Student Poster Book of Abstracts

2012 IEEE Power and Energy Society

Transmission and Distribution Conference and Exhibition

Orlando, Florida May 7-10 2012

IEEE PES

Power & Energy Society®

Welcome Message from the Chair –

IEEE PES Student Activities Subcommittee

On behalf of the Student Activities Subcommittee, I welcome you to the Student Poster Contest at the 2012 IEEE Power & Energy Society Transmission and Distribution Conference and Exposition held at Orlando, FL, USA on May 9, 2012.

At the time of printing this book, we have 71 extended abstracts from students from different parts of the world confirmed to participate in the 2012 IEEE PES T&D student poster contest. This book of extended abstracts is aimed at documenting the many outstanding research projects, some at their early stages, and providing a glimpse of some of the activities of interest to our society at various educational institutions around the world which is presented at this meeting in form of posters by students. The research topics of these abstracts (posters) fall into 15 categories, namely:

1. Smart Sensors, Communication and Control in Energy Systems
2. Smart Grid Technology
3. Cyber and Physical Security of the Smart Grid
4. Advanced Computational Methods for Power System Planning, Operation, and Control
5. System-Wide Events and Analysis Methods
6. Intelligent Monitoring and Outage Management
7. Integrating Renewable Energy into the Grid
8. Substation and Distribution Automation
9. Dynamic Performance and Control of Power Systems
10. Market Interactions in Power Systems
11. Asset Management
12. Flexible AC Transmission Systems
13. Power Electronics
14. Electric Machine and Drives
15. Power System Modeling and Simulation

All students are invited to attend the Collegiate/GOLD/Industry Luncheon to be held on May 9, 2012 from 11.30 AM to 1 PM. The student poster contest winners will be announced at closing reception on May 10 between 2.30 PM – 4 PM.

Continuous support from the Grainger Foundation, and IEEE Power & Energy Society, and its members, especially, the Power and Energy Education Committee (PEEC) for the student activities is gratefully acknowledged.

The subcommittee acknowledges the service of Dr. Aaron St. Leger, Assistant Professor, in the Dept. of Electrical Engineering and Computer Science at the United States Military Academy, West Point, NY, who compiled this book of extended abstracts.

Siddharth (Sid) Suryanarayanan
Fort Collins, Colorado, USA.

IEEE PES Student Activities Subcommittee

Chair
Dr. Siddharth Suryanarayanan
Assistant Professor, Electrical and Computer Engineering
Colorado State University
Fort Collins, CO 80523-1373, USA
sid.suryanarayanan@ieee.org

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Assistant Professor
School of Electrical Engineering and Computer Science
Washington State University
PO Box 642752
EME 102
Spokane St Pullman
Washington 99164-2752, USA
asrivast@eecs.wsu.edu

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Associate Professor,
Department of Electrical and Computer Engineering,
Schulich School of Engineering, University of Calgary,
2500 University Drive NW, Calgary,
Alberta, T2N 1N4, Canada
h.zareipour@ucalgary.ca

Webmaster
Dr. Jignesh M. Solanki
Assistant Research Professor
Lane Department of Computer Science and Electrical Engineering
West Virginia University
395 Evansdale Drive,
Morgantown, WV 26506-6109, USA
jmsolanki@csee.wvu.edu

LIST OF PARTICIPANTS AND POSTER TITLES

Smart Sensors, Communication and Control in Energy Systems:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
9	1000063	07-4528	Economic Scheduling of Distributed Energy Storage Devices on Electric Distribution Networks	Reza Arghandeh
10	1000077	07-4470	Control of Aggregate Electric Water Heaters for Load Shifting and Balancing Intermittent Renewable Energy Generation in a Smart Grid Environment	Seyyed Ali Pourmousavi Kani
11	1000022	07-3967	Power System Reliability Enhancement Considering Smart Monitoring and Indication Smart sensors	Bamdad Falahati

Smart Grid Technology:

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12	12345		Analysis and Design of Demand Response Programs Under Weather Uncertainty	Jiayi Jiang
13	1000023	07-4062	Investigating the Development and Real Time Applications of a Smart Grid Test Bed	Saugata Biswas
14	1000064	07-4544	Limiting Ramp Rates of the Wind Power Output using a Battery System	Duehee Lee
15	1000079	07-4592	Offshore Wind Farm Study in South Carolina Power System	Tingting Wang
16	1000083	07-4613	Optimizing EV Charge/Discharge Schedule in Smart Residential Buildings	Diogenes Molina
17	1000094	07-4965	Cost to Benefit Analysis using Direct Load Control Application in Smart Grid	Abdur Rehman
18	1000101	07-5014	Synchrophasor Measurement based Situational Awareness System for Smart Grid - A Scalable Framework	Karthikeyan Balasubramaniam
19	1000105	07-4964	Applications of synchrophasor in utilities.	Nagoras Nikitas
20	1000111	07-5203	Coordinated Voltage Regulation in Active Distribution System Using Centralized Optimal Controller	Ravindran Vinoth
21	1000112	07-5249	Artificial Neural Network-Based Classifier for Power System Events	Penn Markham
22	1000113	07-5266	Development of an Agent-Based Distribution Test Feeder with Smart-Grid Functionality	Pedram jahangiri
23	1000005	07-3446	Processing and Visualization of Disturbance Data Stored in a Phasor Data Concentrator	Om Dahal

Cyber and Physical Security of the Smart Grid:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
24	1000044	07-4390	Using Graph Theory to Analyze the Vulnerability of Smart Electrical Grids	Timothy Ernster

Advanced Computational Methods for Power System Planning, Operation, and Control:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
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28	1000034	07-3778	Selection of an Optimal Structuring Element for Mathematical Morphology Based Disturbance Detection Tools	Suresh Gautam
29	1000036	07-4350	Fault Location Identification using Bayesian Data Fusion for SPS	Joseph Dieker
30	1000038	07-4352	Economic Analysis of Grid Level Energy Storage for the Application of Load Leveling	Robert Kerestes
31	1000067	07-3704	Novel fully distributed optimization control of generators for shipboard power system	Yinliang Xu
32	1000070	07-4559	Optimal Dispatch and Coordination of Distributed Energy Resources using Model Predictive Control	Ebony Mayhorn

System-Wide Events and Analysis Methods:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
33	1000035	07-3446	Processing and Visualization of Disturbance Data Stored in a Phasor Data Concentrator	Om Dahal
34	1000041	07-4362	Ensemble Learning Approach for the Estimation of Weather-Related Outages on Overhead Distribution Feeders	Padmavathy Kankanala
35	1000066	07-4044	Distributed State Estimation using Phasor Measurement Units	Woldu Tuku
36	1000097	07-5017	Rotor Angle Difference Estimation for Multi-Machine System Transient Stability Assessment	Zhenhua Wang

Intelligent Monitoring and Outage Management:

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38	1000095	07-4956	A new open conductor identification technique for single wire earth return system	Pengfei Gao

Integrating Renewable Energy into the Grid:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
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40	1000031	07-4307	Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances	Renke Huang
41	1000038	07-4352	Medium Voltage DC Network Modeling and Analysis with Preliminary Studies for Optimized Converter Configuration through PSCAD Simulation Environment	Brandon Grainger
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45	1000076	07-4573	Wind Power in Combined Energy and Reserve Market - Market Modeling and Combined Scheduling	Dawei He
46	1000082	07-4600	SOC Feedback Control for Wind and ESS Hybrid Power System Frequency Regulation	Jie Dang
47	1000089	07-4722	Energy Storage Control for Integration of Single-Phase Sources into a Three-Phase Micro-Grid with Wind Power Estimation	Prajwal Gautam
48	1000092	07-3399	Smart Dispatch of Controllable Loads with High Penetration of Renewables	Simon Kwok Kei Ng
49	1000100	07-5015	Identification and Estimation of Loop Flows in Power Networks with High Wind Penetration	Manish Mohanpurkar
50	1000109	07-5182	Voltage Profile Simulation using OpenDSS in High Penetration PV scenario	Touseef Ahmed Faial Mohammed
51	1000117	07-5277	Self-Regulated Optimal Battery Bridged PV Micro-Source for Smart Grid Applications	Paul O'Connor
52	1000121	07-5280	Modeling and Coordinated Control of Grid Connected PV/Wind Inverter in a Microgrid	Junbiao Han

Substation and Distribution Automation:

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54	1000024	07-4092	Fault Diagnosis and Prognosis for Substations	Jeong Hun Kim
55	1000115	07-5278	An Investigation of Capacitor Control Actions for Voltage Spread Reduction in Distribution Systems	Nicole Segal
56	1000118	790012	Plug-in Hybrid Electric Vehicle Modeling and Its Impact on North American Electric Distribution Network	Satish Kasani

Dynamic Performance and Control of Power Systems:

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58	1000073	07-4518	Design of Power System Stabilizer Based on Microcontroller for Power System Stability Enhancement	Samer Said
59	1000093	07-3288	Wide-Area Measurement Based Nonlinear Control of a Parallel AC/DC Power System	Hua Weng
60	1000114	07-5276	Loading Effects on Nonlinear Observability Measurement for Shipboard Power Systems	Juan Jimenez
61	1000120	07-4576	Comparison of Different Methods for Impedance Calculation and Load Frequency Control in Microgrid	Hessam Keshtkar

Market Interactions in Power Systems:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
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Asset Management:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
63	1000047	07-4339	Inventory and Evolution of Member Communication in a Volunteer Organization: Helping PES Better Disseminate Information to its Members	Laurie Stewart
64	1000048	07-4378	Network Robustness of Large Power Systems	Ricardo Moreno

Flexible AC Transmission Systems:

No.	Student Reg. No.	T&D Reg. No.	Title of Poster	Student Names
65	1000038	07-4352	High Voltage Power Electronic Technologies for Renewable to Grid Integration	Brandon Grainger
66	1000067	07-4531	System Identification based VSC-HVDC DC Voltage Controller Design	Ling Xu

Power Electronics:

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Electric Machine and Drives:

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69	1000025	07-3785	Design of a Governor and Voltage Regulator for a Laboratory Generator	Anil KC

Power System Modeling and Simulation:

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71	1000030	07-4304	Time Domain Simulation of a Three-Phase Cycloconverter for LFAC Transmission Systems	Yongnam Cho
72	1000037	07-4349	Optimization of Storage Integration into MVDC in Shipboard Power System(SPS)	Amanuel Kesete
73	1000042	07-4045	Optimal Placement of PMUs for Islanding in Sub-transmission network	Abderrohmone Elondaloussi
74	1000061	07-4525	National Long-term Transmission Overlay Design: Process and Preliminary Results	Yifan Li
75	1000062	07-4527	Dynamic Modeling of Doubly-fed Induction Machine Considering the Asymmetric Coil Distribution and Slot Existence	Liangyi Sun
76	1000065	07-4545	Electrical Distribution Architectures for Future Commercial Facilities	Emmanuel Taylor
77	1000102	07-5079	Microgrids and Blackstart operation	Sudarshan A Natarajan
78	1000106	07-4690	Short-term Load Forecasting of a University Campus with an Artificial Neural Network	David Palchak
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80	20289851		A Novel Optimization Approach to Solve Power Flow Problem Using Complementarity	Mehrdad Pirnia
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Economic Scheduling of Distributed Energy Storage Devices on Electric Distribution Networks

R. Arghandeh, J. Woyak, R. P. Broadwater, D. Bish

Keywords—Distribution Network, Energy Storage, Control

I. Summary

UTILITIES face increasing pressure to improve reliability while reducing capital expenditures. Utility-operated distributed energy storage (DES) devices have the ability to accomplish both of these tasks. The stored energy may be used during outages to maintain power to customer equipment. The utility can simultaneously rely on these devices to reduce loading and provide voltage support during hours in which the system is operating under stress, rather than investing in equipment upgrades.

Utilities operating in regions with competitive electric energy markets pay different prices at different locations and at different times of day. These prices are called the Locational Marginal Prices (LMP). Therefore, the utility can reduce the cost of operating the storage devices by charging during periods when the LMP is lower.

In order to be able to serve the load during an outage, the battery must be charged sufficiently in advance of the outage. At any given hour, the utility may estimate the number of hours for which a given DES device could sustain an outage. During periods of heavier load, a DES unit that is fully charged cannot sustain an outage for as long as when the load is lighter. During these periods of lighter load, the utility may choose to sacrifice some of its outage support hours to discharge the battery if the price of energy is high enough. This opportunity motivates the development of an economic scheduling algorithm that can decide when to charge and discharge the battery for maximum profit while still keeping enough reserve capacity to sustain an outage for a sufficient period of time. Since the load is constantly changing, the utility can benefit greatly by using a dynamic reserve capacity requirement.

This optimum scheduling algorithm has as its objective to maximize profits subject to constraints arising from the DES specifications, the dynamic reserve requirements, as well as system-level operating constraints. These system-level operating constraints include requirements to discharge the batteries to resolve overloads or to provide voltage support. When the system-level constraints are violated, the dynamic reserve requirements may be overridden—it is better to prevent outages at the present time than to prepare for unknown potential future outages.

The algorithm and results presented here demonstrate the potential profits available to the utility under different load scenarios.

Reza. Arghandeh is with with Virginia Tech – ECE Department, Blacksburg, VA 24061, USA. (e-mail: reza6@vt.edu).
Jeremy Woyak is with with Virginia Tech – ECE Department, Blacksburg, VA 24061, USA. (e-mail: jerwoyak@vt.edu).
Robert Broadwater is Professor of Virginia Tech – ECE Department, Blacksburg, VA 24061, USA. (e-mail: dew@vt.edu).
Douglas Bish is Assistant Professor of Virginia Tech – ISE Department, Blacksburg, VA 24061, USA. (e-mail: drb1@vt.edu).

II. CES Optimal Control System Overview

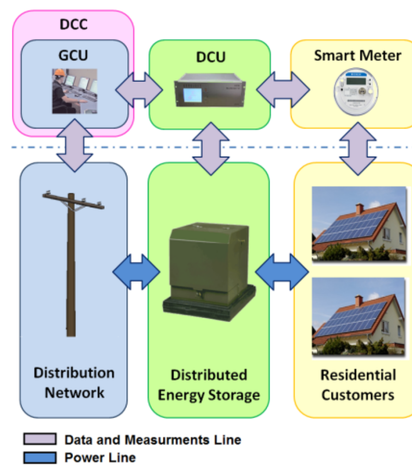

Fig. 1. DES control system architecture. (DCU: DES Control Unit, GCU: Group DES Control Unit, DCC: Distribution Control Center)

III. Selected Simulation Results

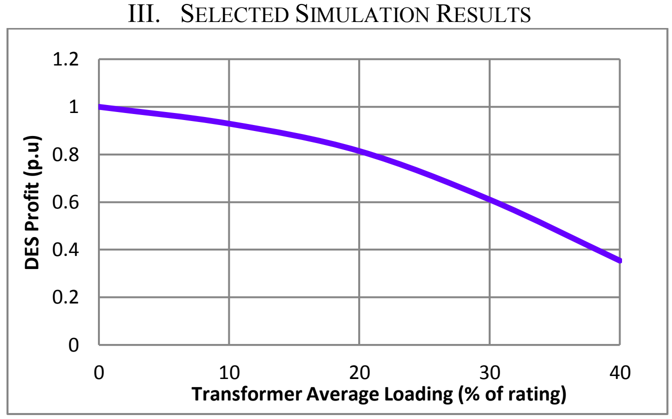

Fig. 2. DES Operation Profit vs. Distribution Transformer Loading.

Control of Aggregate Electric Water Heaters for Load Shifting and Balancing Intermittent Renewable Energy Generation in a Smart Grid Environment

S.N. Patrick*, S.A. Pourmousavi*

Advisor: Dr. M.H. Nehrir*

THE majority of electrical energy in the United States is produced by fossil fuels, which release harmful greenhouse gas emissions. The U.S. Department of Energy has established goals for a smart electric power grid, which facilitates the incorporation of clean, renewable generation sources, such as wind. A major challenge in incorporating renewable energy sources onto the power grid is balancing their intermittent and often unpredictable power generation. In addition, wind generation is typically higher at night, when consumer demand is low.

Residential electric water heaters (EWHs), which currently account for about 20% of the U.S. residential daily energy demand, are the largest contributors to the morning and evening peaks in residential power demand. This simulation study tested the hypothesis that controlling the thermostat setpoints of EWHs can shift EWH electrical energy demand from hours of higher demand to hours of lower demand, provide a large percentage of the balancing reserves necessary to integrate wind energy generation onto the electric power grid, while maintaining safe water temperatures and without significantly increasing average daily power demand or maximum power demand of the EWHs. In the experimental simulation, during high demand hours and/or low available wind power, the thermostat setpoints of a group of EWHs with higher temperature were set to a minimum, so that the EWHs consume minimal energy. Conversely, during low-demand hours and/or high-wind periods (when excess wind power generation may be available), the thermostat setpoints of a group of EWHs with lower temperature were increased by the utility to a maximum so that the EWHS absorb the available power. In order to assure customers' safety, a mixing valve was used on each individual EWH to mix the high-temperature water with cold water to reduce the water temperature to a safe value for customer use before exiting the faucet.

The above strategy proved to be useful in shifting the residential demand from high-demand hours to low demand periods, reduced the aggregate residential peak demand, and absorbed most of the excess available wind power during high-wind periods. As a result, the utility's need for fossil-fueled spinning and non-spinning reserve capacity is reduced, which would also result in emission reduction.

Several goals were set for the above EWH power management strategy, which is listed below in priority order.

- GOAL 1: Maintain customer comfort level
- GOAL 2: Load shifting from on-Peak to off-Peak hours
- GOAL 3: Peak load reduction or equality
- GOAL 4: Total energy demand reduction or equality
- GOAL 5: Economic benefit to customer
- GOAL 6: Provide desired balancing reserves

Simulation results show that the EWHs' thermostat setpoint strategy resulted in a significant load shifting of aggregate residential load from on-peak to off-peak hours and flattened the load profile, which helps reduce the balancing reserves needed by the utility. The daily energy consumption of EWHs increased slightly (about 7%) due to heat loss of the EWHs, which is a result of storing high-temperature (150-160^{o}F) hot water. This increase in EWH energy consumption can be compensated by the cost of the ancillary services that the customers provide to the utility. Therefore utilities will need to offer a financial incentive to the customers to encourage them to participate in the program.

In general, the proposed EWH thermostat setpoint strategy can increase the reliability of the system and economically benefit the utility and customers through direct payment. In particular, when time-of-use pricing was implemented in conjunction with the afore-mentioned EWH thermostat setpoint control, the energy consumed during on-peak hours was reduced significantly, while the EWH water temperature remained within safe limits.

* Electrical and Computer Engineering Department, Montana State University, Bozeman, MT.

Power System Reliability Enhancement Considering Smart Monitoring and Indication

Bamdad Falahati and Yong Fu
Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, 39762, USA
Email: bf229@msstate.edu, fu@ece.msstate.edu

Abstract—With improvements in smart sensing and digital instrumentation technologies, small, low-cost sensors have been installed in power networks, thus providing new opportunities for smart monitoring and indication (M&I). Smart M&I consists of analog/digital sensors, measurement units, control devices, and protective relays inside a digital communication network working together to gather local information about the power grid, to be recorded in the servers and to demonstrate human machine interfaces (HMI). To keep a power system operating reliably, it is necessary to continuously monitor and indicate crucial points of the power network. This paper introduces various aspects of power system monitoring and indication and proposes a mathematic model to numerically assess the positive effects of smart M&I on the power system's reliability. Based on the Markov model, the formulation used to calculate the updated failure and repair rates of the power equipment is extracted.

I. Key Equations

Reliability Enhancement formulation:

$$\mu_0 \le \mu_i \qquad 2 \le i \le N$$

$$\mu_1 = \mu_0$$

$$\lambda_0 = \sum_{i=1}^{N+1} \lambda_i$$

$$\lambda_i \times P_{Up_i} = \mu_i \times P_{Dn_i} \qquad \forall\, 1 \le i \le N$$

$$\lambda_{N+1} \times P_{Up_1} = \mu_{N+1} \times P_{Up_2}$$

$$P_{Up_1} + P_{Up_2} + \sum_{i=1}^{N} P_{Dn_i} = 1$$

$$P_{Up_1} = \frac{1}{1 + \sum_{i=1}^{N+1} \frac{\lambda_i}{\mu_i}}$$

$$P_{Up_2} = \frac{\frac{\lambda_{N+1}}{\mu_{N+1}}}{1 + \sum_{i=1}^{N+1} \frac{\lambda_i}{\mu_i}}$$

$$P_{Up} = P_{Up_1} + P_{Up_2} = \frac{1 + \frac{\lambda_{N+1}}{\mu_{N+1}}}{1 + \sum_{i=1}^{N+1} \frac{\lambda_i}{\mu_i}}$$

$$\lambda_{MI} = \sum_{i=1}^{N} \lambda_i$$

$$P_{Up} = \frac{\mu_{MI}}{\lambda_{MI} + \mu_{MI}}$$

$$\mu_{MI} = \frac{\lambda_{MI} \times P_{UP}}{1 - P_{UP}}$$

$$\kappa_\lambda = \frac{\lambda_{MI}}{\lambda_0}$$

$$\kappa_\mu = \frac{\mu_{MI}}{\mu_0}$$

$$P_{Up} = \frac{1 + \frac{\lambda_{N+1}}{\mu_{N+1}}}{1 + \sum_{i=1}^{N+1} \frac{\lambda_i}{\mu_i}} \ge \frac{1}{1 + \sum_{i=1}^{N} \frac{\lambda_i}{\mu_i}} \ge \frac{1}{1 + \sum_{i=1}^{N} \frac{\lambda_i}{\mu_0}} \ge \frac{1}{1 + \frac{\lambda_0}{\mu_0}} = P_{Up_0}$$

II. Key Chart

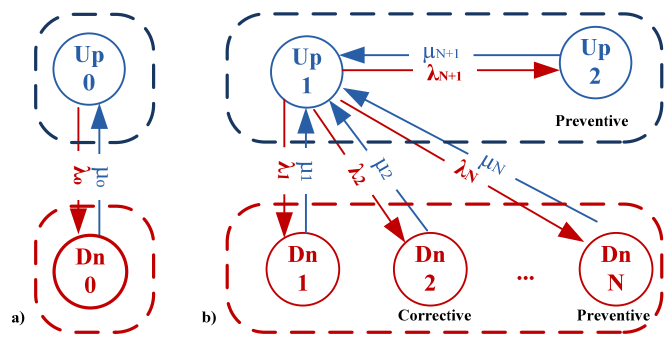

Fig. 1. Reliability assessment procedure

III. Key Results

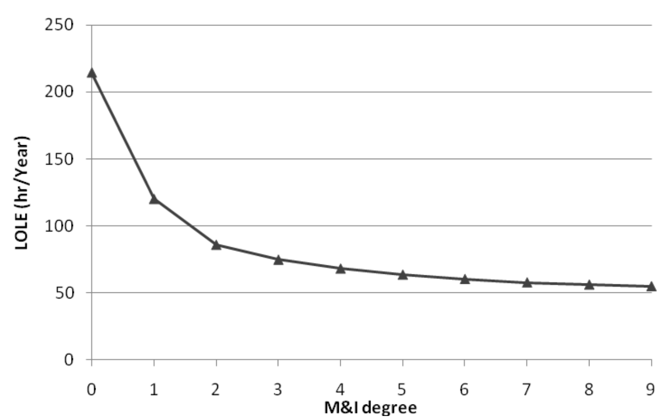

Fig.2. LOLE decreases as M&I degree increases

Analysis and Design of Demand Response Programs Under Weather Uncertainty

Jiayi Jiang, Farshid Shariatzadeh, Anurag Srivastava and Sandip Roy
School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA 99163, USA,
Email: jiayijiang0128@gmail.com, farshid.shariatzade@gmail.com, asrivast@eecs.wsu.edu and sroy@eecs.wsu.edu

***Abstract*—This poster begins a study of demand response programs operating in the presence of weather uncertainty. Specifically, we model the behavior and performance of a direct load control (DLC) program for a home air conditioning system, when weather (temperature) is uncertain and residential power prices are variable. We study both performance forecasting and DLC design in this context, bringing to bear influence-model- and ensemble-forecast- based weather forecasting tools to achieve these goals.**

I. Motivation and Problem Formulation

Power suppliers and distributors are motivated to reduce power consumption during high-usage periods, both to avoid commitment of expensive generation units and due to stability and security concerns. Direct load control (DLC) programs, as one type of demand-response mechanism, permit such reduction of consumption by compelling or incentivizing end-users to reduce consumption. DLC programs for private homes, in particular, provide price incentives to schedule consumption at low-demand periods: that is, the varying price of power on the market is passed on to the consumer, whereupon the consumer is motivated to reduce usage to reduce cost. Thus, when DLCs are implemented, the question of how residential end-users can control/optimize scheduling of high-power-consumption appliances (HVAC, water heater, lighting, etc) becomes important. In this poster, we study control and optimization of a home's HVAC system, for DLC. Specifically, we pursue forecasting and in turn optimal design of an HVAC system in the face of weather (specifically, temperature) uncertainty. Let us first present a model for HVAC system operation under DLC (on a hot day when air conditioning is needed). A clocked model is assumed, in which signals are tracked and control actions are taken at discrete time intervals (labeled k=0,1,2…) over a horizon. First, the customer is modeled as providing a desired temperature profile T_k^{cust}, as well as bounds T_k^{max} $and\ T_k^{min}$, over the horizon of interest. At each time instance, the actual indoor temperature is denoted as T_k^{in}, the outside temperature is denoted as T_k^{out}, and the price of power is denoted as P_k (where, in some situations, the price may have a dependence on the outside temperature). We assume that current temperature and price are available to the controller, and that forecasts may or may not be available. Based on available information, the controller chooses a goal temperature profile T_k^{cont}, that meets the customer's bounds but may differ from the desired profile. The HVAC is then modeled as being turned on (m_k=1) and off (m_k=0) to meet the controller's profile, as follows: if $\varepsilon T_k^{in} + (1-\varepsilon)(T_k^{out}) - z \geq T_{k+1}^{cont}$, where ε captures heat transfer rate between the outside and inside of the home and z describes the cooling provided by the HVAC, then m_k =1, otherwise m_k =0. For this operational model, we note that the home temperature then evolves as $T_{k+1}^{in} = \varepsilon T_k^{in} + (1-\varepsilon)(T_k^{out}) - m_k z$. Finally, we envision the control scheme as incurring a cost over the time horizon, which reflects both the power cost and the comfort level of the home. A plausible cost measure is: $C = \sum_{k=1}^{n}(m_k D P_k + |T_k^{cust} - T_k^{in}|)$, where D captures the power consumption per 15 minutes by the air conditioner. Let us stress that the model described here can be naturally extended to capture HVAC operations (rather than only air conditioning), and to consider multiple residential customers: these extensions will be discussed on the poster.

On the poster, the above model for HVAC control for a DLC will be motivated in detail, and simulations will be provided. In addition, two uses of the model will be explored:

1) Performance Forecasting – The model will be used to forecast HVAC performance under weather and price uncertainty, for a given control scheme (i.e., rule for choosing the controller temperature profile T_k^{cont}). Specifically, the influence-modeling paradigm will be brought to bear to generate stochastic scenarios (i.e., possible futures or profiles) of outdoor temperature at the home, and across a region of interest. We will also explore whether these temperature forecasts can be translated to price forecasts over a 24-hour time horizon. Using the stochastic futures of temperature/price, we will obtain a statistical characterization of the performance (cost) of the HVAC operation.

2) Control Design – We will pursue design of both reactive (i.e., no forecasts are available) and forecast-based control schemes, to improve or optimize HVAC control. Specifically, we will 1) compare several simple control schemes, and 2) seek for designs that optimize the expected cost.

Investigating the Development and Real Time Applications of a Smart Grid Test Bed

Saugata S. Biswas, *Student Member*, *IEEE*, Ceeman B. Vellaithurai, *Student Member*, *IEEE*,
and Anurag K. Srivastava, *Senior Member*, *IEEE*
Smart Grid Demonstration & Research Investigation Lab (SGDRIL),
The School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA

***Abstract*—With the attempt of making the power grid smarter and intelligent, many researchers are now concentrating their research on "Smart Grid" technologies aimed at upgrading the power system by using state-of-the-art computer based online monitoring and control tools along with advanced communication facilities. Presently, smart grid technologies have started spreading their spectrum over diverse applications in the power system with the aim of fully automating the power grid, right from micro to a macro level. Several algorithms have been developed for smart grid applications which need to be tested and validated before industrial deployment. This poster is a modest attempt to present the findings of the effort that has been made to model a smart power grid in real time by developing a "smart grid research test bed" and validating different smart grid algorithms using it. The algorithms that have been or will be tested using the hardware test bed include a substation automation algorithm and a real time voltage stability algorithm (based on synchrophasors). This poster also addresses another important issue in the synchrophasor industry, *viz.* PMU testing, which has been performed in the Lab using the same test bed.**

I. Development Of Smart Grid Research Test Bed

A smart grid research test bed, as shown in the figure below, has been developed to model the real life smart grid.

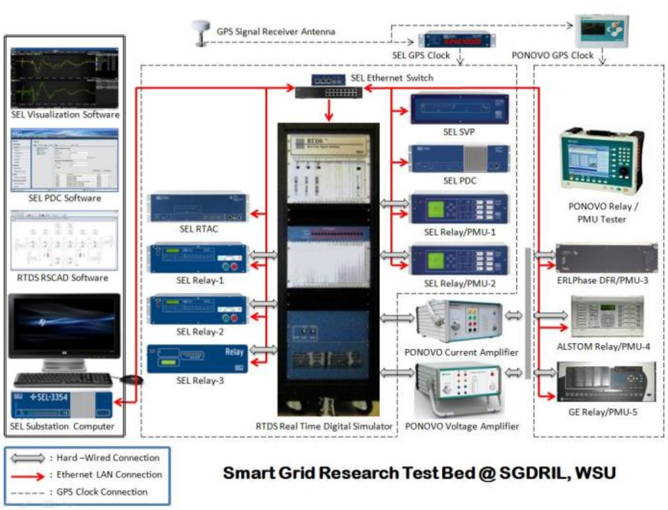

Fig-1

The test bed is an integration of several intelligent electronic devices (IEDs) like Relays, Phasor Measurement Units (PMUs), GPS clocks, Substation Computer, Real Time Automation Controller (RTAC), Synchrophasor Vector Processor (SVP), Hardware and Software Phasor Data Concentrators (PDC), and Visualization Software. The power system model is simulated in real time using the Real Time Digital Simulator (RTDS). All these devices communicate through a central Ethernet switch in a local area network. Simulated signals generated by the RTDS are fed by hard wired connections either directly to the low level inputs of the IEDs, or are suitably amplified using the current and voltage amplifiers before connecting to the high level inputs. The test bed also has a Relay/PMU tester for testing PMUs. Interoperability features as in a real life smart grid, are also taken care of in this test bed, as the different hardware devices used are from different vendors.

II. Applications Of The Smart Grid Research Test Bed

The three main applications of the smart grid research test bed are summarized below –

A. *Substation Automation*

IEDs, which contain valuable system information and can be programmed, are being deployed in substations to monitor and control the power system. One such Algorithm has been implemented using the hardware test bed.

B. *Real Time Voltage Stability*

With the advent of synchrophasors, real time voltage stability studies have gained momentum. The ability of the test bed to simulate, monitor and control power system models in real time has been used to implement a synchrophasor based voltage stability algorithm.

C. *PMU Testing*

Recently, deployment of PMUs in power grids to capture real time data is increasing. These PMUs need to be tested for their accuracy and precision before they are installed in the power grid. Hence, the test bed facility has also been used for PMU testing purposes.

III. Acknowledgment

We are thankful to SEL for sponsoring the project on Substation Automation. Additionally, we would also like to thank PSERC, PONOVO, GE, ALSTOM, ERLPhase, and RTDS for their support in this project.

Limiting Ramp Rates of the Wind Power Output using a Battery System

Duehee Lee
and Ross Baldick
University of Texas at Austin
Austin, Texas 78712-0240
Email: dlee, baldick@ece.utexas.edu

Peter Son
Xtreme Power Systems, LLC
Kyle, Texas 78640
Telephone: (512) 268–8191
www.xtremepower.com

***Abstract*—The goal of this paper is to establish a battery system in order to limit ramp rates of the wind power output. Battery operation policies are established, and then battery parameters, such as the power rating and battery capacity, are decided through the simulation. The battery system is verified through the sum of all wind power sampled from all wind farms in Electricity Reliability Council of Texas (ERCOT).**

I. Introduction

Wind power output has a lower capacity credit than conventional generators because of severe ramp events. Even though conventional generators could be dispatched to offset minor ramp events, ramp rates bigger than the Ramp Rate Limit (RRL) are still the challenge to the balance between demand and supply. Moreover, sudden and uni-directional ramp events make long and steep supply changes. However, a battery system can limit not only single severe power changes, but also long and steep ramp events.

II. Battery Mechanism

A battery has three operation modes: charging, discharging, and inactive. At every operational interval, a battery is in one of operation modes. Because of internal resistances, it is assumed that there is 10 % loss of discharging energy. The level of charged energy over the battery capacity is measured by the State of Charge (SOC). Because of the memory effect, it is assumed that a battery can be charged up to 90 %, and can be discharged down to 10 % of battery capacity. Sum of battery output and wind power output is called the net production. The difference between the previous net production and the present wind power becomes the battery input.

III. Design the Battery System

The power rating and battery capacity are decided to design the battery system. The power rating is decided as the absolute value of maximum difference between the ideal wind power and real wind power output. The ideal wind power always satisfies the RRL. The battery size is decided recursively by running a simulation repeatedly, so the battery size is increased from the initial value until the net production satisfies the RLL. Battery operates by following three policies: *a*) A battery charges when ramp-up event violates the upper RRL and discharges when ramp-down event violates the lower RRL. *b*) A battery tries to stay at 0.5 SOC level. *c*) In other cases, the net production is allowed to follow the wind power output.

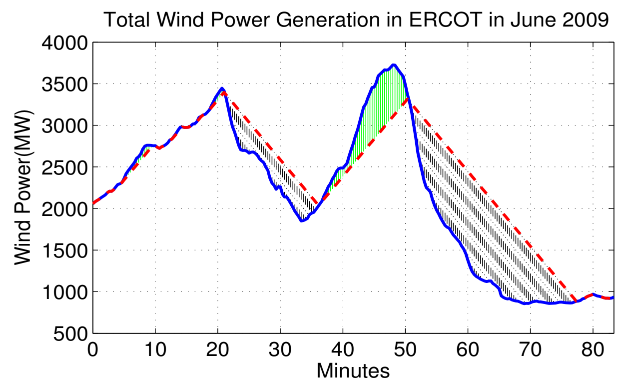

Fig. 1. Wind power output is compensated by the battery operation. Green line represents charging, and black dotted line represents discharging.

