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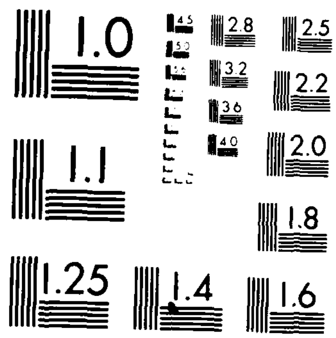

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SECURING CONTINUOUS CLEAN POWER:
Considerations to be made when constructing facilities utilizing sensitive or never off line electrical equipment.

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A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

SUMMER 1986

TO THE US NAVY FOR THE CHANCE TO EARN
MY MASTER'S DEGREE
AND
TO MY WIFE, SUZANNE, FOR HELPING ME
REACH THIS GOAL THROUGH HER
HELP, HARD WORK, AND
ENDLESS PATIENCE

ABSTRACT

With today's computers and other highly sensitive and sophisticated electronic equipment, commercial grade electric power can no longer be relied on to provide the quality of power needed. Due to the stricter power quality requirements of electronic equipment being used, the commercially supplied power must be conditioned to fall within equipment manufacturer's specifications. This is accomplished by either power enhancement or power synthesis.

Power enhancement is the modification of existing incoming power by filtering, isolating, increasing, decreasing, or clipping the waveform of the voltage before it is delivered to the equipment. Power synthesis is the creating of a new, completely isolated, power output using the commercial supplied power as an energy source. These methods have been used with varying degrees of success. Power synthesis provides the most complete power conditioning but this method is also the most costly.

Of the different methods of power conditioning, the Uninterruptible Power Supply (UPS) is the most effective. UPS systems basically fall within two categories. The first is the Rotary UPS. This UPS uses a motor-alternator combination to produce the quality power needed. Then there is the Static (Solid State) UPS which uses an inverter to

produce the quality power. Advantages and disadvantages of each system must be examined before choosing a system.

The critical loads and each component must be considered when designing an UPS to meet specifications. Also load hardware factors must be considered along with application factors. Load hardware factors are those characteristics of the load that determine the design, performance limits, and capabilities or the UPS. The load application factors are requirements of a particular project independent of the load hardware factors.

After a decision has been made as to which UPS system that will be considered, a computer program is used to help decide if it is cost effective for the company considering it. The program is user friendly. It asks a series of questions and then provides information and makes a recommendation based on cash benefit or deficit.

The information provided will help in the analysis of the requirements of an UPS. If it is decided an UPS is not needed, other methods of power conditioners are available. These come with varying degrees of effectiveness and varying price ranges.

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CHAPTER ONE

INTRODUCTION

1.1 Problems with Commercial Power

Before the use of highly sensitive and advanced electronics, we could ignore variation in commercially supplied electrical power that was less extreme than severe long term undervoltages or overvoltages, complete power outages, or lightning-strike level transients.[1] Today, with the increasing usage of data processors, computers, advanced communication systems, and many other semiconductor-controlled devices, previously disregarded power disturbances create a threat to the proper operation of the equipment. Any power aberration, no matter how brief, that can cause errors in data handling or cause a shut down of the computer is a serious problem.

There are basically three types of power line disturbances. The first are transients and oscillatory overvoltages or short term voltage aberration. These can be caused by lightning, power network switching (especially those involving large capacitors or inductors), or operation of on site loads. These transients (spikes) and oscillatory transients are around 200 to 400% higher or lower than average rated voltage. They can surge even higher or lower depending on conditions. The duration of the spikes are from 0.5 to 200 microseconds wide and can oscillate up to

16.7 milliseconds at frequencies of 0.2 to 5 KHz and higher. The second are momentary undervoltage or overvoltage or intermediate voltage aberration. Causes for these types of disturbances are faults on the power system, large load changes, utility equipment malfunctions, or on site load changes. They are characterized by a drop to between 80 to 85% or an increase to above 110% of the rated average voltage. These normally last between 4 to 60 cycles, depending on the type of power system and the on site power distribution. The third is a power outage or long term voltage aberration. This can also be caused by faults on the power system, utility or on site equipment malfunctions, or unacceptable load changes. In an outage, power drops below 80% of rated voltage and will last anywhere from 2 seconds to infinity.[2] Figure 1 illustrates these types of power line disturbances.

One of the most extensive records of actual disturbances to power supply systems was done by George A. Allen and Donald Segal, both of IBM, in 1974. This study included both utility source and on site generated voltage disturbances. The monitoring was conducted from 1970 to 1972, accumulating about 109 monitor-months of data on sites representing a climatic and geographical cross section of the United States. It included representive loads from heavy and light industry, office buildings, retail stores, residences, and a mixture of these locations. Experience,

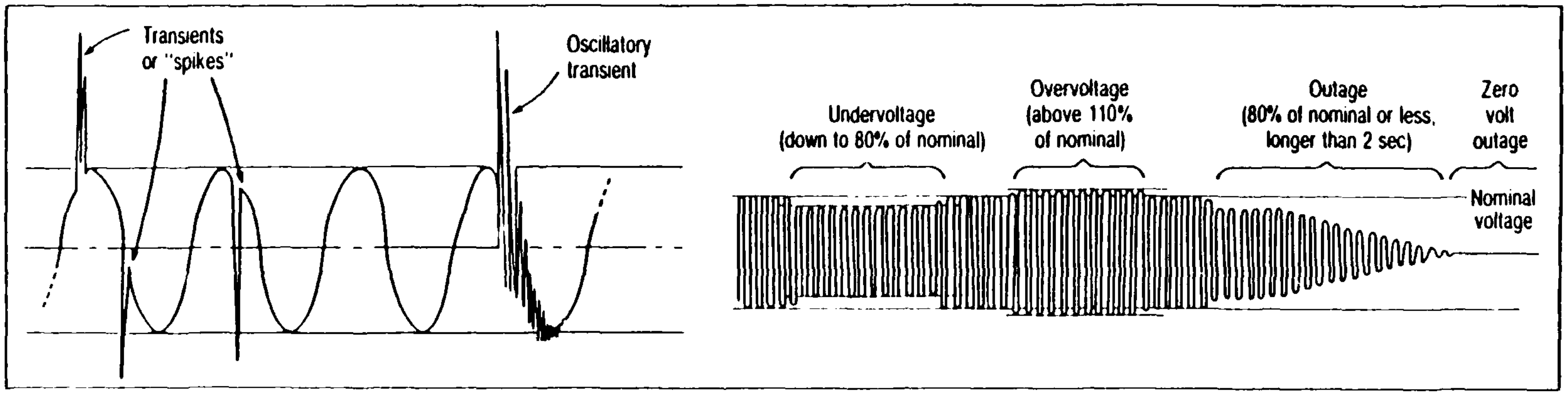


Fig. 1 Power Line Disturbances[3]

since this monitoring was performed, shows that this data is still accurate. If there are any differences, they would be that the total number of occurrences is probably higher today than in the early 1970's.[4] Results of this study is shown in Figure 2.

We have examined three types of voltage aberrations that can cause disturbances in the power supply but two more types of aberrations need to be considered. These are frequency aberration and noise. Frequency aberration occurs when the line frequency maintained by the power companies varies. The power company uses an average when stating their operational frequency. During a given period that the power company uses to average its frequency, it may generate a lower frequency for a period and then generate a higher frequency the remaining time to average out at 60 Hz. This can have a negative impact on many loads. Frequency aberration can also be caused when a utility switches distribution paths if the substations being switched are not in phase. Also, this can happen when switching from the primary power source to a secondary power source, like a diesel engine generator, inside a facility. The final aberration examined will be noise. Noise is defined as unwanted electrical signals that are superimposed on a useful waveform. There are two different types of noise. Transverse noise is the voltage noise between two

Disturbance	**Ave monthly occurrences**	**Percent**	**Notes**
Oscillatory (decaying) transients	62.6	48.8	< 16 ms (1 cycle) duration and > 15% of system voltage
Voltage spikes	50.7	39.5	> 15% of system voltage
Undervoltage	14.4	11.2	> 8 ms (½ cycle) duration and > 10% of system voltage
Overvoltage	None	--	> 8 ms (½ cycle) duration and > 10% of system voltage
Total outage (blackout)	0.6	0.5	Mean outage 11 minutes
	128.3	**100.0**	

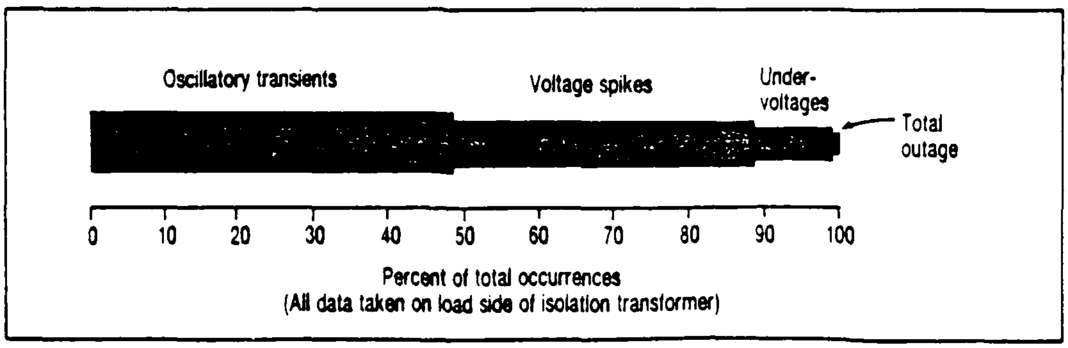
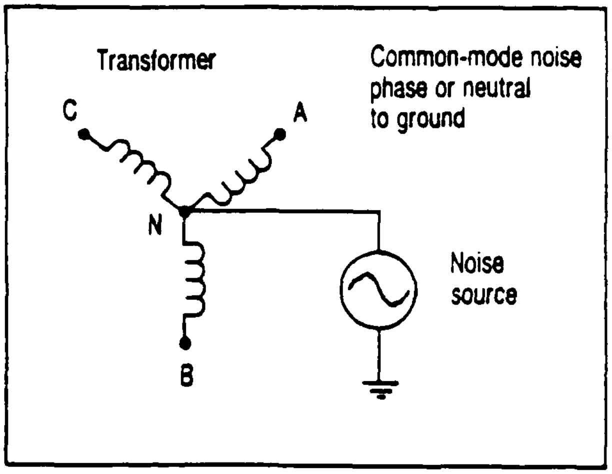


Fig. 2 Allen-Segall Data[5]

conductors. Common-mode noise, in a three phase system, is the voltage noise, that exist between the line and ground. Figure 3 illustrates transverse and common-mode noise.

