/pi
|      krt3       =   1.732050808 = sqrt(3)
|      k2rt3opi   =   1.10265779 = 2*sqrt(3)/pi
|      k2ort3     =   1.154700538 = 2/sqrt(3)
|
|              INTERNAL (STATE OR STATE RELATED)
|      er&z&      =   Rectifier AC side voltage magnitude
|      ei&z&      =   Inverter AC side voltage magnitude
|      delr&z&    =   Rectifier AC side voltage angle
|      deli&z&    =   Inverter AC side voltage angle
|      idc&z&     =   DC link current
|      idc&z&d    =   DC link current derivative
|      betar&z    =   firing angle for rectifier
|      vr&z       =   link-side rectifier voltage
|      vi&z       =   link-side inverter voltage
|
|              INTERNAL (NOT STATE RELATED)
|
|              MACROS
|      rcc        =   establish rectifier control angles

```

```

!-----"
INCLUDE 'c:\acsl\freqchg\rcc.mac'

MACRO freqchg(iqr,idr,iqi,idi , &
              vqr,vdr,vqi,vdi,idcr,betai,lfd,lbrake,z)

!--- DC link parameters
CONSTANT xdc&z& = 1.68          !---DC rectance [per unit]
CONSTANT rdc&z& = 0.02          !---DC resistance [per unit]
CONSTANT idc&z&ic = 0.0         !---DC current ic [per unit]

!---Invoke rcc to define rectifier current control angle
rcc(beta&z = idc&z&,idcr,lbrake,z)

!---Establish the rectifier ac currents (iqr,idr)
iqr = k2rt3opi*idc&z&*COS(beta&z&)
idr = k2rt3opi*idc&z&*SIN(beta&z&)

!---Establish the inverter ac currents (iqi,idi)
IF(lfd) THEN
  iqi = k2rt3opi*idc&z&*COS(betai)
  idi = k2rt3opi*idc&z&*SIN(betai)
ELSE
  iqi = -k2rt3opi*idc&z&*COS(betai)
  idi = k2rt3opi*idc&z&*SIN(betai)
ENDIF

!---Establish the rectifier dc side voltage
RTP(er&z&,delr&z& = vqr,vdr)
vr&z& = k3rt3opi*er&z&*COS(beta&z&)

!---Establish the inverter dc side voltage
RTP(ei&z&,deli&z& = vqi,vdi)
vi&z& = k3rt3opi*ei&z&*COS(betai)

!---Establish the DC-LINK Current
idc&z&d = wo/xdc&z&*(vr&z& + vi&z& - rdc&z&*idc&z&)
idc&z& = INTEG(idc&z&d,idc&z&ic)

MACRO END

```

A.7 Rectifier Current Controller

```

!=====
!
!               DC-LINK CURRENT CONTROL MODEL
!
!               Copyright 1992
!               by
!               Timothy J. McCoy
!
!=====
!
!   macro:      rcc
!   function:    rectifier current control, P-I type controller.

```

```

1
1
1          CONCATENATION
1  z          = frequency changer identifier
1
1          INPUTS
1  idc         = dc link current [PER UNIT]
1  idcr        = dc link reference current [PER UNIT]
1
1          OUTPUTS
1  betar       = dc-link current control angle
1
1          CONSTANTS
1  gbetar&z&  = Controller Amplitude
1  tubetar&z& = Controller Time Constant
1  umin&z&    = minimum rectifier angle (maximum current)
1  umax&z&    = maximum rectifier angle (minimum current)
1
1          INTERNAL
1  u&z&ic     = rectifier control angle ic
1  u&z&d      = rectifier control angle derivative
1  ierr&z&    = dc link current error
1=====

```

```

MACRO rcc (betar , idc,idcr,lbrake,z)

```

```

CONSTANT umin&z&  = -0.0
CONSTANT umax&z&  = 0.99
CONSTANT gbetar&z& = 30.0
CONSTANT taubetar&z = 0.01
CONSTANT u&z&ic   = 0.0
CONSTANT ierr&z&ic = 0.0

```

```

ierr&z = (idcr - idc)
u&z&d  = (-u&z& + gbetar&z&*(ierr&z&))/taubetar&z
u&z&    = BOUND(umin&z&,umax&z&,LIMINT(u&z&d,u&z&ic,umin&z&,umax&z&))

```

```

IF(lbrake)THEN
  betar = kpio2
ELSE
  betar = ACOS(u&z&)
ENDIF

```

```

MACRO END !---of rcc

```

A.8 Induction Motor

```

1-----
1
1          THREE-PHASE INDUCTION MACHINE MODEL
1
1          Copyright 1992 by Timothy J. McCoy
1-----
1=====
1
1          Record of Changes

```

```

1
1  No. Date      By      Summary
1  ---  -
1  0.  11-16-92 tjm      Model written.
1  1.  11-29-92 tjm      Included stator transients to eliminate
1                          algebraic loop problem.
1
1  2.  11-30-92 tjm      MODEL VERIFIED.
1  =====
1
1  macro:      indmac
1  function:    Models a symmetrical three-phase induction machine
1
1                  with stator electric transients included.
1
1                  CONCATENATION
1  z            = synchronous machine identifier
1
1                  INPUTS
1  vd          = D-axis terminal voltage [per unit]
1
1  vq          = Q-axis terminal voltage [per unit]
1  tm          = Mechanical Torque [per unit]
1
1                  OUTPUTS
1  wrn         = Machine speed [per unit]
1  iqs         = Q-axis terminal current [per unit]
1  ids         = D-axis terminal current [per unit]
1
1                  CONSTANTS
1  wb          = base electrical speed [rad/sec]
1  rs&z        = Stator winding resistance [per unit]
1  rr&z        = Rotor winding resistance [per unit]
1  xm&z        = Stator to rotor mutual reactance [per unit]
1  xls&z       = Stator winding leakage reactance [per unit]
1  xlr&z       = Rotor winding leakage reactance [per unit]
1  h&z         = Rotor inertia [sec]
1  xaq&z&z     = reactance used in calculating mutual coupling flux
1
1                  INTERNAL (STATE OR STATE RELATED)
1  siqs&z&z&d = rates of change of stator flux linkages [per unit]
1  sids&z&z&d
1  siqs&z      = Q-axis stator flux linkage [per unit]
1
1  sids&z      = D-axis stator flux linkage [per unit]
1  siqr&z&z&d = rates of change of rotor flux linkages
1  sidr&z&z&d
1  siqr&z      = Q-axis rotor flux linkage [per unit]
1  sidr&z      = D-axis rotor flux linkage [per unit]
1  simq&z      = Q-axis mutual coupling flux
1  simd&z      = D-axis mutual coupling flux
1  wm&z        = rotor speed [rad/sec]
1  wm&z&z&d    = rate of change of rotor speed [rad/sec^2]
1  iqr&z       = Q-axis rotor current [per unit]
1  idr&z       = D-axis rotor current [per unit]

```

```

1
1
1          INTERNAL (NOT STATE RELATED)
1      sigrzzic = rotor flux linkage ics [per unit]
1      sidrzzic
1      sigszzic = stator flux linkage ics [per unit]
1      sideszzic
1      wnzzzic  = rotor mechanical speed ic [rad/sec]
1=====
MACRO indmac (z,tm,wrn,iqs,ids,vq,vd)

INITIAL

!---set initial rotor speed and fluxes to zero
    CONSTANT wnzzzic  = 0.0
    CONSTANT sigrzzic = 0.0
    CONSTANT sidrzzic = 0.0

    sigszzic = vd
    sideszzic = vq

!---compute reactance used in calculating mutual flux
    xaqzzz  = 1/(1/xmzzz + 1/xlszzz + 1/xlrzzz)

END !---of initial section

1=====
1          Begin Derivative Section
1=====
!---mutual coupling flux
    simqzzz = xaqzzz*(sigszzz/xlszzz + sigrzzz/xlrzzz)
    simdzzz = xaqzzz*(sideszzz/xlszzz + sidrzzz/xlrzzz)

!---Rates of Change of stator flux-linkages
    sigszzzd = wb*(vq - rszzz*iqs - sideszzz)
    sideszzd = wb*(vd - rszzz*ids + sigszzz)

!---Rates of Change of rotor flux-linkages
    sigrzzzd = -(wb - wnzzz)*sidrzzz + &
                wb*(rrzzz/xlrzzz)*(simqzzz - sigrzzz)
    sidrzzzd = (wb - wnzzz)*sigrzzz + &
                wb*(rrzzz/xlrzzz)*(simdzzz - sidrzzz)

!---Mechanical equation
    wnzzzd = (tezzz - tm)*wb/(2*hzzz)

!---integrate state equations to obtain flux linkages & rotor speed
    sigrzzz = INTEG(sigrzzzd,sigrzzic)
    sidrzzz = INTEG(sidrzzzd,sidrzzic)
    sigszzz = INTEG(sigszzzd,sigszzic)
    sideszzz = INTEG(sideszzd,sideszzic)
    wnzzz = INTEG(wnzzzd,wnzzic)

!---Compute stator currents in terms of fluxes
    iqs = (sigszzz - simqzzz)/xlszzz

```

```

ids      = (sids&z& - simd&z&)/xls&z

!---Compute Electromagnetic Torque
te&z&    = (sids&z&*iqs - siqs&z&*ids)

!---Compute per unit mechanical speed
wrn      = wms&z&/wb

!=====
!                               End of Derivative Section
!=====

```

MACRO END : of indmac

A.9 Gas Turbine

```

!=====
!
!                               LM-2500 Gas Turbine Generator macro
!                               Copyright 1993 by Timothy J. McCoy
!
!-----
!
!NOTE:  The macros used in this model were provided by CODE: 2753 of
!        NSWC Annapolis and are used with permission. Only minor
!        changes were made to allow the model to run on a PC.
!
!-----
!*****
!      NOTE:  this model requires the following compiler
!             command line options:  "/zi /AH /B1 fl.exe"
!             and linker command line options:  "/CO"
!*****
!-----
!
!                               RECORD OF CHANGES
!
!      NO.  DATE      BY      SUMMARY
!      ---  -
!      0    4-05-93   tjm      Model Written.
!-----
!
!                               MACRO DEFINITIONS
!-----
INCLUDE 'c:\acsl\lm2500\LM25a.mac'
INCLUDE 'c:\acsl\lm2500\tgid2.mac'
INCLUDE 'c:\acsl\lm2500\LM25crpm.mac'
!-----
!
!                               CONCATENATION
!
!      z      concatenation variable
!
!
!                               INPUTS
!
!      lpwrds  = true for constant power mode
!              false for constant speed mode
!
!      wrnzord = ordered speed in pu
!
!      wrnzordi = ordered speed ic in pu

```

```

!      tez      = synchronous machine torque in pu
!      tezi     = synchronous machine torque ic in pu
!      wrnzi    = synchronous machine speed ic
!
!              OUTPUTS
!      wrnz     = synchronous machine speed
!      qptzpu   = per unit turbine torque on generator base
!=====
!---The following constants apply to all turbines defined
!---by following macro model
CONSTANT jjg = 16505      ! generator inertia in lbm-ft^2
CONSTANT ngb = 3600      ! generator base rpm
CONSTANT qgb = 36.52e3    ! generator base torque
!---invoke miscellaneous constants macro
      LM25mc0(ki,kqhp,kgc,p2,t2,theta2,sqrth2,thta2v,thet2n,delta2)

MACRO turbine(z,lpwrdz,wrnzord,wrnzordi,tez,tezi,wrnzi,wrnz,qptzpu)

INITIAL
      CONSTANT hp&z&ordi = 0.0      ! ordered turbine hp ic
      tesm&z&i = -tezi*qgb         ! convert from pu to ft-lbf
      n&z&i = wrnzi*ngb            ! convert from rpm to pu
      hp&z&i = n&z&i*tesm&z&i/kqhp  ! generator hp
      npt&z&ordi = wrnzordi*npt&z&b ! convert from pu to rpm

END !---of initial

!---Invoke load interface macro
tgid2(z, qpt&z& , jjpt&z& , npt&z&b , qpt&z&b , tesm&z&i , tesm&z& , &
      jjg , ngb , n&z&i , dnpt&z& , npt&z& , npt&z&i , qpt&z&i , dn&z& , n&z&)

!---Invoke throttle input command macro
LM25crpm4(z, npt&z&b , npt&z&ord , npt&z&ordi , npt&z&i , npt&z& , &
      hp&z&b , hp&z& , hp&z&i , hp&z&ord , hp&z&ordi , lpwrdz , &
      tic&z&ul , tic&z&ll , ticmd&z& , ticmd&z&i)

!---Invoke gas gen/ power turb macro
LM25gt0(z, t2, delta2, sqrth2, thet2n, thta2v, ki, kgc, &
      Farg0, Farg1, tic&z& , wfuel&z& , &
      npt&z&i , qpt&z&i , ngg&z&i , jjpt&z& , ps3&z& , ps3&z&i , &
      p54&z& , p54&z&i , wfuel&z&i , ngg&z& , npt&z& , npt&z&b , &
      qpt&z& , qpt&z&b , hp&z&b)

!---Invoke power lever angle macro
fsee0(z, p2, t2, ticmd&z& , npt&z& , npt&z&i , p54&z& , &
      p54&z&i , ticmd&z&i , alpha&z&i , tic&z& , alpha&z& , nref&z&)

!---Invoke main fuel control macro
mfc0(z, t2, thet2n, sqrth2, alpha&z& , ngg&z& , ps3&z& , &
      Farg0, Farg1, ngg&z&i , ps3&z&i , wfuel&z&i , alpha&z&i , wfuel&z&)

!---convert from pu to ft-lbf
tesm&z& = -tez*qgb

!---convert from rpm to pu

```

```

wrnz      = n&z&/ngb

!---convert from pu to rpm
npt&z&ord = wrnzord*npt&z&b

!---generator hp
hp&z& = n&z&*tesm&z&/kqhp

!---ordered turbine hp in power demand mode
CONSTANT hp&z&ord = 0.0

!---turbine torque in pu on gen base
qptzpu = qpt&z * (npt&z&b/ngb) /qgb

MACRO END !---of turbine.mac
!===== LM25mac0.mod =====
!-----
!   file name:  LM25mac0.mod      clp      8-apr-91      v-1g92-0
!-----
!
!   This model is a MACRO representation of an LM2500 gas turbine
!   engine that has been developed to permit cloning in simulations
!   requiring two or more LM2500 engines. The LM2500 consists of
!   four parts:(1) a Power Lever Angle Controller (FSEE), (2) a
!   Main Fuel Controller (MFC), (3) a Gas Generator, and (4) a Power
!   Turbine. For convenience, separate MACROS have been developed
!   for the FSEE and the MFC to permit substituting other control
!   system models as the need arises. In all, four MACROS have
!   been developed as listed below:
!
!   (1) LM25mc0.mac ---- Defines miscellaneous constants
!       specific to the LM2500 model.
!
!   (2) fsee0.mac ----- Characterizes the Power Lever Angle
!       Controller used with the LM2500 model.
!
!   (3) mfc0.mac ----- Characterizes the Main Fuel Controller
!       used with the LM2500 model.
!
!   (4) LM25gt0.mac ---- Characterizes the Gas Generator and
!       Power Turbine portion of the LM2500
!       model.
!
!   This model has been extracted from the program IED_FULL_1.CSL
!   developed by PDI Corp. for DTRC Code 2753 and reported in
!   reference [1] below. The simulation developed in reference [1]
!   used reference [2] for the FSEE and MFC models, reference [3]
!   for the Gas Generator and Power Turbine Dynamics Models, and
!   reference [4] for the Alarms and Simulation Shutdown features.
!
!   This model requires the following files which contain function
!   data and the necessary lookup routines:
!
!       /models/LM2500/fun/data/LM25lib1.a
!       /models/lookup/lookuplib.a

```

In addition to the basic model changes needed to develop the appropriate MACROS, the following changes have been made to simplify the model:

- (1) Use PDI simplification of FSEE for the high frequency, nonlinear loop [$\text{thdot2} = f(e23, \text{snegv1})$]; that is, substitute IED_REDUCED_1.CSL code from page C-9 of reference [1] for IED_FULL_1.CSL code on page B-9 used to calculate alpha.
- (2) Further simplify FSEE model by eliminating the thetam calculation by adjusting the limits on the LIMINT for alpha, then eliminate the calculation of e2 and adjust the calculation of e21. This modification has been taken from work reported in reference [5].
- (3) Modify the MPC model to simplify afl, dfl, afrl, dfri, emffb, and xmv circuit calculations. This modification has been taken from work reported in reference [5].

Simulation validation runs were made to examine the gas turbine response for the above modifications. The results indicated that the modifications had negligible effect on the overall transient response of the gas turbine. Any further changes, corrections, or modifications to this model should be noted in the CHANGE RECORD started below:

MODELING CONVENTIONS:

- (1) Use CAPS for ACSL statements, ACSL variables, etc.
- (2) Use lower case for all model variables.
- (3) Begin Table names, Function names and related control variables with a capital letter.

MODEL REFERENCES:

- [1] Mathematical Models and ACSL Simulation of the Integrated Electric Drive Study Ship, LM2500 Gas Turbine and Gas Turbine Control System, PDI Corp. Report 324-041-02, June 1990.
- [2] LM2500 Simplified Non Linear Engine and Control System Simulation, General Electric Marine and Industrial Projects Department, G. E. Document MID-TD-2500-13, January 1978, Revised April 1978.
- [3] LM2500 Nonlinear Simplified Engine Model for IEC, General


```

: The power lever angle (PLA) controller (FSEE) model for the
: LM2500 gas turbine. It has been developed based on references
: [1],[2], and [5] of LM2500.ref. It is essentially a MACRO
: version of the model included in the simulation reported
: in [1] with a few modifications based on [5].
:
: This model requires the following files which contain
: function data and the necessary lookup routines:
:
:     /models/LM2500/fun/data/LM25lib1.a
:     /models/LM2500/fun/data/lookuplib.a
:
: -----
: CHANGE RECORD:
: -----
:
: Version   Date      Engr   Description
: -----
: 0         17apr91   clp    Model developed and installed.
:
: 1         30apr91   clp    Add tic to MACRO argument list and change
:         all references to tic&z& to tic
:
: 2         2may91    clp    Modified MACRO argument list (added z's
:         to most arguments)
:
: 3         16may91   clp    Change nref&z& to nrefz, add to argument
:         list, and make appropriate code mods
:
: 4         02nov92   tjm    Added parenthesis in p2t2&z&i and qcal&z&i
:         assignment statements to fix compiler error for PC use.
:
: -----
:
: MACRO fsee0(z,p2,t2,ticmdz,nptz,nptzi,p54z,p54zi,ticmdzi, &
:         alphazi,ticz,alphaz,nrefz)
:
: inputs:      z = concatenation variable
:              p2 = compressor inlet pressure
:              t2 = compressor inlet total temperature
:              ticmdz = throttle input command from control system
:              nptz = power turbine shaft speed
:              nptzi = npt IC
:              p54z = power turbine inlet pressure
:              p54zi = p54 IC
:              ticmdzi = ticmd IC
:              alphazi = alpha IC
:
: outputs:     ticz = bounded ticmdz
:              alphaz = rotary actuator position (actual TIC to MFC)
:
: ----- Power turbine torque limit -----
:              (20000 <= qref <= 45000 lb-ft)
:              (qref selected for vq=9.0 volts)

```

```

CONSTANT    qref&zz&  = 45000    ! -- torque ref [lb-ft]
CONSTANT    vqsf&zz&  = 5000     ! -- torq lim scale factor [lb-ft/volt]
CONSTANT    gl&zz&    = 0.22     ! -- torque lim gain

! ----- Power turbine RPM limit -----
!           (2800 <= nref <= 3900 rpm)
!           (nref selected for vr=7.344 volts)

CONSTANT    nrefz     = 3672     ! -- npt limit [rpm]
CONSTANT    vnsf&zz&  = 500     ! -- npt lim scale factor [rpm/volt]
CONSTANT    g3&zz&    = 0.5     ! -- npt limit gain

! ----- Power turbine RPM rate limit -----
!           (dnref = 180 rpm/sec --- fixed)
!           (dnref selected for vr=0.5 volts)

CONSTANT    dnref&zz& = 180      ! -- npt rate lim [rpm/sec]
CONSTANT    vrsf&zz&  = 360     ! -- rate lim scale factor
[(rpm/sec)/volt]
CONSTANT    g5&zz&    = 0.5     ! -- npt rate lim gain

! ----- Define upper/lower limits for the command input and
!           the TIC rate limiter plus the gain for the rate
!           limiter
CONSTANT    tic&zz&ul  = 113.5   ! -- command input UL and LL
CONSTANT    tic&zz&ll  = 13.0    ! -- [degrees]

CONSTANT    ticrl&zz&ul = 22.5   ! -- TIC rate limiter UL and LL
CONSTANT    ticrl&zz&ll = -89.0  ! -- [deg/sec]
CONSTANT    krate&zz&  = 10.     ! -- gain constant

! ----- Define upper/lower mechanical limits for alpha
CONSTANT    alpha&zz&ul = 120.0  ! -- [degrees]
CONSTANT    alpha&zz&ll = 13.0   ! -- [degrees]

! ----- Define the gain in the calculation of drpmdt
CONSTANT    krat&zz&   = 0.16    ! -- nondimensional

! ++++++ Begin INITIAL section ++++++
INITIAL
! ----- Calculate TIC rate-limited integrator output IC
ticrl&zz&i  = BOUND ( tic&zz&ll, tic&zz&ul, ticmdzi )

! ----- Calculate reference voltages and ICs for power
!           turbine torque, RPM, and RPM rate limits
vq&zz&      = (qref&zz& / vqsf&zz&)
vn&zz&      = (nrefz / vnsf&zz&)
vr&zz&      = (dnref&zz& / vrsf&zz&)

```

```

!          >>>> NOTE: The p54zi calculation has been moved to the
!          LM25gt0 MACRO since that is where the function is
!          shown in references [1] and [2]

e0&z&i      = 0.0
p54l&z&i    = p54zi
p54ll&z&i   = p54l&z&i * 1.015
nptl&z&i    = nptzi
enpt&z&i    = nptl&z&i * 0.002
enptl&z&i   = enpt&z&i
p54q&z&i    = p54ll&z&i / p2
nptq&z&i    = nptl&z&i / sqrt(t2)
!
!          Put variables based on function lookups
!          in a PROCEDURAL
!
PROCEDURAL (qmap&z&i = p54q&z&i, nptq&z&i)
  qmap&z&i    = Fqmap(p54q&z&i, nptq&z&i)
END
!
!          End IC function lookup PROCEDURAL
!
qmapl&z&i    = qmap&z&i
p2t2&z&i    = p2 * ( t2 ** (-0.157))
qcal&z&i    = (qmapl&z&i * p2t2&z&i)
tabtr&z&i    = qcal&z&i * 0.0002 * ( 1 - .66 / .3 )
tglag&z&i    = enpt&z&i * (1.0 - (2.3 / .047))

END !---of initial

! ++++++ Begin DERIVATIVE Section ++++++

! ----- Calculate and BOUND TIC

ticz      = BOUND ( tic&z&ll, tic&z&ul, ticmdz )

! ----- Calculate Rate Limited TIC

ticrl&z&i = INTEG ( BOUND (ticrl&z&ll, ticrl&z&ul, &
                      krate&z&i * (ticz - ticrl&z&i)), ticrl&z&i )

! ----- Calculate vtrqgs (torque limiting)

p54l&z&i    = REALPL ( 0.014, p54z, p54l&z&i )
p54ll&z&i   = REALPL ( 0.04, p54l&z&i * 1.015, p54ll&z&i )
p54q&z&i    = p54ll&z&i / p2
nptl&z&i    = REALPL ( 0.144, nptz, nptl&z&i )
nptq&z&i    = nptl&z&i / sqrt(t2)
qmap&z&i    = Fqmap ( p54q&z&i, nptq&z&i )
qmapl&z&i   = REALPL ( 0.03, qmap&z&i, qmapl&z&i )
qcal&z&i    = (p2 * (t2 ** (-0.157))) * qmapl&z&i
tabtrl&z&i  = LEDLAG ( 0.66, 0.3, qcal&z&i * 0.0002 , tabtr&z&i )
e5&z&i      = (vq&z&i - tabtrl&z&i)
delvtq&z&i  = BOUND ( -9999., 0.0, e5&z&i )
vtrqgs&z&i  = (delvtq&z&i * gl&z&i)

```

```

! ----- Calculate vtop (topping governor)

enpt&z& = (0.002 * nptl&z&)
tglag&z& = LEDLAG ( 2.3, 0.047, enpt&z&, tglag&z&i )
e7&z& = (vn&z& - tglag&z&)
e6&z& = BOUND ( -9999., 0.0, e7&z& )
vtop&z& = (e6&z& * g3&z&)

! ----- Calculate vrate (Acceleration Limiting)
!
!       Note that the next two lines match the block diagram
!       in effect but need to be expressed this way to handle
!       the initial conditions properly

      enptl&z& = INTEG ( (enpt&z& - enptl&z&) / 0.04, enptl&z&i)
      drpmdt&z& = krat&z& * 4.7 * (enpt&z& - enptl&z&) / 0.04
      e9&z& = (vr&z& - drpmdt&z&)
      e8&z& = BOUND ( -9999., 0.0, e9&z& )
      vrate&z& = (e8&z& * g5&z&)

! ----- Calculate snegvl

      snegvl&z& = MIN ( vtrqgs&z&, MIN ( vtop&z&, vrate&z&))

! ----- Calculate ALPHA (see notes at top on modifications
!       to this section)

e2l&z& = (ticrl&z& - alphaz) * 0.094066

PROCEDURAL ( xk3l&z& = e5&z&, e7&z&)
  xk3l&z& = 14.0
  IF ((e5&z& .LT. 0.35) .or. (e7&z& .LT. 0.35)) xk3l&z& = 2.2
END

e22&z& = BOUND ( -14.0, xk3l&z&, e2l&z& * 60.0)

PROCEDURAL ( e23&z& = e5&z&, e7&z&, e9&z&, e22&z&)
  e23&z& = e22&z& / 3.0
  IF ((e5&z& .LT. 0.0) .or. (e7&z& .LT. 0.0) .or. (e9&z& .LT. 0.0)) &
    e23&z& = e22&z& / 40.0
END

PROCEDURAL ( thdot2&z& = e23&z& , snegvl&z& )
  IF ((e23&z& + snegvl&z&) .LT. -6.766 ) thdot2&z& = -131.646
  IF ((e23&z& + snegvl&z&) .GE. -6.766 &
    .AND. (e23&z& + snegvl&z&) .LT. -0.08445) &
    thdot2&z& = (93.0 * (e23&z& + snegvl&z&) + 7.854 ) / 4.72
  IF ((e23&z& + snegvl&z&) .GE. -0.08445 .AND. &
    (e23&z& + snegvl&z&) .LT. 0.08445) thdot2&z& = 0.0
  IF ((e23&z& + snegvl&z&) .GE. 0.08445 .AND. &
    (e23&z& + snegvl&z&) .LT. 1.316) &
    thdot2&z& = (93.0 * (e23&z& + snegvl&z&) - 7.854 ) / 4.72
  IF ((e23&z& + snegvl&z&) .GE. 1.316 .AND. &
    (e23&z& + snegvl&z&) .LT. 109.84) &
    thdot2&z& = (93.0 * (e23&z& + snegvl&z&) + 2159.42 ) / 94.0

```



```

1      wfuelzi = wfuelz IC
1
1      outputs: alphazi = alpha IC
1      wfuelz = fuel flow rate

1 ----- Declare array, variable and constant types

DIMENSION      mfw&z&(3)

1 ----- Define some constants for the MFC model

CONSTANT      mfw&z&      = 159.4, 2091.3, 13659.6
CONSTANT      mfkac&z&    = 0.582
CONSTANT      mfkfr&z&    = 0.17259
CONSTANT      mfkmv&z&    = 23.0
CONSTANT      mfkna&z&    = 4.608E-8

1 ++++++ Begin INITIAL Section ++++++
INITIAL
1 ----- Calculate MFC model ICs ==> NOTE: the wfuelzi
1      and ps3zi calculations have been moved to the
1      LM25gt0 MACRO since that is where the functions
1      are shown in reference [1]

emffb&z&i      = 0.0
xmv&z&i        = BOUND ( 0.0, 1.0, (-mfw&z&(2) + &
                        sqrt(mfw&z&(2)**2.0 - 4.0*mfw&z&(3)*(mfw&z&(1) &
                        - wfuelzi)))/(2.0*mfw&z&(3)))
arllg&z&i      = xmv&z&i
drllg&z&i      = xmv&z&i
ps3wc&z&i      = ps3zi
nggl&z&i       = nggzi
1
1      Put variables based on function lookups
1      in a PROCEDURAL
1
PROCEDURAL (alphazi = nggzi,Farg1)
      alphazi = Ordngg( 0.0, nggzi,Farg1)
END !---End IC function lookup PROCEDURAL

END !---of initial

1 ++++++ Begin DERIVATIVE Section ++++++

1 ----- The MFC section has been modified to simplify the
1      calculation of AFL and DFL based on reference [5]

1 ----- Demand gas generator speed

dngg&z&        = Ordngg (alphaz, 0.0, Farg0)

1 ----- Error signal

engg&z&        = (mfkn&z&*((dngg&z&**2) - (nggz**2)) - emffb&z&)
emfsat&z&      = BOUND (dfl&z&, afl&z&, engg&z&)

```



```

: -----
: CHANGE RECORD:
: -----
:
: Version   Date     Engr   Description
: -----
:      0     17apr91  clp    Model developed and installed.
:
:      1     30apr91  clp    Add torque base (qptb) calculation
:
:      2       2may91  clp    Modified MACRO argument list (added z's
:              to appropriate arguments)
:
:      3     14may91  clp    Add horsepower base to MACRO argument list
:              as hpzb and make necessary code changes
: -----

```

```

MACRO LM25gt0(z,t2,delta2,sqrth2,thet2n,thta2v,ki,kgc,Farg0,Farg1, &
          ticz,wfuelz,nptzi,qloadi,nggz,iptz,ps3z,ps3zi,p54z, &
          p54zi,wfuelzi,nggz,nptz,nptzb,gez,qptzb,hpzb)

```

```

: inputs:      z = concatenation variable
:              t2 = compressor inlet total temperature
:              delta2 = ambient pressure correction factor
:              sqrth2 = square root of theta2
:              thet2n = temperature correction factor
:              ki = conversion factor for rotational accel
:              kgc = conversion factor for pounds mass to slugs
:              Farg0 = FORWARD lookup function interpolation flag
:              Farg1 = BACKWARD lookup fun interp (ARG 1 dependent)
:              ticz = throttle input command
:              wfuelz = fuel flow rate
:              nptzi = power turbine shaft speed IC
:              qloadi = qload IC
:
: outputs:nggz = gas generator speed IC
:              iptz = rotational inertia of power turbine
:              ps3z = compressor discharge static pressure
:              ps3zi = psi3 IC
:              p54z = power turbine inlet pressure
:              p54zi = p54z IC
:              wfuelzi = wf IC
:              nggz = gas generator speed
:              nptz = power turbine shaft speed
:              nptzb = power turbine shaft speed base RPM
:              gez = power turbine shaft output torque
:              qptzb = power turbine shaft base torque [LB-FT]

```

```

: ----- Declare array, variable and constant types

```

```

LOGICAL      lt54&z&a, lngg&z&a

```

```

INTEGER      kalarm&z&, kshtdn&z&, ktbl&z&

! ----- Define the difference between gas generator
!           turbine exhaust temperature (T51) and power
!           turbine inlet temperature (T54) as a function of
!           gas generator speed (NGG) and power turbine speed
!           (NPT) [DEG F]. See DHHs notes of 1/8/90 for the
!           source of this data

TABLE Tdt54&z&,2,6,6/
      0.0, 54.19, 76.32, 86.50, 96.67, 999999.0, &
      0.0, 500.0, 2000.0, 3000.0, 3960.0, 99999.0, &
      46.3, 46.3, 31.3, 47.3, 58.3, 58.3, &
      46.3, 46.3, 31.3, 47.3, 58.3, 58.3, &
      52.3, 52.3, 38.3, 50.3, 61.3, 61.3, &
      52.3, 52.3, 44.3, 55.3, 63.3, 63.3, &
      52.3, 52.3, 50.1, 61.3, 68.3, 68.3, &
      52.3, 52.3, 50.1, 61.3, 68.3, 68.3/

! ----- Define the power turbine speed setpoint
!           and the gas generator design rpm

CONSTANT      nptzb      = 3600.      ! -- power turbine rpm base
CONSTANT      hpzb       = 25000.0    ! -- power turb base horsepower
CONSTANT      ngg&z&b    = 9827.      ! -- gas gen design rpm base (100 pct)

! ----- Define the inertia of the gas generator rotor
!           This value is from LM25mac0.mod reference [2]

CONSTANT      igg&z&     = 566.7785   ! -- lbm-ft**2

! ----- Define the inertia of the power turbine. Use
!           value specified by GE (via Lee Tupper)
!           (iptz= 1915 for validation check, see ref [2])

CONSTANT      iptz       = 2171.5     ! -- lbm-ft**2

! ++++++ Begin INITIAL Section ++++++
INITIAL
! ----- Initialize alarm and shutdown parameters

lt54&z&a = .FALSE.
lngg&z&a = .FALSE.
kalarm&z& = 0
kshtdn&z& = 0

! ----- Calculate power turbine base torque

qptzb = (hpzb * ftlbhp * rpmrad) / nptzb

! ----- Calculate gas generator and power turbine
!           model ICs, p54zi for the FSEE model, and
!           ps3zi and wfuelzi for the MFC model

kpngg&z& = (100.0 / ngg&z&b)

```

```

nptrz&zi = nptzi / sqrth2
delwf&zi = 0.0
!
!           Put variables based on function lookups
!           in a PROCEDURAL
!
PROCEDURAL(pnggr&zi,t4pl&zi,t5lpl&zi,p54r2&zi,ps3r2&zi,wfuelzi &
           = nptrz&zi,delwf&zi,qloadi,delta2,Fargl,thta2v,thet2n)

pnggr&zi = Fdqp(0.0,nptrz&zi,delwf&zi,qloadi/delta2,Fargl)
t4pl&zi = Ft4(pnggr&zi,nptrz&zi,delwf&zi) * thta2v
t5lpl&zi = Ft5l(pnggr&zi,nptrz&zi,delwf&zi) * thta2v
p54r2&zi = Fp54(pnggr&zi,nptrz&zi,delwf&zi)
ps3r2&zi = Fps3(pnggr&zi,nptrz&zi,delwf&zi)
wfuelzi = Fwfs(pnggr&zi,nptrz&zi)* thet2n * delta2
END
!
!           End IC function lookup PROCEDURAL
!
nggzi = (pnggr&zi / kpngg&zi) * sqrth2
p54zi = p54r2&zi * delta2
ps3zi = ps3r2&zi * delta2
END !---of initial

! ++++++ Begin DERIVATIVE Section ++++++

! ----- GAS GENERATOR SECTION -----

! ----- Calculate delwf

wfsr2&zi = Fwfs(pnggr&zi,nptrz&zi)
delwf&zi = ( (wfuelz / (thet2n * delta2) ) - wfsr2&zi )

! ----- Calculate remainder of gas generator model
!           variables

t4r2&zi = Ft4(pnggr&zi,nptrz&zi,delwf&zi)
w4r2&zi = Fw4(pnggr&zi,delwf&zi)
t4p&zi = (t4r2&zi * thta2v)
w4&zi = w4r2&zi * ( delta2 / sqrth2)
tut4h&zi = 0.206785 * ( w4&zi ** 0.8 ) / ( t4p&zi ** 0.4 )
t4pl&zi = REALPL(1/tut4h&zi,t4p&zi,t4pl&zi)
t4u&zi = ( t4p&zi - t4pl&zi ) * tut4h&zi * 49.979957
dt4hs&zi = - ( t4u&zi / w4&zi )
t4&zi = (dt4hs&zi + t4p&zi)
q4r2&zi = Fq4( pnggr&zi,nptrz&zi,delwf&zi )
q4&zi = ( q4r2&zi * delta2 )
dq4s&zi = ( ( dt4hs&zi / t4p&zi ) * q4&zi )
dqhr2&zi = Fdqh( pnggr&zi,delwf&zi )
qh&zi = ( ( dqhr2&zi * delta2 ) + dq4s&zi )
nggz = INTEG( qh&zi * ( ki / igg&zi ) , nggzi )
pngg&zi = ( nggz * kpngg&zi )
pnggr&zi = pngg&zi / sqrth2
ps3r2&zi = Fps3(pnggr&zi,nptrz&zi,delwf&zi)
ps3z = ps3r2&zi * delta2

```

! ----- POWER TURBINE SECTION -----

```
t51r2&z& = Ft51(pnggr&z&,nptr&z&,delwf&z&)
w54r2&z& = Fw54(pnggr&z&,delwf&z&)
t51p&z& = t51r2&z& * thta2v
w54&z& = w54r2&z& * ( delta2 / sqrth2)
tut51h&z& = 0.06875 * ( w54&z& ** 0.8 ) / ( t51p&z& ** 0.4 )
t51pl&z& = REALPL(1/tut51h&z&,t51p&z&,t51pl&z&i)
t51u&z& = ( t51p&z& - t51pl&z& ) * tut51h&z& * 116.0073
dt51hs&z& = - ( t51u&z& / w54&z& )
t51&z& = (dt51hs&z& + t51p&z&)
t54&z& = t51&z& - 459.7 - Tdt54&z& (pnggr&z&, nptr&z&)
t51q&z& = (t51&z& / t51p&z&)
p54r2&z& = Fp54(pnggr&z&,nptr&z&,delwf&z&)
p54z = p54r2&z& * delta2 * sqrt ( t51q&z& )
dqptr&z& = Fdqp(pnggr&z&,nptr&z&,delwf&z&,0.0,Farg0)
gez = t51q&z& * dqptr&z& * delta2
```

```
nptr&z& = nptz / sqrth2
```

! ----- Alarm and simulation shutdown section -----

```
PROCEDURAL ( kalarm&z&, kshtdn&z& = t54&z&, nggz, nptz, ticz )
```

```
!
  IF ((t54&z& .GT. 1500.0) .AND. (.NOT. lt54&z&a)) THEN
    lt54&z&a = .TRUE.
    kalarm&z& = kalarm&z& + 1
    PRINT L01&z
    L01&z&..FORMAT(/,' ===> ALARM Condition: t54&z& .GT. 1500 <===',/)
  ELSE IF ((t54&z& .LT. 1500.0) .AND. lt54&z&a) THEN
    lt54&z&a = .FALSE.
    kalarm&z& = kalarm&z& - 1
  ELSE
    CONTINUE
  ENDIF
!
  IF (t54&z& .GT. 1530.0) THEN
    kshtdn&z& = kshtdn&z& + 1
    PRINT L02&z
    L02&z&..FORMAT(/,' ===> SHUTDOWN Condition: t54&z& .GT. 1530 <===',/)
  ENDIF
!
  IF ((nggz .GT. 9700.0) .AND. (.NOT. lngg&z&a)) THEN
    kalarm&z& = kalarm&z& + 2
    PRINT L03&z
    L03&z&..FORMAT(/,' ===> ALARM Condition: nggz .GT. 9700 <===',/)
  ELSE IF ((nggz .LT. 9700.0) .AND. lngg&z&a) THEN
    lngg&z&a = .FALSE.
    kalarm&z& = kalarm&z& - 2
  ELSE
    CONTINUE
  ENDIF
!
  IF (nggz .GT. 10122.0) THEN
```

```

        kshtdn&z& = kshtdn&z& + 2
        PRINT L04&z
L04&z&..FORMAT(/,' ===> SHUTDOWN Condition: nggz .GT. 10122 <===',/)
ENDIF
!
IF (nptz .GT. 3960.0) THEN
    kshtdn&z& = kshtdn&z& + 4
    PRINT L05&z
L05&z&..FORMAT(/,' ===> SHUTDOWN Condition: nptz .GT. 3960 <===',/)
ENDIF
!
IF ((nptz .LT. 100.0) .AND. (ticz .GT. 30.0)) THEN
    kshtdn&z& = kshtdn&z& + 8
    PRINT L06&z
L06&z&..FORMAT(/,' ===> SHUTDOWN Condition: nptz .LT. 100 <===',/)
ENDIF
!
END

! ----- See if any of the data lookup tables were overrun

PROCEDURAL ( ktbl&z& = pnggr&z&,nptr&z&,p54q&z&,nptq&z&,nggz,t2 )
    ktbl&z& = 0
!
    IF ((pnggr&z& .LT. 46.81) .OP. (pnggr&z& .GT. 99.73)) THEN
        ktbl&z& = ktbl&z& + 1
        PRINT Lt1&z, pnggr&z
        Lt1&z&..FORMAT(/,' ===> TABLE OVERRUN : 46.81 < pnggr&z& < 99.73', &
            ' <===',/, ' ( pnggr&z& = ',F6.2,' )',/)
    ENDIF
!
    IF ((nptr&z& .LT. 600.0) .OR. (nptr&z& .GT. 4000.0)) THEN
        ktbl&z& = ktbl&z& + 2
        PRINT Lt2&z, nptr&z
        Lt2&z&..FORMAT(/,' ===> TABLE OVERRUN : 600 < nptr&z& < 4000', &
            ' <===',/, ' ( nptr&z& = ',F7.1,' )',/)
    ENDIF
!
    IF ((p54q&z& .LT. 1.00) .OR. (p54q&z& .GT. 4.60)) THEN
        ktbl&z& = ktbl&z& + 4
        PRINT Lt3&z, p54q&z
        Lt3&z&..FORMAT(/,' ===> TABLE OVERRUN : 1.00 < p54q&z& < 4.60', &
            ' <===',/, ' ( p54q&z& = ',F4.2,' )',/)
    ENDIF
!
    IF ((nptq&z& .LT. 21.933) .OR. (nptq&z& .GT. 175.467)) THEN
        ktbl&z& = ktbl&z& + 8
        PRINT Lt4&z, nptq&z
        Lt4&z&..FORMAT(/,' ===> TABLE OVERRUN : 21.93 < nptq&z& < 175.47', &
            ' <===',/, ' ( nptq&z& = ',F7.2,' )',/)
    ENDIF
!
    IF ((nggz .LT. 4000.0) .OR. (nggz .GT. 10000.0)) THEN
        ktbl&z& = ktbl&z& + 32
        PRINT Lt5&z, nggz

```

```

Lt5&z&..FORMAT(/,' ===> TABLE OVERRUN : 4000 < nggz < 10000', &
' <===',/, ' ( pnggr&z& = ',F7.1,' )',/)
ENDIF
!
IF ((t2 .LT. 430.0) .OR. (t2 .GT. 595.0)) THEN
    ktbl&z& = ktbl&z& + 64
    PRINT Lt6&z, t2
    Lt6&z&..FORMAT(/,' ===> TABLE OVERRUN : 430 < t2 < 595', &
' <===',/, ' ( t2 = ',F6.1,' )',/)
ENDIF
!
END

! This simulation termination criteria should be enabled when the
! final outer loop controls and generator and motor models are
! installed.

TERMT (kshtdn&z& .gt. 0,' ===> TURBINE SHUTDOWN OCCURRED ')
TERMT (ktbl&z& .gt. 0,' ===> TABLE OVERRUN OCCURRED ')

MACRO END

```

```

! >>>>>> End Gas Generator and Power Turbine Model MACRO <<<<<<<
! -----

```

A.10 Gas Turbine Governor

```

! =====
! >>>>>> Begin Power Turbine Shaft Speed Control Model MACRO <<<<<
! =====
! file name: LM25crpm4.mac   clp 22-nov-91
!
! This macro is a slight modification of "LM25crpm2.mac"
! to permit testing of the reduced-order models of the
! electrical components.
!
! This program generates a throttle input command (ticmdz)
! to control power turbine shaft speed to a reference input
! which is equated to the base shaft RPM (for the LM2500 the
! base speed is fixed at 3600 RPM). The controller sums two
! inputs (ticn and tics) which are generated by a P/I
! controller and a horsepower demand circuit, respectively.
! The power demand circuit accepts a desired per unit steady
! state power demand and determines the equivalent steady
! state power lever angle (tics). (NOTE: the P/I controller
! has been "tuned" to a reference speed of 3600 RPM and the
! table "Talpha&z&" has been developed for that speed.)
!
! The P/I controller generates an error signal,
!
!     nerr = nptref - npt
!
! -----
!
! MODELING CONVENTIONS:

```

```

| -----
|
| (1) Use CAPS for ACSL statements, ACSL variables, etc.
|
| (2) Use lower case for all model variables.
|
| (3) Begin Table names, Function names and related control
|     variables with a capital letter.
|
| -----
|
| CHANGE RECORD:
| -----
|
| Version   Date      Engr   Description
| -----
|      0     22nov91  clp    Model developed and installed.
|
|      1     13may92  ow     deleted "CONSTANT lpwrdz = .FALSE."
|
|      2     19jun92  ow     deleted variables hpgen, lpwrdz, and hpgeni
|
|      3     02nov92  tjm    declared lholdz&PI as LOGICAL to fix PC
|                               compiler problem.
| -----

```

```

MACRO LM25crpm4(z,nptzb,nptzord,nptzordi,nptzi,nptz,hpzb, &
               hpgen,hpgeni,hpzord,hpzordi,lpwr, &
               ticzul,ticzll,ticmdz,ticmdzi)

```

```

| inputs:      z = concatenation variable
|              nptzb = power turbine shaft speed base RPM
|              nptzord = ordered power turbine shaft RPM
|              nptzordi = ordered power turbine shaft RPM IC
|              nptzi = power turbine shaft speed IC
|              nptz = power turbine shaft speed RPM
|              hpzb = power turbine shaft base horsepower
|              hpgen = generator horsepower
|              hpgeni = generator horsepower IC
|              hpzord = ordered turbine horsepower
|              hpzordi = per unit turb horsepower desired IC
|              lpwr = true for power demand mode
|
| outputs: ticmdz = throttle input command
|          ticmdzi = throttle input command IC

```

```

| ----- Define the table for alpha= f(percent qpt). This
|          table was originally developed using LM25test.csl
|          with alphaqpt.rtc to obtain IC values of alpha for
|          kqload values corresponding to the percent base
|          load torque of a 25000 SHP power turbine operating
|          a 3600 RPM. Then, when the controller was added
|          to LM25test.csl, the data was refined by setting
|          khpsatl to the per unit equivalent of percent HP

```

```

!           and using the command sequence:
!
!           SET tstp=0
!           START
!           ANALYZ/TRIM
!           D khpsst1, alphas1
!
!           to determine the trimmed value of alphas1. An
!           additional point was added for khpsst1=1.05 pu.
!

TABLE Talphas1,1,16/
-100.0, 00.0, 05.0, 10.0, 20.0, 30.0, 40.0, 50.0,
  60.0, 70.0, 80.0, 90.0, 100.0, 105.0, 110.0, 999.9,
  13.000, 13.000, 49.4295, 54.6614, 61.0988, 66.6192,
  71.5426, 75.7921, 80.0053, 84.1948, 88.9893, 94.0248,
  98.9640, 102.5660, 108.0, 108.0 /

LOGICAL lhold&z&PI

! ++++++ Begin INITIAL Section ++++++

INITIAL

lhold&z&PI = .false.
! ----- Power turbine shaft speed reference setpoint

npt&z&ri = nptzordi

! ----- Calculate speed controller throttle input
!           command IC

nerr&z&i = npt&z&ri - nptzi
pcntrl&z&i = kcl&z& * nerr&z&i
icntrl&z&i = nerr&z&i
ticn&z&i = pcntrl&z&i + icntrl&z&i

pwr&z&i = 100 * (hpszordi / hpzb)
tics&z&i = Talphas1(pwr&z&i)

ticmdzi = (ticn&z&i + tics&z&i)

END ! ++++++ of INITIAL

! ++++++ Begin DERIVATIVE Section ++++++

! ----- Shaft speed control constants

CONSTANT kcl&z& = 0.5, tcl&z& = 3.0

! ----- P/I integrator bound

CONSTANT iclim&z& = 70.0      ! limit integrator to avoid windup

```

```

! ----- Shaft speed controller ( generates throttle input
!           command -- ticmdz = ticn + tics). A simple P/I
!           controller generates the ticn term given a
!           reference speed, the actual speed and a calculated
!           delta RPM proportional to horsepower demand. The
!           tics term is based on a per unit desired horsepower
!           input command. Since constant speed is assumed,
!           the per unit horsepower is also the per unit torque.

hpt&z&ord = RSW(lpwr,hpzord,hpgen)      ! ordered turbine hp
npt&z&r = nptzord
hp&z&d = BOUND(0.0, hpzb, hpt&z&ord)    ! -- limit demand to rated HP

nerr&z& = (npt&z&r - nptz)              ! speed error
pcntrl&z& = (kcl&z& * nerr&z&)          ! proportional control
icntrl&z& = LIMINT((kcl&z&/tcl&z&)*nerr&z&*kholdPI&z&, nerr&z&i, &
                  -iclim&z&, iclim&z&) ! integral control

ticn&z& = pcntrl&z& + icntrl&z&        ! -- ticn

pwr&z& = 100 * (hpt&z&ord / hpzb)      ! -- percent power demand
tics&z& = Talpha&z&(pwr&z&)           ! -- tics

PROCEDURAL (ticmdz, kholdPI&z& = ticzul,ticzll)
  ticmdz = (ticn&z& + tics&z&)
  IF((nerr&z& .GT. 0.0) .AND. (ticmdz .GT. (ticzul+1.0)))THEN
    lhold&z&PI = .TRUE.
  ELSE IF ((nerr&z& .LT. 0.0) .AND. (ticmdz .LT. (ticzll-1.0)))THEN
    lhold&z&PI = .TRUE.
  ELSE
    lhold&z&PI = .FALSE.
  ENDIF
  kholdPI&z& = RSW(lhold&z&PI, 0.0, 1.0)
END ! of procedural

MACRO END

```

```

!>>>>>>> End Power Turbine Shaft Speed Control Model MACRO <<<<<<<<
!-----

```

A.11 Gas Turbine Mechanical Interface

```

! *****
! >>>>> Begin Source/Load Interface Dynamics Model MACRO <<<<<
! *****
! file name:  tgid2.mac   clp 13-may-91
!
! This program models the mechanical dynamics interface
! between a prime mover (such as a gas turbine) and its load
! (such as a generator) as a simple reduction gear. The
! model includes a reduction gear and all variables are
! referred to the DRIVE (source) shaft. It does not include
! shaft torsional dynamics. One SIGNIFICANT VARIATION is
! that it computes drive shaft acceleration as d(RPM)/dt
! rather than d(RAD/SEC)/dt. A gear torque loss term is
! included in the model. The gear loss coefficient, pctid,

```

```

1  has been set to a nominal value of 0.01 which can be
1  changed at run time.
1
1  The model is a modification of tgid1.mac which has been
1  developed for all variables referred to the load shaft.
1  As in the case of tgid1.mac, the inertia inputs must be
1  specified in the WR^2 (LBM-FT^2) form.
1
1  Needs following parameters:
1
1      rpmrad, gcons
1
1  from: /home/ra4/patterson/acsl/constants.mod
1
1  -----
1
1  MODELING CONVENTIONS:
1  -----
1
1  (1) Use CAPS for ACSL statements, ACSL variables, etc.
1
1  (2) Use lower case for all model variables.
1
1  (3) Begin Table names, Function names and related control
1  variables with a capital letter.
1
1  -----
1
1  CHANGE RECORD:
1  -----
1
1  Version   Date      Engr    Description
1  -----
1      0      15may91  clp    Model developed and installed.
1
1      1      06apr93  tjm    Changed pctidl to pctidaz& to allow
1      using more than one unit.
1
1  -----
1
1  MACRO tgid2(z,qsrc,jjsrc,nsrcl,qsrcb,qloadi,qload,jjload,nloadb, &
1      nloadi,dnsrc,nsrcl,nsrcl,qsrci,dnload,nload)
1
1  inputs:      z = concatenation variable (1, 2, g1, etc)
1      qsrc = input (source) shaft drive torque [LB-FT]
1      jjsrc = input shaft inertia [LB-FT^2]
1      nsrcl = input shaft base speed [RPM]
1      qsrcb = input shaft base torque [LB-FT]
1      qloadi = output (load) shaft initial torque [LB-FT]
1      qload = output (load) shaft torque [LB-FT]
1      jjload = output shaft inertia [LB-FT^2]
1      nloadb = output shaft base speed [RPM]
1      nloadi = output shaft initial speed [RPM]
1
1  outputs:  dnsrc = input shaft base accel [RPM/SEC]

```

```

!          nsrc = input shaft base speed [RPM]
!          nsrci = input  shaft initial speed [RPM]
!          qsrci = input shaft initial torque [LB-FT]
!          dnload = output (load) shaft accel [RPM/SEC]
!          nload = output (load) shaft speed [RPM]

CONSTANT    pctid&z& = 0.01      ! -- percent loss torque factor

! +++++++ Begin INITIAL Section +++++++

INITIAL

! ----- Calculate gear speed ratio

id&z&gr = nsrcl / nloadb

! ----- Calculate total inertia referred to load shaft

iitid&z& = (jjsrc / gcons) + (jjload / gcons) / id&z&gr**2

! ----- Calc initial source shaft speed

nsrci = nloadi * id&z&gr

! ----- Calc torque loss constant and initial torque loss

cqlid&z& = (pctid&z& * qsrcb) / (nsrcl*nsrcl)
qlid&z&i = cqlid&z& * nsrci * ABS(nsrci)

! ----- Calc initial source shaft torque

qsrci = (qloadi + qlid&z&i) / id&z&gr

END ! +++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section +++++++

! ----- Calc LOAD shaft speed (accel) in units of
!          RPM (RPM/SEC)

qlid&z& = cqlid&z& * nsrc * ABS(nsrc)

dnsrc = (rpmrad * (qsrc - (qload/id&z&gr) - qlid&z&) / iitid&z&)
nsrc = INTEG (dnsrc, nsrci)

! ----- Calc SOURCE shaft speed (accel) in units of
!          RPM (RPM/SEC)

dnload = dnsrc / id&z&gr
nload = nsrc / id&z&gr

MACRO END

! >>>>>>> End Source/Load Interface Dynamics Model MACRO <<<<<<<<
! -----

```

A.12 Mechanical Load

```
=====
|
|               Mechanical Load Model
|
|       Copyright 1992 by Timothy J. McCoy
|
=====
|
| Macro:      load.mac
|
| Function:   Models a mechanical load applied to a motor.  Allows
|             various types of loads to be simulated through the use
|             of a second order polynomial.
|
|             Concatenation
| z           = machine identifier
|
|             Inputs
| wm          = machine speed [per unit]
|
|             Outputs
| tm          = mechanical load torque[per unit]
|
|             Constants
| a&z&       = quadratic polynomial constant [ ]
| b&z&       = linear polynomial constant [ ]
| c&z&       = constant term of polynomial [ ]
|
|             State variables
|             NONE
|
|             Initial Conditions
|             NONE
|
=====

MACRO load (z,wm,tm)

    CONSTANT a&z& = 0.0
    CONSTANT b&z& = 0.0
    CONSTANT c&z& = 0.0

INITIAL

END !--- of initial section

!---beginning of derivative section

    tm = a&z&*wm**2 + b&z&*wm + c&z&

!---end of derivative section
MACRO END
```

A.13 Ship's Service Load

```
!-----
!
!                               Ship's Service Load
!
!                               Copyright 1993 by Timothy J. McCoy
!
!-----
!                               Record of Changes
!
!  No.   Date    By      Summary
!  ---   -
!    0   3-27-93 tjm    Model written.
!-----
!  macro: shipserv.mac
!  function: models a constant power load
!             CONCATENATION
!  z        = motor identifier
!
!             INPUTS
!  vd        = D-axis terminal voltage [per unit]
!  vq        = Q-axis terminal voltage [per unit]
!
!             OUTPUTS
!  id        = D-axis terminal current [per unit]
!  iq        = Q-axis terminal current [per unit]
!
!             CONSTANTS
!  p&z&     = Real power load [per unit]
!  q&z&     = Reactive power load [per unit]
!
!             INTERNAL
!  NONE
!-----
MACRO shipserv (id,iq , vd,vq,z)
!-----
!                               Begin Derivative Section
!-----
!---parameters
CONSTANT p&z&      = 0.0
CONSTANT q&z&      = 0.0

PROCEDURAL(id,iq,q&z&,p&z&)
  vt&z&2 = vd*vd + vq*vq
  id     = (vd*p&z& + vq*q&z&)/vt&z&2
  iq     = (vq*p&z& - vd*q&z&)/vt&z&2
END !---of procedural

MACRO END !---of shipserv
```

A.14 Base Conversions

```
!-----
```

```

|
|
|               BASE CONVERSION MACRO
|
|       Copyright 1993 by Timothy J. McCoy
|
|=====
|               Record of Changes
|
|   No.   Date   By      Summary
|   ---   -
|   0     4-08-93 tjm    Model written.
|=====
|
|   macro:   baseconv
|   function: calculates conversion factors for converting
|               quantities from one base to another base.
|
|               CONCATENATION
|
|               NONE
|
|               INPUTS
|   basev1 = base voltage converted from
|   basev2 = base voltage converted to
|   basekw1 = base power converted from
|   basekw2 = base power converted to
|
|               OUTPUTS
|   kv12   = voltage conversion factor
|   kkw12  = power conversion factor
|   ki12   = current conversion factor
|   kz12   = impedance conversion factor
|
|               CONSTANTS
|
|               NONE
|=====
| MACRO baseconv(kv12,kkw12,ki12,kz12 , basev1,basev2,basekw1,basekw2)
|
| kv12   = basev1/basev2
| kkw12  = basekw1/basekw2
| ki12   = kkw12/kv12
| kz12   = kv12**2/kkw12
|
| MACRO END : of baseconv

```

A.15 Miscellaneous Constants

```

|-----
|
|               PHYSICAL CONSTANTS INCLUSION FILE
|
|       Copyright 1993 by Timothy J. McCoy
|
|-----
|               CONSTANTS

```

```

1
1  NAME                VALUE                USED BY
1  -----
1  krt3                = SQRT(3)            = 1.7320508  vreg2.mac, freqchg2.mac
1  krt302              = SQRT(3)/2          = 0.8660254  vreg2.mac
1  kpio2               = PI/2              = 1.570796   conmtr.mac
1  k3rt3opi            = 3*SQRT(3)/PI       = 1.6539866  freqchg2.mac
1  k2rt3opi            = 2*SQRT(3)/PI       = 1.1026577  freqchg2.mac, conmtr,mac
1  k2ort3              = 2/SQRT(3)          = 1.1547005  freqchg2.mac
1  kpi                 = PI                = 3.1415927  conmtr.mac
1  -----
1  PARAMETER (krt3o2   = 0.8660254)
1  PARAMETER (kpio2    = 1.570796)
1  PARAMETER (k3rt3opi = 1.6539866)
1  PARAMETER (krt3     = 1.7320508)
1  PARAMETER (k2rt3opi = 1.1026577)
1  PARAMETER (k2ort3   = 1.154700538)
1  PARAMETER (kpi      = 3.1415927)
1  !---END of 'constant.inc'

```

A.16 Circuit Breaker