TABLE I
Comparison between conventional ways and a battery system

Energy [MWh]	Curtailment	Battery Operation
Energy Loss	2908.5	672.1
Reserve Requirement	5256.3	0

IV. Simulation & Result

Total wind power generation in ERCOT, which is sampled in June 2009 at every minute, is used to verify the battery system. Total capacity is 8,000 MW, and maximum wind power is 4,500 MW. The battery operation interval is also one minute. The RRL is given as 30[MW/minutes]. In TABLE I, conventional ways and a battery system are compared. For conventional ways, curtailment and reserve services are used. For the battery system, 1188 [MW] / 2770 [MWh] battery is used. TABLE I shows that a battery can limit ramp rates less energy loss and zero reserve requirement. A large battery capacity is used because of double ramp events in Fig. 1.

V. Conclusion & Future Works

In conclusion, the power rating, battery capacity, and operation policies are decided to reduce violation of ramping limit in the wind power system.

Offshore Wind Farm Study in South Carolina Power System

Tingting Wang, Ph.D student
Electrical and Computer Engineering Department
Clemson University, Clemson, SC, 29634

Dr.Elham Makram, Fellow IEEE
Electrical and Computer Engineering Department
Clemson University, Clemson, SC, 29634

***Abstract*— South Carolina, as part of the eastern American coastline, possesses potential offshore wind energy over twice the amount of its state level consumption [1]. The South Carolina Offshore Wind Project aims to integrate 80MW by 2014 and 1GW by 2020 into the power system. Offshore wind farms, with large capacity and long distance to the shore, have to consider the impact on the system before their installation. This poster mainly studied steady state and switching transient impact on South Carolina power system.**

In steady state analysis part, offshore wind farm configuration is figured out; the selection of wind power injection interface buses considering the cost wind farm is introduced. After wind power is divided among utilities, the maximum wind could be absorbed by different utilities are studied as well as overloaded transformers or transmission lines and voltage violation at buses.

For switching transient study, it is difficult to model each generator with detailed models because of simulation time constraint. On the other hand, wind farms consisting of large numbers of relatively small and identical generating units makes equivalent possible. In this poster, a DFIG based wind farm equivalent model is presented for switching transient operation analysis. After the equivalent model results are verified with detailed model, several switching operations are designed to study their impact on the system connected.

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Optimizing EV Charge/Discharge Schedule in Smart Residential Buildings

Casey Hubbard, *Student Member, IEEE*, Coby Lu, *Student Member, IEEE*, Russell Turner, *Student Member, IEEE*, Diogenes Molina, *Student Member, IEEE*, and Ronald Harley, *Fellow, IEEE*

Department of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA

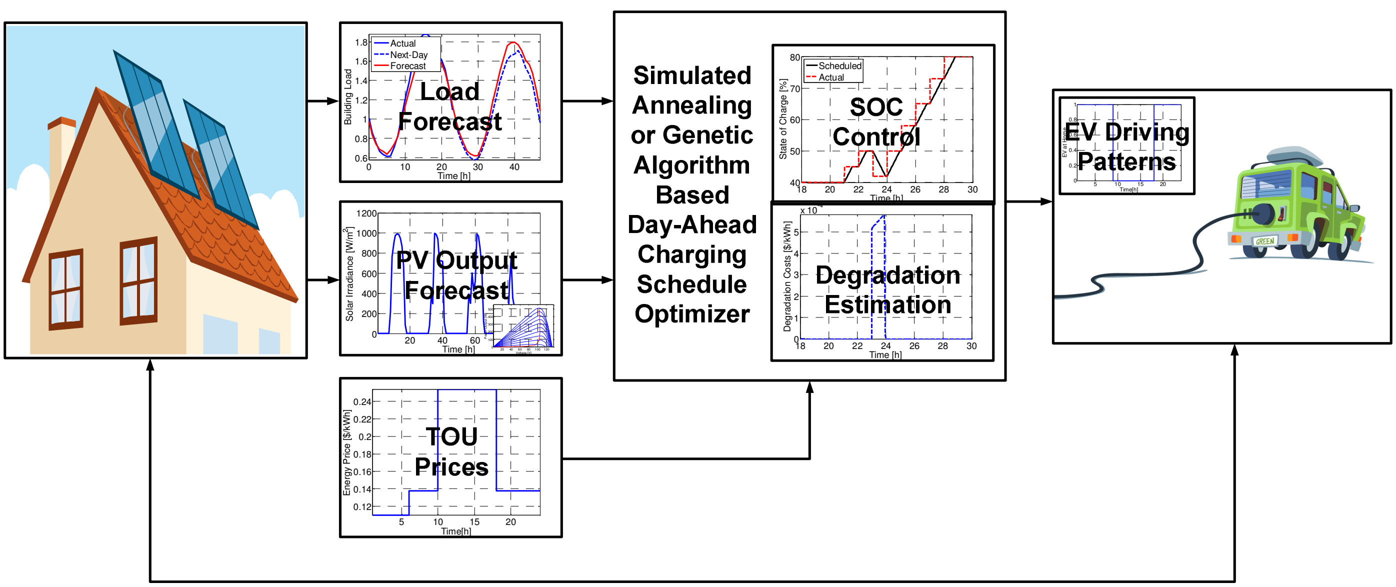
***Abstract*—As the level of penetration of electric vehicles (EVs) increases they will begin to play an important role on the operation of the smart grid. Utilities have recognized that time-differentiated pricing schemes can help mitigate the negative impact that high EV penetration would have on congestion by giving economic incentives to consumers to charge their EV batteries during off-peak periods. Devices that can automatically react to time-varying prices optimally can potentially increase the benefits of widespread EV utilization without the need for active consumer participation.**

This poster presents a mechanism for finding the optimal EV day-ahead charge/discharge schedule to minimize daily energy costs in residential buildings assuming time-varying electricity prices. It is assumed that the building is equipped with photovoltaic (PV) panels. Day-ahead forecasts of the PV array output and of the residential load are generated locally and used to ensure that the optimal policy accounts for the unique characteristics of the location of the building, its effect on daily solar irradiance and on the PV panels output, and to exploit the behavioral patters of the occupants of the residence. EV battery degradation due to each discharge cycle is estimated to ensure that long term costs resulting from accelerated battery replacement do not offset the benefits of day-to-day optimization. Linear regression models and artificial neural networks are used online to generate the day-ahead forecasts.

The optimal day-ahead schedule is constrained to ensure that battery charge/discharge rate limits are respected, and that the EV is fully charged by the time the consumer is ready to leave the residence. Simulated annealing and the genetic algorithm are evaluated in terms of convergence speed and computational costs to select the more effective optimization algorithm between the two for this application. Simulation models developed in MATLAB Simulink coupled with real weather, load, and pricing data are used to evaluate the adequacy of the proposed algorithm. The energy resulting from EV discharging is never sold back to the utility to mitigate some of the technical issues that arise from vehicle-to-grid (V2G) operation.

The optimization routine is executed at each hour interval to improve the robustness of the algorithm to inaccurate day-ahead forecasts and to allow for potential schedule changes due to unpredictable modifications of the consumer schedule and departure time. Executing the routine at each hour with a receding time horizon can also accommodate more demanding stochastic pricing schemes such as real time pricing.

I. Key Figures



This work was supported by the Opportunities Research Scholars program at the department of Electrical and Computer Engineering at the Georgia Institute of Technology, Atlanta, GA, USA

Cost to Benefit Analysis using Direct Load Control Application in Smart Grid

Abdur Rehman, *Student Member, IEEE*, Malik Baz, *Student Member, IEEE*, and Anurag K Srivastava, *Senior Member, IEEE*

Smart Grid Demonstration and Research Investigation Laboratory, The School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA 99163, USA.

Email: *ar.rehman@wsu.edu, malik.elbaz@wsu.edu*

***Abstract*—One application of the Smart Grid is for the utility company or distribution system operators to switch off or cycle specific loads during system peak demand. Improper use of these Direct Load Control (DLC) algorithm without planning may lead to instability in the grid resulting in blackouts or brownout. This work addresses the types of loads that can be easily controlled in residential district and the cost to benefit analysis of the DLC operation for the specific load.**

I. INTRODUCTION

With smart grid initiative, some of the consumer loads has a potential to be regulated and or controlled directly by the utility company or distribution system operators [1]. These loads are identified as those unnecessary to be on the grid around the clock and if they were switched off or shifted, it would not affect the consumer much in a negative way. The aspect of the utilities controlling the loads is known as Direct Load Control (DLC). The benefits for the utility to control these kind of loads are numerous. These types of loads operating at peak times can stress the lines as well as the grid as a whole, thus resulting in blackout or brownout. If DLC is not used properly in planned way, it may also result in blackout or brownout [2].

These types of loads would be generally controlled by the utilities in the event of peak system demand or to meet specific grid conditions [3-5]. The duration of the DLC load would be minimal; until the utility can re-gain the balance in the system, thus controlling the load only for a crucial amount of time. Only subtle, high demand loads will be controlled and it should not be noticeable to the consumer.

The fact that the utility has control over the load, pushes the grid in a whole new direction. In a direction, leading to more economical, stable and reliable operation. The implementation of this type of mechanism in a large scale is only possible today with enhanced communication, favorable policy and incentives. Utilities and distribution system operators (DSO) will not only be able to balance the grids from the generation side, but balance and control it from the load side as well.

III. KEY ANALYSIS

Determining the right type of load to control at given time will enable the utility or DSO to model or simulate the reduction in peak time usage. The power usage on high demand loads in residential area are dynamic and cycle through either turning on or off. If DLC devices have 2 way communications that allows DSO to see which aggregated loads are turned on in a given geography, they can calculate the cost to benefit ratio (CBR) for exploring possible incentive to be offered to meet the grid reliability goals.

This work attempts to analyze the types of loads that can be controlled easily for a given geography and the cost to benefit analysis for aggregated load. A complex algorithm will be studied to model specific loads for a location of N number of homes, the amount of power each load is drawing, whether the load is turned on or off at the time of DLC operation, the number of loads to turn off to accomplish a reduction of X amount, the CBR for controlling that specific load, and finally, a list of the best possible loads to turn off given the input, starting from the best CBR.

IV. SUMMARY

Direct Load Control will enable the utilities to prevent a possible blackout and or brownout. Giving the utilities, an ability to control the load will empower them to keep the required balance in the system. This work discusses the best plan of action through the cost to benefit ratio of each load.

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Synchrophasor Measurement based Situational Awareness System for Smart Grid – A Scalable Framework

Karthikeyan Balasubramaniam, and Ganesh Kumar Venayagamoorthy, *Senior Member*, IEEE
Real-Time Power and Intelligent Systems Laboratory
Holcombe Department of Electrical and Computer Engineering
Clemson University, Clemson, South Carolina 29634, USA
bbalasu@clemson.edu, and gkumar@ieee.org

Synchrophasors make power grids more observable by collecting data from various locations, time-align and process them as a coherent data set. . In power systems, optimal power flow dispatch is updated every five minutes. Variations between dispatches are handled by local controllers with little or no system wide information. Local controllers with system wide information have better situational awareness and can formulate better control strategy. A limiting factor to this approach is communication delays. Power system wide area communication delays range from several milliseconds to several seconds depending on the communication media and distance. One way to deal with this is to have an intelligent system which can predict state values for one or more time steps ahead of time. A novel synchrophasor measurement based situational awareness system for smart grid using cellular neural networks (CNN) framework is proposed. Recurrent neural network (RNN) is used as computational engine for each cell as RNNs have dynamic memory. By using information from phasor measurement units (PMUs) that are optimally located in a power system, each layer predicts a state variable for one or more time steps.

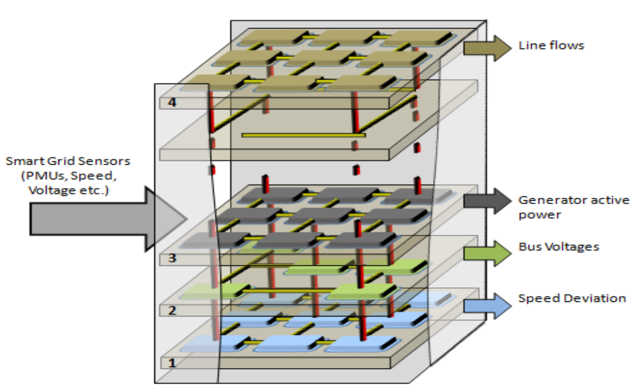

Fig 1: Each block represents a cell, where RNN is used as computational engine. Spatial dynamics are captured by connectivity i.e. information flow between cells, while temporal dynamics are captured by RNN. The four different layers predict speed deviation, terminal voltage, generator active power output and line flows. In addition to cells being connected to each other within a layer, there is also information flow between layers. This coupling enables better prediction.

Data from remote PMUs are replaced by the respective CNN cells' time delayed predicted state values for next time step. This enables local controllers to take real-time control action with system wide information. A 12-bus test power system is used to develop and demonstrate the effectiveness of the proposed situational awareness system.

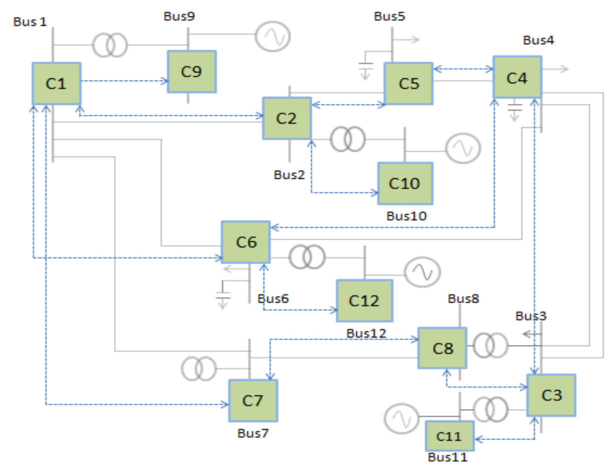

Fig 2: Voltage prediction layer connectivity. Cells are superimposed on top of one line diagram of 12 bus test system. Voltage prediction at all the 12 buses is to be carried out and hence there are 12 cells. The blue dashed lines represent the connectivity between each cell where direction of information flow is indicated by arrows.

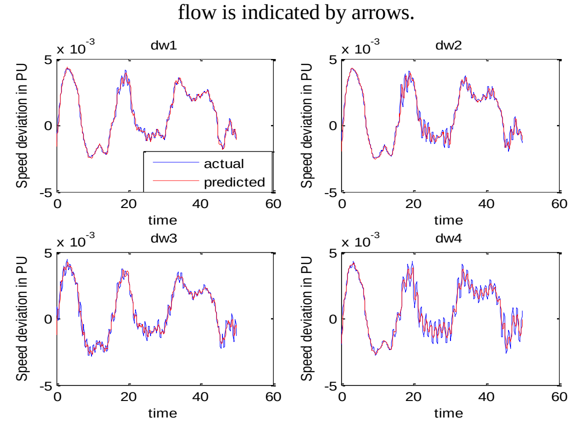

Fig 3: Testing results for speed deviation prediction of all four generators. Data is sampled at 10 Hz.

Applications of synchrophasor in utilities.

Zagoras Nikitas and Ganesh Kumar Venayagamoorthy, Senior Member, IEEE
Real-Time Power and Intelligent Systems Laboratory
Holcombe Department of Electrical and Computer Engineering Clemson University
Clemson, South Carolina 29634, USA
nzagora@clemson.edu and gkumar@ieee.org

The spate of blackouts on power systems, in the past few years, throughout the world is driving the need for the wide scale deployment of synchrophasors also widely known as phasor measurement units (PMUs). Synchrophasors have become the measurement system of choice in the electric power systems industry. This is due to the fact that synchrophasors provide a variety of information relevant to the status of the grid; while simultaneously reporting the exact time of the logging. This is achieved via a satellite interconnection with a Global Positioning System (GPS). A smarter grid has become a major driving force towards the development of novel technologies in the electric energy delivery industry around the world. Scientists and engineers around the world have developed or are in the process of developing numerous new applications for the deployment of synchrophasors. Synchrophasor technology promises to enhance the planning, design and operation of the power grid. This technology can give self-healing properties in the grid as in facilitating the integration of various power generation solutions, while facilitating the optimization of asset utilization. This research aims in collecting and categorizing all the applications that are used or proposed for a future use in the utilities. (Navin B. Bhatt, 2009)

Synchrophasors, phasor measurement units (PMUs), applications, utilities, smart grid.

I. KEY FIGURES

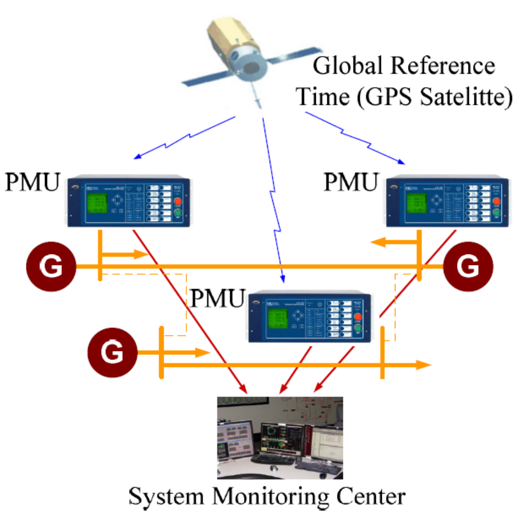

Figure 1. A typical architecture of a system with synchrophasors (G. N. Korres, P. S. Georgilakis, & N. M. Manousakis, 2011).

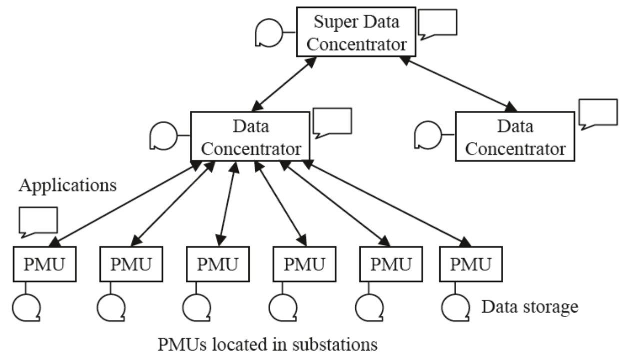

Figure 2. Hierarchy of the phasor measurement systems, and levels of phasor data concentrators (A.G. Phadke & J.S. Thorp, 2008).

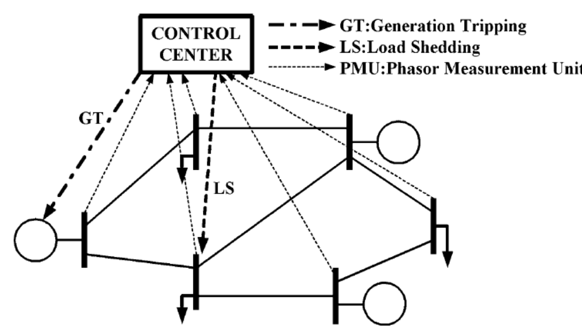

Figure 3. A phasor measurement unit protection schematic (Yi-Jen Wang, Chih-Wen Liu, & Yuin-Hong Liu, 2004).

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Coordinated Voltage Regulation in Active Distribution System Using Centralized Optimal Controller

Ravindran Vinoth, Ward T. Jewell, Edwin Sawan and Visvakumar Aravinthan
Department of Electrical and Computer Engineering, Wichita State University, Wichita, KS 67260, USA
E-mail: vkravindran@wichita.edu

***Abstract*-- The basic function of voltage regulation in the distribution system is to keep the steady state voltage within an acceptable range all the time. With increasing penetration of grid connected distributed solar photovoltaic (PV) sources, voltage regulation is becoming challenging. In particular, capacitor banks and voltage regulators that normally boost voltage slightly may push utilization voltages either above or below the standard limits because of PV's variable nature. This can adversely affect the expected 99.999% reliability requirement of smart grid and also decrease the life span of voltage regulating equipment due to excessive operations. Wide coordination using remote control, real time measurement of data, accurate load and solar forecasting and communication infrastructure enabled by the smart grid initiative has the potential to limit this effect. This paper presents a centralized controller which dispatches a coordinated schedule for the switched voltage regulators, capacitor banks and desired reactive power of distributed PV generators based on real time measurements to effectively regulate the feeder voltage and reduce the line losses, at the same time satisfying the equality and inequality constraints on the switching of voltage regulating equipment and power flow equations at the nodes.**

I. Key Equations

The Multi objective function for the controller is given by

$$J = \min\left(\sum_{i=1}^{n}\left(w_i^1\left(V_i^{desired} - V_i^{actual}\right)^2 + w_i^2\left(P_{loss,i}^{line}\right)\right)\right) \quad (1)$$

Subject to the constraints

$$N_{tap} = \sum_{i=1}^{n}\left|TAP_i - TAP_{i-1}\right| \le N_{tap}^{\max} \quad (2)$$

$$N_{cap} = \sum_{i=1}^{n}\sum_{bank=1}^{n}\left|CAP_{bank,i} \oplus CAP_{bank,i-1}\right| \le N_{cap}^{\max} \quad (3)$$

$$V_{\min} \le V_{branch,i} \le V_{\max} \quad (4)$$

$$L\left(P,Q,V,\delta\right) = 0 \quad (5)$$

II. Key Figures

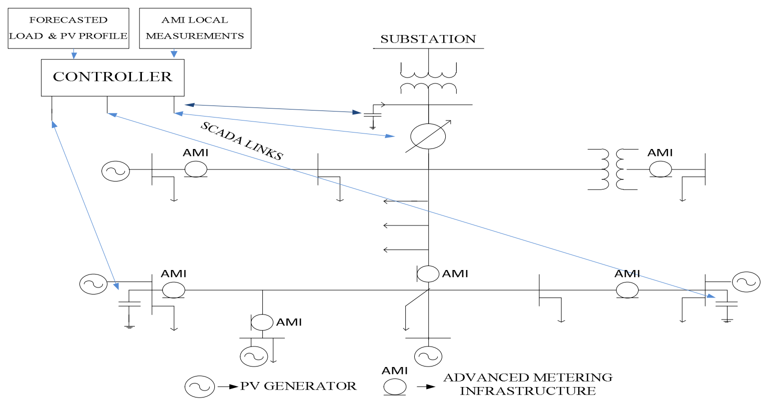

Fig. 1: Modified IEEE 13 Node Test System

III. Key Results

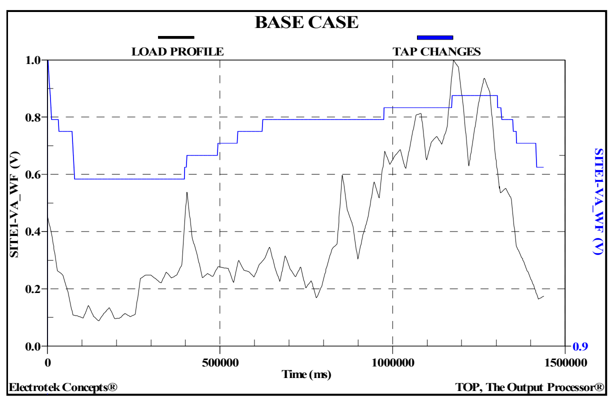

Fig.2: Simulation Results of Tap Operations and Daily Load Profile

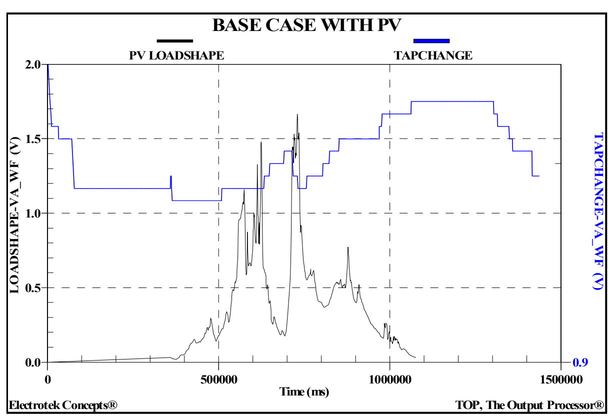

Fig. 3: Simulation Results of Tap Operations with Distributed PV Sources

Artificial Neural Network-Based Classifier for Power System Events

Penn Markham and Yilu Liu
Department of Electrical Engineering and Computer Science
University of Tennessee, Knoxville, 37996

Abstract**-- The Frequency Monitoring Network (FNET) uses Frequency Disturbance Recorders (FDRs) to collect time-synchronized frequency and angle measurements from electric power systems around the world. Once received by the FNET servers, the measurements are time-aligned, stored, and retained for additional processing.**

Detection and classification of frequency signatures caused by system disturbances ("events") are two of the most critical functions of the FNET server application. FNET can detect several different types of disturbances, including generator trips, load shedding, and oscillations. The software-based event classifiers used by the FNET server application have traditionally relied upon empirically-derived models of system behavior. While these perform reasonably well, they are difficult to develop since each classifier must be configured for a particular grid.

This paper presents different configurations of Artificial Neural Network (ANN)-based classifiers for power system events that can successfully identify disturbances in multiple interconnections. Results show that the networks were generally quite accurate (>90%) in terms of choosing the correct event type. Although the classifiers sometimes chose the wrong interconnection for a given category, this is inconsequential since the interconnection for a particular FDR is known *a priori*. Most likely, two separate networks will be needed to ensure sufficient overall accuracy. In this case, the so-called "monolithic" classifier (Fig. 1) trained with all types of events would first be used to distinguish between 1) load shedding, 2) generator trip, and 3) line trip/oscillation events. A second network (Fig. 2) would then be used to distinguish between line trips and oscillations if the first network places the event in the third category.

Index Terms**—Frequency Monitoring Network (FNET), Artificial Neural Network, Phasor Measurement Unit, Frequency Disturbance Recorder (FDR), even classification, power system frequency**

I. Key Results

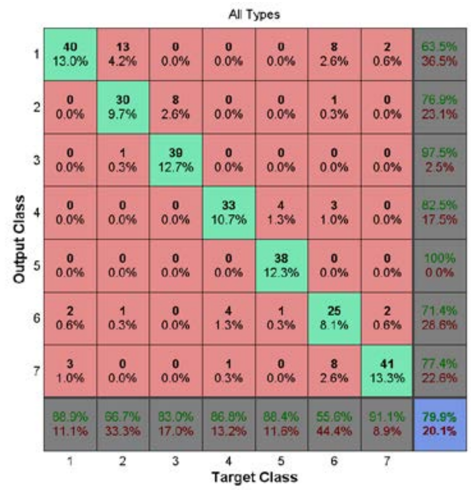

Fig. 1. Confusion matrix for network containing all types of events.

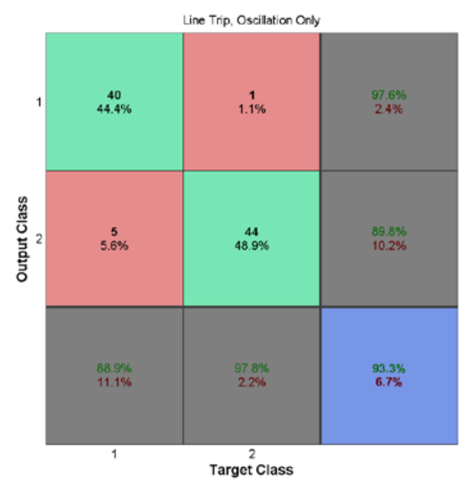

Fig. 2. Confusion matrix for network containing line trip and oscillation cases only.

Development of an Agent-Based Distribution Test Feeder with Smart-Grid Functionality

Pedram Jahangiri, *Student Member, IEEE,* Di Wu, *Student Member, IEEE,* Wanning Li, *Student Member, IEEE,* Dionysios C. Aliprantis, *Senior Member, IEEE,* and Leigh Tesfatsion, *Member, IEEE*

***Abstract*—This poster reports on the development of an agent-based distribution test feeder with smart-grid functionality. The test feeder is based on an actual distribution feeder with various additional features incorporated, including rooftop photovoltaic generation and price-responsive loads (e.g., plug-in electric vehicles and intelligent air-conditioning systems). This work aims to enable the integrated study of wholesale electric power markets coupled with detailed representations of the retail-side distribution systems.**

***Index Terms*—Air conditioning, electric vehicles, multi-agent systems, photovoltaic systems, power distribution, smart grid.**

Pedram Jahangiri (S'10) received the B.S. and M.S. degrees in electrical engineering from Isfahan University of Technology and Sharif University of Technology, Iran, in 2006 and 2008, respectively. He is currently working toward the Ph.D. degree in the Department of Electrical and Computer Engineering at Iowa State University, with research emphasis on smart distribution systems. He has been previously employed as a researcher by the Electric Ship Research and Development Consortium, Mississippi State University, MS, USA, and by the Automation of Complex Power Systems Center, RWTH University, Aachen, Germany.

Di Wu (S'08) received the B.S. and M.S. degrees in electrical engineering from Shanghai Jiao Tong University, China, in 2003 and 2006, respectively. He is currently a Ph.D. candidate in the Department of Electrical and Computer Engineering at Iowa State University. His research interests include impacts of plug-in electric vehicles on power systems; planning of national energy and transportation infrastructures; power electronics, with applications in hybrid electric vehicles and wind energy conversion systems.

Wanning Li (S'12) received the B.S. degree in electrical engineering from Harbin Institute of Technology, China, in 2011. She is currently working toward the Ph.D. degree in the Department of Electrical and Computer Engineering at Iowa State University. Her research interest lies in energy market risk management, and market efficiency assessment.

Dionysios C. Aliprantis (SM'09) received the Diploma in electrical and computer engineering from the National Technical University of Athens, Greece, in 1999, and the Ph.D. from Purdue University, West Lafayette, IN, in 2003. He is currently an Assistant Professor of Electrical and Computer Engineering at Iowa State University. He was a recipient of the NSF CAREER award in 2009. He serves as an Associate Editor for the *IEEE Power Engineering Letters*, and the *IEEE Transactions on Energy Conversion*. His research interests are related to electromechanical energy conversion and the analysis of power systems. More recently his work has focused on technologies that enable the integration of renewable energy sources in the electric power system, and the electrification of transportation.

Leigh Tesfatsion (M'05) received the Ph.D. degree in economics from the University of Minnesota in 1975. She is Professor of Economics, Mathematics, and Electrical and Computer Engineering at Iowa State University. Her principal research area is agent-based test bed development, with a particular focus on restructured electricity markets. She is an active participant in IEEE PES working groups and task forces focusing on power economics issues. She serves as associate editor for a number of journals, including *J. of Energy Markets*.

Processing and Visualization of Disturbance Data Stored in a Phasor Data Concentrator

Om P. Dahal and Sukumar M. Brahma

Klipsch School of Electrical and Computer Engineering,
New Mexico State University
Las Cruces, NM 88003-8001, USA
E-mail: {omp,sbrahma}@nmsu.edu

***Abstract*—Phasor measurement unit (PMU) data stored in Phasor Data Concentrators (PDCs) offer an excellent centralized repository of signatures of many events that are typically either not logged, or locally logged. The data also provide angle information across power systems, and can give quick and accurate assessment of stress. When the system is stressed, it may be advantageous to know the smallest of changes in real time, since such knowledge can better inform control schemes and any adaptive relaying action for Remedial Action Schemes (RAS), thus improving the chances of averting system instability. Therefore, data mining and real time classification of disturbance events recorded on PDCs is a useful exercise. Unfortunately, in most cases, data stored in the PDCs is simply archived, or used for some off-line applications.**

For this purpose, a suitable data mining and visualization method, as well as a classification method is required. This poster explores one data visualization method using disturbance files from the PDC owned by the Public Service Company of New Mexico (PNM). This PDC stores data from four PMUs at four major 345-kV substations in the PNM system. The poster shows what raw PDC data look like, and how these data need to be pre-processed before being used. The performance of the Minimum Volume Enclosing Ellipsoid (MVEE) method is explored to create signatures from a pre-processed disturbance file from the PDC. Results are presented, and analyzed. Based on the results, scope of future work is presented.

I. Key Equations

If the data window has *m* samples and number of PMU measurements equal *n*, a measurement matrix *S* can be constructed as shown in (1):

$$S := [s_1|s_2|.....|s_m]. \tag{1}$$

Where, s_1, s_2,....., s_m are column vectors of height *n*.

A minimum volume enclosing ellipsoid $E_{Q,c}$ in R^n is specified by a $n \times n$ symmetric positive-definite matrix Q and a center $c \in R^n$ and is defined as:

$$E_{Q,c} := \{x \in R^n : (x - c)^T Q(x - c) \leq 1\}. \tag{2}$$

The problem of determining the minimum volume enclosing ellipsoid containing all points of *S* is equivalent to finding a vector $c \in R^n$ and $n \times n$ positive definite symmetric matrix Q, which minimizes $det(Q^{-1})^{\frac{1}{2}}$, subject to (3).

$$min_{Q,c} \quad det(Q^{-1})^{\frac{1}{2}}$$

$$subject\ to$$

$$(x_i - c)^T Q(x_i - c) \leq 1, i = 1, 2, ..., m. \tag{3}$$

$$Q > 0$$

The volume of the MVEE is given by:

$$Vol(E_{Q,c}) = \frac{\pi^{\frac{n}{2}}}{\Gamma(\frac{n+2}{2})}\ det(Q^{-1})^{\frac{1}{2}} \tag{4}$$

Where $\Gamma(.)$ is the standard gamma function in calculus.

II. Key Figures

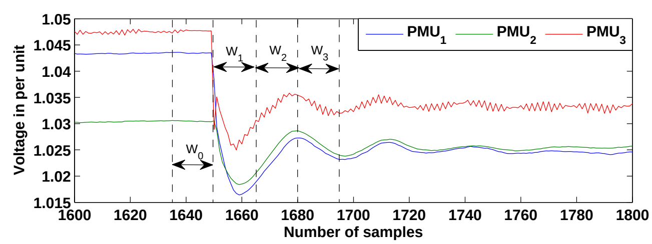

Fig. 1. Plots of three PMU-voltages from a disturbance file stored on PDC.