Other than problems that can be caused outside a power supply, the commercial power supply itself has become a problem as today's technology has become more advanced and sensitive. The utility industry sets its own standards to govern the commercial power supplier in the tolerances for power that is delivered to the customer. The American National Standards Institute (ANSI) specifies the profile for utility power. To demonstrate that this commercial power is not reliable enough to supply the customer with the power required to operate computer gear and other similar equipment efficiently, an overlay of the Computer Business Equipment Manufacturers Association's (CBEMA) voltage envelope for reliable operation has been placed over the ANSI standards to show potential problem areas. As you see from the shaded area on Figure 4 there are potential problems in the momentary outage area and the high voltage transient area in the supplied power. During a brownout, which are becoming more frequent every year, voltages at the computers or other sensitive equipment will probably drop below a tolerable level. Brownouts not only happen by accident, they also are planned and carried out by the power companies. The voltage is reduced to reduce the utility's load, especially during peak demand times. As one can see,

Common-mode noise
(phase or neutral to ground)



Transverse noise
(phase to neutral)

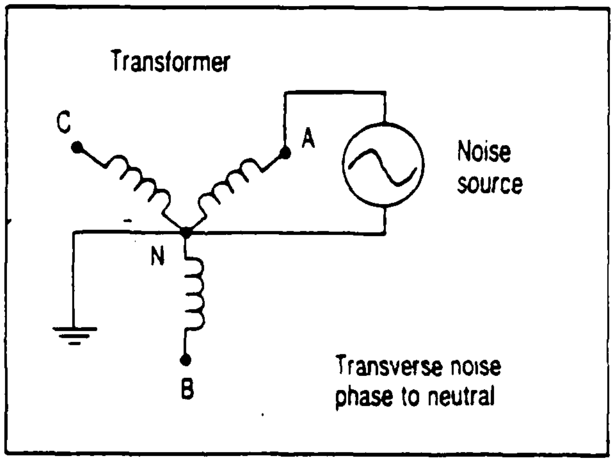


Fig. 3 Transverse and Common-mode noise[6]

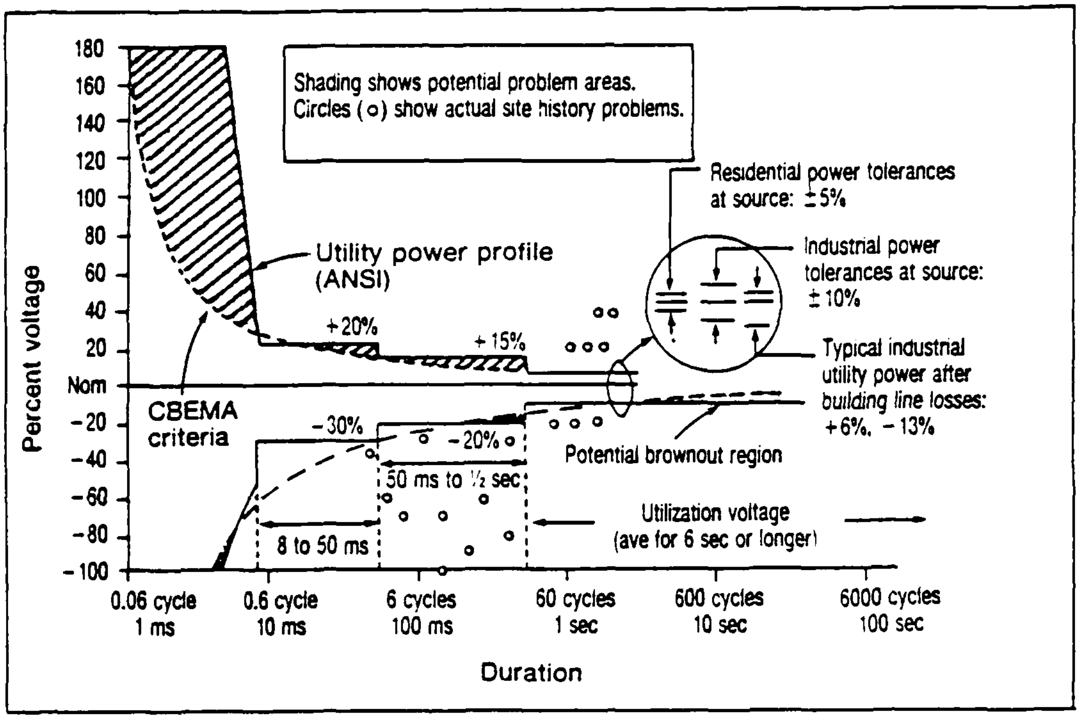


Fig. 4 Utility Power Profile with [7]
CBEMA Criteria Overlay

commercial power is not of high enough quality to be relied upon by today's business managers utilizing equipment involving modern electronics.

1.2 Correction Technic

There are two basic categories in which the technic used to condition incoming power before it is delivered to the electrical equipment. They are power enhancement and power synthesis. Power enhancement equipment is only capable of modifying or improving the income power by filtering, isolating, increasing, decreasing, or clipping the voltage waveform before it is delivered to the equipment. Power synthesis equipment creates its own new, completely isolated, power output using the incoming power as its energy source. This output power produced can be engineered to fall entirely within the equipment's tolerance requirements and provide an adequate safety margin. Figure 5 illustrates these processes.

Power enhancement can be provided by spike suppressors, voltage regulators, isolating transformers, or any combination of these items with varying degrees of success on different power problems. Power synthesis can be accomplished by static magnetic synthesizers, rotating machines, and static electric semiconductor inverters. The magnetic synthesizer utilizes inductors, capacitors, and pulse transformers to create the required output power.

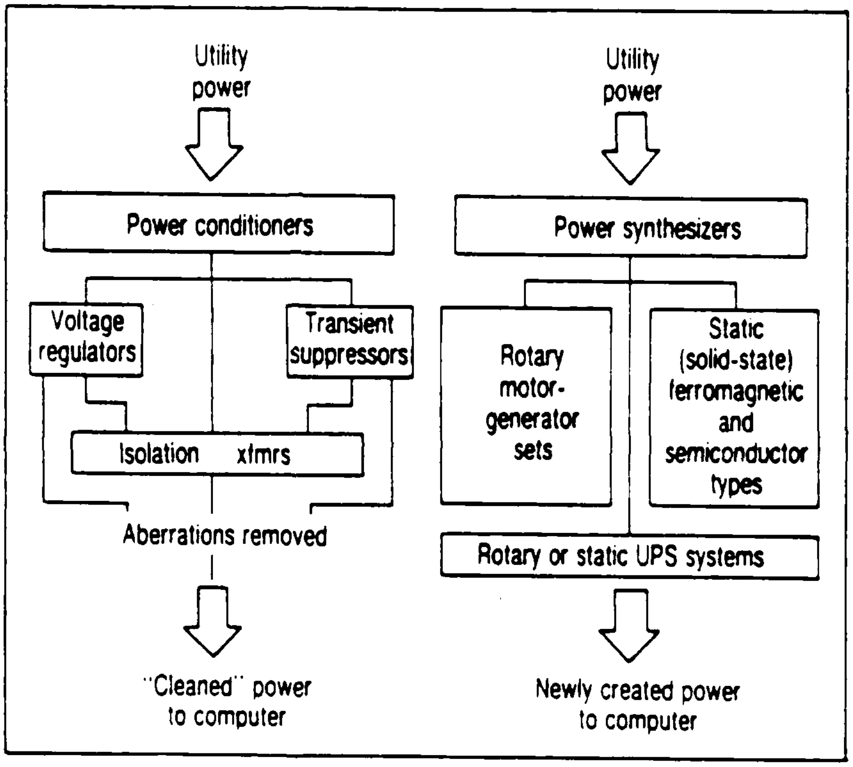


Fig. 5 Illustrations of Power Enhancers and Power Synthesizers [8]

Rotating machines usually utilize a synchronous motor, which is powered by the original input power, driving an alternator to produce the required output power. A battery system can be added to the motor-alternator set to truly make it an uninterruptible power supply. The static electronic semiconductor inverter is supplied by DC power created from the AC input power and have batteries in the DC power stage to supply input power in case of an outage. This DC power is inverted into the required AC output power. This system is what is normally referred to as an Uninterruptible Power Supply (UPS).

In deciding the method required to solve incoming power problems, you must determine the severity and extent of the problem accurately. Next, the most effective technic must be chosen that will solve the existing problems in the most effective manner. Lastly, the cost of the technic being considered must be taken into account. In other words, their cost effectiveness must be determined.

There are a couple of power protection methods that can solve some power problems that do not require conditioning or synthesis. These are dedicated lines and dual feeders. First, the dedicated line is a circuit that is run from the power distribution point to the critical load with no other uses allowed. The dedicated line offers little isolation to the critical load because it is fed by the same transformer feeding the other loads of the facility. Because of this, it only serves to eliminate some of the noise and spikes generated from other loads inside the facility. It has almost no affect on any problems created outside the facility and therefore, the effective results of this method are marginal. Next, the dual feeds is a method to isolate the critical load from aberration. In this approach the facilities containing the critical load are supplied with power from two separate generating stations. The lines are connected to a transfer switch and if problems are noted with the line supplying power, the power supply is automatically transferred to the other line. The problems with this method is that it is only effective against brown or blackouts and is totally ineffective against most other problems.[9]

Of the four types of power enhancers, the spike suppressor is least effective but it is also the least expensive. The spike suppressor varies in size. It ranges from a simple wall plug unit, which someone may have to protect their home computer, to a larger system for an industrial plant. Usually this device is a series of capacitors, size designated by the size of the load it is to protect, that will suppress high voltage spikes.[10] This device is not effective against any other type of power aberration. Next, the shielded isolation transformer is a transformer with the primary winding and secondary winding electrically and electrostatically isolated from each other.

The design of the transformer, which relies on magnetic coupling to transfer power from the primary to the secondary winding, provides the electrical isolation. A grounded aluminum or copper shield, located between the primary and secondary winding, provides the electrostatic isolation. This device can eliminate high frequency voltage spikes of short duration but it offers no protection against voltage fluctuations, brownouts, or blackouts. Also, if the duration of the voltage spike is in the tens of microseconds range it only offers limited protection. The line voltage regulator takes the incoming commercial power and steps it either up or down to provide the desired voltage output. The voltage regulator is suitable for applications where incoming power is reliable but of poor quality. There are two types of voltage regulators currently used. These are the ferroresonant transformer with an automatic transformer tap changing device. The ferroresonant transformer is used with loads requiring limited power, where as, the changeable taps transformer is used with loads requiring more power. The voltage regulators are capable of maintaining a constant output voltage and demonstrate varying degrees of success against other types of voltage aberrations. Neither type provide adequate protection against frequency and noise aberrations, or blackouts. The last type of power enhancers is a combination of the three before mentioned devices. The results of these combinations are a higher degree of efficiency in the areas they protect but they still miss the areas of frequency and noise aberration or blackouts.

Among the three types of power synthesizers, all rate fairly equal in effectiveness of solving all types of incoming power problems. The main difference here is the ability to handle extended voltage drops and blackouts. The motor-alternator set is a little more effective than the magnetic synthesizer because of its design. The rotating of the motor-alternator set will carry it through an outage of short duration where as the magnetic synthesizer would go off line. The most effective and expensive is the UPS. A battery system supplies blackout ride through and also accounts for most of the added cost.[11] Based on data from George Allen's and Donald Segall's study Figure 6, 7, and 8 show the rating of each type of power correction device verses power aberration, effectiveness of each device on all types of power aberrations, and costs of each system. In Figure 8, set one alternative at 100% relative cost. Give each other alternative a (%) relative cost using the alternative chosen as a base. The performance cost index is equal to the (%) total effectiveness divided by the (%) relative cost.

Equipment	E (enhancer) or S (synthesizer)	Oscillatory transients	Voltage spikes	Over and undervoltage	Outages
Spike suppressor, filtered	E	Good, if filtered	Excellent	No effect	No effect
Regulator with spike suppressor	E	Partial good with filter	Excellent	Excellent	No effect
Isolation xfmr, shielded	E	See Note 1	No effect	No effect	No effect
Isolation xfmr, shielded, with spike suppressor	E	See Note 1	Excellent	No effect	No effect
Isolation xfmr with spike suppressor and voltage regulator	E	See Note 1	Excellent	Excellent	No effect
Motor-alternator set	S	Excellent	Excellent	Excellent (See Note 2)	
Magnetic synthesizer	S	Excellent	Excellent	Excellent (See Note 2)	
Uninterruptible power supply	S	Excellent	Excellent	Excellent	

Note 1: Little effect on normal-mode (phase-to-phase) transients; excellent suppression of common-mode (phase-to-ground) transients with properly grounded shield.

Note 2: Excellent down to a minimum voltage, below which the synchronous motor will drop out and output will be lost; or the magnetic synthesizer will not be able to sustain output voltage. Synthesizer minimum voltage is usually lower than motor-alternator minimum for a given load.