```

1  -----
1
1                      Circuit Breaker Model
1
1                      Copyright 1993 by Timothy J. McCoy
1
1  =====
1                      Record of Changes
1
1  No.   Date   By   Summary
1  ---   -
1  0     4-21-93 tjm   Model written.
1  =====
1  macro: cb.mac
1  function: models a lossless switch for disconnecting generators
1             from the main bus (works for components which input
1             currents and output voltages).
1
1                      CONCATENATION
1
1                      INPUTS
1  lcb    = logical variable to indicate closed (.TRUE.)
1          or open (.FALSE.)
1  vdbus  = D-axis bus voltage [per unit]
1  vqbus  = Q-axis bus voltage [per unit]
1  vdgen  = D-axis generator terminal voltage [per unit]
1  vqgen  = Q-axis generator terminal voltage [per unit]
1  id     = D-axis generator terminal current [per unit]
1  iq     = Q-axis generator terminal current [per unit]
1
1                      OUTPUTS
1  vdcb   = D-axis circuit breaker voltage [per unit]
1  vqcb   = Q-axis circuit breaker voltage [per unit]
1  idcb   = D-axis circuit breaker current [per unit]

```

```

:   iqcb      = Q-axis circuit breaker current [per unit]
:
:               CONSTANTS
:
:               INTERNAL
:
:=====
MACRO cb (vdcb,vqcb,idcb,iqcb , lcb,vdbus,vqbus,vdgen,vqgen,id,iq)
:=====
:               Begin Derivative Section
:=====
IF(lcb)THEN
    vdcb      = vdbus
    vqcb      = vqbus
    idcb      = id
    iqcb      = iq
ELSE
    vdcb      = vdgen
    vqcb      = vqgen
    idcb      = 0.0
    iqcb      = 0.0
ENDIF
MACRO END !---of cb

```

A.17 Inverse Park's Transform

```

:-----
:
:               INVERSE PARK'S TRANSFORMATION DQ-->ABC VARIABLES
:
:               Copyright 1992 by Timothy J. McCoy
:
:-----
:
:=====
:               Record of Changes
:
:   No.  Date    By    Summary
:   ---  -
:   0.  12-1-92  tjm    Model written.
:   1.  12-3-92  tjm    Removed Definition of twopi3, it is defined
:                       in 'constants.inc'.
:   2.  12-6-92  tjm    Changed to unitary form of transformation.
:   3.  3-15-93  tjm    Changed back to Prof. Kirtley's transformation
:=====
:
:   macro:      ipark
:   function:    Performs an inverse D-Q transformation on its inputs.
:
:               CONCATENATION
:
:               none
:
:               INPUTS

```

```

!      fq      = Q-axis variable [per unit]
!      fd      = D-axis variable [per unit]
!      theta   = the integral of the speed of rotation of the D-Q
!                reference frame.
!
!                OUTPUTS
!      fa      = A-phase variable [per unit]
!
!      fb      = B-phase variable [per unit]
!      fc      = C-phase variable [per unit]
!
!                CONSTANTS
!      k2pio3   = 2*pi/3 = 2.094395
!      krt2o3   = sqrt(2/3) = 0.81649658
!
!                INTERNAL (STATE OR STATE RELATED)
!      none
!
!                INTERNAL (NOT STATE RELATED)
!      none
!=====
CONSTANT k2pio3 = 2.094395

MACRO ipark (fa,fb,fc,fq,fd,theta)

!=====
!                Begin Derivative Section
!=====

fa = (fd*cos(theta)          - fq*sin(theta))
fb = (fd*cos(theta - k2pio3) - fq*sin(theta - k2pio3))
fc = (fd*cos(theta + k2pio3) - fq*sin(theta + k2pio3))

!=====
!                End of Derivative Section
!=====

MACRO END : of ipark

```

A.18 Park's Transform

```

!-----
!
!                PARK'S TRANSFORMATION ABC-->DQ VARIABLES
!
!                Copyright 1992 by Timothy J. McCoy
!
!-----
!
!=====
!                Record of Changes
!
!      No.  Date    By    Summary
!      ---  -
!      0.   12-1-92  tjm    Model written.
!
!=====

```

```

1  1. 12-3-92  tjm    Removed Definition of twopi3, it is defined
1                      in 'constants.inc'.
1  2. 12-6-92  tjm    Changed to unitary form of transformation.
1  3. 3-15-93  tjm    Changed back to Prof. Kirtley's transformation
1 =====
1
1  macro:      park
1  function:   Performs a D-Q transformation on its inputs.
1
1
1                      CONCATENATION
1  z          = synchronous machine identifier
1
1                      INPUTS
1  fa         = A-phase variable [per unit]
1
1  fb         = B-phase variable [per unit]
1  fc         = C-phase variable [per unit]
1  theta      = the integral of the speed of rotation of the D-Q
1                reference frame.
1
1                      OUTPUTS
1  fq         = Q-axis variable [per unit]
1  fd         = D-axis variable [per unit]
1
1                      CONSTANTS
1  k2pio3     = 2*pi/3 = 2.094395
1  krt2o3     = sqrt(2/3) = 0.81649658
1
1                      INTERNAL (STATE OR STATE RELATED)
1  none
1
1                      INTERNAL (NOT STATE RELATED)
1  none
1 =====
1  CONSTANT k2o3 = 0.66666667
1
1  MACRO park (fq,fd , fa,fb,fc,theta)
1
1 =====
1                      Begin Derivative Section
1 =====
1
1  fd = k2o3*(fa*cos(theta)+fb*cos(theta-k2pio3)+ &
1        fc*cos(theta + k2pio3))
1  fq = -k2o3*(fa*sin(theta)+fb*sin(theta-k2pio3)+ &
1        fc*sin(theta + k2pio3))
1
1 =====
1                      End of Derivative Section
1 =====
1  MACRO END : of park

```

A.19 Ship Dynamics

```
|-----|
|
|               SHIP DYNAMICS MODEL
|
|       Copyright 1993 by Timothy J. McCoy
|
|       The macros used herein were written by
|       C.L. Patterson, NSWC, Annapolis, MD
|
|-----|
|               Record of Changes
|
|  No.   Date   By      Summary
|  ---   -
|  0     3-29-93 tjm    Model written.
|-----|
|
|  macro:      ship
|  function:    Models the hydrodynamic propeller load placed on
|
|               a propulsion motor
|
|               INPUTS
|  wrn1        = Starboard propeller shaft speed [per unit]
|  wrn2        = Port propeller shaft speed [per unit]
|
|               OUTPUTS
|  tml         = mechanical torque load on starboard motor [per unit]
|  tml         = mechanical torque load on port motor [per unit]
|
|               CONSTANTS
|  kbaserpm    = base propeller shaft rpm
|  kqbase      = base shaft torque [LB-FT]
|  jjps        = propeller/shaft inertia in [LB/FT^2]
|
|               INTERNAL
|-----Inputs to 'shipla.mac'
|  np1rpm      = propeller shaft speed [RPM]
|  np2rpm      = propeller shaft speed [RPM]
|  wesea       = seaway velocity factor [per unit]
|  lheadr      = logical ( = .T. to begin headreach calc)
|
|-----Inputs to 'seaway.mac'
|  vs1pu       = ship velocity normalized [per unit]
|
|-----Outputs from 'shipla.mac'
|  jjps        = total prop/shaft inertia [LB-FT^2]
|  np1rpm      = initial shaft speed [RPM]
|  qp1         = initial shaft torque [LB-FT]
|  qp1         = shaft torque [LB-FT]
|  qp1fi       = initial shaft frictional loss torque [LB-FT]
|  qp1f        = shaft frictional loss torque [LB-FT]
|  np2rpm      = initial shaft speed [RPM]
```

```

:      qp2i = initial shaft torque [LB-FT]
:      qp2 = shaft torque [LB-FT]
:      qp2fi = initial shaft frictional loss torque [LB-FT]
:      qp2f = shaft frictional loss torque [LB-FT]
:      vs1pu = per unit ship speed
:      lcalchr = logical ( = .T. to permit headreach calc)
:      lvship0 = logical ( SCHEDULE flag = .T. when vs=0.0)
:      headrpu = headreach on vs1 per unit base
:      t0vship = time at which headreach calc starts
:      tvship0 = time req'd to stop ship from start of headr
:      xvship0 = headreach distance on vs1 per unit base
:      qpsbaf = propeller shaft breakaway friction [LB-FT]
:      nprpmb = propeller shaft speed base [RPM]
:      qpbase = propeller shaft torque base [LB-FT]
:
:-----Outputs from 'seaway.mac'
:      wesea = seaway velocity factor [per unit]
:      lsea = logical flag set .TRUE. to invoke seaway
:      ldoppler = logical flag set .TRUE. to invoke an
:                  effective doppler seaway frequency
:=====
:                  MACROS
:=====
INCLUDE 'c:\acsl\ship\macros\shipla.mac'
INCLUDE 'c:\acsl\ship\macros\seaway1.mac'
INCLUDE 'c:\acsl\ship\macros\constant.inc'
:=====

MACRO ship (tm1,tm2 , wrn1,wrn2,kbaserpm)

:=====
:                  Begin Derivative Section
:=====

:---convert shaft speed to rpm
np1rpm = wrn1*kbaserpm
np2rpm = wrn2*kbaserpm

:---convert shaft torque to per unit for output
tm1     = -qp1/qpbase
tm2     = -qp2/qpbase

:---Invoke ship dynamics macro
shipla(1,np1rpm,np2rpm,wesea , lheadr,jjps,np1rpmi,qp1i,qp1,qp1fi, &
      qp1f,np2rpmi,qp2i,qp2,qp2fi,qp2f,vs1pu,lcalchr,lvship0, &
      headrpu,t0vship,tvship0,xvship0,qpsbaf,nprpmb,qpbase)

:---Invoke seaway macro
seaway(1,lsea,ldoplr,vs1pu,wesea)

:=====
:                  End of Derivative Section
:=====
MACRO END : of ship

```

```

| -----
| ----- ACSL MODEL CONSTANTS
|
| file name: constants.mod
|
| created: 13-JAN-86 CLP (VAX ACSL_CONS.MOD)
|
| revision: 26-feb-91 clp modified for SUN,
|               mod pi, add twopi
|
|           19-apr-91 clp add elec pwr sys
|               parameters: forfve,
|               ninety, twopio3,
|               omega60b
|
|           18-oct-91 clp add inertia constant
|               factors khhl and khh2
|
| -----
|
| >>>> ESTABLISH GENERAL CONSTANTS <<<<
|
| ----- Miscellaneous Model Constants -----
|
| PARAMETER (pi = 3.1415926536)      ! [non-dimensional]
| PARAMETER (twopi = 6.28318530718)  ! [non-dimensional]
| PARAMETER (sqrt2 = 1.41421)       ! [non-dimensional]
| PARAMETER (sqrt3 = 1.73205)       ! [non-dimensional]
|
| PARAMETER (rho = 1.9905)           ! [(lb-sec^2)/ft^4]
| PARAMETER (gcons = 32.174)        ! [ft/sec^2]
|
| PARAMETER (ftlbhp = 550.)          ! [ft-lb/sec)/hp]
| PARAMETER (watthp = 745.7)         ! [watts/hp]
| PARAMETER (kwathp = .7457)         ! [kilowatts/hp]
|
| ----- RPM = RAD/SEC * [ 60. / (2. * PI) ] -----
|
| PARAMETER (rpmrad = 9.549296)      ! [rpm/(rad/sec)]
|
| ----- FT/SEC = KNOTS * [ 6076.1 / 3600. ] -----
|
| PARAMETER (fpskt = 1.687806)       ! [(ft/sec)/knot]
|
| ----- Inertia constant factors for use in calculating HH
| given the inertia in JJ (WR^2 [lbm-ft^2]) form, the
| shaft speed in N [rpm], and either KVA or Q [lbf-ft].
|
| ----- for the form: HH = khhl * ( JJ * N^2 / KVA)
|
| khhl = (1/2)*[(1/2.204)*(1/3.2808)^2]*(2*pi/60)^2
|
| PARAMETER (khhl = 2.3094e-7)

```

```

! ----- for the form: HH = khh2 * ( JJ * N / Q)
!
!       khh2 = khh1 * (kwathp / ftlbhp)

PARAMETER (khh2 = 2.99165e-3)

! ----- Useful constants and parameters for -----
!       electrical power systems simulations
!       involving solid state, 6-pulse rectifier
!       circuits. Based on data provided by
!       Purdue for the Pulse Power charger model.
!       (added by ==> clp 19,25-apr-91)

PARAMETER (eps = 1.0e-6)           ! a small number

PARAMETER (omega60b = 377.0)       ! [ base radian freq for 60 Hz ]

PARAMETER (forfive = 0.78539816) ! [ (pi/4) equiv 45 deg ]
PARAMETER (ninety = 1.57079633)  ! [ (pi/2) equiv 90 deg ]
PARAMETER (twopio3 = 2.0943951) ! [ (2*pi/3) equiv 120 deg ]

PARAMETER (cfac6P = 1.10265779) ! current factor -- (2*sqrt(3))/pi
PARAMETER (vfac6P = 1.6539867)  ! voltage factor -- (3*sqrt(3))/pi
PARAMETER (zfac6P = 0.9549297)  ! impedance factor -- 3/pi

! ----- Model function lookup flags -----

INTEGER      Farg0, Farg1, Farg2, Farg3
INTEGER      Fargs0, Fargs1, Fargs2, Fargs3

CONSTANT Farg0 = 0      ! FORWARD lookup
CONSTANT Farg1 = 1      ! BACKWARD lookup
CONSTANT Farg2 = 2      ! 1,2, or 3 flags the
CONSTANT Farg3 = 3      ! dependent argument
CONSTANT Fargs0 = 0
CONSTANT Fargs1 = 1
CONSTANT Fargs2 = 2
CONSTANT Fargs3 = 3

!       >>>>> END of ESTABLISH GENERAL CONSTANTS <<<<<
! -----

! -----
! >>>>> Begin Source/Load Interface Dynamics Model MACRO <<<<<
! -----
! file name: mpidif.mac clp 7-oct-91
!
! This program models the mechanical dynamics interface
! between a prime mover (such as a gas turbine or motor) and its
! load (such as a generator or propeller) as a simple reduction
! gear. The model includes a reduction gear and all variables
! are referred to the output (load) shaft. It does not include
! shaft torsional dynamics. One SIGNIFICANT VARIATION is that

```

```

| it computes drive shaft acceleration as d(RPM)/dt rather than
| d(RAD/SEC)/dt. A gear torque loss term is included in the
| model. The gear loss coefficient, pctid, has been set to a
| nominal value of 0.005 which can be changed at run time.
|
| The model is a modification of tgid1.mac which was developed
| for all variables referred to the load shaft. The differences
| are that this model also accepts load shaft friction as an
| input and the gear ratio is given as a constant rather than
| being calculated. Since propeller shaft friction can be
| significant at low shaft speed, the model checks to see if
| shaft sticking occurs.
|
| This model is a modified version of that developed by PDI as
| the subroutine SHAFT.FOR in a MACRO form which employs the ACSL
| SCHEDULE function to determine shaft sticking. NOTE: The sign
| of the friction torque is determined within the shaft friction
| function (QlApsf.for for shipla).
|
| As in the case of tgid2.mac, the inertia inputs must be
| specified in the WR^2 (LBM-FT^2) form. For this model a
| gearbox inertia term is included.
|
| Needs following parameters:
|
|         rpmrad, gcons, khh2
|
| from: /home/ra4/patterson/acsl/constants.mod
|
| -----
|
| MODELING CONVENTIONS:
| -----
|
| (1) Use CAPS for ACSL statements, ACSL variables, etc.
|
| (2) Use lower case for all model variables.
|
| (3) Begin Table names, Function names and related control
|     variables with a capital letter.
|
| -----
|
| CHANGE RECORD:
| -----
|
| Version   Date      Engr   Description
| -----
| 0         07oct91   clp    Model developed and installed.
|
| 1         21-oct91  clp    Make gear ratio a constant rather than
|         the calculation of [ nsrcb / nloadb ]
|
| 2         02jun92   jgc    pctid&zz& and qlid&zz& changed to pctids&zz&
|         and qlids&zz& so as to not conflict with

```

```

1               same variables in turbine model
1
1      3      08jun92  jgc  the constant cqlid&z& is changed to cqlids&z&
1                        so as to not conflict with turbine constant;
1                        also this constant is computed in INITIAL
1      -----
MACRO  mpidif(z,qsrc,jjsrc,nsrcb,qsrcb,qloadi,qload,qloadb,jjload, &
        nloadb,nloadi,qloadfi,qlsfgr,lstukzgr,qloadsbf,dnsrc, &
        nsrc,nsrci,qsrci,dnload,nload,delqzgr,ngrlzpu)

1  inputs:      z = concatenation variable (1, 2, g1, etc)
1               qsrc = input (source) shaft drive torque [LB-FT]
1               jjsrc = input shaft inertia [LB-FT^2]
1               nsrcb = input shaft base speed [RPM]
1               qsrcb = input shaft base torque [LB-FT]
1               qloadi = output (load) shaft initial torque [LB-FT]
1               qload = output (load) shaft torque [LB-FT]
1               qloadb = output (load) shaft torque base [LB-FT]
1               jjload = output shaft inertia [LB-FT^2]
1               nloadb = output shaft base speed [RPM]
1               nloadi = output shaft initial speed [RPM]
1               qloadfi = load shaft initial friction torque [LB-FT]
1               qlsfgr = load shaft friction torque [LB-FT]
1               lstukzgr = logical (= .T. if shaft stuck)
1               qloadsbf = load shaft breakaway force [LB-FT]
1
1  outputs:     dnsrc = input shaft base accel [RPM/SEC]
1               nsrc = input shaft base speed [RPM]
1               nsrci = input shaft initial speed [RPM]
1               qsrci = input shaft initial torque [LB-FT]
1               dnload = output (load) shaft accel [RPM/SEC]
1               nload = output (load) shaft speed [RPM]
1               delqzgr = load shaft accel torque difference [LB-FT]
1               ngrlzpu = load shaft speed [per unit]
1
CONSTANT  pctids&z& = 0.005      ! -- percent loss torque factor
CONSTANT  jjmpid&z& = 665600    ! -- gearbox WR^2 [LBM-FT^2] referred
1               to load shaft (20700 LBF-FT-S^2)
CONSTANT  mpid&z&gr = 6.0       ! -- gear ratio (nsrc / nload) based
1               on data provided by Code 27B (HNR)
1  ++++++ Begin INITIAL Section ++++++
INITIAL
1  ----- Calculate total inertia referred to load shaft
jjmpid&z&t = jjsrc * mpid&z&gr**2 + jjmpid&z& + jjload
hhmpid&z&t = khh2*jjmpid&z&t*(nsrcb/mpid&z&gr)/(qsrcb*mpid&z&gr)
iimpid&z& = jjmpid&z&t / gcons

1  "This is a test, this constant must be defined"
cqlids&z& = (pctids&z& * qsrcb) / (nsrcb*nsrcb)

1  ----- Calc initial source shaft speed and torque
PROCEDURAL (nsrci,qsrci = nloadi,mpid&z&gr,pctids&z&,qsrcb,nsrcb, &
        qloadi,qloadfi)
1  IF (ABS(nloadi) .LT. 0.1) THEN      ! --- Assume shaft is at rest
        nsrci = 0.0

```

```

    qsrci = 0.0
ELSE
    nsrcli = nloadi * mpid&z&gr

    ! ----- Calc torque loss constant and initial torque loss
    !           on source shaft side
    cqlids&z&i = (pctids&z&i * qsrcb) / (nsrcli*nsrcli)
    qlids&z&i = cqlids&z&i * nsrcli * ABS(nsrcli)
    ! ----- Calc initial source shaft torque
    qsrci = qlids&z&i + (qloadi+qloadfi) / mpid&z&gr
ENDIF
END      ! --- of PROCEDURAL
END !      ++++++ of INITIAL

! ++++++ Begin DERIVATIVE Section ++++++

! ----- Calc LOAD shaft speed (accel) in units of
!           RPM (RPM/SEC)
qlids&z&i = cqlids&z&i * nsrcli * ABS(nsrcli) ! source shaft loss torque
delqzgr = (qsrc-qlids&z&i)*mpid&z&gr - qload
qs&z&fgr = RSW (lstukzgr,-delqzgr, qlsfgr)
dnload = (rpmrad / iimpid&z&i) * (delqzgr + qs&z&fgr)
nload = INTEG (dnload, nloadi)
ngrlzpu = nload / nloadb      ! --- per unit gearbox shaft speed

! ----- Check gearbox load shaft condition for shaft
!           stuck condition
chkgr&z&ls = RSW (lstukzgr, ABS(delqzgr) - qloadbfi, nload)
SCHEDULE shaft&z&i .XZ. chkgr&z&ls
! ----- Calc SOURCE shaft speed (accel) in units of
!           RPM (RPM/SEC)
dnsrc = dnload * mpid&z&gr
nsrcli = nload * mpid&z&gr
MACRO END

MACRO shaftstk (z,qloadbfi,nloadi,delqzgr,qloadfi,qlsfgr,lstukzgr,nload)
!   inputs:      z = concatenation variable (1, 2, g1, etc)
!               qloadbfi = load shaft breakaway friction torque [LB-FT]
!               nloadi = output shaft initial speed [RPM]
!               delqzgr =
!               qloadfi = load shaft rotating friction torque [LB-FT]
!
!   outputs:  qlsfgr = load shaft friction torque [LB-FT]
!             lstukzgr = logical (= .T. if shaft stuck)
DISCRETE shaft&z&i
! ----- Handle shaft sticking friction
INITIAL
    LOGICAL  lstukzgr
    lstukzgr = ABS(nloadi) .LT. 0.1
END
! ----- Stuck flag toggles unless force exceeds breakout
!           force on crossing zero
lstukzgr = (.NOT. lstukzgr) .AND. (ABS(delqzgr) .LT. qloadbfi)
! ----- Determine shaft friction for stuck or rotating
!           condition (sign of qloadfi pre-determined in table)

```

```

qlsfgr = RSW (lstukzgr, 0.0, qloadf)
! ----- Reset shaft speed exactly to zero
nload = 0.0
! ----- Record status
CALL LOGD (.TRUE.)
END ! of DISCRETE stick&z&gr
MACRO END ! of shaftstk
! >>>>>>> End Source/Load Interface Dynamics Model MACRO <<<<<<<<
!
! =====
! >>>>> Begin Seaway Dynamics Model MACRO <<<<<<
! =====
! file name: seaway1.mac clp 11-sep-91
!
! This program models seaway hydrodynamic characteristics
! for a ship hull moving through the water in one degree of
! freedom. It assumes that ship speed is normalized and that
! nominal values for the seaway conditions are those given in
! the original GE RFP spec. This model has the capability
! to simulate a variation in the frequency of wave encounter
! based on the relative speed between the ship and the seaway.
!
! This approach is patterned after method given in the original
! GE RFP spec -- on page 20, wherein:
!
! 
$$V_e = V_m * (1 - W_e * \sin(2\pi t/T)).$$

!
! This program calculates the value of:
!
! 
$$w_{sea} = W_e * \sin(2\pi t/T)$$

!
! and outputs wsea to the ship velocity equation in the model
! shipla.mac.
!
! The following numerical data is given in [3], based on
!  $V_m$  (mean ship speed):
!


|                       |      |      |      |
|-----------------------|------|------|------|
| T (period, sec)       | 6    | 10   | 15   |
| $W_e$ (moderate seas) | 0.10 | 0.12 | 0.13 |
| $W_e$ (heavy seas)    | 0.40 | 0.47 | 0.50 |


!
! To permit investigation of doppler frequency effects,
! assume the following values for lambda (wavelength):
!


|            |   |    |    |
|------------|---|----|----|
| wavelength | 4 | 12 | 25 |
|------------|---|----|----|


!
! For an initial case, assume  $T=6$ ,  $W_e=0.10$ , and  $L=4$ 
!
! Needs following parameters:
!


|       |
|-------|
| twopi |
|-------|


!

```

```

: from: /home/ra4/patterson/acsl/constants.mod
:
: -----
:
: MODELING CONVENTIONS:
: -----
:
: (1) Use CAPS for ACSL statements, ACSL variables, etc.
:
: (2) Use lower case for all model variables.
:
: (3) Begin Table names, Function names and related control
:     variables with a capital letter.
:
: -----
:
: CHANGE RECORD:
: -----
:
: Version   Date      Engr   Description
: -----
: 0         xxxxx91   clp    Model developed and installed.
:
: 1         20Aug92   ow     moved lsea and ldoppler to output list.
:
: -----
:
: MACRO seaway(z,lsea,ldoplr,vshipu,wesea)
:
:   inputs:      z = concatenation variable (1, 2, g1, etc)
:                vshipu = ship velocity normalized (per unit)
:
:   outputs:     wesea = seaway velocity factor [per unit]
:                lsea = logical flag set .TRUE. to invoke seaway
:                ldoppler = logical flag set .TRUE. to invoke an
:                        effective doppler seaway frequency
:
: ----- define basic constants for ship seaway dynamics
:
: LOGICAL      lsea, ldoplr
:
: CONSTANT     lsea = .FALSE., ldoplr = .FALSE.
: CONSTANT     tsea = 6.0, wesmax = 0.10, wave = 4.0
:
: ++++++ Begin INITIAL section ++++++
:
: INITIAL
:
: ----- calculate seaway encounter frequency [RAD/SEC]
:           based on tsea (constant frequency) and a
:           constant for computing doppler frequency
:
: wsefsea = twopi / tsea
: kdfrq = twopi / wave

```

END ! ++++++++ of INITIAL

! ++++++ Begin DERIVATIVE Section ++++++

! ----- calculate seaway velocity magnitude. The REALPL
! function has been included to smooth the
! initial seaway encounter.

! NOTE: This code has been placed within a PROCEDURAL
! to circumvent an ACSL implicit loop flag.
! That is, when combined with "shipla.mac",
! the following expression occurs:

! vs1pu = INTEG() * (1 - wesea),

! where, wesea = f(vs1pu,t)

! To achieve the desired result, the variable
! "vshippu" has been left out of the argument
! list.

PROCEDURAL (wesea = lsea,ldoplr,wesmax)
IF (.NOT. lsea) t0sea = 0.0
IF (lsea .AND. (t0sea .EQ. 0.0)) t0sea = t
weseamg = REALPL(tsea/5.0, RSW(lsea, wesmax, 0.0), 0.0)
seafreq = RSW(ldoplr, kdfrq * ABS(vshippu + weseamg + 0.001), wesea)
seatime = RSW(lsea, (t - t0sea), 0.0)
wesea = weseamg * SIN(seatime)
END ! -- of PROCEDURAL

MACRO END

! >>>>>>> End Source/Load Interface Dynamics Model MACRO <<<<<<<<<<<<
! -----

! =====
! >>>>>> Begin Propeller/Ship Dynamics Model MACRO <<<<<<
! =====

! file name: shipla.mac clp 23-aug-91

! This program models the propeller and hydrodynamic
! characteristics for a ship hull moving through the water
! in one degree of freedom. The simulated ship is that
! represented by shipl data. The hull resistance, the
! propeller torque, and the propeller thrust characteristics
! have been normalized. The characteristics (torque and thrust)
! have been represented as functions of two variables (per unit
! ship speed and per unit propeller shaft speed). The ship hull
! resistance function has been characterized using a 10th order
! polynomial to fit the available data for the full AHEAD/ASTERN
! maneuvering range. This model also includes the friction torque
! function for the propeller shafts associated with the ship hull.

! The model assumes an initial ship speed (per unit) which can
! be selected at run time. Using this ship speed and the ship

```

| resistance data table, a per unit shaft speed is calculated
| and converted to shaft RPM to be output along with the base
| RPM value. It is assumed that the two propeller shafts are
| operating at the same initial shaft speed.
|
| To calculate headreach, set the logical flag lheadr = .TRUE.
| A mode-controlled integrator is used to calculate headreach
| in terms of per unit ship speed. The ACSL SCHEDULE statement
| is used to determine when the ship speed reaches zero.
|
| Propeller shaft speed inputs are in RPM and the model is set
| up to respond to a seaway input (wesea). If a seaway is not
| to be used, set wesea = 0.0. The function lookup table (QlApsf)
| is used to calculate and output propeller shaft frictional
| torque (LB-FT) as a function of shaft RPM.
|
| This model requires the following files which contain
| function data:
|
|     /models/hydro/TQlAlib.a
|     /models/lookup/lookuplib.a
|
| Needs following parameters:
|
|     rpmrad, gcons, khh2
|
| from: /home/ra4/patterson/acsl/constants.mod
|
| -----
|
| MODELING CONVENTIONS:
| -----
|
| (1) Use CAPS for ACSL statements, ACSL variables, etc.
|
| (2) Use lower case for all model variables.
|
| (3) Begin Table names, Function names and related control
|     variables with a capital letter.
|
| -----
|
| CHANGE RECORD:
| -----
|
| Version   Date      Engr    Description
| -----
| 0         7oct91    clp     Model developed and installed.
|
| 1         18oct91   clp     Added hhps inertia calculation
|
| 2
|
| -----
|
| MACRO  shipla(z,nplrpm,np2rpm,wesea,lheadr,jjps,nplrpmi,qpli, &

```

```

qp1,qp1fi,qp1f,np2rpmi,qp2i,qp2,qp2fi,qp2f,vslpu, &
lcalchr,lvship0,headrpu,t0vship,tvship0,xvship0, &
qpsbaf,nprpmb,qpbase)

```

```

!   inputs:      z = concatenation variable (1, 2, g1, etc)
!               nplrpm = propeller shaft speed [RPM]
!               np2rpm = propeller shaft speed [RPM]
!               wsea = seaway velocity factor [per unit]
!               lheadr = logical ( = .T. to begin headreach calc)
!
!   outputs:      jjps = total prop/shaft inertia [LB-FT^2]
!               nplrpmi = initial shaft speed [RPM]
!               qp1i = initial shaft torque [LB-FT]
!               qp1 = shaft torque [LB-FT]
!               qp1fi = initial shaft frictional loss torque [LB-FT]
!               qp1f = shaft frictional loss torque [LB-FT]
!               np2rpmi = initial shaft speed [RPM]
!               qp2i = initial shaft torque [LB-FT]
!               qp2 = shaft torque [LB-FT]
!               qp2fi = initial shaft frictional loss torque [LB-FT]
!               qp2f = shaft frictional loss torque [LB-FT]
!               vslpu = per unit ship speed
!               lcalchr = logical ( = .T. to permit headreach calc)
!               lvship0 = logical ( SCHEDULE flag = .T. when vs=0.0)
!               headrpu = headreach on vs1 per unit base
!               t0vship = time at which headreach calc starts
!               tvship0 = time req'd to stop ship from start of headr
!               xvship0 = headreach distance on vs1 per unit base
!               qpsbaf = propeller shaft breakaway friction [LB-FT]
!               nprpmb = propeller shaft speed base [RPM]
!               qpbase = propeller shaft torque base [LB-FT]
!   ----- define logical variables

```

```

LOGICAL      lheadr
!---LOGICAL      lcalchr
! --- lvship0 handled by SCHEDULE

```

```

CONSTANT      lheadr = .FALSE.

```

```

! ----- define basic propeller constants

```

```

CONSTANT      qpbase = 1239071.4
CONSTANT      nprpmb = 144.7185
CONSTANT      nprpsb = 2.4120      !---shaft RPS base
CONSTANT      jjprop = 1313000     !---inertia w/ 25 pct H2O [LB-FT^2]
CONSTANT      jjshft = 166000      !---shaft inertia [LB-FT^2]

```

```

! ----- define reference values for time and distance to
!               stop ship. Based on cutting motor torque to a
!               value of 0.0 per unit at a rate of -1.0 pu/sec.
!               The coastdown from vslpu = 1.0 per unit ship
!               speed until 0.1 pu propeller shaft speed is
!               reached. Then apply -0.5 pu motor torque at a
!               rate of -1.0 pu/sec.

```

```

CONSTANT      tvs0ref = 696.262 , xvs0ref = 207.220

! ----- define basic constants for ship hull dynamics

CONSTANT      k10res = -15.1636679
CONSTANT      k09res = 20.3594595
CONSTANT      k08res = 15.9458303
CONSTANT      k07res = -23.5962574
CONSTANT      k06res = - 5.1990814
CONSTANT      k05res = 8.6572075
CONSTANT      k04res = - 0.2317509
CONSTANT      k03res = 0.9698059
CONSTANT      k02res = - 0.0573738
CONSTANT      k01res = 0.2023390
CONSTANT      k00res = 0.0000000
CONSTANT      kvship = 0.0075497
! --- per unit conversion factor

! ++++++ Begin INITIAL Section ++++++

INITIAL
! ----- calculate combined propeller/shaft inertia

jjps = jjprop + jjshft          ! --- WR^2 form

hhps = khh2 * (jjps * nprpmb / qpbase)

! ----- calculate shaft breakaway friction [LB-FT]

qpsbaf = qlapsf(0.0)

! ----- set initial ship speed (per unit)

CONSTANT      vslpui = 0.0
CONSTANT      vslpu0 = 0.00001   ! use when calculating T/Q for Vs==0.0

! ----- calculate initial ship resistance (per unit)

vslpu2i = vslpui * vslpui
vslpu3i = vslpu2i * vslpui
vslpu4i = vslpu3i * vslpui
vslpu5i = vslpu4i * vslpui
vslpu6i = vslpu5i * vslpui
vslpu7i = vslpu6i * vslpui
vslpu8i = vslpu7i * vslpui
vslpu9i = vslpu8i * vslpui
vslpu10i = vslpu9i * vslpui

rslpu10 = k10res * vslpu10i + k09res * vslpu9i + k08res * vslpu8i
rslpu11 = k07res * vslpu7i + k06res * vslpu6i + k05res * vslpu5i
rslpu12 = k04res * vslpu4i + k03res * vslpu3i + k02res * vslpu2i
rslpu13 = k01res * vslpui + k00res
rslpui = rslpu10 + rslpu11 + rslpu12 + rslpu13

! ----- calculate initial propeller thrust (per unit)

```

```

tp1pui = rslpui / 2.0
tp2pui = tp1pui

! ----- calculate initial prop rpm, torque and shaft
!           loss torque for each propeller

PROCEDURAL (nplrpmi, nplpui, qpli, qplpui = vslpui, tp1pui)

  IF (vslpui .LT. 0.0) THEN      ! --- use functions for reverse Vs
    nplpui = TlAvsr(0.0, vslpui, tp1pui, Fargs1)
    nplrpmi = nplpui * nprpmb
    qplpui = QlAvsr(nplpui, vslpui, 0.0 , Fargs0)
    qpli = qplpui * qpbase
  ELSEIF (vslpui .EQ. 0.0000) THEN !---use functions for forward Vs
    nplpui = TlAvsf(0.0, vslpu0, tp1pui, Fargs1)
    nplrpmi = nplpui * nprpmb
    qplpui = QlAvsf(nplpui, vslpu0, 0.0 , Fargs0)
    qpli = qplpui * qpbase
  ELSE
    ! --- use functions for forward Vs
    nplpui = TlAvsf(0.0, vslpui, tp1pui, Fargs1)
    nplrpmi = nplpui * nprpmb
    qplpui = QlAvsf(nplpui, vslpui, 0.0 , Fargs0)
    qpli = qplpui * qpbase
  ENDIF

END ! --- of PROCEDURAL

np2pui = nplpui
np2rpmi = nplrpmi
qp2pui = qplpui
qp2i = qpli

qplfi = QlApsf(nplrpmi)      ! shaft frictional loss torque
qp2fi = QlApsf(np2rpmi)

END ! ++++++ of INITIAL

! ++++++ Begin DERIVATIVE Section ++++++

! ----- calculate thrust and torque for both propellers

nplpu = nplrpm / nprpmb
np2pu = np2rpm / nprpmb

IF (vslpu .LT. 0.0) THEN      ! --- use functions for reverse Vs
  ! ---- prop shaft 1
  tp1pu = TlAvsr(nplpu, vslpu, 1.0, Fargs0)
  qplpu = QlAvsr(nplpu, vslpu, 1.0, Fargs0)
  ! ---- prop shaft 2
  tp2pu = TlAvsr(np2pu, vslpu, 1.0, Fargs0)
  qp2pu = QlAvsr(np2pu, vslpu, 1.0, Fargs0)
ELSEIF (vslpu .EQ. 0.0000) THEN ! --- use functions for forward Vs
  ! ---- prop shaft 1
  tp1pu = TlAvsf(nplpu, vslpu0, 1.0, Fargs0)

```

```

qp1pu = QlAvsf(np1pu, vs1pu0, 1.0, Fargs0)
! ---- prop shaft 2
tp2pu = TlAvsf(np2pu, vs1pu0, 1.0, Fargs0)
qp2pu = QlAvsf(np2pu, vs1pu0, 1.0, Fargs0)
ELSE ! --- use functions for forward Vs
! ---- prop shaft 1
tp1pu = TlAvsf(np1pu, vs1pu, 1.0, Fargs0)
qp1pu = QlAvsf(np1pu, vs1pu, 1.0, Fargs0)
! ---- prop shaft 2
tp2pu = TlAvsf(np2pu, vs1pu, 1.0, Fargs0)
qp2pu = QlAvsf(np2pu, vs1pu, 1.0, Fargs0)
ENDIF

qp1 = qp1pu * qpbase
qp2 = qp2pu * qpbase
qp1f = QlApsf(np1rpm) ! --- shaft frictional torque loss
qp2f = QlApsf(np2rpm)
! ----- calculate ship resistance

vs1pu2 = vs1pu * vs1pu
vs1pu3 = vs1pu2 * vs1pu
vs1pu4 = vs1pu3 * vs1pu
vs1pu5 = vs1pu4 * vs1pu
vs1pu6 = vs1pu5 * vs1pu
vs1pu7 = vs1pu6 * vs1pu
vs1pu8 = vs1pu7 * vs1pu
vs1pu9 = vs1pu8 * vs1pu
vs1pu10 = vs1pu9 * vs1pu

rs1pu0 = k10res * vs1pu10 + k09res * vs1pu9 + k08res * vs1pu8
rs1pu1 = k07res * vs1pu7 + k06res * vs1pu6 + k05res * vs1pu5
rs1pu2 = k04res * vs1pu4 + k03res * vs1pu3 + k02res * vs1pu2
rs1pu3 = k01res * vs1pu + k00res
rs1pu = rs1pu0 + rs1pu1 + rs1pu2 + rs1pu3

! ----- calculate ship speed (per unit) with seaway
! effects included

vs1pu = INTEG( kvship * (tp1pu + tp2pu - rs1pu), vs1pu ) &
* ( 1 - wseas )

! ----- Calculate headreach to the point at which
! ship speed goes to zero.
!
! ----- The following PROCEDURAL insures that lheadr .AND.
! lcalchr are .NOT. simultaneously .FALSE. since that
! condition would cause unwanted calculation of headrpu.
! It also updates tovship until lheadr=.TRUE. to set
! the start time for the headreach calculation.

!---PROCEDURAL (lcalchr, tovship = lheadr)
!--- IF (.NOT. lheadr) THEN
!--- lcalchr = .TRUE.
!--- lvship0 = .FALSE.
!--- tovship = T

```

```

!--- ENDIF
!---END   ! of PROCEDURAL

!          lcalchr      lheadr      mode      operation
!          -----
!          true         false       ic        set headreach = 0.0
!          false        false       op
!          true         true        op        calculate headreach
!          false        true        hold      hold headreach value

!---headrpu = MODINT( vs1pu, 0.0, lcalchr,lheadr ) !---scaled headreach

!---SCHEDULE stopvs/lvship0 .XZ. vs1pu      ! --- Check for vs1pu ==>
0.0

! ----- Calculate the percent time/distance to stop ship
!           with respect to the reference values.

!---tvship0pct = (tvship0 / tvs0ref) * 100
!---xvship0pct = (xvship0 / xvs0ref) * 100

! ----- Calculate the percent values for prop shaft
!           speed/torque,ship speed, headreach (wrt xvs0ref)
!           and time for plotting purposes

!---pctnpl = nplpu * 100
!---pctqpl = qp1pu * 100
!---pctnp2 = np2pu * 100
!---pctqp2 = qp2pu * 100
!---pctvs1 = vs1pu * 100
!---pcthdr = (headrpu / xvs0ref) * 100
!---pcttim = (t / tvs0ref) * 100

! ----- Terminate the simulation run when shaft speed or
!           ship speed exceeds MAX/MIN values for data
!           in function lookup tables.

TERMT (vs1pu .GT. 1.1, &
      ' Run Terminated ==> Ship speed exceeded MAX value')
TERMT (vs1pu .LT. -0.7, &
      ' Run Terminated ==> Ship speed exceeded MIN value')
TERMT (nplpu .GT. 1.16, &
      'Run Terminated ==> Prop shaft RPM exceeded Qfrict MAX value')
TERMT (nplpu .LT. -1.0, &
      'Run Terminated ==> Prop shaft speed exceeded T/Q MIN value')

MACRO END

!---MACRO stopvs(z,lheadr,lcalchr,lvship0,headrpu, &
!---          t0vship,tvship0,xvship0)

!--- DISCRETE stopvs

!--- IF (lheadr .AND. lcalchr .AND. lvship0) THEN

```

```

|---- lcalchr = .FALSE.
|---- tvship0 = T - t0vship
|---- xvship0 = headrpu
|---- CALL LOGD(.TRUE.)
|---- ENDIF

|---- END ! of DISCRETE stopship

|----MACRO END

| >>>>>>> End Propeller/Ship Dynamics Model MACROS <<<<<<<<
| -----

```

A.20 Motor Controller

```

|-----
|
|                                     Motor Controller
|
|                                     Copyright 1993 by Timothy J. McCoy
|
|-----
|                                     Record of Changes
|
|
|  No.   Date    By      Summary
|  ---   -
|  0     3-22-93 tjm     Model written.
|  1     4-13-93 tjm     Added control of firing angle.
|-----
|  macro: contmtr.mac
|  function: controls motor excitation and inverter firing angle
|             CONCATENATION
|  z        = motor identifier
|
|             INPUTS
|  id       = D-axis stator current [per unit]
|  iq       = Q-axis stator current [per unit]
|  vd       = D-axis stator voltage [per unit]
|  vq       = Q-axis stator voltage [per unit]
|  xdmsq    = difference between D and Q-axis synchronous reactances
|  xq       = Q-axis synchronous reactance [per unit]
|
|             OUTPUTS
|  eaf      = motor excitation [per unit]
|  betai    = inverter firing angle [rad]
|
|             CONSTANTS
|  eis&z&  = desired stator flux linkage [per unit]
|  eaf&min  = minimum excitation voltage [per unit]
|  eaf&max  = maximum excitation voltage [per unit]
|  eaf&ic   = excitation voltage initial condition [per unit]
|  geaf&z  = field excitation controller gain
|  taueaf&z = field excitation controller time constant
|  beta&min = minimum inverter firing angle [rad]
|  beta&max = maximum inverter firing angle [rad]

```

```

1  beta&ic    = inverter firing angle initial condition [rad]
1  gbeta&z    = inverter firing angle controller gain
1  taubeta&z  = inverter firing angle controller time constant
1  phis&z     = desired power factor angle [rad]
1
1  =====(must be defined in the calling program)=====
1          Defined in 'constant.inc'
1  k2rt3opi   = 2*sqrt(3)/pi
1  kpi        = pi = 3.141592654
1
1          INTERNAL
1  vt&z       = motor terminal voltage [per unit]
1  ia&z       = motor terminal current [per unit]
1  del&z      = motor torque angle [rad]
1  phi&z      = motor power factor angle [rad]
1  iaqxq&z    = round rotor component of synchronous reactance
1              voltage drop
1  ids&z      = D-axis component of stator current calculated from
1              desired link current
1  idx&z      = saleint component of synchronous reactance
1              voltage drop
1  ep&z       = desired field excitation from round rotor phasor
1              diagram
1  eaf&z      = desired field excitation, including saliency
1  eaferr&z   = error in field excitation
1  eafd&z     = time derivative of field excitation
1  betas&z    = desired inverter firing angle
1  betaerr&z  = error in inverter firing angle
1  beta&z&d   = time derivative of inverter firing angle
1
1  =====
1
MACRO contmtr (eaf,betai , &
               id,iq,vd,vq,edpp,eqpp,xdpp,xdmxq,xq,lbrake,z)
1  =====
1          Begin Derivative Section
1  =====
1  ---parameters
1  CONSTANT eis&z    = 1.0
1  CONSTANT eaf&min  = 0.0
1  CONSTANT eaf&max  = 4.0
1  CONSTANT geaf&z   = 100.0
1  CONSTANT tau&eaf&z = 0.1
1  CONSTANT eaf&ic   = 1.0
1  CONSTANT betamin&z = kpio2
1  ---CONSTANT betamax&z = 3.14
1  ---CONSTANT beta&z&ic = 3.13
1  ---CONSTANT gbeta&z   = 1.0
1  ---CONSTANT taubeta&z = 0.1
1  CONSTANT beta&z    = 2.2
1  CONSTANT phis&z    = 0.2
1
1  ---Calculation of desired excitation
1  --- (solution of phasor diagram)
1  RTP( vt&z,del&z = vq,vd)

```

```

RTP( ia&z&,phip&z& = iq,id)
iajxq&z = ia&z&*xq
idx&z& = ABS(id*xdmxq)
ep&z& = SQRT(eis&z&**2 + iajxq&z&**2 + &
            2.0*eis&z&*iajxq&z&*SIN(kpio2 + phis&z&))
eaf&z& = ep&z& + idx&z

!---field flux error signal
eaferr&z= eaf&z& - eaf

!---P-I type controller on field excitation
eaf&d = (geaf&z&*(eaferr&z&))/taueaf&z
eaf = BOUND(eaf&min,eaf&max,LIMINT(eaf&d,eaf&ic,eaf&min,eaf&max))

!---calculation of desired inverter firing angle
!---betas&z = kpi - ABS(del&z&) - phis&z

!---error in inverter firing angle
!---betaerr&z= betas&z& - betai

!---P-I type controller on inverter firing angle
!---beta&z&d = (gbeta&z&*(betaerr&z&))/taubeta&z
!---beta&z& = BOUND(betamin&z,betamax&z,LIMINT(beta&z&d,&
!---            beta&z&ic,betamin&z,betamax&z))

IF(lbrake)THEN
    betai = betamin&z
ELSE
    betai = beta&z
ENDIF
MACRO END !---of contmtr

```

A.21 Speed Controller

```

|=====
|
|                                     MOTOR SPEED CONTROLLER MODEL
|
|                                     Copyright 1993
|                                     by
|                                     Timothy J. McCoy
|=====
|
| macro:      speedcon
| function:    motor speed control, P-I type controller.
|
|                                     CONCATENATION
| z           = frequency changer identifier
|
|                                     INPUTS
| spdref      = reference speed [per unit]
| wrn         = motor speed [per unit]
|
|                                     OUTPUTS

```

```

!   idcr          = dc link reference current [PER UNIT]
!   lfwd          = logical variable indicating forward torque
!
!               CONSTANTS
!   gspeed&z&z   = Controller Amplitude
!   tauspeed&z&z = Controller Time Constant
!   idcr&min      = minimum dc link current [per unit]
!   idcr&max      = maximum dc link current [per unit]
!
!               INTERNAL
!   idcr&ic       = dc link current ic
!   idcr&d        = dc link current derivative
!   speederr&z&z  = speed error
!=====
MACRO speedcon (idcr,lfwd,lbrake , spdref,wrn,idc,z)

!---parameters
CONSTANT idcr&ic      = 0.0
CONSTANT idcr&min     = 0.0
CONSTANT idcr&max     = 1.0
CONSTANT idcr&dmax    = 5.0
CONSTANT idcr&dmin    = -5.0
CONSTANT spderr&z&ic  = 0.0
CONSTANT dz&z&z       = 0.05
CONSTANT threshold&z = 0.1
CONSTANT taufast&z&z = 0.1
CONSTANT glarge&z&z  = 50.0
CONSTANT tauslow&z&z = 20.0
CONSTANT gsmall&z&z  = 5.0

!---Speed control
IF (spdref .LT. 0.0) THEN
    lfwd = .FALSE.
    speederr&z&z = -(spdref - wrn)
ELSE
    lfwd = .TRUE.
    speederr&z&z = (spdref - wrn)
ENDIF

switchvar&z = BCKLSH(spderr&z&ic,dz&z&z,speederr&z&z)

IF (ABS(switchvar&z&z).GT.threshold&z&z) THEN
    tauspeed&z = taufast&z
    gspeed&z&z = glarge&z
ELSE
    tauspeed&z = tauslow&z
    gspeed&z&z = gsmall&z
ENDIF

IF ((SIGN(1.0,spdref).NE.SIGN(1.0,wrn)).AND.(wrn.GT.0.06)) THEN
    kbrake&z = 0.0
    IF ((idc .LT. 0.05).AND.(.NOT.lbrake)) lbrake = .true.
ELSE
    IF ((wrn .LE. 0.04).AND.(lbrake)) lbrake = .false.
    kbrake&z = 1.0

```

ENDIF

```
idcr&d = BOUND(idcr&dmin,idcr&dmax, &
              (-idcr + gspeed&z&*(speederr&z&))/tauspeed&z)
idcom&z = BOUND(idcr&min,idcr&max, &
              LIMINT(idcr&d,idcr&ic,idcr&min,idcr&max))
idcr    = idcom&z&*kbrake&z
```

MACRO END !---of speedcon

A.22 Synchronous Motor

```
!-----
!
!               THREE-PHASE SYNCHRONOUS MOTOR MODEL
!               written in generator coordinates
!
!               Copyright 1993 by Timothy J. McCoy
!
!-----
!               Record of Changes
!
!   No.   Date   By   Summary
!   ---   -
!   0     1-28-93 tjm   Model written.
!   1     2-14-93 tjm   Removed delta from argument list.
!   2     2-19-93 tjm   Revised definitions of vd & vq to correct
!                       error in derivation.
!   3     2-20-93 tjm   Changed currents to generator coordinates.
!   4     3-27-93 tjm   Removed calculation of delta
!   5     4-10-93 tjm   Revised voltage calculation to account for
!                       speed variation.
!-----
!
!   macro:      symmtr4
!   function:    Models a three-phase synchronous motor
!               with stator resistance and electric
!               transients neglected.
!
!               CONCATENATION
!   z           = synchronous machine identifier
!
!               INPUTS
!   wrn         = Machine speed [per unit]
!   iq          = Q-axis stator current in rotor frame [per unit]
!   id          = D-axis stator current in rotor frame [per unit]
!   eaf         = Field excitation [per unit]
!   tm          = Mechanical torque [per unit]
!
!               OUTPUTS
!   vq          = Q-axis stator voltage in rotor reference frame
!   vd          = D-axis stator voltage in rotor reference frame
!
!   te         = Electrical torque [per unit]
!   wrn        = Rotor speed [per unit]
!
```



```

edpp&z&d = (-edpp&z& + (xq&z& - xqpp&z&)*iq)/tqopp&z
eqp&z&d = (-alpha&z&*eqp&z& + i
          (alpha&z& - 1.0)*eqpp&z& + eaf)/tdopt&z

!---integrate to obtain flux linkages, speed and rotor angle.
eqpp&z& = INTEG(eqpp&z&d,eqpp&z&ic)
edpp&z& = INTEG(edpp&z&d,edpp&z&ic)
eqp&z& = INTEG(eqp&z&d,eqp&z&ic)
wm&z& = INTEG(wm&z&d,wm&z&ic)
thm&z& = INTEG(thm&z&d,thm&z&ic)
!--- delta&z = INTEG(wm&z& - wo,delta&z&ic)

!---Compute voltages in terms of state variables
vq = wrn*(eqpp&z& - xdpp&z&*id)
vd = wrn*(edpp&z& + xqpp&z&*iq)

!---Compute per unit speed for output
wrn = wm&z& / wo

=====
!
!               End of Derivative Section
!
=====
MACRO END ! of synmtr4

-----
!
!               THREE-PHASE SYNCHRONOUS MOTOR INITIALIZATION MODEL
!
!               Copyright 1992 by Timothy J. McCoy
!
=====
!
!               Record of Changes
!
!
!   No.   Date   By   Summary
!   ---   -
!   0    1-28-92   tjm   Model written.
!
=====
!
!   macro:      mtr4ic
!   function:    Initializes varous parameters for use with the
!                synchronous motor model synmtr4.
!
!               CONCATENATION
!   z          = synchronous machine identifier
!
=====
MACRO mtr4ic(z)

!---Initialize rotor reference angle
!--- CONSTANT delta&z&ic = 0.0
!--- CONSTANT thm&z&ic = 0.0

!---Calculate paramater alpha
alpha&z& = (xd&z& - xdpp&z&)/(xdp&z& - xdpp&z&)

```

```

!---Assume motor initially at rated speed
CONSTANT wnz&ic = 377.0
CONSTANT iq&ic = 0.0
CONSTANT id&ic = 0.0
edpp&ic = (xq&ic - xqpp&ic)*iq&ic
eqp&ic = -(alpha&ic - 1.0)*(xdp&ic - xdpp&ic)*id&ic + eaf&ic
eqpp&ic = eqp&ic - (xdp&ic - xdpp&ic)*id&ic

```

MACRO END : of symntric

A.23 Synchronous Generator

```

!-----
!
!               THREE-PHASE SYNCHRONOUS GENERATOR MODEL
!               written in generator coordinates
!
!               Copyright 1993 by Timothy J. McCoy
!-----
!               Record of Changes
!
!   No.   Date   By   Summary
!   ---   -
!   0     1-28-93 tjm   Model written.
!   1     2-14-93 tjm   Removed delta from argument list.
!   2     2-19-93 tjm   Revised definitions of vd & vq to correct
!                       error in derivation.
!   3     2-20-93 tjm   Changed currents to generator coordinates.
!   4     3-27-93 tjm   Removed calculation of delta
!   5     4-9-93  tjm   Revision "b" removed mechanical equations for
!                       use with gas turbine model.
!-----
!
!   macro:      symntr4b
!   function:    Models a three-phase synchronous motor
!               with stator resistance and electric
!               transients neglected.
!
!               CONCATENATION
!   z           = synchronous machine identifier
!
!               INPUTS
!   wrn         = Machine speed [per unit]
!   iq          = Q-axis stator current in rotor frame [per unit]
!   id          = D-axis stator current in rotor frame [per unit]
!   eaf         = Field excitation [per unit]
!
!               OUTPUTS
!   vq          = Q-axis stator voltage in rotor reference frame
!   vd          = D-axis stator voltage in rotor reference frame
!
!   te         = Electrical torque [per unit]

```

```

:
:
:               CONSTANTS
:
:------(must be defined in the calling program)-----
:
:   wo          = base electrical speed [rad/sec]
:   xq&z        = Q-axis synchronous reactance [per unit]
:   xd&z        = D-axis synchronous reactance [per unit]
:   xqpp&z      = Q-axis subtransient reactance reactance [per unit]
:   xdpp&z      = D-axis subtransient reactance reactance [per unit]
:   xdp&z       = D-axis transient reactance [per unit]
:   xl&z        = Armature leakage reactance [per unit]
:   tdop&z      = D-axis transient open circuit time constant [per unit]
:   tdopp&z     = D-axis subtransient open circuit time constant [per unit]
:   tqopp&z     = Q-axis subtransient open circuit time constant [per unit]
:------(defined in macro mtr4ic)-----
:   alpha&z     = (xd - xdpp)/(xdp - xdpp)
:
:               INTERNAL (STATE OR STATE RELATED)
:   eqpp&z      = Q-axis voltage behind subtransient reactance [per unit]
:   edpp&z      = D-axis voltage behind subtransient reactance [per unit]
:   eqp&z       = Q-axis voltage behind transient reactance [per unit]
:
:               INTERNAL (NOT STATE RELATED)
:
:   Defined in macro symmtric() located in this file.
:   eqpp&z&ic = eqpp ic [per unit]
:   edpp&z&ic = edpp ic [per unit]
:   eqp&z&ic  = eqp ic [per unit]
:
:   Defined in macro excitmtr().
:   eaf&ic    = field excitation initial condition
:
:-----This model requires a separate exciter for the field winding.
:
:-----
MACRO symmtr4b (te,vq,vd , eaf,iq,id,wrn,z)
:-----
:               Begin Derivative Section
:-----
:---Compute Electromagnetic Torque
:---(positive for motor action)
:   te        = (-eqpp&z&ic*iq - edpp&z&ic*id + (xdpp&z&ic - xqpp&z&ic)*id*iq)

:---Rates of Change of state variables
:   eqpp&z&d = (eqp&z&ic - eqpp&z&ic - (xdp&z&ic - xdpp&z&ic)*id)/tdopp&z
:   edpp&z&d = (-edpp&z&ic + (xq&z&ic - xqpp&z&ic)*iq)/tqopp&z
:   eqp&z&d  = (-alpha&z&ic*eqp&z&ic +
:               (alpha&z&ic - 1.0)*eqpp&z&ic + eaf)/tdop&z

:---integrate to obtain flux linkages, speed and rotor angle.
:   eqpp&z&ic = INTEG(eqpp&z&d,eqpp&z&ic)
:   edpp&z&ic = INTEG(edpp&z&d,edpp&z&ic)
:   eqp&z&ic  = INTEG(eqp&z&d,eqp&z&ic)

```

```

!---Compute voltages in terms of state variables
  vq = (eqpp&z& - xdpp&z&*id)
  vd = (edpp&z& + xqpp&z&*iq)

!=====
!               End of Derivative Section
!=====
MACRO END ! of symmtr4

!-----
!
!       THREE-PHASE SYNCHRONOUS MOTOR INITIALIZATION MODEL
!
!       Copyright 1992 by Timothy J. McCoy
!
!=====
!               Record of Changes
!
!   No.   Date   By      Summary
!   ---   ----   -
!   0    1-28-92   tjm    Model written.
!
!=====
!
!   macro:      mtr4bic
!   function:    Initializes varous parameters for use with the
!                 synchronous motor model symmtr4.
!
!               CONCATENATION
!   z          = synchronous machine identifier
!
!=====
MACRO mtr4bic(z)

!---Calculate paramater alpha
  alpha&z& = (xd&z& - xdpp&z&)/(xdp&z& - xdpp&z&)

!---Assume motor initially at rated speed
  CONSTANT iq&z&ic = 0.0
  CONSTANT id&z&ic = 0.0
  edpp&z&ic = (xq&z& - xqpp&z&)*iq&z&ic
  eqp&z&ic = -(alpha&z& - 1.0)*(xdp&z& - xdpp&z&)*id&z&ic &
    + eaf&z&ic
  eqpp&z&ic = eqp&z&ic - (xdp&z& - xdpp&z&)*id&z&ic

MACRO END ! of symmtric

```

A.24 Voltage Regulator

```

!-----
!
!               GENERATOR VOLTAGE REGULATOR MODEL
!
!       Copyright 1992 by Timothy J. McCoy
!

```

```

|-----|
| macro: vreg2.mac
| function: Limited PI type voltage regulator for a
|           synchronous generator.
|           This model comes from section 2.4 of notes from 6.686.
|
| concatenation:
|   z      = generator exciter identifier
|
| inputs:
|   vd      = D-axis terminal voltage [per unit]
|   vq      = Q-axis terminal voltage [per unit]
|
| outputs:
|   eaf     = Generator exciter voltage [per unit]
|
| constants:
|   vtrf&z  = reference terminal voltage [per unit]
|   geaf&z  = gain of exciter
|   taueaf&z = time constant of exciter
|   eaf&z&ic = ic for generator exciter voltage
|   eafmin&z = minimum value of excitation voltage [per unit]
|   eafmax&z = maximum value of excitation voltage [per unit]
|
| internal:
|   eaf&z&d = rate of change of exciter voltage
|   verr&z  = error voltage [per unit]
|-----|
MACRO vreg2 (eaf , vd,vq,z)

