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RPPR Final Report
as of 17-Jan-2020

Agency Code:

Proposal Number: 67231MAREP **Agreement Number: W911NF-15-1-0498**
INVESTIGATOR(S):

Name: Saeed Jafarzadeh
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Country: USA
DUNS Number: 124724761 EIN: 770314545
Report Date: 02-Nov-2019 Date Received: 15-Jan-2020
Final Report for Period Beginning 03-Aug-2015 and Ending 02-Aug-2019
Title: Quantitative Forecasting for Renewable Power Generation: Fuzzy Logic Approach
Begin Performance Period: 03-Aug-2015 **End Performance Period:** 02-Aug-2019
Report Term: 0-Other
Submitted By: Saeed Jafarzadeh Email: sjafarzadeh@csub.edu
Phone: (661) 654-6005
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: **STEM Participants:**

Major Goals: A major challenge in utilizing renewable energy resources for the electric grid is their volatility. Since electric power cannot be stored in large quantities, the balance of generation and load is critical for the operation of power systems. Therefore, system operators need to know an accurate forecast of their load and generation. While the accuracy in load forecasting is often satisfactory, satisfactory level of forecast accuracy for renewable generation is harder to achieve.
The project takes advantage of fuzzy logic as a tool to model a broader range of uncertainties in renewable generation. By combining fuzzy logic and probabilistic models, the project will develop a framework that is able to address both stochastic and linguistic uncertainties in renewable generation. The mathematical challenge is in mixing stochastic methodologies with fuzzy logic to achieve broader methodologies.
>> Goal 1: Involve CSUB undergraduate students in advanced research.
>> Goal 2: Conduct research leading to development of a theoretical framework for analysis of power systems with high levels of renewable energy penetration.

Accomplishments: >> Goal 1: In response to the interest expressed by CSUB students in participating in research in the area of electric power systems, the PI formed a team of undergraduate students that conduct research for this project. The students work on research projects that contribute to the technical goals of the project. Most undergraduate students lack the theoretical background for such research-intensive project. Therefore, each student required the PI's attention and time. The PI had regular meetings with each student, where they can discuss their work and progress.
>> Goal 2: Three main sub-projects were suggested in the original proposal: Renewable Energy Forecast, Power Flow Analysis, and Power System State Forecast. Student researchers are involved in research in all these areas and already made great progress. One specific theoretical area of focus in this project is the application of the extension principle for a variety of the tools used in power systems operation with renewable energies. Such application is very challenging in practice because of the theoretical nature of the extension principle, which involves tedious computations. This might be the main reason for the limited work on this topic in the scientific community of fuzzy logic. The research team worked on different aspects of this problem and achieved significant results. The fundamental idea behind our work is to implement the extension principle by reducing fuzzy sets to their alpha-cuts. This let us reduce a fuzzy problem into a set of interval problems. The results are beneficial to a variety of engineering application where linguistic uncertainties exist, including power systems with high levels of renewable energy penetration. The outcomes of our research are published or are under review for publication at major conferences and journals. We constantly receive positive feedback on this approach from the scientific community of fuzzy logic. In part because of revisiting the unconventional extension principle, which is typically avoided in applications due to its challenging computations.

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Training Opportunities: The students had the opportunity to learn Matlab as part of this project. While they are introduced to this software in our curriculum, their research experience is quite different and requires additional training. Most students involved in this project will experience this software to the level that should satisfy any graduate school, research facility, or industry standards.
In addition, most students are exposed to advanced topics of power engineering and mathematics. The level of research project they are being trained for is high enough to prepare them for competition in nation-wide or global conferences against PhD students. In fact, they already won some of such competitions!

Results Dissemination: Our focus has been on publishing the outcomes of this research project. The resulting published and under review publications are reported in the Extranet system.

Honors and Awards: •Best student paper award at IEEE World Congress on Computational Intelligence 2016.
- First place poster presentation at Emerging Researchers National Conference in STEM 2016.
- Multiple first and second places in student research competition at CSUB.
- Multiple first place standing in annual student poster presentation at CSUB during the lifetime of the project.