Fig. 6 Power Conditioner Ratings [12]

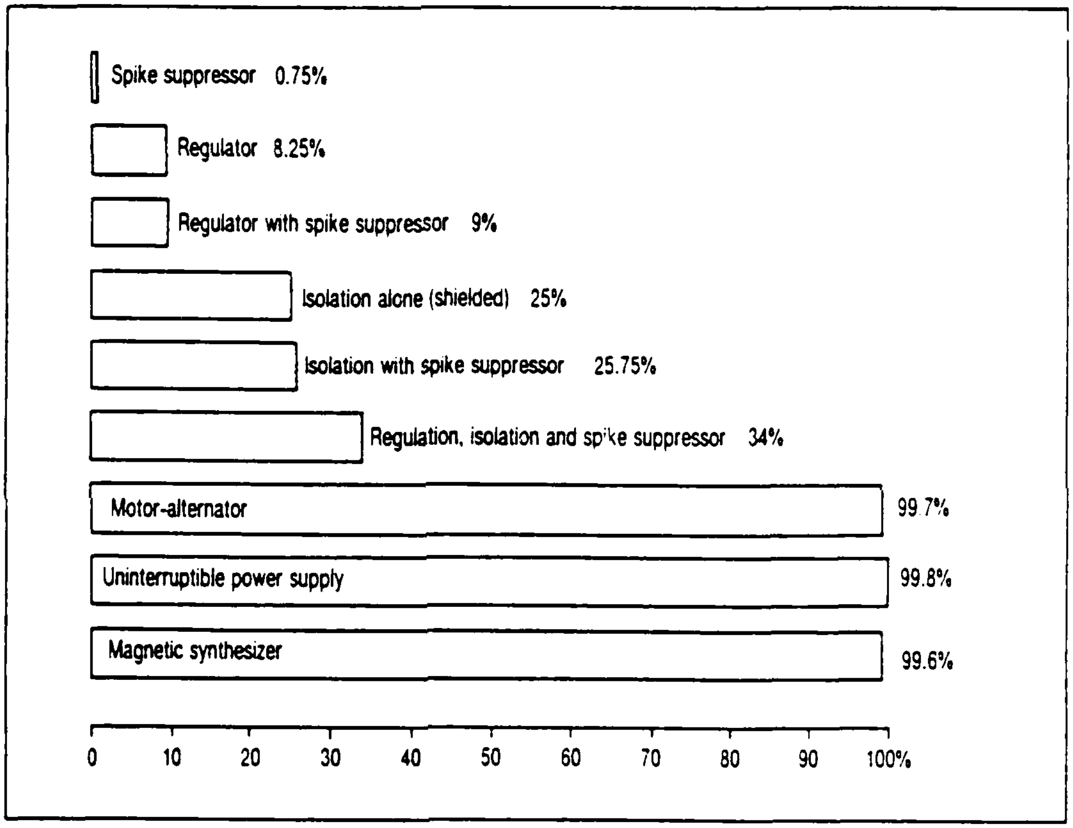


Fig. 7 Power Conditioner Effectiveness [13]

	Spike suppressor	Regulator	Regulator with spike suppressor	Shielded isolation xfmr	Isolation xfmr with spike suppressor	Isolation xfmr with regulator and spike suppressor	Motor-alternator set	Uninterruptible power supply	Magnetic synthesizer
Installation cost	$3,000	$25,000	$26,000	$4,500	$6,000	$28,000	$40,000	$130,000	$25,000
Maintenance cost	– –	$ 1,000	$ 1,100	$ 100	$ 100	$ 1,000	$ 1,000	$ 8,000	$ 100
Operating efficiency	– –	96%	96%	97%	97%	93%	83%	85%	91%
Energy cost/year	– –	$ 1,400	$ 1,400	$1,050	$1,050	$ 2,800	$ 6,000	$ 5,300	$ 3,500
Total cost per year	$ 600	$ 7,400	$ 7,700	$2,050	$2,350	$ 9,400	$15,000	$ 39,300	$ 8,600
Total effectiveness	0.75%	8.25%	9%	25%	25.75%	34%	99.7%	99.8%	99.6%
Relative cost									
PCI*									

Basis: 100-kVA output
Continuous (24-hr) operation
$0.05 per kWh cost of power
5-year straight-line depreciation

*Performance-cost index (PCI) = $\frac{\text{\% total effectiveness}}{\text{\% relative cost}}$

Fig. 8 Power Protection Costs [14]

This should provide an idea of the problems with commercial electrical power and some of the equipment and devices available to deal with them. A further examination of the most effective systems will be covered in the chapters to follow.

CHAPTER TWO

UNINTERRUPTIBLE POWER SUPPLY: UPS DESIGNS

2.1 Rotary UPS Equipment

Of the different types of power synthesizers the motor-alternator set was the earliest type and has been increasing in use because of rapid advances in design and capabilities.[15] First let's look at the motor-alternator combination by itself and then later look at the rotary UPS capability with the addition of batteries.

The motor-alternator set for sensitive electronic equipment must be a high quality dependable unit. The motor can either be a synchronous or inductive type. This is attached to an alternator, either as a single shaft unit or as two separate pieces of equipment. The alternator, when propelled by the motor, then produces high quality AC power.

One way to incorporate the motor-alternator set with the use of equipment such as computers is through a power distribution center. This center provides grounding facilities along with monitoring and alarm functions in the equipment or computer room environment. By designing the motor-alternator set and the enclosure for low noise, the placing of it directly in the work area not only will save the investor money on installation costs but also allow for taking advantage of certain tax benefits. When incorporated as part of the equipment it can be depreciated in 5 to 8 years instead of over the life of the lease or building if it is included as part of the building's permanent wiring.[16]

Both types of motor-alternator sets, single-shaft or multi-piece, have advantages and disadvantages and these must be weighed when making a decision. An advantage of the single-shaft design is that it has fewer moving parts, a bearing at each end of the shaft, and it is more compact. In this design the motor windings are at one end of the shaft and the alternator winding are at the other. This design in itself causes one of its main disadvantages which are shaft currents. These currents show up as voltage disturbances in the output power. To solve these problems the use of an isolating step down transformer is usually required.

The separate machine design calls for the machines to be connected through the use of insulated couplings or belts and pulleys. With this design you eliminate the shaft currents but because there are two separate machines the number of bearings double. If the belt and pulley system is used, it must also be maintained and opens another area up to a chance of malfunction. Also in the belt driven system there is a loss in efficiency. A big advantage of the separate machine design is the ability to oversize the motor. This can allow a greater variance in input power without effecting the output power. It can allow the motor to run in a three phase system with one phase out without overheating because the motor would not be fully loaded. The increased motor size can also increase blackout ride-through because of its larger rotational mass.

Both types of motors, synchronous and inductive, have been used effectively in the motor-alternator combination. An advantage of the synchronous motor is that it has no slip. This means that if the motor is rated at 1750 RPM then it will rotate at that rate for a frequency of exactly 60 Hz. This points out one of its disadvantages. If the frequency varies, so does its speed. Through field studies it has been found that the frequency of commercial power varies between 58.7 to 60.7 Hz.[17] This range is larger than the +/- 0.5 Hz recommended for areas such as computer operations. Another disadvantage is that a synchronous motor cannot be started without help from another motor or additional auxiliary winding usually of the squirrel-cage design on the armature. If the speed of the synchronous motor drops below starting or pull-in speed, it will go off line and must be disconnected from the input line. This must be done automatically to stop the motor from acting like a generator, sending current back down the input line, and using up its kinetic energy needed to ride through short outages.

The induction motor does not have any of the problems that are encountered with the synchronous motor but it does have "slip". Basically this means that if the motor is rated at 1750 RPM then it would actually be rotating around 1710 RPM. The amount of slip will vary with load and input voltage. If this type of motor is used on a common shaft design the output frequency would be lower by the percent drop in RPM. To solve the problem of slip you can either purchase a precision-built low-slip induction motor, which is expensive, or use a motor-alternator set with an adjustable-speed drive. A belt-and-pulley system is such a system that is relatively low cost.[18] This can be accomplished by utilizing adjustable pulleys and belts allowing the alternator to be driven at or above synchronous speed while the motor operates at normal slip speed.

The motor-alternator set has a unique ability to ride through voltage sags and extended brownouts without any adverse effect on the output power supply. They can also supply continuous power through many short term blackouts (milliseconds). This ability is mainly due to speed and mass of its rotating parts. The rotating motion of the machine stores a large amount of kinetic mechanical energy which is released and turned into output power during a brownout or blackout.[19] Design of the motor-alternator set can improve the duration of the ride-through period before the output power drops below acceptable levels.

Now that the motor-alternator set has been examined, let's add a backup battery system to convert the rotary equipment into a rotary UPS system. At first the rotary UPS consisted of diode rectifiers, a DC motor, a flywheel, an AC generator (alternator) and battery supply. The rectifier changed AC power to DC to drive the motor which turned the alternator to supply input power. The flywheel was used to provide ride-through power in case of a severe voltage drop or blackout while the power supply was switched to the battery system. Later the DC motor was changed to an AC motor and the flywheel was replaced with silicon-controlled rectifiers (SCRs). Control of the frequency is accomplished by changing the firing angle of the SCRs. Next an inverter bypass switch was added to increase design efficiency.[20] Figures 9, 10, and 11 demonstrate the evolution of the rotary UPS. These diagrams show the use of a single unit motor-alternator set as more efficient but this is only one opinion and the separate motor-alternator set may be more desirable based on the advantages and disadvantages discussed earlier. In my opinion a separate motor and alternator offers the most flexibility, advantages, and securer quality levels of power.

2.2 Static (Solid-State) UPS

The solid-state UPS system performs in the same manner as the rotary UPS system except the motor-alternator set is replaced with a DC to AC power inverter and control

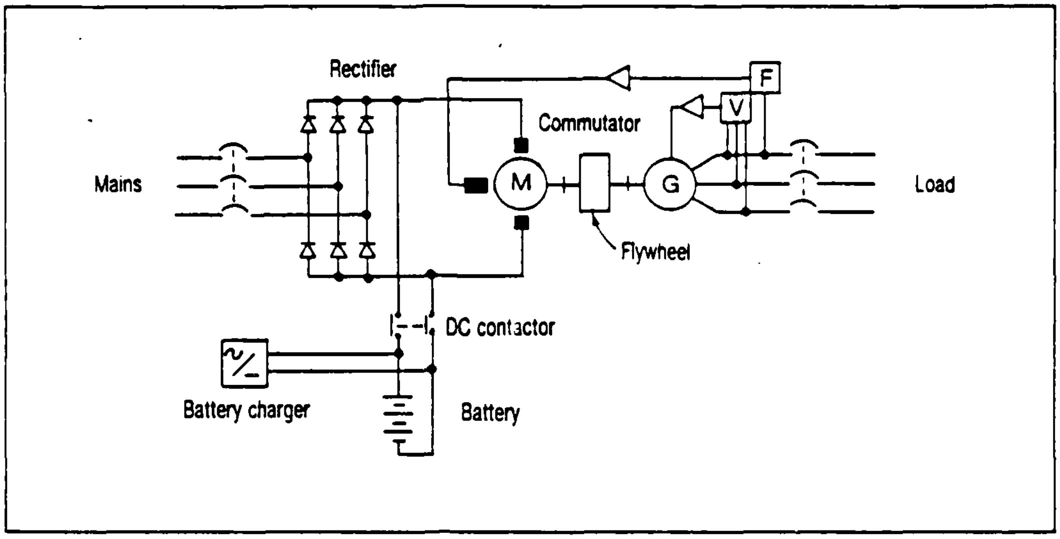


Fig. 9 Early Rotary UPS with DC Motor[21]

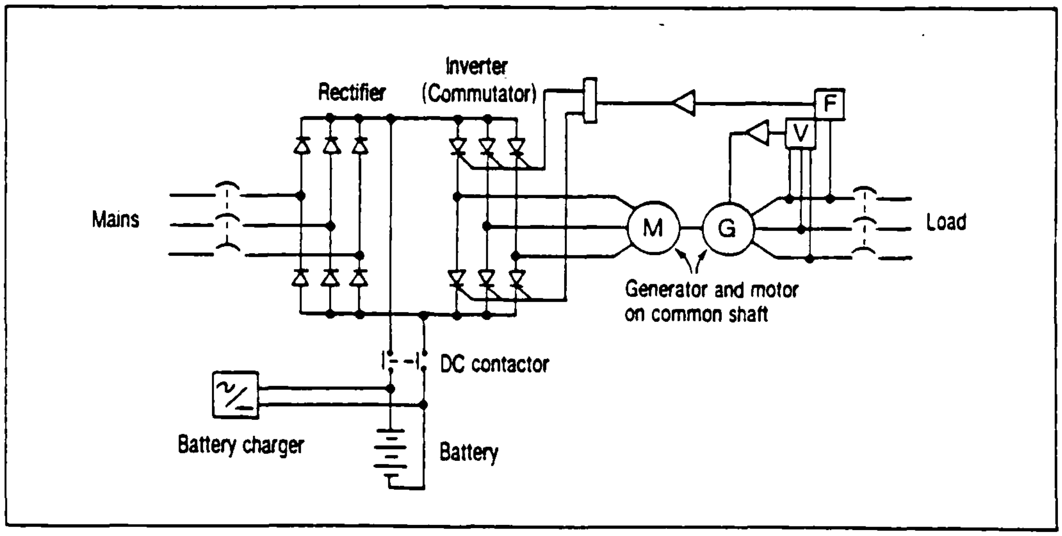


Fig. 10 AC Motor and SCR Inverter[22]