!---parameters
  CONSTANT vtrf&z = 1.001, geaf&z = 100.0, taueaf&z = 0.1, &
    eaf&z&ic = 1.0, eafmin&z = 0.0, eafmax&z = 3.0

RTP( vt&z&,del&z& = vq,vd)

verr&z& = vtrf&z-vt&z
eaf&d = (-eaf + geaf&z*(verr&z&))/taueaf&z
eaf = BOUND(eafmin&z,eafmax&z,LIMIT(eaf&d,eaf&z&ic,eafmin&z,eafmax&z))

MACRO END : of vreg2

```

Appendix B: Parameter Values

The following listing provides the parameter values used for the various components within the simulations.

B.1 Synchronous Machines

Parameter	18MVA Generator	2.5 MW Generator	20,000 HP Motor	Units
x_d	1.77	1.63	1.76	per unit
x_q	1.64	1.01	1.157	per unit
x_d''	0.15	0.18	0.542	per unit
x_q''	0.15	0.28	0.494	per unit
x_d'	0.18	0.25	0.608	per unit
x_l	0.13	0.075	0.337	per unit
t_{do}''	0.04	0.38	0.039	seconds
t_{qo}''	0.09	0.19	0.193	seconds
t_{do}'	3.19	3.79	2.1	seconds
H	0.92	1.91	0.773	seconds
ω_{base}	3,600	900	150	rpm
V_{base}	4,160	450	5,000	volts
P_{base}	16,200	2,500	14,914	Kw

B.2 Voltage Regulators

Parameter	18MVA Generator	2.5 MW Generator	20,000 HP Motor	Units
Gain	100	100	100	none
Time Constant	0.1	0.1	0.05	seconds

B.3 DC-link Current Controller

Gain: 30.0

Time Constant: 0.01 Seconds

B.4 Speed Controller

Parameter	Fast Mode	Slow Mode	Units
Gain	50	5	None
Time Constant	0.1	20	Seconds

B.5 Speed Governors

Parameter	Diesel	Gas Turbine	Units
Gain	5	0.5	None
Time Constant	2	3	Seconds

Appendix C: Two Motor Run

The following simulation run was made to show that the system would work properly with two frequency changer / motor combinations connected to the bus. In this simulation, both motor speed inputs and the ship speed start out at 0.5 per unit. This condition is held for 15 seconds to allow the speed governors on the prime movers to stabilize. At T=15 seconds, the #2 motor speed command is set to 0.9 per unit. As expected, the ship begins to accelerate. At T=30 seconds, motor #1 speed command is set to -0.5 per unit. This action causes the acceleration of the ship to cease. Eventually the ship speed stabilizes at about 0.6 per unit after 120 seconds. The following plots illustrate the first 40 seconds of the simulation. This is to show the electrical transients in the motors and generators as the speed command inputs are given to each respective motor. As with all previous simulations, the ship's service load is set to 0.2 per unit at 0.8 power factor lagging.

System #3: Steady at 0.5 per unit load on both shafts
Listing of values

T 160.000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZNBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZERNFL F	ZZJEFL F	ZZNIST 49
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

State Variables	Derivatives	Initial Conditions
EDPPG1 0.10793700	Z99995-4.0735E-05	EDPPG1IC 0.
EDPPG2 0.07827220	Z99992-3.7487E-05	EDPPG2IC 0.
EDPPM1-0.09764770	Z99930 1.1096E-04	EDPPM1IC 0.
EDPPM2-0.09764770	Z99925 1.1096E-04	EDPPM2IC 0.
ENPTL1 7.19995000	Z99942 0.	ENPTL1I 7.20000000
EQPG1 1.03021000	Z99994-1.0709E-04	EQPG1IC 1.00000000
EQPG2 1.03484000	Z99991 5.5553E-05	EQPG2IC 1.00000000
EQPM1 1.17462000	Z99929-2.4433E-04	EQPM1IC 1.00000000
EQPM2 1.17462000	Z99924-2.4433E-04	EQPM2IC 1.00000000
EQPPG1 1.02334000	Z99996-9.3806E-05	EQPPG1IC 1.00000000

EQPPG2 1.02266000
EQPPM1 1.16128000
EQPPM2 1.16128000
IDC1 0.22691600
IDC2 0.22691600
NGG1 7620.78000
NPT1 3599.98000
THMM1 24632.4000
THMM2 24632.4000
TICRL1 54.4810000
WMG2 374.077000
WMM1 171.107000
WMM2 171.107000
Z99901 0.
Z99903 0.50609400
Z99905 0.23668500
Z99909 0.23668500
Z99914 0.29332400
Z99917 0.29332400
Z99919 1.40698000
Z99921 1.40698000
Z99933 0.39940100
Z99935 7620.79000
Z99937 94.6835000
Z99939-3.3439E-05
Z99941 54.5261000
Z99944-345.138000
Z99948-0.65392500
Z99952 494.585000
Z99954 3599.98000
Z99956 26.9439000
Z99958 26.5456000
Z99964 1475.83000
Z99967 2005.19000
Z99973-0.08812110
Z99981 0.12512000
Z99986 1.00000000
Z99988 1.27530000
Z99990 1.39421000

Z99993 3.0887E-05
Z99931-2.4439E-04
Z99926-2.4439E-04
Z99915 0.00218158
Z99912 0.00218158
Z99965-0.24833000
Z99978-0.00255082
Z99927 171.107000
Z99922 171.107000
Z99959 0.00648499
Z99979 6.3236E-05
Z99928 0.01276840
Z99923 0.01276840
Z99900 0.
Z99902 4.1570E-04
Z99904-3.0047E-04
Z99908-3.0047E-04
Z99913-0.02582970
Z99916-0.02582970
Z99918 0.00965595
Z99920 0.00965595
Z99932-6.6878E-05
Z99934-0.24414100
Z99936-0.02441410
Z99938-1.5869E-05
Z99940-0.01026270
Z99943-1.1160E-04
Z99947 5.9287E-04
Z99951-0.52897100
Z99953 0.
Z99955-0.00359245
Z99957-0.00367846
Z99963-0.03127510
Z99966-0.07290180
Z99972 0.00382487
Z99980-6.6678E-05
Z99985 0.
Z99987 2.6107E-04
Z99989 6.2704E-04

EQPPG2IC 1.00000000
EQPPM1IC 1.00000000
EQPPM2IC 1.00000000
IDC1IC 0.
IDC2IC 0.
NGG1I 7193.84000
NPT1I 3600.00000
THMM1IC 0.
THMM2IC 0.
TICRL1I 13.0000000
WMG2IC 377.000000
WMM1IC 0.
WMM2IC 0.
Z99899 0.
VS1PUI 0.
IDCR2IC 0.
IDCR1IC 0.
U2IC 0.99000000
U1IC 0.99000000
EAFM2IC 1.00000000
EAFM1IC 1.00000000
XNV1I 0.31609000
NGGL1I 7193.84000
PS3WC1I 68.0631000
EMFFB1I 0.
ALPHA1I 40.9791000
TGLAG1I-345.140000
TABTR1I 0.
QMAPL1I 0.
NPTL1I 3600.00000
P54LL1I 21.7097000
P54L1I 21.3889000
T51PL1I 1416.04000
T4PL1I 1875.14000
NERR1I 0.
TMECH2IC 0.
FUEL2IC 0.
EAFG2IC 1.00000000
EAFG1IC 1.00000000

Algebraic Variables

Common Block /ZZCOMU/

AFL1 0.17723600
ALPHA1LL 13.0000000
ALPHAG2 20.7143000
ARLLG1I 0.31609000
BASEKWM1 14914.0000
BASENG2 900.000000
BASEQM1 949455.000
BASEVG2 450.000000
BETA1I 2.20000000
BETAM2 2.20000000
BETAR1 1.27309000
CYL2 8.00000000

AFRL1 0.17265700
ALPHA1UL 120.000000
ALPHAM1 18.4545000
BASEKMG1 16200.0000
BASEKWM2 14914.0000
BASENM1 150.000000
BASEQM2 949455.000
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BETAMINM1 1.57080000
BETAR2 1.27309000
DELAY2 0.49478600

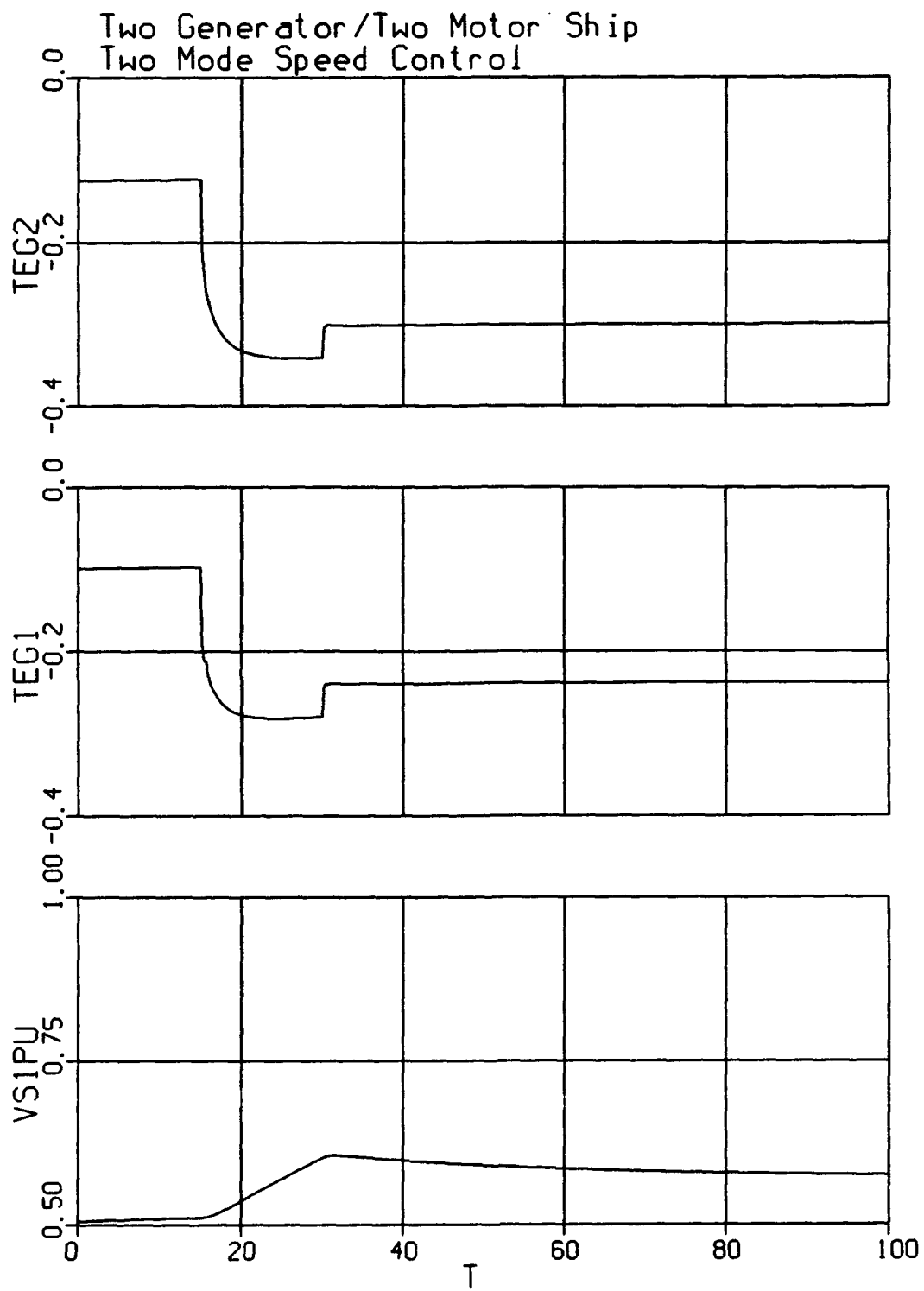
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BASEVM2 5000.00000
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BETAMINM2 1.57080000
CQLID1 2.8143E-05
DELG1 0.11955700

DELG2 0.10880500	DELI1-0.19875100	DELI2-0.19875100
DELM1-0.16062700	DELM2-0.16062700	DELR1 0.14401700
DELR2 0.14401700	DELTA2 1.00000000	DELV 1.0000E-04
DELVTQ1 0.	DELWF1-0.60571300	DELWFI 0.
DFL1-0.75945400	DFRL1-0.17252300	DN1-0.00255082
DNGG1 7620.72000	DNPT1-0.00255082	DNREF1 180.000000
DQ4S1 0.23181200	DQHR21-0.68991700	DQPTR1 3975.34000
DRLLGI 0.31609000	DRPMDT1 0.	DT4HS1 0.06348980
DT51HS1 0.05651400	DZ1 0.05000000	DZ2 0.05000000
E01I 0.	E211-0.00424787	E221-0.25487200
E231-0.08495740	E51 8.45539000	E61 0.
E71 0.14404000	E81 0.	E91 0.45838300
EAFERRM1 9.6560E-06	EAFERRM2 9.6560E-06	EAFG1 1.39421000
EAFG1D 6.2704E-04	EAFG2 1.27530000	EAFG2D 2.6107E-04
EAFM1 1.40698000	EAFM1D 0.00965595	EAFM1MAX 3.00000000
EAFM1MIN 0.	EAFM2 1.40698000	EAFM2D 0.00965595
EAFM2MAX 3.00000000	EAFM2MIN 0.	EAFMAXG1 3.00000000
EAFMAXG2 3.00000000	EAFMING1 0.	EAFMING2 0.
EAFSM1 1.40699000	EAFSM2 1.40699000	EDPPG1D-4.0735E-05
EDPPG2D-3.7487E-05	EDPPM1D 1.1096E-04	EDPPM2D 1.1096E-04
EI1 0.46625000	EI2 0.46625000	EISM1 1.00000000
EISM2 1.00000000	EMFTB1-3.3439E-05	EMFSAT1-3.5977E-06
ENGG1-3.5977E-06	ENPT1 7.19995000	ENPT1I 7.20000000
EPM1 1.28501000	EPM2 1.28501000	EQPG1D-1.0709E-04
EQPG2D 5.5553E-05	EQPM1D-2.4433E-04	EQPM2D-2.4433E-04
EQPPG1D-9.3806E-05	EQPPG2D 3.0887E-05	EQPPM1D-2.4439E-04
EQPPM2D-2.4439E-04	ER1 0.94481700	ER2 0.94481700
ERRBOUND 1.0000E-04	ERX1-3.5977E-06	FARG0 0
FARG1 1	FARG2 2	FARG3 3
FARGS0 0	FARGS1 1	FARGS2 2
FARGS3 3	FUEL2 0.19580600	FUEL2MAX 1.00000000
FUEL2MIN 0.	FUELAG2 0.05038960	G11 0.22000000
G31 0.50000000	G51 0.50000000	GBETAR1 30.0000000
GBETAR2 30.0000000	GEAFG1 100.000000	GEAFG2 100.000000
GEAFM1 100.000000	GEAFM2 100.000000	GLARGE1 50.0000000
GLARGE2 50.0000000	GM1 1.50000000	GM2 1.50000000
GSMALL1 5.00000000	GSMALL2 5.00000000	GSPEED1 5.00000000
GSPEED2 5.00000000	HG1 0.92400000	HG2 1.91000000
HHPS 0.51678100	HM1 1.28978000	HM2 1.28978000
HP1 2475.06000	HP1B 2500.0000	HP1D 2475.06000
HP1I 0.	HP1ORD 0.	HP1ORDI 0.
HPT1ORD 2475.06000	IAJXQM1 0.28949400	IAJXQM2 0.28949400
IAM1 0.25021100	IAM2 0.25021100	ICLIM1 70.0000000
ICNTRL1-0.08812110	ICNTRL1I 0.	ID1GR 1.00000000
IDBM1 0.	IDBM2 0.	IDC1D 0.00218158
IDC2D 0.00218158	IDCBG2 0.32394500	IDCOM1 0.23668500
IDCOM2 0.23668500	IDCR1 0.23668500	IDCR1D-3.0047E-04
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IDCR1MIN 0.	IDCR2 0.23668500	IDCR2D-3.0047E-04
IDCR2DMAX 5.00000000	IDCR2DMIN-5.00000000	IDCR2MAX 0.80000000
IDCR2MIN 0.	IDG1 0.22926900	IDG1IC 0.
IDG1M1 0.29932500	IDG2 0.17392700	IDG2ERR 0.
IDG2IC 0.	IDG2M1 0.32394500	IDI1 0.20229500
IDI2 0.20229500	IDL2 0.14486000	IDM1 0.20229500
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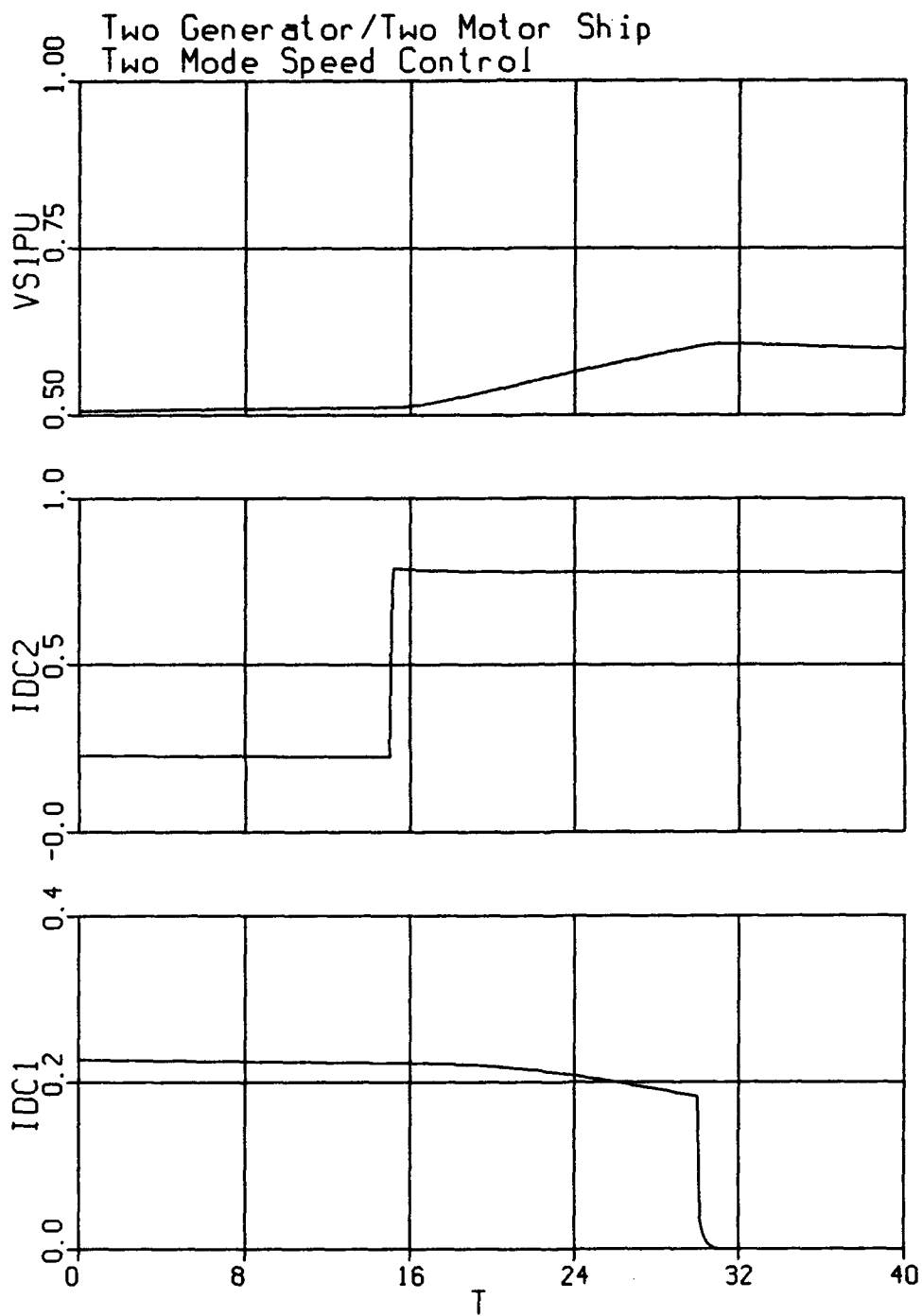
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IDXM2 0.12198400	IERR1 0.00976887	IERR1IC 0.
IERR2 0.00976887	IERR2IC 0.	IGG1 566.778000
IITID1 580.484000	IQBM1 0.	IQBM2 0.
IQCBG2 0.19968600	IQG1 0.07243820	IQG1IC 0.
IQG1M1 0.09457250	IQG2 0.10721200	IQG2ERR 0.
IQG2IC 0.	IQG2M1 0.19968600	IQI1-0.14724900
IQI2-0.14724900	IQL2 0.14747300	IQM1-0.14724900
IQM1IC 0.	IQM2-0.14724900	IQM2IC 0.
IQR1 0.07339300	IQR2 0.07339300	JJG 16505.0000
JJPROP 1.3130E+06	JJPS 1.4790E+06	JJPT1 2171.50000
JJSHFT 166000.000	K00RES 0.	K01RES 0.20233900
K02RES-0.05737380	K03RES 0.96980600	K04RES-0.23175100
K05RES 8.65721000	K06RES-5.19908000	K07RES-23.5963000
K08RES 15.9458000	K09RES 20.3595000	K10RES-15.1637000
KALARM1 0	KBRAKE1 1.00000000	KBRAKE2 1.00000000
KC11 0.50000000	KDFRQ 1.57080000	KGC 32.1740000
KGOV2 0.20000000	KHOLDPI1 1.00000000	KI 307.240000
KIG1M1 1.30556000	KIG2M1 1.86253000	KKWG1M1 1.08623000
KKWG2M1 0.16762800	KPNGG1 0.01017600	KQHP 5252.10000
KRAT1 0.16000000	KRATE1 10.0000000	KSETDN1 0
KTBL1 0	KTURBO2 0.50000000	KVG1M1 0.83200000
KVG2M1 0.09000000	KVSHIP 0.00754970	KZG1M1 0.63727300
KZG2M1 0.04832140	LBRAKE1 F	LBRAKE2 F
LCBG2 T	LDOPLR F	LFWD1 T
LFWD2 T	LHEADR F	LHOLD1PI F
LNGG1A F	LPWRD1 F	LSEA F
LT541A F	MAXIT 10.0000000	MFKAC1 0.58200000
MFKFR1 0.17259000	MFKMV1 23.0000000	MFKN1 4.6080E-08
MFW1 159.400000	2091.30000	13659.6000
N1 3599.98000	N1I 3600.00000	N2 893.042000
NERR1 0.02294920	NGB 3600.00000	NGG1B 9827.00000
NGGL1 7620.79000	NMAX2 950.000000	NMIN2 400.000000
NP1PU 0.47042900	NP1PUI 5.3832E-06	NP1RPM 68.0797000
NP1RPMI 7.7905E-04	NP2PU 0.47042900	NP2PUI 5.3832E-06
NP2RPMI 7.7905E-04	NP2RPM 68.0797000	NPRPMB 144.719000
NPRPSB 2.41200000	NPT1B 3600.00000	NPT1ORD 3600.00000
NPT1ORDI 3600.00000	NPT1R 3600.00000	NPT1RI 3600.00000
NPTL1 3599.98000	NPTQ1 158.067000	NPTQ1I 158.068000
NPTR1 3599.98000	NPTR1I 3600.00000	NREF1 3672.00000
NSET2 900.000000	P1 0.16000000	P2 14.6960000
P2T21 5.50753000	P541 26.5455000	P541I 21.3889000
P54L1 26.5456000	P54LL1 26.9439000	P54Q1 1.83342000
P54Q1I 1.47725000	P54R21 26.5450000	P54R21I 21.3889000
PAMB 14.6960000	PCNTRL1 0.01147460	PCNTRL1I 0.
PCTID1 0.01000000	PHIPM1 2.20000000	PHIPM2 2.20000000
PHISM1 0.20000000	PHISM2 0.20000000	PNGG1 77.5494000
PNGGR1 77.5494000	PNGGR1I 73.2049000	PS31 94.6826000
PS31I 68.0631000	PS3R21 94.6826000	PS3R21I 68.0631000
PS3WC1 94.6835000	PWRD1 9.90022000	PWRD1I 0.
Q1 0.12000000	Q41 7320.23000	Q4R21 7320.23000
QCAL1 2723.95000	QCAL1I 0.	QGB 36520.0000
QH1-0.45810500	QLID1 364.725000	QLID1I 364.730000
QMAP1 494.570000	QMAP1I 0.	QMAPL1 494.585000
QP1 234474.000	QP1F 6194.13000	QP1FI 92443.6000

QP1I-0.23332300	QP1PU 0.18923400	QP1PUI-1.8831E-07
QP2 234474.000	QP2F 6194.13000	QP2FI 92443.6000
QP2I-0.23332300	QP2PU 0.18923400	QP2PUI-1.8831E-07
QPBAS 1.2391E+06	QPSBAF 92466.4000	QPT1 3975.49000
QPT1B 36473.0000	QPT1I 364.730000	QPT1PU 0.10885800
QREF1 45000.0000	RDC1 0.02000000	RDC2 0.02000000
RS1PU0 0.09625660	RS1PU1-5.8911E-04	RS1PU2 0.09581350
RS1PU3 0.10240200	RS1PU 0.29388300	RS1PUI0 0.
RS1PUI1 0.	RS1PUI2 0.	RS1PUI3 0.
RS1PUI 0.	SEAFRQ 1.04720000	SEATIME 0.
SNEGVL1 0.	SPDERR1IC 0.	SPDERR2 6.95807000
SPDERR2IC 0.	SPDREF1 0.50000000	SPDREF2 0.50000000
SPEEDERR1 0.04613510	SPEEDERR2 0.04613510	SQORTH2 1.00000000
SWITCHVAR1 0.02903650	SWITCHVAR2 0.02903650	T0SEA 0.
T2 518.700000	T41 2004.96000	T4P1 2004.90000
T4PL1 2005.19000	T4R21 2004.90000	T4U1-3.64363000
T511 1475.59000	T51P1 1475.53000	T51PL1 1475.83000
T51Q1 1.00004000	T51R21 1475.53000	T51U1-3.62814000
T541 966.618000	TABTR11 0.54461100	TALPHA1(32) 999.900000
Z99976(16) 108.000000	Z99977(16) 999.900000	TAMB 59.00000000
TAUBETAR1 0.01000000	TAUBETAR2 0.01000000	TAUEAFG1 0.10000000
TAUEAFG2 0.10000000	TAUEAFM1 0.10000000	TAUEAFM2 0.10000000
TAUFAST1 0.10000000	TAUFAST2 0.10000000	TAUGOV2 2.00000000
TAUSLOW1 20.00000000	TAUSLOW2 20.00000000	TAUSPEED1 20.00000000
TAUSPEED2 20.00000000	TC11 3.00000000	TDOPG1 3.19000000
TDOPG2 3.79000000	TDOPM1 2.10000000	TDOPM2 2.10000000
TDOPPG1 0.04000000	TDOPPG2 0.38000000	TDOPPM1 0.03900000
TDOPPM2 0.03900000	TDT541(48) 99999.0000	Z99968(36) 68.30000000
Z99969(12) 99999.0000	TEG1-0.09887520	TEG1IC 0.
TEG2-0.12512000	TEM1 0.18932100	TEM2 0.18932100
TESM1 3610.92000	TESM1I 0.	TGLAG1 7.19996000
THDOT21-0.00996538	THET2N 1.00000000	THETA2 1.00000000
THRESHOLD1 0.10000000	THRESHOLD2 0.10000000	THTA2V 1.00000000
TIC1 54.4816000	TIC1LL 13.00000000	TIC1UL 113.500000
TICMD1 54.4816000	TICMD1I 13.00000000	TICN1-0.07664650
TICN1I 0.	TICRL1LL-89.00000000	TICRL1UL 22.50000000
TICS1 54.5570000	TICS1I 13.00000000	TMAP(116) 950.000000
Z99997(96) 0.92280000	Z99998(20) 950.000000	TMG2 0.12512000
TMM1-0.18923400	TMM2-0.18923400	TORQ2 0.12508700
TP1PU 0.17447200	TP1PUI 0.	TP2PU 0.17447200
TP2PUI 0.	TQOPPG1 0.09000000	TQOPPG2 0.19000000
TQOPPM1 0.19300000	TQOPPM2 0.19300000	TSEA 6.00000000
TSTOP 160.000000	TURBOLAG2 0.44439700	TUT4H1 0.25220100
TUT51H1 0.10368500	TVS0REF 696.262000	U1 0.29332400
ULD-0.02582970	U2 0.29332400	U2D-0.02582970
UMAX1 0.99000000	UMAX2 0.99000000	UMIN1 0.
UMIN2 0.	VDBIC 0.	VDBUS 0.12826000
VDCBG2 0.12826000	VDERR 0.	VDG1 0.11880200
VDG2 0.10829200	VDI1-0.09205850	VDI2-0.09205850
VDM1-0.07733350	VDM2-0.07733350	VDR1 0.13560000
VDR2 0.13560000	VERRG1 0.01394270	VERRG2 0.01275330
VI1-0.45383500	VI2-0.45383500	VN1 7.34400000
VNSF1 500.000000	VQ1 9.00000000	VQBIC 1.00000000
VQBUS 0.95895700	VQCBG2 0.95895700	VQERR 0.
VQG1 0.98894700	VQG2 0.99134900	VQI1 0.45707100

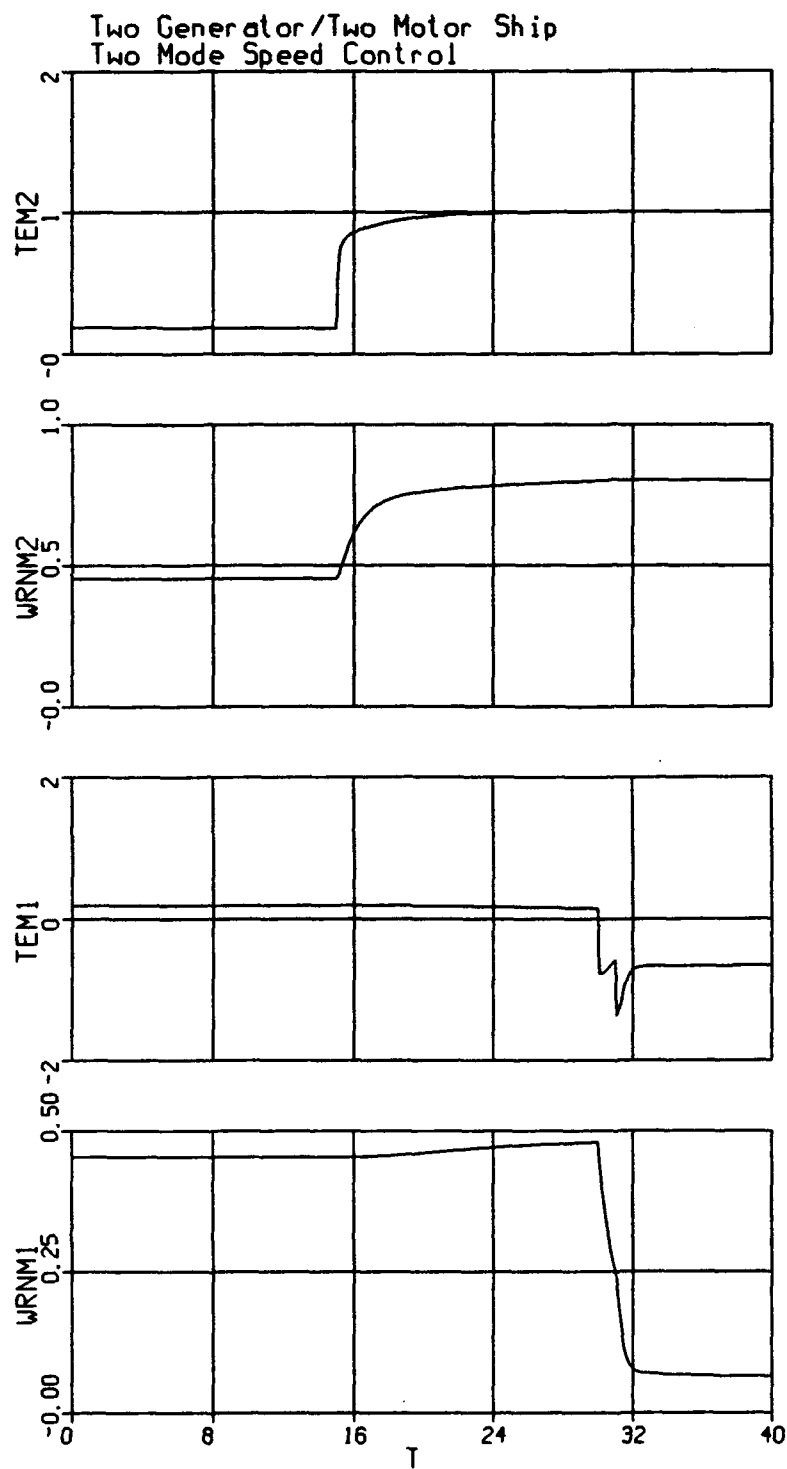
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VQR1 0.93503600	VQR2 0.93503600	VQSF1 5000.00000
VR1 0.45838300	VR2 0.45838300	VRATE1 0.
VRSF1 360.000000	VS1PU0 1.0000E-05	VS1PU10 0.00110232
VS1PU10I 0.	VS1PU2 0.25613100	VS1PU2I 0.
VS1PU3 0.12962600	VS1PU3I 0.	VS1PU4 0.06560300
VS1PU4I 0.	VS1PU5 0.03320130	VS1PU5I 0.
VS1PU6 0.01680290	VS1PU6I 0.	VS1PU7 0.00850387
VS1PU7I 0.	VS1PU8 0.00430375	VS1PU8I 0.
VS1PU9 0.00217810	VS1PU9I 0.	VS1PU 0.50609400
VT12 0.93604900	VTG1 0.99605700	VTG2 0.99724700
VTM1 0.48352500	VTM2 0.48352500	VTOP1 0.
VTREFG1 1.01000000	VTREFG2 1.01000000	VTRQGS1 0.
W41 57.3892000	W4R21 57.3892000	W541 64.1990000
W54R21 64.1990000	WAVE 4.00000000	WEPSEA 1.04720000
WESEA 0.	WESEAMG 0.	WESMAX 0.10000000
WFAC1 4302.86000	WFSR21 3173.84000	WFUEL1 3173.23000
WFUEL1I 2185.21000	WMG1 376.998000	WMG2D 6.3236E-05
WMM1D 0.01276840	WMM2D 0.01276840	WO 377.000000
WRN1ORD 1.00000000	WRN1ORDIC 1.00000000	WRNG1 0.99999400
WRNG1IC 1.00000000	WRNG2 0.99224700	WRNM1 0.45386500
WRNM2 0.45386500	XDC1 1.68000000	XDC2 1.68000000
XDG1 1.77000000	XDG2 1.63000000	XDM1 1.76000000
XDM2 1.76000000	XDMXQM1 0.60300000	XDMXQM2 0.60300000
XDPG1 0.18000000	XDPG2 0.25000000	XDPM1 0.60800000
XDPM2 0.60800000	XDPPG1 0.15000000	XDPPG2 0.18000000
XDPPM1 0.54200000	XDPPM2 0.54200000	XG1 0.10000000
XG2 0.10000000	XK3L1 2.20000000	XL1 0.10000000
XLG1 0.13000000	XLG2 0.07500000	XLM1 0.33700000
XLM2 0.33700000	XM1 0.10000000	XMV1 0.39936800
XQG1 1.64000000	XQG2 1.01000000	XQM1 1.15700000
XQM2 1.15700000	XQPPG1 0.15000000	XQPPG2 0.28000000
XQPPM1 0.49400000	XQPPM2 0.49400000	XVSOREF 207.220000
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Z99878 0.19968600	Z99879-1.50261000	Z99880 0.19953500
Z99881 0.19978700	Z99882 0.19968800	Z99884 1
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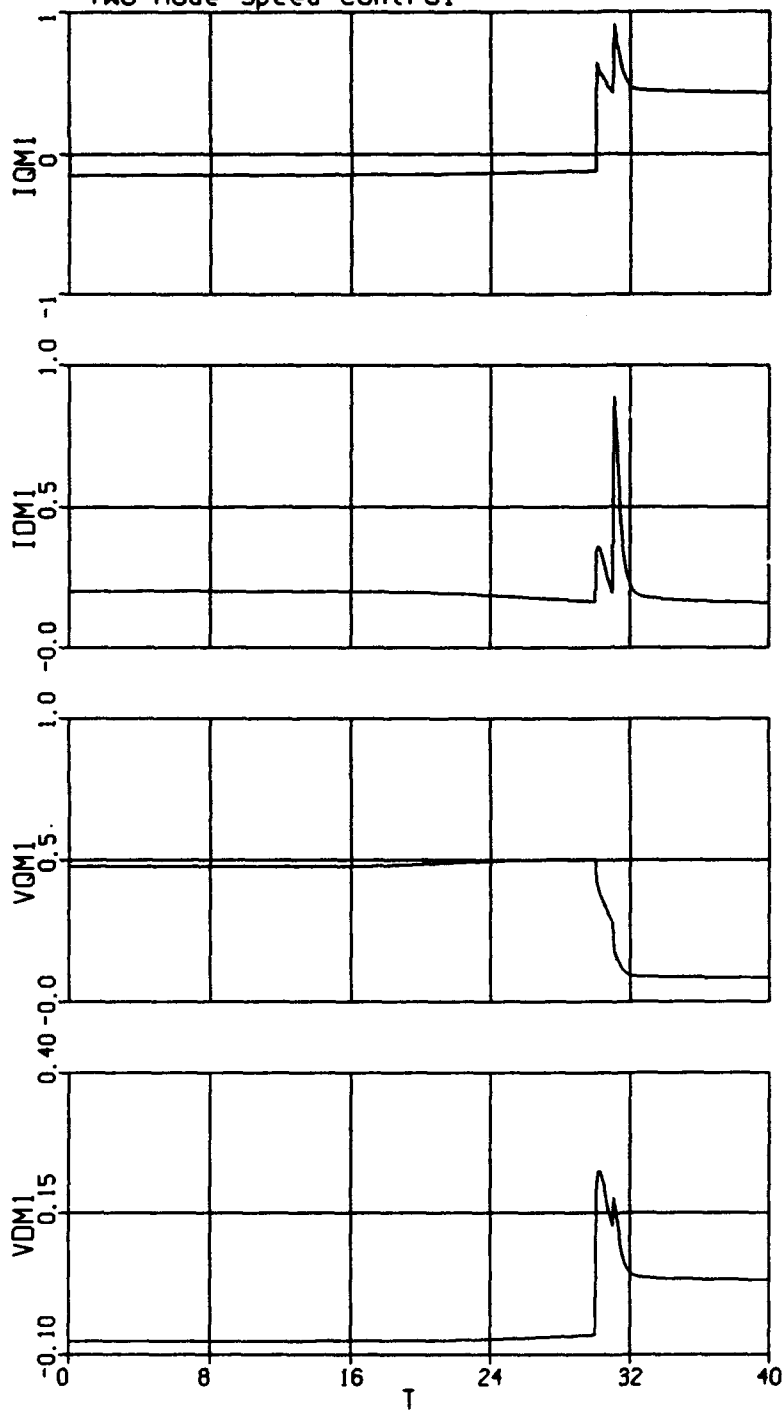


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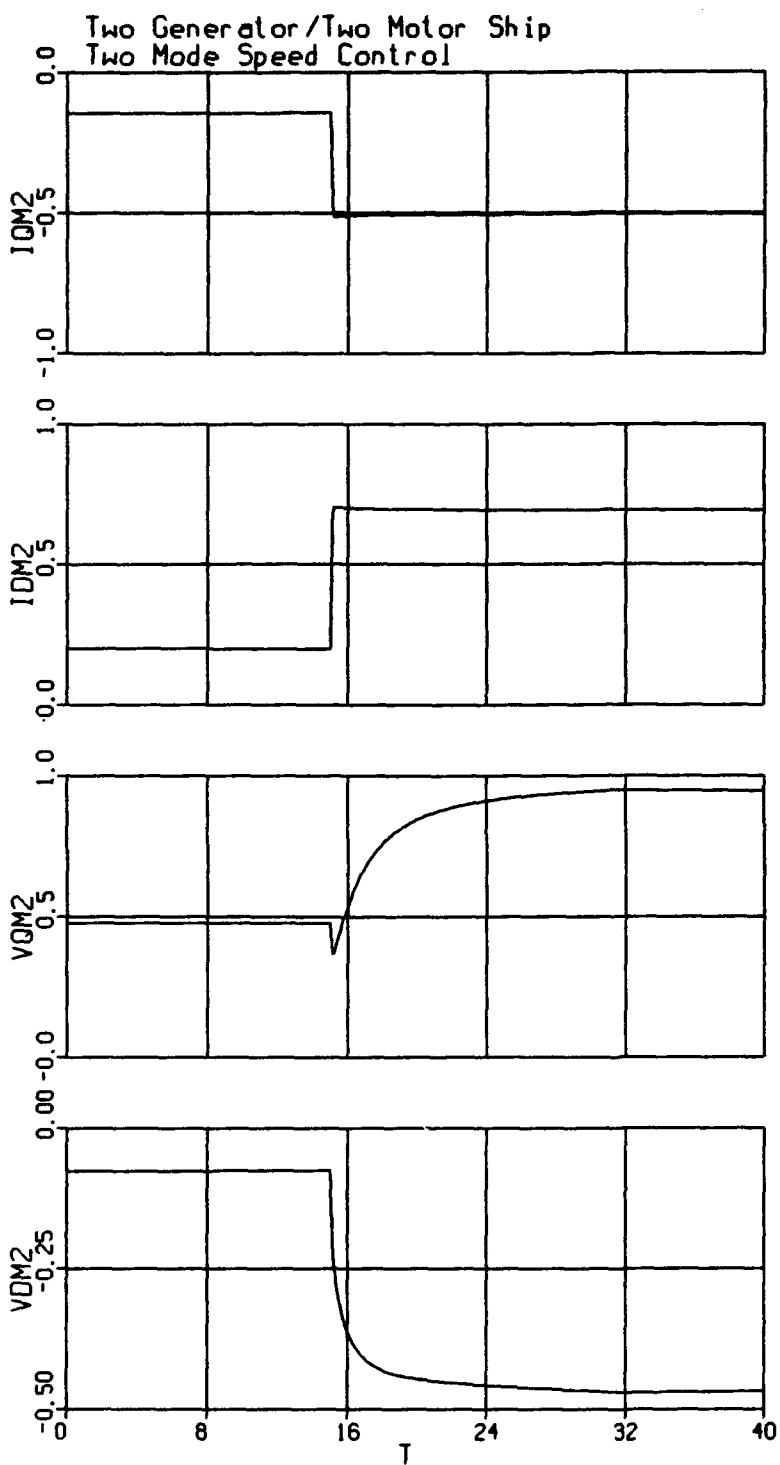


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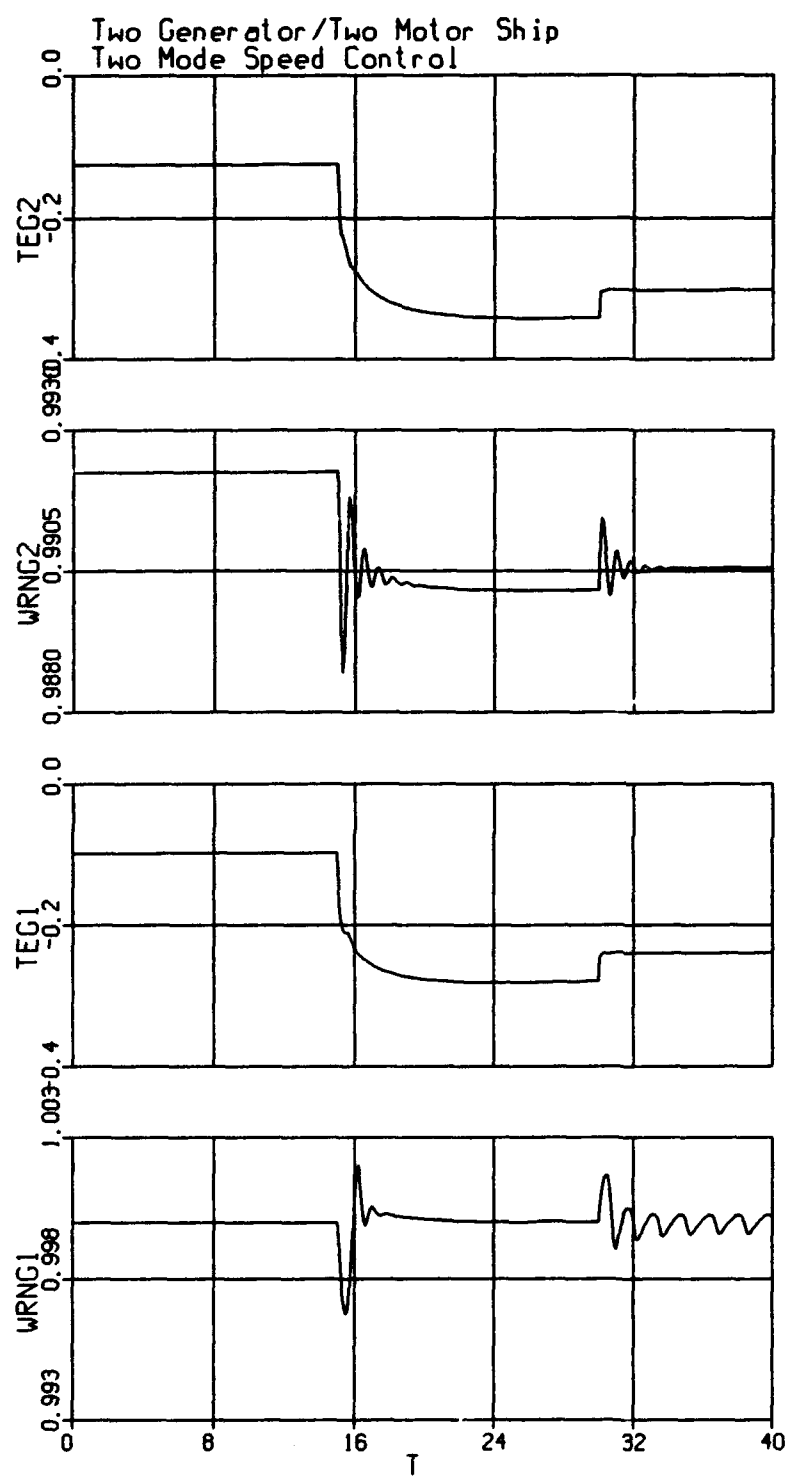
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Two Mode Speed Control



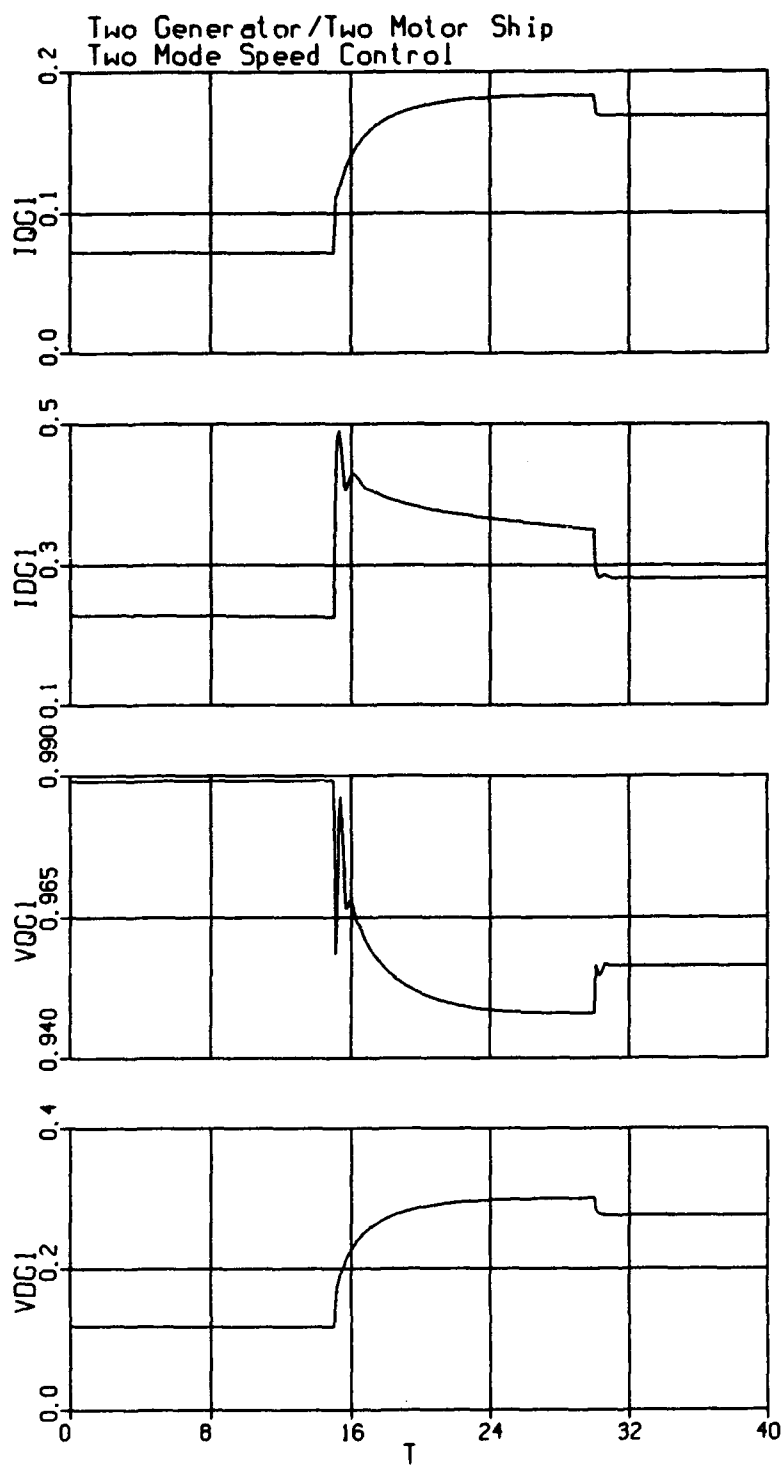
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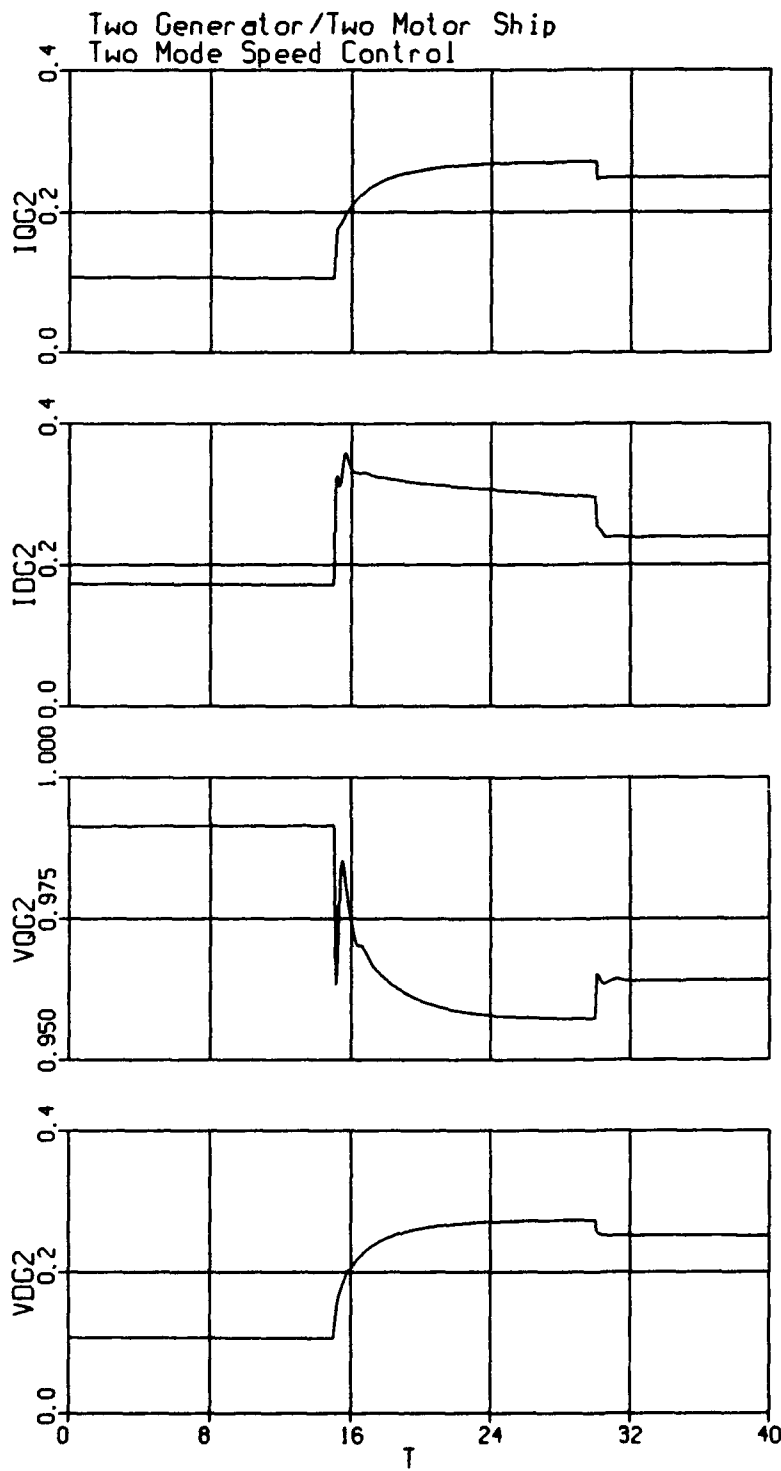
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Appendix D: Simulation Output

This appendix contains an ACSL debug dump of all model values followed by graphical outputs of important variables of interest. The debug dump is rather lengthy, but this will allow re-creation of the simulation in the future if required. See appendix F for a dictionary of the variable names.

D.1 Acceleration From Rest

T 150.000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZNBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 42
ZZNAST 0	IALG 1	NSTP 100
MAXT 0.10000000	MINT 1.0000E-08	

State Variables	Derivatives	Initial Conditions
EDPPG1 0.20712500	Z99995 2.8048E-05	EDPPG1IC 0.
EDPPG2 0.26969000	Z99992-2.4818E-05	EDPPG2IC 0.
EDPPM1-0.42161800	Z99926-2.2142E-05	EDPPM1IC 0.
ENPTL2 7.19999000	Z99940-4.7684E-05	ENPTL2I 7.20000000
EQPG1 1.03756000	Z99994-2.1611E-05	EQPG1IC 1.00000000
EQPG2 1.00525000	Z99991 7.1674E-06	EQPG2IC 1.00000000
EQPM1 1.11792000	Z99925 8.2020E-07	EQPM1IC 1.00000000
EQPPG1 1.01382000	Z99996 5.3622E-06	EQPPG1IC 1.00000000
EQPPG2 0.99599300	Z99993-7.4970E-06	EQPPG2IC 1.00000000
EQPPM1 1.06026000	Z99927-1.4624E-05	EQPPM1IC 1.00000000
IDC1 0.97999000	Z99918 6.6976E-05	IDC1IC 0.
NGG2 7939.00000	Z99963-8.2527E-04	NGG2I 7193.84000
NPT2 3599.99000	Z99976-0.02691890	NPT2I 3600.00000
THMG1 56018.5000	Z99978 373.192000	Z99977 0.
THMG2 56552.3000	Z99929 376.999000	Z99928 0.
THMM1 44224.0000	Z99923 366.055000	THMM1IC 0.
TICRL2 64.6034000	Z99957 0.00938416	TICRL2I 13.00000000
WMG1 373.192000	Z99979-7.4413E-04	WMG1IC 377.000000
WMM1 366.055000	Z99924 0.01456500	WMM1IC 0.
Z99913 0.	Z99912 0.	Z99911 0.
Z99915 1.00474000	Z99914 7.6095E-05	VS1PUI 0.
Z99917 1.00000000	Z99916 0.	IDCR1IC 0.
Z99920 0.60061100	Z99919-0.03035660	ULIC 0.99000000
Z99922 2.12437000	Z99921 0.	EAFM1IC 1.00000000