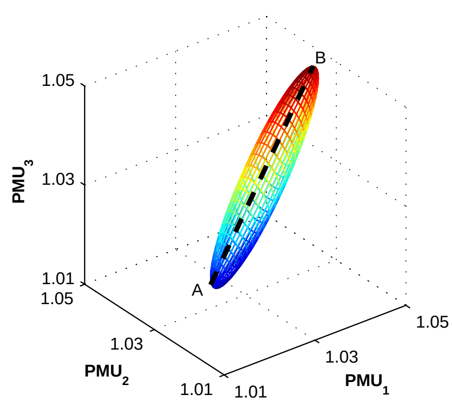

Fig. 2. The MVEE for window - W_1 in Fig. 1.

Using Graph Theory to Analyse the Vunerability of Smart Electrical Grids

Timothy A. Ernnster
School of Electrical Engineering & Computer Science
Washington State University
Pullman, WA

Anurag K. Srivastava
School of Electrical Engineering & Computer Science
Washington State University
Pullman, WA

***Abstract*— Threat assessments play a key role in determining appropriate mitigation strategies to counter credible threats to the power system. In order to further understand the capability of a malicious agent to coordinate an attack on the power grid given limited system information, graph theory based centrality measures are utilized for power systems vulnerability analysis. Results are compared to vulnerability analysis indices utilizing DC power flow based linear sensitivity factors with complete power system information. Correlations of centrality and linear sensitivity factor based vulnerability rankings are performed, and matched pair comparisons of top rankings are presented using the nonparametric Wilcoxon signed rank statistical test. Evidence is presented in support of the edge betweeness centrality measure in determining sensitive line outages based solely on the branch impedance values of a power system. Results obtained for four different test case systems indicate the threat potential of a system attack planned from limited topology information.**

I. Key Equations

The equations for degree, eigenvector, closeness centrality, vertex betweeness centrality, and edge betweeness centrality:

$$C_D(i) = \frac{|Y_{ii}|}{n-1} \quad (1) \qquad C_E(i) = \frac{1}{|\lambda_{max}|}\sum_{j=1}^{n}|A_{ij}x_j| \quad (2)$$

$$C_C(i) = \frac{(n-1)}{\sum_{j\in V\setminus i} d_G(i,j)} \quad (3)$$

$$C_{Bv}(i) = \sum_{j\neq i\neq k\in V}\frac{\sigma_{jk}(i)}{\sigma_{jk}} \quad (4) \qquad C_{Be}(i) = \sum_{j\neq k\in V}\frac{\sigma_{jk}(i)}{\sigma_{jk}} \quad (5)$$

II. Key Figures

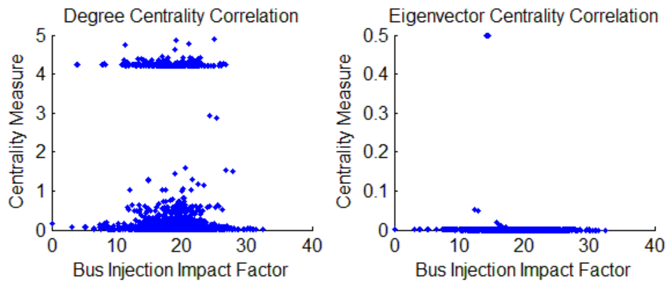

Fig. 1. Polish 2383 Bus System correlations: degree and eigenvector centrality with the bus injection impact factor (BIIF).

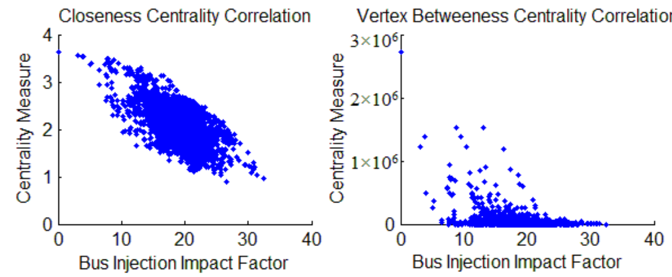

Fig. 2. Polish 2383 Bus System correlations: closeness and vertex betweeness centrality with the bus injection impact factor (BIIF).

III. Key Results

Statistical results indicating similarity between centrality and DC power flow based sensitivity contingency ranking schemes.

TABLE I
WILCOXON SIGNED RANK TEST FOR TOP 10 VULNERABILITIES – CLOSENESS CENTRALITY MATCHED TO THE BIIF INDEX

Test System	N	Estimated Median	Lower Bound	Upper Bound	Achieved Confidence
IEEE-14	10	1	-1.0	4.5	94.7%
IEEE-30	10	3.0	0.0	6.5	94.7%
IEEE-57	10	4.5	-1.0	11.5	94.7%
Polish-2383	10	80	20	404	94.7%

TABLE II
WILCOXON SIGNED RANK TEST FOR TOP 10 VULNERABILITIES – EDGE BETWEENESS CENTRALITY MATCHED TO THE LOIF INDEX

Test System	N	Estimated Median	Lower Bound	Upper Bound	Achieved Confidence
IEEE-14	10	3.0	-1.5	7.0	94.7%
IEEE-30	10	5.0	-2.0	11.5	94.7%
IEEE-57	10	6.0	-1.5	10.0	94.7%
Polish-2383	10	5.0	-1.5	58	94.7%

IV. Summary

Centrality measures can be utilized in evaluating power system vulnerability to a coordinated branch outage attack. This is useful in developing attack models for an attacker possessing only limited system topology information.

This research was funded by Department of Energy (DoE) Award Number DE-OE0000097 (Trustworthy Cyber Infrastructure for the Power Grid).

Optimal Power Dispatch via Constrained Distributed Sub-gradient algorithm

Wei Zhang, *Student Member*, *IEEE*, Yinliang Xu, *Student Member*, *IEEE*, Wenxin Liu, *Member*, IEEE
New Mexico State University, Las Cruces, NM 88001
Email: {wzhang; daneilxu;wliu}@nmsu.edu

***Abstract*—Optimal Power Dispatch aims to minimize the cost the generation by properly allocating the power output of each generator. The distributed algorithm is attracting more and more attention of the researchers as it can survive single-point-failures and can also avoid centralized data processing, which leads to efficient task distribution. This paper reports the newly application developments of distributed optimization in power systems.**

The authors aims to solve the distributed optimization considering both inequality and equality constraints. Based on distributed sub-gradient algorithm, the equality constraints are integrated in the process of discovering the optimal. As the inequality constraints are violated, the algorithm utilizes the projection theorem to limit these variables in proper bounds, in the meanwhile, reconfigures the distributed optimization network to precede the optimization among the other variables. The configuration logic is designed in such way that the variables can consume the optimization process while still guarantee the global optimization. And a distributed control system is proposed to implement the algorithm. The control system can adaptively optimize the generation when system operating conditions changes while maintain the stability of the system. 4-bus system and IEEE-30 bus system is tested to verified effectiveness of the algorithm and the practicability of designed control system.

Keywords-component; formatting; style; styling; insert (key words)

I. Key Equation

$$\begin{cases} Min \ \sum_{i}^{n} f_i(x_i) & \text{(a)} \\ \text{s.t.} \ \sum_{i=1}^{n} x_i = c & \text{(b)} \\ \text{s.t.} \ x_i^{\min} \le x \le x_i^{\max}] & \text{(c)} \end{cases} \quad (1)$$

$f_i(x_i)$ is convex and twice continuously differentiable function.

$$x(k+1) = x(k) - \alpha(k) W \nabla f'(x(k)) \quad (2)$$

$$x_i(k+1) = \begin{cases} x_i(k) & i \in x(k)^C \\ x_i(k) - \alpha(k) W_{ij}(k) f'(x_j) & i, j \in x(k)^{\bar{C}} \end{cases} \quad (3)$$

II. Distributed Control System

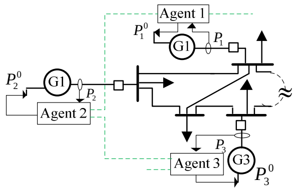

Fig. 1 Architecture of distributed control system

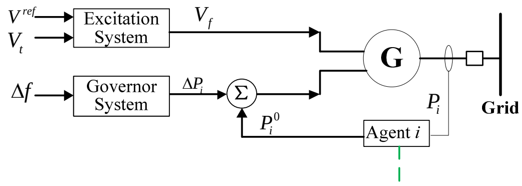

Fig. 2 The control system of a generator

III. Key Results

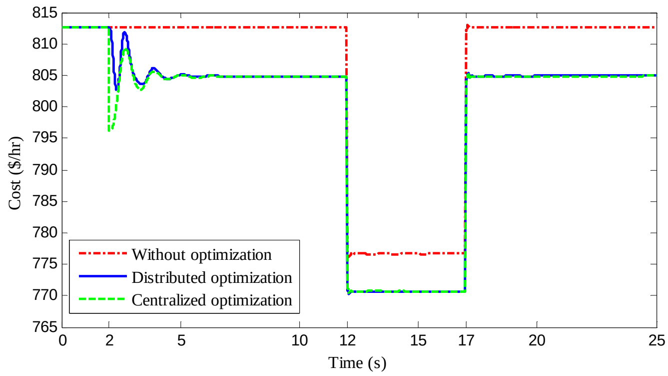

Fig. 3 Comparsion of results for different optimization methods

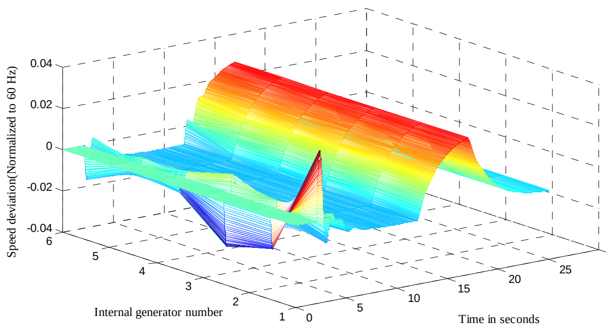

Fig. 4 Speed deviation of the generators

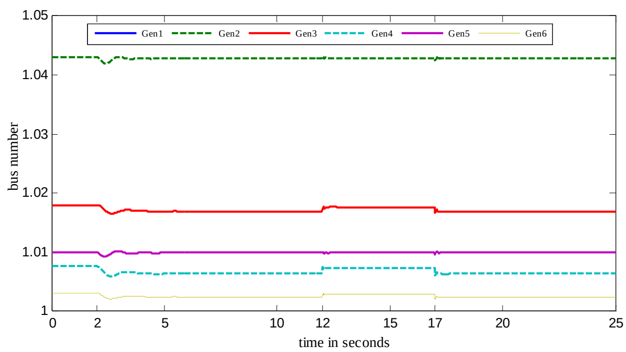

Fig. 5 The terminal voltages profiles of generator connected buses

- sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an "inset", not an "insert". The word alternatively is preferred to the word "alternately" (unless you really mean something that alternates).
- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [7].

IV. Using the Template

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

A. Authors and Affiliations

The template is designed so that author affiliations are not repeated each time for multiple authors of the same affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization). This template was designed for two affiliations.

1) For author/s of only one affiliation (Heading 3): To change the default, adjust the template as follows.

a) Selection (Heading 4): Highlight all author and affiliation lines.

b) Change number of columns: Select the Columns icon from the MS Word Standard toolbar and then select "1 Column" from the selection palette.

c) Deletion: Delete the author and affiliation lines for the second affiliation.

d) For author/s of more than two affiliations: To change the default, adjust the template as follows.

e) Selection: Highlight all author and affiliation lines.

f) Change number of columns: Select the "Columns" icon from the MS Word Standard toolbar and then select "1 Column" from the selection palette.

g) Highlight author and affiliation lines of affiliation 1 and copy this selection.

h) Formatting: Insert one hard return immediately after the last character of the last affiliation line. Then paste down the copy of affiliation 1. Repeat as necessary for each additional affiliation.

i) Reassign number of columns: Place your cursor to the right of the last character of the last affiliation line of an even numbered affiliation (e.g., if there are five affiliations, place your cursor at end of fourth affiliation). Drag the cursor up to highlight all of the above author and affiliation lines. Go to Column icon and select "2 Columns". If you have an odd number of affiliations, the final affiliation will be centered on the page; all previous will be in two columns.

B. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named "Heading 1", "Heading 2", "Heading 3", and "Heading 4" are prescribed.

C. Figures and Tables

1) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE I. TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

a. Sample of a Table footnote. (Table footnote)

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an MSW document, this method is somewhat more stable than directly inserting a picture.

To have non-visible rules on your frame, use the MSWord "Format" pull-down menu, select Text Box > Colors and Lines to choose No Fill and No Line.

Figure 1. Example of a figure caption. (figure caption)

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Acknowledgment (Heading 5)

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression, "One of us (R. B. G.) thanks . . ." Instead, try "R. B. G. thanks". Put sponsor acknowledgments in the unnumbered footnote on the first page.

References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first . . ."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

[1] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. (references)

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] K. Elissa, "Title of paper if known," unpublished.

[5] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[7] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

Selection of Optimal Structuring Element for Fault Detection Tools Based on Mathematical Morphology

Suresh Gautam and Sukumar M. Brahma

Klipsch School of Electrical and Computer Engineering,
New Mexico State University
Las Cruces, NM 88003-8001, USA
E-mail: {gautam,sbrahma}@nmsu.edu

***Abstract*—Recent literature in the area of power systems reports the use of Mathematical Morphology (MM) as a promising tool for different applications; both online and offline applications are reported. Real time applications for disturbance detection are also reported. A function called the structuring element(SE) is the main component of MM that plays a pivotal role in MM operations, and hence all MM-based applications. However, there is no clear guideline for the selection and optimization of the structuring element for any particular application. This document reports a study performed to generalize and optimize a structuring element for the detection of power system faults. Different power system fault cases are simulated using time domain simulation software. The current and voltage waveforms from the simulation are used to illustrate the selection process. Results are analyzed and some guidelines are suggested for the selection of an optimal structuring element for power system fault detection.**

I. Key Equations

Dilation and erosion:

$$y_d(n) = (f \oplus g)(n) = max\{f(n-m) + g(m)\}, \quad 0 \leq (n-m) \leq n, m \geq 0 \tag{1}$$

$$y_e(n) = (f \ominus g)(n) = min\{f(n+m) - g(m)\}, \quad 0 \leq (n+m) \leq n, m \geq 0 \tag{2}$$

Closing and opening:

$$y_c(n) = (f \bullet g)(n) = ((f \oplus g) \ominus g)(n) \tag{3}$$

$$y_o(n) = (f \circ g)(n) = ((f \ominus g) \oplus g)(n) \tag{4}$$

Closing-Opening Difference Operator:

$$y_{codo}(n) = [(f \bullet g)(n) - (f \circ g)(n)] \tag{5}$$

II. Key Figures

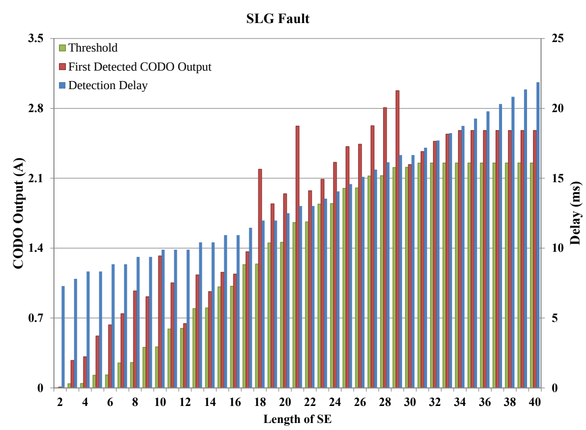

Fig. 1. CODO output for current waveform with varying length of the SE.

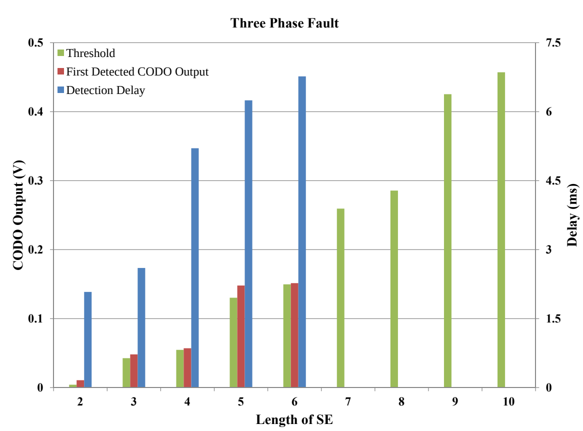

Fig. 2. CODO Output for voltage waveform with varying length of the SE.

Fault Location Identification using Bayesian Analysis for SPS

Joseph Dieker*, Sanjoy Das, Noel N. Schulz, Bala Natarajan, and Caterina Scoglio
Department of Electrical and Computer Engineering
Kansas State University
Manhattan, Kansas, USA
*Email: jdieker@ksu.edu

***Abstract*—In a shipboard power system there are many chances for faults along lines. It is very important to identify the location and isolate these faults in order to save the equipment and loads. The shipboard system represented in this poster is a based on an all-electric ship that is presented by Corzine. It includes both AC and DC voltages and multiple generators distributed among the system. The power system is modeled in MATLAB Simulink using the SimPowerSys toolbox. The model includes two buses one on the starboard and the other on the port. Each bus has eight lines that provide power to the loads. This poster only considers faults at the ends on the lines. Sensors on the end of the lines will collect data in order to determine where the fault has occurred. There are three types of loads in the system: vital, semi-vital, and non-vital. All the non-vital loads are connected directly to one of the buses. However, the vital loads are connected to both buses using switches. The fault location identification algorithm being presented will use data collected from simulations of different switch configurations and different loads (within ±5% of the original value). After the data is collected, Bayesian techniques are used to determine where the fault is located. Assuming the distribution is Gaussian, the mean can be found and the location of the fault can be determined using Maximum Likelihood (ML) approximation.**

This work supported by the United States Office of Naval Research under grant N00014-10-1-0431 (DEPSCoR program)

Economic Analysis of Grid Level Energy Storage for the Application of Load Leveling

Robert J. Kerestes, *Student Member, IEEE* and Gregory F. Reed, *Member, IEEE*
Center for Energy / ECE Department, University of Pittsburgh, Pittsburgh PA, 15213, USA
Email: rjk39@pitt.edu and reed5@pitt.edu

***Abstract* – This article briefly describes the poster to be submitted on grid level energy storage for the application of load leveling for the 2012 IEEE PES T&D show in Orlando, Florida.**

I. Introduction

The benefits that exist on behalf of energy storage appear to be nearly limitless and there is no exception to this in power systems. Energy storage can be used to flatten an electrical load by charging the storage when the system load is low and discharging the storage when the system load is high.

One of the biggest benefits that load leveling can yield is the elimination of expensive gas turbine generators. Gas turbine generators are used because they can react to drastic changes in the system load compared to other generators. Their downfall however, is that they expensive. But if the load is level enough, there is no need to use gas turbine generators because there aren't any drastic changes in the load profile.

Load leveling requires a storage device to have a very large capacity. Both sodium sulfur (NaS) batteries and pumped hydro storage are chosen in this study and the results for each is compared in the poster. This study shows that energy storage used for the application of load leveling can be economically beneficial depending on the type of storage that is used. Battery storage is not quite ready to be used for this application but with some improvements to the technology it could be soon. Pumped storage on the other hand is the cheapest form of grid level energy storage and can generate a great deal of economic gain in today's power systems.

II. General Poster Description

The poster is divided into seven sections providing a comprehensive summary of the thesis work done by the student on grid level energy storage used for load leveling. The poster background color is a light blue and each segmented area has the same background color. The header of the poster contains the logos of the sponsors for this work. On the far left of the poster, the energy storage applications of peak shaving and load leveling are compared. Below this is a comparison of the NaS battery and pumped hydro energy storage. Both the pros and cons of each form of storage are compared here.

The top middle section of the poster describes the thermal generation units that were used for this study. Three generation sources were used, which were coal, oil and gas. For each source of generation the heat input vs. power output curves are given. Next, described on the poster, the economic dispatch problem is set up for two cases. The first case being the case in which no energy storage is used and the second case in which energy storage is used to level the load. The top right corner of the poster shows the modeling of the storage units. The continuous model of charging and discharging profiles are discretized so power can be allocated hourly. The effect of leveling the system load can be seen in Fig. 1.

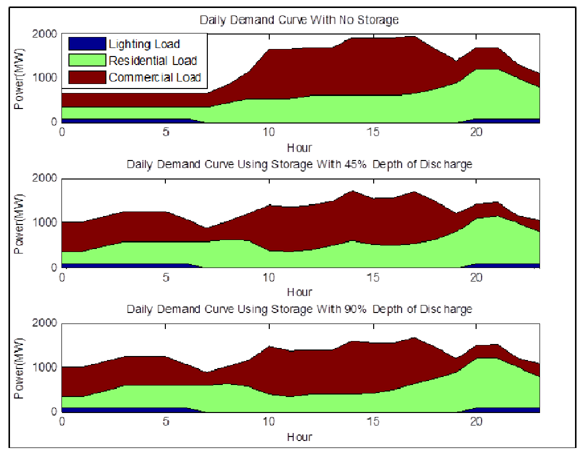

Fig. 1: Load Profile with no storage (top), 45% depth of discharge (mid), 90% depth of discharge

Fig. 1 shows the load without energy storage and then the effect of energy storage for 45% depth of discharge and 90% depth of discharge. Finally in the final section, in the bottom right corner of the poster, the economic effect of the load leveling is shown. The price is calculated for all three forms of generation for the case in which there is no energy storage used and the price of the coal and oil generation are calculated and added to the price of energy storage for the case in which there is energy storage used. The cost of generation and energy storage is then used to calculate the length of time needed for a return on investment for the energy storage. This study shows that it is economically feasible to use pumped hydro energy storage for load leveling but it is not economically feasible to use NaS battery storage for load leveling.

III. Biographies

Robert J. Kerestes (M'2011) is a Ph.D. student and **Gregory F. Reed** (M'1985) is the Director of the Electric Power Initiative, Associate Director of the Center for Energy, and Professor of Electric Power Engineering in the Swanson School of Engineering at the University of Pittsburgh.

This work was supported by funding from the PA DCED BFTDA and the Westinghouse Corporate Research Center. R. J. Kerestes and G.F. Reed are with the Department of Electrical & Computer Engineering and the Center for Energy, in the Swanson School of Engineering at the University of Pittsburgh, Pittsburgh, PA 15210 USA (e-mails: rjk39@pitt.edu, reed5@pitt.edu)

Novel fully distributed optimization control of generators for shipboard power system

Yinliang Xu, Wei Zhang, and Wenxin Liu
New Mexico State University, Las Cruces, NM
Email: danielxu@nmsu.edu

***Abstract*— For shipboard power system, the components like generators, invertors, various loads and etc. are more prone to failure during attack. To increase the survivability of the power system, it is essential to ensure there is no component like a master controller, which is critical for operation. Based on the state of art Multi-agent system (MAS) technic, this paper proposes a novel fully distributed optimization control strategy of generators for shipboard power system. Each generator is associated with an agent, which knows the generation capacity and can measure the local frequency. The proposed strategy only requires communications within local network and the solution is stable, reliable, adaptive, and cost efficient. By controlling each generator's output power using consensus theorem and subgradient optimization algorithm, the supply-demand balance can be maintained with improved system dynamic performance. One important feature of the proposed algorithm is its ability to enable the shipboard power system to continue operation with one or more generators' failure so that vital loads can still be powered. Simulation results demonstrate the effectiveness of the proposed algorithm.**

Keywords- Distributed optimization control; shipboard power system; multiagent system.

I. KEY EQUATIONS

Coordinate control of multi-generators in an autonomous microgrid can be formulized as a distributed optimization problem. The objective function is described as:

$$\min F = \min\left(\sum_{i=1}^{m} k_i P_{G,i}^{\max} - \sum_{i=1}^{n} P_{L,i} - P_{Loss}\right)^2 \quad (1)$$

$$P_{G,i}^{*} = k_i P_{G,i}^{\max} \quad (2)$$

where $P^{*}_{G,i}$ is the active power generation setting of the i^{th} generator.

In the paper, the objective is achieved by controlling the utilization level k_i of each generator. The remaining problem regards how to determine the utilization level k_i through local network communications. According to the consensus-based global information discovery algorithm and the distributed subgradient method, the problem can be solved using

$$\dot{k}_i = \sum_{j=1}^{m} a_{ij}(k_j - k_i) - d_i \frac{\partial F}{\partial k_i}$$
$$0 \le k_i \le 1, \quad i = 1, 2, \cdots m \quad (3)$$

where d_i is the optimization step size, and a_{ij} is the information exchange coefficient between two neighboring agents.

$$a_{ij} = \begin{cases} 2/(n_i + n_j + 1) & j \in N_i \\ -\sum_{j \in N_i} 2/(n_i + n_j + 1) & i = j \\ 0 & otherwise \end{cases} \quad (4)$$

where n_i and n_j is the numbers of agents that are connected to agent i and j respectively.

$$\frac{d\Delta f}{dt} = K_f\left(\sum_{i=1}^{m} P_{G,i}^{*} - \sum_{i=1}^{n} P_{L,i} - P_{Loss}\right) - D_f \Delta f \quad (5)$$

The coordinative control law for the utilization level control of the i^{th} DFIG is designed as (6).

$$\dot{k}_i = \sum_{j=1}^{m} a_{ij}(k_j - k_i) - D_i \Delta f \quad (6)$$

where Δf is frequency deviation. Eq. (6) can also be represented using matrix format as in (7).

$$\dot{K} = A \cdot K - D \cdot \Delta f \quad (7)$$

II. KEY FIGURES

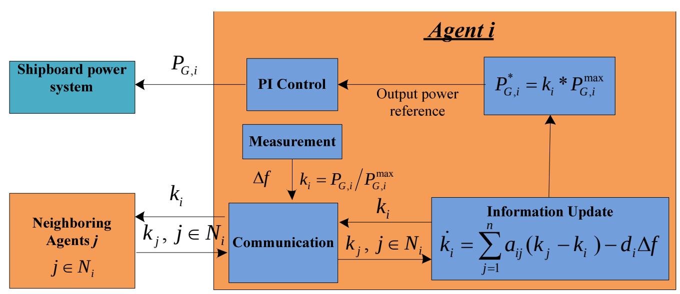

Fig. 1. Proposed fully distributed control algorithm diagram

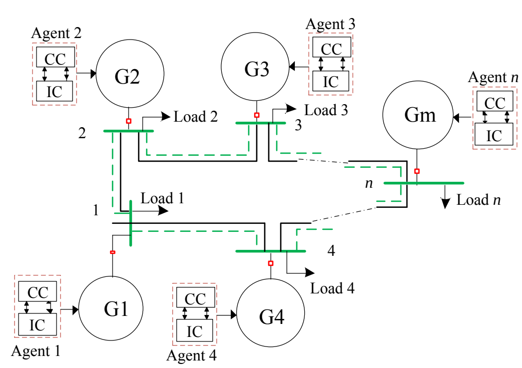

Fig. 2. System Configuration of two level control: upper-level coordination control (CC) and lower-level implementation control (IC)

Optimal Dispatch and Coordination of Distributed Energy Resources using Model Predictive Control

Ebony Mayhorn, Karen Butler-Purry
Texas A&M University,
College Station, TX, USA

Karanjit Kalsi, Marcelo Elizondo, Jianming Lian
Pacific Northwest National Laboratory,
Richland, WA, USA

Wei Zhang, Ohio State University
Columbus, OH, USA

Abstract— **In an isolated power system (rural microgrid), distributed wind generation can be used to complement distributed fossil fueled generators. The uncertainty and variability due to high penetration of wind generation challenges the system operations. Other distributed energy resources (DERs), such as energy storage and demand response (DR) provided by a population of HVAC loads, can be deployed to help balance the system and to maximize the use of renewable energy. However, DR control and its coordination with other DERs make the problem particularly challenging.**

In this work, an optimal control strategy is proposed to coordinate DR, energy storage and diesel generators to maximize wind penetration, while maintaining system economics and normal operation. The problem is formulated as a multi-objective optimization problem with the goals of minimizing fuel costs and changes in power output of diesel generators, minimizing costs associated with low battery life of energy storage, minimizing the use of external control of DR devices, and maintaining spinning reserves. Diesel generators, energy storage and DR are coordinated to compensate for both renewable generation and load variability. DR, represented by a controlled population of HVACs, is dispatched using distributed toggle control. Model predictive control (MPC) is used to solve the aforementioned problem, while making use of a reduced order aggregate model of a HVAC population. Simulation studies demonstrate the efficacy of the closed-loop MPC in compensating for uncertainties in the system caused by wind and demand. Simulations also show how DERs, including DR, can be dispatched similar to conventional generators.

Keywords- model predictive control, coordination of distributed energy resources, demand response, dispatch of distributed energy resources

Processing and Visualization of Disturbance Data Stored in a Phasor Data Concentrator

Om P. Dahal, *Student Member, IEEE*, Sukumar M. Brahma, *Senior Member, IEEE*

***Abstract*—Phasor measurement unit (PMU) data stored in Phasor Data Concentrators (PDCs) offer an excellent centralized repository of signatures of many events that are typically either not logged, or locally logged. The data also provide angle information across power systems, and can give quick and accurate assessment of stress. When the system is stressed, it may be advantageous to know the smallest of changes in real time, since such knowledge can better inform control schemes and any adaptive relaying action for Remedial Action Schemes (RAS), thus improving the chances of averting system instability. Therefore, data mining and real time classification of disturbance events recorded on PDCs is a useful exercise. Unfortunately, in most cases, data stored in the PDCs is simply archived, or used for some off-line applications.**

For this purpose, a suitable data mining and visualization method, as well as a classification method is required. This poster explores one data visualization method using disturbance files from the PDC owned by the Public Service Company of New Mexico (PNM). This PDC stores data from four PMUs at four major 345-kV substations in the PNM system. The poster shows what raw PDC data look like, and how these data need to be pre-processed before being used. The performance of the Minimum Volume Enclosing Ellipsoid (MVEE) method is explored to create signatures from a pre-processed disturbance file from the PDC. Results are presented, and analyzed. Based on the results, scope of future work is presented.

Om P. Dahal (e-mail: omp@nmsu.edu), and Sukumar M. Brahma (e-mail: sbrahma@nmsu.edu) are with the Klipsch School of Electrical and Computer Engineering, New Mexico State University, Las Cruces, NM 88003, USA.

Ensemble Learning Approach for the Estimation of Weather-Related Outages on Overhead Distribution Feeders

Padmavathy Kankanala
Electrical and Computer Engineering
Kansas State University
Manhattan, KS 66502

Sanjoy Das
Electrical and Computer Engineering
Kansas State University
Manhattan, KS 66502

Anil Pahwa
Electrical and Computer Engineering
Kansas State University
Manhattan, KS 66502

***Abstract*— Outages in overhead distribution system caused by different environmental factors, such as weather, trees and animals significantly impact the reliability. Wind and lightning continue to be the major weather related causes of outages on overhead power distribution lines. Linear and exponential regression models and Neural Networks are proposed and presented previously. In this paper, a new algorithm, called mean field annealing (MFA), is implemented for the estimation of weather related outages. A new modification to mean field annealing is presented which converges rapidly than neural network. Results obtained for four districts in Kansas of different sizes are compared with observed outages to evaluate the performance of the model for estimating these outages. The results are also compared with previously studied regression and neural network models to determine an appropriate model to represent effects of wing and lightning on outages.**

Keywords- Power distribution system, weather effects, Mean field annealing, neural networks, power system reliability.

I. Mean Field Annealing

MFA algorithm combines the characteristics of the simulated annealing and Hopfield neural networks. MFA exhibits the rapid convergences of the neural network while preserving the solution quality afforded by simulated annealing.

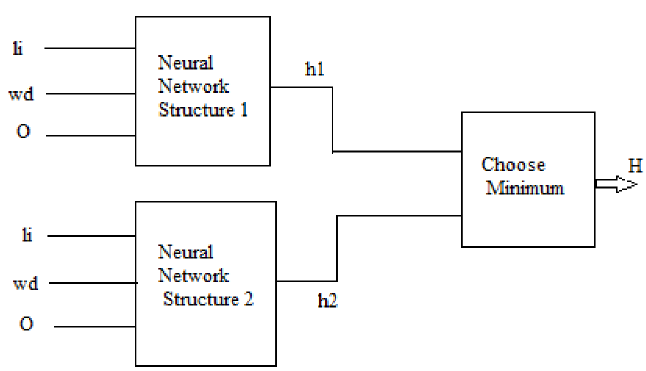

Fig.1. Ensembled MFA Strucutre

II. Key Figures & Results

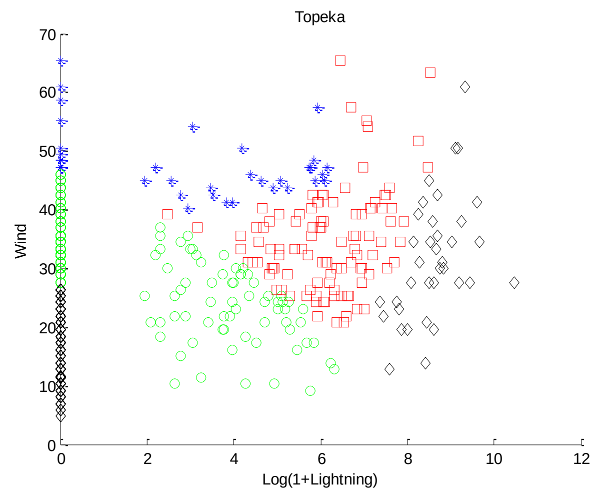

Fig. 2. Clustering of data entries for Topeka

TABLE I: SUMMARY OF MFA MODELS FOR TOPEKA

		MSE	AAE	Correlation
Regression Models	Model 1	26.3223	1.8910	0.6635
	Model 2	25.4041	1.7738	0.6775
	Model 3	24.9123	1.7891	0.6852
	Model 4	24.7515	1.7765	0.6876
	Model 5	26.7432	1.7968	0.6607
	Model 6	35.4894	1.7278	0.5176
Neural networks		24.2970	1.7318	0.6946
Ensemble MFA	With li as input	24.8422	1.5934	0.6953
	With log(1+li) as input	**23.2716**	**1.4821**	**0.7196**

Distributed State Estimation using Phasor Measurement Units

Woldu Tuku* and Noel N. Schulz
Department of Electrical and Computer Engineering
Kansas State University
Manhattan, KS, USA
*Watuku@ksu.edu

Abstract: As the size of electric power system is increasing, the techniques to protect, monitor and control it are becoming more sophisticated. Government, utilities and various organizations are striving to have more reliable power grid. Several research projects are working to minimize risks in the grid. The goal of the research is to achieve a robust and accurate state estimation (SE) of the power grid. Utilities are leading teams to change the traditional way of state estimation to real time state estimation. Currently most of the utilities use traditional centralized SE algorithm. Although the traditional methods have been enhanced with advancement in technologies, including PMUs, most of these advances have remained local with individual utility state estimation. There is an opportunity to establish a coordinated SE approach integration the PMU data across a system, including multiple utilities and this is using Distributed State Estimation (DSE). This coordination will minimize cascading effects on the power line. DSE is the best option to minimize the communication time and to provide accurate data to the operators. This project will introduce DSE techniques with the help of PMU data for the utilities under Southwest Power Pool (SPP). The proposed DSE algorithm will split the traditional central state estimation into multiple local state estimations and show how to reduce calculating time compared with centralized state estimation.