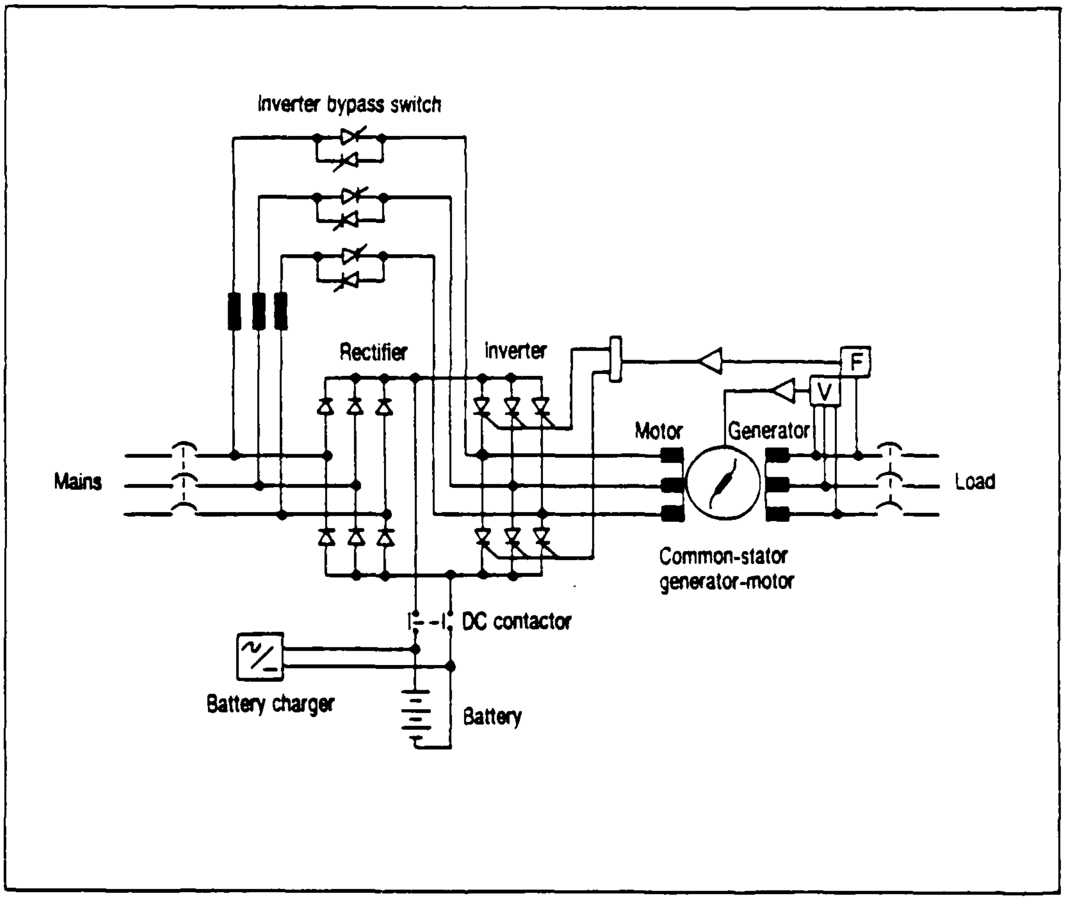


Fig. 11 Current System with Bypass Switch [23]

circuitry to assure that output power is within specifications. This eliminates all requirements for maintenance of the motor and alternator along with reducing the moving parts in the system. The AC power is converted to DC power through a configuration of diodes called a rectifier. The diodes only allow current to flow in one direction and by arranging the diodes into a rectifier circuit you can obtain a voltage that closely approaches a DC voltage as shown in Figure 12. These diodes can be interchanged with SCRs to provide a more controlled rectification of the AC to DC voltage as seen in Figure 13. This DC voltage is used to charge the battery system and is converted back into the required AC power by the inverter. The inverter uses SCRs in its conversion. The output current, voltage, and frequency are monitored and a controller circuit controls the firing angle of the SCRs to assure power quality. This system like the rotary UPS also has a transfer switch for transferring the power supply to the batteries if there is a problem with the input power.

In choosing an UPS system attention must be paid to how and where the system is to be utilized. One advantage that should be looked into is that if money is a problem the motor-alternator set can be installed in stages. First installing the motor-alternator set and then later adding the battery system, since it is a major portion of the cost of any UPS system.

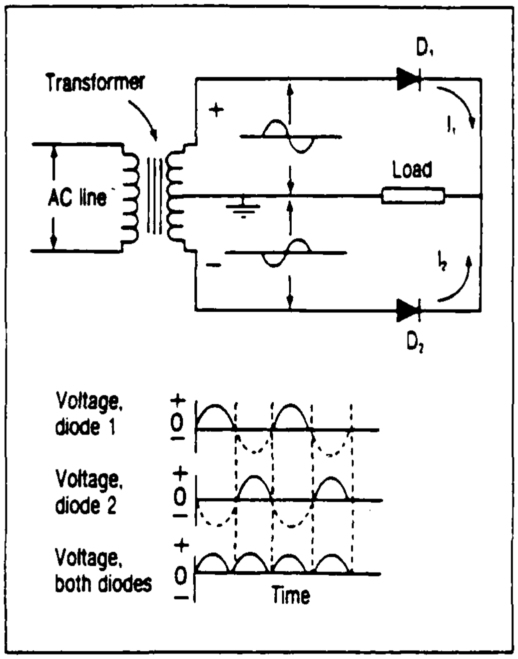


Fig. 12 Full Wave Rectifier[24]

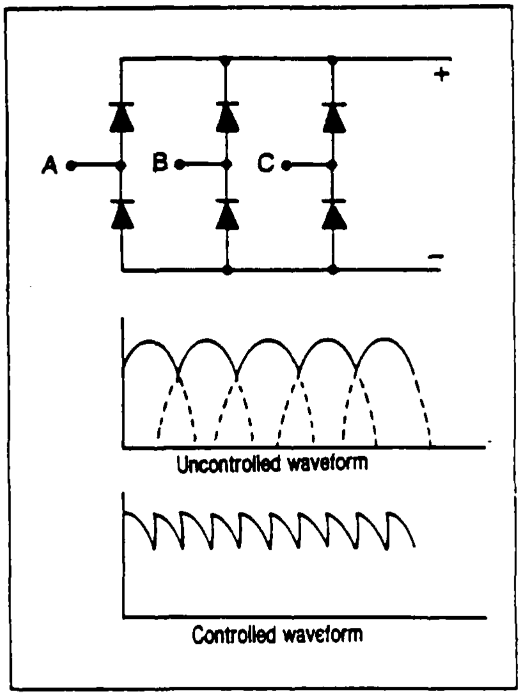


Fig. 13 Uncontrolled and Controlled Waveform[25]

CHAPTER THREE

FUNCTIONAL ANALYSIS OF UPS: COMPONENTS AND CRITICAL LOADS

3.1 Critical Loads

When selecting a method that will solve the incoming power problems a facility is experiencing, we must look closely at the critical loads. These are electrical or electronic equipment that are not allowed to go off line or are sensitive to power aberrations. The function performed by this load is usually associated with the ability of an organization to clear a profit, the life, health, and well being of individuals, or the security and safety of a facility.[26] These loads are said to be critical because of the affects they have on profit or loss, life or death, and safety or danger. Examples of these loads are robotics, where a failure of the computer control system can result in damage to equipment or produce and a loss in profit; the ICU or emergency room in a hospital, where a failure of power could cause an individual's death; and data processing equipment or computers, where downtime and recovery time are losses in revenues. The effects of power aberrations on the critical loads can be evaluated in terms of downtime, recovery time, memory loss, and equipment damage.

Downtime and recovery time refer [illegible] time that the critical load is not per[illegible] of time required to bring the system back [illegible] that it was before the power line aberration caused the system to go down. The time each of these situations lasts can be from milliseconds to hours or days, and one is not dependent on the other. An example of how this time in which the critical load is not operational, is the telephone company's computer system used to monitor and in billing of long distance calls. The phone system itself is run by DC power but the computers are run by commercial AC power. If an aberration in the AC power causes the computers to go down, phone calls can still be made but there would be no record of billing for any calls made during the down period. The phone company estimates that power loss in a small area could cost the company around $694 a minute in lost billing.[27]

Memory loss is associated mainly with computers. In the computer we have basically two types of memory. These are read only memory (ROM) or random access memory (RAM). ROM is built into the computer's logic circuitry. This type memory cannot be altered or changed unless logic circuitry is changed. Power aberrations have little effect on this type of memory except they can destroy the circuitry itself causing costly repairs and making the computer useless until the circuitry is replaced. On the other hand, RAM memory is information that is electrically stored in the computers working memory. In order for this information to be saved it must be transferred onto a tape or disc for hard storage.

During the time that information is being entered into the computer and before it is saved, is the period that it is most vulnerable. Aberration such as spikes or noise can cause information to be changed or cause errors in calculation that the operator would not be aware of until much later. If there is an outage any information that had not been saved would be lost. This could be very costly in production and rework costs.

Equipment damage occurs usually when a power aberration makes it to the electronic components or equipment within the critical load. An example of this is a voltage spike causing an electrical component's voltage rating to be exceeded. This could cause early failure, increase downtime, and high repair costs. Another is a voltage drop causing a current increase through a motor and the motor burning itself out. This would cause the motor to be rebuilt or replaced.

The critical load plays a large part in selecting the power protection system. It determines the size and capability of the system. Also, it helps to determine the reliability requirements of the system.

3.2 UPS Rectification

When looking at the rectification stage of the UPS system we must take into consideration whether a forward of reverse transfer system is being used. In the forward transfer system, the critical load is powered by the commercial power with the UPS off line and in standby status. Because the UPS is off line except when commercial power is interrupted or fails, the rectifier/charge must only be large enough to charge the battery system. In case of an interruption the power is switched to battery power until power is restored to normal. This is not the ideal situation because this leaves the critical load vulnerable to transients of noise.[28]

A reverse transfer system uses the UPS as a buffer between commercial power and the critical load. It is on line all the time and therefore the rectifier/charger must be large enough to supply power to the inverter, which in turn, supplies power to the critical load. As discussed in the previous chapter, the rectifier uses a series of diodes or thyristors (SCRs) to convert the AC power to DC power. In a full wave rectifier shown in Figure 14, near DC current with a frequency of 120 Hz is created.