Z99931 0.48354200	Z99930-6.6314E-07	XMV2I 0.31609000
Z99933 7939.00000	Z99932 0.	NGGL2I 7193.84000
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Z99937-3.3157E-07
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 Z99942-345.140000
 Z99946-1.73586000
 Z99950 1313.25000
 Z99952 3599.99000
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 Z99962 1539.07000
 Z99965 2130.50000
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 Z99986 1.00000000
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 Z99990 1.50550000

Z99936 7.2369E-08
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 Z99951-0.02882220
 Z99953-5.0712E-06
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 Z99964-0.01189530
 Z99970 0.00154622
 Z99980 1.4538E-05
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 Z99987 0.00220656
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 ALPHA2I 40.9791000
 TGLAG2I-345.140000
 TABTR2I 0.
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 NPTL2I 3600.00000
 P54LL2I 21.7097000
 P54L2I 21.3889000
 T51PL2I 1416.04000
 T4PL2I 1875.14000
 NERR2I 0.
 TMECH1IC 0.
 FUEL1IC 0.
 EAFG2IC 1.00000000
 EAFGL1IC 1.00000000

Algebraic Variables

Common Block /ZZCOMU/

AFL2 0.16428700
 ALPHA2LL 13.0000000
 ALPHAG2 54.0000000
 BASEKWG1 2500.00000
 BASENG1 900.000000
 BASEQM1 949455.000
 BASEVM1 5000.00000
 CQLID2 2.8143E-05
 DELG1 0.29216700
 DELR1 0.42805300
 DELVTQ2 0.
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 DNGG2 7939.00000
 DQ4S2 0.03920190
 DRLLG2I 0.31609000
 DT51HS2 5.5702E-04
 E222-0.09077050
 E62 0.
 E92 0.50003600
 EAFGLD-0.00187397
 EAFM1 2.12437000
 EAFM1MIN 0.
 EAFMING1 0.
 EDPPG1D 2.8048E-05
 EI1 0.91375200
 EMFSAT2-2.5686E-08
 ENPT2I 7.20000000
 EQPG2D 7.1674E-06
 EQPPG2D-7.4970E-06
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 FARGS3 3
 FUEL1MIN 0.
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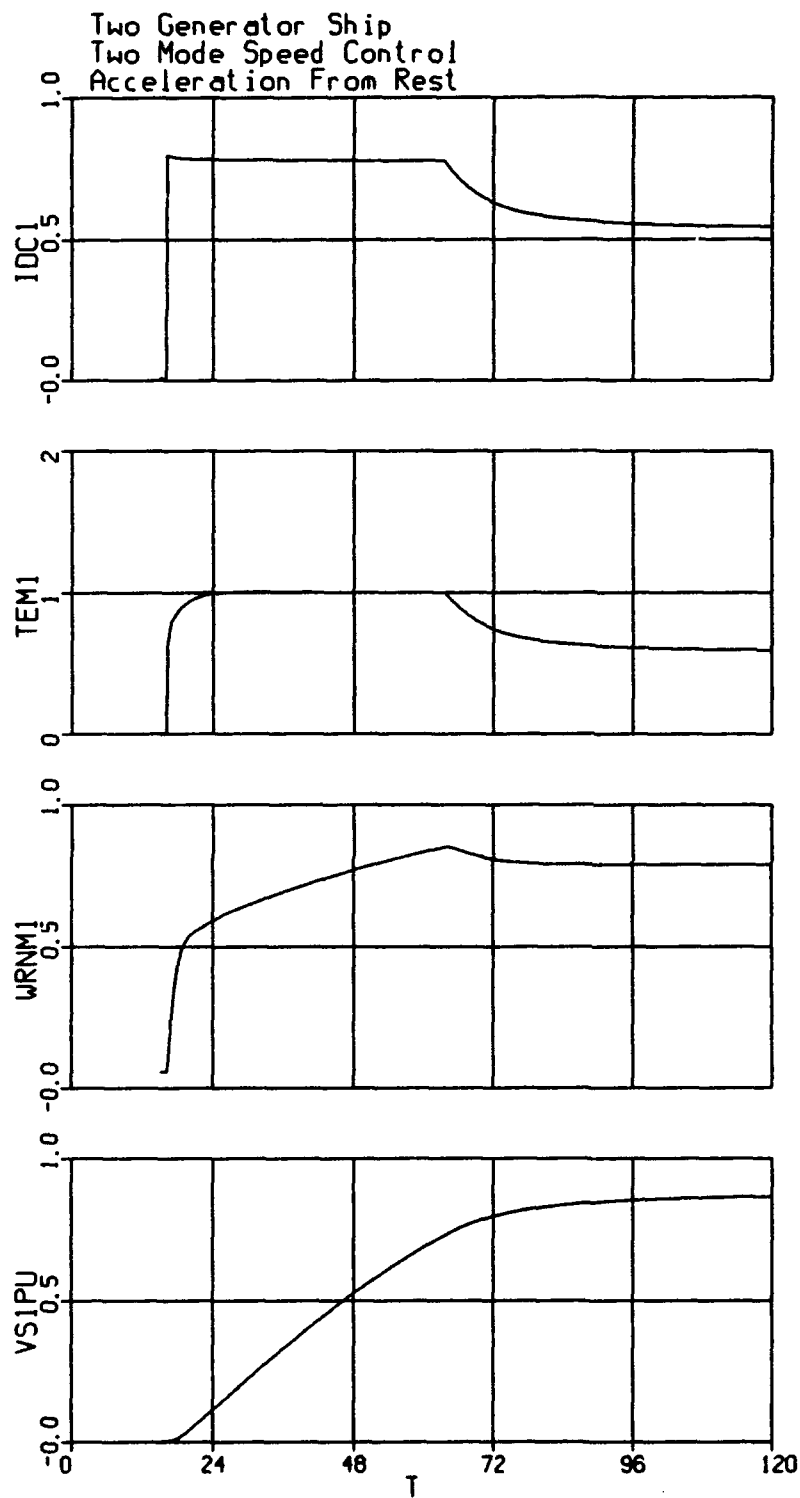
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 DNPT2-0.02691890
 DQHR22-0.04072430
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 DELAY1 0.41613500
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 DELV 1.0000E-04
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 DN2-0.02691890
 DNREF2 180.000000
 DQPTR2 9984.12000
 DT4HS2 0.00812641
 E212-0.00151284
 E52 7.55344000
 E82 0.
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 EAFG2D 0.00220656
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 EQPPG1D 5.3622E-06
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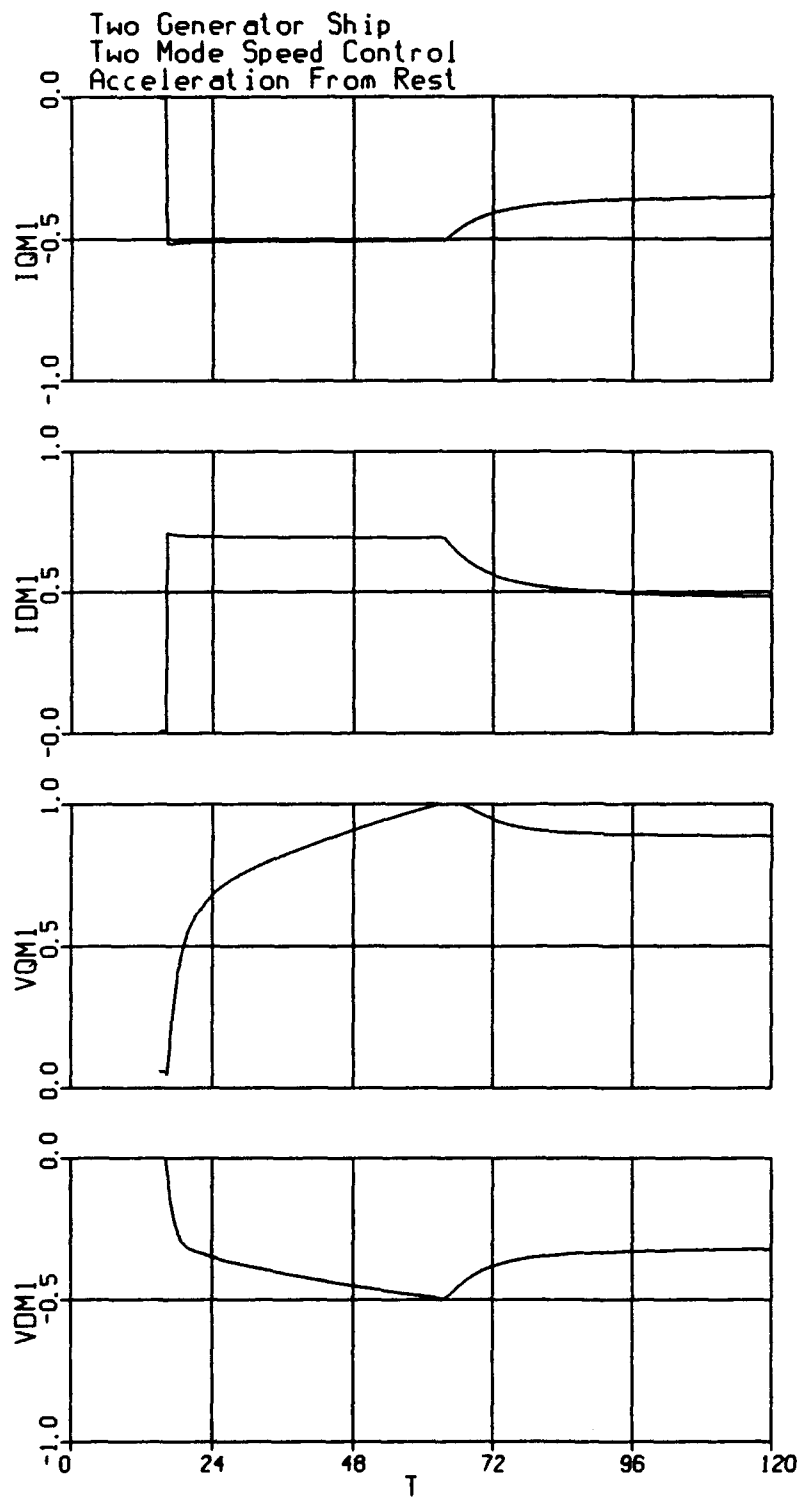
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HP2ORD 0.	HP2ORDI 0.	HPT2ORD 6594.62000
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ICNTRL2I 0.	ID2GR 1.00000000	IDC1D 6.6976E-05
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IDG1 0.33911600	IDG1IC 0.	IDG2 0.30839800
IDG2ERR 0.	IDG2IC 0.	IDL2 0.17026800
IDM1 0.87365600	IDM1IC 0.	IDR1 0.86397900
IDSML 0.89149500	IDXM1 0.53757100	IERR1 0.02001020
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IQG1 0.28374100	IQG1IC 0.	IQG2 0.18099900
IQG2ERR 0.	IQG2IC 0.	IQL2 0.11576500
IQM1-0.63593000	IQM1IC 0.	IQR1 0.64901600
JJG 16505.0000	JJPROP 1.3130E+06	JJPS 1.4790E+06
JJPT2 2171.50000	JJSHFT 166000.000	K00RES 0.
K01RES 0.20233900	K02RES-0.05737380	K03RES 0.96980600
K04RES-0.23175100	K05RES 8.65721000	K06RES-5.19908000
K07RES-23.5963000	K08RES 15.9458000	K09RES 20.3595000
K10RES-15.1637000	KALARM2 0	KC12 0.50000000
KDFRQ 1.57080000	KGC 32.1740000	KGOV1 0.20000000
KHOLDPI2 1.00000000	KI 307.240000	KIG1M1 1.86253000
KIG2M1 1.30556000	KKWG1M1 0.16762800	KKWG2M1 1.08623000
KPNGG2 0.01017600	KQHP 5252.10000	KRAT2 0.16000000
KRATE2 10.0000000	KSHTDN2 0	KTBL2 0
KTURBO1 0.50000000	KVG1M1 0.09000000	KVG2M1 0.83200000
KVSHIP 0.00754970	KZG1M1 0.04832140	KZG2M1 0.63727300
LDOPLR F	LFWD1 T	LHEADR F
LHOLD2PI F	LNGG2A F	LPWRD2 F
LSEA F	LT542A F	MAXIT 10.0000000
MFKAC2 0.58200000	MFKFR2 0.17259000	MFKMV2 23.0000000
MFKN2 4.6080E-08	MFW2 159.400000	2091.30000
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NP2PUI 5.3832E-06	NP2RPMI 7.7905E-04	NP2RPM 145.645000
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QPT2PU 0.27338800	QREF2 45000.0000	RDC1 0.02000000
RS1PU0 21.9066000	RS1PU1-20.8741000	RS1PU2 0.68955800
RS1PU3 0.20329700	RS1PU 1.92537000	RS1PUI0 0.
RS1PUI1 0.	RS1PUI2 0.	RS1PUI3 0.
RS1PUI 0.	SEAFRQ 1.04720000	SEATIME 0.
SNEGVL2 0.	SPDERR1 9.07117000	SPDREF1 1.00000000
SPEEDERR1 0.02903100	SQRTH2 1.00000000	T0SEA 0.
T2 518.700000	T42 2130.46000	T4P2 2130.46000
T4PL2 2130.50000	T4R22 2130.46000	T4U2-0.59452800
T512 1539.07000	T51P2 1539.07000	T51PL2 1539.07000
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T542 1026.56000	TABTR12 1.44656000	TALPHA2(32) 999.900000
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TC12 3.00000000	TDOPG1 3.79000000	TDOPG2 3.19000000
TDOPM1 2.10000000	TDOPPG1 0.38000000	TDOPPG2 0.04000000
TDOPPM1 0.03900000	TDT542(48) 99999.0000	Z99966(36) 68.3000000
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TEG2IC 0.	TEM1 1.01593000	TESM2 9621.03000
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THET2N 1.00000000	THETA2 1.00000000	THTA2V 1.00000000
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TICS2 64.6200000	TICS2I 13.0000000	TMAP(116) 950.000000
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TP1PU 0.96772600	TP1PUI 0.	TP2PU 0.96772600
TP2PUI 0.	TQOPPG1 0.19000000	TQOPPG2 0.09000000
TQOPPM1 0.19300000	TSEA 6.00000000	TSTOP 150.000000
TURBOLAG1 0.36562600	TUT4H2 0.29891600	TUT51H2 0.12377200
TVS0REF 696.262000	U1 0.60061100	U1D-0.03035660
UMAX1 0.99000000	UMIN1 0.	VDBIC 0.
VDBUS 0.31494000	VDERR 0.	VDG1 0.28657300
VDG2 0.29684000	VDM1-0.71440700	VDR1 0.37984100
VERRG1 0.01505320	VERRG2 0.01495830	V11-0.88942200
VN2 7.34400000	VNSF2 500.000000	VQ2 9.00000000
VQBIC 1.00000000	VQBUS 0.91889700	VQERR 0.
VQG1 0.95278300	VQG2 0.94973400	VQM1 0.56970600
VQR1 0.83249900	VQSF2 5000.00000	VR1 0.90902200
VR2 0.50000000	VRATE2 0.	VRSF2 360.000000
VS1PU0 1.0000E-05	VS1PU10 1.04838000	VS1PU10I 0.
VS1PU2 1.00949000	VS1PU2I 0.	VS1PU3 1.01427000
VS1PU3I 0.	VS1PU4 1.01908000	VS1PU4I 0.
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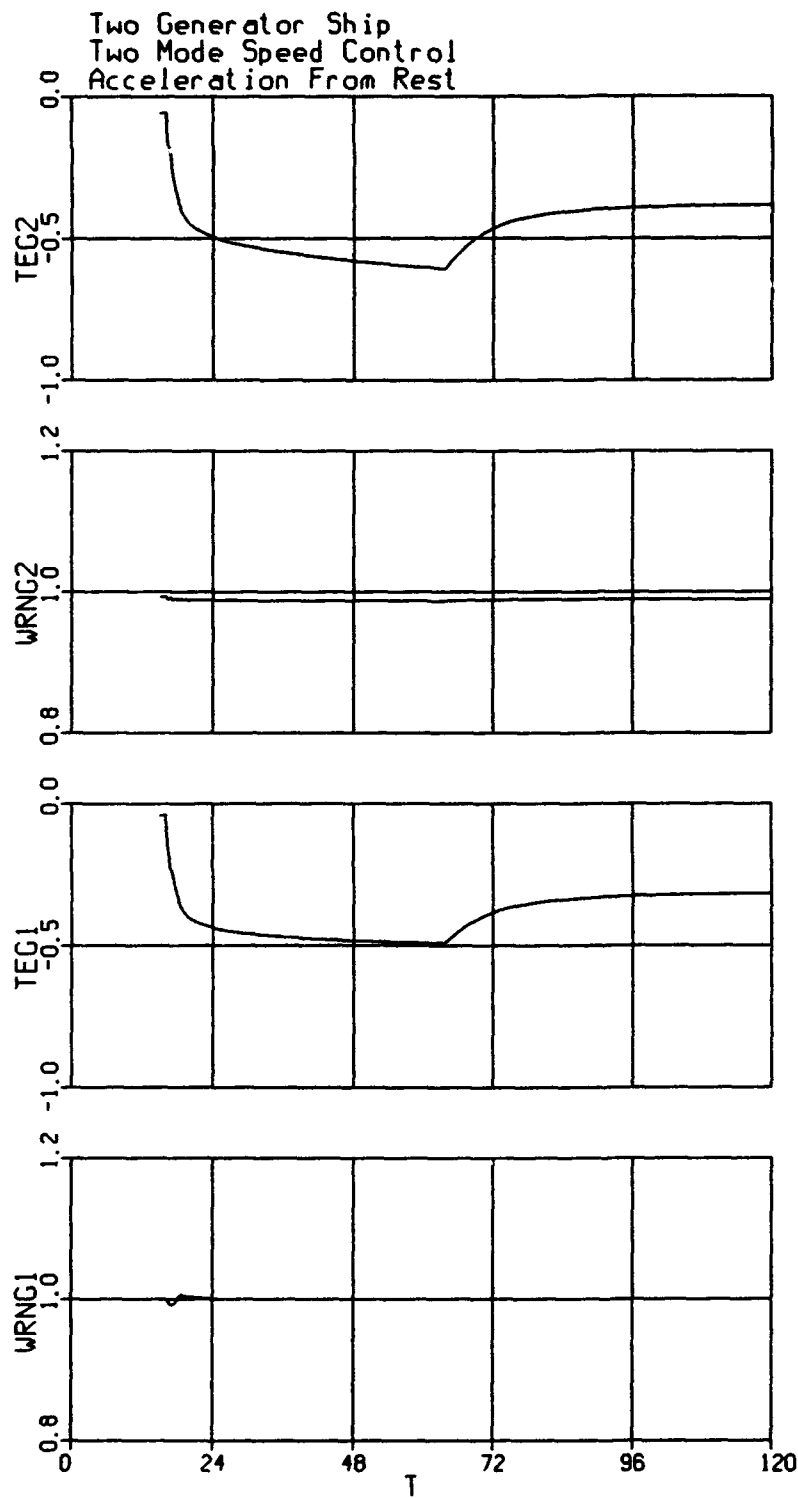
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VTREFG1 1.01000000	VTREFG2 1.01000000	VTRQGS2 0.
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W54R22 81.8123000	WAVE 4.00000000	WEPSEA 1.04720000
WESEA 0.	WESEANG 0.	WESMAX 0.10000000
WFAC2 5787.87000	WFSR22 4364.46000	WFUEL2 4364.42000
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WRN2ORDIC 1.00000000	WRNG1 0.98989900	WRNG2 0.99999700
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XDC1 1.68000000	XDG1 1.63000000	XDG2 1.77000000
XDM1 1.76000000	XDMXQM1 0.60300000	XDPG1 0.25000000
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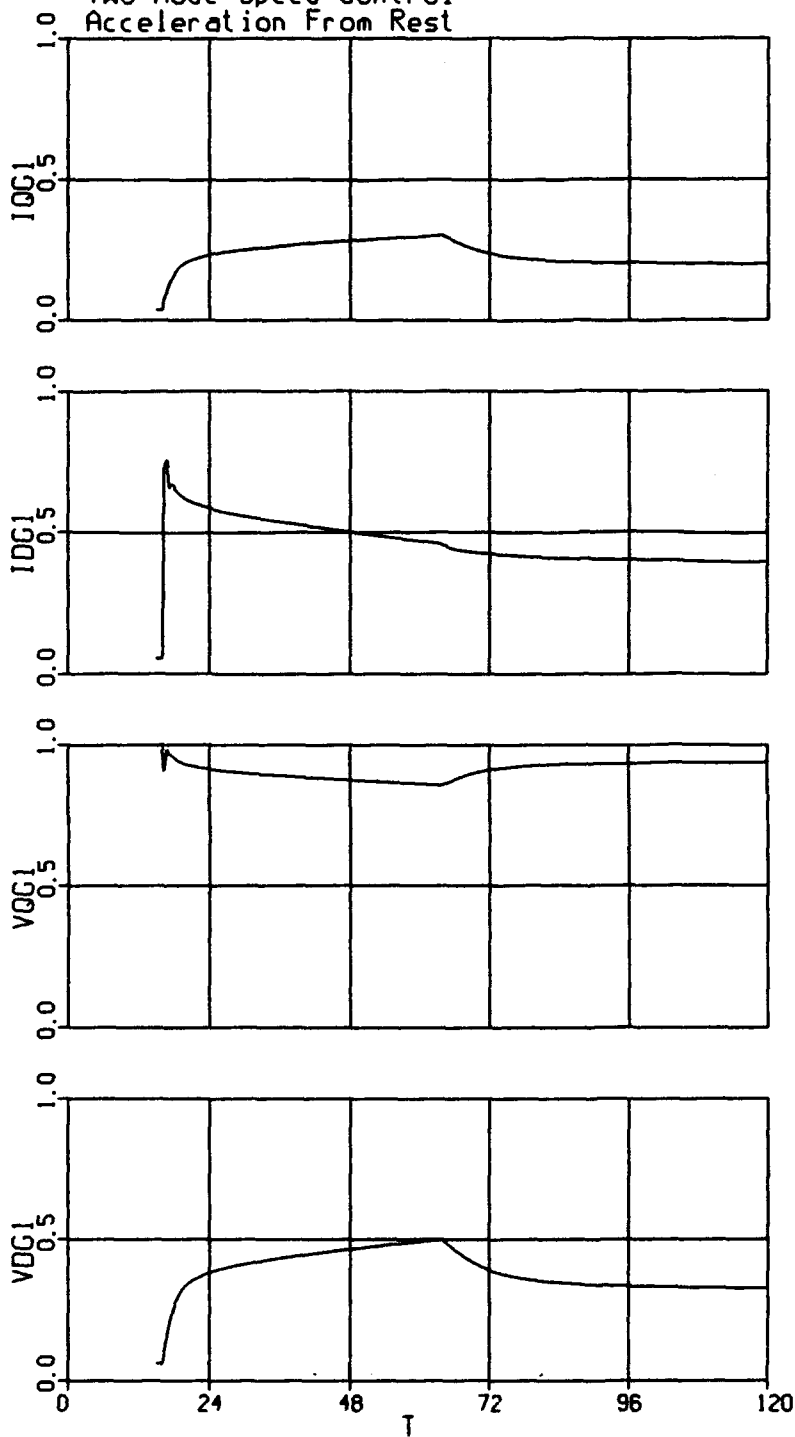


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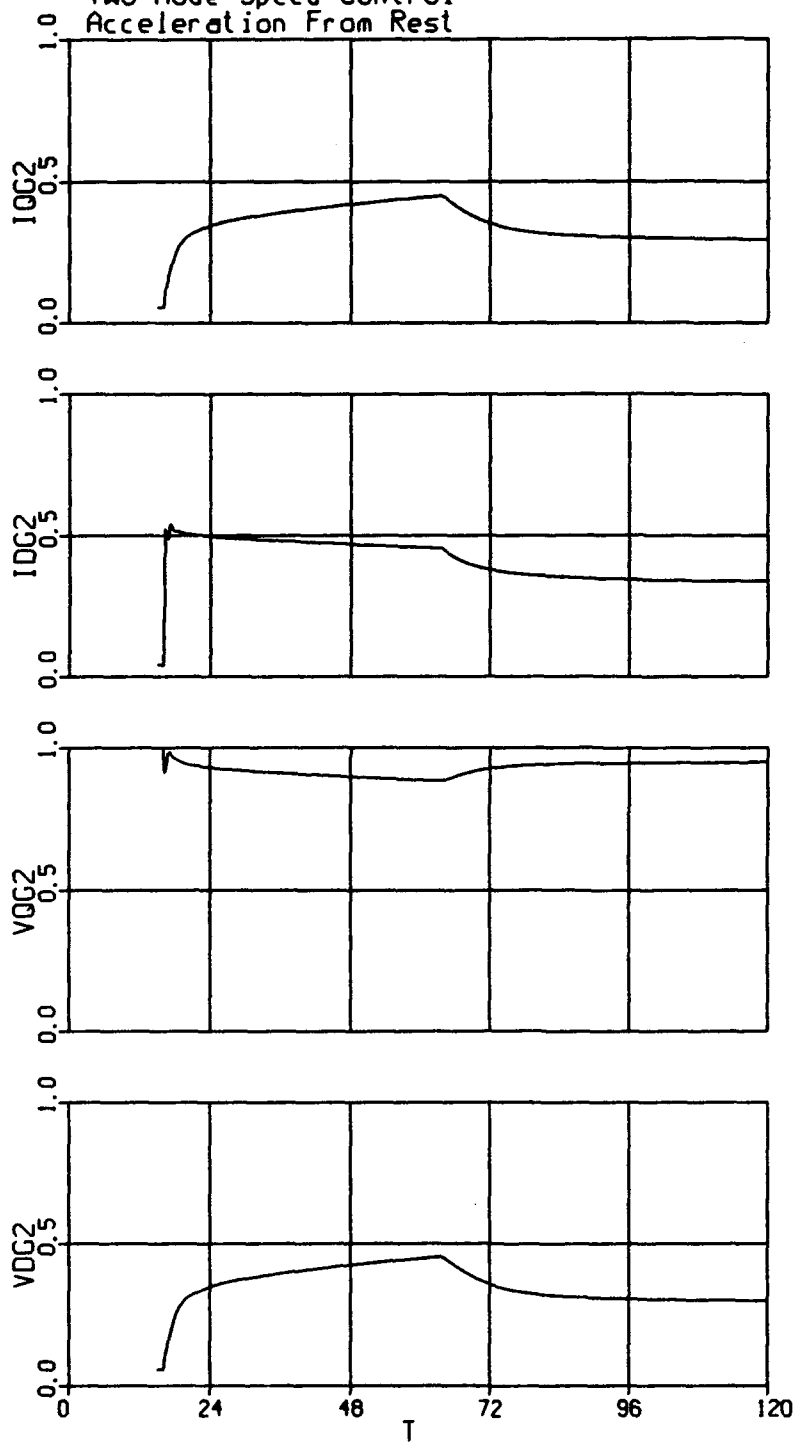
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Two Generator Ship
Two Mode Speed Control
Acceleration From Rest



9 93/04/27 13:15:10

Two Generator Ship
Two Mode Speed Control
Acceleration From Rest



10 93/04/27 13:15:10

D.2 Single Mode Speed Control in Moderate Seas

System #2: moderate waves

T 150.000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZNBLK 1	ZZICOM 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	WSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

State Variables

EDPPG1 0.10393600
 EDPPG2 0.13385500
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 EQPG2 1.02220000
 EQPM1 0.99769300
 EQPPG1 1.03125000
 EQPPG2 1.01603000
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 IDC1 0.58815000
 NGG2 7652.43000
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Derivatives

Z99995 0.01313510
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 Z99942 4.0531E-04
 Z99994 0.00710219
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 Z99996 0.00520087
 Z99993 0.00142611
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 Z99922 0.11471900
 Z99965 38.1411000
 Z99978 0.31122000
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Initial Conditions

EDPPG1IC 0.
 EDPPG2IC 0.
 EDPPM1IC 0.
 ENPTL2I 7.20000000
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 EQPPG1IC 1.00000000
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 NGG2I 7193.84000
 NPT2I 3600.00000
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 TABTR2I 0.
 QMAFL2I 0.
 NPTL2I 3600.00000
 P54LL2I 21.7097000
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 T51PL2I 1416.04000
 T4PL2I 1875.14000
 WERR2I 0.
 TMECH1IC 0.
 FUEL1IC 0.
 EAPG2IC 1.00000000
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Algebraic Variables

Common Block /ZZCOMU/

AFL2 0.16580000
 ALPHA2LL 13.0000000
 ALPHAG2 54.0000000
 BASEKWG1 2500.00000
 BASENG1 900.000000
 BASEQM1 949455.000
 BASEVM1 5000.00000
 CQLID2 2.8143E-05
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 DELVTQ2 0.
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 DT51HS2-3.17897000
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 E62 0.
 E92 0.49969500
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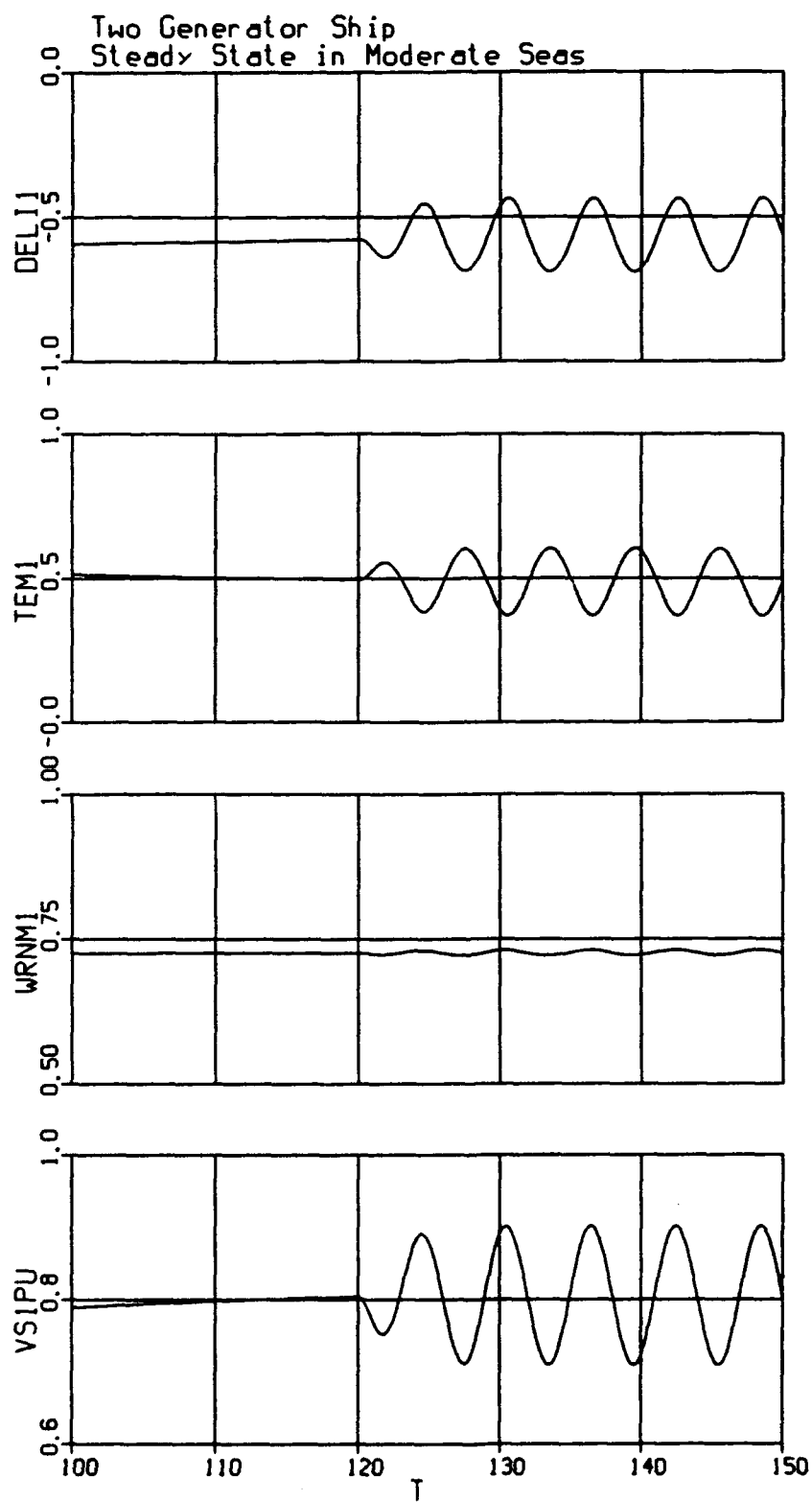
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 CYL1 8.00000000
 DELG2 0.14855900
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 DELWF2 80.2798000
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 DQHR22 90.7505000
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 EAFMAXG1 3.00000000
 EAFMING2 0.
 EDPPG2D 0.01724740
 EISM1 1.00000000
 ENGG2 4.7579E-04
 EPM1 1.28377000
 EQPM1D 0.00350416
 EQPPM1D-0.00344501
 ERX2 4.7579E-04
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 FARGS1 1
 FUEL1 0.25527800
 FUELAG1 0.05042310
 G52 0.50000000
 GEAFG2 100.000000
 HG1 1.91000000
 HM1 1.28978000
 HP2D 2993.90000
 HP2ORDI 0.
 ICLIM2 70.0000000
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 IDCR1D 0.11261300
 IDCR1MAX 1.00000000
 IDG1IC 0.
 IDG2ERR 0.
 IDL2 0.14877000
 IDR1 0.59921300
 IERR1 0.01275110
 IITID2 580.484000
 IQG1M1 0.27155200
 IQG2IC 0.

ALPHA2 55.7961000
 ALPHAG1 20.7143000
 ARLLG2I 0.31609000
 BASEKWM1 14914.0000
 BASENM1 150.000000
 BASEVG2 4160.00000
 BETAR1 1.17830000
 DELAY1 0.47403000
 DELI1-0.56631600
 DELV 1.0000E-04
 DELWF2I 0.
 DN2 0.31122000
 DNREF2 180.000000
 DQPTR2 4761.81000
 DT4HS2-5.38298000
 E212 0.00711710
 E52 8.35195000
 E82 0.
 EAFG1 1.47432000
 EAFG2D 0.00328422
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 EAFMAXG2 3.00000000
 EAFSM1 1.60680000
 EDPPM1D-0.05109890
 EMFFB2 0.00540942
 ENPT2 7.19953000
 EQPG1D 0.00710219
 EQPPG1D 0.00520087
 ER1 0.91761100
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 FARG3 3
 FARGS2 2
 FUEL1MAX 1.00000000
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 GBETAR1 30.0000000
 GEAFM1 100.000000
 HG2 0.92400000
 HP2 2993.90000
 HP2I 0.
 HPT2ORD 2993.90000
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 IDCR1DMAX 10.0000000
 IDCR1MIN 0.
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 IDG2IC 0.
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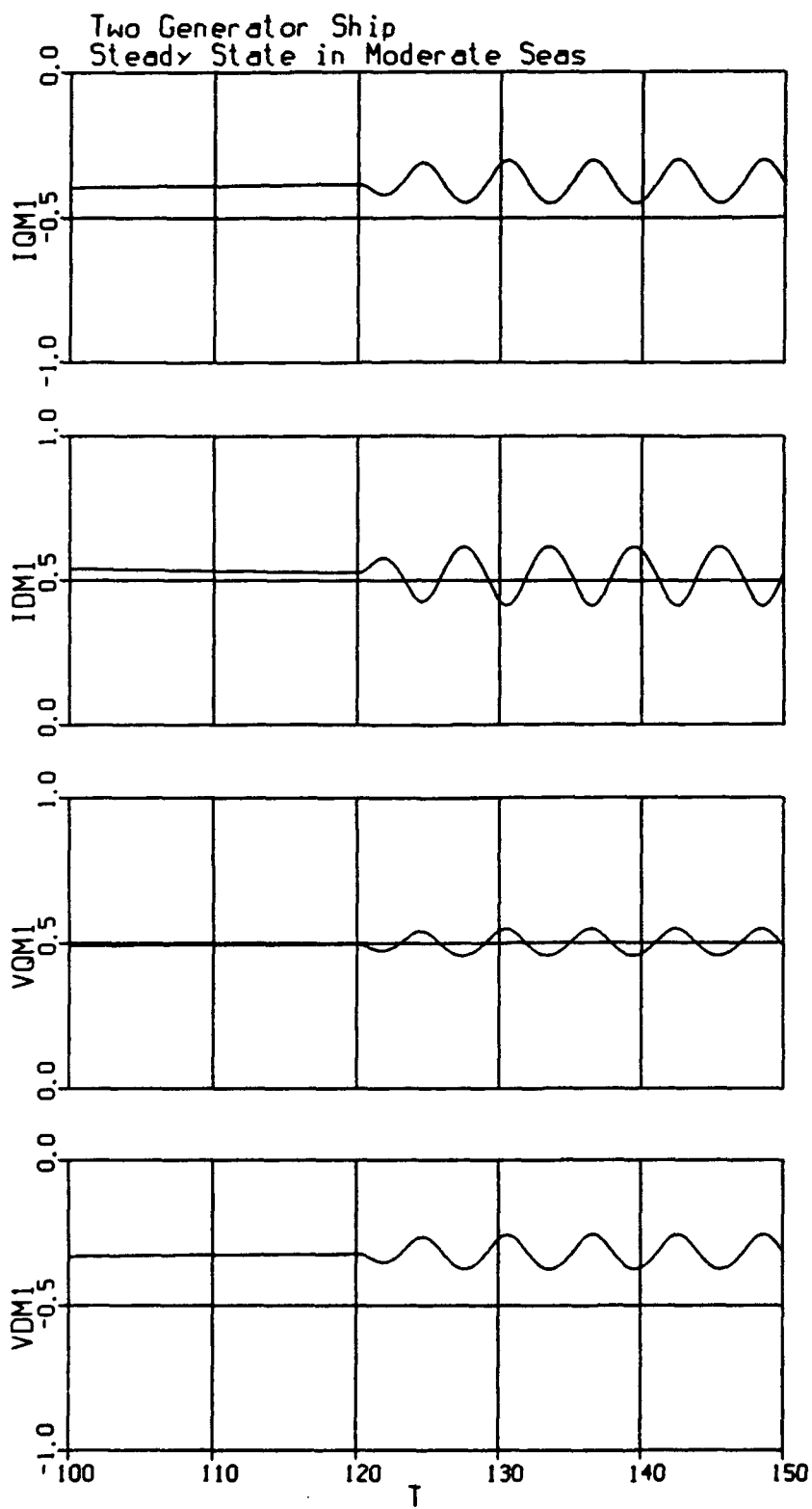
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JJPS 1.4790E+06	JJPT2 2171.50000	JJSHFT 166000.000
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K03RES 0.96980600	K04RES-0.23175100	K05RES 8.65721000
K06RES-5.19908000	K07RES-23.5963000	K08RES 15.9458000
K09RES 20.3595000	K10RES-15.1637000	KALARM2 0
KC12 0.50000000	KDFRQ 1.57080000	KGC 32.1740000
KGOV1 0.20000000	KHOLDPI2 1.00000000	KI 307.240000
KIG1M1 1.86253000	KIG2M1 1.30556000	KKWG1M1 0.16762800
KKWG2M1 1.08623000	KPNGG2 0.01017600	KQHP 5252.10000
KRAT2 0.16000000	KRATE2 10.0000000	KSHTDN2 0
KTBL2 0	KTURBO1 0.50000000	KVG1M1 0.09000000
KVG2M1 0.83200000	KVSHIP 0.00754970	KZG1M1 0.04832140
KZG2M1 0.63727300	LDOPLR F	LFWD1 T
LHEADR F	LHOLD2PI F	LNCG2A F
LPWRD2 F	LSEA T	LT542A F
MAXIT 10.0000000	MFKAC2 0.58200000	MFKFR2 0.17259000
MFKMV2 23.0000000	MFKN2 4.6080E-08	MPW2 159.400000
2091.30000	13659.6000	N1 892.447000
N2 3599.80000	N2I 3600.00000	NERR2 0.20288100
NGB 3600.00000	NGG2B 9827.00000	NGGL2 7650.92000
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NP1PUI 5.3832E-06	NP1RPM 108.827000	NP1RPMI 7.7905E-04
NP2PU 0.75199100	NP2PUI 5.3832E-06	NP2RPMI 7.7905E-04
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NPTQ2 158.058000	NPTQ2I 158.068000	NPTR2 3599.80000
NPTR2I 3600.00000	NREF2 3672.00000	NSET1 900.000000
P1 0.16000000	P2 14.6960000	P2T22 5.50753000
P542 27.0521000	P542I 21.3889000	P54L2 27.0445000
P54LL2 27.4282000	P54Q2 1.86637000	P54Q2I 1.47725000
P54R22 27.0809000	P54R22I 21.3889000	PAMB 14.6960000
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PNGGR2I 73.2049000	PS32 98.2213000	PS32I 68.0631000
PS3R22 98.2213000	PS3R22I 98.0631000	PS3WC2 98.0760000
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QP2F 9902.20000	QP2FI 92443.6000	QP2I-0.23332300
QP2PU 0.49680800	QP2PUI-1.8831E-07	QPBASE 1.2391E+06
QPSBAF 92466.4000	QPT2 4751.70000	QPT2B 36473.0000
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RS1PU2 0.36779100	RS1PU3 0.16232200	RS1PU 0.83822800
RS1PUI0 0.	RS1PUI1 0.	RS1PUI2 0.
RS1PUI3 0.	RS1PUI 0.	SEAFRQ 1.04720000
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SPDREF1 0.75000000	SPEEDERR1 0.02448650	SQTH2 1.00000000

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T4U2 317.494000	T512 1494.29000	T51P2 1497.47000
T51PL2 1480.31000	T51Q2 0.99787700	T51R22 1497.47000
T51U2 209.707000	T542 984.969000	TABTR12 0.64804800
TALPHA2(32) 999.900000	Z99976(16) 108.000000	Z99977(16) 999.900000
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TAUEAFG2 0.10000000	TAUEAFM1 0.05000000	TAUGOV1 2.00000000
TAUSPEED1 0.10000000	TC12 3.00000000	TDOPG1 3.79000000
TDOPG2 3.19000000	TDOPM1 2.10000000	TDOPPG1 0.38000000
TDOPPG2 0.04000000	TDOPPM1 0.03900000	TDT542(48) 99999.0000
Z99968(36) 68.3000000	Z99969(12) 99999.0000	TEG1-0.18102100
TEG2-0.11960800	TEG2IC 0.	TEM1 0.48552300
TESM2 4368.10000	TESM2I 0.	TGLAG2 7.20041000
THDOT22 1.14064000	THET2N 1.00000000	THETA2 1.00000000
THTA2V 1.00000000	TIC2 55.9891000	TIC2LL 13.0000000
TIC2UL 113.500000	TICMD2 55.9891000	TICMD2I 13.0000000
TICN2 0.05593920	TICN2I 0.	TICRL2LL-89.0000000
TICRL2UL 22.5000000	TICS2 55.9332000	TICS2I 13.0000000
TMAP(116) 950.000000	Z99997(96) 0.92280000	Z99998(20) 950.000000
TMG1 0.18034100	TMM1-0.49680800	TMM2-0.49680800
TORQ1 0.19478400	TP1PU 0.45199400	TP1PUI 0.
TP2PU 0.45199400	TP2PUI 0.	TQOPPG1 0.19000000
TQOPPG2 0.09000000	TQOPPM1 0.19300000	TSEA 10.0000000
TSTOP 150.000000	TURBOLAG1 0.42360600	TUT4H2 0.25599600
TUT51H2 0.10533900	TVS0REF 696.262000	U1 0.38249300
UID 0.00397265	UMAX1 0.99000000	UMIN1 0.
VDBIC 0.	VDBUS 0.15935100	VDERR 0.
VDG1 0.14476000	VDG2 0.14748700	VDM1-0.31321700
VDR1 0.18415700	VERRG1 0.01474720	VERRG2 0.01355870
VI1-0.56824200	VN2 7.34400000	VNSF2 500.000000
VQ2 9.00000000	VQBIC 1.00000000	VQBUS 0.95886300
VQERR 0.	VQG1 0.98466900	VQG2 0.98546600
VQM1 0.49264800	VQR1 0.89894100	VQSF2 5000.00000
VR1 0.58051600	VR2 0.50000000	VRATE2 0.
VRSF2 360.000000	VS1PU0 1.0000E-05	VS1PU10 0.11040400
VS1PU10I 0.	VS1PU2 0.64357200	VS1PU2I 0.
VS1PU3 0.51629200	VS1PU3I 0.	VS1PU4 0.41418400
VS1PU4I 0.	VS1PU5 0.33227100	VS1PU5I 0.
VS1PU6 0.26655700	VS1PU6I 0.	VS1PU7 0.21384000
VS1PU7I 0.	VS1PU8 0.17154900	VS1PU8I 0.
VS1PU9 0.13762100	VS1PU9I 0.	VS1PU 0.80222900
VT12 0.94481100	VTG1 0.99525300	VTG2 0.99644100
VTOP2 0.	VTREFG1 1.01000000	VTREFG2 1.01000000
VTRQGS2 0.	W42 58.9811000	W4R22 58.9811000
W542 65.9670000	W54R22 65.9670000	WAVE 12.0000000
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WESMAX 0.12000000	WFAC2 4437.68000	WFSR22 3279.88000
WFUEL2 3360.16000	WFUEL2I 2185.21000	WMG1D-0.06713930
WMG2 376.979000	WMM1D-1.64936000	WO 377.000000
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WRNG2 0.99994400	WRNG2IC 1.00000000	WRNM1 0.72551300
WRNM2 0.72551300	XDC1 1.68000000	XDG1 1.63000000
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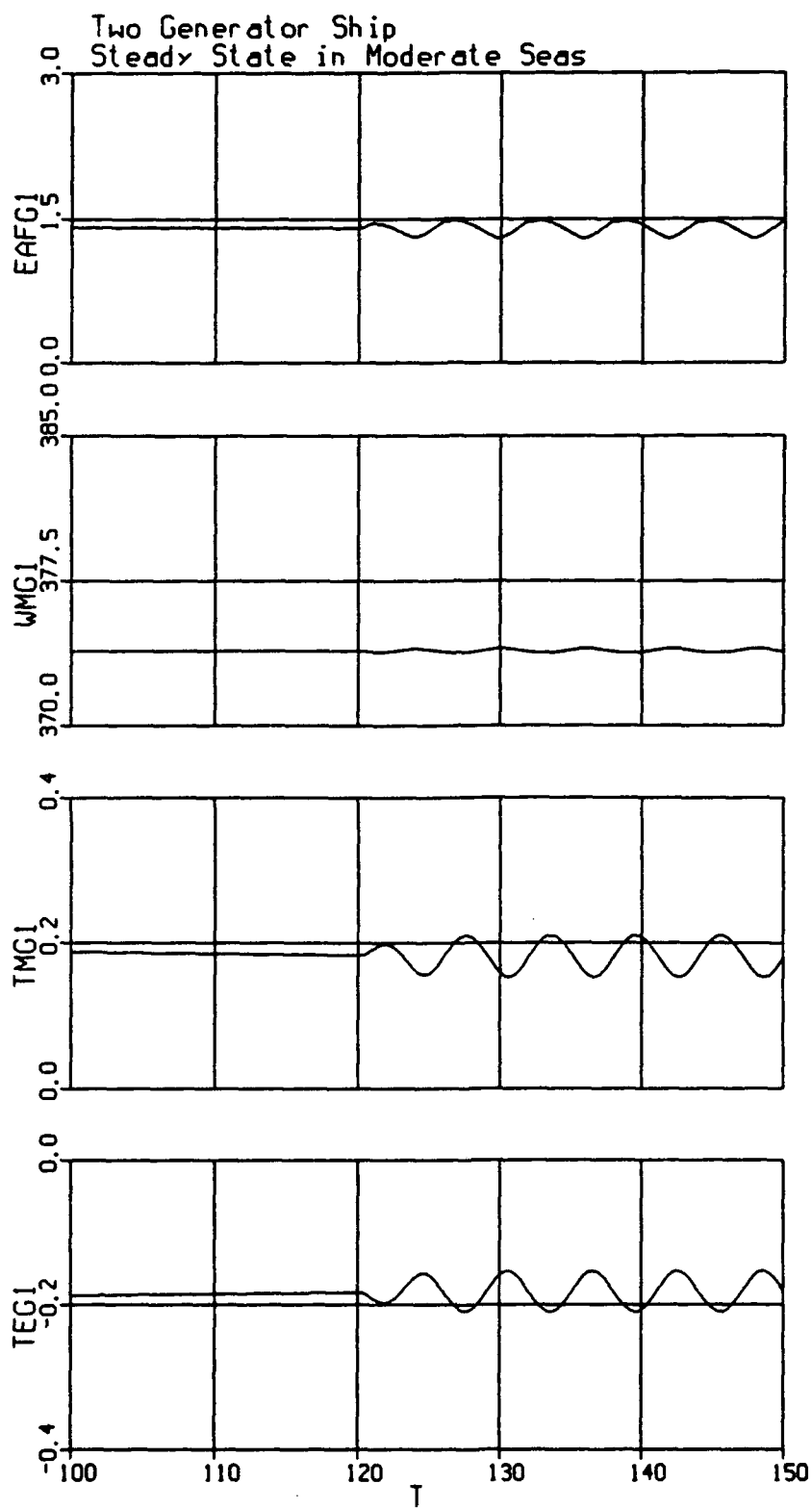
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XLM1 0.33700000	XMV2 0.41353400	XQG1 1.01000000
XQG2 1.64000000	XQM1 1.15700000	XQPPG1 0.28000000
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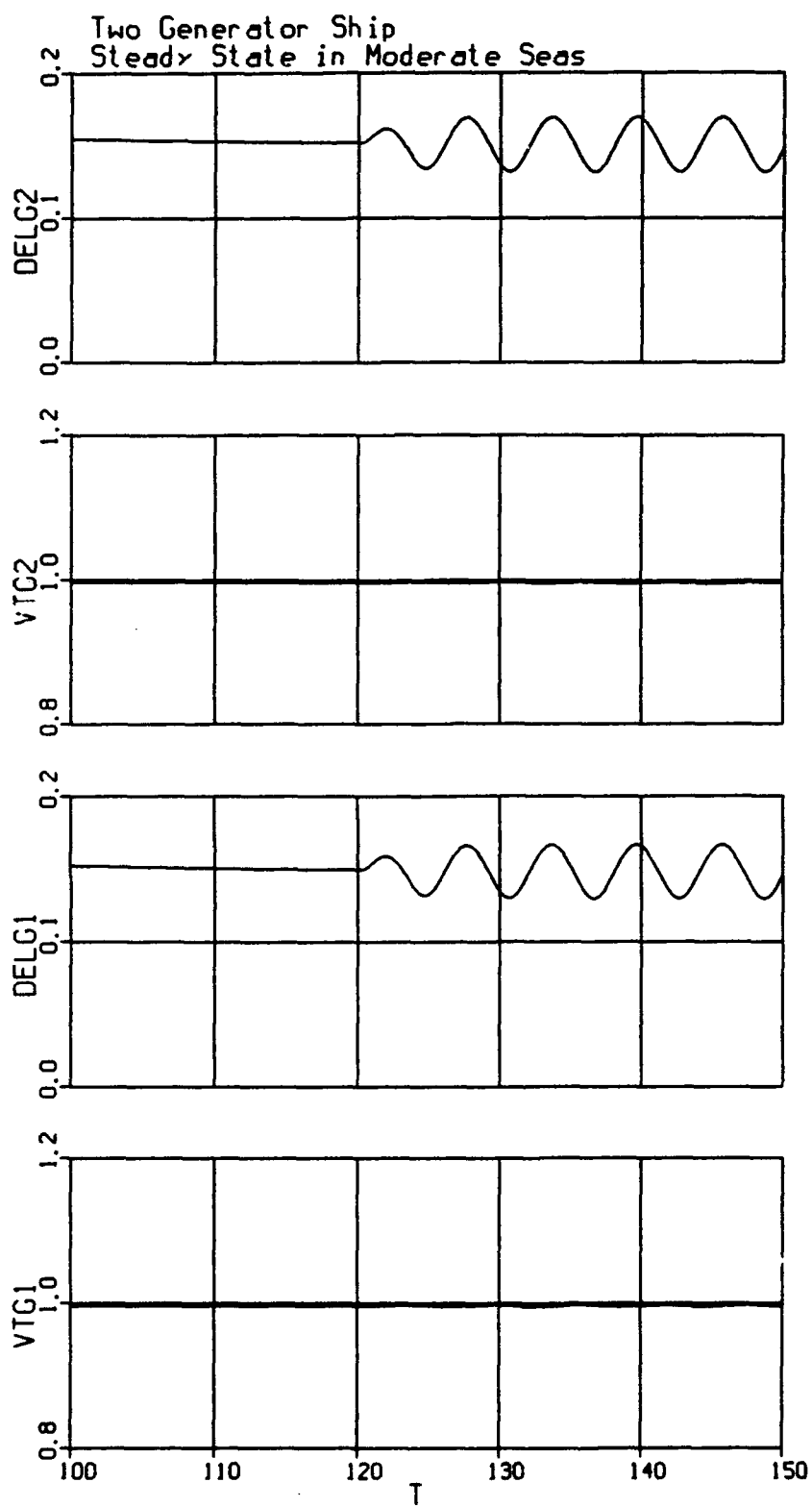
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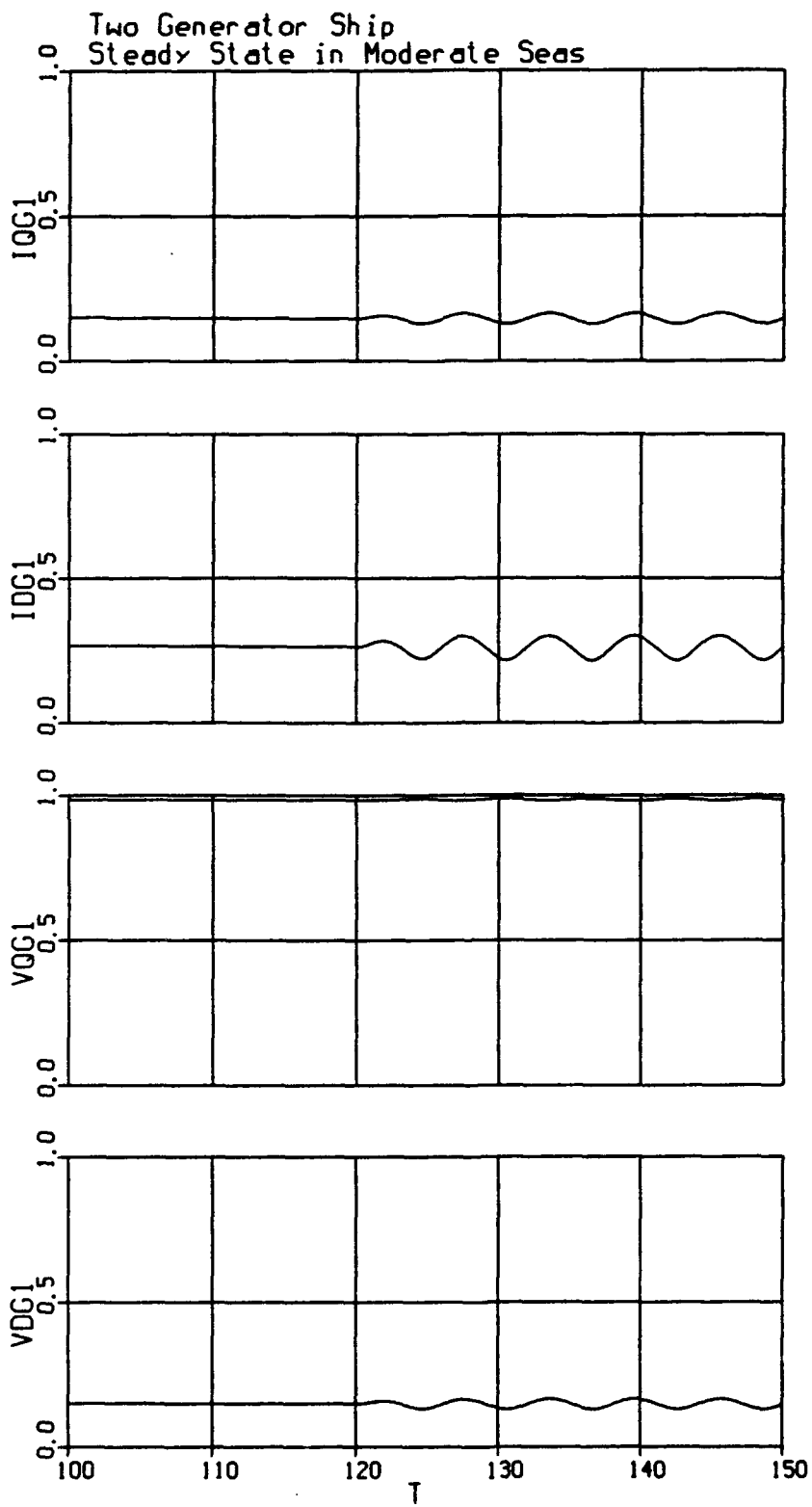
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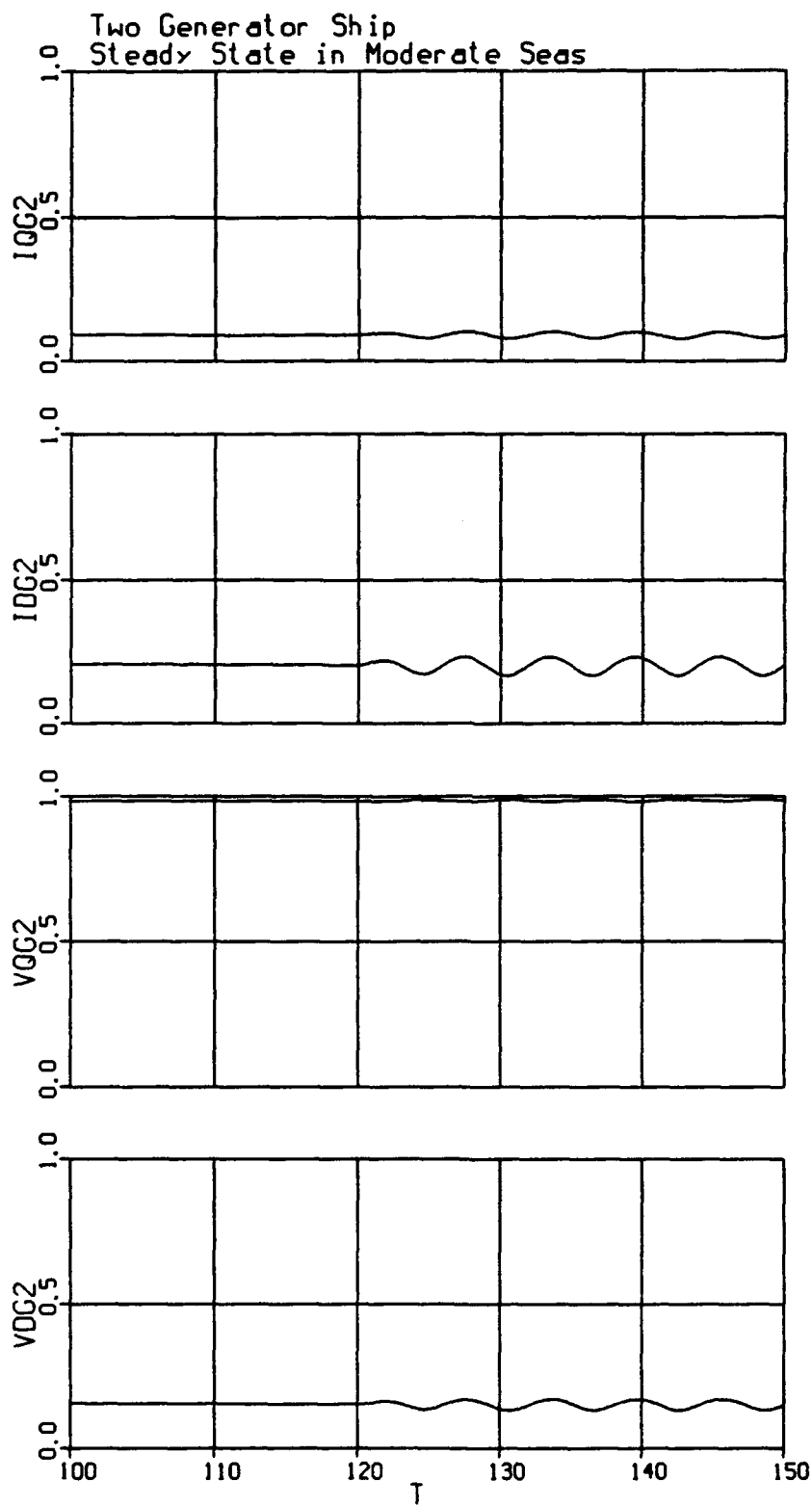
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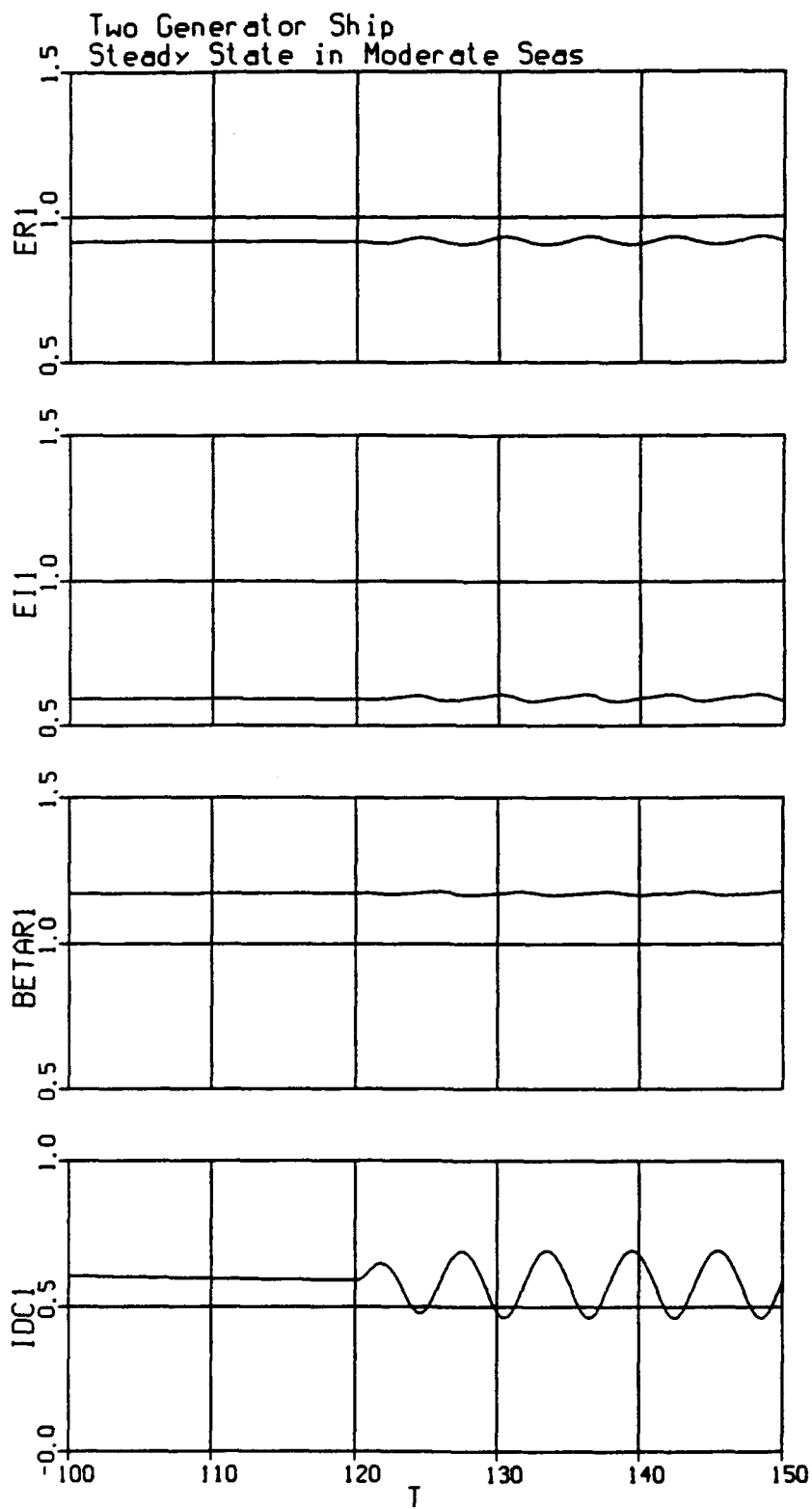
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D.3 Two Mode Speed Control in Moderate Seas

System 2a: Steady state in moderate seas (spderfl = 0.75)

T 180.000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZENBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

State Variables	Derivatives	Initial Conditions
EDPPG1 0.20525400	Z99995-0.00661310	EDPPG1IC 0.
EDPPG2 0.14911100	Z99992-0.00447765	EDPPG2IC 0.
EDPPM1-0.17283700	Z99930 0.00222434	EDPPM1IC 0.
ENPTL1 7.20019000	Z99942-8.3446E-05	ENPTL1I 7.20000000
EQPG1 1.02884000	Z99994 0.00177130	EQPG1IC 1.00000000
EQPG2 1.04152000	Z99991 0.00157604	EQPG2IC 1.00000000
EQPM1 1.31350000	Z99929-0.00192130	EQPM1IC 1.00000000
EQPPG1 1.01869000	Z99996 0.00174403	EQPPG1IC 1.00000000
EQPPG2 1.02238000	Z99993 0.00102810	EQPPG2IC 1.00000000
EQPPM1 1.28998000	Z99931-0.00164469	EQPPM1IC 1.00000000
IDC1 0.40073400	Z99922-0.00367904	IDC1IC 0.
NGG1 7847.97000	Z99965-10.1730000	NGG1I 7193.84000
NPT1 3600.09000	Z99978 0.11062300	NPT1I 3600.00000
THMM1 40970.7000	Z99927 258.282000	THMM1IC 0.
TICRL1 61.6146000	Z99959-0.37452700	TICRL1I 13.0000000
WMG2 373.630000	Z99979 0.02981520	WMG2IC 377.000000
WMM1 258.282000	Z99928-9.36900000	WMM1IC 0.
Z99915 0.12000000	Z99914 1.8626E-08	Z99913 0.
Z99917 0.74532100	Z99916 0.00115009	VS1PUI 0.
Z99919 0.41686300	Z99918-0.00461753	IDCR1IC 0.
Z99924 0.48404500	Z99923-0.01696650	ULIC 0.99000000
Z99926 1.71990000	Z99925 0.02384190	EAFM1IC 1.00000000
Z99933 0.45454600	Z99932-0.00268820	XMV1I 0.31609000
Z99935 7848.38000	Z99934-10.2417000	NGGL1I 7193.84000
Z99937 114.967000	Z99936-0.90255700	PS3WC1I 68.0631000