Keywords: State Estimation; Phasor Measurement Unit, Distributed State Estimation, Supervisory control and data acquisition system

Rotor Angle Difference Estimation for Multi-Machine System Transient Stability Assessment

Zhenhua Wang
Electrical and Computer Engineering Department
Clemson University, Clemson, SC USA
zhenhuw@clemson.edu

Abstract—*A new concept for generator rotor angle difference estimation is introduced in this poster. It is used to replace the well-known weighted average of generator rotor angles (COA or COI) in multi-machine power system transient stability assessment. Compared with COA, the proposed method allows generators to have their own reference for evaluating the transient stability status which can be more reasonable and accurate. Moreover, the proposed technique can be realized at low cost because the rotor angle difference is calculated by only using generator power output which does not add additonal burden to communication channels. Furthermore, the proposed method also has the ability to provide a virtual rotor angle difference for generation units which do not have the rotating structure. This feature gives the proposed technique the potential in studying the trasnsient stability impact of renewable energy sources.*

I. Key Equations

The equations for calculating the first order and second order derivative showed in the poster are:

$$\frac{dP_e(t_1')}{dt} = P_j\frac{2\pi f_j}{f_s}\cos\left(\frac{2\pi f_j}{f_s}t_1' + \varphi_j(t_1')\right)$$

$$= P_j\sin\left(\frac{2\pi f_j}{f_s}t_2 + \varphi_j(t_2)\right) - P_j\sin\left(\frac{2\pi f_j}{f_s}t_1 + \varphi_j(t_1)\right) \quad (1)$$

$$\frac{dP_e(t_2')}{dt} = P_j\frac{2\pi f_j}{f_s}\cos\left(\frac{2\pi f_j}{f_s}t_2' + \varphi_j(t_2')\right)$$

$$= P_j\sin\left(\frac{2\pi f_j}{f_s}t_3 + \varphi_j(t_3)\right) - P_j\sin\left(\frac{2\pi f_j}{f_s}t_2 + \varphi_j(t_2)\right) \quad (2)$$

$$P_j\left(\frac{2\pi f_j}{f_s}\right)^2\sin\left(\frac{2\pi f_j}{f_s}t_1'' + \varphi_j(t_1'')\right)$$

$$= P_j\frac{2\pi f_j}{f_s}\cos\left(\frac{2\pi f_j}{f_s}t_1' + \varphi_j(t_1')\right)$$

$$- P_j\frac{2\pi f_j}{f_s}\cos\left(\frac{2\pi f_j}{f_s}t_2' + \varphi_j(t_2')\right) \quad (3)$$

The detail for calculating $P_j(t_2)$ in the poster is:

$$\left(\sqrt{\frac{d^2P_e(t_1'')}{dt^2}}\Big/\sqrt{P_{ej}(t_2)}\right)$$

$$= \sqrt{\frac{P_j\left(\frac{2\pi f_j}{f_s}\right)^2\sin\left(\frac{2\pi f_j}{f_s}t_1'' + \varphi_j(t_1'')\right)}{P_j\sin\left(\frac{2\pi f_j}{f_s}t_2 + \varphi_j(t_2)\right)}} = \frac{2\pi f_j}{f_s} \quad (4)$$

II. Key Figure

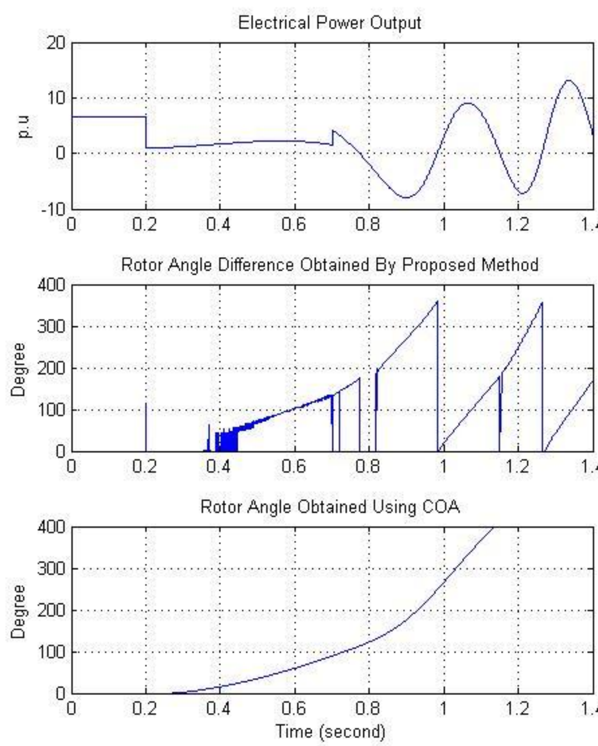

Figure.1 Rotor angle difference obtained by proposed method verses rotor angle difference obtained by COA

A Neural Network based Software Engine for Adaptive Power System Stability

Ashikur Rahman and Dr. Allison Kipple
Department of Electrical Engineering and Computer Science
Northern Arizona University
Flagstaff, Arizona
Email: *ar784@nau.edu and Allison.Kipple@nau.edu*

***Abstract*—This work studies a novel artificial intelligence based method for the assessment of power system security and preemptive protection procedures to ensure transient stability.**

Keywords-transient; feature vector; neural network; static VAR compensator (SVC); power system stabilizer (PSS)

I. Introduction

This work describes a preliminary research investigation into the feasibility of using an Artificial Intelligence (AI) method to predict, detect, and quickly recover from faults in a power system. The goal of the work is to reduce the computational complexity of stability analysis while increasing the flexibility of post-fault recovery procedures, and to introduce a convenient and intelligent power system architecture.

The electric power industry is currently experiencing an unprecedented level of reform. One of the most exciting and potentially profitable contemporary developments is the increasing usage of artificial intelligence techniques in power engineering. Considering today's situation, methods for securing reliable power need to be re-engineered; one reason is that variable renewable energy sources are being added to the power system at the same time that the system is getting more and more interconnected, is reaching its load limits, and is experiencing different types of loads. In current practice, system operators usually refer to written operating procedures to determine system constraints and (in theory, at least) ensure system reliability and stability. With such a simplified view of system conditions, the operators are unable to develop a full understanding of the system's operational limits and assess how the system could be adapted to meet the changing conditions. As a result, many systems have been left in a vulnerable condition where, for instance, widespread blackouts can and do occur.

II. Method and Simulations

The published papers in IEEE proceedings have showed an increasing, though not yet extensive, interest over the past decade in applying AI to power engineering problems. In this case, AI was utilized after first creating a simple two-bus power system in MATLAB Simulink. This model incorporated some variable, regulating and control units which were indispensable for the study: a variable load, Static VAR Compensator (SVC), Power System Stabilizer (PSS) and hydraulic turbine governor. The model contained a 1000 MVA hydraulic generation plant which was coupled to a load center through a 500 kV, 700 km transmission line. The load center was modeled by a 5000 MW resistive load. The load was additionally served by a local, 5000 MVA hydraulic generation plant.

From the state space point of view, each unit had a transfer function which affected the dynamics of the whole system, and the transfer functions were governed by constants or the model parameters. A variety of faults were simulated, the operating parameters of the SVC and PSS were varied to see the effects on transient stability, and the results were included in training pattern sets. A total of 4,608 training data sets were generated by varying the SVC and PSS controller parameters, fault types and load. A feed-forward neural network using the Levenberg–Marquardt algorithm (LMA) was then trained on the parameter combinations that produced stable and unstable results. The training data were tabulated by analyzing load flow and rotor angle stability which were organized as feature vectors for neural network based classification. The performance of the neural network was measured by different methods, namely regression, training state analysis and a confusion matrix.

The trained network was later used to find the best operating condition settings using an optimum solution finder algorithm. The trained network could then simulate the effects of and possible stable configurations to correct various fault situations within a fraction of a second, which is much smaller than any available numerical differential equation solver.

III. Future Work

The approach outlined above may additionally be used in fault diagnosis, security assessment, load forecasting, economic dispatch and harmonic analyzing.

IV. Acknowledgment

This project was funded by Arizona Public Service (APS).

A new open conductor identification technique for single wire earth return system

Pengfei Gao
Student member, IEEE
University of Alberta
Edmonton, Canada
Pgao2@ualberta.ca

***Abstract*—Single wire earth return system (SWER) is widely used in New Zealand, Australia, Brazil, India and some rural parts of North America. It is quite welcome for its simple construction as well as low cost in sparsely populated area. However, the reliability for this scheme is always questioned and maintenance in such area is even more difficult. To develop a method to detect and target fault location is a major consideration for a utility's practice. In this paper, a novel open conductor identification technique is proposed, which involves a bi-direction power line signal communication scheme. A signal generation (SG) and signal detector (SD) will be installed near rec-loser with several similar devices at load points. Computer simulation and lab experiments have demonstrated and verified the proposed scheme operates effective and stable.**

Keywords-open conductor; Single-wire-earth-return; signal detection; safe recloser

I. INTRODUCTION

In SWER system single conductor is used to transmit electricity to distribution feeders and earth is adapted as return path. As long as some fault occurs, all the area supported by this broken conductor will suffer outage. To detect fault location, a straight forward thinking is that to inject a signal upstream which can be received by each feeder downstream, also a feedback signal shall be able to transmitted backwards upstream. Hereby the approximate broken conductor location can be estimated, maintained work will be easier to implement. Some researches aim to couple or induce a current signal along the conductor is introduced in [1], however signal attenuation over limited distance and synchronization issue make such scheme not feasible for large scale utilization. This paper will introduce a new technique to enhance such power line communication.

II. PROPOSED SCHEME

The proposed structure is shown in Fig. 1. In considered SWER, a master SG is installed beside re-closer, which will synchronize all downstream slave SG+SD units with command protocol broadcasted. Also an upper SD is needed at same location to sense upstream report signal, which is actually line current disturbance generated by multiple slaves. At each load point, a slave unit with both signal generator and detector is installed after step-down transformer. It is the same electrical level with real load. The slave power rating can be 120/ 240V.

Base on this principle, the whole detection system forms a communication loop per hour. Every one hour, master SG sends a command downstream to request all slave units to respond individual status. Each slave unit report back with a coded pulse, one at a time sub-sequentially. If any incoming signal is missing, a broken point is targeted at corresponding address. One thing should be identify is because the communication speed is rely on power frequency, the amount of load points is decisive to total time need for one loop [2].

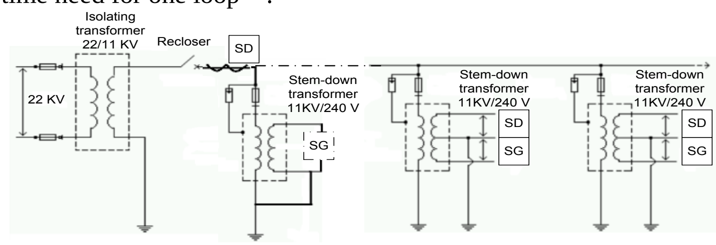

Figure 1. The proposed open conductor identification system

As in Fig. 2, the switching devices for SG are usually thyristor in high-power application. If choosing a pair of anti-paralleled connected thyristor, there are two switches in one cycle on the SG branch and thus eliminate even order harmonics. If conducting one cycle and leave it uncontrolled next cycle, then subtract the system voltage in these two cycles, we can obtain voltage sag, or the disturbance signal [3].

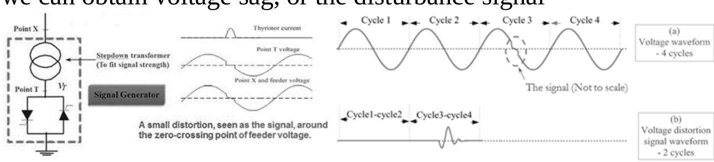

Figure 2. SG schematic and signal extraction method

III. COMPUTER SIMULATION RESULT

Fig. 3 is the simulation result with PS/CAD 4.2, as observed, it is very easy to distinguish the signal from background, by applying FFT winder like Fig. 3, and the expected disturbance signal is thus de-coupled [4].

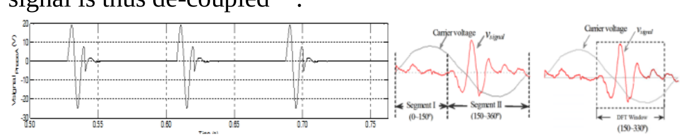

Figure 3. Computer simulation results

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Optimal Operations of Distributed Wind Generation in a Distribution System using PMUs

Manoaj Vijayarengan*, Noel Schulz
Department of Electrical and Computer Engineering
Kansas State University
Manhattan, KS, USA
*Email: manoajvj@ksu.edu

***Abstract*—Wind energy is becoming one of the most widely implemented forms of renewable energy worldwide. Traditionally, wind has been considered a non-dispatchable source of energy due to the uncertainty of wind speed and hence the variable availability of wind power. Advances in technology allow the consideration of the impact of distributed wind turbines and farms on distribution systems. In this case, it is possible to combine the clean energy attributes of wind with the quickly dispatchable nature of a back-up distributed generation plant or storage facility in order to provide the maximum amount of locally generated power economically to the loads present in the distribution feeder. However, a monitoring system needs to be provided that is capable of detecting the changes associated with the distribution feeder load and also the variable generation output that would be obtained from the wind farms. This task can be accomplished using Phasor Measurement Units (PMU) which have very high sampling rates and hence can measure very rapid and dynamic changes in power levels associated with distribution feeder load and wind generation. The data which is obtained from these PMUs can be used to optimize the amount of distributed generation that can be produced locally at the distribution feeder, thus resulting in a reduction in the peak load levels associated with the distribution feeder as seen by the substation monitoring system. Simulations will work to balance load requirements, wind output, and storage or controllable distributed generation providing a stable system utilizing maximum renewable resources. Standard IEEE Distribution Test Feeders are used in the study. Various probabilistic models are implemented for wind energy generation, distribution feeder load and PMU measurements, and the models are analyzed by simulations. The strategy being investigated can also be used to implement other important applications such as distribution system state estimation, protection and instability prediction.**

Keywords-Wind Power; Distributed Generation; PMU; Uncertainty

Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances

Renke Huang, *Student Member, IEEE*, Evangelos Farantatos, *Student Member, IEEE*, George J. Cokkinides, *Senior Member, IEEE*, and A. P. Meliopoulos, *Fellow, IEEE*

***Abstract*— Renewables and other distributed resources including storage, smart appliances, PHEVs with V2G capability, etc. offer the unique opportunity to transform the grid into an active and controllable resource with dramatic impact on (a) system economics, (b) primary energy source utilization and associated shifts in greenhouse gas production, (c) ancillary services and improvements of system stability and security. This work is focused on a hierarchical optimization and DER coordination scheme that achieves these goals. The proposed algorithm achieves optimal operation of the system with levelized load curve and minimized losses. Additional benefits include reduction of conventional generation cycling resulting from the variations of non-dispatchable resources as well as increased utilization of renewables (for example increased capacity credit of renewables).**

I. Hierarchical Optimization Scheme Overview

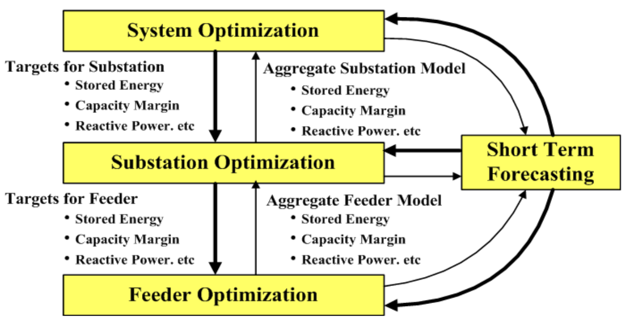

Fig. 1. Hierarchical Optimization Approach

Feeder optimization level:

- Covers all the circuits, resources and customers of one feeder of a substation.
- Determines the optimal operating conditions for the DERs subject to meeting the directives from the higher optimization level over the planning period (typically a day).
- Solution approaches: (a) via successive linear programming and (b) via barrier methods

Substation optimization level:

- The aggregate model of each feeder of the substation is used, along with target values from the upper level to generate the targets (directives) that have to be achieved for each separate feeder.
- A stochastic dynamic programming approach is used that ensures optimal operating conditions of the substation over the planning period (typically a month).

System optimization level:

- Coordinates the operation of the substations and generates the target values that each substation has to achieve for a system level optimal operation. A dynamic programming approach is also used for this level.

II. Key Results

A typical utility system is used as a testbed. The test system has a capacity of 22280MW consisting of 40 generator units with four types of fuel resources (coal, nuclear, oil and natural gas).

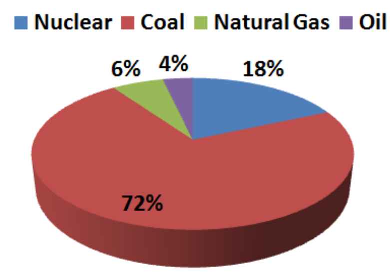

Fig. 2. Generation Mix for the TestBed System

Load levelization/ Peak load reduction:

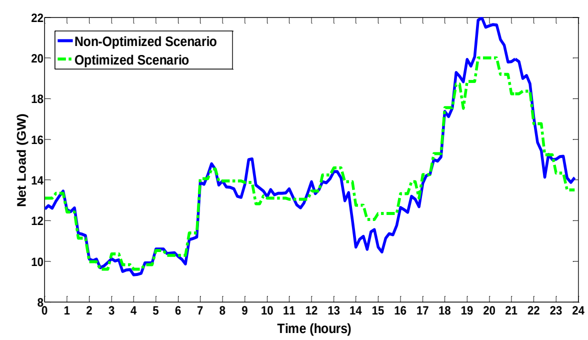

Fig 3. Net load for non- optimized and optimized scenarios (10% wind integration)

Conventional generator cycling reduction:

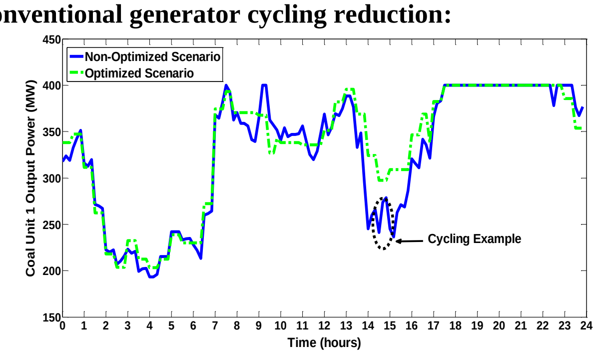

Fig 4. Coal Unit 1 Output Power (10% wind integration)

Medium Voltage DC Network Modeling and Analysis with Preliminary Studies for Optimized Converter Configuration through PSCAD Simulation Environment

Brandon M. Grainger, *Student Member, IEEE* and Gregory F. Reed, *Member, IEEE*
Center for Energy / ECE Department, University of Pittsburgh, Pittsburgh PA, 15213, USA
Email: bmg10@pitt.edu and reed5@pitt.edu

***Abstract* – This article briefly describes the poster to be submitted on Medium Voltage DC (MVDC) technology initiatives at the University of Pittsburgh for the 2012 IEEE PES T&D show in Orlando, Florida.**

I. Introduction

The need for Medium Voltage DC (MVDC) technology development has been driven by the liberalization of the energy market, which has led to installations of large scale wind and solar farms at the transmission and distribution level. There are certainly potential increases in efficiency that can be realized by employing a MVDC network. MVDC systems will help reduce the number of conversion stages required for integrating a lower voltage output of a renewable generation resource to the electric grid operating at a much higher voltage. Hence, the MVDC platform can serve as an additional layer of infrastructure in the electric grid between the transmission and distribution levels.

Applications for DC include solar and wind generation, battery storage, and other forms of green energy resources. The penetration of these technologies is rapidly increasing and they all employ or require a DC integration link of some kind. The same is true of the various loads that are being employed today by consumers, including the advancement in electric vehicles and more sensitive power electronics based loads, many of which are operating at low voltage DC levels. Fig. 1 provides a general set-up for a proposed MVDC architecture.

II. General Poster Description

The poster is divided into eight sections providing a comprehensive summary of the thesis work done by the student on MVDC technology. The poster background color is an ocean blue and each segmented area has a light gray background. The header of the poster contains the logos of the sponsors for this work. On the far left of the poster, the objectives of the research are presented as well as the outcome of the investigations. Below this segment are two high illustrations of the MVDC concept, one which is provided in Fig. 1 and a diagram of the modeled system found in the thesis work. The thesis model is a subsystem of the multiple year MVDC project (Fig. 1).

Reviewing Fig. 1, one will notice that the architecture is heavily consumed with many different types of power conversion equipment including multilevel inverters, rectifiers, and DC/DC converters. Consuming the middle third of the poster, adjacent to the research objectives, are three additional segmented areas. The first area provides a very illustrative and descriptive treatment of the multilevel inverters used in the work, specifically the neutral point clamped topology, and standard pulse width modulation routines. The second area describes the multipulse rectifiers used in the work with colorful and clean illustrations of the rectifier operation. Finally, the third area next to the rectifier description is a discussion of the bidirectional DC/DC converter. This area provides illustrations of theoretical converter operation as well as simulation results.

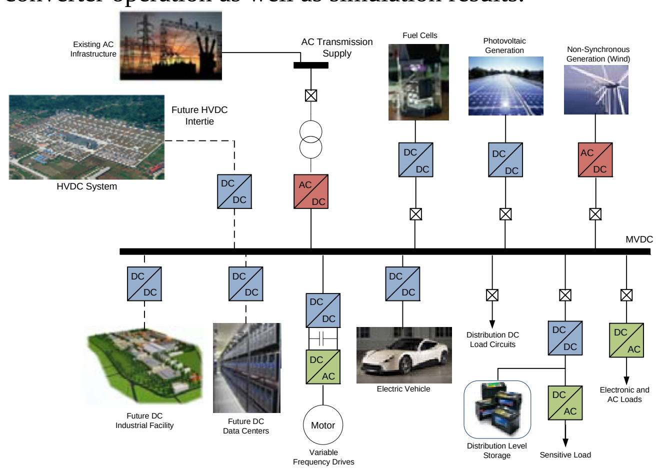

Fig. 1. Medium Voltage DC Network

Fig. 1 includes a number of renewable energy resources including solar and wind. In the system model for the thesis work, only wind generation was emphasized and modeled. Consuming the bottom third of the poster is the wind turbine induction machine torque characteristics as well as the nonlinear, dynamic power curves of the wind turbine. These curves describe the amount of power expected out of the wind turbine and are a function of blade pitch and mechanical speed. An illustration of the output power of the wind turbine model correlated with these curves is provided.

The last region of the poster shows a validation of the interconnected system components including balance of generation and load, system fault responses with illustration of fault location in the network as well as plots of the total harmonic distortion with comparisons to the three and five level multilevel inverters in the thesis model.

III. Biographies

Brandon M. Grainger (M’2006) is a Ph.D. student and **Gregory F. Reed** (M’1985) is the Director of the Electric Power Initiative, Associate Director of the Center for Energy, and Professor of Electric Power Engineering in the Swanson School of Engineering at the University of Pittsburgh.

This work was supported by funding from the PA DCED BFTDA and ABB Corporate Research Center. B.M. Grainger and G.F. Reed are with the Department of Electrical & Computer Engineering and the Center for Energy, in the Swanson School of Engineering at the University of Pittsburgh, Pittsburgh, PA 15210 USA (e-mails: bmg10@pitt.edu, reed5@pitt.edu)

Interface for Inverter Based Distributed Generators

Shiva P. Pokharel, Sukumar M. Brahma, and Satish J. Ranade
Klipsch School of Electrical and Computer Engineering, New Mexico State University, Las Cruces, NM 88003, USA
Email: pokharel@nmsu.edu, sbrahma@nmsu.edu, sranade@nmsu.edu

Abstract*—Integration of distributed generation (DG) with electric distribution systems is ever increasing. In most cases, DGs will be connected to the distribution network through an interfacing transformer. YG/YG transformer connection has some advantages, like being less prone to ferroresonance in cable fed installations, and reduced cost. However, the connection is not very popular for synchronous generator based DG, because the DG contributes to all faults in the utility system, and the third harmonics from the utility system travels through to the DG. When the DG is a dc source, like photovoltaic, the problems with the YG/YG connection can be eliminated with properly designed inverter based interface. This poster describes the performance of an inverter based DG connected to the utility through a YG/YG transformer. The utility system is modeled as a Thevenin equivalent with unbalance of up to 5%, and with the third harmonics of up to 5%. The inverter simulated in this study is controlled with per phase *dq* control strategy. Such control strategy is more suitable when an inverter has to supply power to an unbalanced load, or to an asymmetrical grid. A current limiter is implemented with the control of the inverter to limit its current output to 110% of the DG capacity in case of faults in the utility system. The simulation results show that none of the disadvantages of the YG/YG transformer connection exists with the proposed inverter interface.

I. Key Figures

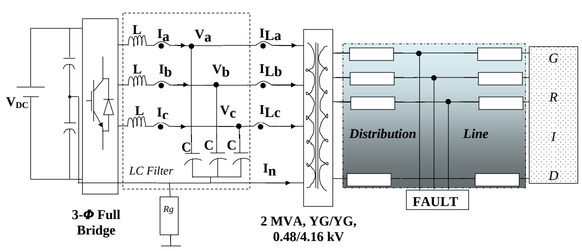

Fig. 1. Grid Connected 3 phase 4 wire Inverter.

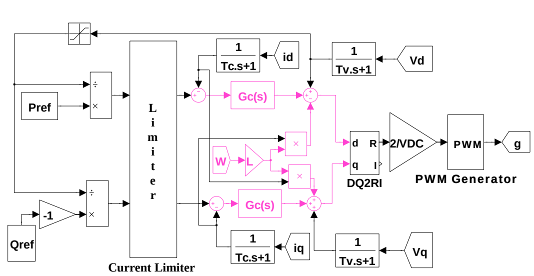

Fig. 2. Inverter control for grid connected operation.

II. Key Results

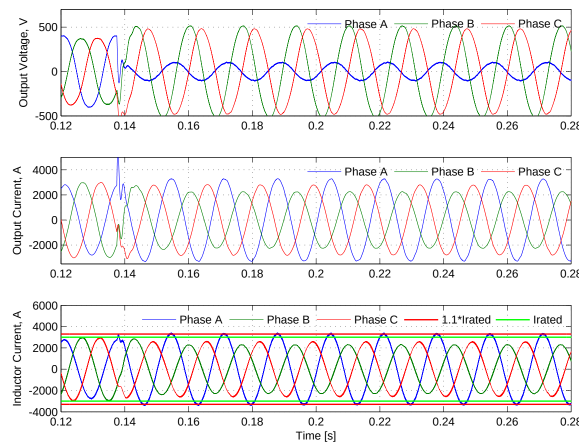

Fig. 3. Inverter response to AG fault.

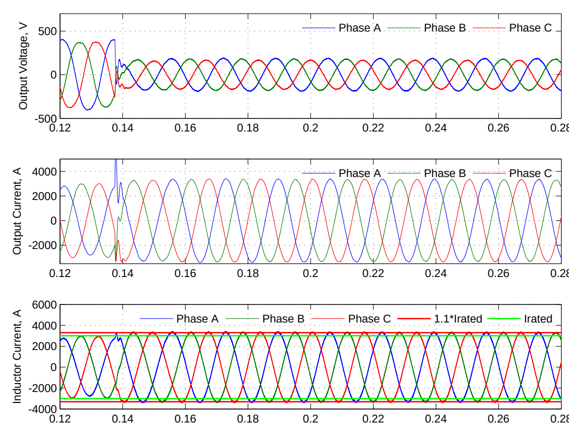

Fig. 4. Inverter response to three-phase fault.

References

[1] R. Arritt and R. Dugan, "Distributed generation interconnection transformer and grounding selection," in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*, july 2008, pp. 1 –7.

Reliability Analysis of Alternate Wind Energy Farms and Interconnections

Dongbo Zhao, *Student Member, IEEE,*
A. P. Sakis Meliopoulos, *Fellow, IEEE*

School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA
dzhao8@gatech.edu

Abstract— With the emerging of new techniques and alternate technologies and topologies for wind power interconnections to the system, reliability issues become important for evaluation of alternative technologies and configurations of wind farms and interconnections. In this poster, AC systems, HVDC transmission systems, and low frequency transmission, typically at 20/16.7 Hz, is considered as alternative technologies for interconnection of remote wind farms to the power grid. Several alternative configurations of wind farms and transmission technologies are considered. Reliability models of the entire configuration have been developed that properly model the various components of the configuration as well as the probabilistic model of the wind power. These models are utilized to determine the reliability advantages/disadvantages of the proposed wind farm/transmission interconnection configurations. These models can be also utilized in reliability analysis of the overall power system.

This poster gives out the general approach of reliability analysis of two of the typical alternate configurations of wind farm using low frequency transmission to point of common coupling to the power system. Reliability components and their characteristics are modeled, with example calculations made to demonstrate the use of the approach.

Keywords-Low frequency transmission, reliability indices, adequacy assessment, wind farm

Penetration Level of Photovoltaic (PV) Systems into the Traditional Distribution Grid

Santosh Chalise and Dr. Allison Kipple
Department of Electrical Engineering and Computer Science
Northern Arizona University
Flagstaff, Arizona, USA
Email: *sc627@nau.edu and allison.kipple@nau.edu*

***Abstract*— This research analyzed the effects of a photovoltaic (PV) plant on a distribution system from a different perspective, namely by considering the impact of the system's flexibility. A MATLAB / Simulink model of a simple distribution system containing a few loads and a PV plant, separated by short line segments, was developed and simulated via scripting techniques to analyze the effects of numerous system configurations. In particular, we analyzed the system's behavior after sudden yet realistic changes in the PV power output (e.g., an 80% drop in power within 1 second) given different load, PV penetration, and grid connection characteristics. The grid voltage and harmonics for each simulation were then analyzed to determine which configurations produced power quality or stability concerns. As a result, general guidelines were developed regarding the maximum penetration level of a PV plant as a function of the flexibility of the distribution system's connection with the transmission grid. At the point where the penetration level became problematic, the use of power electronics and storage techniques to increase the flexibility of the system, thereby increasing the allowable level of PV penetration, were analyzed. While there is no guideline the can guarantee the maximum safe PV penetration level for every possible distribution system, loading level, and flexibility, the results of this study may guide power engineers into making improved estimates for the PV power levels that their distribution systems can safely sustain.**

Keywords-renewable energy; photovoltaic; simulink; grid; integration; penetration level

I. BACKGROUND

To satisfy increasing energy demands, meet CO_2 emission requirements, and address governmental renewable energy standards, the power engineering community has been forced to quickly investigate and address the effects of large, distributed renewable energy plants on transmission and distribution grids. Currently, photovoltaic (PV) systems represent the fastest growing component of renewable power generation. With this rapid increase, the PV penetration level is increasing and raising concerns about stability and power quality, in large part because of the variability and uncertain nature of PV power production. However, informed guidance about safe levels of PV penetration for different situations is lacking, particularly at the distribution level. This motivated us to better define the parameters of this problem.

Funded by: Arizona Public Service

II. KEY FIGURES

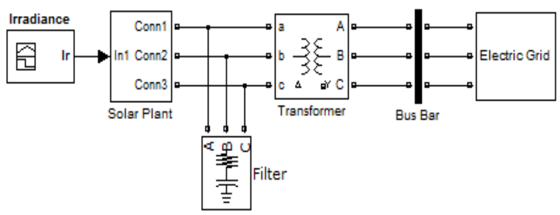

Figure 1: MATLAB Simulink model of an example distribution system.

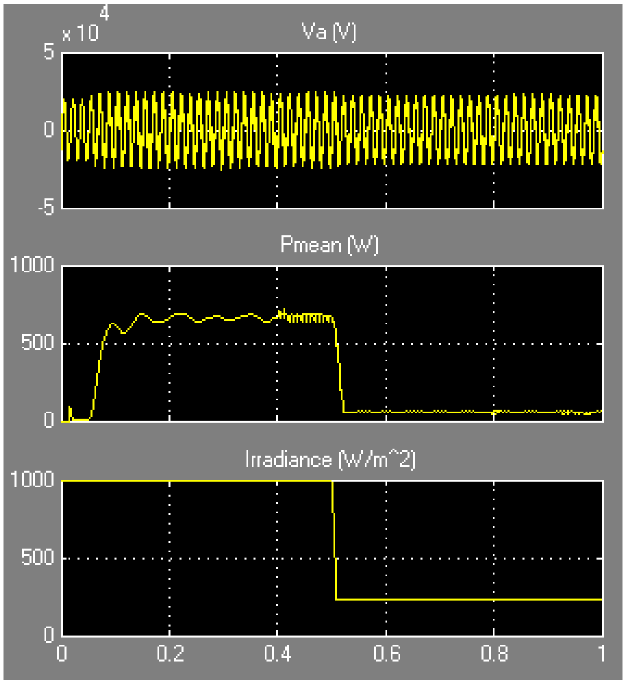

Figure 2: Simulation results when irradiance falls by 80% in 1 second.

Wind Power in Combined Energy and Reserve Market PART I: Market Modeling and Combined Scheduling

D. He, *IEEE Student Member*, Z. Tan, *IEEE Student Member*, J. Liang, *IEEE Student Member*

Abstract: This paper mainly focus on market mechanism research, economic dispatch of wind power in combined energy and reserve market. Based on proposed market mechanism, wind power energy will be updated from nowadays lack of dispatch to fully dispatch .If so, several potential optimal operation control strategies could be re-considered again, says, integration evaluation. In this paper, firstly, an original combined market mechanism will be extended to real system market operation. Secondly, an economic dispatch sample with over 25% penetration of wind power energy running on IEEE benchmark system will be proposed, unlike an offset road, a novel model of wind power cost function need be proposed to dispatch itself, in this section, a reserve market components also need to be considered. Finally a set of software integrating all these functions will be presented.