In three phase applications, the number of pulses that are in a cycle determine how close a DC current can be approximated. The more pulses you have the cleaner the power. This is controlled by the rectifier/charger and is usually a 3, 6, 12, or 24 pulse system. A pulse could be explained as half an AC electrical cycle. Pulses are created by shifting each phase of a three phase system 120 degrees and running it through a specified rectifier

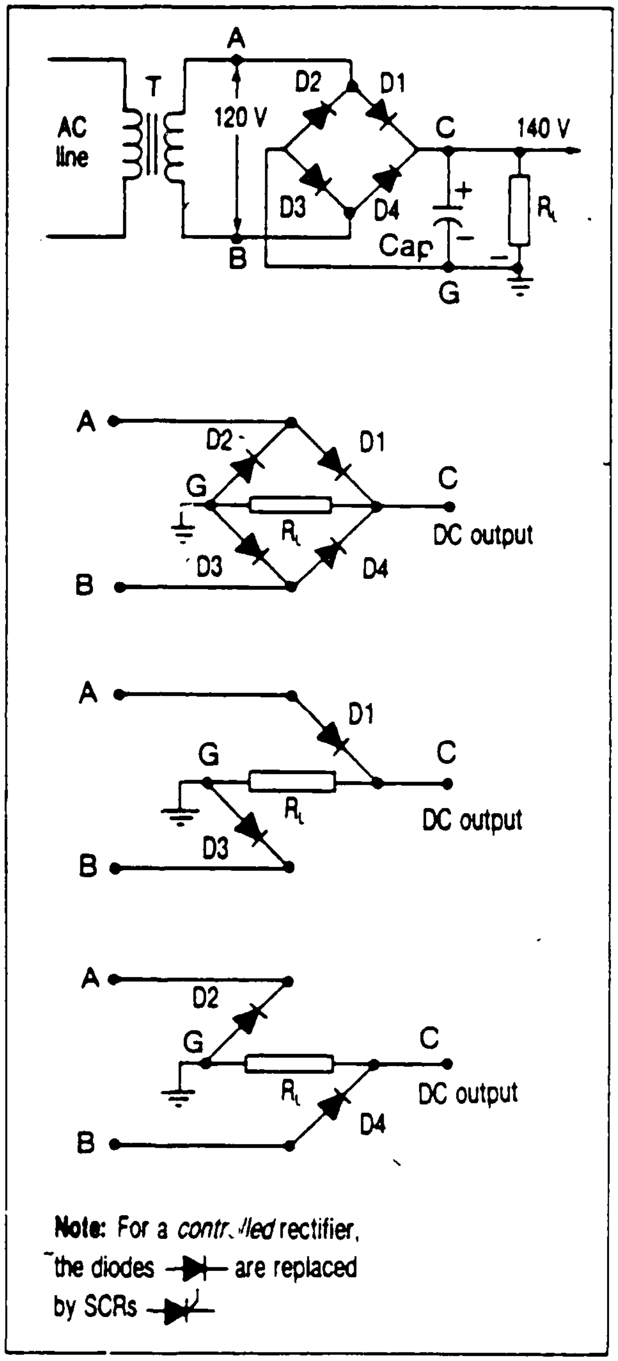


Fig. 14 Full Wave Rectifier with a Frequency of 120 Hz [29]

circuit. In applications less than 200 KW, 12 or 24 pulse rectifiers are rarely used because they are not cost effective.[30]

3.3 UPS Inverters

The inverter supplies the output power of an UPS and for this reason its reliability is critical. The quality of this output power is a direct reflection on its design. The inverter must produce a clean, stable, regulated, low-distortion sine-wave output or three sine-waves offset by 120 degrees in a three phase system. There are two basic technics in producing the required output power. They are electronic and magnetic control inverters.

The electronic inverter uses feedback and logic circuitry to control the waveform of the AC output. Two ways of producing the AC sine-wave form is pulse width modulation or step-wave technologies. Both methods have been used successfully.

The pulse width modulation technic produce waveforms in the manner shown in Figure 15. To control the output voltage, the waveform duty cycle must be varied. Control of the duty cycle must be controlled not only to regulate output voltage but also to minimize filtering need to produce an acceptable output.

The step-wave technic produces waveforms in the manner shown in Figure 16. This is done by adding multiple square

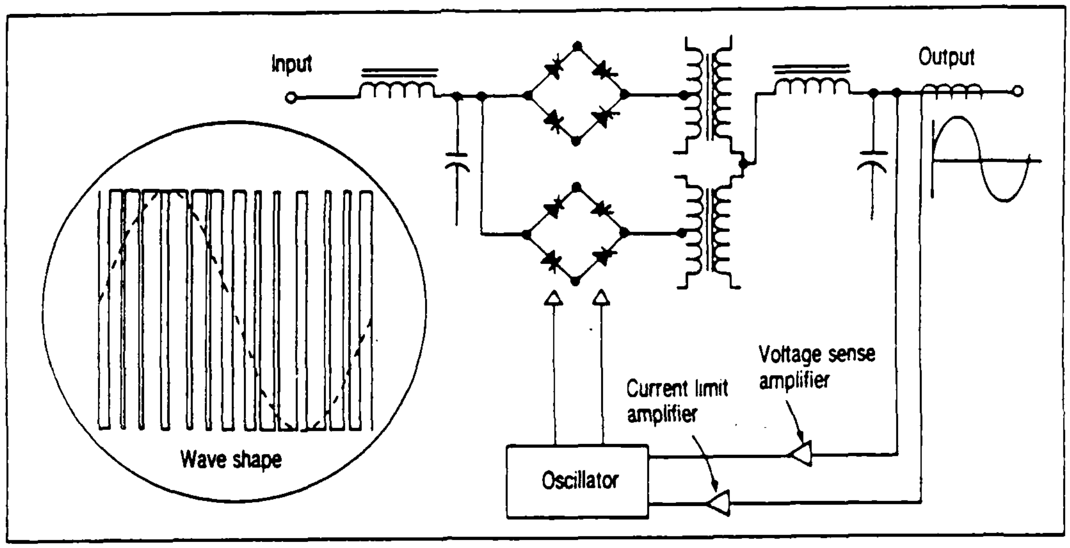


Fig. 15 Pulse-width Modulation [31]

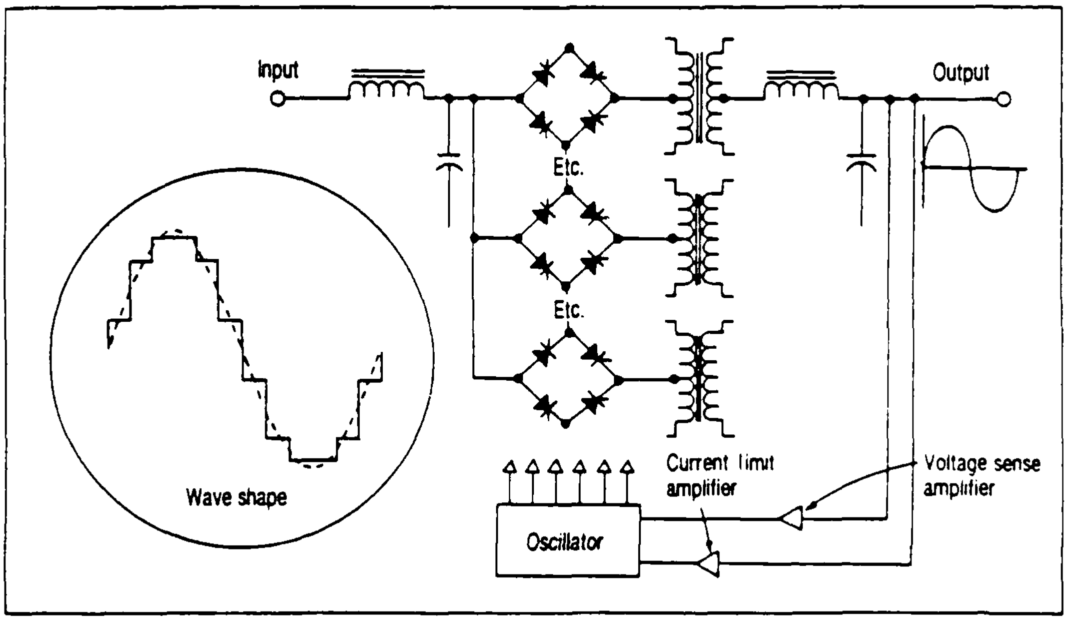


Fig. 16 Step-wave Modulation [32]

waves or changing transformer taps. One way to control the output voltage is by adding two inverter outputs and varying the phase between them. Another way is to use a DC to DC converter at the inverter input and vary the DC power input.

Problems with both of these methods are that they are complex. They are not inherently protected against short circuits in their output and they must rely on their control circuitry to cut back power levels quickly to prevent inverter damage.[33]

Two basic types of magnetic controlled inverters are ferroresonant and delta magnetic. The ferroresonant inverter utilizes the most common magnetic regulation and filtering device which is the ferroresonant transformer. This is basically a single phase inverter which has been adapted to three phase use. The inverter creates a square wave which is designed so that the secondary section is magnetically saturated at a desired voltage, producing a sine-wave that is relatively constant over a wide range of voltages and loads. Advantages of this inverter is that it is rugged, simple and reliable. Disadvantages are that it is larger and heavier than electrically controlled inverters, cannot handle unbalanced loads very well in a three phase configuration, and also requires additional filtering in a three phase system.

The delta magnetic inverter, unlike the ferroresonant inverter, was designed for a three phase system. Because of the configuration of this inverter, much of the filtering requirements have been eliminated. This design is also rugged, simple, and reliable. Other advantages that this design has over other inverters are that output levels are determined by design, there are no control circuits to become unstable, and the inductors within the design give it short circuit protection. It can better handle unbalanced loads and has the capability to store energy, because of its inductors and capacitors, to handle high inrush current loads and loads with discontinuous current waveforms. Figure 17 and 18 give basic schematics of ferroresonant and delta magnetic systems.

3.4 Power Transfer Switches

The transfer switch is responsible for transferring power from the input source to the battery system in case of a power brown or blackout or from the UPS to the bypass line source in case of an inverter problem or failure. They must also be capable of switching back to their original setting once the problems have been solved. For these reasons they must have the ability of monitoring both the input and output power supplies.

There are two different methods of transferring power: break-before-make, and make-before-break. In break-before-make the power supply is interrupted before the

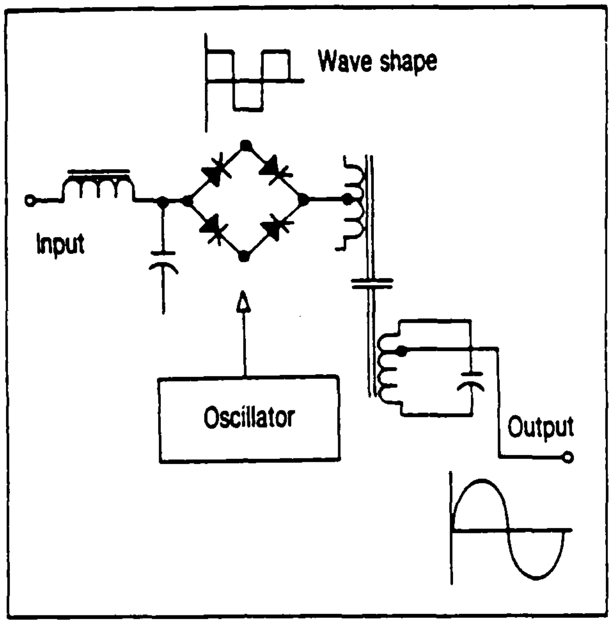


Fig. 17 Ferroresonant Regulation [34]

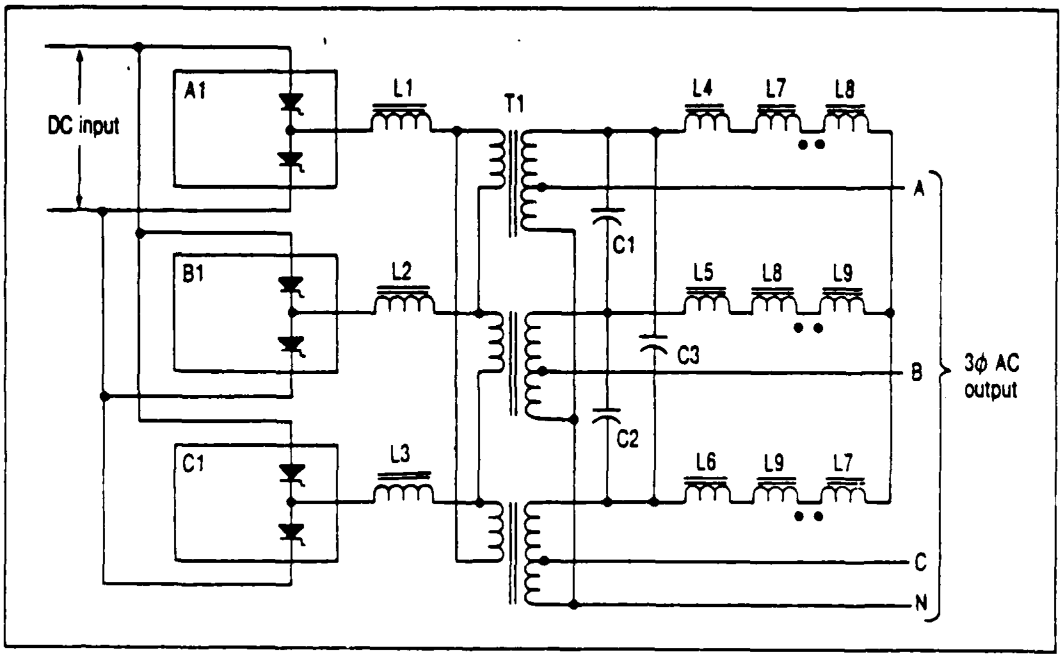


Fig. 18 Delta Magnetic System [35]

switch is made. This would defeat the purpose of an UPS, so we will not be concerned with this type of transfer.