Z99939-0.00134410	Z99938 1.1565E-05	EMFFB1I 0.
Z99941 61.6686000	Z99940-0.34679800	ALPHA1I 40.9791000
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Z99948-1.32032000	Z99947 0.03114100	TABTR1I 0.
Z99952 991.809000	Z99951-23.0062000	QMAPL1I 0.
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Z99956 30.1020000	Z99955-0.13716900	P54LL1I 21.7097000
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Z99964 1504.69000	Z99963-0.47482500	T51PL1I 1416.04000
Z99967 2077.06000	Z99966-1.65186000	T4PL1I 1875.14000
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Z99981 0.25330300	Z99980-0.00837202	TMECH2IC 0.
Z99986 1.00001000	Z99985 0.	FUEL2IC 0.
Z99988 1.42467000	Z99987 0.02460360	EAPG2IC 1.00000000
Z99990 1.57249000	Z99989 0.00110030	EAPG1IC 1.00000000

Algebraic Variables

memon Block /ZZCOMU/

AFL1 0.17869200	AFRL1 0.17527800	ALPHA1 61.6686000
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ALPHAG2 20.7143000	ALPHAM1 18.4545000	ARLLG1I 0.31609000
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BASENG1 3600.00000	BASENG2 900.000000	BASENM1 150.000000
BASEQM1 949455.000	BASEVG1 4160.00000	BASEVG2 450.000000
BASEVM1 5000.00000	BETA11 2.20000000	BETAM1 2.20000000
BETAMINM1 1.57080000	BETAR1 1.06553000	CQLID1 2.8143E-05
CYL2 8.00000000	DELAY2 0.44939600	DELG1 0.22915800
DELG2 0.20836500	DELI1-0.31413500	DELM1-0.26819800
DELR1 0.29093500	DELTA2 1.00000000	DELV 1.0000E-04
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DNGG1 7845.95000	DNPT1 0.11062300	DNREF1 180.000000
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DT51HS1 0.71695700	DZ1 0.05000000	E01I 0.
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E51 7.91686000	E61 0.	E71 0.14398800
E81 0.	E91 0.74022600	EAFERRM1 1.1921E-05
EAFG1 1.57249000	EAFG1D 0.00110030	EAFG2 1.42467000
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EAFMAXG2 3.00000000	EAFMING1 0.	EAFMING2 0.
EAFSM1 1.71991000	EDPPG1D-0.00661310	EDPPG2D-0.00447765
EDPPM1D 0.00222434	EI1 0.75219300	EISM1 1.00000000
EMFFB1-0.00134410	EMFSAT1-1.1638E-04	ENGG1-1.1638E-04
ENPT1 7.20019000	ENPT1I 7.20000000	EPM1 1.50449000
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EQPPG1D 0.00174403	EQPPG2D 0.00102810	EQPPM1D-0.00164469
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FARG0 0	FARG1 1	FARG2 2
FARG3 3	FARGS0 0	FARGS1 1
FARGS2 2	FARGS3 3	FUEL2 0.30261300
FUEL2MAX 1.00000000	FUEL2MIN 0.	FUELAG2 0.05044990
G11 0.22000000	G31 0.50000000	G51 0.50000000
GBETAR1 30.0000000	GEAFG1 100.000000	GEAFG2 100.000000
GEAFM1 100.000000	GLARGE1 50.0000000	GM1 1.50000000
GSMALL1 5.00000000	GSPEED1 5.00000000	HG1 0.92400000
HG2 1.91000000	HHP5 0.51678100	HM1 1.28978000
HP1 5229.24000	HP1B 25000.0000	HP1D 5229.24000
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ICLIM1 70.0000000	ICNTRL1 0.01920150	ICNTRL1I 0.
ID1GR 1.00000000	IDBM1 0.	IDC1D-0.00367904
IDCBG2 0.49866500	IDCOM1 0.41686300	IDCR1 0.41686300
IDCR1D-0.00461753	IDCR1DMAX 5.00000000	IDCR1DMIN-5.00000000
IDCR1MAX 0.80000000	IDCR1MIN 0.	IDG1 0.33603800
IDG1IC 0.	IDG1M1 0.43871900	IDG2 0.26773500
IDG2ERR 0.	IDG2IC 0.	IDG2M1 0.49866500
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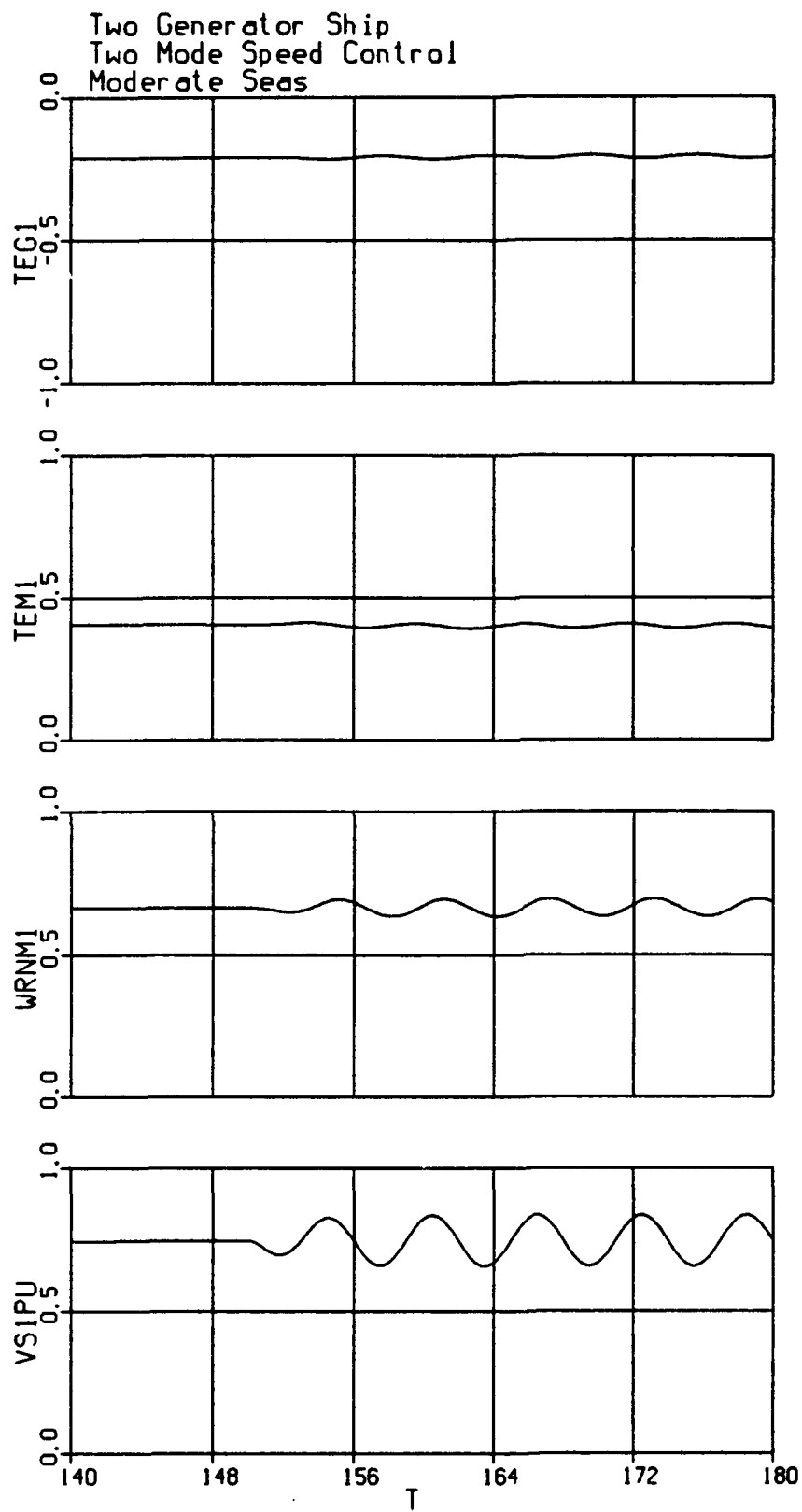
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 IQG2 0.20309600
 IQG2M1 0.37827200
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 JJG 16505.0000
 JJPT1 2171.50000
 K01RES 0.20233900
 K04RES-0.23175100
 K07RES-23.5963000
 K10RES-15.1637000
 KC11 0.50000000
 KGOV2 0.20000000
 KIG1M1 1.30556000
 KKWG1M1 1.08623000
 KQHP 5252.10000
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 KZG1M1 0.63727300
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 LHEADR F
 LPWRD1 F
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 MFKMV1 23.0000000
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 NGB 3600.00000
 NMAX2 950.000000
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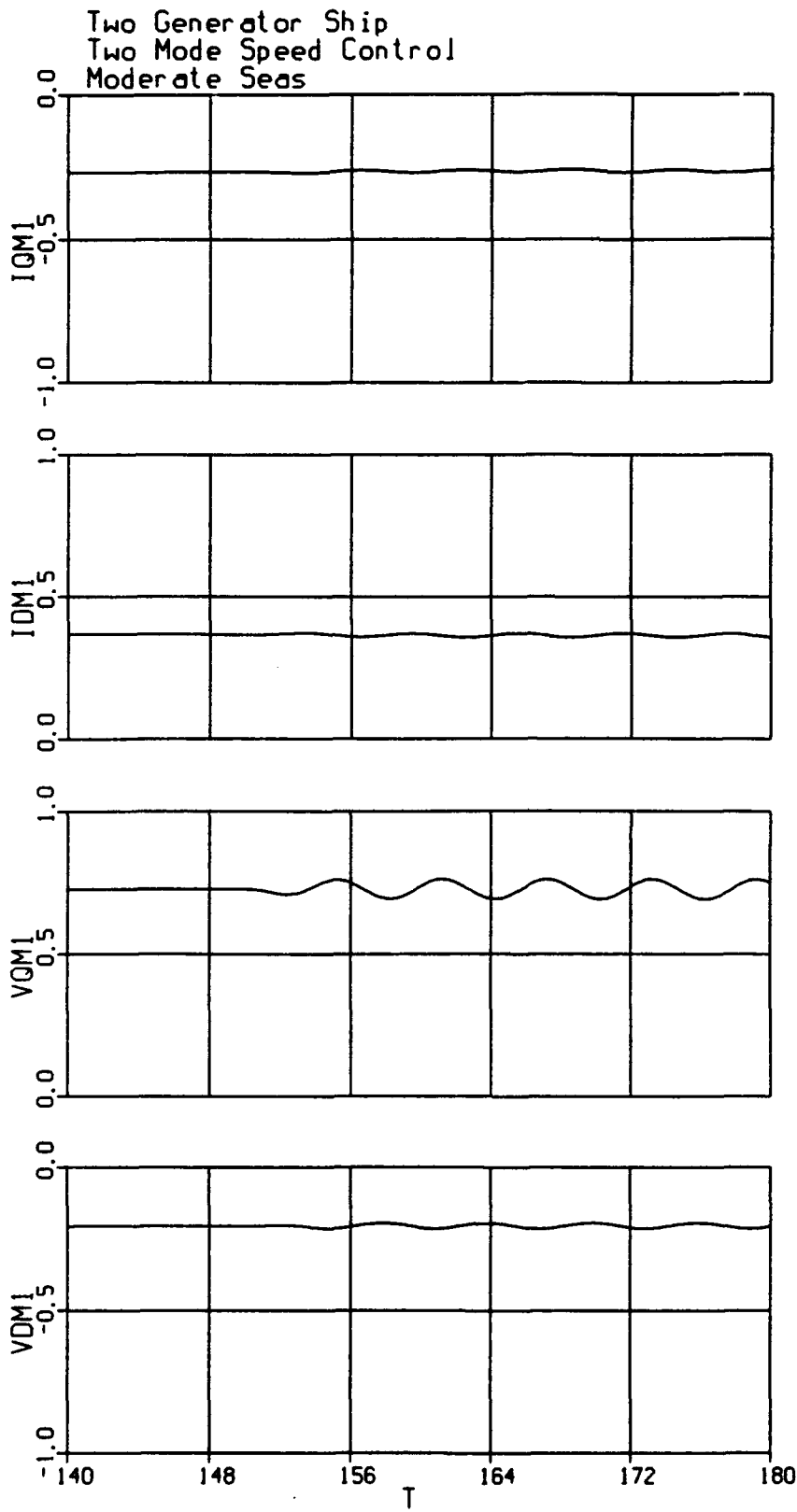
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VDI1-0.23242300	VDM1-0.20641900	VDR1 0.26519300
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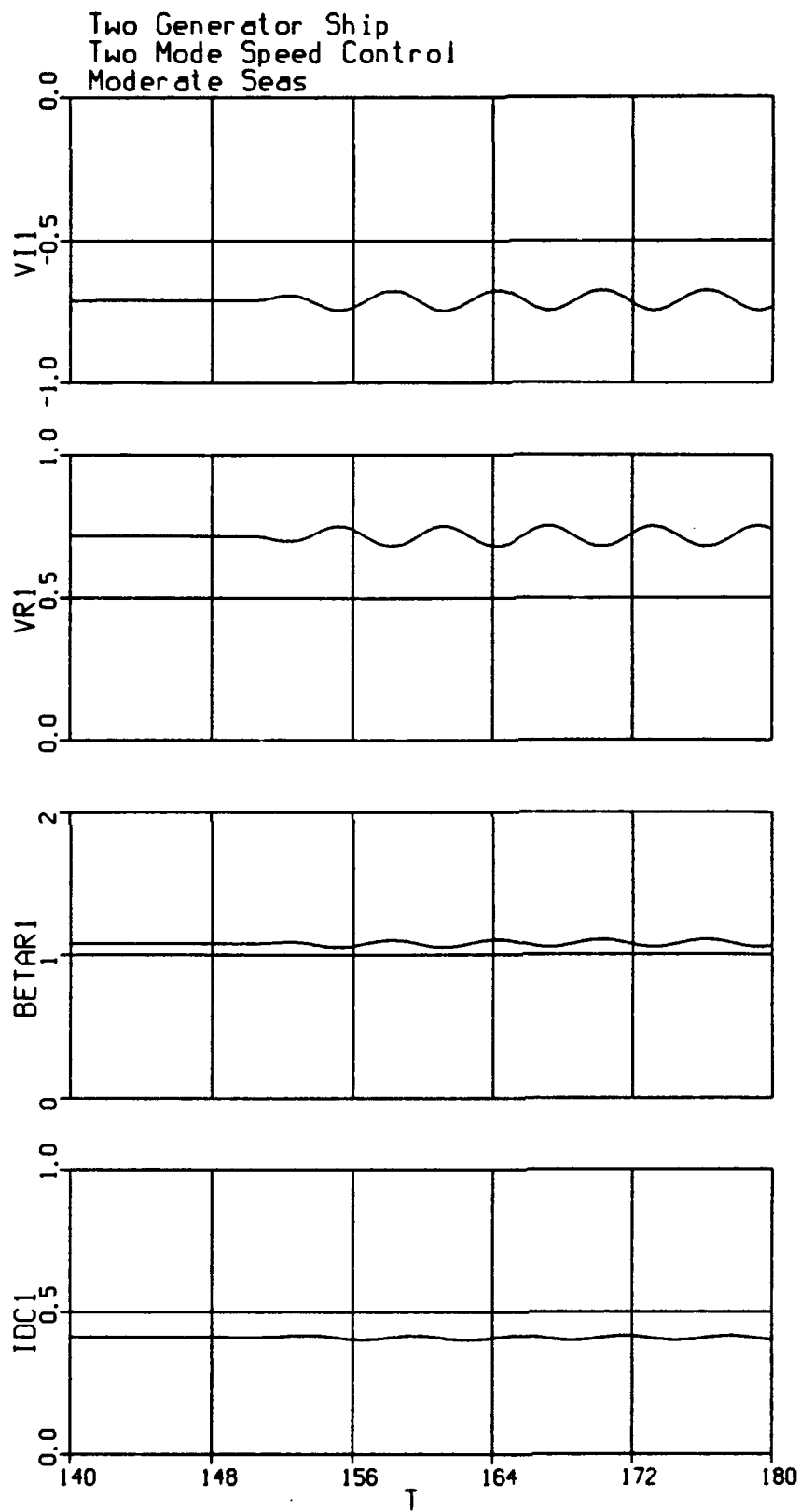
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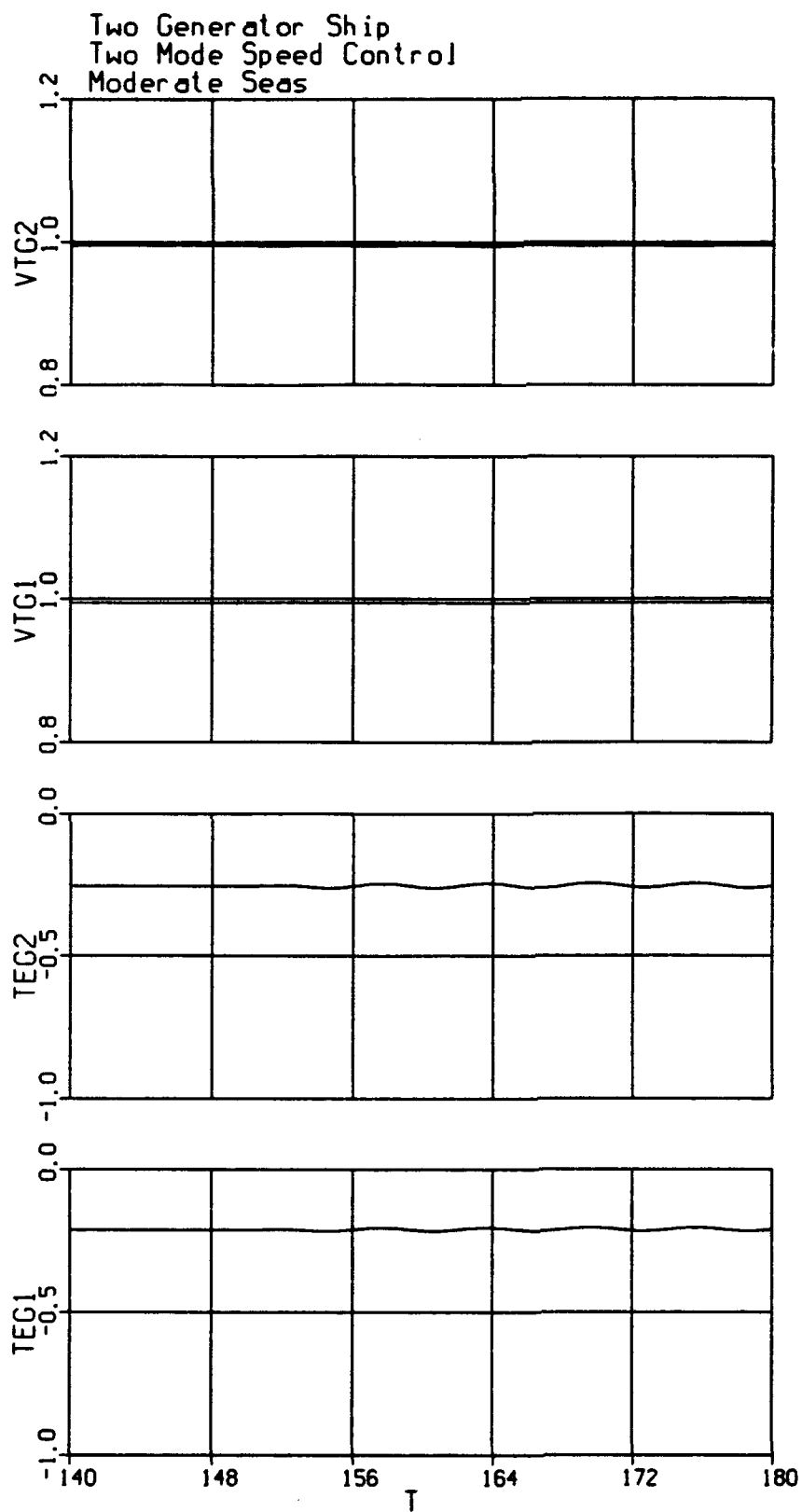
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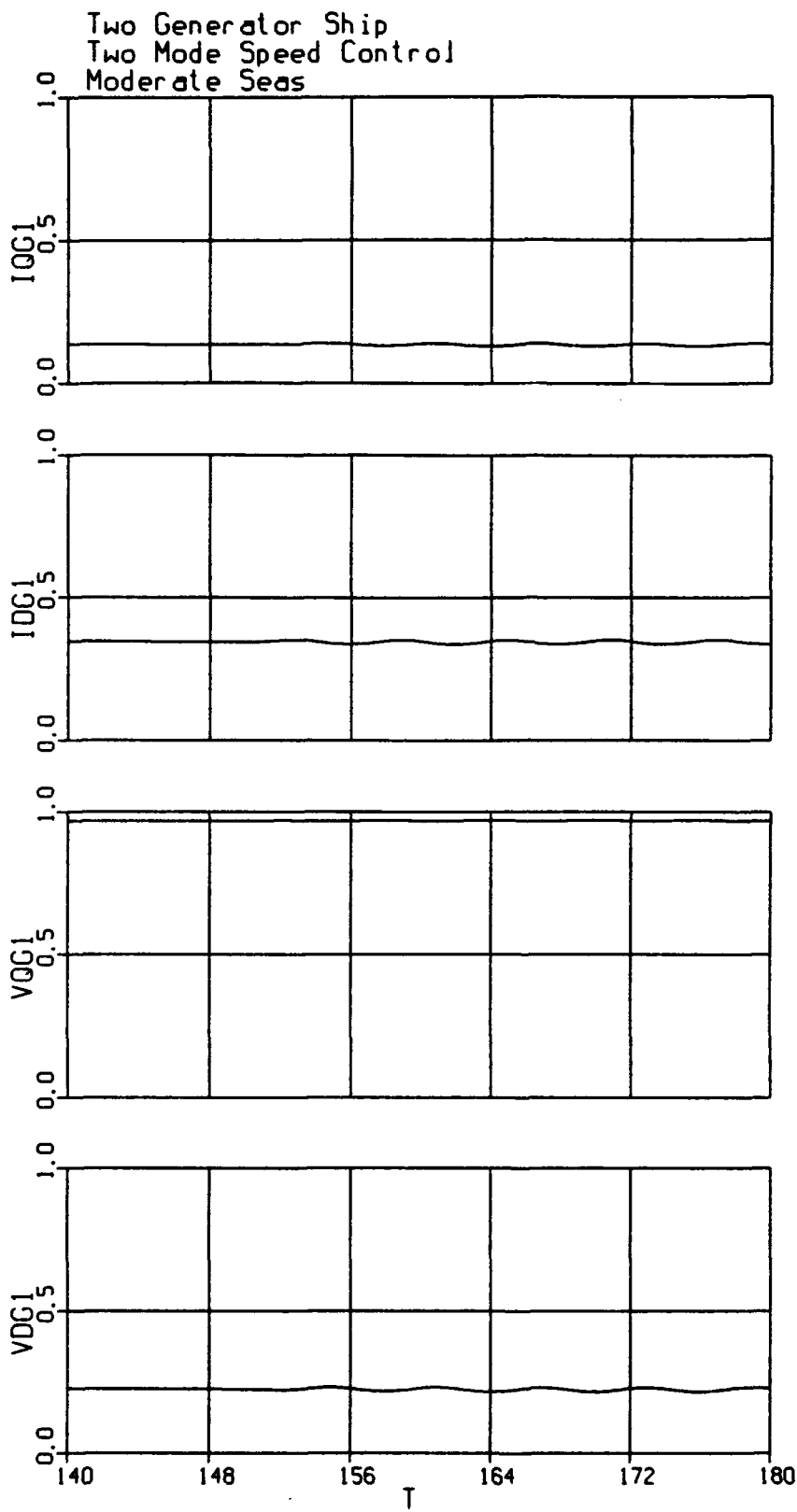
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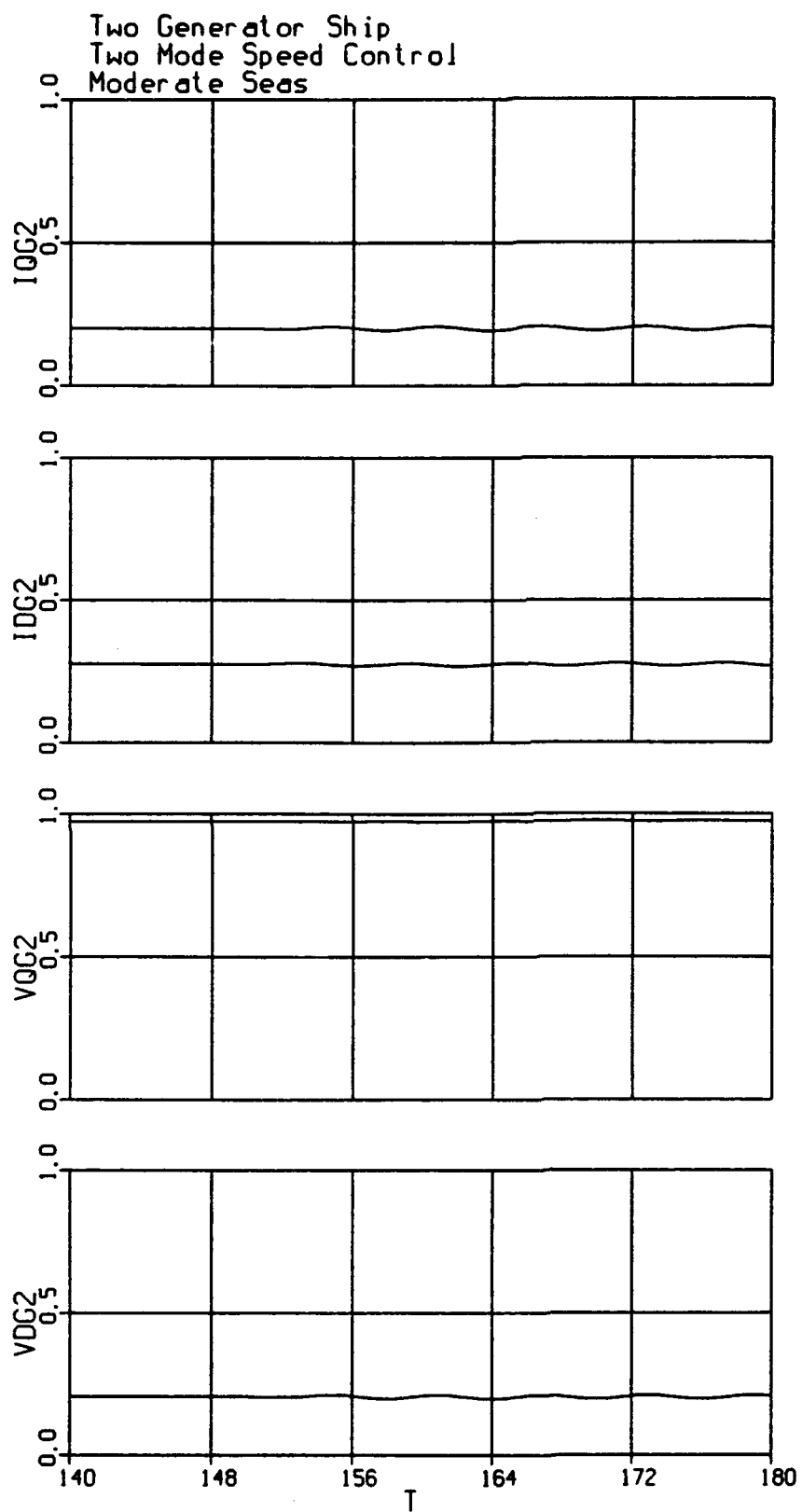
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D.4 Speed Change from 0.4 to 0.8 pu in Moderate Seas

Two mode control: steady at 0.8 pu speed setting

T 300.000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZNBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

State Variables	Derivatives	Initial Conditions
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EDPPM1-0.23521400	Z99930-0.00230476	EDPPM1IC 0.
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EQPG2 1.03287000	Z99991 3.2363E-04	EQPG2IC 1.00000000
EQPM1 0.99515600	Z99929-1.2311E-04	EQPM1IC 1.00000000
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EQPPG2 1.02243000	Z99993 3.8960E-04	EQPPG2IC 1.00000000
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Z99917 0.76386400	Z99916 0.00223154	VS1PUI 0.
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Z99924 0.35788100	Z99923-0.00278652	U1IC 0.99000000
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Algebraic Variables

Block /ZZCOMU/

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BASEQM1 949455.000	BASEVG1 450.000000	BASEVG2 4160.00000
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IDG2M1 0.45373000	IDL2 0.16303200	IDM1 0.48831600
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 P54R22I 21.3889000
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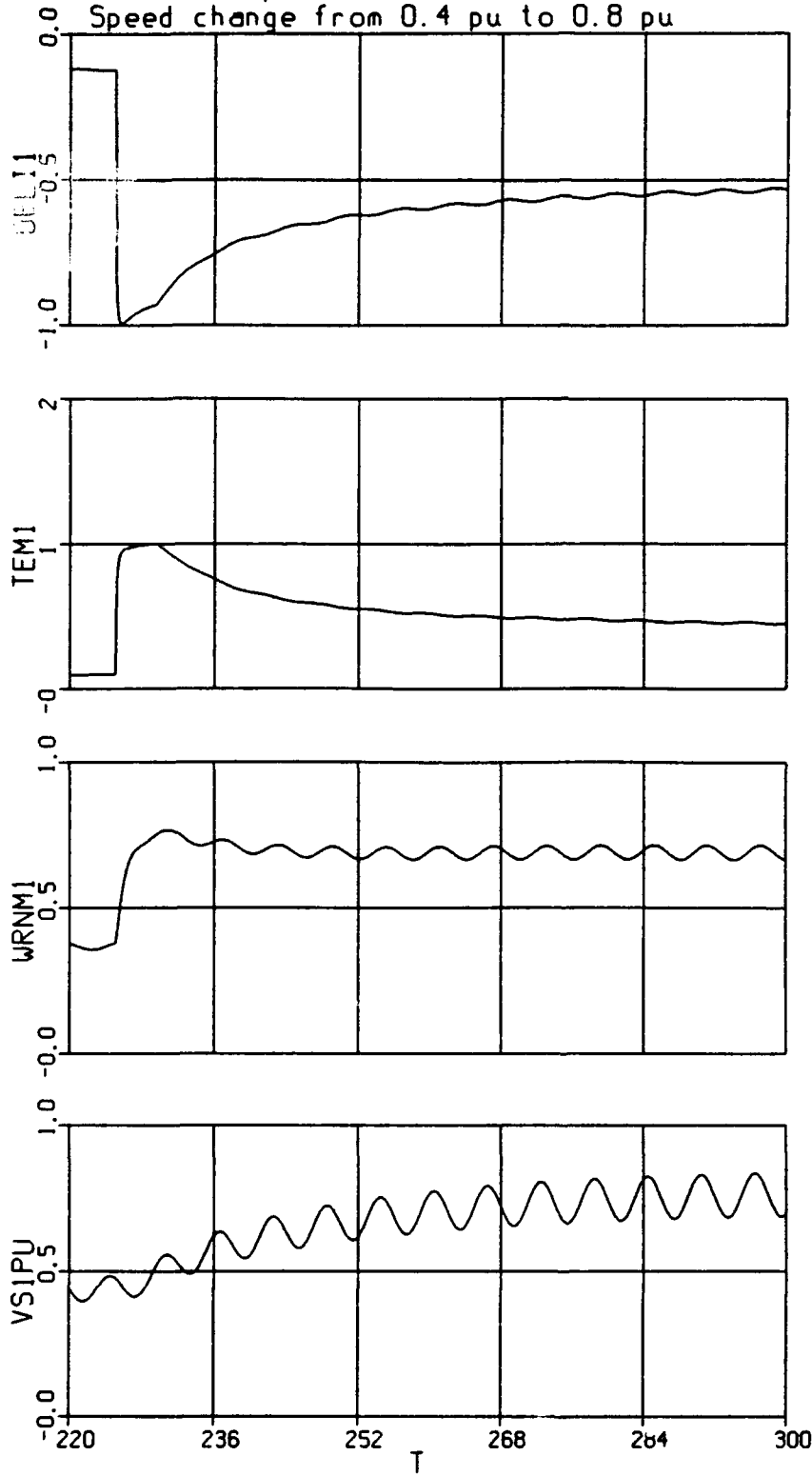
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TAUFAST1 0.10000000	TAUGOV1 2.00000000	TAUSLOW1 20.0000000
TAUSPEED1 20.0000000	TC12 3.00000000	TDOPG1 3.79000000
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TDOPPG2 0.04000000	TDOPPM1 0.03900000	TDT542(48) 99999.0000
Z99968(36) 68.3000000	Z99969(12) 99999.0000	TEG1-0.29958900
TEG2-0.20323500	TEG2IC 0.	TEM1 0.44879900
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Z99998(20) 950.000000	TMG1 0.29941200	TMM1-0.46256500
TMM2-0.46256500	TORQ1 0.29994900	TP1PU 0.44679500
TP1PUI 0.	TP2PU 0.44679500	TP2PUI 0.
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UMIN1 0.	VDBIC 0.	VDBUS 0.23362500
VDERR 0.	VDG1 0.21256500	VDG2 0.21639800
VDM1-0.27342400	VDR1 0.25524000	VERRG1 0.01715190
VERRG2 0.01585990	VI1-0.52486900	VN2 7.34400000
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VQG2 0.97030200	VQM1 0.46476400	VQR1 0.86853000
VQSF2 5000.00000	VR1 0.53585000	VR2 0.50000000
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VTREFG2 1.01000000	VTRQGS2 0.	W42 87.2843000
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WFSR22 5848.37000	WFUEL2 7113.40000	WFUEL2I 2185.21000
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 XDPM1 0.60800000
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 XQG1 1.01000000
 XQPPG1 0.28000000
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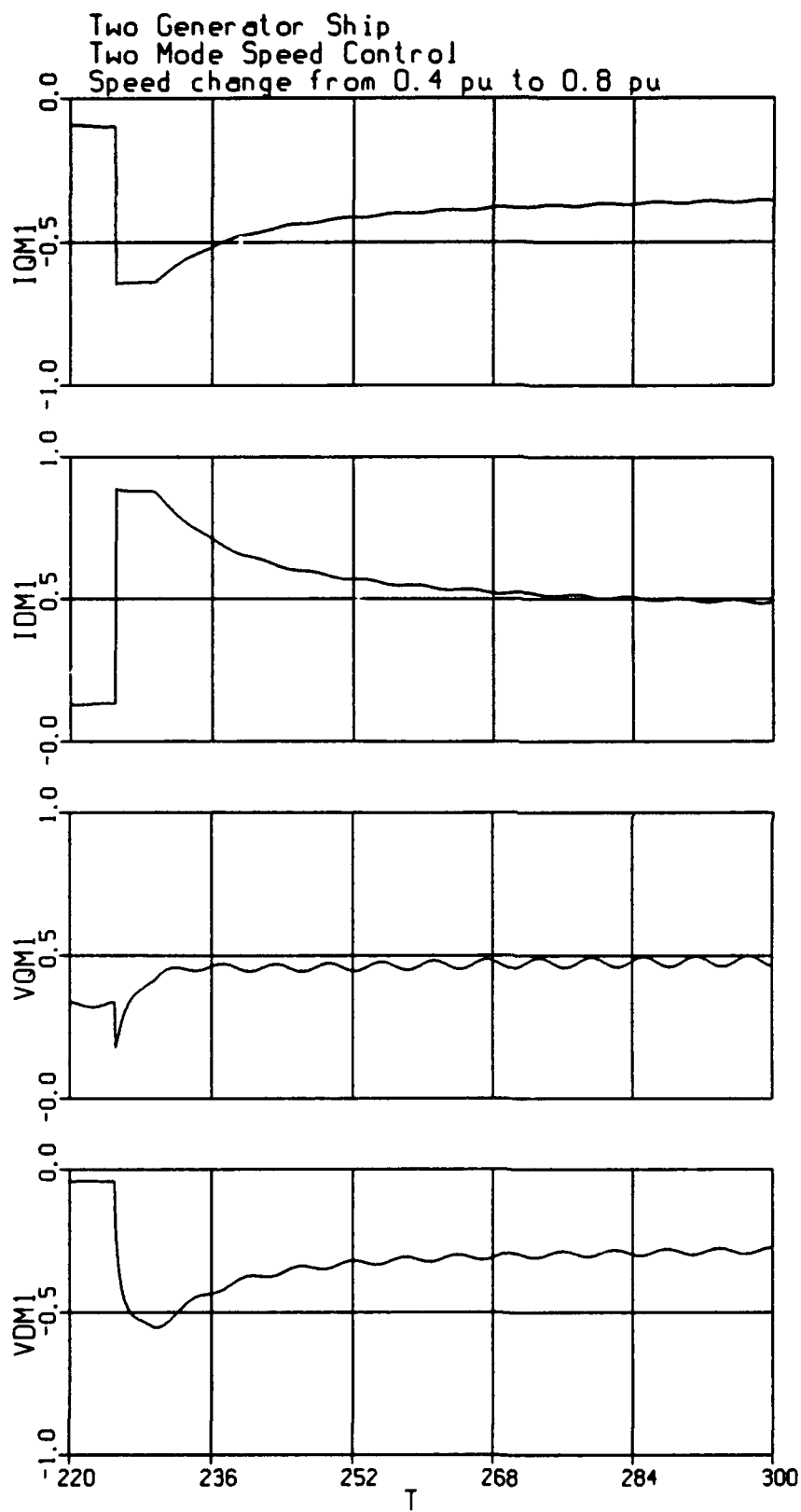
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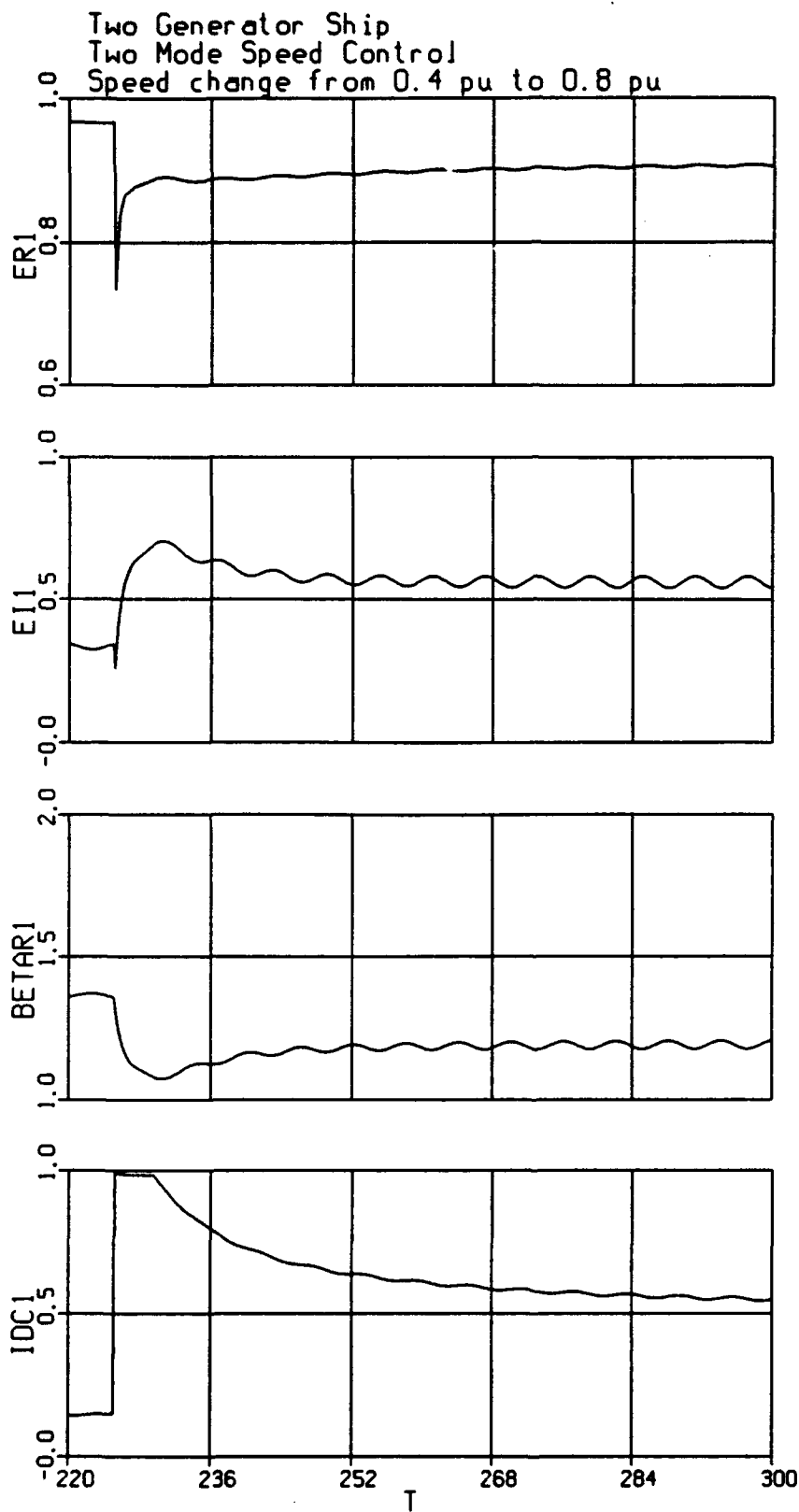
Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu



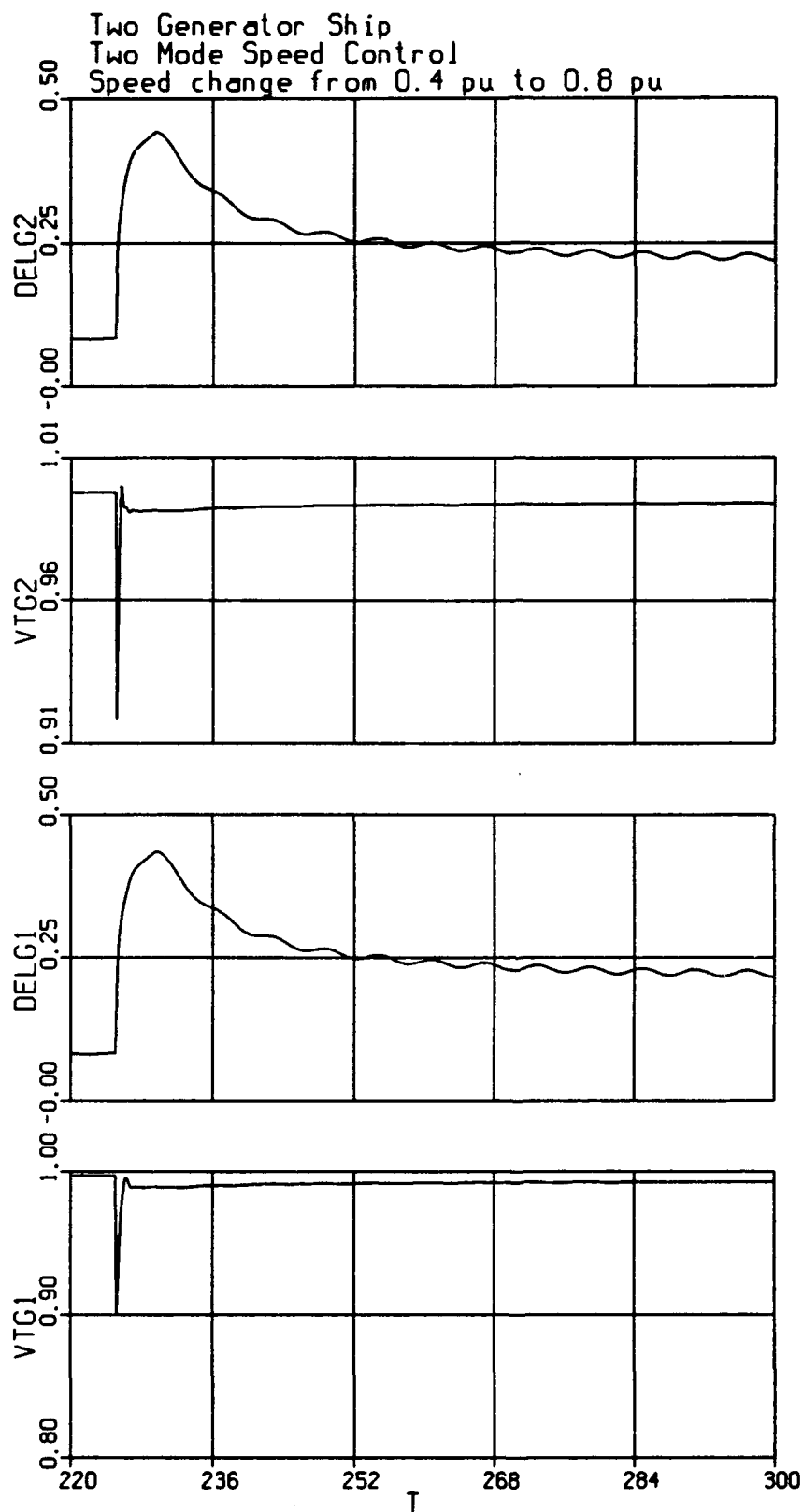
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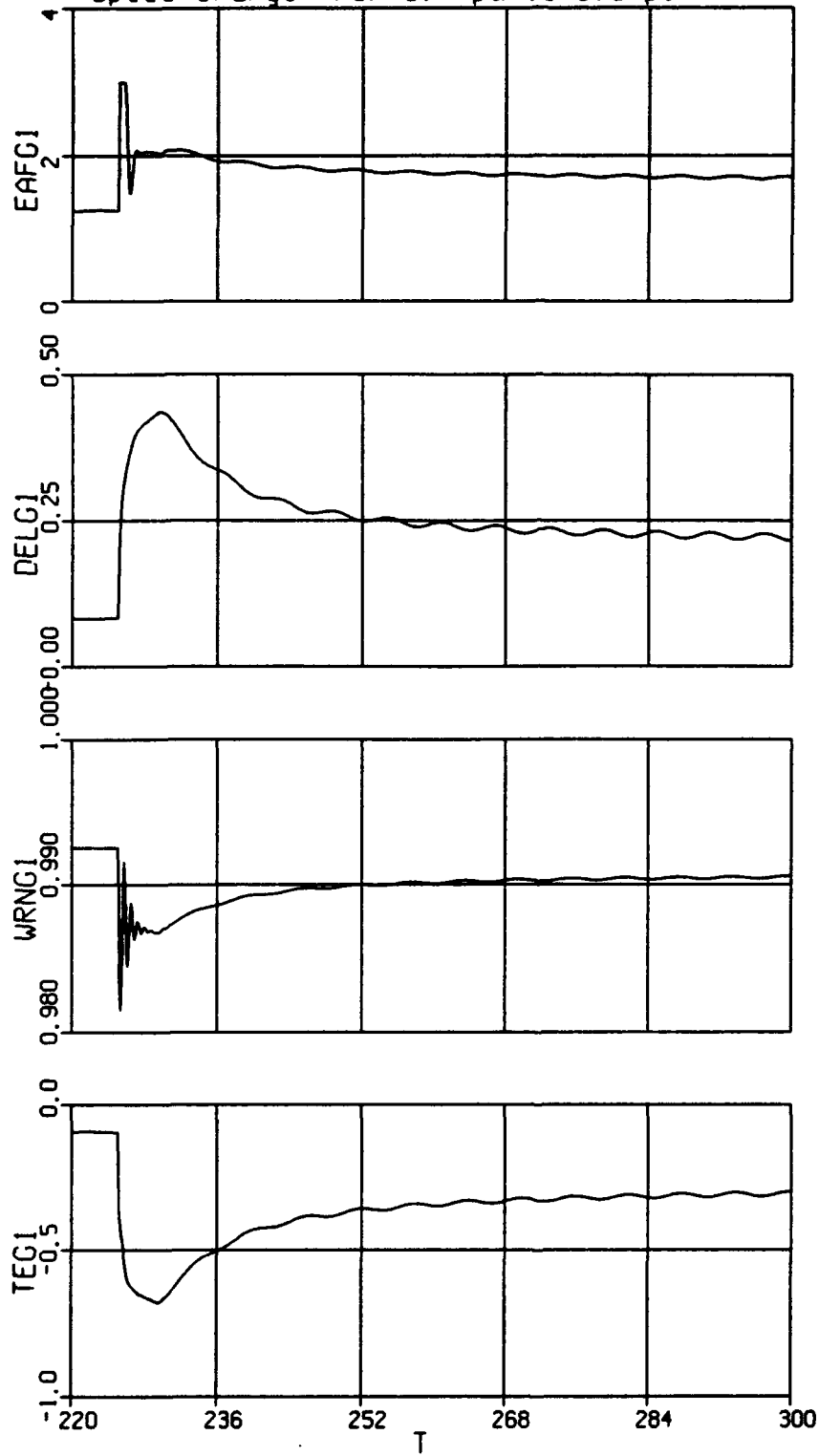


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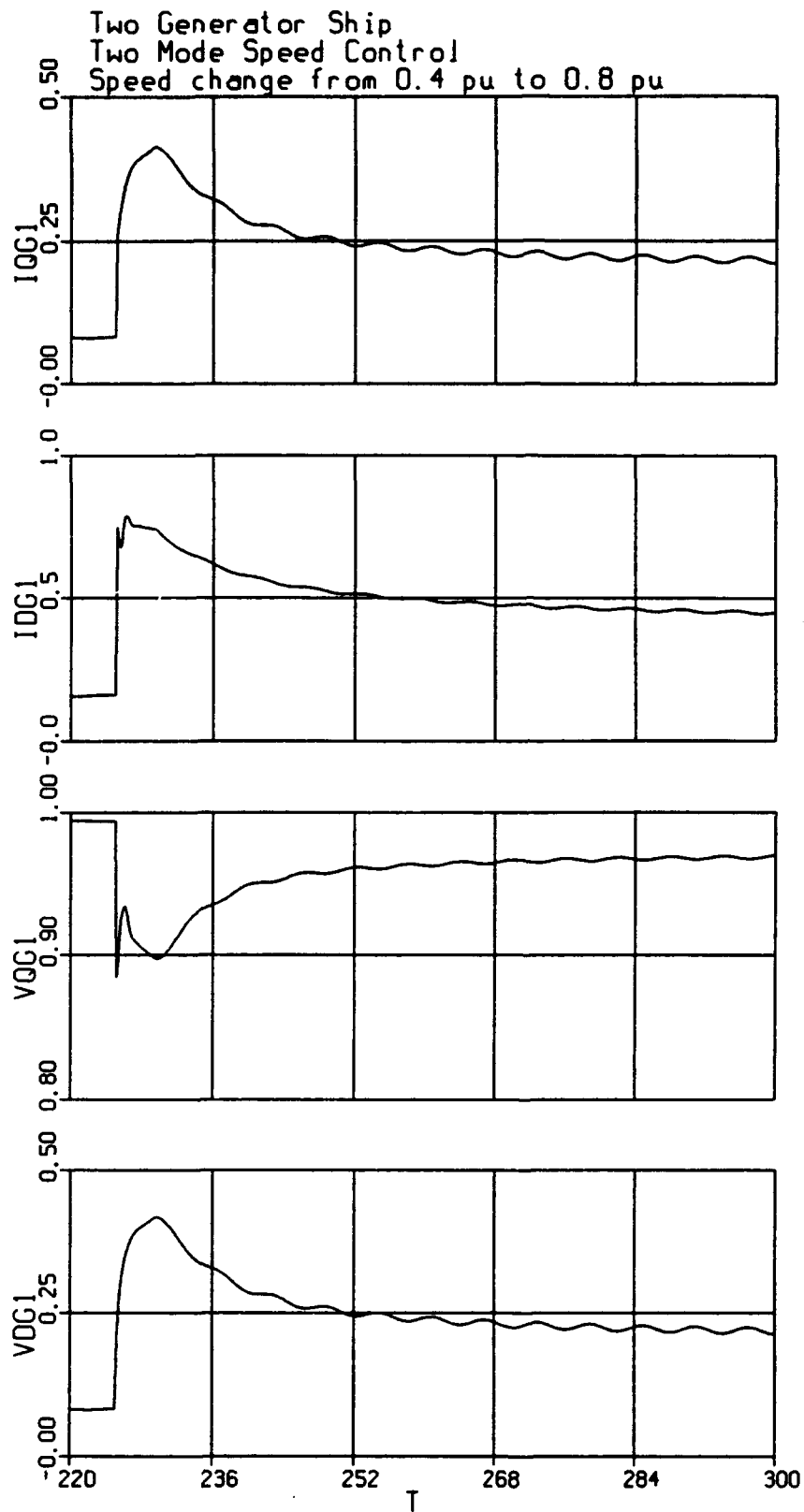


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Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu

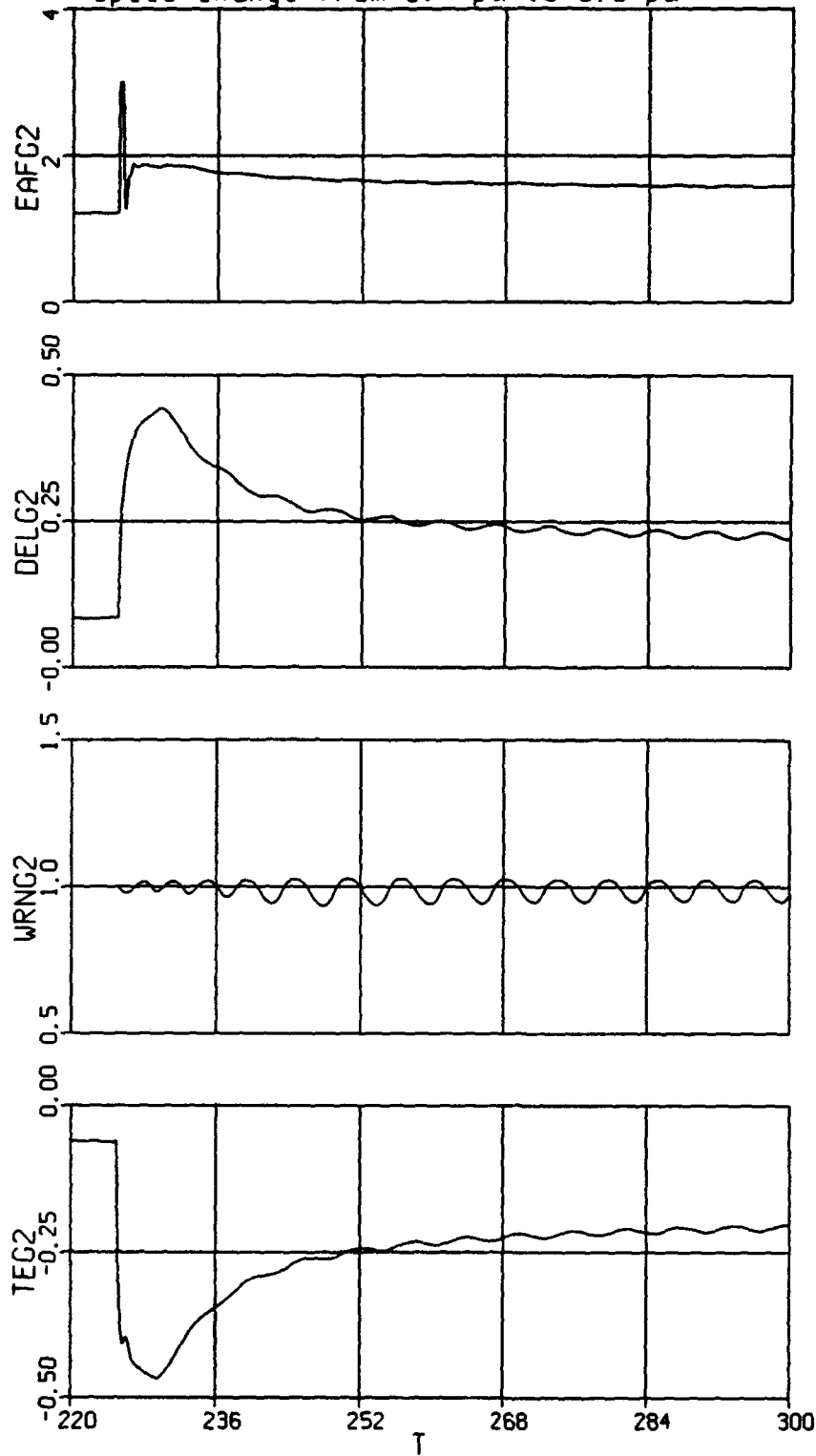


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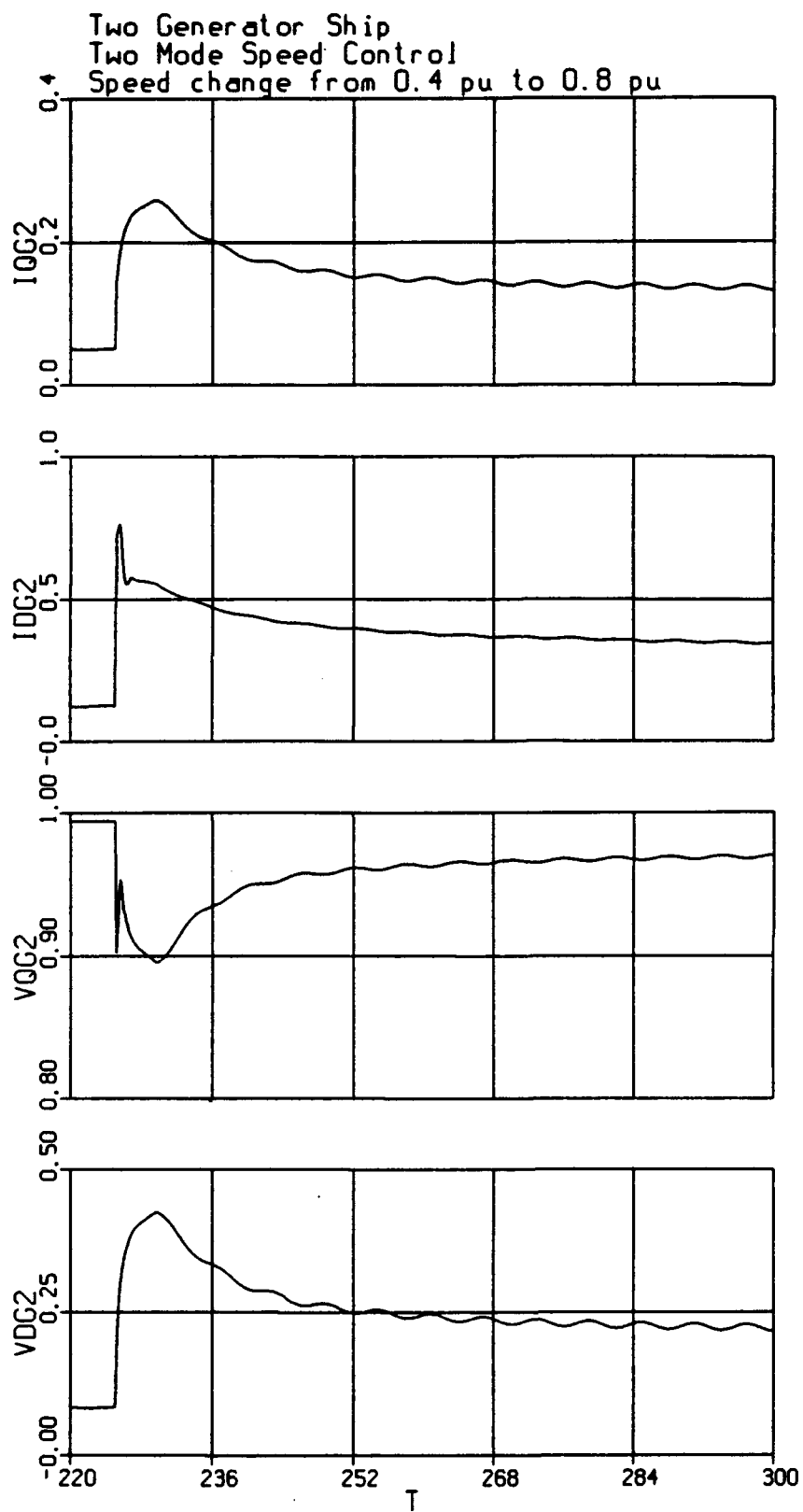


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Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu

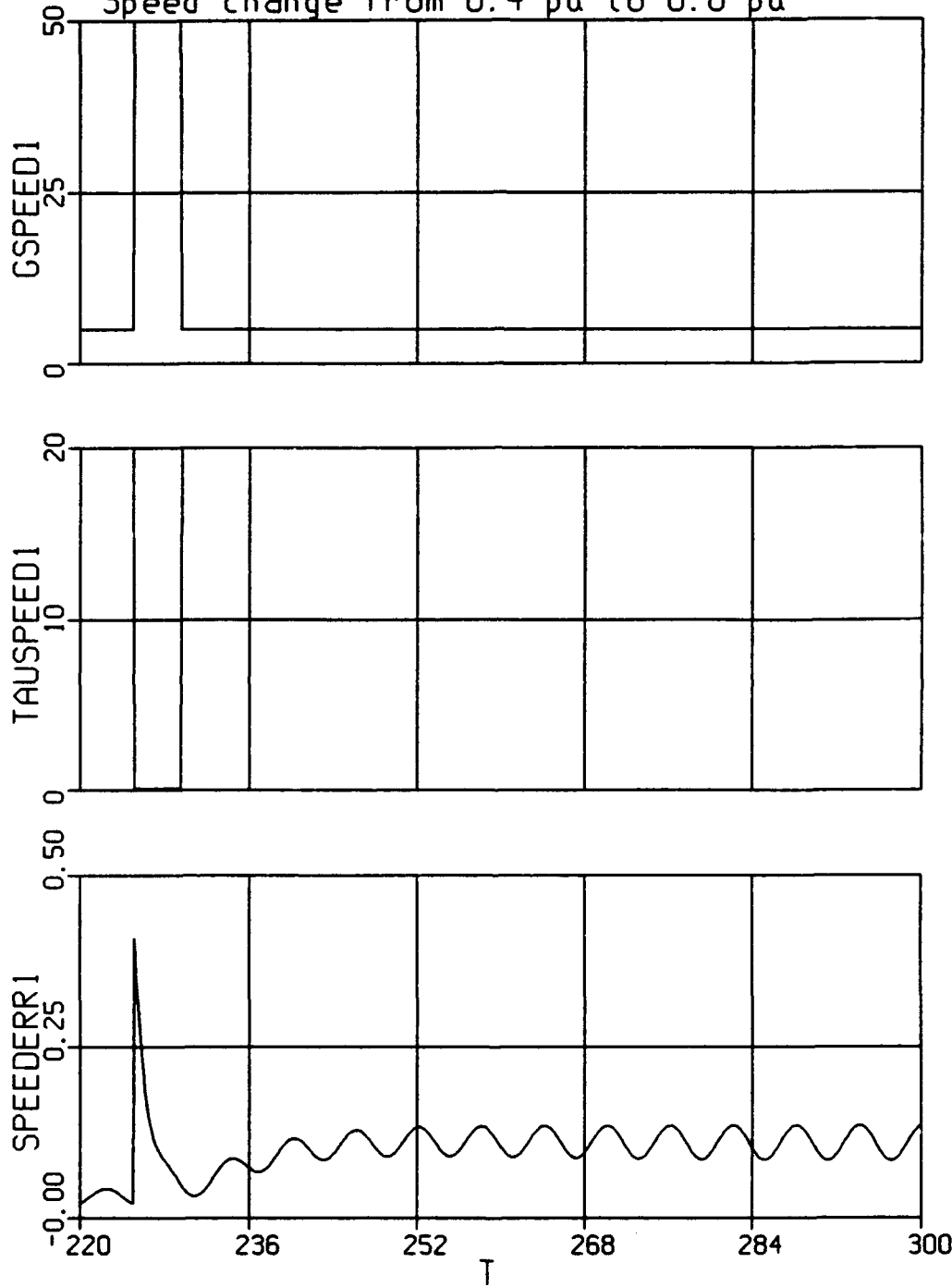


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12 93/04/16 15:10:03

Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu



17 93/04/16 15:10:03

D.5 Crashback

System #2: Crashback with constant betai

T 299.976000	ZETICG 0.	CINT 0.10000000
ZZIERR F	ZENBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

tate Variables	Derivatives	Initial Conditions
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EDPPM1 0.10099800	Z99930-6.2064E-04	EDPPM1IC 0.
ENPTL2 7.20000000	Z99942 0.	ENPTL2I 7.20000000
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EQPG2 1.03049000	Z99991-3.2982E-04	EQPG2IC 1.00000000
EQPM1 1.18300000	Z99929-0.00118243	EQPM1IC 1.00000000
EQPPG1 1.02296000	Z99996-1.0808E-04	EQPPG1IC 1.00000000
EQPPG2 1.02307000	Z99993-1.7520E-04	EQPPG2IC 1.00000000
EQPPM1 1.16925000	Z99931-0.00109473	EQPPM1IC 1.00000000
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NGG2 7660.91000	Z99965-1.02656000	NGG2I 7193.84000
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Z99919 0.24513500	Z99918-0.00144583	IDCR1IC 0.
Z99924 0.31979300	Z99923-5.6624E-04	ULIC 0.99000000
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Algebraic Variables

non Block /ZZCOMU/

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 BASEVM1 5000.00000
 BETAMINM1 1.57080000
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 DELR1 0.16948800
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 DQ4S2 1.09706000
 DRLLG2I 0.31609000
 DT51HS2 0.26799100
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 EMFFB2-1.2782E-04
 ENPT2 7.20000000
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 GEAFM1 100.000000
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 IDR1 0.24496900

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IQL2 0.18035400	IQM1 0.15215500	IQM1IC 0.
IQR1 0.08268140	JJG 16505.0000	JJPROP 1.3130E+06
JJPS 1.4790E+06	JJPT2 2171.50000	JJSHFT 166000.000
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KGC 32.1740000	KGOV1 0.20000000	KHOLDPI2 1.00000000
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LHEADR F	LHOLD2PI F	LNGG2A F
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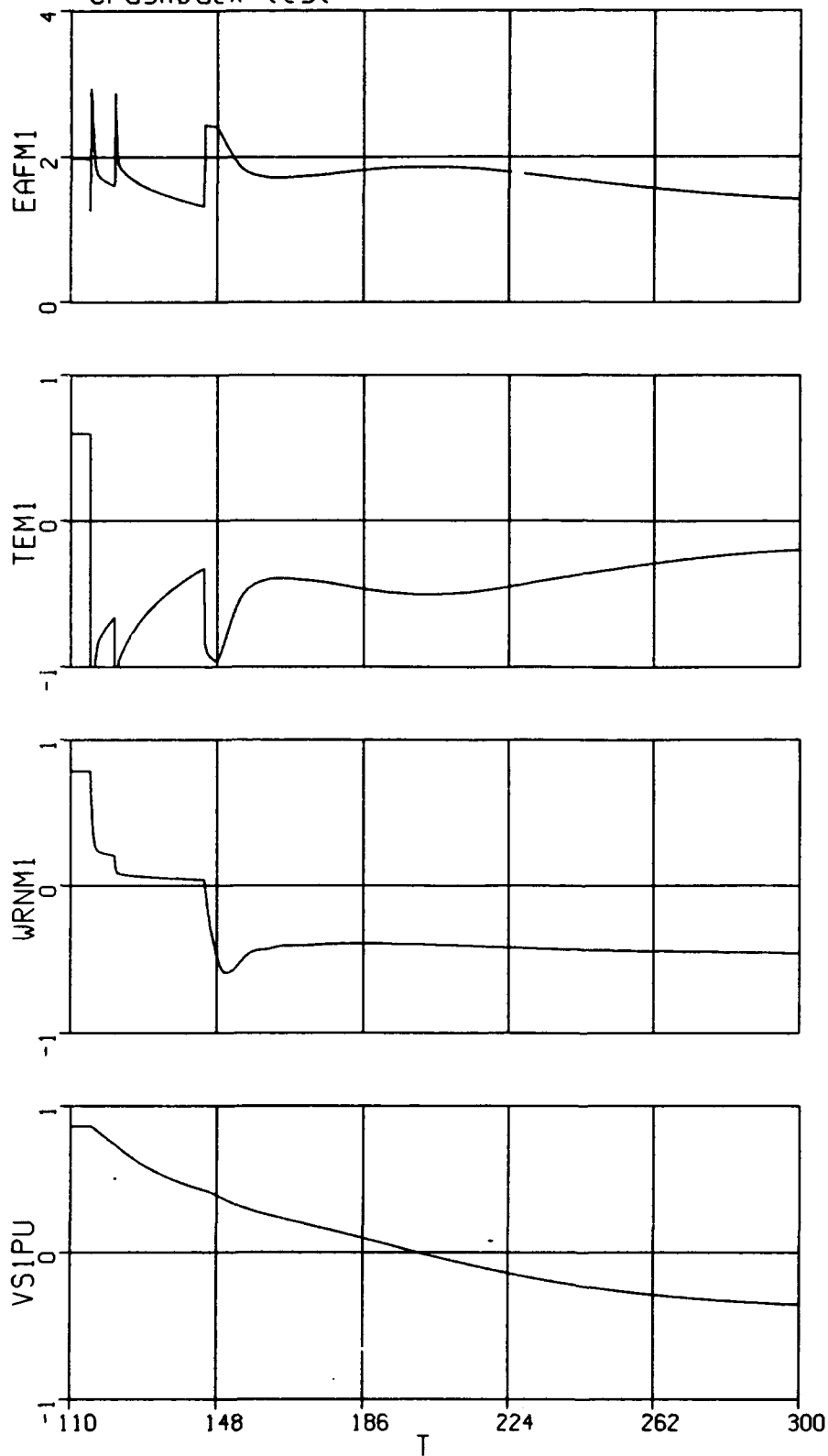
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 TIC2UL 113.500000
 TICN2-0.11594700
 TICRL2UL 22.5000000
 TMAP(116) 950.000000
 TMG1 0.14867200
 TORQ1 0.14840300
 TP2PU-0.15258000
 TQOPPG2 0.09000000
 TSTOP 300.000000
 TUT51H2 0.10642200
 U1D-5.6624E-04
 VDBIC 0.
 VDG1 0.12727000
 VDM1-0.08046350
 VERRG2 0.01421100
 VNSF2 500.000000
 VQBUS 0.95364400
 VQG2 0.98595200
 VQR1 0.92914800
 VR2 0.50000000
 VS1PU0 1.0000E-05
 VS1PU2 0.12584200
 VS1PU3I 0.
 VS1PU5-0.00561775
 VS1PU6I 0.
 VS1PU8 2.5078E-04
 VS1PU9I 0.
 VTG1 0.99703300
 VTOP2 0.
 VTRQGS2 0.
 W542 66.4302000
 WEFSEA 1.04720000

RS1PU2-0.05418350
 RS1PUI0 0.
 RS1PUI3 0.
 SEATIME 0.
 SPDERR1IC 0.
 SQRTH2 1.00000000
 T2 518.700000
 T4PL2 2018.35000
 T512 1480.52000
 T51Q2 1.00018000
 T542 971.106000
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 TAUEAFM1 0.05000000
 TAUSLOW1 20.0000000
 TDOPG1 3.79000000
 TDOPPG1 0.38000000
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 TEM1-0.19749300
 TGLAG2 7.20000000
 THETA2 1.00000000
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 Z99997(96) 0.92280000
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 TP2PUI 0.
 TQOPPM1 0.19300000
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 VDBUS 0.15073700
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 VDR1 0.15900500
 VI1-0.49391900
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 VQI1-0.50321700
 VQSF2 5000.00000
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 VS1PU2I 0.
 VS1PU4 0.01583620
 VS1PU5I 0.
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 VS1PU8I 0.
 VS1PU-0.35474200
 VTG2 0.99578900
 VTREFG1 1.01000000
 W42 59.3867000
 W54R22 66.4302000
 WESEA 0.

RS1PU3-0.07177810
 RS1PUI1 0.
 RS1PUI 0.
 SNEGVL2 0.
 SPDREF1-0.50000000
 SWITCHVAR1 0.05578500
 T42 2017.31000
 T4R22 2017.02000
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 T51R22 1480.25000
 TABTR12 0.63516400
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 TAUFAS1 0.10000000
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 TICMD2I 13.0000000
 TICRL2LL-89.0000000
 TICS2I 13.0000000
 Z99998(20) 950.000000
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 TP1PUI 0.
 TQOPPG1 0.19000000
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 VDERR 0.
 VDI1-0.06524800
 VERRG1 0.01296680
 VN2 7.34400000
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 VQG1 0.98887700
 VQM1-0.48231400
 VR1 0.49860200
 VRSF2 360.000000
 VS1PU10I 0.
 VS1PU3-0.04464140
 VS1PU4I 0.
 VS1PU6 0.00199285
 VS1PU7I 0.
 VS1PU9-8.8964E-05
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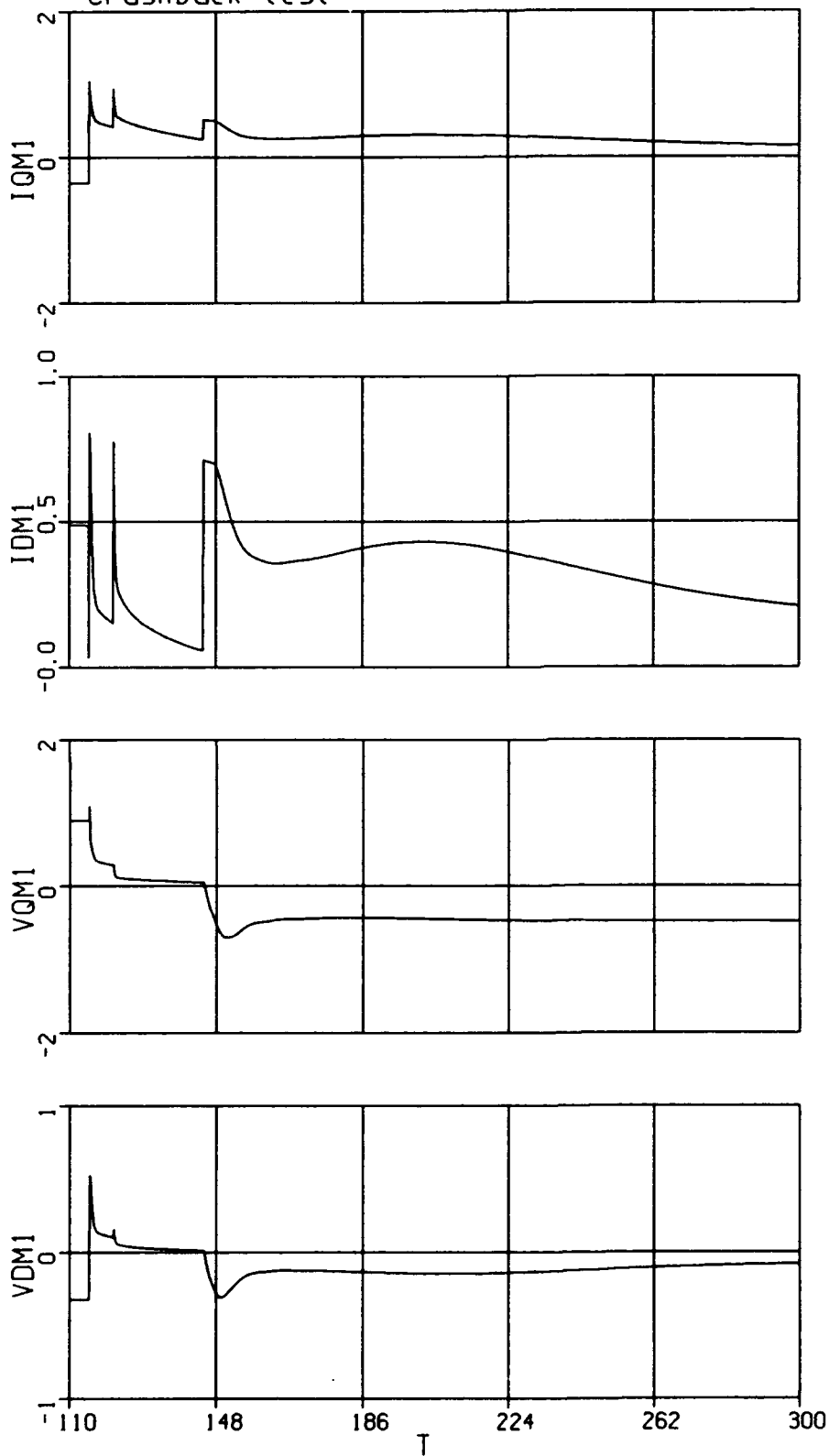
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WRNG2 1.00000000	WRNG2IC 1.00000000	WRNM1-0.45675600
WRNM2-0.45675600	XDC1 1.68000000	XDG1 1.63000000
XDG2 1.77000000	XDM1 1.76000000	XDMXQM1 0.60300000
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XDPPG1 0.18000000	XDPPG2 0.15000000	XDPPM1 0.54200000
XG1 0.10000000	XG2 0.10000000	XK3L2 2.20000000
XL1 0.10000000	XLG1 0.07500000	XLG2 0.13000000
XLM1 0.33700000	XM1 0.10000000	XMV2 0.40944900
XQG1 1.01000000	XQG2 1.64000000	XQM1 1.15700000
XQPPG1 0.28000000	XQPPG2 0.15000000	XQPPM1 0.49400000
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Z99887 0.32301700	Z99888 0.32311900	Z99889 0.32307100
Z99891 1	Z99892 0.11112400	Z99893-1.13941000
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Z99898 1	Z99899 0.94822400	Z99900-0.91074800
Z99901 0.95364500	Z99902 0.95354900	Z99903 0.95361000
Z99905 1	Z99906 0.15073700	Z99907-1.17095000
Z99908 0.15071000	Z99909 0.15075900	Z99910 0.15072900
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Two Generator Ship
Two Mode Speed Control
Crashback test



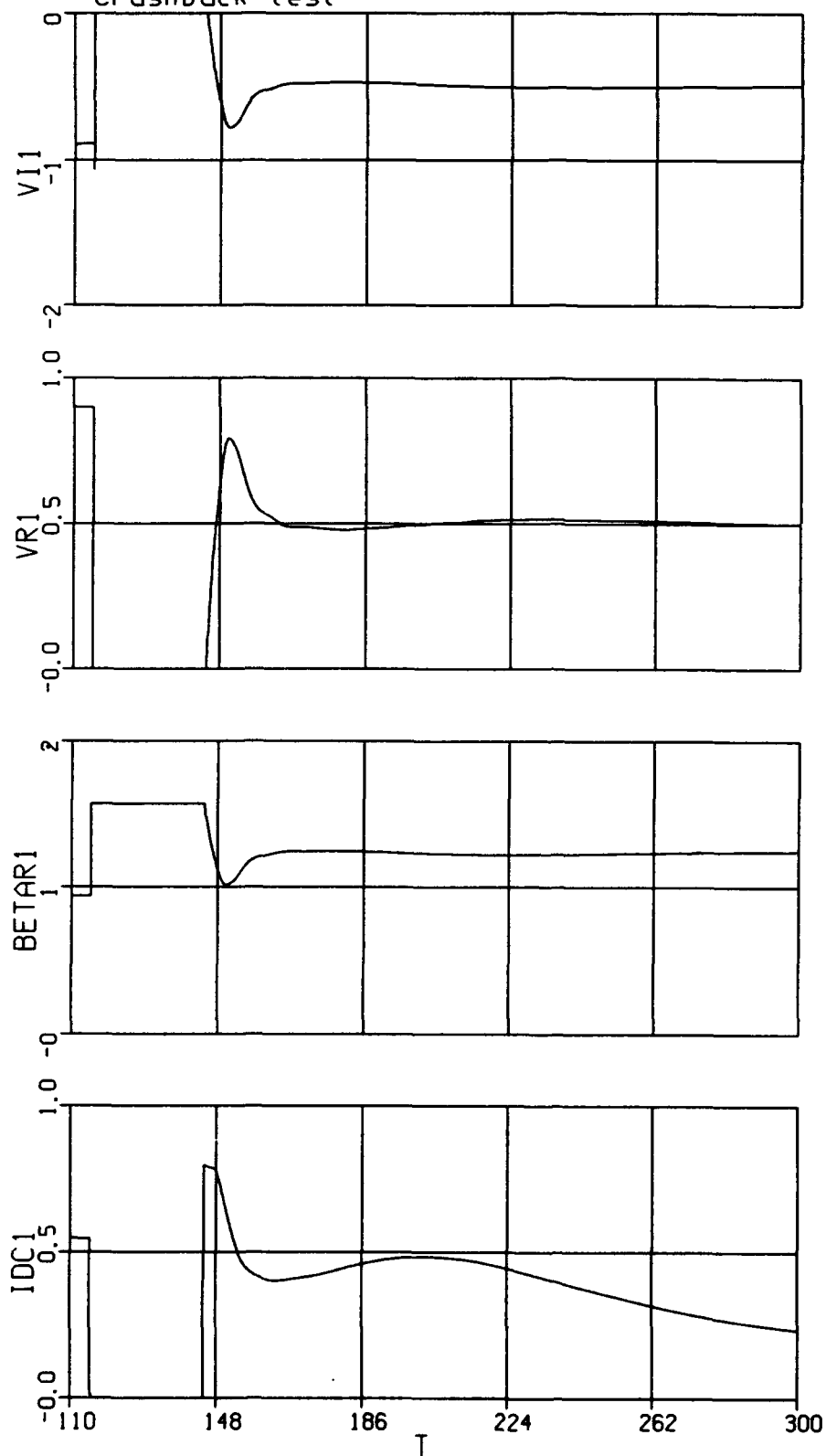
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Two Generator Ship
Two Mode Speed Control
Crashback test



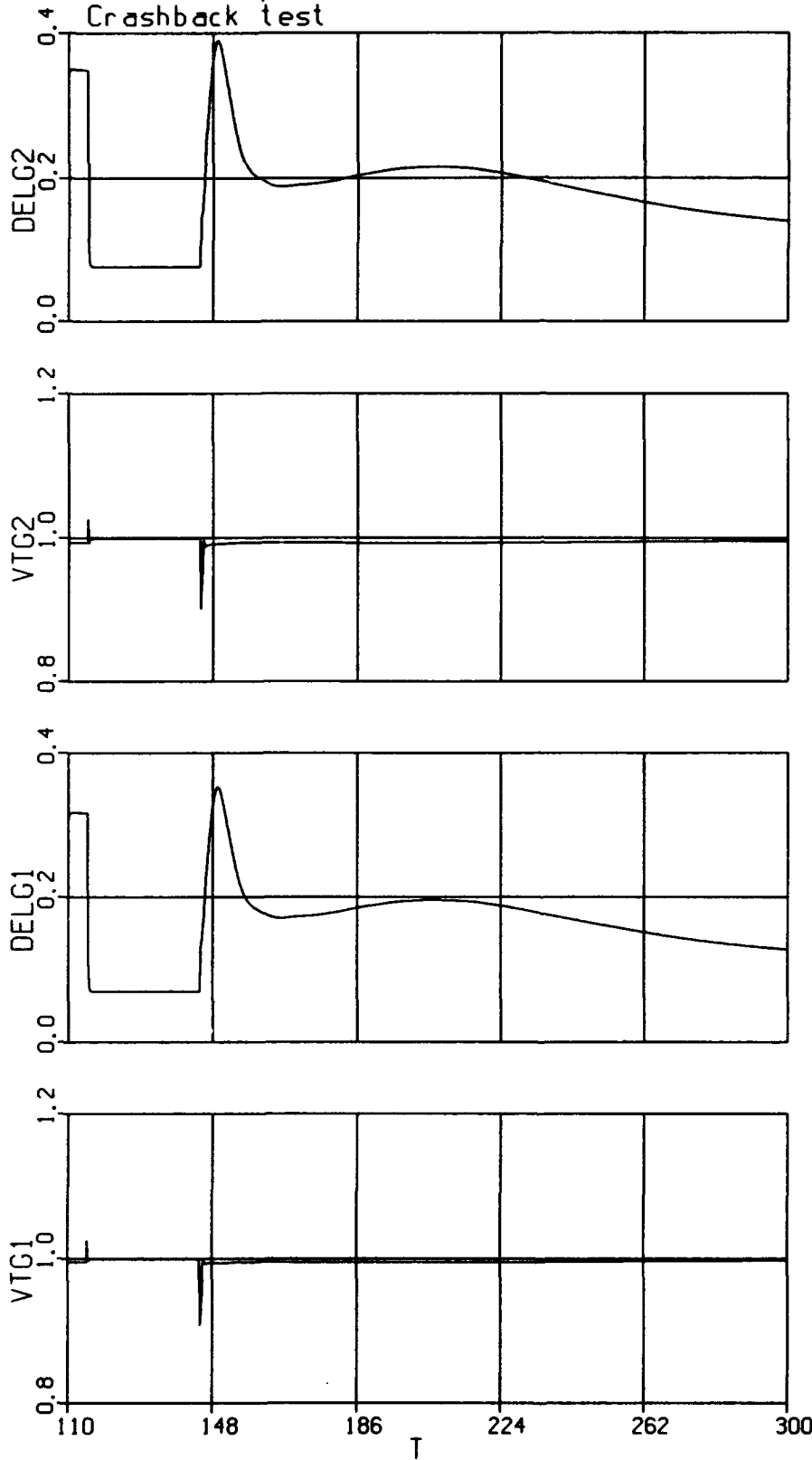
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Two Generator Ship
Two Mode Speed Control
Crashback test



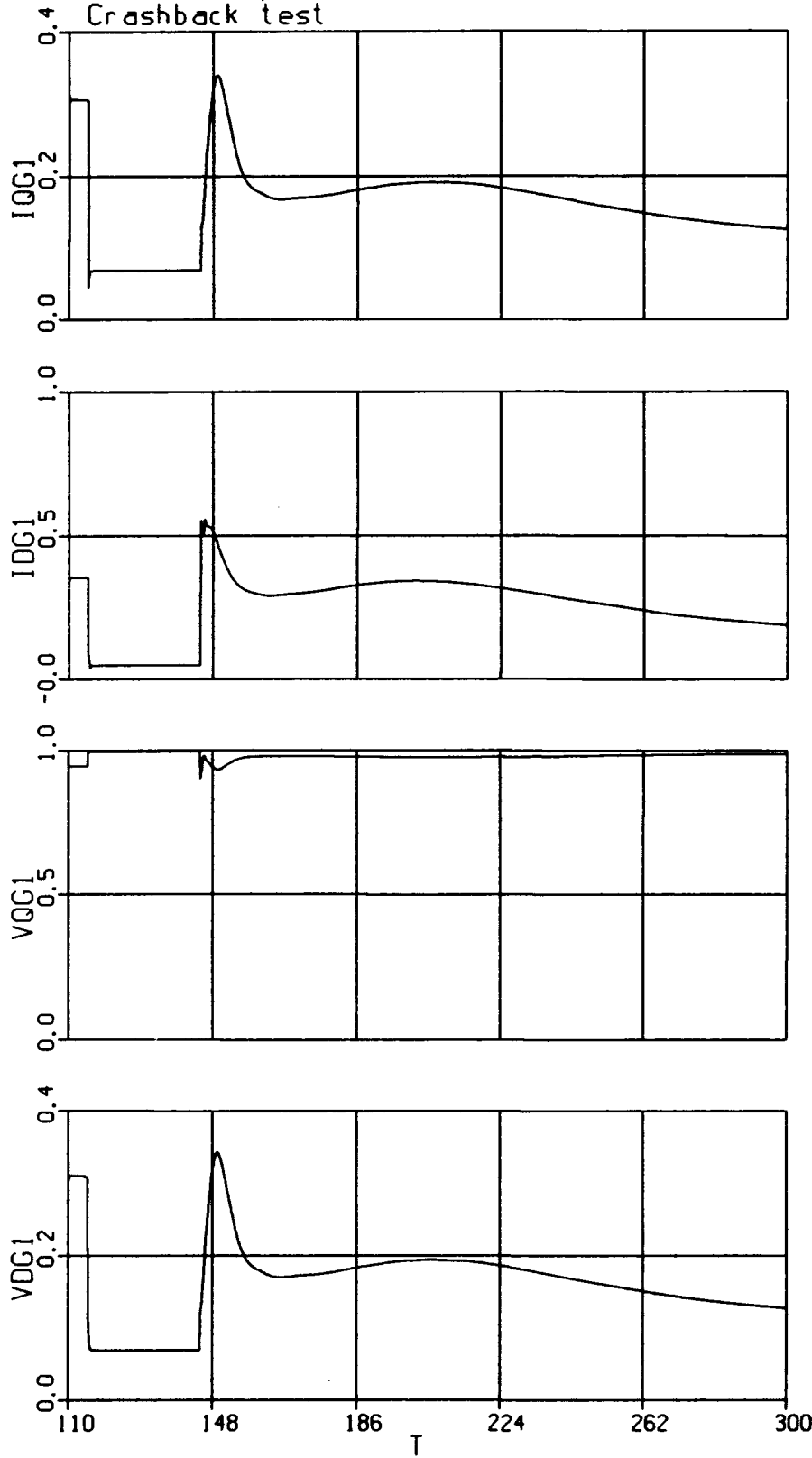
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Two Generator Ship
Two Mode Speed Control
Crashback test



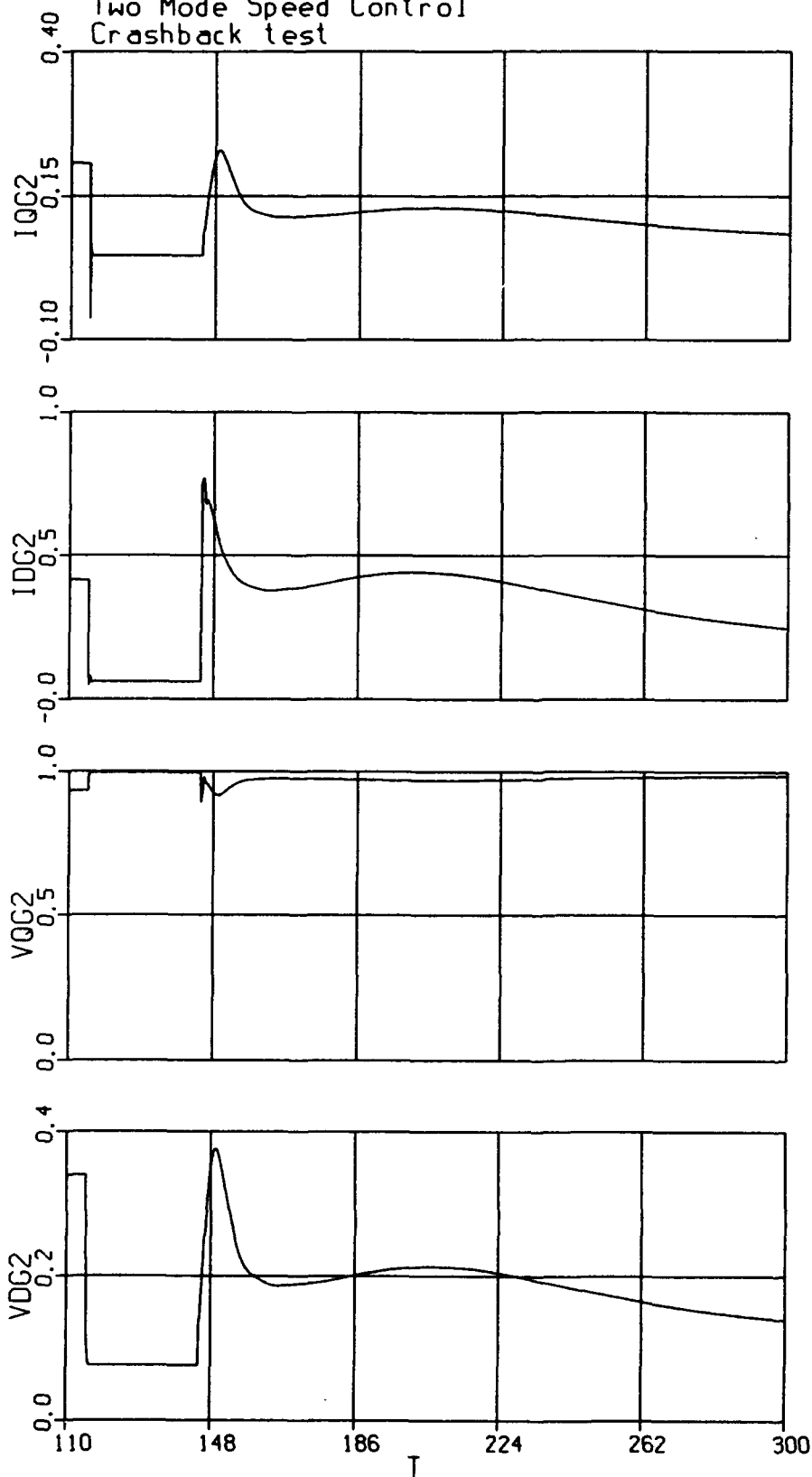
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Two Generator Ship
Two Mode Speed Control
Crashback test



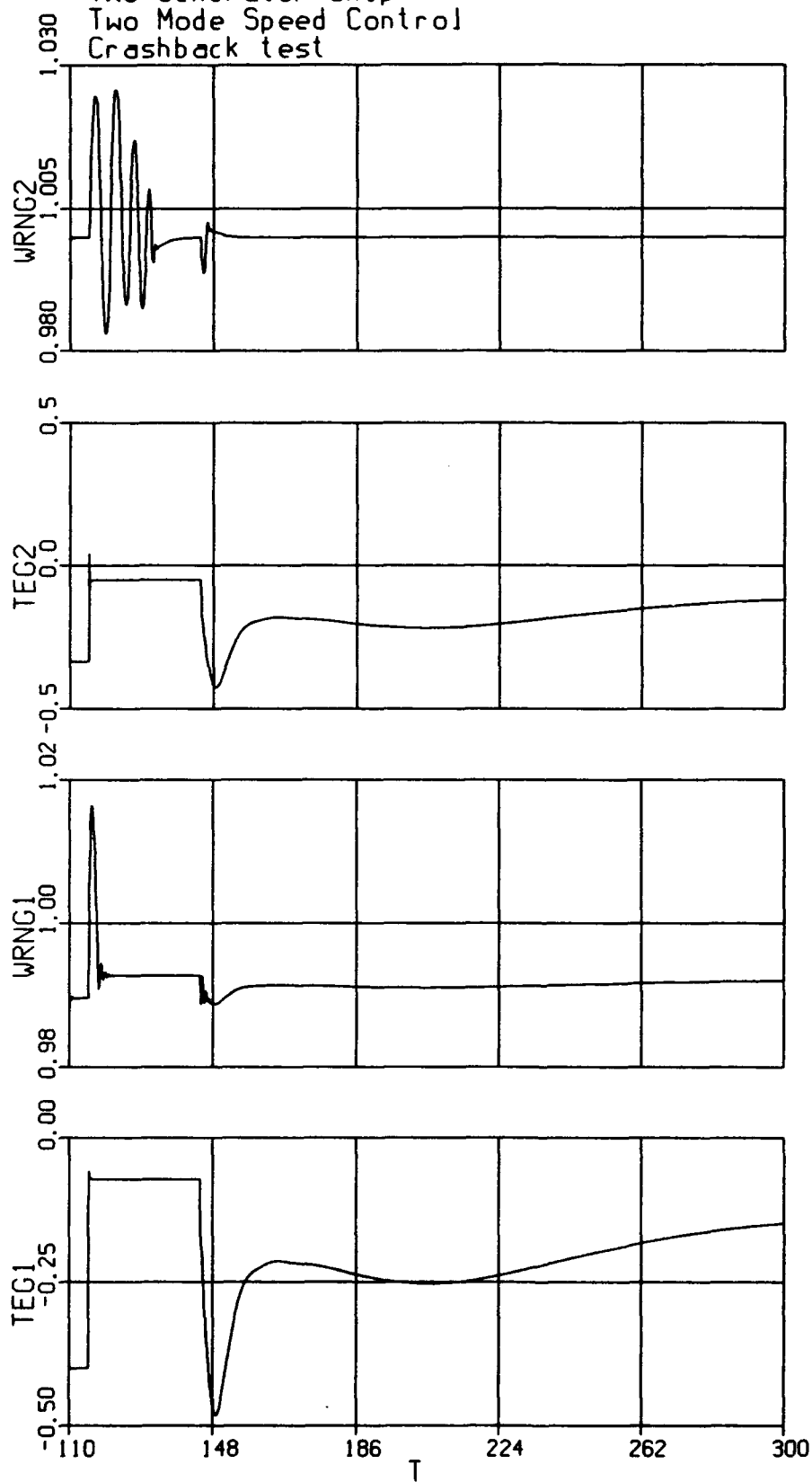
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Two Generator Ship
Two Mode Speed Control
Crashback test



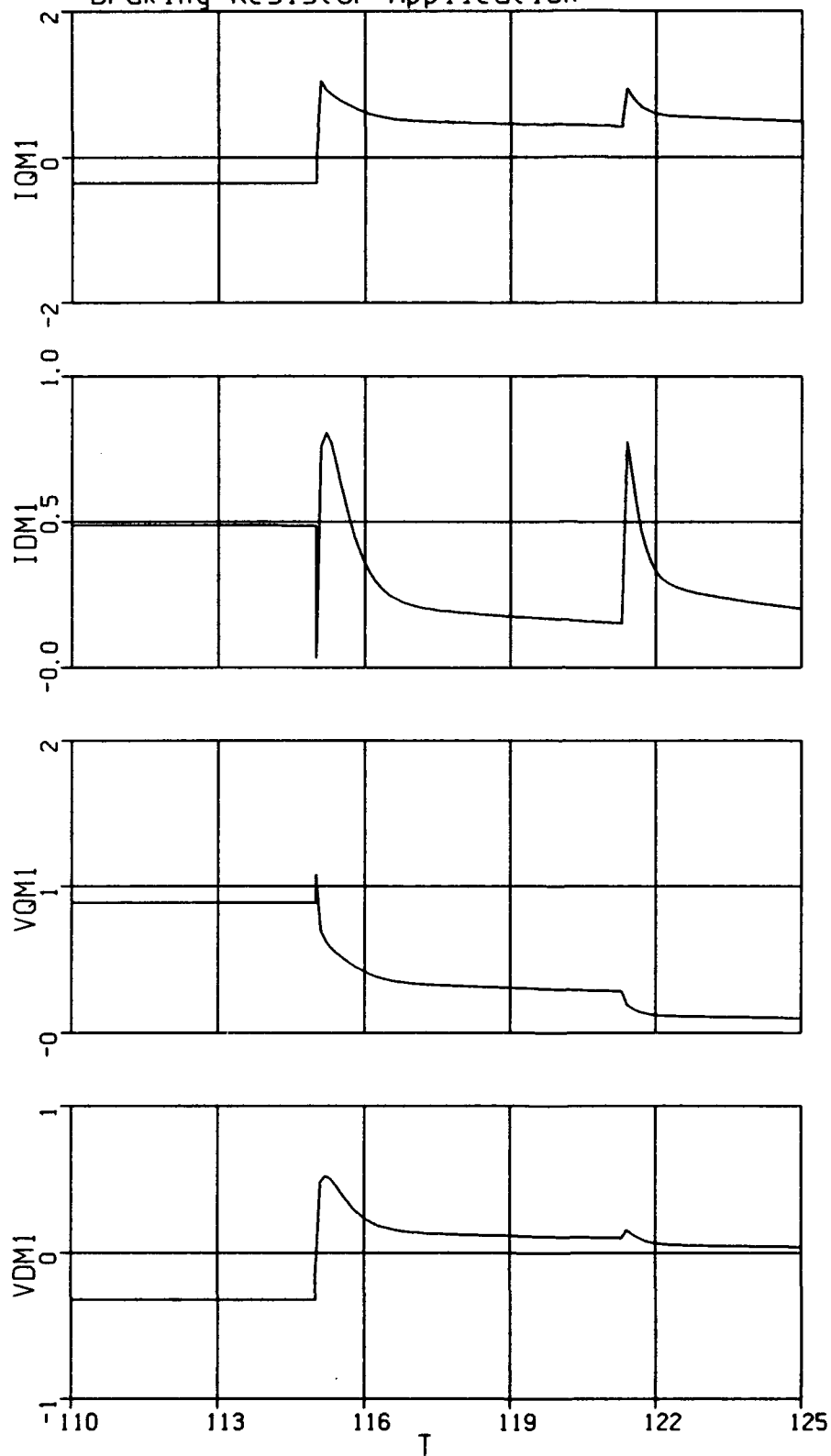
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Two Generator Ship
Two Mode Speed Control
Crashback test



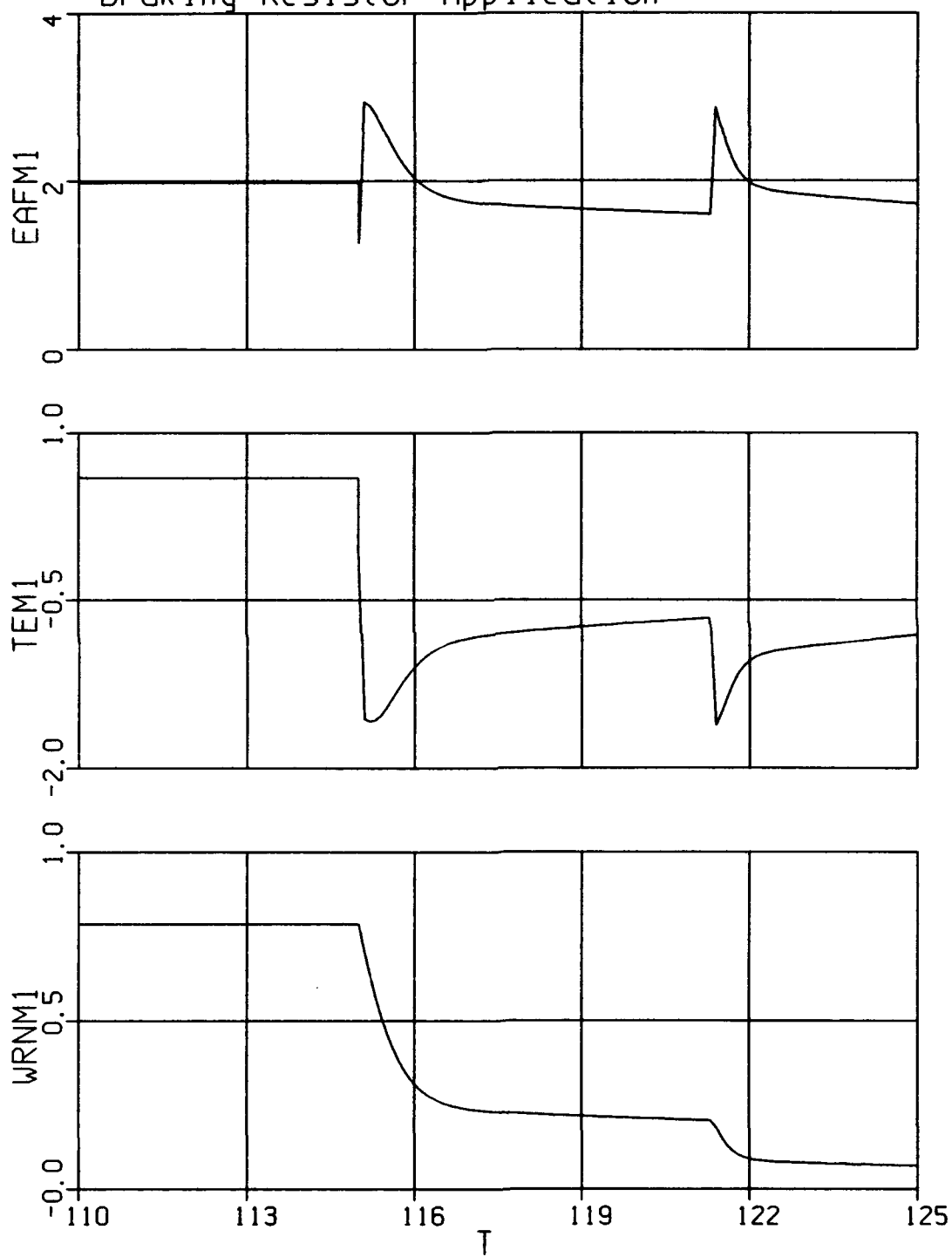
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Two Generator Ship
Two Mode Speed Control
Braking Resistor Application



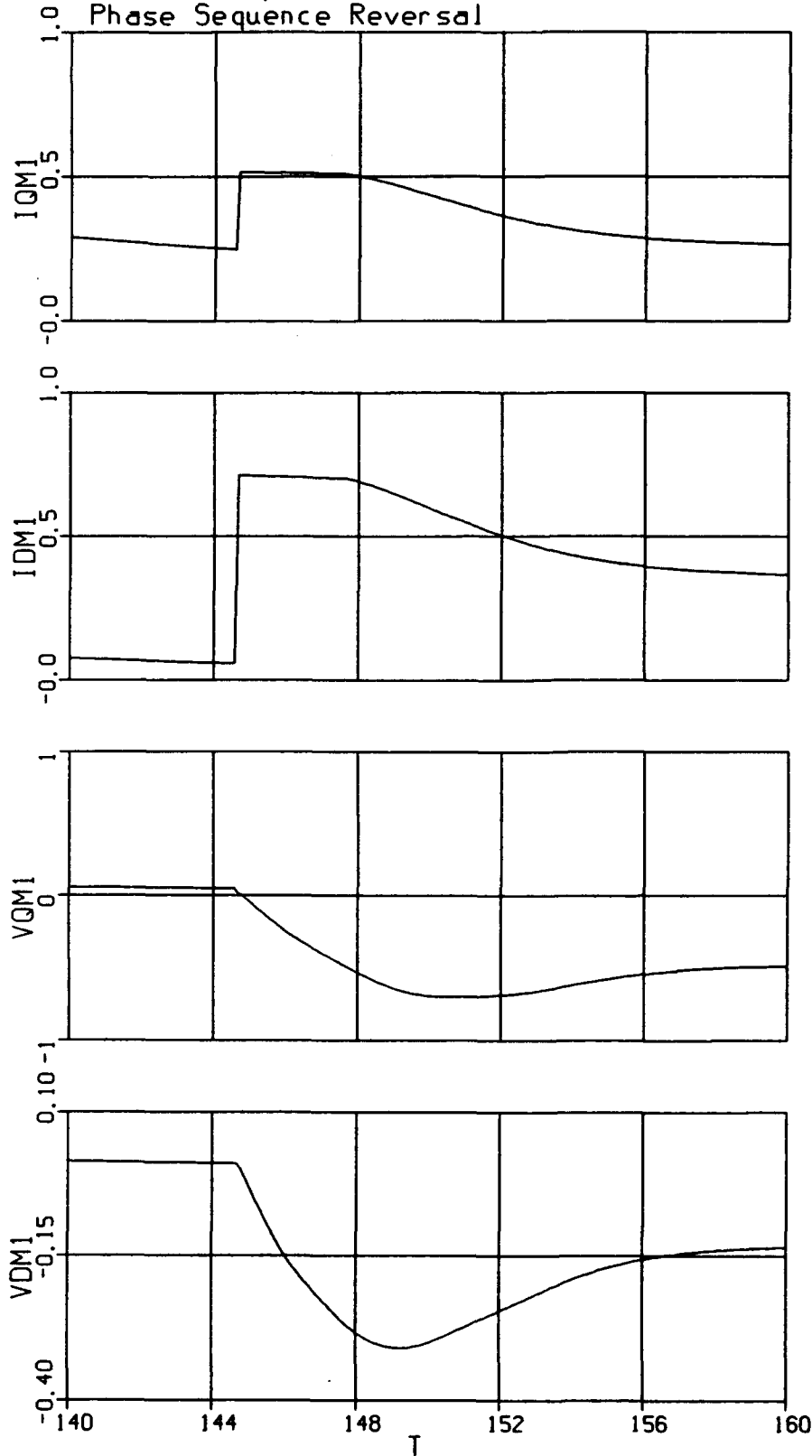
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Two Generator Ship
Two Mode Speed Control
Braking Resistor Application



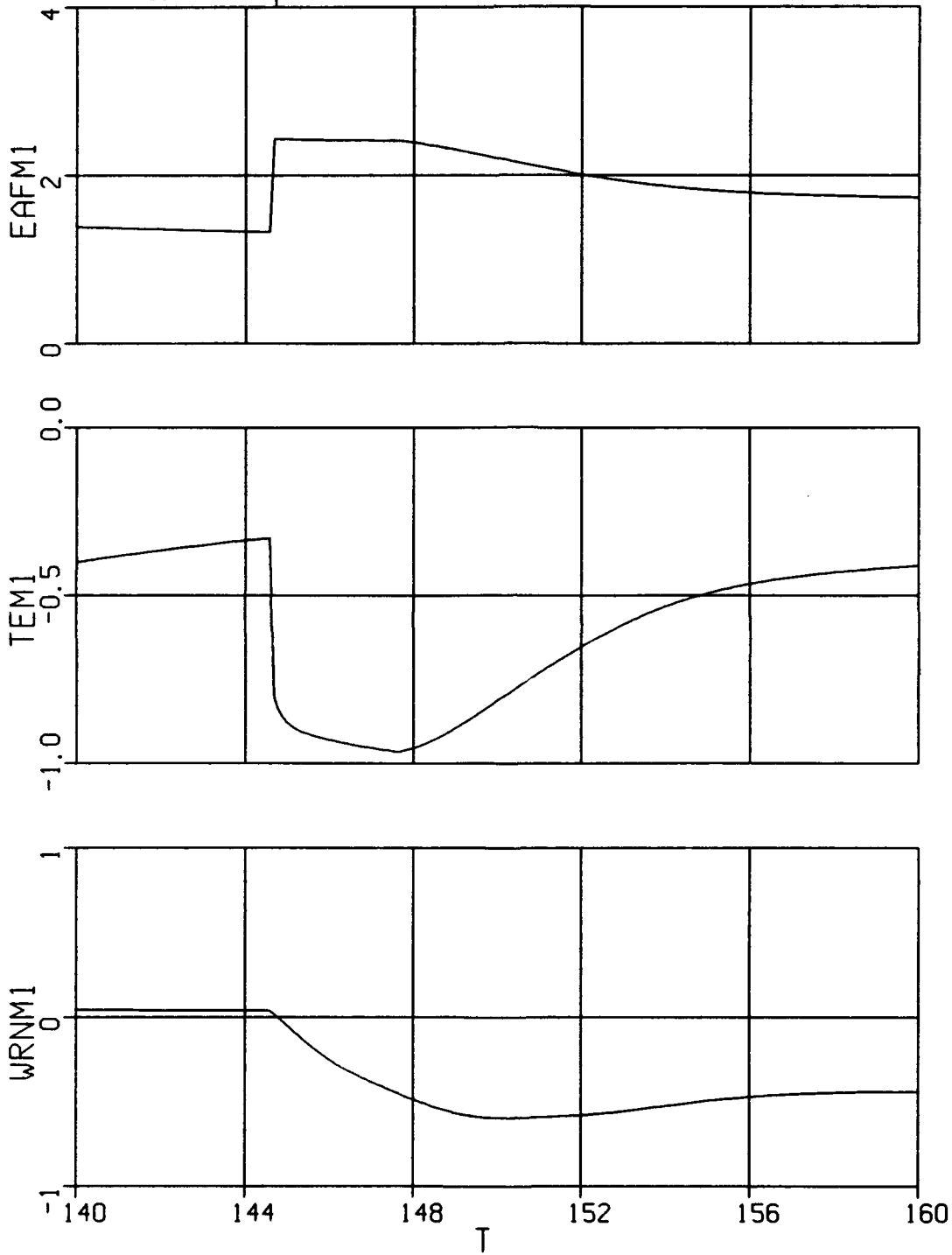
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Two Generator Ship
Two Mode Speed Control
Phase Sequence Reversal



45 93/04/20 10:55:41

Two Generator Ship
Two Mode Speed Control
Phase Sequence Reversal



46 93/04/20 10:55:41

D.6 Generator Failure at 50% Motor Speed

System #2a: Generator #2 failure at 50% ship speed

T 25.0000000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZNBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

tate Variables

EDPPG1 0.29471100
 EDPPG2 1.1644E-24
 EDPPM1-0.09589190
 ENPTL1 7.19898000
 EQPG1 1.02696000
 EQPG2 1.00000000
 EQPM1 1.17125000
 EQPPG1 1.01201000
 EQPPG2 1.00000000
 EQPPM1 1.15814000
 IDC1 0.22284700
 NGG1 8081.00000
 NPT1 3599.47000
 THMM1 27350.3000
 TICRL1 69.1367000
 WMG2 380.807000
 WMM1 171.236000
 Z99915 0.
 Z99917 0.51156600
 Z99919 0.23287300
 Z99924 0.30078100
 Z99926 1.39970000
 Z99933 0.52794400
 Z99935 8081.02000
 Z99937 138.696000
 Z99939-1.8216E-04
 Z99941 69.1148000
 Z99944-345.092000
 Z99948-2.45794000
 Z99952 1857.90000
 Z99954 3599.49000
 Z99956 34.9975000
 Z99958 34.4802000
 Z99964 1572.16000
 Z99967 2214.47000
 Z99973-0.06887140
 Z99981 1.4826E-09
 Z99986 1.00001000
 Z99988 0.99999100
 Z99990 1.81929000

Derivatives

Z99995-1.0629E-04
 Z99992-6.1282E-24
 Z99930 8.4455E-05
 Z99942-2.0266E-04
 Z99994-1.1006E-05
 Z99991-7.3017E-07
 Z99929-1.5063E-04
 Z99996-2.2351E-06
 Z99993-7.8427E-07
 Z99931-1.4827E-04
 Z99922-1.7399E-04
 Z99965-0.48811200
 Z99978-0.05613670
 Z99927 171.236000
 Z99959 0.11779800
 Z99979 1.4632E-07
 Z99928 0.00998080
 Z99914 0.
 Z99916 2.7909E-04
 Z99918-1.9538E-04
 Z99923 6.2585E-05
 Z99925-0.03814700
 Z99932-3.6433E-04
 Z99934-0.62255900
 Z99936-0.02212520
 Z99938 4.2240E-04
 Z99940 0.
 Z99943 0.00927296
 Z99947 0.00717958
 Z99951-0.27262400
 Z99953-0.08816190
 Z99955-0.00118249
 Z99957 0.
 Z99963 3.43217000
 Z99966 1.81239000
 Z99972 0.08772790
 Z99980-2.6981E-09
 Z99985 0.
 Z99987 7.9870E-05
 Z99989-7.5698E-04

Initial Conditions

EDPPG1IC 0.
 EDPPG2IC 0.
 EDPPM1IC 0.
 ENPTL1I 7.20000000
 EQPG1IC 1.00000000
 EQPG2IC 1.00000000
 EQPM1IC 1.00000000
 EQPPG1IC 1.00000000
 EQPPG2IC 1.00000000
 EQPPM1IC 1.00000000
 IDC1IC 0.
 NGG1I 7193.84000
 NPT1I 3600.00000
 THMM1IC 0.
 TICRL1I 13.0000000
 WMG2IC 377.000000
 WMM1IC 0.
 Z99913 0.
 VS1PUI 0.
 IDCRL1IC 0.
 U1IC 0.99000000
 EAFM1IC 1.00000000
 XMV1I 0.31609000
 NGGL1I 7193.84000
 PS3WC1I 68.0631000
 EMFFB1I 0.
 ALPHA1I 40.9791000
 TGLAG1I-345.140000
 TABTR1I 0.
 QMAPL1I 0.
 NPTL1I 3600.00000
 P54LL1I 21.7097000
 P54L1I 21.3889000
 T51PL1I 1416.04000
 T4PL1I 1875.14000
 NERR1I 0.
 TMECH2IC 0.
 FUEL2IC 0.
 EAPG2IC 1.00000000
 EAPG1IC 1.00000000

Algebraic Variables

mon Block /ZZCOMU/

AFL1 0.14660200
 ALPHA1LL 13.0000000
 ALPHAG2 20.7143000
 BASEKMG1 16200.0000
 BASENG1 3600.00000
 BASEQM1 949455.000
 BASEVM1 5000.00000
 BETAMINM1 1.57080000
 CYL2 8.00000000
 DELG2 1.1644E-24
 DELR1 0.39877300
 DELVTQ1 0.
 DFL1-0.79008800
 DNGG1 8080.75000