Index Terms: wind power energy, reserve market, power system, economic dispatch, frequency analysis, reserve capacity.

I. Introduction

Today in most electricity markets, wind producers do not participate in the reserve markets. Wind power is treated as offset to loads, requiring additional reserve to compensate for its variability and intermittency. As the reduction of non-renewable energy percentage, the system reserve may become scarce. However the value of fast reserve will likely increase, providing incentives for wind plants to provide reserve services. Letting wind generation resources to participate in the reserve market will be of mutual interest to system operators and wind producers. J. Liang et al. recently proposed a new market framework which allows wind power participate the regulation market with lower deviation penalties. With the proposed market model, wind power variations may be divided into the energy and reserve markets, possibly reducing the need for additional reserve for intermittent renewable sources. Wind producers benefit from having increased revenue by optimally bidding into the energy and reserve markets to hedge deviation penalties.

In [1], a wind plant's revenue from the combined energy and reserve market is given by

$$R = R_E + R_{UR} = \pi_E P_{cE} + T_E + \pi_{UR} P_{cUR} + T_{UR},$$

where the subscript E denotes quantities in the energy market, subscript UR denotes quantities in the reserve market, $R_{E\ (UR)}$ denotes the revenues, $\pi_{E\ (UR)}$ denotes the day-ahead market prices, and $P_{cE\ (UR)}$ denotes the day-ahead commitments. $T_{E\ (UR)}$ denotes the imbalance revenues (possibly negative) from actual delivery, given by

$$T_E = \begin{cases} \pi_{E+}(P_E - P_{cE}) & P_E \geq P_{cE} \\ \pi_{E-}(P_E - P_{cE}) & P_E < P_{cE} \end{cases},$$

$$T_{UR} = \begin{cases} \pi_{UR+}(P_{UR} - P_{cUR}) & P_{UR} \geq P_{cUR} \\ \pi_{UR-}(P_{UR} - P_{cUR}) & P_{UR} < P_{cUR} \end{cases},$$

where $P_{E\ (UR)}$ denotes the delivered energy or UR, $\pi_{E+\ (UR+)}$ and $\pi_{E-\ (UR-)}$ are the deviation prices.

A. Problem Definition

Traditional combined energy and reserve market mechanism has been used in several electricity markets. The economic dispatch functions are given below:

Minimize

$$\sum_{t=1}^{24}\sum_{k=1}^{N} C_k(P_{Gk}(t)) + C_{ak}(Z_k(t), Z_k(t-1)) + C_{uk}(R_{uk}(t) + C_{dk}(R_{dk}(t))$$

Constraints:

$$\sum_{k=1}^{Ngen} p_k(t) = D(t),\ \sum_{k=1}^{Ngen} r_{pk}(t) = R_p(t),\ \sum_{k=1}^{Ngen} r_{nk}(t) = R_n(t)$$

$$p_k(t) + r_{pk}(t) - p_{\max k} z_k(t) \leq 0$$

$$p_k(t) - r_{nk}(t) - p_{\min k} z_k(t) \geq 0$$

$$0 \leq z_k(t) \leq 1 \ \in Z$$

Other Power Flow Constraints with SECUIRITY Equation

$P_{Gk}(t)$ – generated power, controllable variables

Z_k(t) – generator state function on (1) / off (0)

R_{uk}(t) – up reserve

R_{dk}(t) – down reserve

$D(t)$ – load at time t.

$R_p(t)$ – up reserve requirement at time t.

$R_n(t)$ – down reserve requirement at time t.

$C(x)$ – cost function of each kind of energy

In this work, based on a new wind power market mechanism, the main problem lies in how to implement this new mechanism into the original dispatch functions, and find optimal scheduling.

D. He, Z. Tan, and J. Liang are with Department of Electrical and Computer Engineering, Gatech, Atlanta, GA 30332 USA (e-mail: hedawei@gatech.edu; ztan30@gatech.edu; rharley@ece.gatech.edu; habetler@ece.gatech.edu)

SOC Feedback Control for Wind and ESS Hybrid Power System Frequency Regulation

J. Dang, J. Seuss, L. Suneja *Student Member*, and R. Harley, *Fellow*, *IEEE*

I. Introduction

With an increased penetration of wind generation in power grid, however, its unpredictable characteristics challenge the frequency regulation of power system. Besides WT control, it is intuitive that the timely consumption and supply of energy from an energy storage system (ESS) will strengthen the wind farm's power output's resistance to external changes. Hybrid systems combining the WT with the ESS are studied and the corresponding control schemes are proposed. In this poster, a hybrid power system combining the WT and ESS will be elaborated first, and then an energy management strategy, called SOC feedback control scheme will be proposed. Finally, the performance of the proposed control scheme will be presented.

II. System Description

A. Power System Model

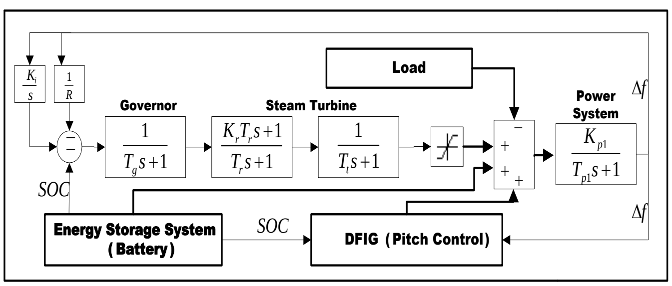

Fig. 1. Power System Simulation Model Block Diagram (R denotes the speed regulation parameter of the governor)

III. Control Strategy

A. SOC Feedback

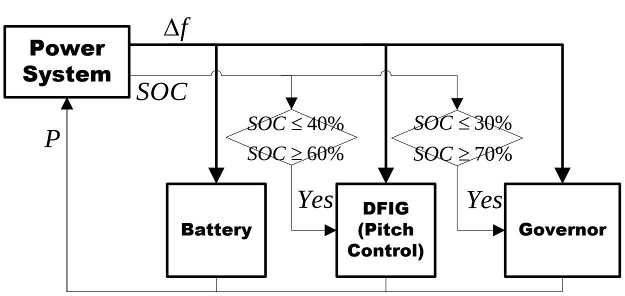

Fig. 2. SOC Feedback Control Scheme Block Diagram

IV. Simulation

1. From 100 sec to 200 sec, with the wind speed and the WT power output fluctuating, the battery charges or discharges in response to the grid frequency deviation.
2. From 200 sec to 300 sec, a load step increase occurs causing the SOC of the battery to go below 40, which triggers the pitch control of the WT. The pitch angle is adjusted to increase the active power output of the WT, regulating the grid frequency and the SOC around 50
3. From 300 sec to 600 sec, a larger step increase in load occurs and the SOC drops below 30 and the synchronous generator's speed governor is triggered. Again, the grid frequency is regulated and the battery is charging back to a SOC of 50.

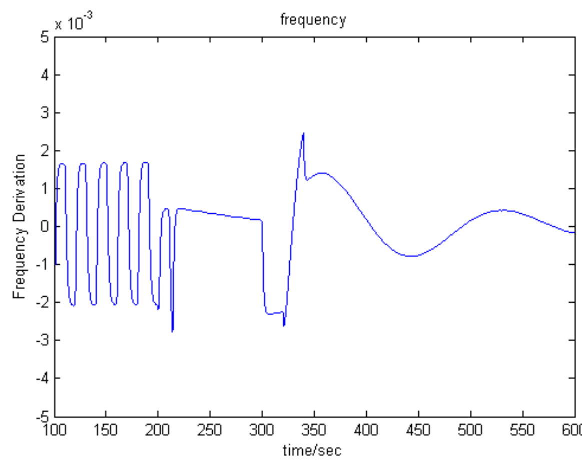

Fig. 3. Grid Frequency Deviation during wind speed fluctuations (100-200 sec) and a load step change (200-600 sec) transient.

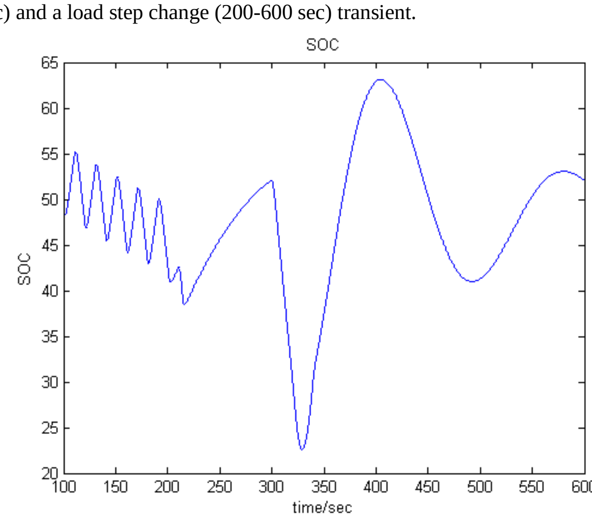

Fig. 4. SOC of the battery during wind speed fluctuations (100-200 sec) and a load step change (200-600 sec) transient.

This work was supported by the.

J. Dang, J. Seuss, L. Suneja and R. Harley are with Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, USA (e-mail: jdang3@gatech.edu, lsuneja3@gatech.edu, jseuss@gatech.edu, rharley@gatech.edu).

Energy Storage Control for Integration of Single-Phase Sources into a Three-Phase Micro-Grid with Wind Power Estimation

Prajwal K. Gautam and G. Kumar Venayagamoorthy
Real-Time Power and Intelligent Systems Laboratory
Holcombe Department of Electrical and Computer Engineering, Clemson, SC 29634, USA
Email: pgautam@clemson.edu and gkumar@ieee.org

***Abstract*— Micro-Grid is an integration of modular distributed energy sources such as wind, solar, etc., together with storage devices, and controllable, critical loads to form a low voltage distribution system. Three-phase solar and a single-phase wind turbine are designed to supply the three-phase system. These results in an unbalanced set of currents which are compensated by the battery energy storage utilizing a multiple reference frame control presented herein. The micro-grid system is studied on a real-time simulation platform. The simulation results demonstrate the effectiveness of the control when the solar and wind sources are connected to the micro-grid. Simulation includes extensive modeling of energy storage system and three-phase photovoltaic system. Single-phase wind generator model is purposed using intelligent methods such as Neural Network.**

I. Key Figure

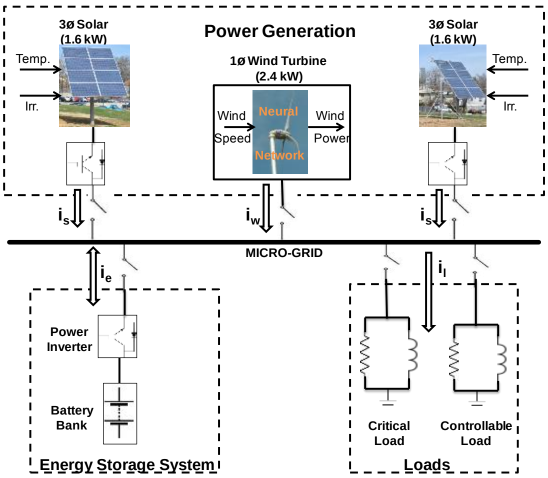

Figure 1. Micro-Grid System

II. Key Equations

The guiding equation for wind turbine generator represented by controllable voltage source is given as

$$V_w = \sqrt{\frac{3}{2}}.V_p.e^{j.30\,deg} + j.\omega_e.L_w.\frac{I_{wp}}{\sqrt{2}}.e^{j.30\,deg} \quad (1)$$

where, V_p is the micro-grid system voltage

$I_{wp} = \frac{2}{\sqrt{3}}.\frac{P_w}{Vp}$ is the current from wind generator

L_w is the inductance of wind generator

P_w is the estimated wind power

III. Energy Storage System Control

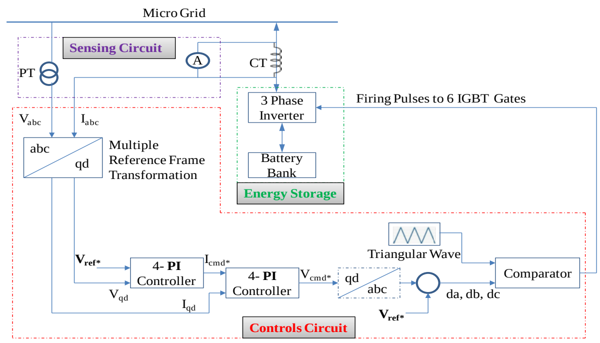

Figure 2. Control Method for Energy Storage System

IV. Key Results

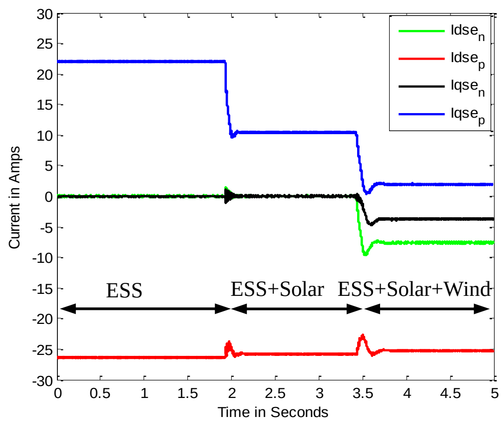

Figure 3. Positive and Negative Sequence Currents Supplied by ESS

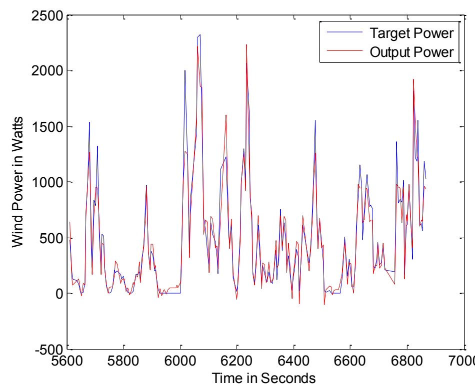

Figure 4. Learning of Wind Turbine Dynamics

Smart Dispatch of Controllable Loads with High Penetration of Renewables

Simon K. K. Ng, *Student Member*, *IEEE* and J. Zhong, *Senior Member*, *IEEE*
Centre for Electrical Energy Systems, Department of Electrical and electronic Engineering, The University of Hong Kong, Hong Kong, China,
Email: kkng@eee.hku.hk, jzhong@eee.hku.hk

***Abstract*—This poster presents a bi-level aggregator-utility optimization model to schedule an energy consumption pattern of controllable loads in a power system with a high penetration of renewables. The upper level is an aggregator's problem which aims to minimize the electricity payment by managing the energy consumption of three types of controllable loads. On the other hand, the lower level is a utility's problem which is a market-clearing model. We derive the Karush-Kuhn-Tucker (KKT) optimality conditions of the lower-level utility's problem as the equilibrium constraint in the upper-level aggregator's problem. Therefore, the bi-level formulation is converted into a form of mathematical program with equilibrium constraints (MPECs) which can be solved analytically. A numerical example is conducted to demonstrate the feasibility of the proposed model.**

I. Key Figures

Fig. 1 Control framework for aggregator

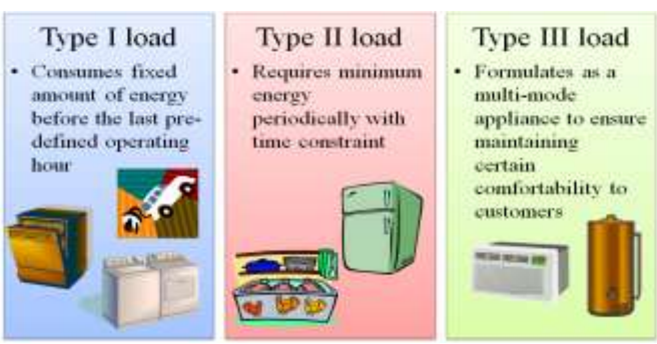

Fig. 2 Three types of controllable load

II. Key Equations

A. Upper-level Aggregator's Problem

$$min \sum_{t\in T} \mu_t \left(\sum_{j\in J} P_{j,t}^{I} + \sum_{k\in K} P_{k,t}^{II} + \sum_{l\in L} P_{l,t}^{III} \right)$$

Subject to

1) Constraints of type I load:

$$P_{j,t}^{I} = x_{j,t}^{I} P_{j}^{I}, \forall j \in J$$

$$\sum_{t\in T} x_{j,t}^{I} = H_{j}^{I}, \forall j \in J$$

2) Constraints of type II load:

$$P_{k,t}^{II} = x_{k,t}^{II} P_{k}^{II}, \forall k \in K$$

$$x_{k,t}^{II} + x_{k,t+1}^{II} + \cdots + x_{k,t+q_k^{II}}^{II} \geq a_k^{II}, \forall k \in K$$

3) Constraints of type III load:

$$x_{l,t}^{III} P_{l}^{III,min} \leq P_{l,t}^{III} \leq x_{l,t}^{III} P_{l}^{III,max}, \forall l \in L$$

$$E_l^{III,min} \leq \sum_{t\in T} (P_{l,t}^{III} \Delta t) \leq E_l^{III,max}$$

B. Lower-level Utility's Problem

$$min \left\{ \sum_{t\in T} \sum_{i\in I} C_{i,t} P_{i,t}^{g} \right\}$$

Subject to

1) Power balance constraints:

$$\sum_{i\in I} P_{i,t}^{g} + P_t^{w} = \sum_{j\in J} P_{j,t}^{I} + \sum_{k\in K} P_{k,t}^{II} + \sum_{l\in L} P_{l,t}^{III} + P_t^{BL}$$

$$: (\mu_t), \forall t \in T$$

III. Key Algorithms

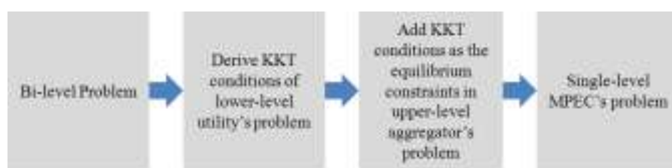

Fig. 3 Procedures of converting bi-level problem into single-level equivalent

IV. Key Results

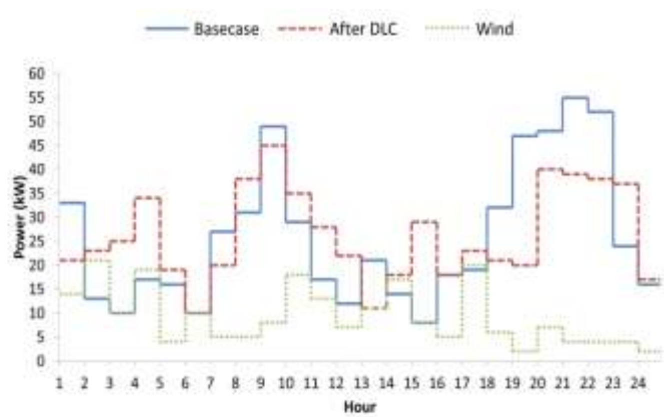

Fig. 4 Load patterns for basecase and with DLC

The DLC algorithm shaves the peak demand and its load pattern is more correlated with the wind power output.

IDENTIFICATION AND ESTIMATION OF LOOP FLOWS IN POWER NETWORKS WITH HIGH WIND PENETRATION

Manish Mohanpurkar, *Student Member IEEE,*
Advanced Power Engineering Laboratory, Department of Electrical and Computer Engineering,
Colorado State University, Fort Collins, CO 80523, USA,
Email: manishm@rams.colostate.edu

***Abstract*—Interconnection is a prominent characteristic of bulk power systems. Bulk power systems were historically based on a centralized generation philosophy. Transmission networks act as backbone or corridors providing electrical connectivity between generation centers to load sink. Locations of generation sites are primarily determined by the availability of the natural resource e.g., thermal power plants are typically located in the vicinity of mines and availability of water. On the other hand, load sinks are governed by factors such as residential, commercial, and industrial zones. Physical laws of electricity i.e., Kirchoff's laws and impedances govern the division of currents on the lines connected at different nodes. Electricity trade paths are determined by bid-sell principle in most deregulated markets. Inconsistencies thus observed between the expected flow and actual flow lead to unscheduled flows or loop flows. Under conventional generation scenarios, the loop flows are of deterministic nature. However, due to numerous environmental concerns and resource exhaustion constraints, conscious measures are being undertaken to complement non-renewable generation by environmentally friendly renewable generation. Wind and solar resources are expected to play a major role. Wind turbine installations have shown a remarkable growth; the U.S. alone recorded a rise from 2472 MW to 40,266 MW from 1999 – 2010 [1]. A study to detect loops and estimate loop flow distributions due to generation resource and load variability is presented with the IEEE 14 bus test system is used as the test model [2].**

Nature of input for the test system leads to a valid adoption of probabilistic load flow analysis. Monte Carlo (MC) simulations are used, since it is a well-known fact that they provide the most accurate results in probabilistic experimentations. Approximately 1200 valid iterations of the MC simulation are run. A Matlab© program is used to generate the random values of generators and control the flow of data in and out of the simulation. Power flow simulations are run in a commercial software package - PowerWorld© using the interface known as SimAuto©. Standard distributions of the random variables are obtained directly from [2]. Branch flows for each transmission line is obtained from the MC simulation; however these actual flows vary significantly from the expected flow. Actual flows are extracted from arbitrary electronic tags set for the network. The difference between actual flow and expected flow is used in a linear estimator.

Size of the system matrix (H) is (number of branches, number of loops). A modified A* search algorithm is developed and implemented to search closed loops in the network. Algorithm uses the Y_{BUS} of the network and provides loops possible and hence the system matrix (H). The algorithm is so programmed to accommodate any network provided the Y_{BUS} is known. Pseudo-inverse method provides the values of loop flows (x) [3]. Finally, the probability density functions of the loop flows and their implications will be detailed. The framework proposed and results provided, indicate that loop flows do have a stochastic nature due to generation resource variability. The estimations of loop flows can be used to obtain numerous indices and confidence levels of the utilization of transmission line capacities. The results can also be used to optimize switching patterns of phase shifting transformers, transmission expansion, and test novel avenues of loop flow minimization algorithms.

I. KEY EQUATION

The linear system of equations used to model minor loop flows in interconnected systems is (from [3]):

$$H^*x = z \qquad (1)$$

where - H is the incidence matrix,
z is the difference branch flows, and,
x is the estimated vector of minor loop flow.

II. KEY FIGURE

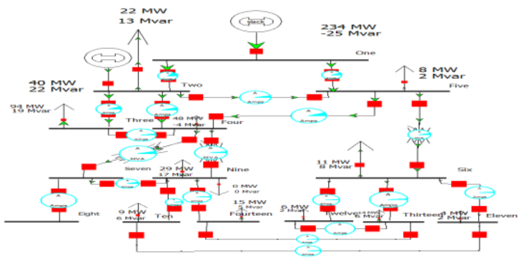

Figure 1: IEEE 14 Bus Test System to detect and test loop flows

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Voltage Profile Simulation using OpenDSS in High Penetration PV Scenario

Touseef Ahmed Faisal Mohammed, H. Krishnaswami
Department of Electrical and Computer Engineering,
University of Texas at San Antonio
San Antonio, Texas, USA
faisaltouseef@gmail.com; Hariharan.Krishnaswami@utsa.edu

***Abstract*— High penetration of PV into the power grid changes the voltage profile in the distribution circuits due to the inherent variability of PV. These frequent voltage variations can reduce the reliability of voltage regulators in the grid. There are a number of modeling and simulations tools available for the study of such high penetration PV scenarios. This poster will specifically utilize OpenDSS to simulate grid voltage profile with a large scale PV system. Results are presented for a model circuit with hourly variations in PV power output and the load. This poster will also explain the capabilities of openDSS in performing these types of high penetration PV grid impact studies.**

Keywords-voltage profile; disribution grid; photo voltaic (PV);distribution system simulator (DSS)

I. INTRODUCTION

OpenDSS [1] was originally developed by Electrotek Concepts, Inc in 1997. It was one of the main tools at Electric Power Research Institute (EPRI) for distribution system simulation tests. In 2008, EPRI made the program open source to promote grid modernization efforts by providing researchers and consultants with a tool to evaluate advanced concepts of smart grid and distribution generation. It was hence renamed from DSS to OpenDSS. This tool has the advantage of performing simulations with variable PV generation, which is expected to reach several GW in the future. The smart grid is expected to integrate several of such distributed PV resources seamlessly. It will accelerate a natural evolution towards more optimal, real-time and intelligent algorithms in distribution system which can be studied through tools like OpenDSS.

In literature, openDSS has been developed used for distributed resource planning, harmonic studies, neutral-earth voltage studies, volt-var control studies, and other special applications. The simulator has also been used to conduct several smart grid research projects, including advanced smart grid functionalities [2], electric vehicle penetration and state estimation. In this poster, a model circuit is used with variable PV generation and load to study the voltage profile with large-scale distributed generation. The results from OpenDSS are presented in the following section.

II. SIMULATION RESULTS

The model distribution circuit used for simulation has a conventional generator, a PV source, transmission lines and a variable load. Both PV and the load are varying with time and they are scripted in code using the Component Object Model (COM) interface which is a unique feature of OpenDSS. The program is a script-driven simulation engine. The OpenDSS architecture consists of executive model and a system model. Executive model processes the main script commands and System model consists of main circuit solution. Fig. 1 shows the change in voltage at the load bus for four different cases where the PV generator output and the load are varied by +/-20%.

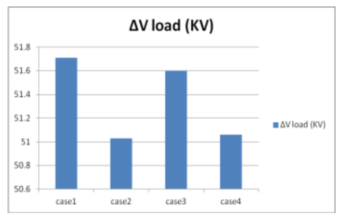

Fig. 1 Load bus voltage profile with variable PV

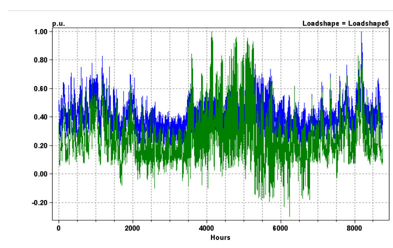

Fig. 2 Load profile for a year in p.u. [1]

The simulator has the capability to project the variability in load profile and PV system output for an entire year. Fig. 2 shows that how OpenDSS can plot load profile of a distribution system. Further results with this feature will be presented in the final poster.

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Self-Regulated Optimal Battery Bridged PV Micro-Source for Smart Grid Applications

Undergraduate Design Team:

Walter Bomela, Matthew Knudson and Paul O'Connor

Faculty Mentors:

Drs. Sukumar Kamalasadan and Valentina Cecchi

Power, Energy and Intelligent Systems Laboratory (PEISL), Department of Electrical and Computer Engineering, University of North Carolina at Charlotte, Charlotte, NC, USA,

Email: *wbomela@uncc.edu, mknudson@uncc.edu, poconno5@uncc.edu, skamalas@uncc.edu and vcecchi@uncc.edu*

***Abstract*— This paper focuses on the preemptive analysis of the effects of a hybrid micro-source on a power distribution system and also the effects of a battery on the entire system when placed in a hybrid micro-source. The main objective of the research is to analyze the effect of a battery as a bridge to provide voltage regulation, ramping and at the same time supply energy to the local load. A complete model for battery, Photo Voltaic (PV) system, power electronics and optimal controller has been designed and developed in Matlab/Simulink®. The results show that a controlled battery bridged micro source can regulate the load voltage and supply power to the load without the need of the DG Electric Power Systems (EPS) voltage regulation.**

I. Introduction

With the continuous increase in penetration from renewable sources (such as PV) eventually these energy sources should support the local load demand of the modern power grid. However the intermittent nature of a PV micro-source poses a problem for voltage regulation at the load, when load changes. A novel solution is to include a battery with the PV micro-source in order to provide a regulated power output and thus a stable voltage at the load. This paper aims to show the feasibility of a DG-regulated voltage seen by the load, due to the inclusion of a battery by demonstrating a self-regulating load voltage of a hybrid micro-source.

II. Design Topology

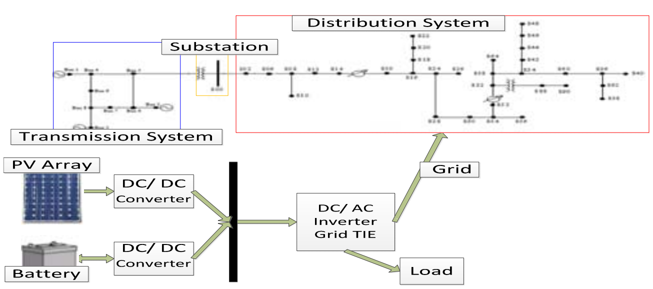

Figure 1: System Topology

Figure 1 shows the system topology. In the proposed design, a properly sized battery is connected to a PV array through the respective converters. The common inverter will be used to control the voltage and power supplied to the local load and to the grid. The ability of architecture to regulate the power and voltage at the point of common coupling (PCC) with the inverter control is illustrated next.

III. Case Studies And Key Figures

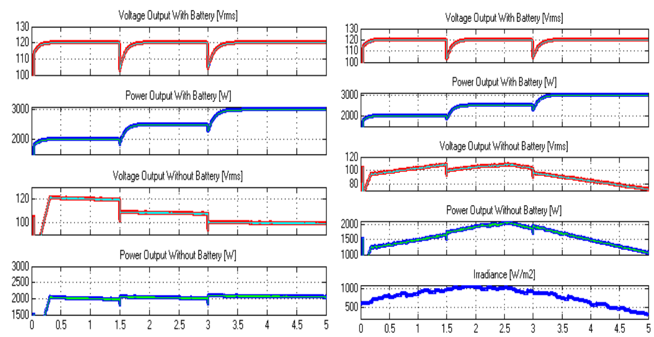

Figure 2: Hybrid-micro source power and terminal voltage for:
a) Constant irradiance b) changing irradiance

Two cases are performed. First, the effect of battery with constant irradiance and changing load is analyzed. Second, the same condition with changing irradiance is analyzed. Figure 2 a) illustrates the effect of battery when the load is varying. A step changing load from 2KW to 3 KW in steps of 0.5 KW is applied and the voltage at the PCC is observed with and without battery. It can be seen that the micro source with battery could maintain the voltage constant irrespective of the change in load. In figure 2b) the PV has a changing irradiance. The voltage is held constant with Battery Bridge even though the PV output changes with irradiance.

IV. Conclusions

A properly sized and controlled battery bridged PV micro-source can regulate the PCC voltage effectively. The main advantage of this method is that due to the self-regulating micro source there is no need for EPS voltage regulation. This also allows the utility to control other feeder voltages effectively. Furthermore, as the micro source power output varies in proportion with the local load, constant power flow from the grid in presence of local load changes, is fully feasible. This could also significantly reduce spinning reserves.

V. References

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Modeling and Coordinated Control of Grid Connected PV/Wind Inverter in a Microgrid

Junbiao Han, *Student Member, IEEE*, Sarika Khushalani Solanki, *Member, IEEE* and, Jignesh Solanki, Member, *IEEE*

***Abstract* – Next generation distribution feeder will have high penetration of renewable generation like Photovoltaic (PV) and wind. The variable nature of PV and wind leads to supply and demand mismatch creating over voltages and power quality issues in feeders. To mitigate over voltages this poster determines sensitivities to develop droop based coordinated active power control of these renewable sources. To mitigate power quality issues dq control is implemented. The results are presented for CIGRE benchmark microgrid modeled in EMTDC/PSCAD with a grid connected PV system and a direct drive wind turbine.**

***Keywords* - Coordinated control, PV, Wind Farm, Power Quality, EMTDC/PSCAD, MATPOWER**

I. Key Equations

The equations used to model PV Panel are shown in (1) to (4):

$$I_{pv} = I_{ph} - I_d - I_r \qquad (1)$$

$$I_{ph} = I_{pho}\left(\frac{S}{1000}\right) + J_T(T - T_{ref}) \qquad (2)$$

$$I_d = I_0\left[e^{\frac{q(V_{pv}+I_{PV}R_d)}{nKT}-1}\right] \qquad (3)$$

$$I_r = \frac{V_{pv}+I_{PV}R_d}{R_{SH}} \qquad (4)$$

The equation used to model maximum power generation of wind is:

$$P_M^{MAX} = \frac{1}{2}\pi\rho R^5 \frac{C_P^{MAX}}{\lambda_{OPT}^3}\omega_M^3 \qquad (5)$$

The equations used to model PV and wind inverter are shown in (6) – (9):

$$\mathrm{P} = \frac{3}{2}\mathrm{E_q I_q} \qquad (6)$$

$$\mathrm{Q} = \frac{3}{2}\mathrm{E_q I_d} \qquad (7)$$

$$\mathrm{E_{sd}} = \mathrm{RI_d + pLI_d + LI_q + E_d} \qquad (8)$$

$$\mathrm{E_{sq}} = \mathrm{RI_q + pLI_q - LI_d + E_q} \qquad (9)$$

From the power flow analysis, the sensitivities are calculated from equation (10) [1]:

$$S_V = \begin{bmatrix}1 & 0\\ 0 & |V|\end{bmatrix}\begin{bmatrix}\frac{\partial P}{\partial \delta} & |V|\frac{\partial P}{\partial V}\\ \frac{\partial Q}{\partial \delta} & |V|\frac{\partial Q}{\partial V}\end{bmatrix}^{-1} = \begin{bmatrix}\frac{\Delta\delta}{dP} & \frac{\Delta\delta}{dQ}\\ \frac{\Delta V}{dP} & \frac{\Delta V}{dQ}\end{bmatrix} \qquad (10)$$

The sensitivity factors are used to calculate required change in active power from the renewable generation using equation (11)

$$V_{Ci} = V_i - \Delta P_i \sum_{j=1,2....}\frac{\Delta V_{Hi}}{\Delta P_{Hj}} \qquad (11)$$

The droop is calculated using equation 12 and is used for over voltage compensation as shown in Figure 1:

$$m_i = \frac{\Delta P}{V_{Ci} - V_i} \qquad (12)$$

II. Key Figure

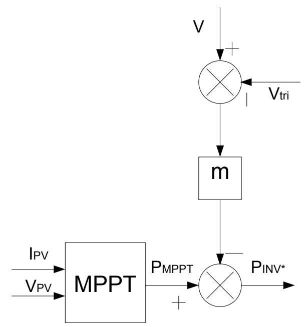

Fig.1: Droop based overvoltage compensation control of PV Inverter and Wind Inverter [1]

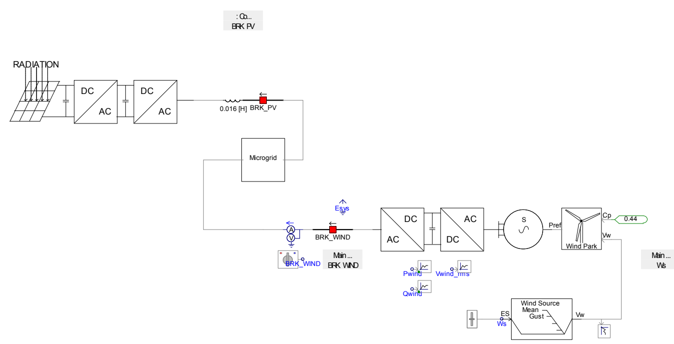

Fig 2: Microgrid test system in PSCAD

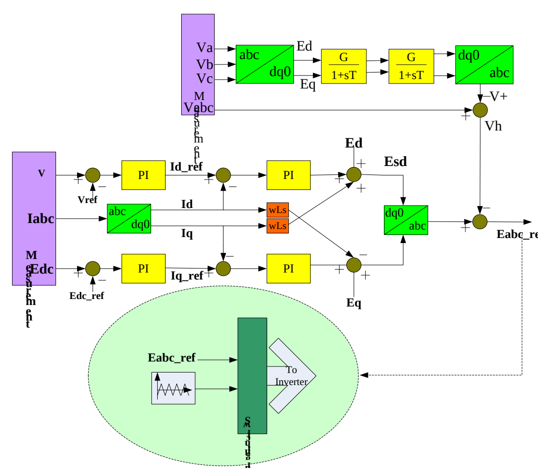

Fig 3: Power quality control of PV and wind inverter

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Health Monitoring of Substation Components

Griet Devriese, *Student Member*, IEEE, Anurag K Srivastava, *Senior Member*, IEEE
Smart Grid Demonstration and Research Investigation Laboratory, The School of Electrical Engineering and Computer Science,
Washington State University, Pullman, WA 99163, USA,
Email: *griet.devriese@email.wsu.edu*

***Abstract*—To provide secure and reliable energy, the electric power grid must function systematically in a managed way. Substations are an integral component of a reliable electric grid and health management of substations is important to continually provide electricity to the consumer. Health monitoring of substation components warrants further discussion and research.**

I. Health Monitoring of Circuit Breakers

Substations are complex systems within the electric power system. Many mechanical and electrical devices within substations work together to ensure flawless transmission and distribution of electricity. With ongoing smart grid activities, intelligent electronic devices create tremendous opportunity for data collection and analysis to ensure each substation component is working optimally. Current industry practices, however, do not utilize this data to its full benefit. By correctly interpreting the data from relays, substation engineers can closely monitor the health of each circuit breaker (CB), trip coil (TC), and transformer. By combining these analyses, substation health can be better assessed. Wave analyses provide information about the electrical properties and mechanical state of TC and CB. Through plotting multiple waves on one axis, a trending methodology can be applied. By comparing the current waveform to the previous, the maximum, and the minimum allowed, percent deviations can be calculated. Analyzing particular sections of each wave in this manner yields information about the functionality of the operations occurring within each substation device.