Make-before-break is the method that is required in an UPS when dealing with the critical load. This method transfers the power from one source to another without interruption. The UPS we are concerned with normally uses what is known as a reverse transfer. Power is transferred to a bypass source if the batteries or inverter fails for any reason. Therefore, this switch should also include a synchronization circuit to assure power sources are synchronized before a transfer is made.[36]

There are three types of transfer switches used in today's UPS systems. The electromechanical switch has motor-actuated circuit breakers on both the inverter and line side. A disadvantage to this type of switch is that they are mechanical. Because they may be seldom used, they can fail because of dust collection and their lubricants drying out. The static switch has multiple SCR's on the inverter and line side. These switches are an improvement over the electromechanical type because of no moving parts, no chance of contamination, and they are much quicker. The third type is a hybrid of the first two. Power is maintained by the SCR's until the inverter electromagnetic breaker opens and bypass breaker closes. Because of the moving parts being added back into this type, it is concluded that the static switch is the most desirable.

3.5 Battery and Auxiliary Power

The battery system of an UPS provides DC power to the inverter in case the input power drops below an acceptable level. The size of the battery system will determine the amount of reserve time available during a power outage. The battery system is usually sized to provide enough power to permit either the critical load to be shut down without negative consequences, to allow time for an auxiliary power source to be brought on line, or to provide power until the original input power is restored to normal. There are two basic types of batteries, primary and secondary. Primary batteries are non-rechargeable. They are discharged once and then discarded. Secondary batteries can be recharged and reused.

Since secondary batteries have the capability of being used more than once, these are the type normally found in UPS systems. Of the different type of secondary batteries, lead-acid and nickel-cadmium batteries are the most widely used in UPS systems. Lead-acid batteries are utilized the most of these two types.

Lead-acid batteries use a highly reactive sponge lead as its negative electrode, lead dioxide of the positive electrode, and sulfuric-acid as an electrolyte. These batteries advantages are low cost along with excellent reliability and performance characteristics. They also are advantageous in UPS applications because of their lower gas output, requiring less ventilation, and low maintenance.

Nickel-cadmium batteries use trivalent nickel oxide for the positive electrode, cadmium for the negative electrode, and a solution of potassium hydroxide as an alkaline electrolyte. The advantages of this type of battery are small in size and weight; excellent high and low temperature performance; and its high rate, short term discharge capability. Disadvantages are the high costs and maintenance requirements.

When selecting a battery system, battery life, discharge and recharging times, cost, size, and installation requirements must be considered. The purpose must also be determined for what the system will be used. Will it be for orderly system shutdown, interim power before auxiliary source can be brought on line, or power supply until original input power returns to normal? The longer the batteries are to supply power and the larger the system that is required, the more installation space at will require and the more it will cost.

The only optional part of an UPS system is an auxiliary power supply.[27] This is usually an engine driven power generator. The auxiliary power supply usually proves cost effective when long term outages are frequent or 100% reliability is necessary. The auxiliary power supply on certain installations can significantly reduce battery cost by reducing the duration battery power is required.

A close examination of the critical load and each component of the UPS system can help in making a cost effective decision when deciding if an UPS is required and what type of each component it should incorporate. If an UPS is required, this system can be designed to meet specified requirements and guidelines specified by the user.

CHAPTER FOUR

SELECTING AN UPS SYSTEM

4.1 Load Hardware Factors

When selecting an UPS system, we must look at both load hardware and application. Load hardware requirements are the characteristics of the load that determines the design, performance limits, and capabilities of the UPS required.[38] The load application factors are requirements of a particular project or use. These are not related to the load hardware.[39]

When looking at load hardware factors, I have selected several factors that should be considered. These are not, by any means, all that should be looked at, but will form a good starting point. These are in no specific order. First, power requirements for the project and critical load must be identified along with any future plans for expansion. It may turn out to be more cost effective to buy a larger system now than to upgrade a system. An alternative is to design and install a system in such a manner that it is easily expanded when the requirement arises. Two ways to determine the current requirements are actually measuring the load demands or by using name plate data. Actual measurement are preferred because of the safety factors added into name plate ratings. Also the number of phases must be considered because a single-phase

UPS cannot handle a three-phase load. A three-phase UPS, on the other hand, can handle a single phase load. So if there are any three-phase demands within the load handled by the UPS, a three-phase UPS must be used.

The power factor is another area that must be considered. Not only is it important in determining the size and types of transformers, wiring, and circuit breakers required, it also is important in deciding which UPS to use. Whether there is a leading or lagging power factor is determined by the position of the current in respect to the voltage when dealing with AC power. This is the difference between the Volt-Amp (VA) and Watt (W) rating of equipment. An example is a 100 KVA generator with a 0.8 power factor will produce 80 KW of power. As can be seen, the power factor can also be called the efficiency factor. Many UPS systems cannot handle a leading power factor but many computer manufacturers are utilizing systems involving leading power factors for economic reasons. Also the load configuration in three-phase systems, whether delta or wye connection, is important because a delta configuration will produce a leading power factor. Connection method for this problem detract from system efficiency and can add another potential problem point in the system.

Frequency stability must be looked into because if the variation in frequency is beyond equipment toleration it can have an adverse effect on the equipment. The UPS must also have the ability of synchronizing its output with that of the AC bypass source and be very precise in its control of output frequency. This is important because of the need to minimize disturbances during transfer to the bypass source and if the equipment, such as computers, contain a clock circuit for billing or time keeping, the frequency deviations can cause clock error. The slew rate, which is the amount of change in frequency, is also important because motor speeds are proportional to frequency. This includes small motors such as disk drives in computers. As discussed earlier, most critical loads can only withstand a maximum slew rate of 0.5 Hz/sec.

Unbalanced loading, overload capacity, and inrush handling capacity are important when planning for an UPS. Most UPS systems have an unbalanced load capability of 20%. This may seem adequate but it is very easy to exceed. When loading exceeds the rated maximum unbalance, components of the UPS are stressed, regulation starts to deteriorate, and distortion increases. Monitoring of the load is the best method of problem prevention. Overload capacity of the UPS will be determined by installation, projected growth, and peak demand. The greater the overload capacity the larger and more expensive the system. A buyer must make sure he is making a cost effective choice. The inrush handling capacity is the ability, when starting the system or equipment, to handle the large current demand. This demand can be 12 to 15 times greater than normal current. The UPS must be designed to tolerate a short circuit or severe overloads if this is the type of critical load it will experience.

Transfer and reserve time are two very important factors to consider. The UPS design and transfer device will determine the transfer time and the critical load will determine the devices used. The five factors to examine in terms of transfer time are: type of transfer required, break-before-make or make-before-break transferring of power; UPS configuration, forward or reverse transfer; and the speed that is required for the transfer to take place. The reserve time will be determined by the cost of down and recovery time, historical data on area power reliability, equipment sensitivity, and cost of reserve. The greater the required reserve time, when dealing with a battery system, the higher the cost. Most battery systems have a power supply of about 15 to 30 minutes. A standby generator should be considered if longer outages are being anticipated.

These are the major load related factors which should be considered when selecting an UPS system. There are more factors that could be considered depending on the sophistication of the load and the system required.

4.2 Application Factors

An application factor must be considered on each separate project. Several of these factors are reviewed in terms of their importance when selecting an UPS. These factors should give the buyer a general idea of regional impact and installment/maintenance costs on an UPS system.

The reliability of the system is of great importance and must be considered from three areas: reliability of commercial power at the facility location, the impact of line aberrations on the critical load at the specified facility location, and the ability of the UPS to operate under the first two considerations. Efficiency is also considered along with reliability because many times trade-offs in efficiency are made to insure reliability.

The geographic location and environmental considerations must include weather, temperature, altitude, humidity, and seismic risk. Weather can increase possibilities of outages or other powerline aberrations. Temperature has an effect on the battery system and its ability to supply reserve power. Altitude has a significant impact on reliability of the UPS. The design will specify at what point above sea level a system will have to be derated. Humidity will affect the life of both UPS components. An area with a higher seismic risk will cause the addition of extra support and increased installation costs.

Physical characteristics such as floor space availability, floor loading capacity, and access space to the unit after installation must be considered before selecting an UPS. Also, the alarms, meters, and controls to be used in the specific application must be determined. This could be built into the unit or at a separate station.

When installing an UPS, consideration must be made for fuse location, grounding capabilities, air conditioning and ventilation requirement, and code requirements. Also, is facility power enough to support the UPS? Will a engine-generator be incorporated and how will the batteries be installed? Who will be performing post installation testing?

Finally, the cost of the UPS system must be considered. A typical installed UPS can cost between $650 to $1500 per KVA. The cost of operating the UPS is usually between $20 to $40 per KVA each year. Maintenance of the system is usually between 3 to 8% of the installed cost per year.[40] Additional costs are delivery expenses and the engine-generator, if used. In the following chapter a computer program has been developed to help determine if an UPS is cost effective in terms of dollars output vs. dollar income.

There are many factors that should be considered in determining the UPS needed. These factors, whether associated with the load hardware or the systems application should be reviewed carefully to avoid a costly mistake of choosing an UPS that cannot fulfill its requirements or cannot operate properly in its environment.