 DQ4S1-5.96718000
 DRLLG1I 0.31609000
 DT51HS1-4.44555000
 E211 0.00206329
 E51 6.95567000
 E81 0.
 EAFG1 1.81929000
 EAFG2D 7.9870E-05
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 EAFMAXG2 3.00000000
 EAFSM1 1.39968000
 EDPPM1D 8.4455E-05
 EMFFB1-1.8216E-04
 ENPT1 7.19897000
 EQPG1D-1.1006E-05
 EQPPG1D-2.2351E-06
 ER1 0.92096700
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 FARG3 3
 FARGS2 2
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 G11 0.22000000
 GBETAR1 30.0000000
 GEAFM1 100.000000
 GSMALL1 5.00000000
 HG2 1.91000000
 HP1 8685.66000
 HP1I 0.
 HPT1ORD 8685.66000
 ICLIM1 70.0000000
 ID1GR 1.00000000
 IDCBG2 0.
 IDCR1D-1.9538E-04
 IDCR1MAX 0.80000000
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 IDG2ERR 0.
 IDI1 0.19866700
 IDM1IC 0.

AFRL1 0.17295400
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 ALPHAM1 18.4545000
 BASEKMG2 2500.00000
 BASENG2 900.000000
 BASEVG1 4160.00000
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 BETAR1 1.26528000
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 DELI1-0.19531300
 DELTA2 1.00000000
 DELWF1 5.39990000
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 DNPT1-0.05613670
 DQHR21 5.06674000
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 E221 0.12379800
 E61 0.
 E91 0.45832200
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 EI1 0.46612500
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 GLARGE1 50.0000000
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 ICNTRL1-0.06887140
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 IDCOM1 0.23287300
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 IDG2IC 0.
 IDL2 0.18192500
 IDR1 0.23434500

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 ARLLG1I 0.31609000
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 BASEVG2 450.000000
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 IDM1 0.19866700
 IDXM1 0.11979600

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 K07RES-23.5963000
 K10RES-15.1637000
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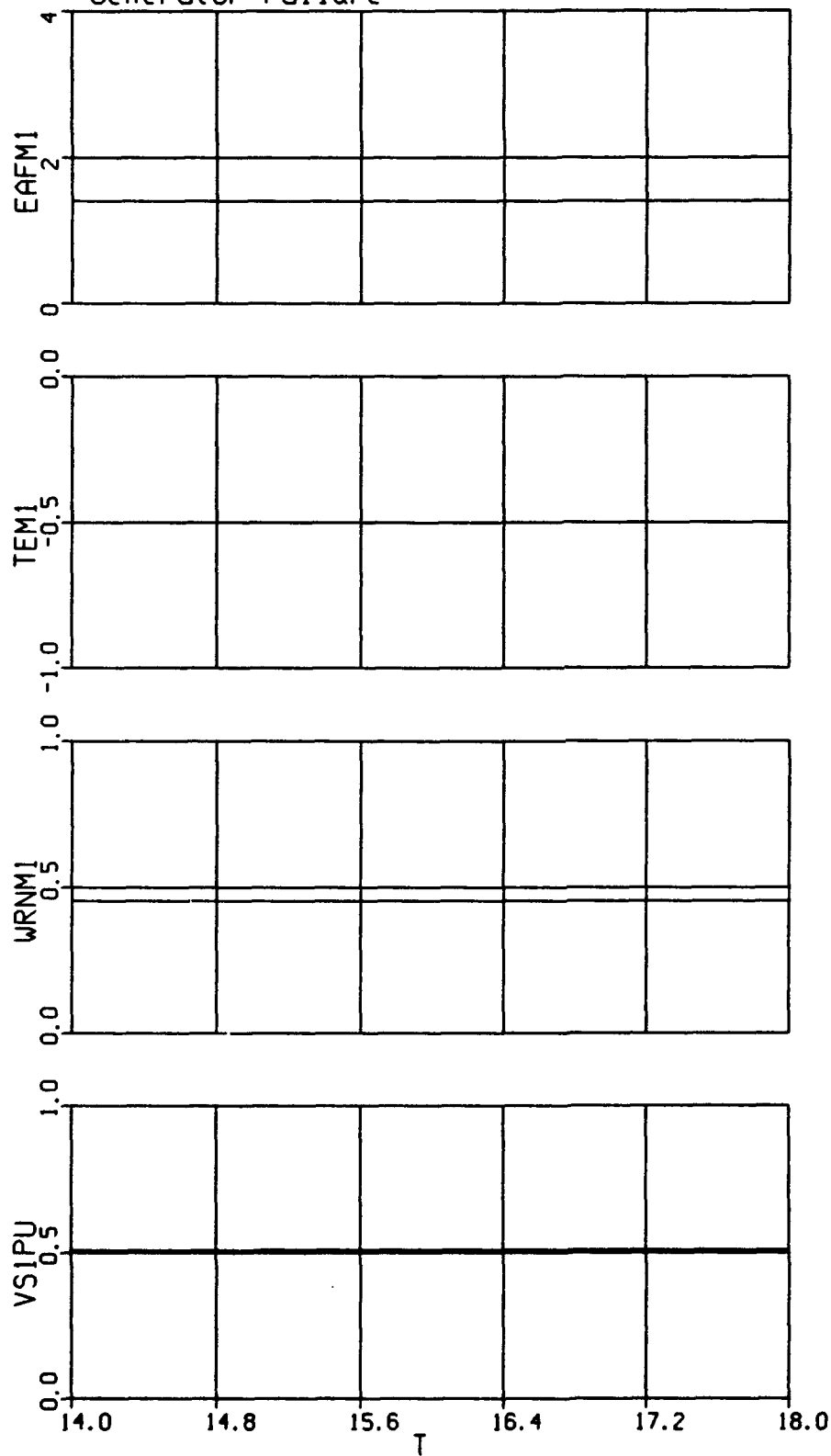
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 KTBL1 0
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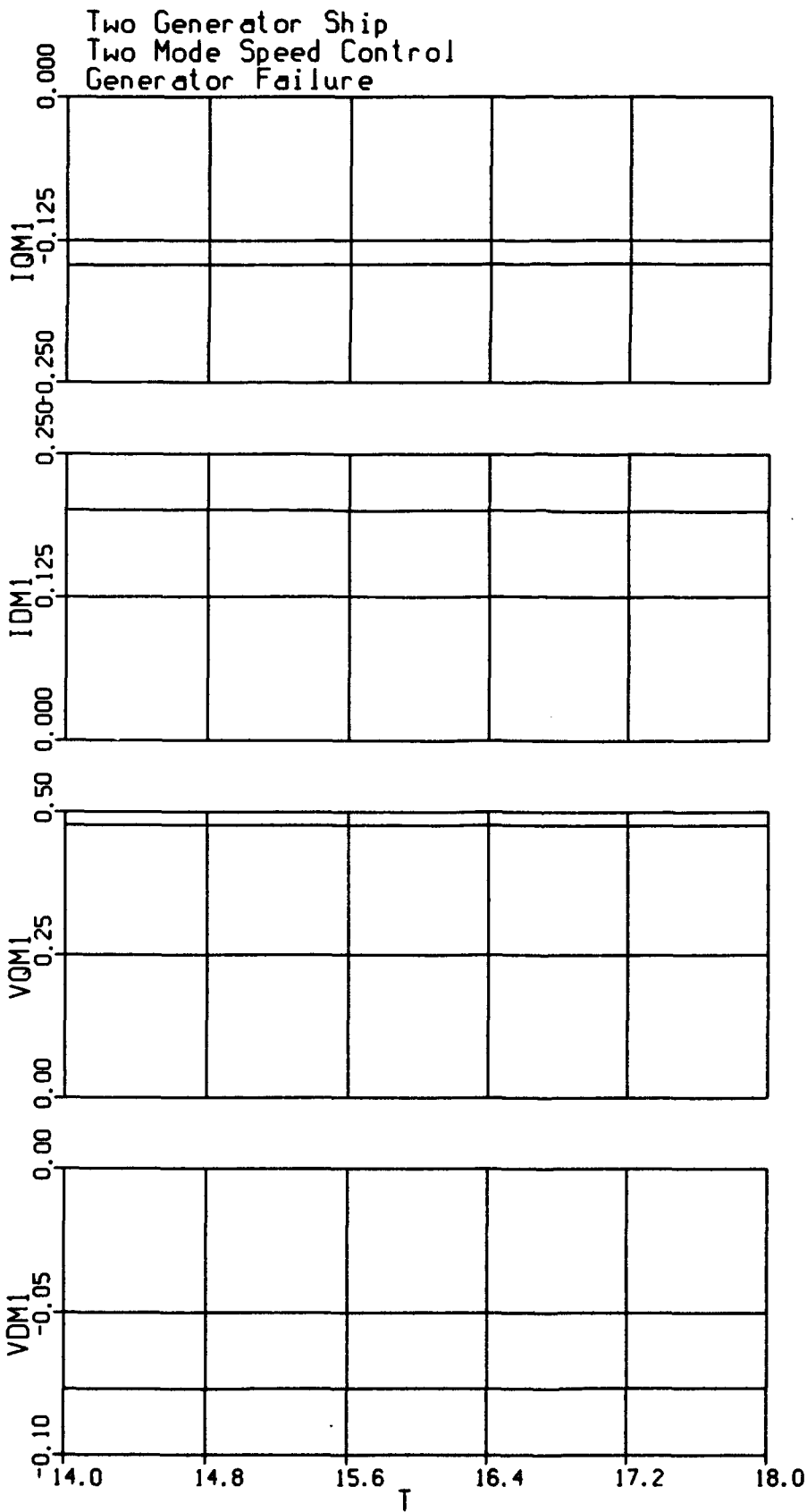
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RS1PU 0.30126600	RS1PUI0 0.	RS1PUI1 0.
RS1PUI2 0.	RS1PUI3 0.	RS1PUI 0.
SEAFRQ 1.04720000	SEATIME 0.	SNEGVL1 0.
SPDERR1IC 0.	SPDERR2-9.10852000	SPDREF1 0.50000000
SPEEDERR1 0.04579310	SQTH2 1.00000000	SWITCHVAR1 0.02905200
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T4U1 90.5831000	T511 1593.90000	T51P1 1598.35000
T51PL1 1572.16000	T51Q1 0.99721900	T51R21 1598.35000
T51U1 398.157000	T541 1079.82000	TABTR11 2.04433000
LPHA1(32) 999.900000	Z99976(16) 108.000000	Z99977(16) 999.900000
TAMB 59.0000000	TAUBETAR1 0.01000000	TAUEAFG1 0.10000000
TAUEAFG2 0.10000000	TAUEAFM1 0.05000000	TAUFAST1 0.10000000
TAUGOV2 2.00000000	TAUSLOW1 20.0000000	TAUSPEED1 20.0000000
TC11 3.00000000	TDOPG1 3.19000000	TDOPG2 3.79000000
TDOPM1 2.10000000	TDOPPG1 0.04000000	TDOPPG2 0.38000000
TDOPPM1 0.03900000	TDT541(48) 99999.0000	Z99968(36) 68.3000000
99969(12) 99999.0000	TEG1-0.34702900	TEGLIC 0.
TEG2 0.	TEM1 0.18514900	TESM1 12673.5000
TESM1I 0.	TGLAG1 7.19854000	THDOT21 0.
THET2N 1.00000000	THETA2 1.00000000	THRESHOLD1 0.10000000
THTA2V 1.00000000	TIC1 69.1485000	TIC1LL 13.0000000
TIC1UL 113.500000	TICMD1 69.1485000	TICMD1I 13.0000000
TICN1 0.19431200	TICN1I 0.	TICRL1LL-89.0000000
TICRL1UL 22.5000000	TICS1 68.9542000	TICS1I 13.0000000
TMAP(116) 950.000000	Z99997(96) 0.92280000	Z99998(20) 950.000000
TMG2 1.4826E-09	TMM1-0.18508100	TMM2-0.18508100
TORQ2 0.	TP1PU 0.16911700	TP1PUI 0.
TP2PU 0.16911700	TP2PUI 0.	TQOPPG1 0.09000000
TQOPPG2 0.19000000	TQOPPM1 0.19300000	TSEA 6.00000000
TSTOP 25.0000000	TURBOLAG2 0.50000000	TUT4H1 0.31613800
TUT51H1 0.13107100	TVS0REF 696.262000	U1 0.30078100
UID 6.2585E-05	UMAX1 0.99000000	UMIN1 0.
VDBIC 0.	VDBUS 0.35020900	VDCBG2 1.1644E-24
VDERR 0.	VDG1 0.32437900	VDG2 1.1644E-24
VDI1-0.09046270	VDM1-0.07600180	VDR1 0.35760000
VERRG1 0.01819210	VERRG2 0.00999999	VI1-0.45371400
VN1 7.34400000	VNSF1 500.000000	VQ1 9.00000000
VQBIC 1.00000000	VQBUS 0.87214100	VQCBG2 1.00000000
VQERR 0.	VQG1 0.93726200	VQG2 1.00000000
VQI1 0.45726300	VQM1 0.47712900	VQR1 0.84870700
VQSF1 5000.00000	VR1 0.45817000	VRATE1 0.
VRSF1 360.000000	VS1PU0 1.0000E-05	VS1PU10 0.00122748
VS1PU10I 0.	VS1PU2 0.26169900	VS1PU2I 0.
VS1PU3 0.13387600	VS1PU3I 0.	VS1PU4 0.06848660
VS1PU4I 0.	VS1PU5 0.03503540	VS1PU5I 0.
VS1PU6 0.01792290	VS1PU6I 0.	VS1PU7 0.00916874
VS1PU7I 0.	VS1PU8 0.00469042	VS1PU8I 0.
VS1PU9 0.00239946	VS1PU9I 0.	VS1PU 0.51156600
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VTREFG2 1.01000000	VTRQGS1 0.	W41 80.1019000
W4R21 80.1019000	W541 89.5631000	W54R21 89.5631000

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WFSR21 5062.36000	WFUEL1 5067.76000	WFUEL1I 2185.21000
WMG1 376.945000	WMG2D 1.4632E-07	WMM1D 0.00998080
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WRNG1 0.99985400	WRNG1IC 1.00000000	WRNG2 1.01010000
WRNM1 0.45420700	WRNM2 0.45420700	XDC1 1.68000000
XDG1 1.77000000	XDG2 1.63000000	XDM1 1.76000000
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XDPM1 0.60800000	XDPPG1 0.15000000	XDPPG2 0.18000000
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XLG2 0.07500000	XLN1 0.33700000	XM1 0.10000000
XMV1 0.52776200	XQG1 1.64000000	XQG2 1.01000000
XQM1 1.15700000	XQPPG1 0.15000000	XQPPG2 0.28000000
XQPPM1 0.49400000	XVSOREF 207.220000	Z99885 0.
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Z99921 0.02905200	Z99945 7.19897000	Z99946 7.19854000
Z99949 2.04649000	Z99950 2.04433000	Z99960 47
Z99961 40	Z99962 54.3832000	Z99970 23
Z99971 68.9542000	Z99974 18	Z99975 13.0000000
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ZZSEED 55555555		

Two Generator Ship
Two Mode Speed Control
Generator Failure

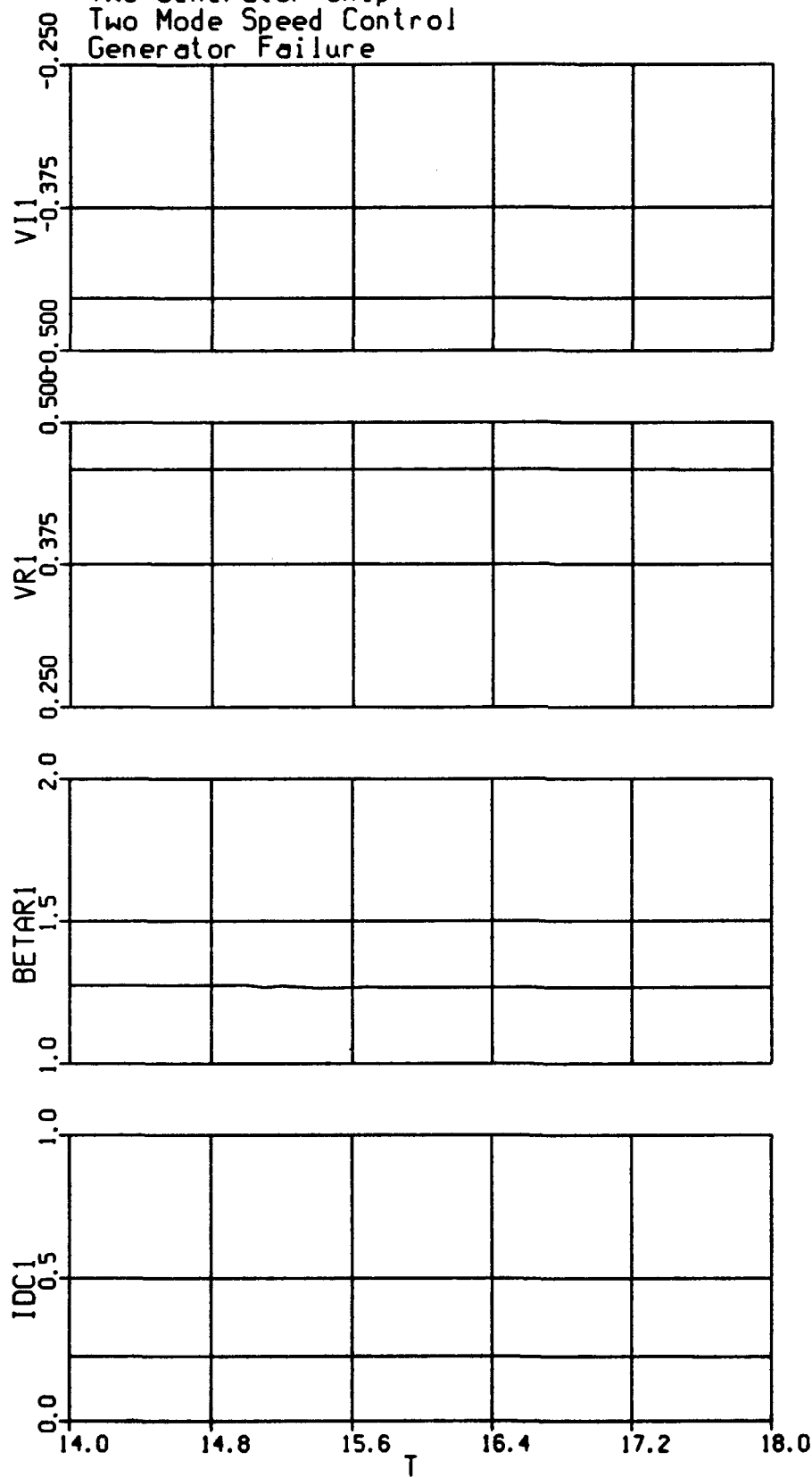


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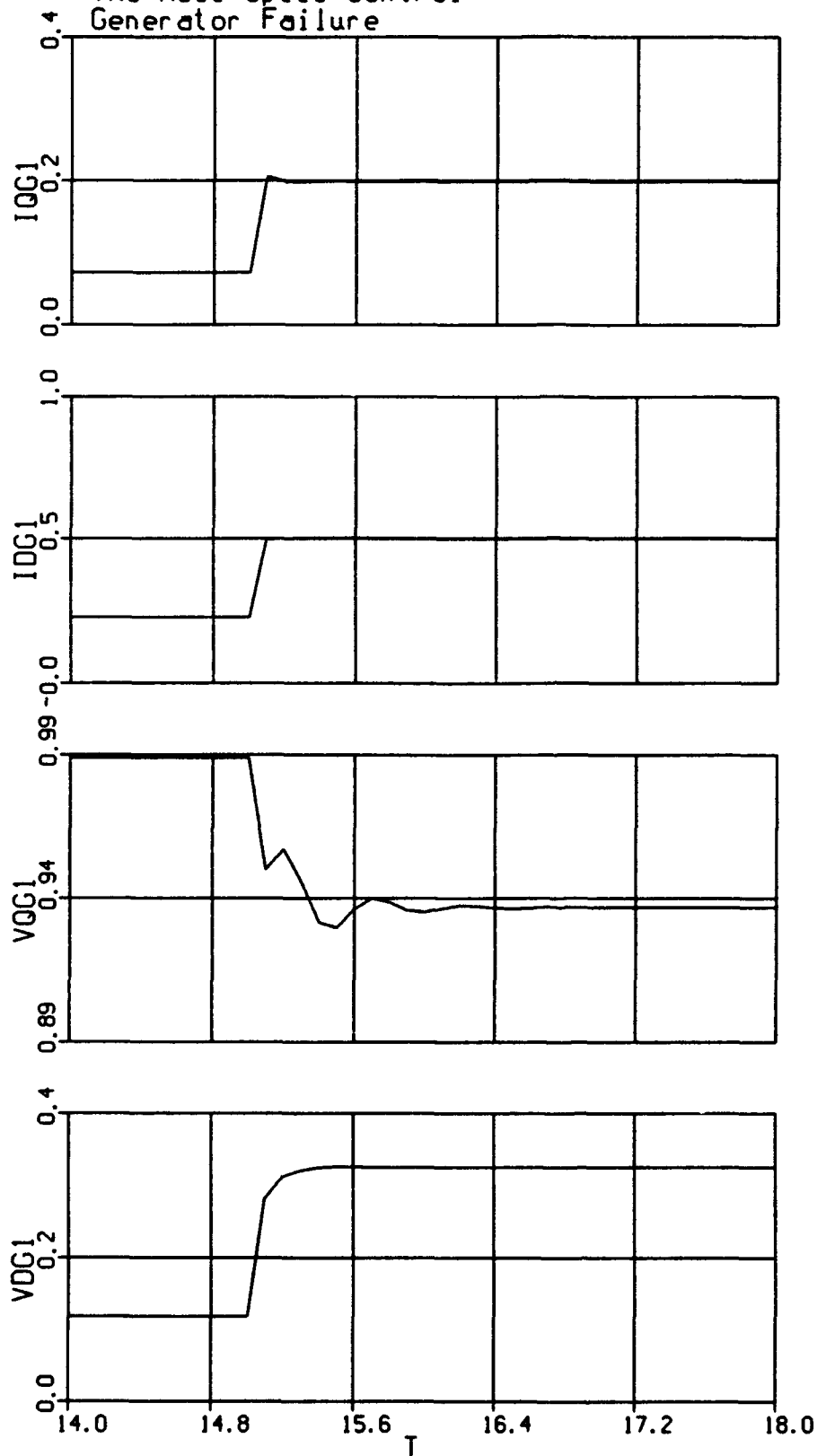
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Two Generator Ship
Two Mode Speed Control
Generator Failure



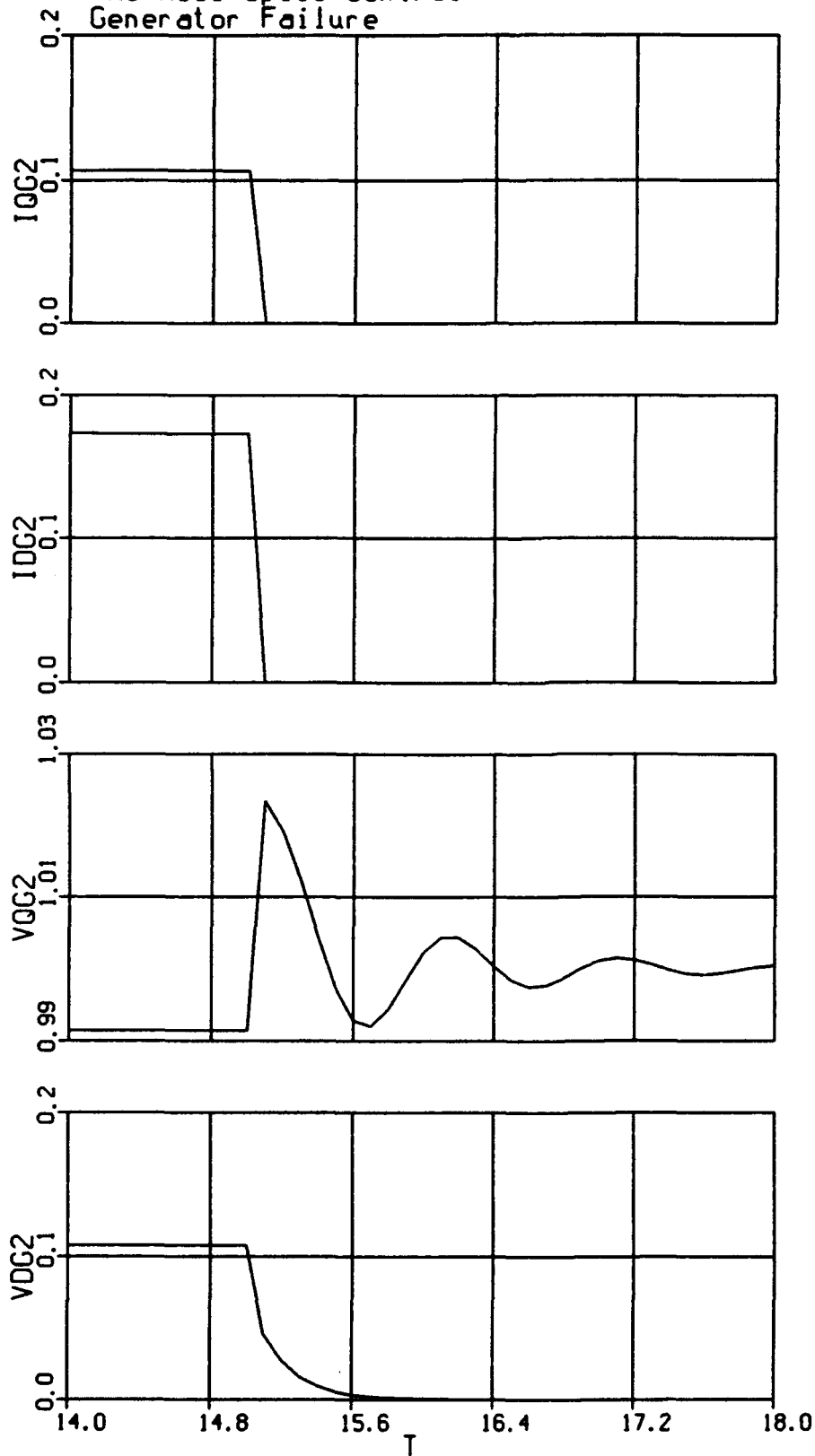
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Two Generator Ship
Two Mode Speed Control
Generator Failure



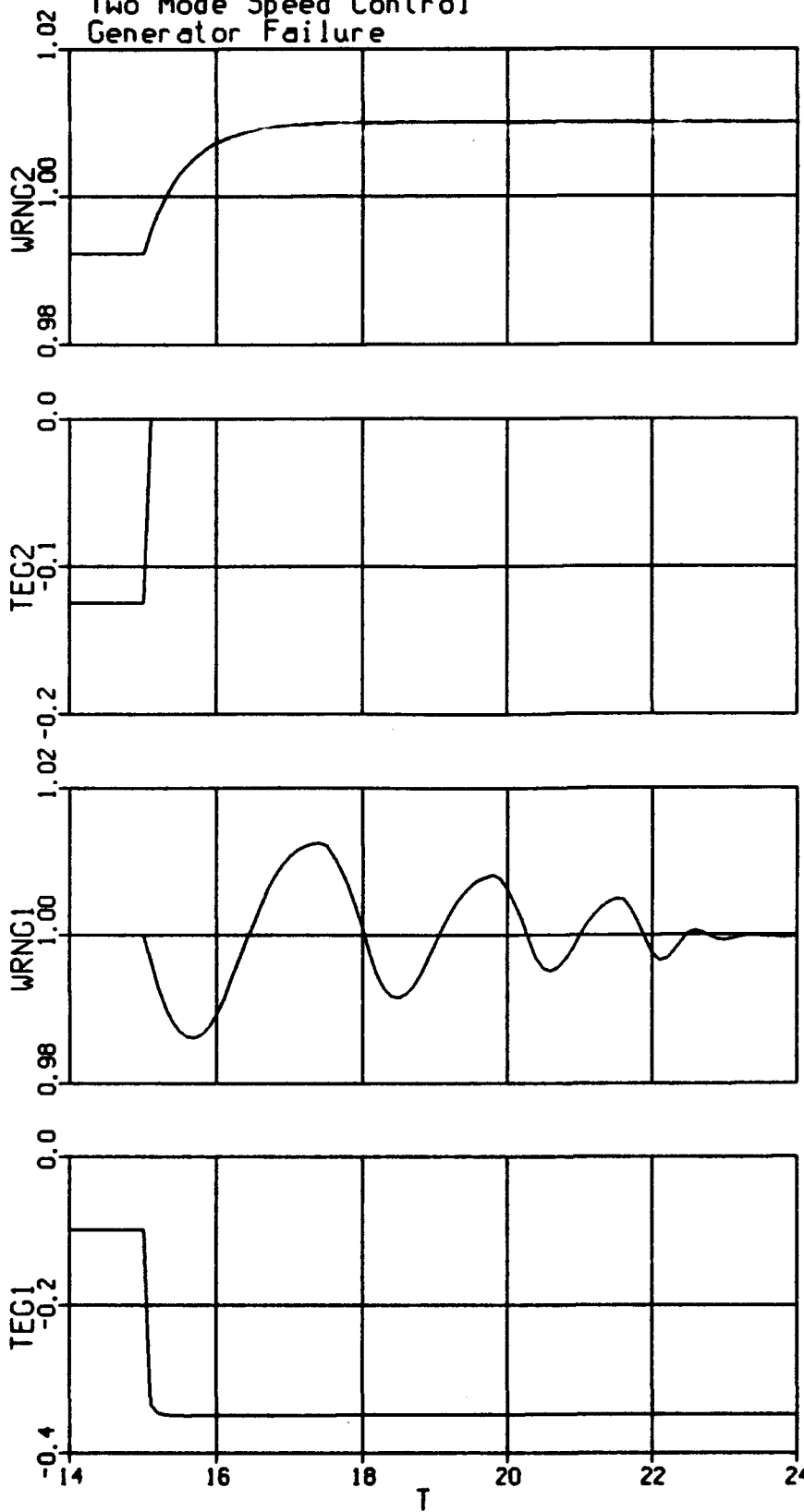
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Two Generator Ship
Two Mode Speed Control
Generator Failure

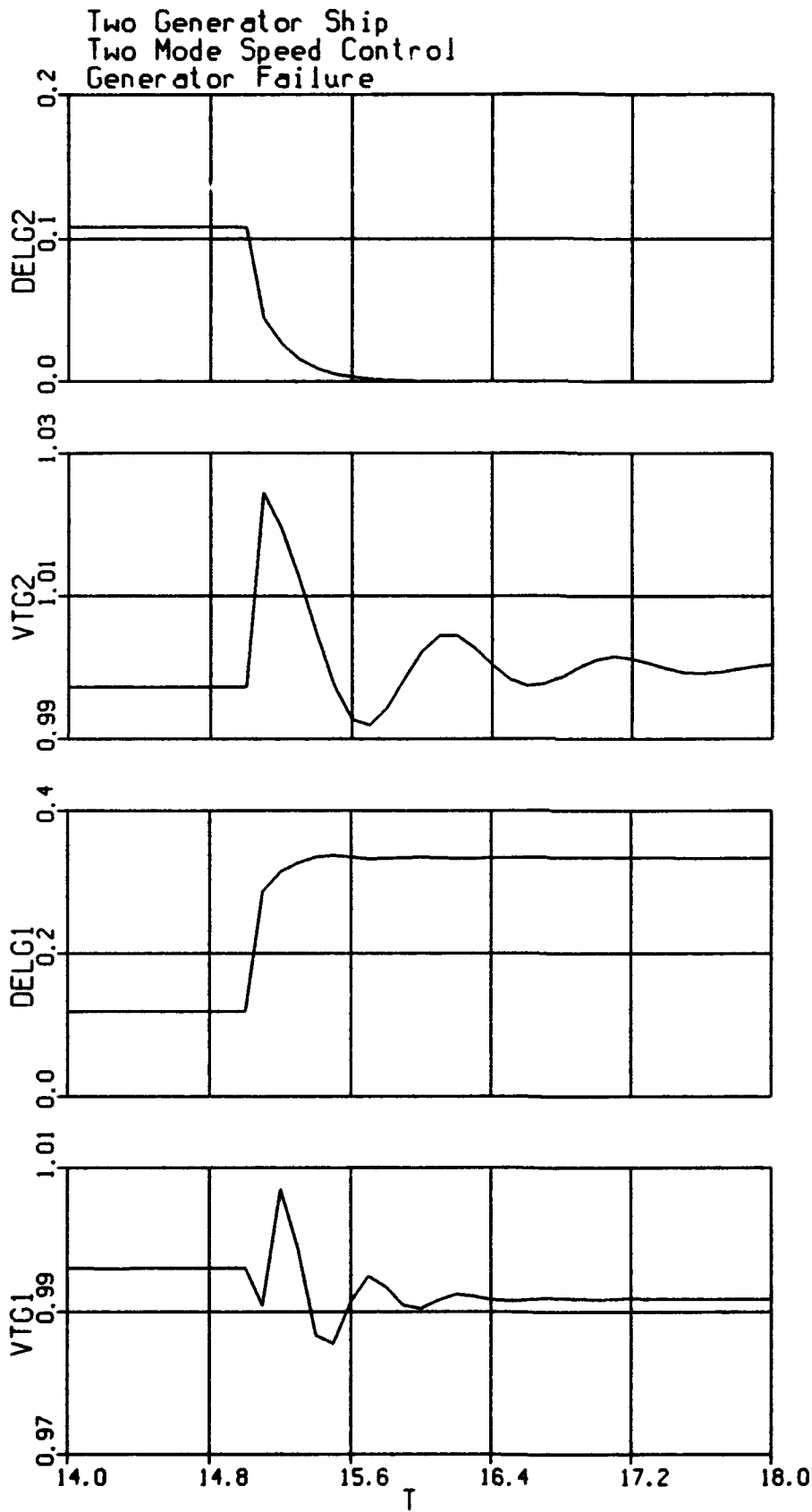


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Two Generator Ship
Two Mode Speed Control
Generator Failure



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D.7 Generator Failure at 90% Motor Speed

System 2a: Generator #2 tripped off line @ T=15 sec

T 18.1803000	ZZTICG 0.	CINT 0.10000000
ZZIERR F	ZZENBLK 1	ZZICON 0
ZZSTFL T	ZZFRFL F	ZZICFL F
ZZRNFL F	ZZJEFL F	ZZNIST 40
ZZNAST 0	IALG 1	NSTP 10
MAXT 0.10000000	MINT 1.0000E-08	

tate Variables	Derivatives	Initial Conditions
EDPPG1 0.72011600	Z99995-1.2195E-04	EDPPG1IC 0.
EDPPG2 1.1850E-08	Z99992-6.2367E-08	EDPPG2IC 0.
EDPPM1-0.23329600	Z99930 4.8301E-05	EDPPM1IC 0.
ENPTL1 6.70086000	Z99942 0.20103500	ENPTL1I 7.20000000
EQPG1 0.75499600	Z99994 1.8228E-04	EQPG1IC 1.00000000
EQPG2 0.99920600	Z99991-0.00232718	EQPG2IC 1.00000000
EQPM1 1.41814000	Z99929-3.8589E-06	EQPM1IC 1.00000000
EQPPG1 0.72741600	Z99996 1.0163E-04	EQPPG1IC 1.00000000
EQPPG2 1.00012000	Z99993-0.00241289	EQPPG2IC 1.00000000
EQPPM1 1.38623000	Z99931 3.5195E-05	EQPPM1IC 1.00000000
IDC1 0.54223500	Z99922-2.6964E-05	IDC1IC 0.
NGG1 9222.09000	Z99965 213.686000	NGG1I 7193.84000
NPT1 3369.03000	Z99978 103.740000	NPT1I 3600.00000
THM1 43180.3000	Z99927 297.195000	THM1IC 0.
TICRL1 113.500000	Z99959 7.6294E-05	TICRL1I 13.0000000
WMG2 391.600000	Z99979 0.08838670	WMG2IC 377.000000
WMM1 297.195000	Z99928-0.00646367	WMM1IC 0.
Z99915 0.	Z99914 0.	Z99913 0.
Z99917 0.86895800	Z99916 3.1753E-05	VS1PUI 0.
Z99919 0.56063000	Z99918-1.1024E-04	IDCR1IC 0.
Z99924 0.55184400	Z99923-5.8413E-04	ULIC 0.99000000
Z99926 1.97503000	Z99925 0.12087800	EAFM1IC 1.00000000
Z99933 0.85020400	Z99932 0.04110780	XNV1I 0.31609000
Z99935 9213.43000	Z99934 216.650000	NGGL1I 7193.84000
Z99937 252.498000	Z99936 13.6253000	PS3WCL1I 68.0631000
Z99939 0.02055390	Z99938-0.01249520	EMFBL1I 0.
Z99941 113.455000	Z99940 3.6030E-04	ALPHA1I 40.9791000
Z99944-321.147000	Z99943-9.62277000	TGLAG1I-345.140000
Z99948-9.63467000	Z99947-0.70087400	TABTR1I 0.
Z99952 7448.08000	Z99951 299.854000	QMAPL1I 0.
Z99954 3354.45000	Z99953 101.262000	NPTL1I 3600.00000
Z99956 57.2223000	Z99955 2.20612000	P54LL1I 21.7097000
Z99958 56.4636000	Z99957 2.14359000	P54L1I 21.3889000
Z99964 1739.47000	Z99963 61.4375000	T51FL1I 1416.04000
Z99967 2615.63000	Z99966 128.343000	T4FL1I 1875.14000
Z99973 0.13876700	Z99972 0.	WERR1I 0.
Z99981 8.9559E-04	Z99980-0.00163522	TMECH2IC 0.
Z99986 1.00001000	Z99985 0.	FUEL2IC 0.
Z99988 0.97231000	Z99987 0.15422600	EAFG2IC 1.00000000
Z99990 2.21734000	Z99989 0.01030920	EAFG1IC 1.00000000

Algebraic Variables

mon Block /ZZCOMU/

AFL1 0.00124403	AFRL1 0.13148200	ALPHA1 113.455000
ALPHA1LL 13.0000000	ALPHA1UL 120.000000	ALPHAG1 54.0000000
ALPHAG2 20.7143000	ALPHAM1 18.4545000	ARLLG1I 0.31609000
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BASENG1 3600.00000	BASENG2 900.000000	BASENM1 150.000000
BASEQM1 949455.000	BASEVG1 4160.00000	BASEVG2 450.000000
BASEVM1 5000.00000	BETAI1 2.20000000	BETAM1 2.20000000
BETAMINM1 1.57080000	BETAR1 0.98622300	CQLID1 2.8143E-05
CYL2 8.00000000	DELAY2 0.54768700	DELG1 0.93128300
DELG2 1.1848E-08	DELI1-0.40188400	DELM1-0.34744000
DELR1 1.12960000	DELTA2 1.00000000	DELV 1.0000E-04
DELVTQ1 0.	DELWF1 1062.24000	DELWF1I 0.
DFL1-0.93544600	DFRL1-0.21369800	DN1 103.740000
DNGG1 9478.28000	DNPT1 103.740000	DNREF1 180.000000
DQ4S1-396.767000	DQHR21 790.963000	DQPTR1 44713.1000
DRLLG1I 0.31609000	DRPMDT1 0.15117800	DT4HS1-50.3455000
DT51HS1-50.5555000	DZ1 0.05000000	E01I 0.
E211 0.00422347	E221 0.25340800	E231 0.08446940
E51 0.58562600	E61 0.	E71 0.18283100
E81 0.	E91 0.74586900	EAFFERRM1 6.0439E-05
EAFG1 2.21734000	EAFG1D 0.01030920	EAFG2 0.97231000
EAFG2D 0.15422600	EAFM1 1.97503000	EAFM1D 0.12087800
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EAFMAG2 3.00000000	EAFMING1 0.	EAFMING2 0.
EAFSM1 1.97509000	EDPPG1D-1.2195E-04	EDPPG2D-6.2367E-08
EDPPM1D 4.8301E-05	EI1 0.91044500	EISM1 1.00000000
EMFFB1 0.02055390	EMFSAT1 0.00124403	ENG1 0.20020900
ENPT1 6.70890000	ENPT1I 7.20000000	EPM1 1.68360000
EQPG1D 1.8228E-04	EQPG2D-0.00232718	EQPM1D-3.8589E-06
EQPPG1D 1.0163E-04	EQPPG2D-0.00241289	EQPPM1D 3.5195E-05
ER1 0.98280500	ERRBOUND 1.0000E-04	ERX1 0.00124403
FARG0 0	FARG1 1	FARG2 2
FARG3 3	FARGS0 0	FARGS1 1
FARGS2 2	FARGS3 3	FUEL2 0.
FUEL2MAX 1.00000000	FUEL2MIN 0.	FUELAG2 0.04813480
G11 0.22000000	G31 0.50000000	G51 0.50000000
GBETAR1 30.0000000	GEAFG1 100.000000	GEAFG2 100.000000
GEAFM1 100.000000	GLARGE1 50.0000000	GM1 1.50000000
GSMALL1 5.00000000	GSPEED1 5.00000000	HG1 0.92400000
HG2 1.91000000	HHPS 0.51678100	HM1 1.28978000
HP1 23742.4000	HP1B 25000.0000	HP1D 23742.4000
HP1I 0.	HP1ORD 0.	HP1ORDI 0.
HPT1ORD 23742.4000	IAJXQM1 0.69177000	IAM1 0.59790000
ICLIM1 70.0000000	ICNTRL1 0.13876700	ICNTRL1I 0.
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IDCBG2 0.	IDCOM1 0.56063000	IDCR1 0.56063000
IDCR1D-1.1024E-04	IDCR1DMAX 5.00000000	IDCR1DMIN-5.00000000
IDCR1MAX 0.80000000	IDCR1MIN 0.	IDG1 0.91921200
IDGLIC 0.	IDG1M1 1.20009000	IDG2 0.
IDG2ERR 0.	IDG2IC 0.	IDG2M1 0.
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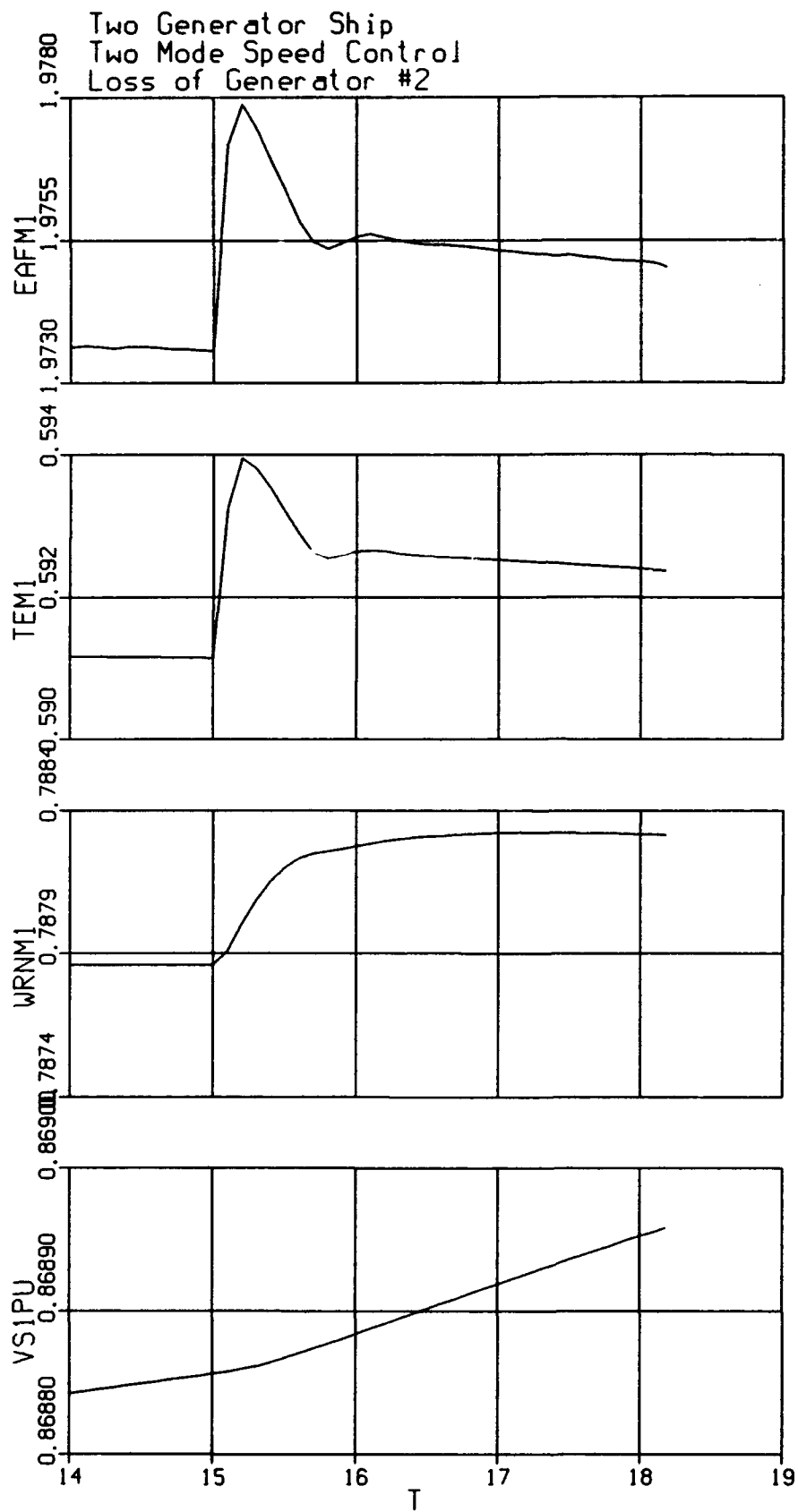
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 KZG1M1 0.63727300
 LCBG2 F
 LHEADR F
 LPWRD1 F
 MAXIT 10.0000000
 MFKMV1 23.0000000
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 NGB 3600.00000
 NMAX2 950.000000
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 NP2PU 0.81708400
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 PS31I 68.0631000
 PS3WC1 252.498000
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 QMAP1 7457.08000
 QP1 734052.000
 QP1I-0.23332300
 QP2 734052.000
 QP2I-0.23332300
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 QPT1B 36473.0000

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 IQBM1 0.
 IQG1IC 0.
 IQG2ERR 0.
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 IQM1IC 0.
 JJPROP 1.3130E+06
 JJSHFT 166000.000
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 K05RES 8.65721000
 K08RES 15.9458000
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 KIG2M1 1.86253000
 KKWG2M1 0.16762800
 KRAT1 0.16000000
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 KVG2M1 0.09000000
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 LSEA F
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 PWRD1 94.9695000
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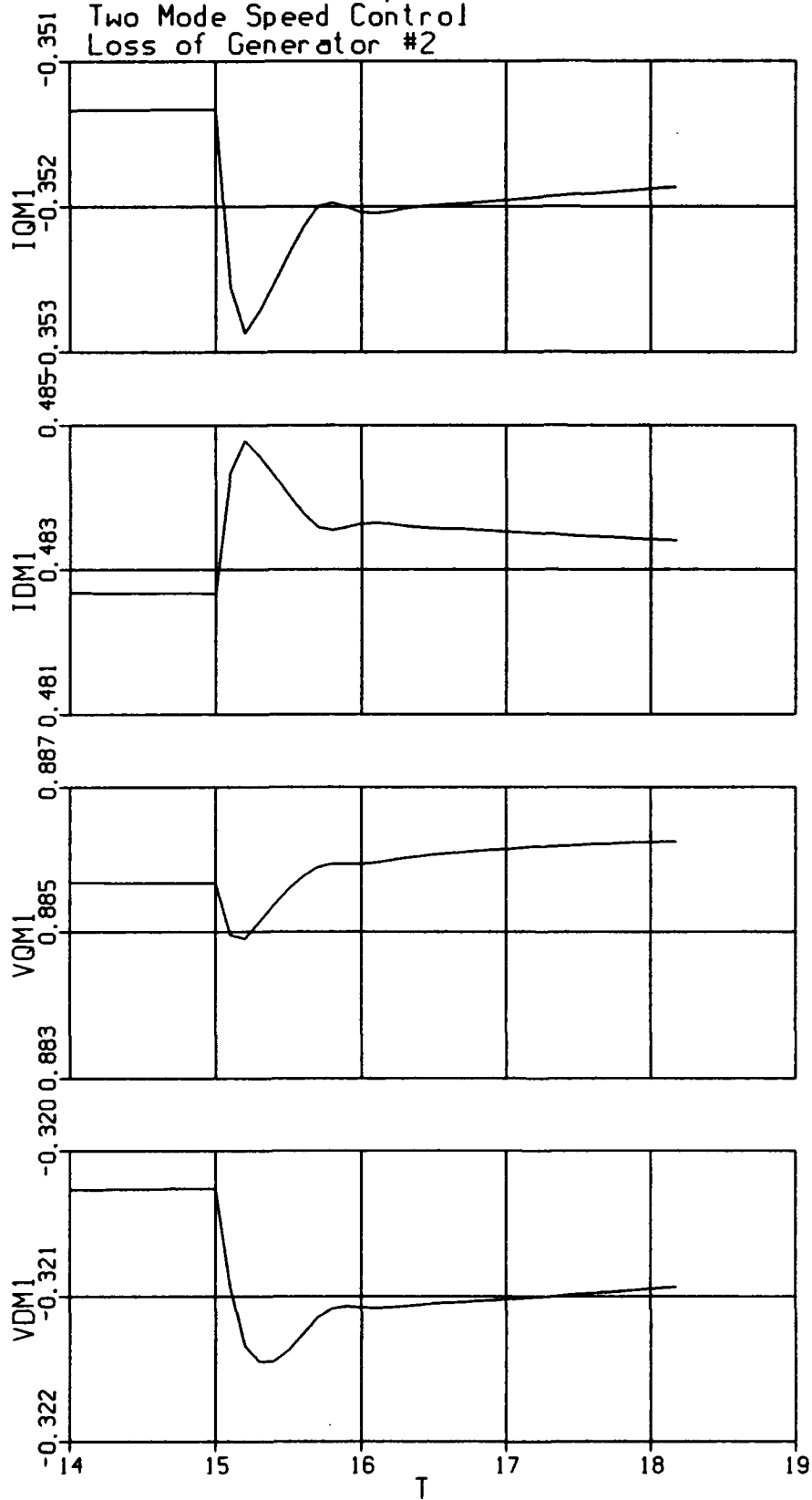
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RS1PUI2 0.	RS1PUI3 0.	RS1PUI 0.
SEAFRQ 1.04720000	SEATIME 0.	SNEGVL1 0.
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SPEEDERR1 0.11168500	SQRT2 1.00000000	SWITCHVAR1 0.09909070
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T4P1 2928.49000	T4PL1 2615.63000	T4R21 2928.49000
T4U1 6414.56000	T511 2052.84000	T51P1 2103.39000
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TAUEAFG2 0.10000000	TAUEAFM1 0.05000000	TAUFAST1 0.10000000
TAUGOV2 2.00000000	TAUSLOW1 20.0000000	TAUSPEED1 20.0000000
TC11 3.00000000	TDOPG1 3.19000000	TDOPG2 3.79000000
TDOPM1 2.10000000	TDOPPG1 0.04000000	TDOPPG2 0.38000000
TDOPPM1 0.03900000	TDT541(48) 99999.0000	Z99968(36) 68.3000000
99969(12) 99999.0000	TEG1-1.01349000	TEGLIC 0.
TEG2 0.	TEM1 0.59237700	TESM1 37012.8000
TESM1I 0.	TGLAG1 7.16117000	THDOT21 3.4987E-04
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THTA2V 1.00000000	TIC1 113.500000	TIC1LL 13.0000000
TIC1UL 113.500000	TICMD1 212.142000	TICMD1I 13.0000000
TICN1 115.623000	TICN1I 0.	TICRL1LL-89.0000000
TICRL1UL 22.5000000	TICS1 96.4793000	TICS1I 13.0000000
TMAP(116) 950.000000	Z99997(96) 0.92280000	Z99998(20) 950.000000
TMG2 8.9559E-04	TMM1-0.59242100	TMM2-0.59242100
TORQ2 0.	TP1PU 0.53850400	TP1PUI 0.
TP2PU 0.53850400	TP2PUI 0.	TQOPPG1 0.09000000
TQOPPG2 0.19000000	TQOPPM1 0.19300000	TSEA 6.00000000
TSTOP 20.0000000	TURBOLAG2 0.49955300	TUT4H1 0.41022900
TUT51H1 0.16882000	TVSOREF 696.262000	U1 0.55184400
UID-5.8413E-04	UMAX1 0.99000000	UMIN1 0.
VDBIC 0.	VDBUS 0.85570000	VDCBG2 1.1850E-08
VDERR 0.	VDG1 0.79261000	VDG2 1.1850E-08
VDI1-0.35612300	VDM1-0.32093600	VDR1 0.88869400
VERRG1 0.02218370	VERRG2 0.00987732	VI1-0.88620300
VN1 7.34400000	VNSF1 500.000000	VQ1 9.00000000
VQBIC 1.00000000	VQBUS 0.46953700	VQCBG2 1.00012000
VQERR 0.	VQG1 0.58953400	VQG2 1.00012000
VQI1 0.83790600	VQM1 0.88624600	VQR1 0.41967500
VQSF1 5000.00000	VR1 0.89704700	VRATE1 0.
VRSF1 360.000000	VS1PU0 1.0000E-05	VS1PU10 0.24546500
VS1PU10I 0.	VS1PU2 0.75508800	VS1PU2I 0.
VS1PU3 0.65614000	VS1PU3I 0.	VS1PU4 0.57015800
VS1PU4I 0.	VS1PU5 0.49544400	VS1PU5I 0.
VS1PU6 0.43052000	VS1PU6I 0.	VS1PU7 0.37410400
VS1PU7I 0.	VS1PU8 0.32508100	VS1PU8I 0.
VS1PU9 0.28248200	VS1PU9I 0.	VS1PU 0.86895800
VT12 0.95268700	VTG1 0.98781600	VTG2 1.00012000
VTM1 0.94256700	VTOP1 0.	VTREFG1 1.01000000
VTREFG2 1.01000000	VTRQGS1 0.	W41 127.411000
W4R21 127.411000	W541 140.978000	W54R21 140.978000

WAVE 4.00000000	WEFSEA 1.04720000	WESEA 0.
WESEAMG 0.	WESMAX 0.10000000	WFAC1 12363.8000
WFSR21 11275.1000	WFUEL1 12337.4000	WFUEL1I 2185.21000
WMG1 352.812000	WMG2D 0.08838670	WMM1D-0.00646367
WO 377.000000	WRN1ORD 1.00000000	WRN1ORDIC 1.00000000
WRNG1 0.93584200	WRNG1IC 1.00000000	WRNG2 1.03873000
WRNM1 0.78831500	WRNM2 0.78831500	XDC1 1.68000000
XDG1 1.77000000	XDG2 1.63000000	XDM1 1.76000000
XDMXQM1 0.60300000	XDPG1 0.18000000	XDPG2 0.25000000
XDPM1 0.60800000	XDPPG1 0.15000000	XDPPG2 0.18000000
XDPPM1 0.54200000	XG1 0.10000000	XG2 0.10000000
XK3L1 2.20000000	XL1 0.10000000	XLG1 0.13000000
XLG2 0.07500000	XLM1 0.33700000	XM1 0.10000000
XMV1 0.87075800	XQG1 1.64000000	XQG2 1.01000000
XQM1 1.15700000	XQPPG1 0.15000000	XQPPG2 0.28000000
XQPPM1 0.49400000	XVS0REF 207.220000	Z99885 0.
Z99886 0.	Z99887 0.	Z99888 0.62855300
Z99889 0.	Z99891 1	Z99892 0.
Z99893 0.	Z99894 0.	Z99895 0.54962200
Z99896 0.	Z99898 1	Z99899 0.46934900
Z99900 0.	Z99901 0.46953800	Z99902 0.46949000
Z99903 0.46952500	Z99905 1	Z99906 0.85570000
Z99907 0.	Z99908 0.85570000	Z99909 0.85587100
Z99910 0.85570700	Z99912 1	Z99920 0.09909070
Z99921 0.09909070	Z99945 6.70890000	Z99946 7.16117000
Z99949 8.20411000	Z99950 8.41437000	Z99960 47
Z99961 41	Z99962 63.1062000	Z99970 29
Z99971 96.4793000	Z99974 18	Z99975 13.00000000
Z99982 116	Z99983 98	Z99984 0.
ZZSEED 55555555		



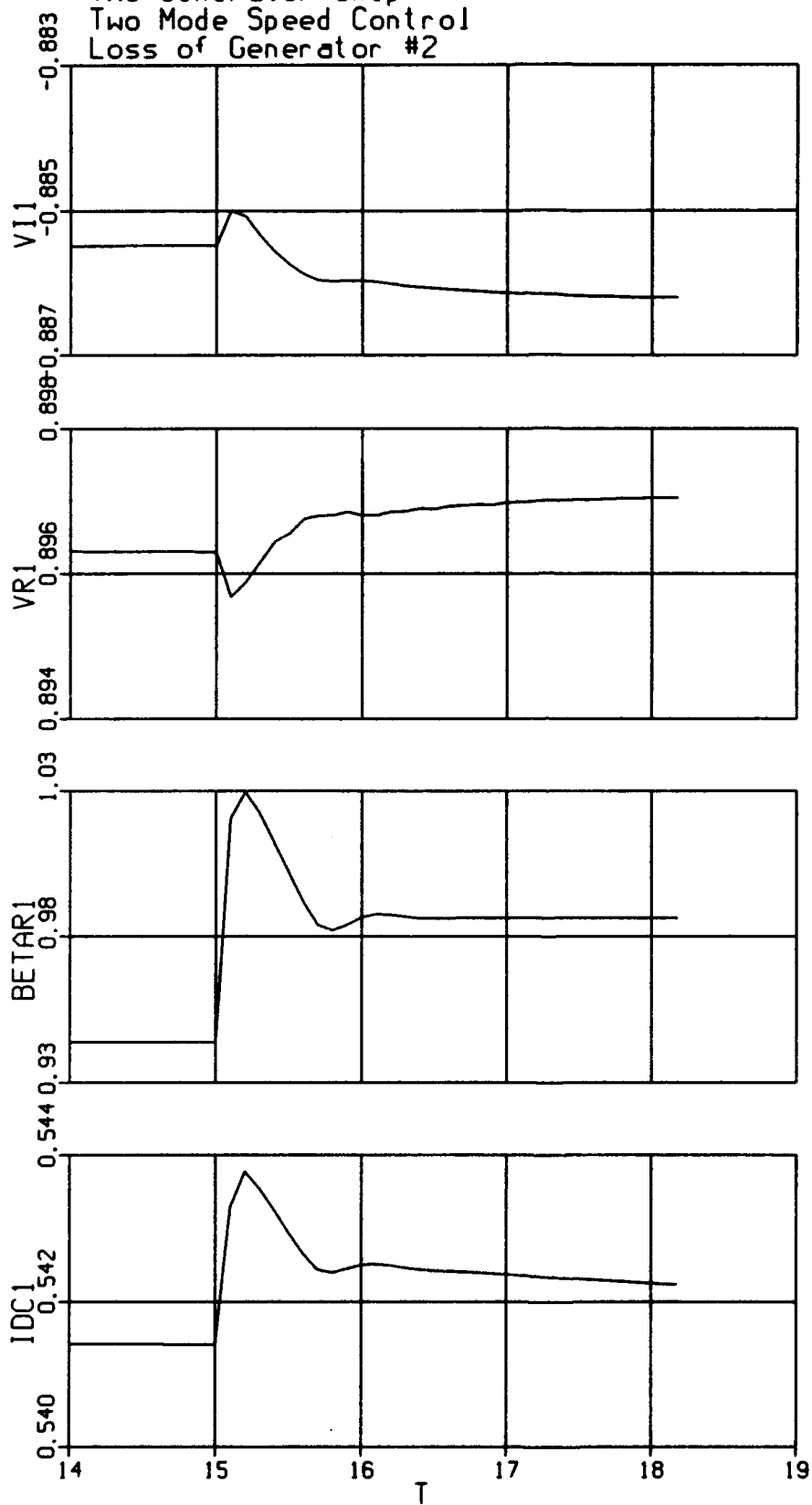
12 93/04/21 10:56:21

Two Generator Ship
Two Mode Speed Control
Loss of Generator #2



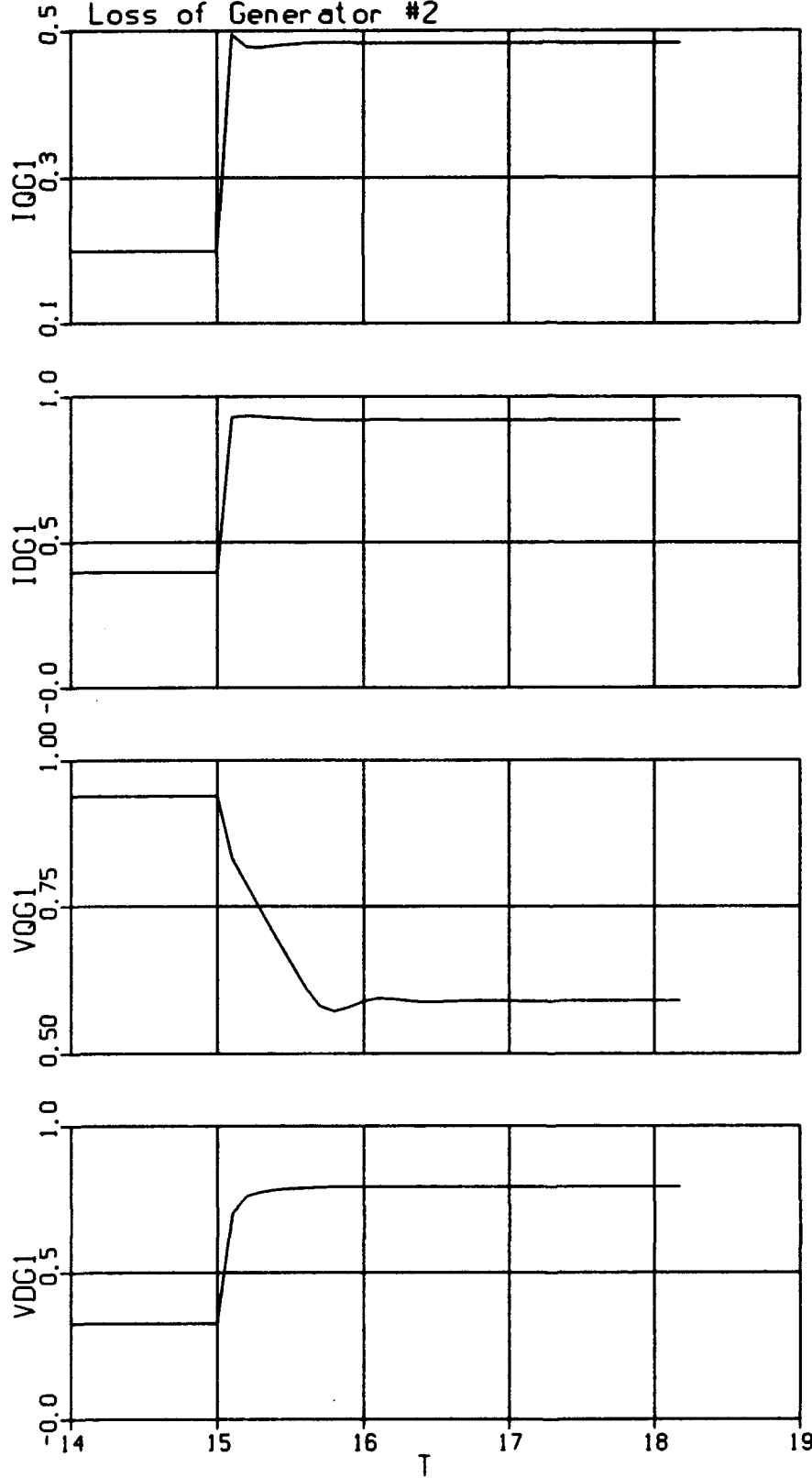
9 93/04/21 10:56:21

Two Generator Ship
Two Mode Speed Control
Loss of Generator #2



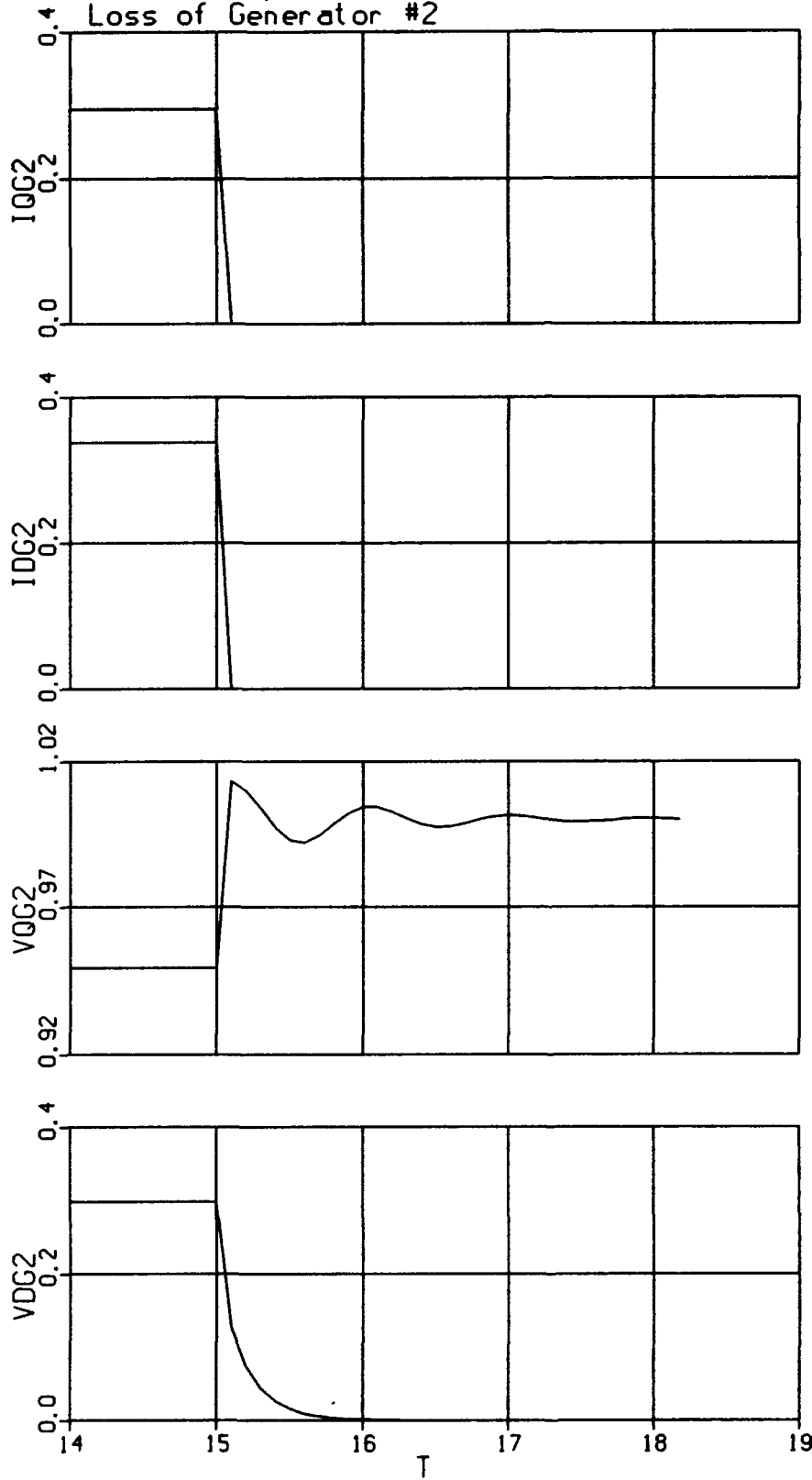
13 93/04/21 10:56:21

Two Generator Ship
Two Mode Speed Control
Loss of Generator #2



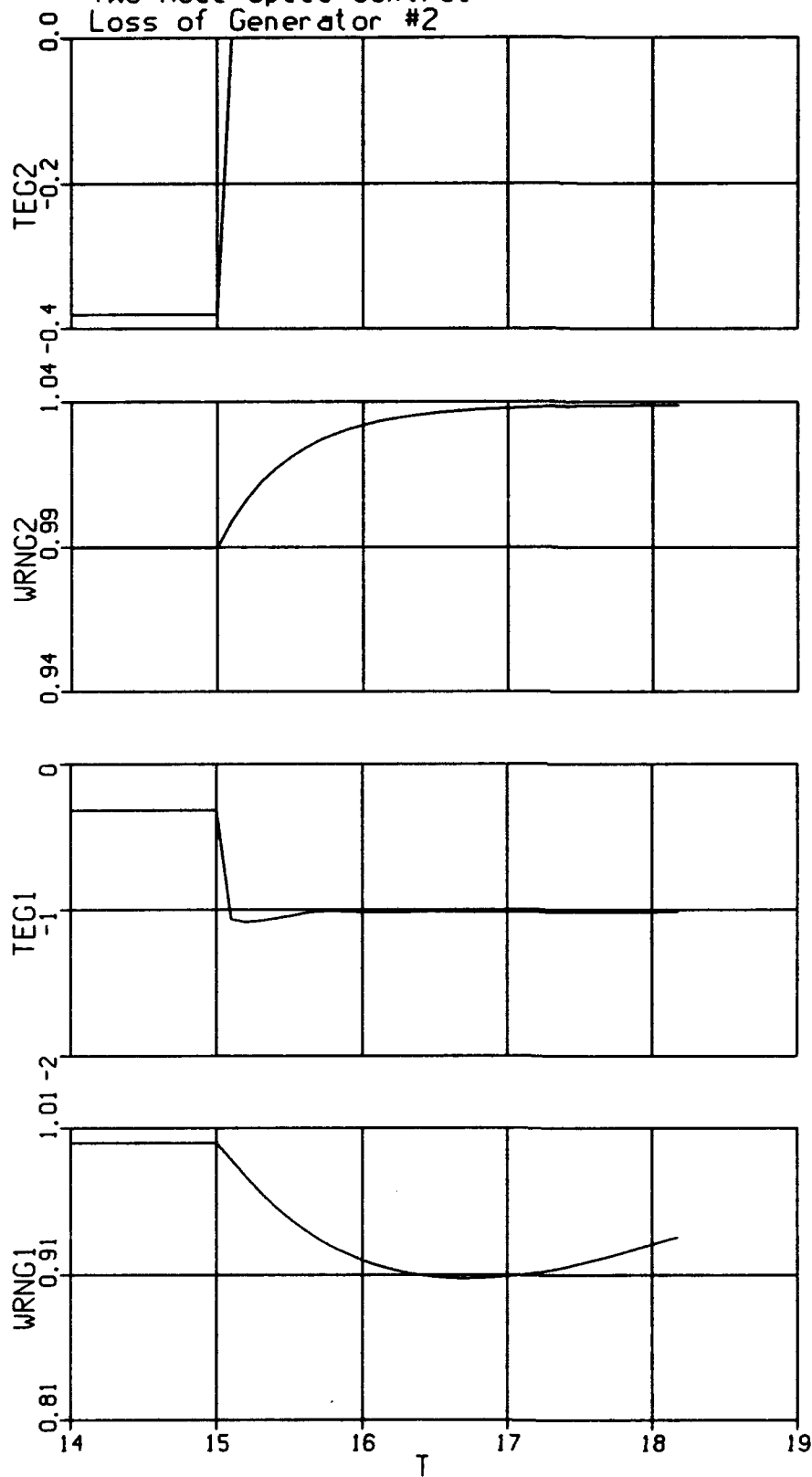
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Two Generator Ship
Two Mode Speed Control
Loss of Generator #2



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Two Generator Ship
Two Mode Speed Control
Loss of Generator #2



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Appendix E: Notes on Use of ACSL

At the beginning of this research several software packages were considered for possible use. ACSL was selected primarily due to the availability of preexisting code written in that language. The PC-Windows version of ACSL was used throughout this research. This section presents the author's views concerning this software package.