II. Key Figures

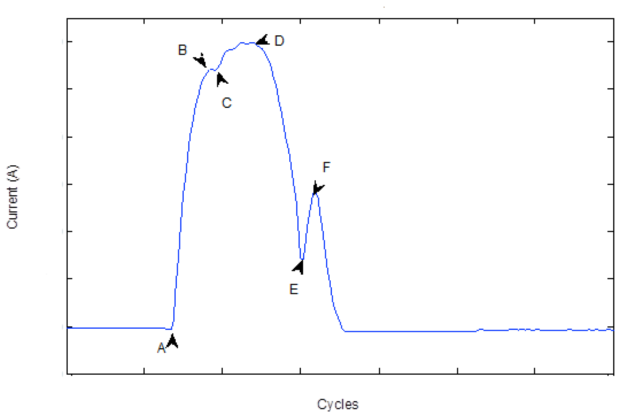

Figure 1. Diagram of A through F segments of typical waveform used for analysis

III. Key Analysis

Comparing the critical points A through F on a trip event waveform provides insight into the mechanical and electrical functionality of the device. Each segment of the waveform correlates to a physical action occurring within the device. Monitoring the changes in resultant waveforms allows operators to see changes in the behavior and health of the substation equipment [1].

Deviations from the norm in section A-B indicates problems with the electrical characteristics of the solenoid or supply current and voltage to the trip coil. Section B-C indicates the level of restrictive forces on the device plunger travel (such as oils and greases in the coil assembly). Section C-D indicates how well the plunger overcomes the trip bar inertia and can reveal component alignment problems. Section D-E represents travel of the plunger, striker pin, and trip bar. At point E the plunger comes to the end of its travel [2].

The project seeks to utilize the data from Schweitzer Engineering Laboratories (SEL) digital relays commonly installed in substations. By analyzing this data, a numerical health index can be assigned to each device.

IV. Summary

Health monitoring of substation devices can reduce the number of visual inspections needed and increase the efficiency of repairs through better component diagnosis. Combined with the health index, substations health monitoring will result in cost savings and an increase in reliability. Continued work in this research area is expected to lead to prognosis studies and the effective prevention of early component loss or unexpected failures.

V. Acknowledgements

The authors would like to thank SEL for providing the financial support for this project.

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Fault Diagnosis and Prognosis for Substations

Jeong Hun Kim, *Student Member, IEEE* and Anurag K Srivastava, *Senior Member, IEEE*
Smart Grid Demonstration and Research Investigation Laboratory (SGDRIL),
The School of Electrical Engineering and Computer Science, Washington State University, Pullman,
E-mail: jeong.kim@email.wsu.edu

***Abstract*—A fault is an unexpected change in a system, such as a component malfunction. Faults may lead to variations in operating condition to degrade overall system performance. In recent years, as more intelligent electronic devices (IEDs) at substations are being used, health monitoring of substation becoming more feasible. This poster addresses using available data from IEDs for health management of substations using diagnostic and prognostic approaches.**

I. Introduction

The concepts of diagnosis and prognosis for substation are processes of assessment of a system's health – past, present and future – based on observed data and available knowledge about the system [1]. Respectively, diagnostics is an assessment about the current and past health of a system based on observed measurements, and prognostics is an assessment of the future health. Since substations are very important and complex systems within the electrical power system, health management of substations is very important to keep the required reliability [2]. With better health monitoring tools of substation using diagnostic and prognostic techniques, not only the efficiency of restorations can be increased, but also the number of inspections can be decreased.

II. Fault Diagnosis

Diagnosis is defined as the identification of the 'nature and cause' of observed response. Behavior of the engineering system may differ from its model making diagnosis more challenging. The concept diagnosis might come from "troubleshooting", which involves determining why a correctly designed piece of equipment is not functioning as it was intended. The explanation for the faulty behavior being that the particular piece of equipment under consideration is at variance in some way with its design.

This research work seeks to utilize the data from Schweitzer Engineering Laboratories (SEL) digital relays commonly installed in substations for diagnosis. By analyzing data from digital relays, a diagnostic algorithm infers a possible root cause of the fault in a substation. The data from digital relays may include more information other than voltages and currents measured from PT and CT coupled with certain components in a substation. Based on these measured responses, possible fault cases should be listed by comparing normal and abnormal operation from a simple model of substation components. It should be further analyzed to narrow down the list of possible root causes of faults/ failures. Diagnostic algorithms can be implemented using available real time controller solutions. Algorithms can also have the features of including a probability factor with each possible root cause of faults/ failures.

III. Fault Prognosis

Prognostic problems are essentially prediction problems based on sequential data. Sequential data may arise in many areas of science and engineering. The data may either be a time series, generated by a dynamical system, or a sequence generated by a 1-dimensional spatial process. One may be interested either in online analysis, where the data arrives in real-time, or in offline analysis, where all the data has already been collected. The prognosis in substation is online analysis on time series of data from digital relays.

This project is focusing on possible propagated faults among substation devices. In order to detect propagated fault the first step is to provide fault data in terms of measurements under abnormal operation of a substation. For experimental studies in a lab setup, communication between SEL devices and Real Time Digital Simulator (RTDS) with a simple substation model in RSCAD can generate real-time data. With changing parameters of certain components on RSCAD model, abnormal operation of substation can be modeled and simulated. With this simulation, fault data under abnormal status can be provided. Then prognostic algorithm built and coded in a SEL substation controller can infer possible propagated faults.

IV. Summary

A fault diagnosis and prognosis tools in a substation will lead to enhanced reliability and economics. Algorithms will monitor the data from IEDs and detect possible faults/ failures with a probability factor. It will also predict propagation of faults/ failures at system level with prognostic techniques such as rule based/ expert system algorithm.

V. Acknowledgement

The authors wish to express special gratitude to SEL for the financial support for this project.

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An Investigation of Capacitor Control Actions for Voltage Spread Reduction in Distribution Systems

Nicole U. Segal and Karen Miu
Center for Electric Power Engineering, Department of Electrical and Computer Engineering
Drexel University, Philadelphia, Pennsylvania, U.S.A.
nus23@drexel.edu, miu@coe.drexel.edu

***Abstract*— This work investigates capacitor control for voltage spread reduction. In particular, the purpose of the work is to observe the relationship between the numbers of load levels and the numbers of capacitor control actions taken in a day. This is important because with Advanced Distribution Automation (ADA) the amount of sensed voltage and load data increases and a re-evaluation of local control schemes which were based on time of day algorithms or voltage set points is warranted.**

Typically, system operators dictate a daily maximum number of capacitor control actions based on the equipment lifetime and maintenance considerations. In [1] and [2] the maximum number of daily switch operations is less than or equal to the number of load levels studied in a day. In this work, voltage spread reduction via capacitor control is studied using an actual distribution circuit given the location and size of capacitors. It is noted under certain circumstances it may be necessary to relax previous capacitor set points for switching.

Simulation results for the system are subjected to multiple load levels. Following [3], it is noted that the peak and minimum load profile as well as the average load profile have been given. Other load levels are created by scaling. Subsequently, control sequences were determined and the number and order of control actions were evaluated.

I. Key Equation

$$\min_{u \in U} \max_{\substack{i,j \in N \\ p \in a,b,c}} \left\| \left| V_i^p(u) \right| - \left| V_j^p(u) \right| \right\| \qquad (1)$$

where, alphabetically:

N : set of all buses

n_{cap} :total number of all capacitors

N_{LL} : number of load levels

$n_{ops}^{\max}$: maximum number of switch operations per capacitor, load level l

p : present phase (a ,b, c) at a bus i

u : final capacitor control scheme, load level l

U : set of possible capacitor control operations

V_i^p : voltage at bus i, phase p

The objective in (1) is subject to electrical constraints, such as, a multi-phase unbalanced power flow with detailed network components. The system is also subject to operating constraints, such as, the maximum number of switch operations, voltage restrictions and thermal limitations.

II. Key Tables

Table I, provides a list of the test circuit's electrical components and their count. The capacitor location, size, and type for the test circuit are shown in Table II. Manual and switched capacitors exist in the circuit. Manual capacitors are considered to be always on. Switched capacitors are limited by the utility's existing control and communications equipment and here will have two states, all on and all off.

TABLE I
Components and Count for Test Circuit

Component	**Count**
Buses	948
Nodes	1224
Lines	941
Switches	23
Capacitors	5
Loads	282

TABLE II
Capacitor Location, Size And Type for Test Circuit

Capacitor Bus Number	Size (kVAr)	Type Manual/ Switched
1333	600	Manual
1937	600	Switchable
1292	600	Switchable
1177	1200	Switchable
1015	600	Switchable

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Plug-in Hybrid Electric Vehicle Modeling and Its Impact on North American Electric Distribution Network

Satish Venkata Kasani, *Student Member, IEEE*, Sarika Khushalani Solanki, *Member, IEEE* and Jignesh.Solanki, *Member, IEEE*

Lane Department of Computer Science and Electrical Engineering, West Virginia University Morgantown, WV 26505, USA

vkasani@mix.wvu.edu and skhushalanisolanki@mail.wvu.edu

***Abstract* — The concern of global warming, hiking gas prices and the federal goal of putting one million electric vehicles on the road by 2015 creates opportunities and research challenges for academia and industry. This penetration of electric vehicles in to the electric network causes significant overloading of system components. This poster develops a model for PHEVs and studies its impact on distribution network considering different charging scenarios and levels of penetration of PHEVs with renewable resources and demand response. Analysis is done on IEEE 8500 node system to evaluate the adaptability of the residential distribution network to support PHEVs in the presence of renewable generation and demand response.**

I. Key Figures and Tables

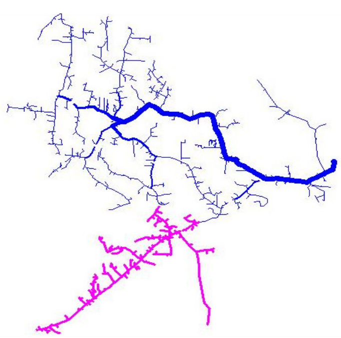


Figure 1. Modifed IEEE 8500 Node System

Table 1. Environmental Assessment of PHEVs (Source: EPRI)

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
PHEV Fleet Penetration Scenario	Low PHEV Fleet Penetration	56%	24%	20%
	Medium PHEV Fleet Penetration	14%	24%	62%
	High PHEV Fleet Penetration	5%	15%	80%

Table 2. Statistics of the feeder data

Elements	Numbers
Nodes	8534
Voltage Regulators	12 Single-Phase
Capacitors	9 Single-phase,1 Three-Phase
Unbalanced Loads(120 V)	2354
3-Winding Service Transformers(7200-120/240	1177
2-Winding Substation Transformer	1
Lines, Cables, Switches	3758

DESIGN OF DECENTRALIZED FUZZY LOGIC LOAD FREQUNCY CONTROLLER-IMPLIMENTAION TO GCC INTERCONNECTED POWER GRID

A. Al-Kuwari*, *student member*, *IEEE,* A. Selawi*, *student member*, *IEEE,* K. Ellithy*, *senior member, IEEE*

*Department of Electrical Engineering
Qatar University
Doha, Qatar
aalkuwari90@gmail.com, ala.selawi@gmail.com., k.ellithy@qu.edu.qa

Abstract— **This project presents an approach for designing a decentralized controller for load frequency control of interconnected power areas. The proposed fuzzy logic load frequency controller (FLFC) is designed to improve the dynamic performance of the frequency and tie line power under a sudden load change in the power areas. The proposed FLFC consists internally of one fuzzy logic controller, designed from the intuitive understanding of the power system's dynamics. The fuzzy logic controller designed in this project calculates the control signal for each area, and it consists of two crisp inputs which are the area control error and its derivative and one output. The output of the fuzzy logic controller is the control input to each area. The proposed FLFC is implemented to the GCC interconnected power grid. Time-domain simulations using MATALB/SIMULINK program were performed to demonstrate the effectiveness of the proposed FLFC. The simulation results show that the proposed FLFC can provide good damping and reduce the overshoot. FLFC also ensures the stability of the power areas for all load demand changes and changes in the areas parameters. Moreover, the proposed controller type is relatively simple and suitable for practical on-line implementation.**

Figure 1 illustrates the SIMULINK block diagram of the two power area in GCC power grid under study (Qatar-Saudi Arabia interconnected systems). Figure 2 show the dynamic performance of one area with the existing conventional controller, the decentralized optimal controller and the designed fuzzy logic controller under sudden changes in the area load.

Keywords-component; Load Frequency Control, State Space, Optimal Control, Decentralized Control, Fuzzy Logic Control

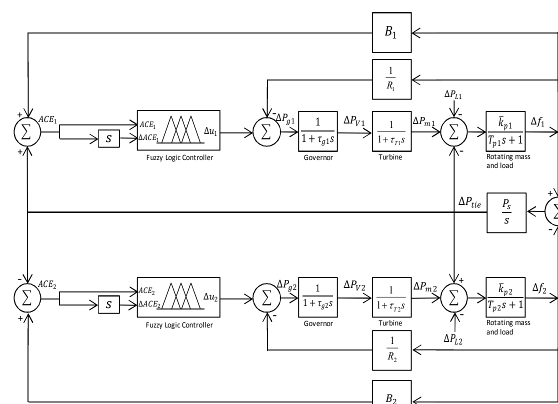


Figure 1. developed block diagram of the two power area

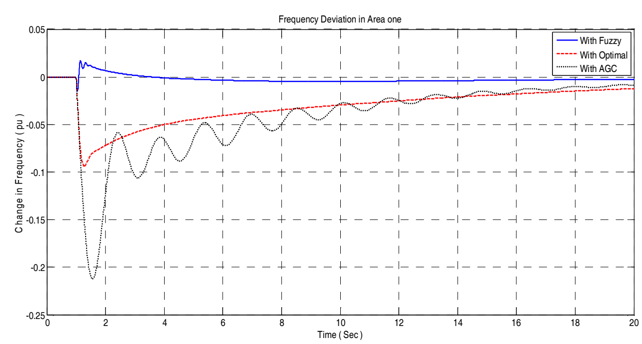


Figure 2. The dynamic performance of area1 with and without the designed FLFC under sudden changes in the area load

Design of Power System Stabilizer Based on Microcontroller for Power System Stability Enhancement

S. Said*, *student member, IEEE*, O. Kahlout*, *student member, IEEE*, K. Ellithy*, *senior member, IEEE*, T. Elfouly**, *member, IEEE*

*Department of Electrical Engineering, **Department of Electrical and Computer Engineering
Qatar University
Doha, Qatar
samer.said@msn.com, o.kahlout.90@gmail.com, k.ellithy@qu.edu.qa, tarekfouly@qu.edu.qa,

Abstract— **The problem of the poorly damped low-frequency oscillations of power systems has been a matter of concern to power engineers for a long time, because they limit power transfers in transmission lines and induce stress in the mechanical shaft of machines. Due to small disturbances, power systems experience these poorly damped oscillations. The stability of power systems is also affected by these low frequency oscillations. These oscillations can be well damped by a proper design of power system stabilizer (PSS). The basic functions of the PSS is to add a stabilizing signal that modulates the voltage error of the excitation system during the disturbance and provides a positive damping to the system which enhance the stability of the system during the disturbances.**

This project presents a design of PSS based microcontroller. Damping torque and eigenvalues analysis are applied to the PSS design. The results of these techniques have been verified by time-domain dynamic simulations. The simulations results are presented for various system disturbances under different system operating points to show the effectiveness and robustness of the designed PSS based microcontroller. The peripheral interface controller (PIC) microcontroller type is used in the PSS design. The optimal sampling time is determined for transferring the s-domain of PSS model to digital (z-domain) model and then it is implemented on microcontroller chip. Moreover, the proposed PSS based microcontroller is relatively simple and suitable for practical on-line implementation, via wide area monitoring system (WAMS) using phasor measurement units (PMUs).

Fig. 1 shows the developed interfacing circuit of MATLAB and PIC18F4520 microcontroller and its hardware while the effectiveness of the designed PSS is shown in Fig. 2.

Keywords-component; PSS, MCU, Damping Torque, PMUs.

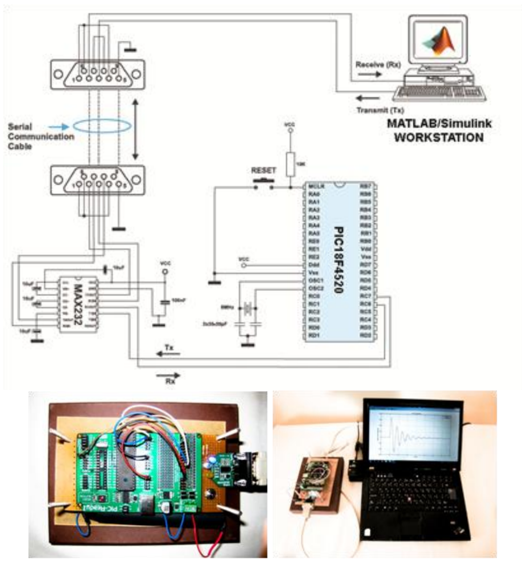


Figure 1. Interfacing Circuit of MATLAB & PIC18F4520 Microcontroller and its Hardware

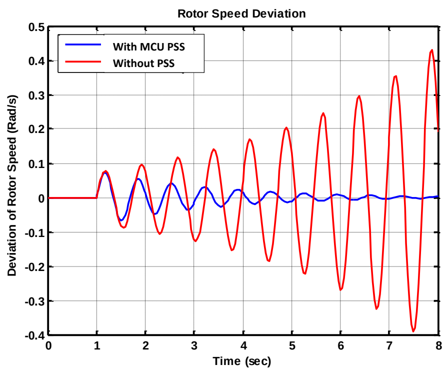


Figure 2. Rotor Speed Deviation Response with & without the designed microcontroller PSS under 1% change in mechanical torque ΔT_m

Wide-Area Measurement Based Nonlinear Control of a Parallel AC/DC Power System

Hua Weng, Zheng Xu, Qingrui Tu
Department of Electric Engineering, Zhejiang University, Hangzhou 310027, Zhejiang Province, China
Email: wenghua@zju.edu.cn; xuzheng007@zju.edu.cn; qingrui.tu@gmail.com

***Abstract*—the supplementary control modulation of the DC transmission line can provide damping torque to generator rotor oscillations for AC/DC power systems. This paper utilizes exact linearization technique to model a parallel AC/DC power system, and establishes a nonlinear control strategy for the supplementary control modulation of the DC transmission line with the wide-area measurement data. The exact linearization technique proposed in this paper utilizes a feedback of the wide-area measurement variables to avoid establishing complicated algebraic equations, which saves a lot of work in controllers designing. The method proposed in this paper is independent on the operation point of the AC/DC system, which means that it is capable of enhancing system performances for various system operating conditions. Simulation results show that the nonlinear controller of the DC transmission line with the wide-area measurement signals makes system oscillations decay quite well for various system operating conditions, while the linear controller shows less robust.**

I. Key Equations

The differential algebraic equations of a parallel AC/DC power system can be described by

$$\dot{\delta}_{12} = \omega_{12} \tag{1}$$

$$\dot{\omega}_{12} = \frac{\omega_0}{2H}(-P_e - \frac{D}{\omega_0}\omega_{12} + P_m) \tag{2}$$

$$\dot{P}_{dc} = \frac{1}{T_d}(-P_{dc} + P_{dcref} + u_1) \tag{3}$$

$$0 = \mathbf{p}(\delta, P_{dc}, \mathbf{U}, \boldsymbol{\theta}) \tag{4}$$

$$P_e = q(P_{dc}, U_2, \theta_2) = P_L + P_{dc} + P_{ac}(U_2, \theta_2) \tag{5}$$

$$y = \delta_{12} \tag{6}$$

According to the Linear quadratic Regular(LQR) theory:

$$J = \frac{1}{2}\int_0^{\infty}[(\mathbf{z} - \mathbf{z}_{ref})^T Q(\mathbf{z} - \mathbf{z}_{ref}) + Rv^2]dt \tag{7}$$

$$v = -R^{-1}B^T P(\mathbf{z} - \mathbf{z}_{ref}) \tag{8}$$

The optimal supplementary control law of the DC transmission line:

$$\begin{aligned} u_1 &= -T_d\dot{P}_{ac} - (-x_3 + P_{dcref}) \\ &- \frac{DT_d}{2H}(-x_3 - P_{ac} - \frac{D}{\omega_0}x_2 + P_m - P_L) - \frac{2HT_d}{\omega_0}v \\ &= -T_d\dot{P}_{ac} - (-x_3 + P_{dcref}) - \frac{DT_d}{\omega_0}\dot{\omega}_{12} - \frac{2HT_d}{\omega_0}\mathbf{k}(\mathbf{z} - \mathbf{z}_{ref}) \end{aligned} \tag{9}$$

II. Key Figures

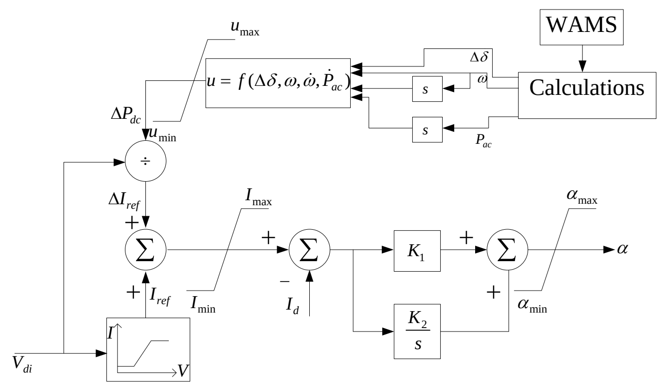


Fig.1. configuration of the supplementary control modulation of the DC system based on WAMS

III. Key Results

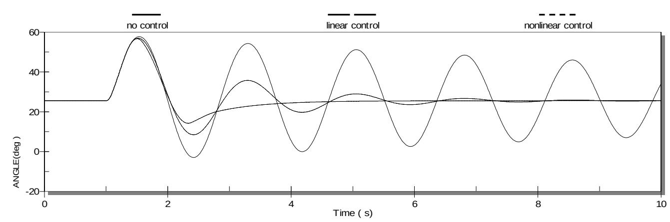


Fig.2 machine rotor angle response

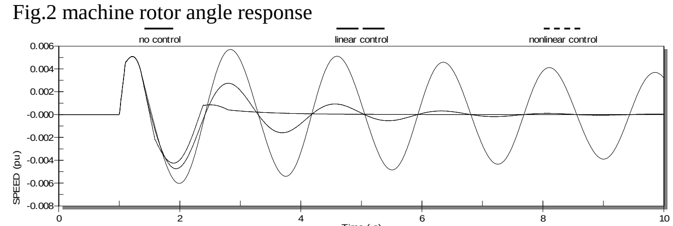


Fig.3 machine rotor angular speed response

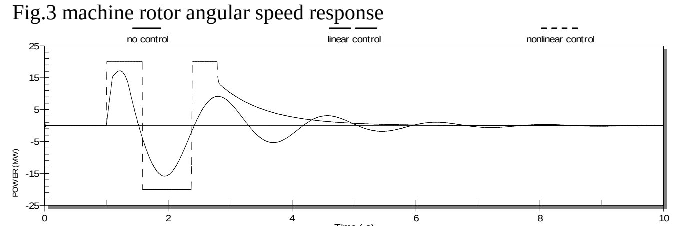


Fig.4 control strategy of DC line supplementary input

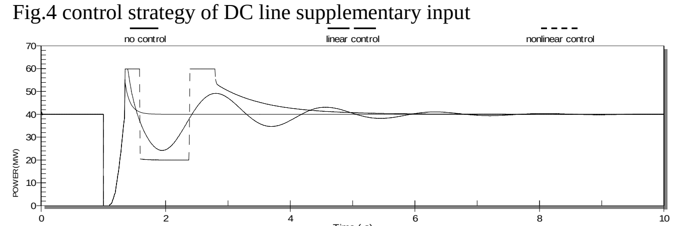


Fig.5 DC line power response

Loading Effects on Nonlinear Observability Measurement for Shipboard Power Systems

Juan C. Jimenez and Chika O. Nwankpa
Center for Electric Power Engineering, Department of Electrical and Computer Engineering, Drexel University
Philadelphia, PA 19104, USA,
Email: jcj26@drexel.edu and con22@drexel.edu

***Abstract*— Existing observability formulations for power systems either evaluate the topology of the system and its embedded sensors or focus on the determination of the state-estimation problem using nonlinear algebraic equations of the system. In either case, the underlying assumption is that the system is at an equilibrium point, and the observability determination relates to the particular equilibrium point in question. Therefore, the observability condition of the system cannot be monitored during perturbations around the system equilibrium points, and existing formulations do not account for the nonlinear dynamics of the system. A simplified model of a shipboard power system that incorporates machines and power electronics converter dynamics is developed and the observability formulation as applied to this system model investigated. A measure of observability is presented through different case studies were loading condition effects are analyzed. This ultimately will lead to the development of system observers for dynamic state estimation and nonlinear control techniques, giving the power system designer/operator the ability to acquire knowledge related to the state of the system during transitions from the desired operating points.**

I. Key Equations

The general model used to investigate power system dynamics is that of the Differential Algebraic Equations (DAE) type in (1):

$$\begin{aligned} F(\dot{x}, x, N) &= Bu \\ p &= h(x, N) \end{aligned} \tag{1}$$

The observability formulation derived from (1) is given in terms of the Jacobian:

$$J_O = \begin{bmatrix} G_x & G_{\dot{x}} & G_w \\ H_x & H_{\dot{x}} & H_w \end{bmatrix} \tag{2}$$

Using (2), the system is observable if the following two conditions hold:

$$1: rank(J_O) = n + rank\begin{bmatrix} G_{\dot{x}} & G_w \\ H_{\dot{x}} & H_w \end{bmatrix} \tag{3}$$

$$2: rank(J_O) \text{ is constant rank on S}$$

The condition number of the observability Jacobian is the metric used to measure how observable the system is and it is defined as:

$$\eta = \frac{\lambda_{\max}(J_o)}{\lambda_{\min}(J_o)} \tag{4}$$

II. Key Figures

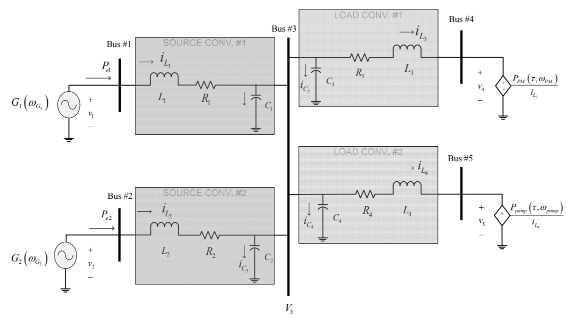


Figure 1. Equivalent dc multiconverter shipboard power system

III. Key Results

$$\begin{bmatrix} \omega_{PM} \\ \omega_{pump} \end{bmatrix} = \begin{bmatrix} \omega^0_{PM} \\ \omega^0_{pump} \end{bmatrix} + \alpha \begin{bmatrix} \Delta\omega_{PM} \\ \Delta\omega_{pump} \end{bmatrix}$$

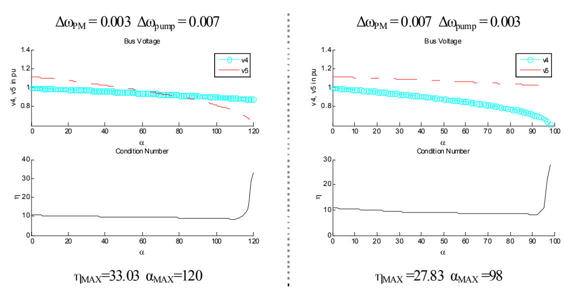


Figure 2. Vα and ηα curves for different loading conditions

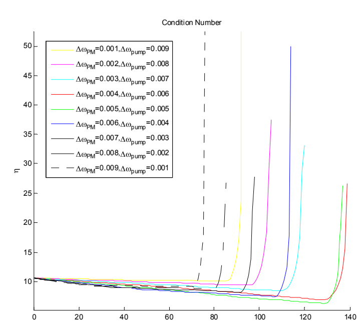


Figure 3. Family of ηα curves

Comparison of Different Methods for Impedance Calculation and Load Frequency Control in Microgrid

Hessam Keshtkar, *Graduate Student Member, IEEE*, Jignesh Solanki, *Member, IEEE* and Sarika Khushalani Solanki, *Member, IEEE*

Lane Department of Computer Science and Electrical Engineering, West Virginia University Morgantown, WV 26505, USA

HKeshtka@mix.wvu.edu and Jignesh.Solanki@mail.wvu.edu

***Abstract*—The accuracy of distribution system analysis depends on precision of component models. One of the components is the distribution line for which different methods have been developed starting with the Carson's equations and approximating the integrals involved. This research work compares these different methods for voltages and line flows by utilizing the impedances obtained in an unbalanced power flow analysis for IEEE 13 node system.**

Proliferation of renewable generation like photovoltaic and wind generation in distribution system creates frequency deviations under islanded operation due to their variable nature. Similarly, a microgrid that is a group of loads and distributed energy sources including renewable sources is subjected to frequency deviations. In this research work, optimized control parameters of renewable sources, Distributed Generation (DG) units, and Energy Storage Systems (ESS) are obtained using differential evolution algorithm for frequency stabilization. Results are presented for a microgrid system with photovoltaic, wind, diesel generators and Energy Storage Systems along with Fuel Cell and Aqua Electrolyzer.

I. KEY EQUATIONS

The original integral equations of Carson's method for impedance calculation are given by

$$Z_s = j\omega \frac{\mu_0}{2\pi} \ln \frac{2h_s}{r} + j\omega \frac{\mu}{\pi} J_s \ (\Omega) \tag{1}$$

$$Z_m = j\omega \frac{\mu_0}{2\pi} \ln \frac{\sqrt{(h_k + h_m)^2 + d^2}}{\sqrt{(h_k - h_m)^2 + d^2}} + j\omega \frac{\mu}{\pi} J_m \ (\Omega) \tag{2}$$

where

$$J_s = P_s + jQ_s = \int_0^\infty \frac{e^{-2h_p\lambda}}{\lambda + \sqrt{\lambda^2 + j\omega\mu/\rho}} \cos(\lambda d)\, d\lambda \tag{3}$$

$$J_m = P_m + jQ_m = \int_0^\infty \frac{e^{-(h_k + h_m)\lambda}}{\lambda + \sqrt{\lambda^2 + j\omega\mu/\rho}} \cos(\lambda d)\, d\lambda \tag{4}$$

For the load frequency control the microgrid system considered in this paper is shown in Fig. 1. Power balance equation for this system is given by

$$P_s = P_{wtg} + P_g + P_{pv} + P_{fc} - P_r \tag{5}$$

II. KEY FIGURES

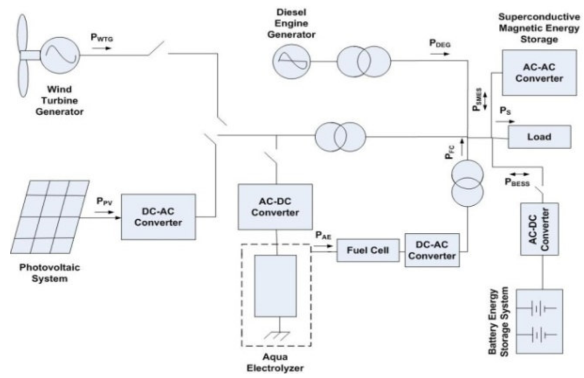


Fig. 1. Configuration of the model microgrid

III. KEY RESULTS

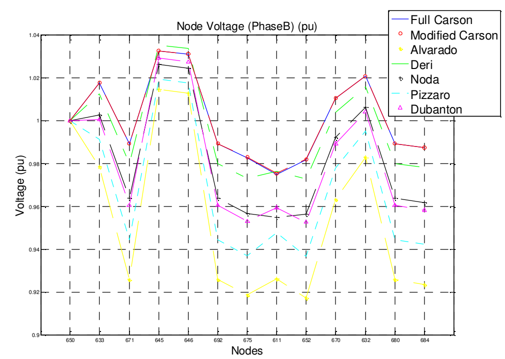


Fig. 2.Power flow results for node voltage in pu with Carson's full and six different approximation methods in IEEE 13-node system.