CHAPTER FIVE

ANALYSIS OF THE COST EFFECTIVENESS OF AN UPS SYSTEM

The following computer program, prepared by Charlie A. Bigelow, is written in BASIC computer language. It will analyze the cost effectiveness of installing an UPS system. It uses information supplied by the computer operator about the prospective UPS system, the location of the facility, and the company utilizing it to calculate whether installation of an UPS will benefit the company financially. It takes into consideration costs of the UPS system (initial and continuous), depreciation over the life of the facility, lost revenue during an outage and recovery time, the track record of the local power supply, and the approximate number of hours off line each year. Recommendations at the end of the program state whether installation of an UPS is advised based on a plus or minus cash flow. The program is user friendly and the information illustrated on page 54 will be needed so the operator can answer the program's 17 questions. Three trial runs have been made to demonstrate the different outputs of the program.

```
10 REM *** THE FOLLOWING PROGRAM WAS PREPARED BY              ***
20 REM *** CHARLIE A. BIGELOW AS PART OF HIS MASTER'S         ***
30 REM *** REPORT SUBMITTED THE SUMMER TERM OF 1986 TO        ***
40 REM ***   THE CIVIL ENGINEERING DEPARTMENT OF THE          ***
50 REM ***             UNIVERSITY OF FLORIDA                  ***
60 PRINT "THIS PROGRAM WILL HELP THE USER DECIDE IF THE UPS"
70 PRINT "HE/SHE IS PROPOSING WILL BE COST EFFECTIVE."
80 PRINT "THIS PROGRAM IS USER FRIENDLY AND WILL ASK ALL "
90 PRINT "QUESTIONS NEEDED TO PROVIDE YOU WITH, WHAT I HOPE "
100 PRINT "WILL BE,USEFUL INFORMATION."
110 PRINT "ENTER TODAY'S DATE. ( ie. 2 JULY 86 )":INPUT DAT$
120 PRINT "WHO WILL BE USING THIS INFORMATION? (ie. PERSON OR "
130 PRINT "COMPANY'S NAME )":INPUT A$
140 REM *** FACILITY SITE INFORMATION ***
150 PRINT " "
160 PRINT "ALL NUMBERS ARE TO BE ENTERED WITHOUT $, %, #,"
170 PRINT "OR ETC."
180 PRINT " "
190 PRINT "HOW MANY HOURS IN A 24 HR DAY DOES YOUR FACILITY "
200 PRINT "REQUIRE CLEAN CONTINUOUS POWER?":INPUT HR
210 PRINT "HOW MANY DAYS IN A 7 DAY WEEK IS YOUR FACILITY "
220 PRINT "OPERATIONAL?":INPUT W
230 PRINT "HOW MANY HOLIDAYS DOES YOUR FACILITY SHUT"
240 PRINT "DOWN FOR?":INPUT H
250 PRINT "WHAT IS THE PROBABILITY OF A POWER OUTAGE"
260 PRINT "( LONG TERM BROWNOUT OR BLACKOUT ) AT THE"
270 PRINT "FACILITIES LOCATION IN A YEAR?":INPUT P
280 PRINT " "
290 PRINT "THIS PROGRAM ASSUMES ALL OUTAGES ARE DURING"
300 PRINT "OPERATIONAL HOURS."
310 PRINT " "
320 PRINT "WHAT IS THE AVERAGE DURATION OF POWER OUTAGES IN"
330 PRINT "THIS FACILITY'S LOCATION? ( IN MINUTES )":INPUT AL
340 PRINT "WHAT IS THE MAXIMUM DURATION OF OUTAGES"
350 PRINT "EXPERIENCED IN THIS LOCATION? ( IN MINUTES )"
360 INPUT ML
370 DW=(52*W)-H
380 HO=DW*HR
390 HD=HO*P
400 REM *** COSTS AND PROFITS OF DOING BUSINESS ***
410 PRINT "WHAT IS THE YEARLY GROSS INCOME OF THE BUSINESS?"
420 INPUT GI
430 PRINT "WHAT IS THE AVERAGE YEARLY WAGE OF YOUR COMPANY'S"
440 PRINT "EMPLOYEES? ( THIS INCLUDES MANAGEMENT AND LABORERS )"
450 INPUT AW
460 PRINT "IN THE CASE OF A POWER OUTAGE, HOW LONG DO YOU"
470 PRINT "ESTIMATE IT WOULD TAKE TO BRING YOUR FACILITY BACK"
480 PRINT "UP TO FULL OPERATION? ( IN HOURS )":INPUT DT
490 PRINT " "
500 PRINT "THIS PROGRAM ASSUMES THE FACILITY CANNOT FUNCTION"
```

```
10 REM *** THE FOLLOWING PROGRAM WAS PREPARED BY          ***
20 REM *** CHARLIE A. BIGELOW AS PART OF HIS MASTER'S     ***
30 REM *** REPORT SUBMITTED THE SUMMER TERM OF 1986 TO    ***
40 REM ***   THE CIVIL ENGINEERING DEPARTMENT OF THE      ***
50 REM ***            UNIVERSITY OF FLORIDA               ***
60 PRINT "THIS PROGRAM WILL HELP THE USER DECIDE IF THE UPS"
70 PRINT "HE/SHE IS PROPOSING WILL BE COST EFFECTIVE."
80 PRINT "THIS PROGRAM IS USER FRIENDLY AND WILL ASK ALL "
90 PRINT "QUESTIONS NEEDED TO PROVIDE YOU WITH, WHAT I HOPE "
100 PRINT "WILL BE,USEFUL INFORMATION."
110 PRINT "ENTER TODAY'S DATE. ( ie. 2 JULY 86 )":INPUT DAT$
120 PRINT "WHO WILL BE USING THIS INFORMATION? (ie. PERSON OR "
130 PRINT "COMPANY'S NAME )":INPUT A$
140 REM *** FACILITY SITE INFORMATION ***
150 PRINT " "
160 PRINT "ALL NUMBERS ARE TO BE ENTERED WITHOUT $, %, #,"
170 PRINT "OR ETC."
180 PRINT " "
190 PRINT "HOW MANY HOURS IN A 24 HR DAY DOES YOUR FACILITY "
200 PRINT "REQUIRE CLEAN CONTINUOUS POWER?":INPUT HR
210 PRINT "HOW MANY DAYS IN A 7 DAY WEEK IS YOUR FACILITY "
220 PRINT "OPERATIONAL?":INPUT W
230 PRINT "HOW MANY HOLIDAYS DOES YOUR FACILITY SHUT"
240 PRINT "DOWN FOR?":INPUT H
250 PRINT "WHAT IS THE PROBABILITY OF A POWER OUTAGE"
260 PRINT "( LONG TERM BROWNOUT OR BLACKOUT ) AT THE"
270 PRINT "FACILITIES LOCATION IN A YEAR?":INPUT P
280 PRINT " "
290 PRINT "THIS PROGRAM ASSUMES ALL OUTAGES ARE DURING"
300 PRINT "OPERATIONAL HOURS."
310 PRINT " "
320 PRINT "WHAT IS THE AVERAGE DURATION OF POWER OUTAGES IN"
330 PRINT "THIS FACILITY'S LOCATION? ( IN MINUTES )":INPUT AL
340 PRINT "WHAT IS THE MAXIMUM DURATION OF OUTAGES"
350 PRINT "EXPERIENCED IN THIS LOCATION? ( IN MINUTES )"
360 INPUT ML
370 DW=(52*W)-H
380 HO=DW*HR
390 HD=HO*P
400 REM *** COSTS AND PROFITS OF DOING BUSINESS ***
410 PRINT "WHAT IS THE YEARLY GROSS INCOME OF THE BUSINESS?"
420 INPUT GI
430 PRINT "WHAT IS THE AVERAGE YEARLY WAGE OF YOUR COMPANY'S"
440 PRINT "EMPLOYEES? ( THIS INCLUDES MANAGEMENT AND LABORERS )"
450 INPUT AW
460 PRINT "IN THE CASE OF A POWER OUTAGE, HOW LONG DO YOU"
470 PRINT "ESTIMATE IT WOULD TAKE TO BRING YOUR FACILITY BACK"
480 PRINT "UP TO FULL OPERATION? ( IN HOURS )":INPUT DT
490 PRINT " "
500 PRINT "THIS PROGRAM ASSUMES THE FACILITY CANNOT FUNCTION"
```

```
510 PRINT "UNTIL FULLY OPERATIONAL"
520 PRINT " "
530 PRINT "WHAT IS THE NUMBER OF EMPLOYEES THAT COULD NOT "
540 PRINT "PERFORM THEIR JOBS BECAUSE OF A POWER OUTAGE?"
550 INPUT TE
560 HI=GI/HO
570 AHW=AW/HO
580 NO=HD/(AL/60)
590 REM *** COST OF AN OUTAGE AND RECOVERY TIME ***
600 CNP=(HD+(NO*DT))*TE*AHW
610 LI=(HD+(NO*DT))*HI
620 TIL=CNP+LI
630 REM *** COST OF UPS ***
640 PRINT "WHAT IS THE INSTALLED COST OF THE UPS YOU ARE"
650 PRINT "PLANNING TO UTILIZE? ( THIS SHOULD INCLUDE THE"
660 PRINT "PURCHASE PRICE OF THE UPS, BATTERY PLANT, AND"
670 PRINT "EXPENSES INCURRED IN INSTALLATION )":INPUT UP
680 PRINT "WHAT IS ESTIMATED OPERATIONAL COST OF THE UPS"
690 PRINT "PER YEAR? ":INPUT OC
700 PRINT "WHAT IS THE ESTIMATED MAINTENANCE EXPENSES"
710 PRINT "PER YEAR?":INPUT ME
720 PRINT "WHAT IS THE RESERVE TIME OF THE BATTERY PLANT"
730 PRINT "YOU PLAN TO USE? ( IN MINUTES )": INPUT R
740 PRINT " "
750 PRINT "IF YOUR RESERVE TIME IS LESS THAN THE AVERAGE"
760 PRINT "OR MAXIMUM OUTAGE DURATION, YOU MAY WANT TO "
770 PRINT "ADD AN AUXILIARY POWER SUPPLY ( ENGINE-GENERATOR )"
780 PRINT "TO COVER THE LONGER OUTAGES.  IF THIS IS ADDED"
790 PRINT "IT MAY LESSEN THE COST OF THE BATTERY PLANT"
800 PRINT "SINCE LESS RESERVE MIGHT BE REQUIRED."
810 PRINT " "
820 PRINT "ARE YOU GOING TO INCORPORATE AN ENGINE-GENERATOR"
830 PRINT "AUXILIARY POWER SUPPLY? KEY ( 1=YES, 2=NO )"
840 INPUT Y
850 IF Y=2 THEN 890
860 PRINT "WHAT IS THE COST OF THE ENGINE-GENERATOR,"
870 PRINT "INCLUDING INSTALLATION COSTS?":INPUT EG
880 GOTO 900
890 EG=0
900 PRINT "WHAT IS THE CURRENT DISCOUNT RATE THAT YOU"
910 PRINT "WILL BE USING ON THE MONEY BORROWED TO"
920 PRINT "INSTALL YOUR UPS SYSTEM? ( ie. 12% SHOULD"
930 PRINT "BE ENTERED AS .12 ) ":INPUT I
940 I1=I*100
950 PRINT "WHAT IS THE USEFUL LIFE YOU EXPECT FROM THE"
960 PRINT "UPS? ( IN YEARS )":INPUT N
970 A=(UP+EG)*(I*(1+I) N/((1+I) N-1))
980 PRINT " "
990 PRINT "DEPRECIATION USED IS STRAIGHT LINE OVER THE"
1000 PRINT "USEFUL LIFE OF THE UPS "
```

```
1010 PRINT " "
1020 DEP=(UP+EG)/N
1030 PRINT " "
1040 UC=OC+ME+A-DEP
1050 PRINT " "
1060 REM *** COST EFFECTIVENESS ***
1070 CE=TIL-UC
1080 ACE=ABS(CE)
1090 REM *** PRINTOUT ***
1100 DEVICE$="SCRN:":WIDTH "SCRN:",80
1110 OPEN DEVICE$ FOR OUTPUT AS #1
1120 PRINT #1,"THE FOLLOWING DATA IS PROVIDED FOR ";A$
1130 PRINT #1,"ON ";DAT$
1140 PRINT #1," "
1150 PRINT #1,"      PROGRAM INFORMATION "
1160 PRINT #1,"      ------------------- "
1170 PRINT #1," "
1180 PRINT #1,"INSTALLED COST OF UPS                      $";UP
1190 PRINT #1,"ENGINE-GENERATOR COST                      $";EG
1200 PRINT #1,"UPS MAINT.COST PER YEAR                    $";ME
1210 PRINT #1,"UPS OPERATIONAL COST PER YEAR              $";OC
1220 PRINT #1,"DISCOUNT RATE                               ";I1;"%"
1230 PRINT #1,"UPS USEFUL LIFE                             ";N;" YEARS"
1240 PRINT #1,"YEARLY COST OF UPS                         $";
1250 PRINT #1, USING "#######.##";UC
1260 PRINT #1,"HOURS LOST DUE TO OUTAGE                    ";
1270 PRINT #1, USING "####.##";HD;
1280 PRINT #1," HOURS"
1290 PRINT #1,"                 PER YEAR"
1300 PRINT #1,"HOURS LOST DUE TO RECOVERY                  ";
1310 PRINT #1, USING "####.##";NO*DT;
1320 PRINT #1," HOURS"
1330 PRINT #1,"               TIME PER YEAR"
1340 PRINT #1,"AVERAGE DURATION OF OUTAGES                 ";AL;" MINUTES"
1350 PRINT #1,"MAXIMUM DURATION OF OUTAGES                 ";ML;" MINUTES"
1360 PRINT #1,"# OF PERSONNEL EFFECTED BY OUTAGE           ";TE
1370 PRINT #1,"AVERAGE HOURLY WAGE OF                     $";
1380 PRINT #1, USING "####.##";AHW
1390 PRINT #1,"PERSONNEL AFFECTED BY THE OUTAGE"
1400 PRINT #1,"INCOME LOST DURING OUTAGE                  $";
1410 PRINT #1, USING "#######.##";LI
1420 PRINT #1,"AND RECOVERY PERIOD"
1430 PRINT #1,"NONPRODUCTIVE WAGES PAID DURING            $";
1440 PRINT #1, USING "#######.##";CNP
1450 PRINT #1,"OUTAGE AND RECOVERY PERIOD"
1460 PRINT #1," "
1470 PRINT #1," "
1480 PRINT #1,"      ----------------------- "
1490 PRINT #1," "
1500 PRINT #1," "
```

```
1510 IF CE<0 THEN 1680
1520 PRINT #1,"THE BENEFIT OF INSTALLING AN UPS IS"
1530 PRINT #1,"                             APPROXIMATELY $";
1540 PRINT #1, USING "#######.##";CE;
1550 PRINT #1," PER YEAR"
1560 PRINT #1," "
1570 PRINT #1,"IT IS RECOMMENDED THAT YOU INVEST IN AN "
1580 PRINT #1,"UPS SYSTEM FROM A FINANCIAL VIEW POINT."
1590 PRINT #1," "
1600 IF ML<R THEN 1670
1610 IF EG>0 THEN 1670
1620 PRINT #1,"SINCE OUTAGES GREATER THAN THE RESERVE TIME"
1630 PRINT #1,"OF THE BATTERY PLANT HAVE BEEN EXPERIENCED"
1640 PRINT #1,"AN , NO ENGINE-GENERATOR IS CURRENTLY PLANNED,"
1650 PRINT #1,"I RECOMMEND YOU RECONSIDER INSTALLING AN"
1660 PRINT #1,"ENGINE-GENERATOR AUXILIARY POWER SYSTEM."
1670 GOTO 1750
1680 PRINT #1,"THE INSTALLATION OF THE UPS WILL COST"
1690 PRINT #1,"                             APPROXIMATELY $";
1700 PRINT #1, USING "#######.##";ACE
1710 PRINT #1,"MORE PER YEAR THAN DOING NOTHING."
1720 PRINT #1," "
1730 PRINT #1,"IT IS NOT RECOMMENDED THAT YOU INVEST IN AN"
1740 PRINT #1,"UPS SYSTEM FROM A FINANCIAL VIEW POINT."
1750 PRINT #1," "
1760 PRINT #1," "
1770 PRINT #1,"IF THE CRITICAL LOAD PERFORMS A FUNCTION THAT"
1780 PRINT #1,"MUST BE SUPPLIED WITH UNINTERRUPTIBLE POWER"
1790 PRINT #1,"NO MATTER WHAT THE COST, IT IS RECOMMENDED"
1800 PRINT #1,"THAT AN UPS WITH AUXILIARY POWER SUPPLY BE "
1810 PRINT #1,"INSTALLED.  THIS RECOMMENDATION APPLIES "
1820 PRINT #1,"WHETHER THE USE OF AN UPS IS COST EFFECTIVE"
1830 PRINT #1,"OR NOT."
1840 PRINT #1," "
1850 PRINT #1," "
1860 PRINT #1,"     ------------------------ "
1870 PRINT #1," "
1880 PRINT #1," "
1890 CLOSE #1
1900 PRINT "MENU FOR EDITING OR PRINTOUT"
1910 PRINT "<1> PRINT SCREEN"
1920 PRINT "<2> HARD COPY"
1930 PRINT "<3> NEW PROGRAM"
1940 PRINT "<4> ADD ENGINE-GENERATOR"
1950 PRINT "<5> END"
1960 PRINT "ENTER # OF OPTION DESIRED.":INPUT Z
1970 IF Z=1 THEN 1100
1980 IF Z=2 THEN 2020
1990 IF Z=3 THEN 110
2000 IF Z=4 THEN 860
2010 END
2020 DEVICE$="LPT1:":WIDTH "LPT1:",80:GOTO 1110
```