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Saeed Jafarzadeh
Person Months Worked: 6.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Sheriff Sadiqbatcha
Person Months Worked: 6.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE World Congress on Computational Intelligence 2016
Date Received: 27-Aug-2016 Conference Date: 25-Jul-2016 Date Published: 30-Jul-2016
Conference Location: Vancouver, Canada
Paper Title: An Analytical Approach for Solving Type-1 and Type-2 Fully Fuzzy Linear Systems of Equations
Authors: Sheriff Sadiqbatcha, Saeed Jafarzadeh
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: North American Power Symposium 2016
Date Received: 27-Aug-2016 Conference Date: 19-Sep-2016 Date Published: 21-Sep-2016
Conference Location: Denver, Colorado, USA
Paper Title: Fuzzified DC Power Flow Analysis
Authors: Sheriff Sadiqbatcha, Saeed Jafarzadeh
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: North American Power Symposium 2016
Date Received: 27-Aug-2016 Conference Date: 19-Sep-2016 Date Published: 21-Sep-2016
Conference Location: Denver, Colorado, USA
Paper Title: Enhancing Wind Power Forecasting
Authors: Saeed Jafarzadeh, Jane Berk
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: North American Power Symposium 2016
Date Received: 27-Aug-2016 Conference Date: 19-Sep-2016 Date Published: 21-Sep-2016
Conference Location: Denver, Colorado, USA
Paper Title: Terminal Voltage Regulation of Generators Using TSK Controllers
Authors: Saeed Jafarzadeh, Sami Fadali
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: North American Power Symposium
Date Received: 28-Aug-2017 Conference Date: 17-Sep-2017 Date Published: 20-Sep-2017
Conference Location: Morgantown, WV
Paper Title: Improved Probabilistic Load Flow using Unscented Transformations
Authors: Juan, Franco and Saeed, Jafarzadeh
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: North American Power Symposium
Date Received: 28-Aug-2017 Conference Date: 17-Sep-2017 Date Published: 20-Sep-2017
Conference Location: Morgantown, WV
Paper Title: Optimization Based Solution for Fuzzy Type-1 and Type-2 Power Economic Dispatch Problems
Authors: Sheriff, Sadiqbatcha and Saeed, Jafarzadeh
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE International Conference on Fuzzy Systems
Date Received: 28-Aug-2017 Conference Date: 09-Jul-2017 Date Published: 20-Jul-2017
Conference Location: Naples, Italy
Paper Title: Particle Swarm Optimization for Solving a Class of Type-1 and Type-2 Fuzzy Nonlinear Equations
Authors: Sheriff, Sadiqbatcha and Saeed, Jafarzadeh and Yiannis, Ampatzidis
Acknowledged Federal Support: **Y**

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as of 17-Jan-2020

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publicat
Conference Name: 2018 IEEE PES Transmission and Distribution Conference & Exposition
Date Received: Conference Date: 16-Apr-2018 Date Published: 30-Apr-2018
Conference Location: Denver, CO, USA
Paper Title: Frequency Regulation of Microgrid with Battery Droop Control
Authors: Ehsan Reihani, Mahdi Motalleb, and Saeed Jafarzadeh
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 0-Other
Conference Name: 2018 North American Power Symposium
Date Received: 22-Aug-2018 Conference Date: 09-Sep-2018 Date Published:
Conference Location: Fargo, ND USA
Paper Title: Unscented Transformations for Probabilistic Load Flow
Authors: Juan Franco, Saeed Jafarzadeh
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: The 2019 World Congress in Computer Science, Computer Engineering, & Applied Computing
Date Received: 15-Jan-2020 Conference Date: 29-Jul-2019 Date Published: 01-Aug-2019
Conference Location: Las Vegas, NV
Paper Title: Uncertainty Propagation in Circuit Analysis using Fuzzy Membership Functions
Authors: Sheriff Sadiqbatcha, Saeed Jafarzadeh
Acknowledged Federal Support: **Y**

Quantitative Forecasting for Renewable Power Generation: A Fuzzy Logic Approach

Funded by ARO Probability and Statistics (PM: Dr. Leonard Wilkins)
Contract Number: W911NF-15-1-0498
Duration of the Project: August 3, 2015- August 2, 2019
PI: Dr. Saeed Jafarzadeh (California State University Bakersfield)

Major Goals

A major challenge in utilizing renewable energy resources for the electric grid is their volatility. Since electric power cannot be stored in large quantities, the balance of generation and load is critical for the operation of power systems. Therefore, system operators need to know an accurate forecast of their load and generation. While the accuracy in load forecasting is often satisfactory, satisfactory level of forecast accuracy for renewable generation is harder to achieve. The project takes advantage of fuzzy logic as a tool to model a broader range of uncertainties in renewable generation. By combining fuzzy logic and probabilistic models, the project will develop a framework that is able to address both stochastic and linguistic uncertainties in renewable generation. The mathematical challenge is in mixing stochastic methodologies with fuzzy logic to achieve broader methodologies.
>> Goal 1: Involve CSUB undergraduate students in advanced research.
>> Goal 2: Conduct research leading to development of a theoretical framework for analysis of power systems with high levels of renewable energy penetration.

Accomplished under Goals

>> Goal 1: In response to the interest expressed by CSUB students in participating in research in the area of electric power systems, the PI formed a team of undergraduate students that conduct research for this project. The students work on research projects that contribute to the technical goals of the project. Most undergraduate students lack the theoretical background for such research-intensive project. Therefore, each student required the PI's attention and time. The PI had regular meetings with each student, where they can discuss their work and progress.
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