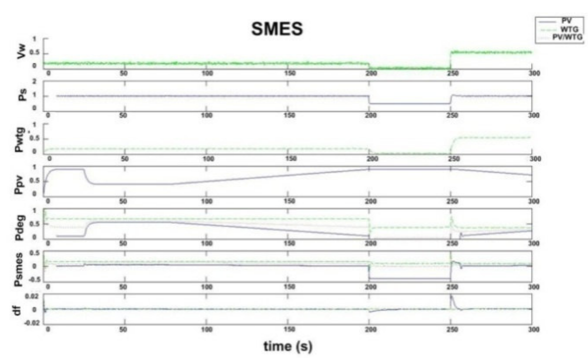


Fig. 3.Power flow and frequency response of one of the microgrid cases.

Arbitrage-Free Energy Storage Options Market Mechanism for Wind Power Integration

Zhenyu Tan, *Student Member, IEEE*, and A. P. Meliopoulos, *Fellow, IEEE*

***Abstract*—In current electricity markets, ISOs are increasing the level of capacity and spinning reserve to compensate for the uncertainty of wind power. Obviously, it is not a sustainable method. Providing adequate power/energy by high power density energy storage devices is becoming more and more realizable. Since wind plants have no obligation to install such an expensive energy storage device, it is better to create an energy storage options market and enable ISOs to manage it. This paper analyzes the economic dispatch problem on both day ahead and real time market considering the energy storage options. For fairness, it is assumed a penalty mechanism if wind generation does not meet its commitment. The ED problem is coordinating with the Energy Storage Device Owners (ESDOs) through bidding curve on options. It is expected that the energy storage options market would significantly reduce the requirement of reserves, thus reducing the cost for overall system. Lastly, this paper gives simulation results based on modifications of IEEE Reliability Test System 1996.**

I. KEY EQUATIONS

Day ahead market modeling

With the introduction of wind power generation, the energy balance equation is shown in equation 1.

$$\sum_{i=1}^{N_T} P_{Gi} + \sum_{i=N_T+1}^{N_T+N_W} P_{Gi} = P_D \qquad 1$$

Where P_{Gi} (i=$N_T+1,\dots N_T+N_W$) represents the output of non-dispatchable wind generation, P_{Gi} (i=1,…,N_T) represents the ith thermal unit generation. In this paper, we assume the new market mechanism allows ISOs to buy call options from energy storage device owners (ESDOs). When the wind power is unable to fulfill the commitment, the operator can exercise the call options to balance the system. At the day ahead market, the unit commitment model for this mechanism is

$$\mathbf{min} \sum_{t=1}^{T}\left(\sum_{i=1}^{N_T} C(P_{Gi})U_{it} + \sum_{i=1}^{N_E} C_B(P_{opt,i,t})B_{it}\right) \qquad 2$$

s.t

$$\sum_{i=1}^{N_T} P_{Gi,t} + \sum_{i=N_T+1}^{N_T+N_W} P_{Gi,t} = P_{D,t} \qquad 3$$

$$\mathrm{P}\left(\sum_{i=1}^{N_T} P_{Gi,t} + \sum_{i=N_T+1}^{N_T+N_W} p_{Gi,t} + \sum_{i=1}^{N_E} P_{opt,i,t}\right) \geq P_{D,t}) \geq 1-\alpha_t \qquad 4$$

$$P_{Gi,min} \leq P_{Gi,t} \leq P_{Gi,max} \qquad 5$$

where: $P_{Gi,t}$ (i=$N_T+1,\dots N_T+N_W$) represents the expected value of $p_{Gi,t}$, $P_{opt,i,t}$ represents the volume of the contract between ISO and the ith ESDO at time t, i.e., the ESDO is responsible for providing active power $P_{opt,i,t}$ if the ISO exercises the option. $1-\alpha_t$ is the probability that the left side of equation (3). U_{it} is 1 if the ith thermal unit is committed at time t and 0 otherwise, B_{it} is 1 if the ISO determines to buy the call option from the ith ESDO. If the option is not exercised, then the ESDO's revenue at time t would be $C_B(P_{opt,i,t})$ (standby cost), otherwise the option would be exercised and the revenue at would be $C_E(P_{opt,i,t})$ (exercise cost). $C(P_{Gi})$ is the cost for the ith thermal generator at time t if the thermal unit is generating $P_{Gi,t}$. The objective is to minimize the cost for thermal units and energy storage call options over time.

Real time market modeling

There are two differences between day ahead market and balancing market: (1) the wind farm would have a much more reliable forecast of available wind power output for the short term (minute to hour) that will determine the needs of the balancing market; (2) the operator has the information that he needs to determine whether the options should be exercised. The objective function for real time market is:

$$\mathbf{min} \quad \sum_{i=1}^{N_T} C(P_{Gi})U_{it} + \sum_{i=1}^{N_E} C_B(P_{opt,i,t})B_{it} + \sum_{i=1}^{N_E} C_E(P_{opt,i,t})E_{it} \qquad 6$$

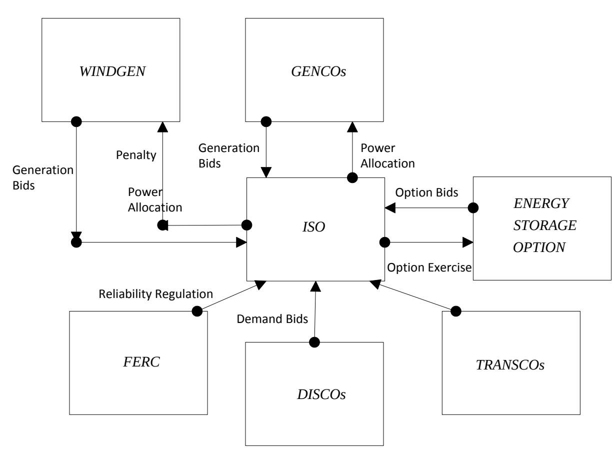
E_{it} is the controllable variable, it is 1 if at time t the ISO exercises the option and exchange active power $P_{opt,i,t}$ with ESDO, and 0 otherwise. The constraint is:

$$E_{it} \leq B_{it} \quad \text{i=1,2…}N_E$$

Other constraints are the same. In order to get $C_E(P_{opt,i,t})$ and $C_B(P_{opt,i,t})$, a bidding curve should be provided by ESDOs, whose optimal bidding strategy is to maximize the revenue.

For fairness, the market design also considers the wind plant penalty if it fails to meet the commitment, i.e., penalty price times the short of power provided by wind farm.

The overall market design for storage is:



Inventory and Evolution of Member Communication in a Volunteer Organization

Helping PES Better Disseminate Information to its Members

Laurie Stewart [#]*,Dr. Sarah Riforgiate[#], Dr. Noel N. Schulz*
Department of Communication Studies[#]
Department of Electrical & Computer Engineering*
Kansas State University
Manhattan, KS
lmstewar@ksu.edu

Abstract— IEEE PES is a growing organization that seeks "to be the leading provider of scientific and engineering information on electric power and energy for the betterment of society, and the preferred professional development source for our members" (PES website). To accomplish this mission, it is critical that communication is effective and clear between staff, volunteer leadership, and members. As PES has grown and changed over the years, its communication practices have evolved as well. A shift from relying on face-to-face communication to virtual communication has made identifying and implementing new technology a necessity if the organization wants to continue to thrive. Email, conference calls, online communities, Twitter, Facebook, and LinkedIn are among the technologies used in PES. Understanding how and why people accept new technology gives PES an advantage in selecting which technology they should adopt and implement. Also, understanding how people engage and implement technology allows PES to share information with their members and encourage greater participation. To address these concerns and questions, in 2012, the IEEE PES President, Dr. Noel Schulz and the PES Governing Board have decided to investigate best communication practices to evaluate and improve PES. This poster presentation highlights communication research and theory that is useful in improving how PES and members interact. Specifically, this poster highlights the best practices for communication as they relate to volunteer organizations like PES. Preliminary findings on the use of new technologies among PES members and practical implications for technology use will be explored.

Keywords- *communication; volunteer organization; technology*

Network Robustness of Large Power Systems

Ricardo Moreno
School of Engineering, Universidad de Los Andes,
Bogotá, Colombia
ri-moren@uniandes.edu.co

Alvaro Torres
School of Engineering, Universidad de Los Andes,
Bogotá, Colombia
atorres@uniandes.edu.co

***Abstract*— while the topology information is, in principle, simple to understand, the determination of a global robustness criterion is more complicated. This paper provides a global criterion to quantify the topological robustness of power system grids based on the development of a graph theoretic approach to capture the topological structure of power system grids using appropriately matrices that identify properties of power networks. The robustness criterion deduced in this paper provides useful information to deal with a range of problems in the context of transmission system expansion.**

Keywords:robustness, graph theory, complex networks.

I. Introduction

The backbone of the power system grid is the transmission system that allows the interconnection between demand and generation resources to perform the function of supplying electric energy. This paper is focused on the network topology in order to quantify the global robustness of the power system grid. Topological properties are deduced from a precise mathematical formulation using graph theoretical concepts.

In recent years, the study of complex networks has attracted a lot of attention in the research community [1], [2]. The study of the power system grid structure allows the identification of complex network characteristics and to have a deeper insight in the behavior of the networks.

While the topology information is, in principle, simple to understand, the determination of a global robustness criterion is more complicated. A first problematic issue lies in the appropriately definition of robustness considering different topological structures. The structure of each power system network in each is determined by two factors, first, the location of generation centers (and the inclusion of dependent location resources as renewables resources), second, the location of load centers such as several main cities.

This paper provides a global criterion to quantify the robustness of power system grids based on the development of a graph theoretic approach to capture the topological structure of power system grids using appropriately matrices that identify topological properties of power networks. The focus of this paper is on the spectral information of power system networks based on the topological characterization of it. Spectral graph theory is a mathematical study of the spectral of matrices that allow the mathematical characterization of networks such as connectivity, the diameter of a graph, clustering coefficients, the expansion, the resilience, the betweenness among nodes and some more. The spectral information deduced from the topological characterization serves to deal with a range of problems.

II. Power System Network and its Associated Graph

We focus on the quantification of the robustness of the power system networks considering the topological structure. For this purpose, it suffices consider the graph model of the power system because it provides a convenient tool for the investigation of structural properties. To make the analysis concrete, we consider a power system consisting of $N+1$ buses and T lines. We denote by $\mathcal{V}=\{0,1,...,\mathrm{N}\}$ the set of network nodes and by $\mathcal{L}=\{\ell_1,\ell_2,...,\ell_\mathrm{T}\}$ the set of transmission lines and transformers that connect the elements in the set $\mathcal{V}$. We associate the undirected graph $\mathcal{G}=\{\mathcal{V},\mathcal{L}\}$ with the power system network. The graph $\mathcal{G}$ has the set of vertices $\mathcal{V}$ and the set of edges $\mathcal{L}$.

III. Prepare Your Paper Before Styling

To start out, since robustness is closely related to connectivity of the network it's relevant to include the connectivity property to define a quantification parameter of the robustness. The connectivity property is important but not enough to define precisely the robustness because, in fact, the power system grid is connected, probably weakly connected, and then the paths between some of the nodes may be too long to provide adequate connection. Therefore, the accurately definition of robustness includes a parameter about the extension of the network. For a graph $\mathcal{G}$ associated with the power system grid with $N+1$ and T lines, the average degree is given by,

$$\mathrm{d}_{\mathrm{adg}}=\frac{2\mathrm{T}}{(\mathrm{N}+1)}. \tag{3}$$

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[2] D.J. Watts. *Small World, The Dynamics of Networks between Order and Randomness*. Princeton University Press, Princeton, New Jersey, 1999.

High Voltage Power Electronic Technologies for Renewable to Grid Integration

Brandon M. Grainger, *Student Member, IEEE* and Gregory F. Reed, *Member, IEEE*
Center for Energy / ECE Department, University of Pittsburgh, Pittsburgh PA, 15213, USA
Email: bmg10@pitt.edu and reed5@pitt.edu

***Abstract* – This article briefly describes the poster to be submitted on High Voltage DC and FACTS technology with application to the current CREZ project in Texas for the 2012 IEEE PES T&D show in Orlando, Florida.**

I. Introduction

The integration of conventional generation sources, (including coal, petroleum, and natural gas), green generation sources like nuclear energy, and renewable sources such as solar and wind power, presents technological obstacles to the current grid system design and operating practices. The focus of the poster will be to characterize these obstacles and present solutions that derive from the integration of transmission technologies, including FACTS compensation devices for AC infrastructure expansion and both conventional and voltage-source converter based HVDC transmission technology. This poster provides a high level treatment of these existing high voltage power electronic technologies, discussing their purpose, and the benefits these devices and systems can provide for integrating generation resources.

Texas employs a number of transmission technologies to ensure system reliability and control power flows. The state's power grid is completely isolated from the remainder of the U.S. and Mexico through the use of HVDC interconnections. This allows for controlled power exchange, while isolating the state from contingencies in AC systems elsewhere. Within the state, transmission consists mostly of high voltage AC lines with some amount of FACTS compensation to ensure power quality and voltage stability.

In July 2007, the Texas Public Utility Commission approved plans for the expansion of the state's transmission networks. These plans, shown in Fig. 1, include enough transmission capacity to transfer 25GW of new generation across the state. In addition, the state's legislators have worked in conjunction with the Electric Reliability Council of Texas (ERCOT) to identify and designate eight Competitive Renewable Energy Zones (CREZs) within the state. These zones have been shown to be highly suitable areas for the development of renewable energy generation. Texas is concurrently committed to the expansion of its transmission grid and supporting technologies.

II. General Poster Description

The poster itself is organized into six distinct regions. The first sector provides a premise for high voltage power electronic research including HVDC and FACTS technologies. The second sector below the first provides a brief description of the various challenges associated with integrating renewable resources including ideas focused on voltage instability, reactive power consumption, subsynchronous resonance, and transporting distant resources.

The center of the poster provides various solutions for the latter problems previously mentioned. One area provides a high level overview of the two main types of HVDC technology including current source converter based and voltage sourced converter based equipment. General benefits are listed as well as illustrations. The second area in the center of the poster contains general benefits of FACTS technology including efficient installations, increased system capacity, enhanced system reliability, and improved system controllability. General illustrations of an SVC and STATCOM are also provided.

Finally, the last two sections on the far right of the poster contain a few high level illustrations of the actions taking place as a result of the CREZ project. Specifically the amount of wind generation (about 10 GW) to be added into the electric power system in Texas as well as the amount of new transmission (around 2300 miles) to be added including series and shunt dynamic compensation.

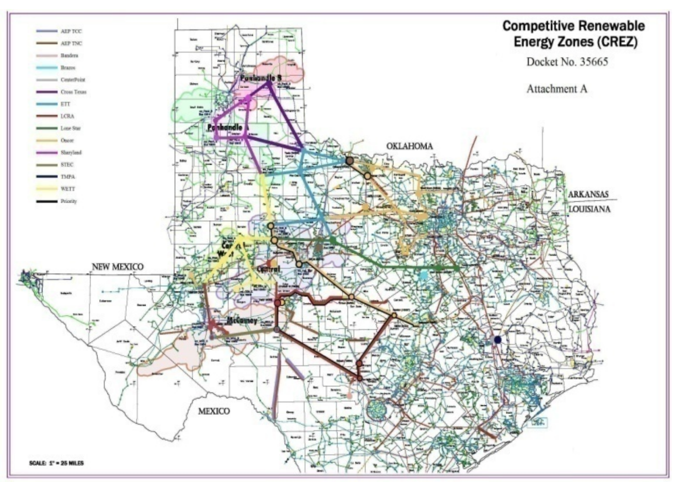

Fig. 1. Planned Texas transmission additions to accommodate primarily new renewable generation resources

The poster header contains an appropriate title, authors, as well as appropriate logos of organizations which have supported this work as well as school logos. The background of the poster is the valve hall of a HVDC installation.

III. Biographies

Brandon M. Grainger (M'2006) is a Ph.D. student and **Gregory F. Reed** (M'1985) is the Director of the Electric Power Initiative, Associate Director of the Center for Energy, and Professor of Electric Power Engineering in the Swanson School of Engineering at the University of Pittsburgh.

This work was supported by funding from the PA DCED BFTDA. B.M. Grainger and G.F. Reed are with the Department of Electrical & Computer Engineering and the Center for Energy, in the Swanson School of Engineering at the University of Pittsburgh, Pittsburgh, PA 15210 USA (e-mails: bmg10@pitt.edu, reed5@pitt.edu)

System Identification based VSC-HVDC DC Voltage Controller Design

Ling Xu, *Student Member, IEEE,* Lingling Fan, *Senior Member, IEEE,* and Zhixin Miao, *Senior Member, IEEE*

***Abstract*—VSC-HVDC system is adopted more and more for its flexible control capability. DC voltage control can affect fault ride through capability. System identification based DC voltage control will be designed in this paper. Simplified linear model of the open-loop system will first be extracted using Matlab System Identification Toolbox. Based on such model, controller specifications of the DC voltage control can be met by proper design. The contribution of this paper is to develop an experiment approach to obtain input/output dynamic responses for the open loop system, where the d-axis current reference is the input and the dc-link voltage is the output. To avoid system instability due to power mismatch, the d-axis current reference is computed from the power transmitted divided by the ac voltage magnitude. Simulation demonstrates the accuracy of the estimated model and the effectiveness of the control.**

I. Key Equations

The DC link model extracted based on System Identification Toolbox is:

$$G(s) = \frac{v_{dc}(s)}{i_d(s)} = \frac{4.848s^5 - 8.438e6s^4 - 2.659e10s^3}{s^5 + 6.342e5s^4 + 6.445e9s^3} \quad \frac{-6.69e15s^2 + 2.843e18s + 1.02e18}{+8.727e14s^2 + 4.292e16s + 3.781e16} \tag{1}$$

The DC link voltage controller is:

$$C(s) = \frac{K_p s + K_i}{s} \tag{2}$$

II. Key Figures

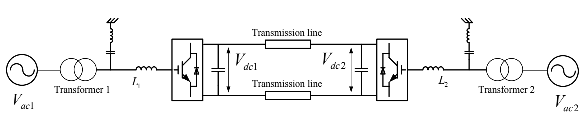

Fig. 1. Topology of a two terminal VSC-HVDC system.

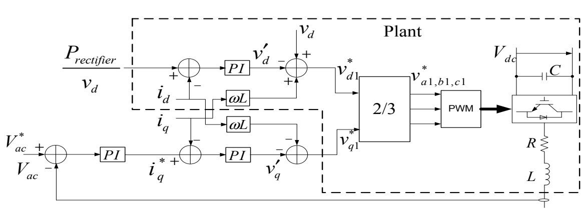

Fig. 2. Detailed controller of the inverter station.

III. Key Results

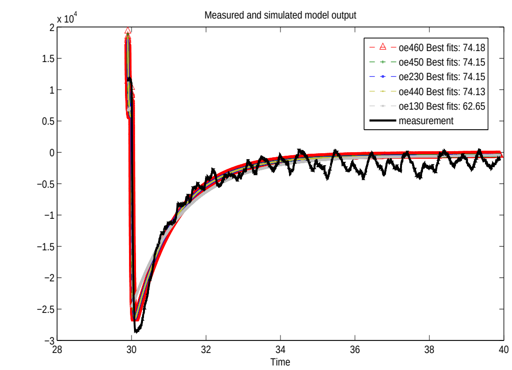

Fig. 3. Identified DC-link models with various orders.

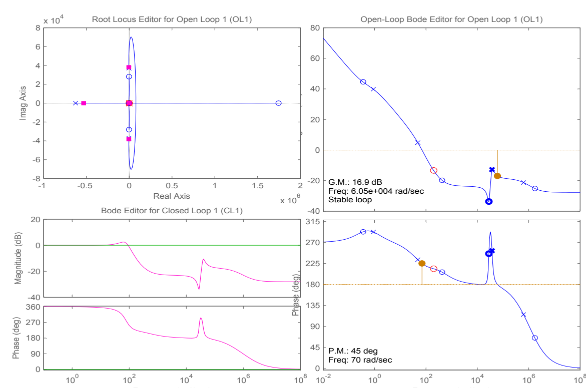

Fig. 4. Controller characteristics plot of identified model.

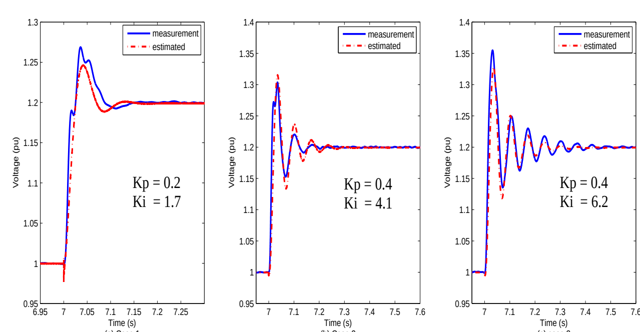

Fig. 5. Validations of identified model with its controller under different combinations of parameters.

L. Xu, L. Fan and Z. Miao are with Department of Electrical Engineering at University of South Florida, Tampa FL (Emails: lxu@mail.usf.edu; linglingfan@usf.edu; and zmiao@usf.edu).

Assessing Merits of GaN for Next Generation Power Electronics

Raghav Khanna, Raymond P. Kovacs, *Student Members, IEEE*,
William E. Stanchina and Gregory F. Reed, *Members, IEEE*
Center for Energy / ECE Department, University of Pittsburgh, Pittsburgh PA, 15213, USA
Email: rak23@pitt.edu

***Abstract* – This article describes the poster developed at the University of Pittsburgh pertaining to the merits and advantages of GaN devices for next generation power electronics. This will be submitted for the 2012 IEEE PES T&D show in Orlando, Florida.**

I. Introduction

The Gallium Nitride (GaN) Heterostructure Field Effect Transistor (HFET) poses as a potential solution to address the technological limits associated with current state of the art switching devices for power electronics. Due to its wide bandgap of 3.4eV, GaN HFETs can sustain relatively adequate performance under high switching frequency and high temperature applications. The high switching frequency capability of GaN HFETs enables their implementation in power converters with smaller filters thereby optimizing the power density of the converter, which is particularly useful in power converters utilized in photovoltaic systems. Further, the ability of GaN HFETs to sustain high temperature applications facilitates the distribution of solar power. For example, it has been reported that 80% of system downtime for power converters utilized in transferring solar power is attributable to the converter component's intolerance to harsh weather conditions. The ability of GaN HFETs to sustain these weather conditions makes it an ideal candidate to replace current state of the art technologies. This poster presents various performance metric benchmark analyses (performed by the authors listed above) that demonstrate the potential advantages of GaN HFETs for next generation power electronics.

II. General Poster Description

The top half of the poster contains three performance metric benchmark figures which compare GaN with current state of the art switching devices for power electronics. From left to right, the first performance metric illustrates the high breakdown voltage of GaN devices with respect to the device's cutoff frequency. In this analysis, the authors utilized the Johnson Figure of Merit (JFOM) for three similarly rated GaN, SiC and Si devices to derive the breakdown voltage versus cutoff frequency characteristic of each device. The derivation of these characteristics for each device began with previously reported device characteristics based on the transistor's gate-length and cutoff frequency. Using the JFOM for each device, the gate-length/cutoff frequency characteristic of each device can be mathematically manipulated to derive the breakdown voltage/cutoff frequency characteristic of the device. This is due to the fact that the JFOM assesses the high frequency performance of high power devices. From the figure, at a cutoff frequency of 1GHz, GaN has the potential of roughly 5X higher operating voltage than SiC and 30X higher than Si. The second figure on the top half of the poster (middle) is a performance metric reported in various literature sources, particularly by the device company International Rectifier. This figure demonstrates the relatively low specific on-resistance of GaN at high breakdown voltages. Further, this figure illustrates that GaN technology has not yet reached its theoretical limit thereby indicating the significant upside potential of GaN for enhancing next generation power electronics. The third figure on the top half of the poster is a benchmark analysis performed by the authors that compares the efficiency of a GaN based boost converter versus Si/SiC based converters. The simulation performed in MATLAB showed that the GaN based converter is more efficient compared to the Si/SiC converters at any device duty cycle.

The bottom half of the poster demonstrates our equivalent device model development of GaN and Si devices in SaberRD (Synopsys). In order to adequately simulate the devices' switching performance, the parasitic nonlinear junction capacitances of each device must be modeled as a function of the drain-source voltage (in addition to the device current-voltage characteristics not shown). The capacitance-voltage characteristics for two similarly rated GaN and Si devices were modeled using reported data from the literature. From the figures, the modeled characteristics are in adequate agreement with the data reported in the literature. Once the current-voltage and capacitance-voltage characteristics of the device are adequately modeled, the switching performance of the device can be modeled in switching test circuits. The results of this switching performance benchmark analysis are found in Table I. The four switching parameters that were simulated were device turn-on loss, device turn-off loss, device turn-on rise time and device turn-off fall time. The GaN device is superior to the Si device in each of the four switching metrics simulated.

TABLE I
Benchmark Switching Parameters for Devices

Device	Turn-on Energy Loss (nJ)	Turn-off Energy Loss (nJ)	Turn-on Rise Time (ns)	Turn-off Fall Time (ns)
GaN	419	117	1.37	6.03
Si	760	197	2.9	7.85

III. Biographies

Raghav Khanna and **Ray Kovacs** are Ph.D. students working for **Dr. William Stanchina** and **Dr. Gregory F. Reed** as part of the Electric Power Initiative at the University of Pittsburgh. Dr. Stanchina is the department chair of the electrical and computer engineering department at the University of Pittsburgh. Dr. Reed is the Associate Director of the Center for Energy, and Professor of Electric Power Engineering in the Swanson School of Engineering at the University of Pittsburgh.

This work was supported by funding from the PA DCED BFTDA. All authors are with the Department of Electrical & Computer Engineering and the Center for Energy, in the Swanson School of Engineering at the University of Pittsburgh, Pittsburgh, PA 15210 USA (e-mails: rak23, reed5@pitt.edu)

Short Circuit Analysis of Induction Machines – Wind Power Application

Dustin F. Howard, *Graduate Student Member, IEEE*, Travis M. Smith, *Senior Member, IEEE*, Michael Starke, *Member, IEEE*, and Ronald G. Harley, *Fellow, IEEE*

***Abstract*--The short circuit behavior of Type I (fixed speed) wind turbine-generators is analyzed in this paper to aid in the protection coordination of wind plants of this type. A simple network consisting of one wind turbine-generator is analyzed for two network faults: a three phase short circuit and a phase A to ground fault. Electromagnetic transient simulations and sequence network calculations are compared for the two fault scenarios. It is found that traditional sequence network calculations give accurate results for the short circuit currents in the balanced fault case, but are inaccurate for the un-faulted phases in the unbalanced fault case. The time-current behavior of the fundamental frequency component of the short circuit currents for both fault cases are described, and found to differ significantly in the unbalanced and balanced fault cases.**

I. Key Equations

The RMS current in an induction generator after a three phase short circuit at the generator terminals is given by

$$\left|\vec{I}(t)\right| = \frac{I_t}{\sqrt{2}} e^{-t/T_t} \qquad (1)$$

Thus the short circuit currents eventually decay to zero according to time constant T_t. The RMS short circuit current after an unsymmetrical fault at the generator terminals is of the general form given by

$$\left|\vec{I}(t)\right| = \left|\frac{I_t}{\sqrt{2}} e^{-t/T_t} e^{j\theta} + \frac{I_{ss}}{\sqrt{2}} e^{j\varphi}\right| \qquad (2)$$

Where the first term corresponds to a transient component which decays to zero and the second term is a steady state component which remains after the fault since one or more of the phases remains unfaulted during an unsymmetrical fault. For short circuit studies and protection planning, it is important to know the parameters of the equations above to estimate the fault currents expected to flow in a wind farm of this type. One method for calculating the initial short circuit currents is building sequence network circuits such as that shown in Fig. 1, which corresponds to a single wind turbine-generator under a single line to ground fault at its terminals. The validity of these type of calculations depend on using the correct *V'* and *X'* in the circuits for the induction generator.

This work has shown that the initial short circuit calculations for unbalanced faults using sequence networks give some error in the current calculations. For example, comparisons between the initial short circuit currents calculated and simulated for a three phase short circuit are shown in Fig. 2. A good match between the calculated and simulated results is seen. However, shown in Fig. 3 are similar calculations for a single line to ground fault. Because of the error in the initial short circuit calculation, the calculations show some error from the simulation results. Therefore, more accurate sequence network models are needed to limit these errors. This work has shown that phase current errors can be as high as 15%, which could potentially result in error in protection relay settings.

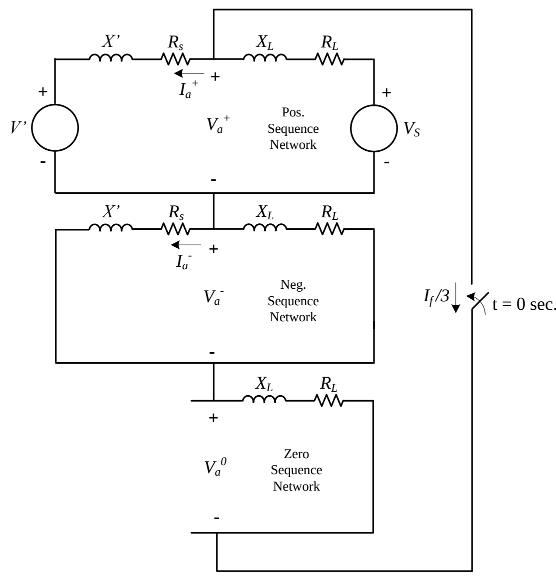

Fig. 1. Sequence network for single line to ground fault at induction generator terminals.

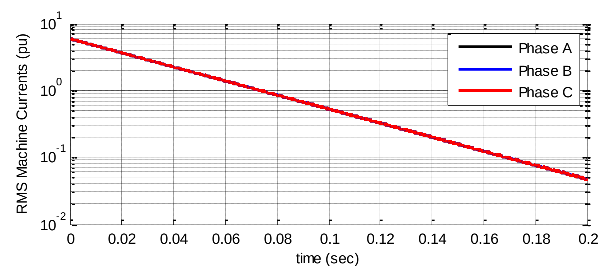

Fig. 2. RMS machine current magnitude over time for a three phase short circuit occurrence at t = 0 (solid = simulated, dashed = calculated).

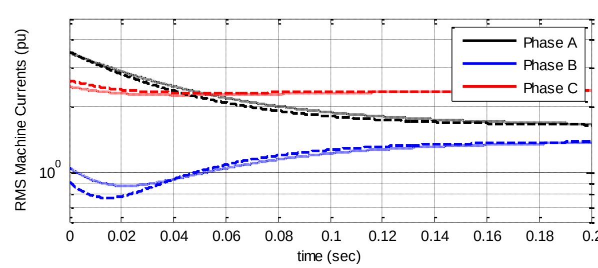

Fig. 3. RMS machine current magnitude over time for a phase A to ground short circuit occurrence at t = 0 (solid = simulated, dashed = calculated).

Design of a Governor and Voltage Regulator for a Laboratory Generator

Anil KC and Satish J. Ranade

Klipsch School of Electrical and Computer Engineering,
New Mexico State University
Las Cruces, NM 88003-8001, USA
E-mail: {kc,sranade}@nmsu.edu

***Abstract*—Customer driven microgrids are small distributed energy resources connected to distribution feeder that provides electricity to customer premises. The penetration of these modular resources provides benefits such as availability of power supply during disturbances, islanded operation and utilization of renewable resources. One of the important challenges of microgrid is voltage and frequency control during grid connected or islanded operation. Microgrids ought to operate stable under faults and various disturbances. To address these challenges and develop solutions a governor and a voltage regulator design have been proposed and widely used to aid the development of microgrid prototype in the laboratory.**

A Governor is a proportional controller and a droop speed control scheme is implemented. Governor changes the turbine speed reference and controls the amount of energy pushed into the prime mover. An Automatic Voltage Regulator automatically adjusts the generator field current to maintain a desired terminal voltage. The El Paso Electric Power Lab equipped with Lab Volt machines is used for the operation of DC motor and synchronous generator. In particular, motor-generator can be coupled together to create a laboratory microgrid.

The turbine or prime mover is simulated using a DC motor. A power electronics based governor is implemented using DC-DC buck converter and PWM controller is generated from the Arduino microcontroller based on Atmel processor. Due to the inherent droop characteristic of DC motor a current feedback is provided so that it behaves as prime mover. The PWM is fed to the buck converter which drives the shaft of the DC motor (prime mover). A PI controller is implemented on software to make the motor current follow the demanded current from speed controller.

A similar hardware design was implemented using a DC-DC buck converter and PWM controller generated from the Arduino microcontroller. The Lab Volt generator bench is equipped with a rotor circuit that takes DC inputs. A close loop current controller feedback is also provided to make the actual rotor current follow a reference current generated from the close loop voltage feedback. A PI controller is designed on the software to make the actual and required current equal under steady state conditions.

I. Key Figures

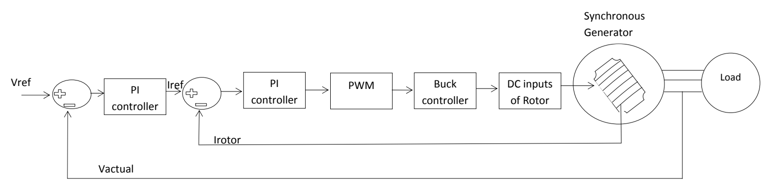

Fig. 1. Block Diagram of Voltage Regulator.

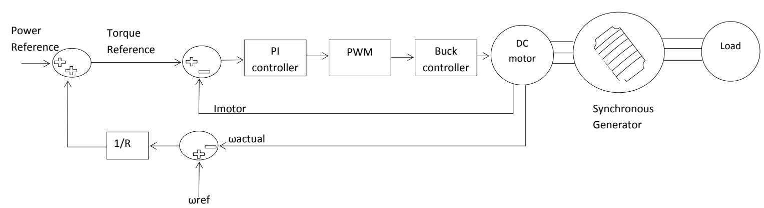

Fig. 2. Block Diagram of Governor.