The author has previously used the UNIX version of ACSL and was impressed with its versatility and ease of use. The Windows version is very user friendly, but command line editing is awkward and difficult. When exercising a simulation, the user inputs various commands from the "ACSL prompt." With the UNIX system, the last several commands issued can be recalled by pressing the up arrow key. The command can then be edited as desired and executed by pressing the return key. The windows version does not allow this type of editing. It is possible to open a separate window for command editing, but this requires cutting and pasting with the mouse which can be time consuming. It is not known if this limitation can be overcome by the ACSL authors or if it is a limitation of the windows operating environment. Generating screen plots with ACSL is straightforward, however the Windows version lacks the proper drivers to write the plots into common PC based graphical formats for inclusion in word processor files. It will only write the plots to bitmap or neutral plot files.

The ACSL macro language is very powerful. The concatenation feature of this language is what made it possible to create the simulation models in an object oriented manner. The latest version of ACSL can be purchased with a graphical front end, similar to SIMULAB and SIMULINK which should only enhance the usefulness of the language.

One of the most useful features of the ACSL language is the numerous variety of integration algorithms available for use. The algorithm can also be changed at run-time without recompiling the model. This feature makes it very easy to compare one algorithm against another. The author has found that the variable step algorithms work best with the models developed herein. This is because there are several fast eigenvalues whose transient decays rapidly at the beginning of a simulation. The variable step algorithms take small steps until these transients die out, then are able to take larger steps during the slower ship dynamics transients.

The ACSL package is a translator which writes a FORTRAN program. A separate FORTRAN compiler is required to generate executable code from the ACSL written program. For the DOS and Windows versions of ACSL, the Microsoft FORTRAN Compiler is recommended. This compiler is fraught with problems. The simulations developed herein use several separately written FORTRAN subroutines in the gas turbine and ship dynamics models. These subroutines were up and operating on a UNIX system when provided to the author. According to the documentation, the Microsoft compiler is able to handle all UNIX extensions to FORTRAN-77 and provide many other extensions. This is not the case. Much time was spent getting these programs to compile on the Microsoft compiler when the same file would compile without error on the FORTRAN-77 compiler installed on project ATHENA. There were also occasional problems getting ACSL written code to compile on the Microsoft compiler. This centered around the definition of variables as LOGICAL type and is still not understood by the author. The size of the programs was also a problem for the compiler. After several attempts at

getting one simulation to compile, it was discovered from the Microsoft Helpline consultant that a specific command line switch must be set to compile any program over a certain size. Of course there is no mention of this limitation in the compiler documentation.

Simulation execution time became rather lengthy for the larger simulations. The two generator system would run at about one second of simulation time for every 2-3 minutes of real time. Most of the simulations described in chapter 5 took 3-5 hours to run. The PC used for simulations contained an Intel 80486-DX CPU operating at 33 MHz (one of the faster PC's available at this time). It is recommended that any future research in this area be carried out on a workstation or a mainframe computer.

Appendix F: Dictionary of Variables

In any programming effort such as this there are a large number of variables and constants which must be named. To aid in this task as well as increase the readability of the code, a set of naming conventions was developed. This can be summarized by the following rules:

1. All logical variables begin with the letter "L".
2. Controller gains begin with the letter "G".
3. Controller time constants begin with the letters "TAU".
4. Miscellaneous constants begin with the letter "K".
5. Initial conditions add the suffix "IC" (or "I") to the base variable name.
6. Derivatives add the suffix "D" to the base variable name.
7. When macros are invoked in a program, the concatenation variable is used as a designation of that unit (ie. G1 for generator #1, M1 for motor #1, etc.).

This convention evolved during the course of this research and parts of the code were written by others, so currently it is not in 100% compliance with this convention. However, the above rules are a useful guide to the reader in decyphering the code. What follows is an alphabetical listing of variables with their meaning and units. As mentioned previously, some of the code used was written previously by others, thus the purpose of all internal variables is not known.

AFL1	GT #1 MFC acceleration limit	Unknown
AFRL1	GT #1 MFC feedback signal	Unknown
ALPHA1	GT #1 PLA	Degrees
ALPHA1LL	GT #1 PLA lower limit	Degrees
ALPHA1UL	GT #1 PLA upper limit	Degrees
ALPHAG1	Gen. #1 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAG2	Gen. #2 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAM1	Mtr. #1 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAM2	Mtr. #2 Ratio of Reactances, See eq. (2.7)	NONE
ARLLG1I	GT #1 MFC feedback signal IC	Unknown
BASEKWG1	Gen. #1 Base Power	KW
BASEKWG2	Gen. #2 Base Power	KW
BASEKWM1	Mtr. #1 Base Power	KW
BASEKWM2	Mtr. #2 Base Power	KW
BASENG1	Gen #1 Base Speed	RPM
BASENG2	Gen. #2 Base Speed	RPM
BASENM1	Mtr. #1 Base Speed	RPM
BASENM2	Mtr. #2 Base Speed	RPM
BASEQM1	Mtr. #1 Base Torque	FT.-LBF.
BASEQM2	Mtr. #2 Base Torque	FT.-LBF.
BASEVG1	Gen. #1 Base Voltage	Volts
BASEVG2	Gen. #2 Base Voltage	Volts
BASEVM1	Mtr. #1 Base Voltage	Volts
BASEVM2	Mtr. #2 Base Voltage	Volts
BETAI1	Inverter #1 firing angle	Radians
BETAI2	Inverter #2 firing angle	Radians
BETAM1	Inverter #1 firing angle	Radians
BETAM2	Inverter #2 firing angle	Radians
BETAMINM1	Inverter #1 minimum allowable firing angle	Radians
BETAMINM2	Inverter #2 minimum allowable firing angle	Radians
BETAMAXM1	Inverter #1 maximum allowable firing angle	Radians
BETAMAXM2	Inverter #2 maximum allowable firing angle	Radians
BETAR1	Rectifier #1 firing angle	Radians
BETAR2	Rectifier #2 firing angle	Radians

CQLID1	GT #1 load interface miscellaneous constant	FT-LB/RPM ²
CYL2	Diesel #2 Number of Cylinders	NONE
DELAY2	Diesel #2 Torque time lag	Seconds
DELG1	Gen. #1 Torque (or load) angle	Radians
DELG2	Gen. #2 Torque (or load) angle	Radians
DELI1	Inverter #1 Load angle	Radians
DELI2	Inverter #2 Load angle	Radians
DELM1	Mtr. #1 Load angle	Radians
DELM2	Mtr. #2 Load angle	Radians
DELR1	Rectifier #1 Load angle	Radians
DELR2	Rectifier #2 Load angle	Radians
DELTA2	GT #1 ambient pressure correction factor	None
DELV	Implicit equation solver increment step size	None
DELVTQ1	GT #1 FSEE internal variable	Unknown
DELWF1	GT #1 gas generator internal variable	Unknown
DELWF1I	IC of DELWF1	Unknown
DFL1	GT #1 MFC deceleration limit	Unknown
DFRL1	GT #1 MFC feedback signal	Unknown
DN1	Derivative of GT #1 power turbine speed	RPM/Sec.
DNGG1	GT #1 demand gas generator speed	RPM
DNPT1	Derivative of GT #1 power turbine speed	RPM/Sec.
DNREF1	GT #1 power turbine RPM rate limit	RPM/Sec.
DQ4S1	GT #1 gas generator internal variable	Unknown
DQHR21	GT #1 gas generator internal variable	Unknown
DQPTR1	GT #1 power turbine internal variable	Unknown
DRLLG1I	GT #1 internal variable	Unknown
DRPMDT1	GT #1 FSEE internal variable	Unknown
DT4HS1	GT #1 power turbine internal variable	Unknown
DT51HS1	GT #1 power turbine internal variable	Unknown
DZ1	Hysteresis in motor #1 speed control	per unit
DZ2	Hysteresis in motor #2 speed control	per unit
E01I	GT #1 FSEE internal variable	Unknown
E21I	GT #1 FSEE internal variable	Unknown
E22I	GT #1 FSEE internal variable	Unknown

E231	GT #1 FSEE internal variable	Unknown
E51	GT #1 FSEE internal variable	Unknown
E61	GT #1 FSEE internal variable	Unknown
E71	GT #1 FSEE internal variable	Unknown
E81	GT #1 FSEE internal variable	Unknown
E91	GT #1 FSEE internal variable	Unknown
EA FerrM1	Mtr. #1 Excitation excitation error signal	per unit
EA FerrM2	Mtr. #2 Excitation excitation error signal	per unit
EA FG1	Gen. #1 Excitation	per unit
EA FG1D	Gen. #1 Excitation derivative	per unit
EA FG1IC	Gen. #1 Excitation initial condition	per unit
EA FG2	Gen. #2 Excitation	per unit
EA FG2D	Gen. #2 Excitation derivative	per unit
EA FG2IC	Gen. #2 Excitation initial condition	per unit
EA FM1	Mtr. #1 Excitation	per unit
EA FM1D	Mtr. #1 Excitation derivative	per unit
EA FM1IC	Mtr. #1 Excitation initial condition	per unit
EA FM2	Mtr. #2 Excitation	per unit
EA FM2D	Mtr. #2 Excitation derivative	per unit
EA FM2IC	Mtr. #2 Excitation initial condition	per unit
EA FM1MAX	Mtr. #1 Maximum excitation	per unit
EA FM1MIN	Mtr. #1 Minimum excitation	per unit
EA FM2MAX	Mtr. #2 Maximum excitation	per unit
EA FM2MIN	Mtr. #2 Minimum excitation	per unit
EA FMAXG1	Gen. #1 Maximum excitation	per unit
EA FMING1	Gen. #1 Minimum excitation	per unit
EA FMAXG2	Gen. #2 Maximum excitation	per unit
EA FMING2	Gen. #2 Minimum excitation	per unit
EA FSM1	Mtr. #1 Excitation set point	per unit
EA FSM2	Mtr. #2 Excitation set point	per unit
EDPPG1	Gen #1 D-axis voltage behind subtransient reactance	per unit
EDPPG1D	EDPPG1 derivative	per unit/Sec.
EDPPG1IC	EDPPG1 initial condition	per unit
EDPPG2	Gen #2 D-axis voltage behind subtransient reactance	per unit

EDPPG2D	EDPPG2 derivative	per unit/Sec.
EDPPG2IC	EDPPG2 initial condition	per unit
EDPPM1	Mtr #1 D-axis voltage behind subtransient reactance	per unit
EDPPM1D	EDPPM1 derivative	per unit/Sec.
EDPPM1IC	EDPPM1 initial condition	per unit
EDPPM2	Mtr #2 D-axis voltage behind subtransient reactance	per unit
EDPPM2D	EDPPM2 derivative	per unit/Sec.
EDPPM2IC	EDPPM2 initial condition	per unit
EI1	Inverter #1 AC-side voltage magnitude	per unit
EI2	Inverter #2 AC-side voltage magnitude	per unit
EISM1	Mtr #1 desired stator flux magnitude	per unit
EISM2	Mtr #2 desired stator flux magnitude	per unit
EMFFB1	GT #1 MFC internal constant	Unknown
EMFSAT1	GT #1 MFC internal variable	Unknown
ENG1	GT #1 gas generator speed error signal	RPM
ENPT1	GT #1 FSEE internal variable	Unknown
ENPT1I	GT #1 FSEE internal variable	Unknown
EPM1	Round rotor component of EISM1	per unit
EPM2	Round rotor component of EISM2	per unit
EQPG1	Gen #1 Q-axis voltage behind transient reactance	per unit
EQPG1D	EQPG1 derivative	per unit/Sec.
EQPG1IC	EQPG1 initial condition	per unit
EQPG2	Gen #2 Q-axis voltage behind transient reactance	per unit
EQPG2D	EQPG2 derivative	per unit/Sec.
EQPG2IC	EQPG2 initial condition	per unit
EQPM1	Mtr #1 Q-axis voltage behind transient reactance	per unit
EQPM1D	EQPM1 derivative	per unit/Sec.
EQPM1IC	EQPM1 initial condition	per unit
EQPM2	Mtr #2 Q-axis voltage behind transient reactance	per unit
EQPM2D	EQPM2 derivative	per unit/Sec.
EQPM2IC	EQPM2 initial condition	per unit
EQPPG1	Gen #1 Q-axis voltage behind subtransient reactance	per unit
EQPPG1D	EQPPG1 derivative	per unit/Sec.
EQPPG1IC	EQPPG1 initial condition	per unit

EQPPG2	Gen #2 Q-axis voltage behind subtransient reactance	per unit
EQPPG2D	EQPPG2 derivative	per unit/Sec.
EQPPG2IC	EQPPG2 initial condition	per unit
EQPPM1	Mtr #1 Q-axis voltage behind subtransient reactance	per unit
EQPPM1D	EQPPM1 derivative	per unit/Sec.
EQPPM1IC	EQPPM1 initial condition	per unit
EQPPM2	Mtr #2 Q-axis voltage behind subtransient reactance	per unit
EQPPM2D	EQPPM2 derivative	per unit/Sec.
EQPPM2IC	EQPPM2 initial condition	per unit
ER1	Rectifier #1 AC-side voltage magnitude	per unit
ER2	Rectifier #2 AC-side voltage magnitude	per unit
ERRBOUND	Max allowable error for implicit loop solve routine	per unit
ERX1	GT #1 MFC internal variable	Unknown
FARG0	Function look up table index	None
FARG1	Function look up table index	None
FARG2	Function look up table index	None
FARG3	Function look up table index	None
FARGS0	Function look up table index	None
FARGS1	Function look up table index	None
FARGS2	Function look up table index	None
FARGS3	Function look up table index	None
FUEL2	Diesel #2 fuel rack position	per unit
FUEL2MAX	Diesel #2 fuel rack maximum position	per unit
FUEL2MIN	Diesel #2 fuel rack minimum position	per unit
FUELAG2	Diesel #2 injection delay	Seconds
G11	GT #1 power turbine torque limit gain	None
G31	GT #1 power turbine RPM limit gain	None
G51	GT #1 power turbine RPM rate limit gain	None
GBETAR1	Rectifier #1 firing angle controller gain	None
GBETAR2	Rectifier #2 firing angle controller gain	None
GEAFG1	Gen. #1 Excitation controller gain	None
GEAFG2	Gen. #2 Excitation controller gain	None
GEAFM1	Mtr. #1 Excitation controller gain	None
GEAFM2	Mtr. #2 Excitation controller gain	None

GLARGE1	Mtr. #1 speed control "fast mode" gain	None
GLARGE2	Mtr. #2 speed control "fast mode" gain	None
GM1	Mtr. #1 braking resistor conductance value	per unit
GM2	Mtr. #2 braking resistor conductance value	per unit
GSMALL1	Mtr. #1 speed control "slow mode" gain	None
GSMALL2	Mtr. #2 speed control "slow mode" gain	None
GSPEED1	Mtr. #1 speed control gain	None
GSPEED2	Mtr. #2 speed control gain	None
HG1	Gen. #1 inertia constant	Seconds
HG2	Gen. #2 inertia constant	Seconds
HHPS	Propeller / shaft inertia constant	Seconds
HM1	Mtr. #1 inertia constant	Seconds
HM2	Mtr. #2 inertia constant	Seconds
HP1	GT #1 generator horsepower	Horsepower
HP1B	GT #1 power turbine base horsepower	Horsepower
HP1D	GT #1 limited horsepower demand	Horsepower
HP1I	GT #1 generator horsepower IC	Horsepower
HP1ORD	GT #1 ordered horsepower (constant power mode)	Horsepower
HP1ORDI	GT #1 ordered horsepower IC(const. power mode)	Horsepower
HPT1ORD	GT #1 ordered horsepower	Horsepower
IAJXQM1	Product of motor current and xq	per unit
IAJXQM2	Product of motor current and xq	per unit
IAM1	Mtr #1 armature current magnitude	per unit
IAM2	Mtr #2 armature current magnitude	per unit
ICLIM1	GT #1 governor integral control limit	Unknown
ICNTRL1	GT #1 governor integral control	Unknown
ICNTRL1I	GT #1 governor integral control IC	Unknown
ID1GR	Unknown	Unknown
IDBM1	Mtr. #1 braking resistor D-axis current	per unit
IDBM2	Mtr. #2 braking resistor D-axis current	per unit
IDC1	Freq. changer #1 DC-link current	per unit
IDC1D	Freq. changer #1 DC-link current derivative	per unit
IDC1IC	Freq. changer #1 DC-link current IC	per unit
IDC2	Freq. changer #2 DC-link current	per unit

IDC2D	Freq. changer #2 DC-link current derivative	per unit
IDC2IC	Freq. changer #2 DC-link current IC	per unit
IDCBG2	Gen. #2 circuit breaker D-axis current	per unit
IDCOM1	Freq. changer #1 commanded DC-link current	per unit
IDCOM2	Freq. changer #2 commanded DC-link current	per unit
IDCR1	Freq. changer #1 reference DC-link current	per unit
IDCR1D	Freq. chgr. #1 reference DC-link current derivative	per unit/Sec.
IDCR1DMAX	Freq. chgr. #1 ref. DC-link current deriv. max limit	per unit/Sec.
IDCR1DMIN	Freq. chgr. #1 ref. DC-link current deriv. min limit	per unit/Sec.
IDCR1MAX	Freq. chgr. #1 ref. DC-link current max limit	per unit
IDCR1MIN	Freq. chgr. #1 ref. DC-link current min limit	per unit
IDCR1IC	Freq. changer #1 reference DC-link current IC	per unit
IDCR2	Freq. changer #2 reference DC-link current	per unit
IDCR2D	Freq. chgr. #2 reference DC-link current derivative	per unit/Sec.
IDCR2IC	Freq. changer #2 reference DC-link current IC	per unit
IDCR2DMAX	Freq. chgr. #2 ref. DC-link current deriv. max limit	per unit/Sec.
IDCR2DMIN	Freq. chgr. #2 ref. DC-link current deriv. min limit	per unit/Sec.
IDCR2MAX	Freq. chgr. #2 ref. DC-link current max limit	per unit
IDCR2MIN	Freq. chgr. #2 ref. DC-link current min limit	per unit
IDG1	Gen. #1 D-axis stator current	per unit
IDG1IC	Gen. #1 D-axis stator current IC	per unit
IDG1M1	Gen. #1 D-axis stator current on Mtr. #1 base	per unit
IDG2	Gen. #2 D-axis stator current	per unit
IDG2ERR	Gen. #2 D-axis stator current error	per unit
IDG2IC	Gen. #2 D-axis stator current IC	per unit
IDG2M1	Gen. #2 D-axis stator current on Mtr. #1 base	per unit
IDI1	Inverter #1 D-axis current	per unit
IDI2	Inverter #2 D-axis current	per unit
IDL2	Ship's service load D-axis current	per unit
IDM1	Mtr. #1 D-axis stator current	per unit
IDM1IC	Mtr. #1 D-axis stator current IC	per unit
IDM2	Mtr. #2 D-axis stator current	per unit
IDM2IC	Mtr. #2 D-axis stator current IC	per unit
IDR1	Rectifier #1 D-axis current	per unit

IDR2	Rectifier #2 D-axis current	per unit
IDXM1	Mtr. #1 salient component of armature reaction flux	per unit
IDXM2	Mtr. #2 salient component of armature reaction flux	per unit
IERR1	Freq. chgr. #1 DC-link current error	per unit
IERR1IC	Freq. chgr. #1 DC-link current error IC	per unit
IERR2	Freq. chgr. #2 DC-link current error	per unit
IERR2IC	Freq. chgr. #2 DC-link current error IC	per unit
IGG1	GT. #1 gas generator inertia constant	lbm-ft ²
IITID1	Unknown	Unknown
IQBM1	Mtr. #1 braking resistor Q-axis current	per unit
IQBM2	Mtr. #2 braking resistor Q-axis current	per unit
IQCBG2	Gen. #2 circuit breaker Q-axis current	per unit
IQG1	Gen. #1 Q-axis stator current	per unit
IQG1IC	Gen. #1 Q-axis stator current IC	per unit
IQG2	Gen. #2 Q-axis stator current	per unit
IQG2ERR	Gen. #2 Q-axis stator current error	per unit
IQG2IC	Gen. #2 Q-axis stator current IC	per unit
IQG2M1	Gen. #2 Q-axis stator current on Mtr. #1 base	per unit
IQI1	Inverter #1 Q-axis current	per unit
IQI2	Inverter #2 Q-axis current	per unit
QIL2	Ship's service load Q-axis current	per unit
IQM1	Mtr. #1 Q-axis stator current	per unit
IQM1IC	Mtr. #1 Q-axis stator current IC	per unit
IQM2	Mtr. #2 Q-axis stator current	per unit
IQM2IC	Mtr. #2 Q-axis stator current IC	per unit
IQR1	Rectifier #1 Q-axis current	per unit
IQR2	Rectifier #2 Q-axis current	per unit
JJG	GT #1 generator inertia	lbm-ft ²
JJPROP	Propeller inertia	lbm-ft ²
JJPS	Propeller & shaft inertia	lbm-ft ²
JJPT1	GT #1 power turbine inertia	lbm-ft ²
JJSHFT	Propeller shaft inertia	lbm-ft ²
K00RES	Ship hull dynamics constant	Unknown
K01RES	Ship hull dynamics constant	Unknown

K02RES	Ship hull dynamics constant	Unknown
K03RES	Ship hull dynamics constant	Unknown
K04RES	Ship hull dynamics constant	Unknown