DATA USED IN TRIAL #1

1.	Number of hours per day operational	24
2.	Number of days per week operational	7
3.	Number of nonworking holidays	0
4.	Probability of a power outage	.001
5.	Average duration of outage (minutes)	18
6.	Maximum duration of outage (minutes)	90
7.	Gross income of business per year	$20,000,000
8.	Average yearly wage of employees	$32,000
9.	Recovery time from any outage (hours)	1
10.	Number of employees effected by outage	150
11.	Installation cost of UPS	$500,000
12.	Yearly operational cost of UPS	$17,500
13.	Yearly maintenance cost of UPS	$30,000
14.	Reserve time of battery plant (minutes)	30
15.	Engine-generator cost	$0
16.	Discount rate	.10
17.	UPS useful life (years)	20

THE FOLLOWING DATA IS PROVIDED FOR TRIAL #1
ON 3 JULY 86

PROGRAM INFORMATION

INSTALLED COST OF UPS	$ 500000
ENGINE-GENERATOR COST	$ 0
UPS MAINT.COST PER YEAR	$ 30000
UPS OPERATIONAL COST PER YEAR	$ 17500
DISCOUNT RATE	10 %
UPS USEFUL LIFE	20 YEARS
YEARLY COST OF UPS	$ 81229.81
HOURS LOST DUE TO OUTAGE PER YEAR	8.74 HOURS
HOURS LOST DUE TO RECOVERY TIME PER YEAR	29.12 HOURS
AVERAGE DURATION OF OUTAGES	18 MINUTES
MAXIMUM DURATION OF OUTAGES	90 MINUTES
# OF PERSONNEL EFFECTED BY OUTAGE	150
AVERAGE HOURLY WAGE OF PERSONNEL EFFECTED BY THE OUTAGE	$ 3.66
INCOME LOST DURING OUTAGE AND RECOVERY PERIOD	$ 86666.66
NONPRODUCTIVE WAGES PAID DURING OUTAGE AND RECOVERY PERIOD	$ 20800.00

THE BENEFIT OF INSTALLING AN UPS IS
APPROXIMATELY $ 26236.85 PER YEAR

IT IS RECOMMENDED THAT YOU INVEST IN AN
UPS SYSTEM FROM A FINANCIAL VIEW POINT.

SINCE OUTAGES GREATER THAN THE RESERVE TIME
OF THE BATTERY PLANT HAVE BEEN EXPERIENCED
AND NO ENGINE-GENERATOR IS CURRENTLY PLANNED,
I RECOMMEND YOU RECONSIDER INSTALLING AN
ENGINE-GENERATOR AUXILIARY POWER SYSTEM.

IF THE CRITICAL LOAD PERFORMS A FUNCTION THAT
MUST BE SUPPLIED WITH UNINTERRUPTIBLE POWER
NO MATTER WHAT THE COST, IT IS RECOMMENDED
THAT AN UPS WITH AUXILIARY POWER SUPPLY BE
INSTALLED. THIS RECOMMENDATION APPLIES
WHETHER THE USE OF AN UPS IS COST EFFECTIVE
OR NOT.

DATA USED IN TRIAL #2

1.	Number of hours per day operational	24
2.	Number of days per week operational	7
3.	Number of nonworking holidays	0
4.	Probability of a power outage	.001
5.	Average duration of outage (minutes)	18
6.	Maximum duration of outage (minutes)	90
7.	Gross income of business per year	$20,000,000
8.	Average yearly wage of employees	$32,000
9.	Recovery time from any outage (hours)	1
10.	Number of employees effected by outage	150
11.	Installation cost of UPS	$500,000
12.	Yearly operational cost of UPS	$17,500
13.	Yearly maintenance cost of UPS	$30,000
14.	Reserve time of battery plant (minutes)	30
15.	Engine-generator cost	$78,750
16.	Discount rate	.10
17.	UPS useful life (years)	20

THE FOLLOWING DATA IS PROVIDED FOR TRIAL #2
ON 3 JULY 86

PROGRAM INFORMATION

INSTALLED COST OF UPS	$ 500000
ENGINE-GENERATOR COST	$ 78750
UPS MAINT.COST PER YEAR	$ 30000
UPS OPERATIONAL COST PER YEAR	$ 17500
DISCOUNT RATE	10 %
UPS USEFUL LIFE	20 YEARS
YEARLY COST OF UPS	$ 86542.25
HOURS LOST DUE TO OUTAGE PER YEAR	8.74 HOURS
HOURS LOST DUE TO RECOVERY TIME PER YEAR	29.12 HOURS
AVERAGE DURATION OF OUTAGES	18 MINUTES
MAXIMUM DURATION OF OUTAGES	90 MINUTES
# OF PERSONNEL EFFECTED BY OUTAGE	150
AVERAGE HOURLY WAGE OF PERSONNEL EFFECTED BY THE OUTAGE	$ 3.66
INCOME LOST DURING OUTAGE AND RECOVERY PERIOD	$ 86666.66
NONPRODUCTIVE WAGES PAID DURING OUTAGE AND RECOVERY PERIOD	$ 20800.00

THE BENEFIT OF INSTALLING AN UPS IS
APPROXIMATELY $ 20924.41 PER YEAR

IT IS RECOMMENDED THAT YOU INVEST IN AN
UPS SYSTEM FROM A FINANCIAL VIEW POINT.

IF THE CRITICAL LOAD PERFORMS A FUNCTION THAT MUST BE SUPPLIED WITH UNINTERRUPTIBLE POWER NO MATTER WHAT THE COST, IT IS RECOMMENDED THAT AN UPS WITH AUXILIARY POWER SUPPLY BE INSTALLED. THIS RECOMMENDATION APPLIES WHETHER THE USE OF AN UPS IS COST EFFECTIVE OR NOT.

DATA USED IN TRIAL #3

1.	Number of hours per day operational	24
2.	Number of days per week operational	7
3.	Number of nonworking holidays	0
4.	Probability of a power outage	.001
5.	Average duration of outage (minutes)	18
6.	Maximum duration of outage (minutes)	90
7.	Gross income of business per year	$10,000,000
8.	Average yearly wage of employees	$32,000
9.	Recovery time from any outage (hours)	1
10.	Number of employees effected by outage	150
11.	Installation cost of UPS	$500,000
12.	Yearly operational cost of UPS	$17,500
13.	Yearly maintenance cost of UPS	$30,000
14.	Reserve time of battery plant (minutes)	30
15.	Engine-generator cost	$78,750
16.	Discount rate	.10
17.	UPS useful life (years)	20

THE FOLLOWING DATA IS PROVIDED FOR TRIAL #3
ON 3 JULY 86

PROGRAM INFORMATION

INSTALLED COST OF UPS	$ 500000
ENGINE-GENERATOR COST	$ 78750
UPS MAINT.COST PER YEAR	$ 30000
UPS OPERATIONAL COST PER YEAR	$ 17500
DISCOUNT RATE	10 %
UPS USEFUL LIFE	20 YEARS
YEARLY COST OF UPS	$ 86542.25
HOURS LOST DUE TO OUTAGE PER YEAR	8.74 HOURS
HOURS LOST DUE TO RECOVERY TIME PER YEAR	29.12 HOURS
AVERAGE DURATION OF OUTAGES	18 MINUTES
MAXIMUM DURATION OF OUTAGES	90 MINUTES
# OF PERSONNEL EFFECTED BY OUTAGE	150
AVERAGE HOURLY WAGE OF PERSONNEL EFFECTED BY THE OUTAGE	$ 3.66
INCOME LOST DURING OUTAGE AND RECOVERY PERIOD	$ 43333.33
NONPRODUCTIVE WAGES PAID DURING OUTAGE AND RECOVERY PERIOD	$ 20800.00

THE INSTALLATION OF THE UPS WILL COST APPROXIMATELY $ 22408.92 MORE PER YEAR THAN DOING NOTHING.

IT IS NOT RECOMMENDED THAT YOU INVEST IN AN UPS SYSTEM FROM A FINANCIAL VIEW POINT.

IF THE CRITICAL LOAD PERFORMS A FUNCTION THAT MUST BE SUPPLIED WITH UNINTERRUPTIBLE POWER NO MATTER WHAT THE COST, IT IS RECOMMENDED THAT AN UPS WITH AUXILIARY POWER SUPPLY BE INSTALLED. THIS RECOMMENDATION APPLIES WHETHER THE USE OF AN UPS IS COST EFFECTIVE OR NOT.

CHAPTER SIX

CONCLUSION

In today's world of sophisticated and sensitive electronic equipment, it is being discovered that commercial supplied AC power is not of acceptable quality and must be improved in order to be utilized. The two methods we have discussed that can handle this problem are power enhancement and power synthesis. Each of these methods have been used with varying degrees of success and as the devices level of effectiveness has increased so has the cost of implementation.

To obtain continuous, clean, reliable power, the UPS system is the only alternative. There are basically two types, the rotary and the solid state UPS systems. The effectiveness and reliability of these systems are based on their design and the reliability of its individual components. When deciding on a design of an UPS system, each component must be considered along with load hardware and application factors.

Finally we must look to see if the UPS system is cost effective. If it proves not to be and it is felt that the risk of not having an UPS is acceptable, then other alternatives must be examined to select the most cost effective method of protection desired. This should be based on the amount of risk the company determines is acceptable and the amount of money it is willing to spend.

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