K05RES	Ship hull dynamics constant	Unknown
K06RES	Ship hull dynamics constant	Unknown
K07RES	Ship hull dynamics constant	Unknown
K08RES	Ship hull dynamics constant	Unknown
K09RES	Ship hull dynamics constant	Unknown
K10RES	Ship hull dynamics constant	Unknown
KALARM	GT #1 alarm condition flag	None
KBRAKE1	Mtr. #1 braking resistor constant	None
KBRAKE2	Mtr. #2braking resistor constant	None
KC11	GT #1 governor gain	None
KDFRQ	Seaway encounter wavenumber	Rad. / Ft.
KGC	GT #1 pounds mass to slugs conversion factor	lbm-ft / lbf-sec ²
KGOV2	Diesel #2 governer gain	None
KHOLDPI1	GT #1 governor limit constant	None
KI	GT #1 rotational acceleration conversion factor	lbm-rpm-ft / lbf-sec
KIG1M1	Gen. #1 current base conversion factor	None
KIG2M1	Gen. #2 current base conversion factor	None
KKWG1M1	Gen. #1 power base conversion factor	None
KK1G2M1	Gen. #2 power base conversion factor	None
KPNGG1	GT #1 percent base gas generator speed	1 / RPM
KQHP	GT #1 torque-rpm to horsepower conversion factor	ft-lbf / min-hp
KRAT1	GT #1 FSEE constant	None
KRATE1	GT #1 FSEE constant	None
KSHTDN1	GT #1 shutdown flag	None
KTBL1	GT #1 table overrun flag	None
KTURBO2	Diesel #2 turbocharger constant	None
KVG1M1	Gen. #1 voltage base conversion factor	None
KVG2M1	Gen. #2 voltage base conversion factor	None
KVSHIP	Ship speed per unit conversion factor	Unknown
KZG1M1	Gen. #1 base impedance conversion factor	None

KZG2M1	Gen. #2 base impedance conversion factor	None
LBRAKE1	Mtr. #1 braking condition logical flag	None
LBRAKE2	Mtr. #2 braking condition logical flag	None
LCBG2	Gen. #2 circuit breaker logical flag	None
LDOPLR	Seaway doppler logical flag	None
LFWD1	Mtr. #1 forward torque logical flag	None
LFWD2	Mtr. #2 forward torque logical flag	None
LHEADR	Headreach calculation logical flag (disabled)	None
LHOLD1PI	GT #1 governor logical flag	None
LNGG1A	GT #1 alarm flag	None
LPWRD1	GT #1 power demand flag	None
LSEA	Seaway flag	None
LT541A	GT #1 alarm flag	None
MAXIT	Maximum # of iterations for implicit loop solutions	None
MFKAC1	GT #1 MFC constant	Unknown
MFKFR1	GT #1 MFC constant	Unknown
MFKMV1	GT #1 MFC constant	Unknown
MFKN1	GT #1 MFC constant	Unknown
MFW1	GT #1 MFC constant array	Unknown
N1	Gen. #1 speed	RPM
N1I	Gen. #1 speed IC	RPM
N2	Gen. #2 speed	RPM
NERR1	Gen. #1 speed error	RPM
NGB	Genarator base rpm	RPM
NGG1B	GT #1 base gas generator speed	RPM
NGGL1	GT #1 MFC output gas generator speed	RPM
NMAX2	Diesel #2 maximum speed	RPM
NMIN2	Diesel #2 minimum speed	RPM
NP1PU	#1 Propeller shaft speed	per unit
NP1PUI	#1 Propeller shaft speed IC	per unit
NP1RPM	#1 Propeller shaft speed	RPM
NP1RPMI	#1 Propeller shaft speed IC	RPM
NP2PU	#2 Propeller shaft speed	per unit
NP2PUI	#2 Propeller shaft speed IC	per unit

NP2RPM	#2 Propeller shaft speed	RPM
NP2RPMI	#2 Propeller shaft speed IC	RPM
NPRPMB	Base propeller speed	RPM
NPRPSB	Base propeller speed	RPS
NPT1B	GT #1 power turbine base speed	RPM
NPT1ORD	GT #1 power turbine ordered speed	RPM
NPT1ORDI	GT #1 power turbine ordered speed IC	RPM
NPT1R	GT #1 power turbine reference speed	RPM
NPT1RI	GT #1 power turbine reference speed IC	RPM
NPTL1	GT #1 FSEE internal variable	Unknown
NPTQ1	GT #1 FSEE internal variable	Unknown
NPTQ1I	GT #1 FSEE internal variable IC	Unknown
NPTR1	GT #1 power turbine internal variable	Unknown
NPTR1I	GT #1 power turbine internal variable IC	Unknown
NREF1	GT #1 power turbine speed limit	RPM
NSET2	Diesel #2 governor setpoint speed	RPM
P1	Ship's service real load power setting	per unit
P2	GT #1 compressor inlet pressure	psia
P2T21	GT #1 FSEE internal constant	Unknown
P541	GT #1 power turbine exhaust pressure	psia
P541I	GT #1 power turbine exhaust pressure IC	psia
P54L1	GT #1 FSEE internal constant	Unknown
P54LL1	GT #1 FSEE internal constant	Unknown
P54Q1	GT #1 FSEE internal constant	Unknown
P54Q1I	GT #1 FSEE internal constant IC	Unknown
P54R21	GT #1 internal constant	Unknown
P54R21I	GT #1 internal constant IC	Unknown
PAMB	Ambient pressure	psia
PCNTRL1	GT #1 governor proportional control	None
PCNTRL1I	GT #1 governor proportional control IC	None
PCTID1	Unknown	Unknown
PHIPM1	Mtr. #1 armature current angle	Radians
PHIPM2	Mtr. #2 armature current angle	Radians
PHISM1	Mtr #1 desired power factor angle	Radians

PHISM2	Mtr #2 desired power factor angle	Radians
PNGG1	GT #1 percent gas generator speed	percent
PNGGR1	GT #1 gas generator internal variable	Unknown
PNGGR1I	GT #1 gas generator internal variable IC	Unknown
PS31	GT #1 compressor discharge pressure	psia
PS31I	GT #1 compressor discharge pressure IC	psia
PS3R21	GT #1 gas generator internal variable	Unknown
PS3R21I	GT #1 gas generator internal variable IC	Unknown
PS3WC1	GT #1 MFC internal variable	Unknown
PWRD1	GT #1 governor power demand	percent
PWRD1I	GT #1 governor power demand IC	percent
Q1	Ship's service load reactive power setting	per unit
Q41	GT #1 gas generator internal variable	Unknown
Q4R21	GT #1 gas generator internal variable	Unknown
QCAL1	GT #1 FSEE internal variable	Unknown
QCAL1I	GT #1 FSEE internal variable	Unknown
QGB	Gen. #1 base torque	Ft-lbf
QH1	GT #1 gas generator internal variable	Unknown
QLID1	GT #1 internal variable	Unknown
QLID1I	GT #1 internal variable	Unknown
QMAP1	GT #1 FSEE internal variable	Unknown
QMAP1I	GT #1 FSEE internal variable	Unknown
QMAPL1	GT #1 FSEE internal variable	Unknown
QP1	#1 propeller shaft torque	Ft-lbf
QP1F	#1 propeller shaft friction torque	Ft-lbf
QP1FI	#1 propeller shaft friction torque IC	Ft-lbf
QP1I	#1 propeller shaft torque IC	Ft-lbf
QP1PU	#1 propeller shaft torque	per unit
QP1PUI	#1 propeller shaft torque	per unit
QP2	#2 propeller shaft torque	Ft-lbf
QP2F	#2 propeller shaft friction torque	Ft-lbf
QP2FI	#2 propeller shaft friction torque IC	Ft-lbf
QP2I	#2 propeller shaft torque IC	Ft-lbf
QP2PU	#2 propeller shaft torque	per unit

QP2PUI	#2 propeller shaft torque	per unit
QPBASE	Propeller shaft base torque	per unit
QPSBAF	Propeller shaft breakaway friction	Ft-lbf
QPT1	GT #1 power turbine torque	Ft-lbf
QPT1B	GT #1 power turbine base torque	Ft-lbf
QPT1I	GT #1 power turbine torque IC	Ft-lbf
QPT1PU	GT #1 power turbine torque	per unit
QREF1	GT #1 torque reference	Ft-lbf
RDC1	#1 DC-link resistance	per unit
RDC2	#2 DC-link resistance	per unit
RS1PU0	Ship resistance component	Unknown
RS1PU1	Ship resistance component	Unknown
RS1PU2	Ship resistance component	Unknown
RS1PU3	Ship resistance component	Unknown
RS1PU	Ship resistance component	Unknown
RS1PUI0	Ship resistance component	Unknown
RS1PUI1	Ship resistance component	Unknown
RS1PUI2	Ship resistance component	Unknown
RS1PUI3	Ship resistance component	Unknown
RS1PUI	Ship resistance component	Unknown
SEAFREQ	Doppler shifted wave frequency	Rad. / Sec.
SEATIME	Phase shifted time for seaway calculation	Seconds
NEGVL1	GT #1 FSEE internal variable	Unknown
SPDERR1IC	#1 shaft speed error IC	per unit
SPDERR2	Diesel #2 speed error	RPM
SPDERR2IC	#2 shaft speed error IC	per unit
SPDREF1	Propeller #1 shaft speed reference	per unit
SPDREF2	Propeller #2 shaft speed reference	per unit
SPEEDERR1	Propeller #1 shaft speed error	per unit
SPEEDERR2	Propeller #2 shaft speed error	per unit
SQRT2	GT #1 nondimensional temperature constant	None
SWITCHVAR1	Propeller #1 shaft speed error with hysteresis	per unit
SWITCHVAR2	Propeller #2 shaft speed error with hysteresis	per unit
T0SEA	Time reference for seaway calculations	Seconds

T2	GT #1 compressor inlet temperature	° R
T41	GT #1 gas generator internal variable	Unknown
T4P1	GT #1 gas generator internal variable	Unknown
T4PL1	GT #1 gas generator internal variable	Unknown
T4R21	GT #1 gas generator internal variable	Unknown
T4U1	GT #1 gas generator internal variable	Unknown
T511	GT #1 gas tenerator exhaust temperature	° F
T51P1	GT #1 power turbine internal variable	Unknown
T51PL1	GT #1 power turbine internal variable	Unknown
T51Q1	GT #1 power turbine internal variable	Unknown
T51R21	GT #1 power turbine internal variable	Unknown
T51U1	GT #1 power turbine internal variable	Unknown
T541	GT #1 power turbine inlet temperature	° F
TABTR11	GT #1 FSEE internal variable	Unknown
TALPHA1	GT #1 governor load compensation value	None
TAMB	GT #1 ambient temperature	° F
TAUBETAR1	Rectifier #1 controller time constant	Seconds
TAUBETAR2	Rectifier #2 controller time constant	Seconds
TAUEAFG1	Gen. #1 field excitation controller time constant	Seconds
TAUEAFG2	Gen. #2 field excitation controller time constant	Seconds
TAUEAFM1	Mtr. #1 field excitation controller time constant	Seconds
TAUEAFM2	Mtr. #2 field excitation controller time constant	Seconds
TAUFAST1	Staft #1 speed controller "fast mode" time constant	Seconds
TAUFAST2	Staft #2 speed controller "fast mode" time constant	Seconds
TAUGOV2	Diesel #2 governer time constant	Seconds
TAUSLOW1	Staft #1 speed controller "slow mode" time constant	Seconds
TAUSLOW2	Staft #2 speed controller "slow mode" time constant	Seconds
TAUSPEED1	Staft #1 speed controller time constant	Seconds
TAUSPEED2	Staft #2 speed controller time constant	Seconds
TC11	GT #1 governor time constant	Seconds
TDOPG1	Gen. #1 D-axis open circuit transient time constant	Seconds
TDOPG2	Gen. #2 D-axis open circuit transient time constant	Seconds
TDOPM1	Mtr. #1 D-axis open circuit transient time constant	Seconds
TDOPM2	Mtr. #2 D-axis open circuit transient time constant	Seconds

TDOPPG1	Gen. #1 D-axis open ckt subtransient time constant	Seconds
TDOPPG2	Gen. #2 D-axis open ckt subtransient time constant	Seconds
TDOPPM1	Mtr. #1 D-axis open ckt subtransient time constant	Seconds
TDOPPM2	Mtr. #2 D-axis open ckt subtransient time constant	Seconds
TDT541	GT #1 gas gen. exhaust to PT inlet temp difference	° F
TEG1	Gen. #1 electromagnetic torque	per unit
TEG1IC	Gen. #1 electromagnetic torque IC	per unit
TEG2	Gen. #2 electromagnetic torque	per unit
TEG2IC	Gen. #2 electromagnetic torque IC	per unit
TEM1	Mtr. #1 electromagnetic torque	per unit
TEM2	Mtr. #2 electromagnetic torque	per unit
TESM1	Gen. #1 electromagnetic torque for GT use	ft-lbf
TESM1I	Gen. #1 electromagnetic torque for GT use IC	ft-lbf
TGLAG1	GT #1 FSEE internal variable	Unknown
THDOT21	GT #1 internal variable	Unknown
THET2N	GT #1 nondimensional constant	None
THETA2	GT #1 nondimensional temperature	None
THRESHOLD1	Shaft #1 speed error required for switching control modes	per unit
THRESHOLD2	Shaft #2 speed error required for switching control modes	per unit
THTA2V	GT #1 constant	None
TIC1	GT #1 throttle input command	Degrees
TIC1LL	GT #1 throttle input command lower limit	Degrees
TIC1UL	GT #1 throttle input command upper limit	Degrees
TICMD1	GT #1 governor control signal	Degrees
TICMD1I	GT #1 governor control signal IC	Degrees
TICN1	GT #1 governor PI control signal	Degrees
TICN1I	GT #1 governor PI control signal IC	Degrees
TICRL1LL	GT #1 governor control signal lower rate limit	Deg. / Sec.
TICRL1UL	GT #1 governor control signal upper rate limit	Deg. / Sec.
TICS1	GT #1 governor power demand control signal	Degrees
TICS1I	GT #1 governor power demand control signal IC	Degrees
TMAP	Diesel #1 torque map table	per unit
TMG2	Gen. #2 mechanical torque	per unit

TMM1	Mtr. #1 mechanical torque	per unit
TMM2	Mtr. #2 mechanical torque	per unit
TORQ2	Diesel #2 instantaneous torque	per unit
TP1PU	Shaft #1 propeller thrust	per unit
TP1PUI	Shaft #1 propeller thrust IC	per unit
TP2PU	Shaft #2 propeller thrust	per unit
TP2PUI	Shaft #2 propeller thrust IC	per unit
TQOPPG1	Gen. #1 Q-axis open ckt subtransient time constant	Seconds
TQOPPG2	Gen. #2 Q-axis open ckt subtransient time constant	Seconds
TQOPPM1	Mtr. #1 Q-axis open ckt subtransient time constant	Seconds
TQOPPM2	Mtr. #2 Q-axis open ckt subtransient time constant	Seconds
TSEA	Seaway wave period	Seconds
TSTOP	Simulation termination time	Seconds
TURBOLAG2	Diesel #2 turbocharger lag	Seconds
TUT4H1	GT #1 gas generator internal variable	Unknown
TUT5IH1	GT #1 power turbine internal variable	Unknown
TVS0REF	Reference ship stopping time	Seconds
U1	Rectifier #1 control variable	None
U1D	Rectifier #1 control variable IC	None
U2	Rectifier #2 control variable	None
U2D	Rectifier #2 control variable IC	None
UMAX1	Rectifier #1 control variable maximum value	None
UMAX2	Rectifier #2 control variable maximum value	None
UMIN1	Rectifier #1 control variable minimum value	None
UMIN2	Rectifier #2 control variable minimum value	None
VDBIC	Bus D-axis voltage IC	per unit
VDBUS	Bus D-axis voltage	per unit
VDCBG2	Gen. #2 circuit breaker voltage	per unit
VDERR	D-axis voltage error for implicit loop calculation	per unit
VDG1	Gen. #1 D-axis terminal voltage	per unit
VDG2	Gen. #2 D-axis terminal voltage	per unit
VDI1	Inverter #1 D-axis terminal voltage	per unit
VDI2	Inverter #2 D-axis terminal voltage	per unit
VDM1	Mtr. #1 D-axis terminal voltage	per unit

VDM2	Mtr. #2 D-axis terminal voltage	per unit
VDR1	Rectifier #1 D-axis terminal voltage	per unit
VDIR	Rectifier #2 D-axis terminal voltage	per unit
VERRG1	Gen. #1 terminal voltage error	per unit
VERRG2	Gen. #2 terminal voltage error	per unit
VI1	Inverter #1 DC-side voltage	per unit
VI2	Inverter #2 DC-side voltage	per unit
VN1	GT #1 FSEE power turbine speed reference voltage	volts
VNSF1	GT #1 FSEE power turbine speed scale factor	RPM / volt
VQ1	GT #1 FSEE power turbine torque reference voltage	volts
VQBIC	Bus Q-axis voltage IC	per unit
VQBUS	Bus Q-axis voltage	per unit
VQCBG2	Gen. #2 circuit breaker voltage	per unit
VQERR	Q-axis voltage error for implicit loop calculation	per unit
VQG1	Gen. #1 Q-axis terminal voltage	per unit
VQG2	Gen. #2 Q-axis terminal voltage	per unit
VQI1	Inverter #1 Q-axis terminal voltage	per unit
VQI2	Inverter #2 Q-axis terminal voltage	per unit
VQM1	Mtr. #1 Q-axis terminal voltage	per unit
VQM2	Mtr. #2 Q-axis terminal voltage	per unit
VQR1	Rectifier #1 Q-axis terminal voltage	per unit
VQR2	Rectifier #2 Q-axis terminal voltage	per unit
VQSF1	GT #1 FSEE power turbine torque scale factor	lbf-ft / volt
VR1	Rectifier #1 DC-side voltage	per unit
VR2	Rectifier #1 DC-side voltage	per unit
VRATE1	GT #1 FSEE rate limit	volts
VRSF1	GT #1 FSEE rate limit scale factor	rpm / sec-volt
VS1PU0	Zero ship speed	per unit
VS1PU10	(Ship speed) ¹⁰	per unit
VS1PU10I	(Ship speed) ¹⁰ IC	per unit
VS1PU2	(Ship speed) ²	per unit
VS1PU2I	(Ship speed) ² IC	per unit
VS1PU3	(Ship speed) ³	per unit
VS1PU3I	(Ship speed) ³ IC	per unit

VS1PU4	(Ship speed) ⁴	per unit
VS1PU4I	(Ship speed) ⁴ IC	per unit
VS1PU5	(Ship speed) ⁵	per unit
VS1PU5I	(Ship speed) ⁵ IC	per unit
VS1PU6	(Ship speed) ⁶	per unit
VS1PU6I	(Ship speed) ⁶ IC	per unit
VS1PU7	(Ship speed) ⁷	per unit
VS1PU7I	(Ship speed) ⁷ IC	per unit
VS1PU8	(Ship speed) ⁸	per unit
VS1PU8I	(Ship speed) ⁸ IC	per unit
VS1PU9	(Ship speed) ⁹	per unit
VS1PU9I	(Ship speed) ⁹ IC	per unit
VS1PU	Ship speed	per unit
VT12	Unknown	Unknown
VTG1	Gen. #1 terminal voltage	per unit
VTG2	Gen. #2 terminal voltage	per unit
VTM1	Mtr. #1 terminal voltage	per unit
VTM2	Mtr. #2 terminal voltage	per unit
VTOP1	GT #1 topping governor value	Unknown
VTREFG1	Gen. #1 terminal voltage reference value	per unit
VTREFG2	Gen. #2 terminal voltage reference value	per unit
VTRQGS1	GT #1 FSEE torque limiting value	Unknown
W41	GT #1 gas generator internal variable	Unknown
W4R21	GT #1 gas generator internal variable	Unknown
W541	GT #1 power turbine internal variable	Unknown
W54R21	GT #1 power turbine internal variable	Unknown
WAVE	Seaway wave wavelength	per unit
WEFSEA	Radian frequency of waves	Rad. / Sec.
WESEA	Seaway velocity factor	per unit
WESEAMG	Seaway internal variable	Unknown
WESMAX	Maximum sea induced variation in ship speed	per unit
WFAC1	GT #1 MFC internal variable	Unknown
WFSR21	GT #1 gas generator internal variable	Unknown
WFUEL1	GT #1 MFC fuel flow rate	Unknown

WFUEL1I	GT #1 MFC fuel flow rate IC	Unknown
WMG1	Gen. #1 rotational speed	Rad. / Sec.
WMG2	Gen. #2 rotational speed	Rad. / Sec.
WMG2D	Gen. #2 rotational acceleration	Rad. / Sec. ²
WMM1	Mtr. #1 rotational speed (electrical)	Rad. / Sec.
WMM1D	Mtr. #1 rotational acceleration	Rad. / Sec. ²
WMM1IC	Mtr. #1 rotational speed IC	Rad. / Sec.
WMM2	Mtr. #2 rotational speed (electrical)	Rad. / Sec.
WMM2D	Mtr. #2 rotational acceleration	Rad. / Sec. ²
WMM2IC	Mtr. #2 rotational speed IC	Rad. / Sec.
WO	Base electrical frequency	Rad. / Sec.
WRN1ORD	GT #1 ordered speed	per unit
WRN1ORDIC	GT #1 ordered speed IC	per unit
WRNG1	Gen. #1 rotational speed	per unit
WRNG1IC	Gen. #1 rotational speed IC	per unit
WRNG2	Gen. #2 rotational speed	per unit
WRNG2IC	Gen. #2 rotational speed IC	per unit
WRNM1	Mtr. #1 rotational speed	per unit
WRNM2	Mtr. #2 rotational speed	per unit
XDC1	DC-link #1 reactance	per unit
XDC2	DC-link #2 reactance	per unit
XDG1	Gen. #1 D-axis synchronous reactance	per unit
XDG2	Gen. #2 D-axis synchronous reactance	per unit
XDM1	Mtr. #1 D-axis synchronous reactance	per unit
XDM2	Mtr. #2 D-axis synchronous reactance	per unit
XDMXQM1	Mtr. #1 difference between Xd and Xq	per unit
XDMXQM2	Mtr. #2 difference between Xd and Xq	per unit
XDPG1	Gen. #1 D-axis transient reactance	per unit
XDPG2	Gen. #2 D-axis transient reactance	per unit
XDPM1	Mtr. #1 D-axis transient reactance	per unit
XDPM2	Mtr. #2 D-axis transient reactance	per unit
XDPPG1	Gen. #1 D-axis subtransient reactance	per unit
XDPPG2	Gen. #2 D-axis subtransient reactance	per unit
XDPPM1	Mtr. #1 D-axis subtransient reactance	per unit

XDPPM2	Mtr. #2 D-axis subtransient reactance	per unit
XG1	Gen. #1 Transmission line reactance	per unit
XG2	Gen. #2 Transmission line reactance	per unit
XK3L1	GT #1 FSEE internal variable	Unknown
XL1	Rectifier #1 transmission line reactance	per unit
XLG1	Gen. #1 leakage reactance	per unit
XLG2	Gen. #2 leakage reactance	per unit
XLM1	Mtr. #1 leakage reactance	per unit
XLM2	Mtr. #2 leakage reactance	per unit
XM1	Mtr. #1 transmission line reactance	per unit
XMV1	GT #1 MFC internal variable	Unknown
XQG1	Gen. #1 Q-axis synchronous reactance	per unit
XQG2	Gen. #2 Q-axis synchronous reactance	per unit
XQM1	Mtr. #1 Q-axis synchronous reactance	per unit
XQM2	Mtr. #2 Q-axis synchronous reactance	per unit
XQPPG1	Gen. #1 D-axis subtransient reactance	per unit
XQPPG2	Gen. #2 D-axis subtransient reactance	per unit
XQPPM1	Mtr. #1 D-axis subtransient reactance	per unit
XQPPM2	Mtr. #2 D-axis subtransient reactance	per unit
XVS0REF	Reference ship stopping distance	Unknown