Developing PHEV Charging Load Profile Based on Transportation Data Analyses

Zahra Darabi and Mehdi Ferdowsi
Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, 39762, USA
Emails: *zd8r4@mst.edu, ferdowsi@mst.edu*

Abstract— Plug-in hybrid electrical vehicles (PHEV) technology is one of the most promising solutions for reducing petroleum consumption. A PHEV can be recharged through a plug connected to the electric power grid. Therefore, PHEVs increase the load of the electric power grid. Consequently, there are concerns about their negative impact on power generation, transmission, and distribution installations. PHEV charging load profile (PCLP) is an approach to examine the aggregated impact of PHEVs on the power grid; however developing a PCLP requires some basic data which is not easily available. This paper focuses on the information required for generating a PCLP and proposes answers to three key questions i) when does each vehicle begin to be charged, ii) how much energy is required to charge it, and iii) what level of charge is available. The data obtained from transportation surveys, as sources for the information on vehicles and trips characteristics, are used in this work to extract applicable information which leads to the development of a PCLP.

I. Key Data

Three key questions:

- when each vehicle begins to be charged,
- how much energy is required to charge it,
- what level of charge is available**.**

Statistical Study:

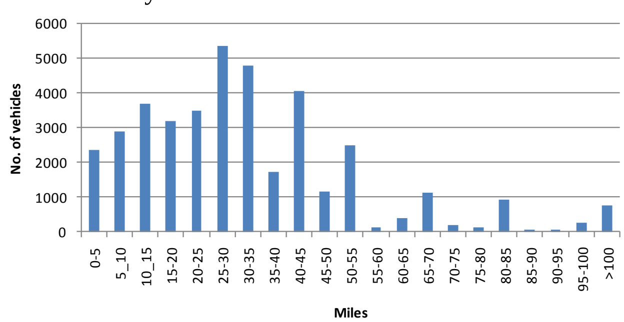

Fig. 1. Number of vehicles and miles driven

TABLE I
Number and Percentage of Each Type of Vehicles in NHTS

Vehicle Type	1	2	3	4
Number	23,818	4,686	5,139	5,536
Percentage	60.85%	11.94%	13.1%	14.11%

TABLE II
Energy Requirement for Four Types of PHEV20

Type	Total kWh	kWh/mile
Compact Sedan	6.51	0.3255
Mid-size Sedan	7.21	0.3605
Mid-size SUV	8.75	0.4375
Full-size SUV	10.15	0.5075

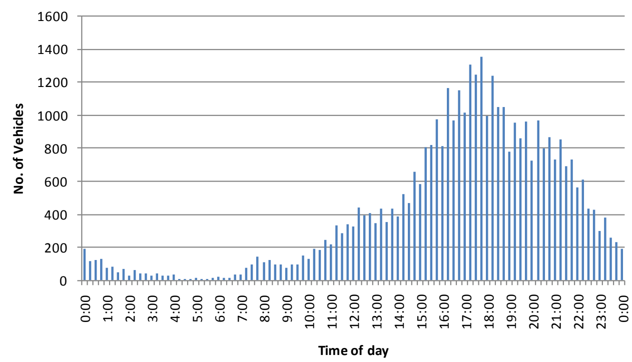

Fig. 2. Number of vehicles arriving each hour

TABLE III
Charging Levels

Level / Reference	1	2	3
EPRI- NEC	120VAC, 15A (12A) 1.44 kW	240VAC, 1phase, 40A	480VAC, 3phase, 60 to 150 kW
SAEJ1772	120VAC, 12A, 1phase 1.44 kW	208-240VAC, 1phase 32A, 6.66-7.68kW	208-600VAC, 3phase, 400A, >7.68 kW

II. Key Results

Policy 1: Vehicles, arriving between 0:00 and 16:00, get charging level of 7.68 kW and the rest get that of 1.4 kW

Policy 2: Vehicles, arriving after 16, are charged 2 hours later

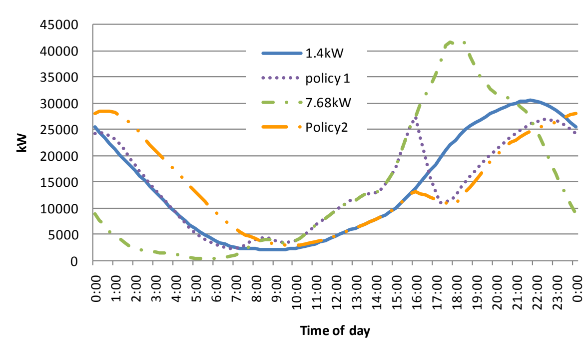

Fig. 3. Comparing PCLPs of PHEV30 based on charging levels of 1.4 and 7.68 kW and policies 1and 2

Time Domain Simulation of a Three-Phase Cycloconverter for LFAC Transmission Systems

Yongnam Cho, Student Member, IEEE, George J. Cokkinides, Senior Member, IEEE, and
A. P. Meliopoulos, Fellow, IEEE

***Abstract*—This paper presents an advanced time domain model of a three-phase cycloconverter for Low Frequency alternating Current (LFAC) transmission systems. The model is based on the quadratic integration method. The proposed time domain model has been demonstrated to be accurate, robust, and reliable as compared to other integration methods such as the trapezoidal integration. The goal of this paper is to present a realistic model of a three phase cycloconverter and to integrate this model in an advanced time domain simulation method for LFAC systems. Examples of wind farms with LFAC transmission systems are presented. Furthermore, the proposed method is expected to be used for transient stability studies, harmonic studies, and fault studies of wind farms with LFAC transmission systems.**

I. KEY EQUATION

The mathematic form of the quadratic integration is illustrated to the set of general differential equations: $\frac{dx}{dt} = Ax + Bu$ (1)

By application of the quadratic integration, the algebraic companion form is denoted as follows:

(2)

$$\begin{bmatrix} \frac{h}{24}A & I-\frac{h}{3}A \\ I-\frac{h}{6}A & -\frac{2h}{3}A \end{bmatrix} \cdot \begin{bmatrix} x(t) \\ x_m \end{bmatrix} = \begin{bmatrix} \left(I+\frac{5h}{24}A\right) \\ \left(I+\frac{h}{6}A\right) \end{bmatrix} \cdot x(t-h) + \begin{bmatrix} -\frac{h}{24}B & \frac{h}{3}B \\ \frac{h}{6}B & \frac{2h}{3}B \end{bmatrix} \begin{bmatrix} u(t) \\ u_m \end{bmatrix} + \begin{bmatrix} \frac{5h}{24}B \\ \frac{h}{6}B \end{bmatrix} \cdot u(t-h)$$

where h is the integration time step (interval), I is the identity matrix, and t_m is the mid-point of the integration time step $[t\text{-}h, t]$.

II. MODLE OF CYCLOCONVERTER

This section presents the application of the quadratic integration to a three-phase six-pulse cycloconverter. This converter consists of three physical components: three-phase isolation transformers, electrical switches, and circulating current circuits as Figure 1.

These physical components are modeled separately by state differential equations, and the application of quadratic integration to the equations leads to an algebraic companion form in terms of voltages and currents at two future points in time. Standard nodal analysis methods are used to obtain the algebraic companion form of a three phase six-pulse cycloconverter from the component algebraic companion forms.

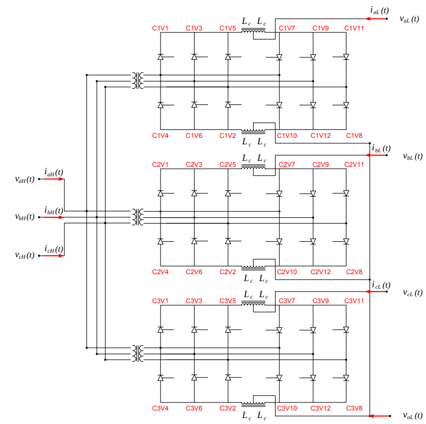

Figure 1. Three phase six-pulse cycloconverter.

III. SIMUALATION

The methodology is demonstrated with an example system that includes a LFAC transmission system, which is connected to the equivalent source of an offshore wind farm. The simulations on the LFAC transmission system demonstrate the properties of the quadratic integration over a complex switching subsystem, and realistic three phase six-pulse cycloconverter model can be used for transient stability studies for several applications of LFAC transmission

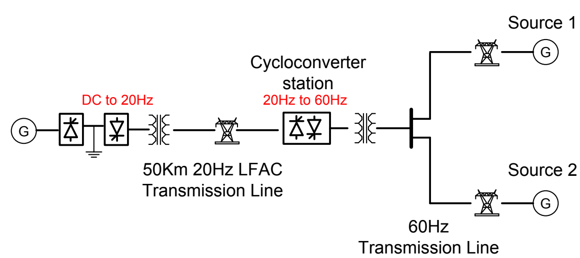

Figure 2. A LFAC example system

Simulation results show the three-phase voltages and current at both side of the cycloconverter station of the figure 2 in steady state.

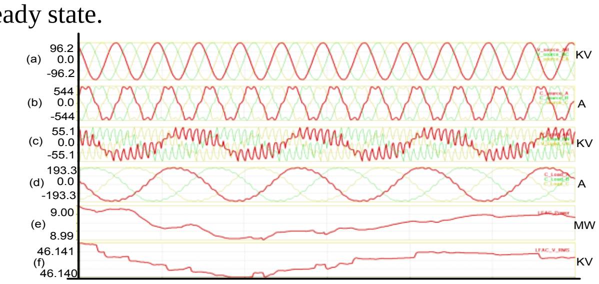

Figure 3. A LFAC example system

Optimizatin of Storage Systems Integration into MVDC in Shipboard Power System(SPS)

Amanuel Kesete*, Noel N. Schulz, Sanjoy Das, Bala Natarajan, Caterina Scoglio
Department of Electrical and Computer Engineering
Kansas State University
Manhattan, KS, USA
*Email: akesete@ksu.edu

Abstract**—** Electric storage systems can play very important role in improving quality of service (QOS) in future all-electric ships. Reliable electric power is very critical for smooth operation of ships during normal conditions and survivability of the ships during hostile conditions. This work is aimed at optimizing the integration of battery and ultra-capacitor storage system into the Medium Voltage DC System (MVDC) in Shipboard Power System (SPS). First the models are built and tested before being integrated to the MVDC. The next step is to optimize the integration of the storage systems satisfying constraints like size, weight and volume. Unlike terrestrial systems, ships have very limited space and volume, therefore storage systems have to be optimized satisfying all those constraints. Multi-objective optimization algorithm will be implemented since the objectives are more than two. Battery energy system has high energy density and is used as a backup power source when there is power outage in the ship. Ultra-capacitor storage system is more suitable for handling short time transients or spikes as it has high power density and fast discharging rate. Therefore, the combination of both storage systems is suitable for improving the quality of power supply in future all-electric ships

Keywords: Storage System; Multi-objective optimization; battery; Ultra-capacitor

This work supported by the United States Office of Naval Research under grant N00014-10-1-0431 (DEPSCoR program)

Optimal Placement of PMUs for Islanding in Sub-transmission Network

Abderrahmane Elandaloussi, Dr. Noel Schulz, and Dr. Anil Pahwa

Department of Electrical and Computer Engineering, Kansas State University Manhattan, KS USA

aelanda1@ksu.edu, noels@ksu.edu, apahwa@ksu.edu

***Abstract* -- Renewable energy, such as solar and wind farms, has increased in popularity recently with a mixture of improved opportunities related to environmental concerns, decreasing dependence on petroleum fuel and decreased capital and operational costs of its technologies. While traditionally the power system paradigm was to maintain interconnectivity as much as possible, the increased penetration of various distributed generation, including wind and solar, is providing new opportunities to look at operational cases for intentional islanding or micro-grid operations. Additionally communications and controls advances have enabled devices, such as Phasor Measurement Units (PMUs), to help provide a real-time snapshot of the power system status allowing power system personnel to consider islanding as one of their solutions. Using PMU data to identify and develop strategies for the real-time operation of power systems including DG at the sub-transmission level and below will be important in providing stability and understanding the impact of renewables on the systems. This poster will discuss the optimal placement of PMUs on the sub-transmission level including strategies for possible islanding of systems where DG enables micro-grids to maintain reliability. Discussions will include information on the number of PMUs and the types of data and analysis needed to make these decisions.**

Keywords: Sub-transmission system; Islanding; PMU

National Long-term Transmission Overlay Design: Process & Preliminary Results

Yifan Li and Dr. James D. McCalley (Advisor)
Department of Electrical and Computer Engineering, Iowa State University, Ames IA 50010
Email:yfli@iastate.edu and jdm@iastate.edu

***Abstract*--There are six major driven factors for today's national electric transmission system studies: meet load increase; reliability enhancement; renewable deliverability; inter-regional power exchange; congestion release; retirement. In this paper, a synthesis long-term, nationwide planning approach has been developed, which includes scenario design, candidate selection and investment optimization. Four scenarios have been designed with different generation technology emphasis: reference, high-wind, high-solar and high-geothermal. Next, an iterative minimum spanning tree (MST) algorithm has been applied to select good transmission candidate, in terms of right of way (ROW) availability, geographical and climate factors. Based on the location-specified information of selected candidates, transmission investment portfolio has been optimized to minimize the total investment and production cost on a 40 years' time horizon. Transmission technology suggestions have been provided as well. This study could provide reference for future work on this issue and other related problems, including renewable energy integration, generation interconnection, etc.**

***Index Terms*--Power transmission, power system planning, graph theory, network topology, optimization method, mathematical programming, HVDC transmission**

I. Key Equations

To be summarized and displayed on the poster.

II. Key Figures

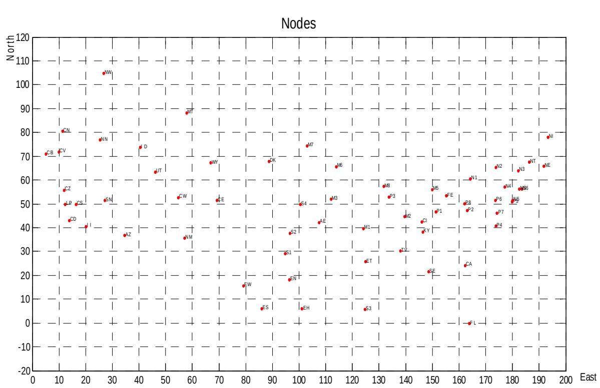

Fig. 1 62 Nodes Location Plot for the U.S. Continental Area

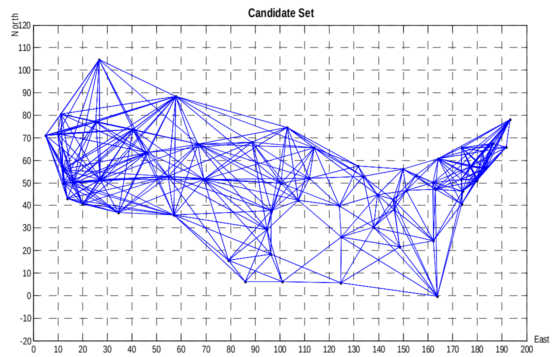

Fig. 2 Plot of 383 Transmission Candidates for U.S. Continental Area

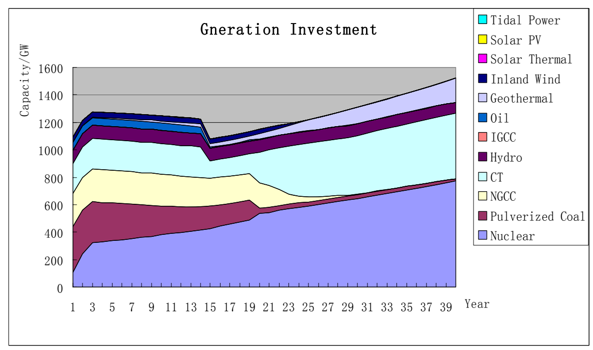

Fig. 3 Generation Investment Portfolio for the Reference Case

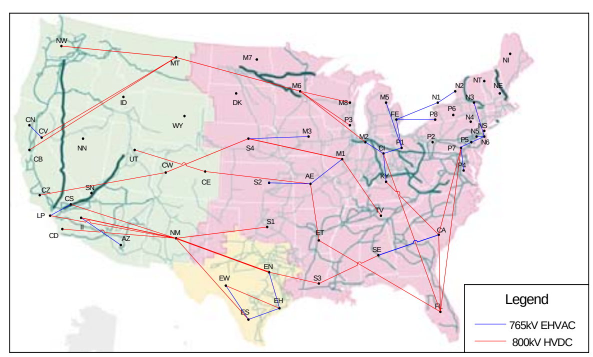

Fig. 4 Major Transmission Investments for Reference Case

III. Key Results

To be summarized and displayed on the poster.

Dynamic Modeling of Doubly-fed Induction Machine Considering the Asymmetric Coil Distribution and Slot Existence

Liangyi Sun, *Student Member, IEEE* and A. P. Meliopoulos, *Fellow, IEEE*

***Abstract*— In this poster, a physically based mathematical model of doubly-fed induction machine (DFIM) is presented in two steps. First the internal electromechanical model (IEM) of the machine is presented. The IEM model is expressed in terms of the actual self and mutual inductances of the machine windings. It considers the machine constructed of six winding on the same magnetic circuit. Each of the six winding has two terminals. Secondly, the connectivity model is shown which depends on whether the machine rotor and stator circuits are connected delta or wye (four cases).**

Different from the common approach, where the machine stator self-inductances and stator mutual inductances are assumed to be constants would be biased and contain significant error compared to actual values if the slots existence is not absolutely symmetric or the distribution of the coils in the slots is not continuous or fully symmetric, the model of DFIM presented in this poster, whose stator self-inductances and stator mutual inductances are dependent on the relative angle difference between the stator and rotor of the machine, could bring more accurate simulation results.

I. KEY EQUATIONS

Stator Self-Inductances:

$$L_{aas} = L_s + L_{m1} \cdot \cos 2\theta + L_{m2} \cdot \sin 2\theta \quad (1)$$

$$L_{bbs} = L_s + L_{m1} \cdot \cos(2\theta - \frac{4\pi}{3}) + L_{m2} \cdot \sin(2\theta - \frac{4\pi}{3}) \quad (2)$$

$$L_{ccs} = L_s + L_{m1} \cdot \cos(2\theta + \frac{4\pi}{3}) + L_{m2} \cdot \sin(2\theta + \frac{4\pi}{3}) \quad (3)$$

Stator Mutual Inductances:

$$L_{abs} = L_{bas} = -M_s - L_{t1} \cdot \cos 2\theta - L_{t2} \cdot \sin 2\theta \quad (4)$$

$$L_{bcs} = L_{cbs} = -M_s - L_{t1} \cdot \cos(2\theta - \frac{4\pi}{3}) - L_{t2} \cdot \sin(2\theta - \frac{4\pi}{3}) \quad (5)$$

$$L_{cas} = L_{acs} = -M_s - L_{t1} \cdot \cos(2\theta + \frac{4\pi}{3}) - L_{t2} \cdot \sin(2\theta + \frac{4\pi}{3}) \quad (6)$$

Where, L_s, M_s is the self-inductance due to space-fundamental air-gap flux and the armature leakage flux; the additional components that vary with 2θ is due to the rotor saliency.

Algebraic Companion Form: the dynamic model of the device is converted into the following algebraic form:

$$\begin{bmatrix} i(t) \\ 0 \end{bmatrix} = Y_{eq} \cdot X(t) + \begin{bmatrix} X^T(t) \cdot F_{eq1} \cdot X^T(t) \\ \vdots \\ X^T(t) \cdot F_{eqn} \cdot X^T(t) \end{bmatrix} - B_{eq} \quad (7)$$

II. KEY FIGURES

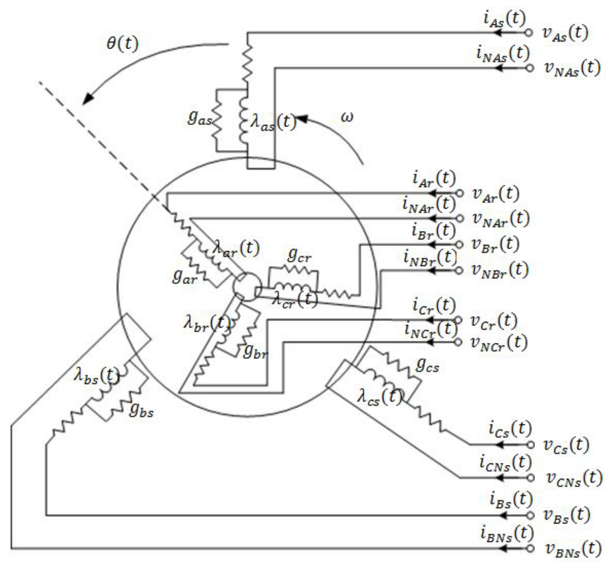

Fig. 1. Compact doubly-fed induction machine description

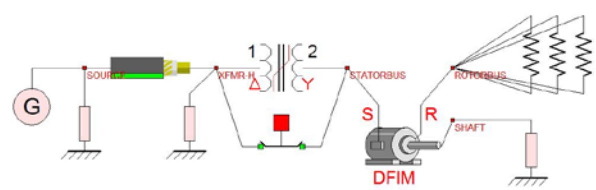

Fig. 2. Doubly-fed induction machine test case

III. KEY RESULTS

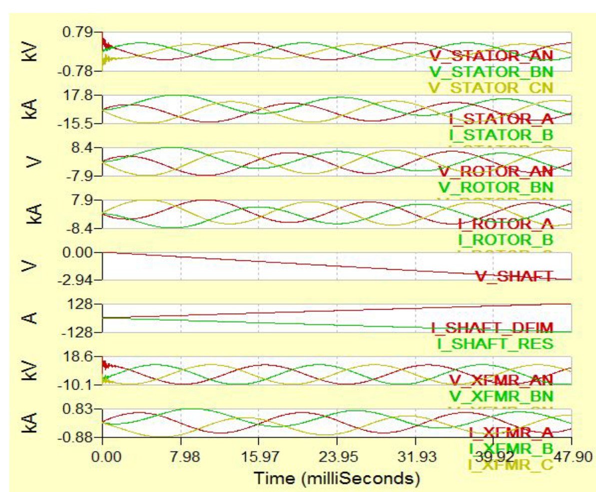

Fig. 3. DFIG system simulation results (Voltage & Current)

Electrical Distribution Architectures for Future Commercial Facilities

Emmanuel Taylor, *Student Member, IEEE* and Gregory F. Reed, *Member, IEEE*

***Abstract* – This article briefly describes the poster to be submitted on datacenter electrical distribution architectures at the University of Pittsburgh for the 2012 IEEE PES T&D show in Orlando, Florida.**

I. Introduction

Global industries, governments, organizations, and institutions rely on the operation of datacenters in order to successfully meet their day-to-day objectives. The increased reliance on datacenters combined with the shear growth of the industry sector has led to more careful considerations for datacenter design.

Historically, datacenters have sprouted where needed, and have increased capacity as demand for data services has increased. However, many datacenters are currently operating at or near capacity, and are not able to expand under the restraints of their facility electrical distribution systems. For the reasons stated, stakeholders in the datacenter industry have begun to consider alternative electrical distribution systems that provide the same functionality, with greater reliability and operating efficiency, as well as lower capital costs and ease-of-installation.

Among the many alternatives proposed, facility-level DC distribution, at a voltage near 400 V DC, has emerged as the option providing the most benefit. A number of studies have shown that DC distribution provides savings, in terms of energy efficiency, space utilization, and required cooling within a datacenter.

Growth in the datacenter industry has allowed for efficiency increases in other sectors of the economy. Centralized computing facilities allow other industries to focus their resources on their core competencies. However, datacenters themselves are unnecessarily inefficient. For every watt consumed utilized to process data, at least 0.9 watts are required support power conversion and conditioning processes, and another 0.6 watts are required to cool the datacenter equipment. By migrating to a DC distribution architecture, conversions can be eliminated, increasing the system efficiency, while decreasing cooling needs.

Research has shown that DC distribution exhibits higher efficiency, compared to baseline AC systems. However, the issue of transient propagation in alternative distribution architectures has not been quantified. The research work of the University of Pittsburgh focuses on the transient aspect of datacenter electrical distribution.

This work was supported by funding from the PA DCED BFTDA. E. Taylor and G.F. Reed are with the Department of Electrical & Computer Engineering and the Center for Energy, in the Swanson School of Engineering at the University of Pittsburgh, Pittsburgh, PA 15210 USA (e-mails: ejt7@pitt.edu, reed5@pitt.edu)

II. General Poster Description

This poster is designed simply, in order to make a visual impact on the viewer, and provide necessary information in an efficient manner. This poster is designed as a mechanism for generating interest and eliciting conversation.

The poster expresses the purpose behind the research being pursued. The poster illustrates single line diagrams relevant to the AC benchmark system, as well as the DC architecture used for comparison. Key characteristics of each system are described. Results and future work are presented in a concise manner.

The AC system single line diagram is representative of a standard datacenter distribution architecture. The facility is fed from a 480 V, three phase utility supply. This AC supply is conditioned using double-conversion online uninterruptible power supply. The conditioned voltage supply is fed through the facility using AC cable. Power distribution units provide isolation and protection for the sensitive electronic equipment. Server power supply units are fed an AC voltage. Within the server power supply, this voltage is power factor corrected, rectified, and filtered to provide a 12 V supply. Voltage regulators further step down the DC voltage to levels suitable for individual electronic devices, including server processors and fans.

In the DC comparison system, the utility voltage is rectified, filtered, and regulated, feeding a facility DC bus. An active rectifier feeds DC buswork and cabling, distributing DC voltage throughout the facility. This DC supply is fed directly into the server power supplies. Server power supplies are only required to step down and regulate the input voltage. The server voltage regulators and electronics operate in the same manner as in the AC system. The DC system provides the same functionality, with reduced infrastructure and higher efficiency.

The single line diagrams also demonstrate the way in which auxiliary facility services are connected into the electrical distribution network. Additional savings are realized by feeding variable frequency drives with direct DC power, eliminating the diode rectifiers commonly found in VFD topologies.

Although higher efficiencies can be achieved, the propagation of voltage transients in the DC system must be thoroughly investigated to ensure equipment safety and system reliability.

III. Biographies

Emmanuel Taylor (M'2007) is a graduate research assistant and **Gregory F. Reed** (M'1985) is the Director of the Power and Energy Initiative and Associate Professor of the Swanson School of Engineering at the University of Pittsburgh.

Microgrids and Blackstart Operation

Sudarshan Natarajan
Advanced Power Engineering Laboratory, Department of Electrical and Computer Engineering,
Colorado State University, Fort Collins, CO 80521, USA.
Email: Sudarshan.Natarajan@colostate.edu

***Abstract*— Traditionally, distribution power systems have been designed to operate in a centralized generation and radial feeder topology. These were normally motivated by simplicity in design of protection systems. Recently growing demands for increased efficiency of generation systems with requirements for integration of renewables have led to the concepts of Distributed Generation (DG) and microgrids. With the adoption of the Smart Grid Initiative (SGI) for grid modernization in the United States, several options are being explored in transmission and distribution engineering. Among the important objectives in the distribution realm is the ability to integrate all generation and storage options.**

An important point highlighted by the SGI is the ability of the modern grid to resist attacks. This means that in the event of an attack (physical or cyber) on the grid, critical load resources must not lose supply. One way to achieve this is through the introduction of microgrids. The Centre for Electricity Reliability Technology Solutions (CERTS) defines a microgrid as an aggregation of loads, microsources and associated controls providing heat and electricity to a localized region [1]. An important functionality of a microgrid is the ability to disconnect from the main grid on sensing a disturbance on the grid.

Microgrids provide an ideal platform for the introduction of renewables. The microgrid studied as a part of this research consisted of a mix of generation. The microgrid utilized biomass generation as the renewable resource to produce electricity. The microgrid site is planned to have two 1600kW biomass generators which have very specific operational constraints. Biomass generators are low inertia machines which make them ideal to serve as swing machines.

Another important functionality of the microgrid is the ability to efficiently utilize both electricity and the waste heat generated as a by-product. This improves the overall efficiency of the system. Such plants are known as Combined Heat and Power plants (CHP). Heat energy cannot be transported over long distances efficiently. Hence, the overall efficiency of centralized thermal plants is generally as low as 35 – 40%. On the other hand, the proximity of a microgrid to loads permits utilization of waste heat for space heating hence improving the overall efficiency of the system to as high as 85 – 90% [1].

Blackstart operation is an important functionality in microgrids. While some microgrids can continue to supply the loads within the microgrid, without interruption, on disconnecting from the main grid (CERTS Walnut Chest facility), most others will drop the load on disconnection. Such units must have the capability to blackstart. Blackstart defines a set of steps that must be followed to bring up generation and load when all support from the grid is lost.

I. Introduction

A notional microgrid studied as a part of this work consisted of three 2.05kW diesel engines, and three 2.05 kW natural gas engines that served as dispatchable resources in addition to the biomass generation resource. Load feeders were classified as feeders carrying critical load and others with loads of lower priority. In future, PV and wind resources are also planned to be included into the mix.

Simulations and studies were conducted on blackstart sequence for the generators and load bring-up and the best mix of generators for reliable operation of the microgrid. An algorithm inspired from [2] was exclusively engineered for the notional microgrid.

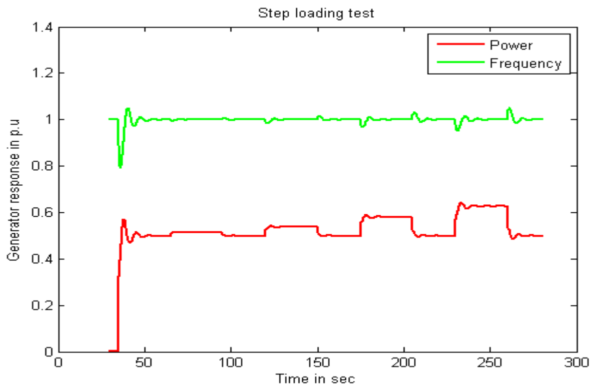

Figure 1. Snapshot of blackstart operation. Step loading and frequency deviation of system running 3 Natural Gas generators.

Frequency and voltage deviation studies were conducted, and conclusions were drawn regarding the changes that would be required to relays and switches to avoid false tripping.

II. References

[1] R. Lasseter, et al., "Integration of Distributed energy resources: The CERTS microgrid concept," Apr 2002. [Online] {Available} http://certs.lbl.gov/pdf/50829.pdf

[2] N. Cai, X. Xu, J. Mitra, "Hierarchical Multi-agent Control Scheme for a Black Start-Capable Microgrid," IEEE PES Gen. Meeting, San Diego, pp. 1-7, July 2011.

Acknowledgement: Thanks to NREL, US Marine Corps and US Navy for supporting this work.

Short-Term Load Forecasting of a University Campus with an Artificial Neural Network

David Palchak
Department of Mechanical Engineering
Colorado State University
Fort Collins, CO

Abstract— **Electrical load forecasting is a tool that has been utilized by distribution designers and operators as a means for resource planning and generation dispatch. The techniques employed in these predictions are proving useful in the growing market of consumer, or end-user, participation in electrical energy consumption. These predictions are based on exogenous variables, such as weather, and time variables, such as day of week and time of day. The participation of the end-user is a cornerstone of the Smart Grid initiative laid out by the 110th Congress [1], and is being made possible by the emergence of enabling technologies such as advanced metering infrastructure (AMI). The real-time data provided by the AMI, as well as the load forecast, is utilized for the detection of anomalous events, as well as the management of electrical loads, termed demand-side management (DSM).**

I. Methods and Results

This case study focuses on the ability of an artificial neural network (ANN) to predict the 24-hour load profile of the main campus of Colorado State University. The ANN is trained and validated using real historical data in conjunction with historical local weather data. The architecture of the ANN is decided using a combination of historical success [2]and statistical information about the forecasting performance. Figure 1 shows an example of a 24-hour prediction of the ANN.

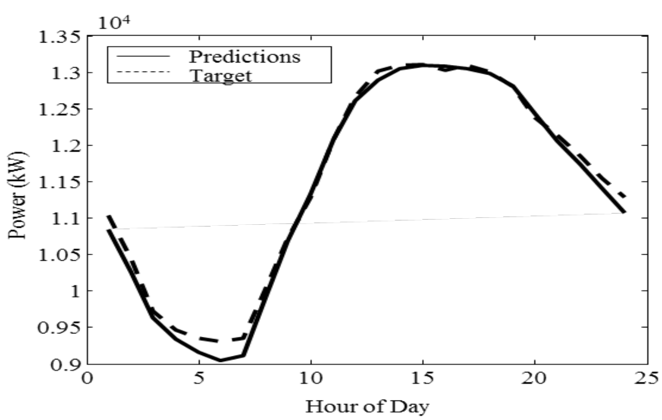

Figure 1. Typical load profile and forecast of 24-hour day.

A number of error measures are examined to quantify the performance of the ANN, and are also used to help determine relevant DSM applications. Mean average percent error (MAPE) is the most widely used measure in neural network literature. The average MAPE over all 121 test days is 2.48%, which, according to [3], falls in the "normal" range expected for a 24-hour prediction. Other performance measures that provide relevant information about the predictive abilities of the ANN are: 1) the difference in total electric energy between forecast and target over a 24 hour period 2) peak hour miss, and 3) maximum error over the 24 hour period.

The energy difference is the ratio of the difference in electric energy consumption corresponding to the forecast and the observed values to the electric energy consumed corresponding to the observed values, for a 24-hour period (*n*=24).

$$Energy\ difference = \frac{\int_0^{n-1} \vec{F} - \int_0^{n-1} \vec{T}}{\int_0^{n-1} \vec{T}} * 100 \qquad (1)$$

The average energy difference over all of the test days is 1%, which suggests that this ANN might be well-suited for DSM applications where energy savings is the goal.

The other error measures are not only an indication of the performance, but can improve upon the application of the predictive knowledge gained from this ANN. Knowing the ability of the ANN to predict the peak hour, for example, not only points out limitations of the model, but could result in successful localized applications.

References

[1] 110th United States Congress, "'Smart Grid,' Title XIII, Energy Independence and Security Act 2007.".

[2] H. S. Hippert, C. E. Pedreira, and R. C. Souza, "Neural networks for short-term load forecasting: a review and evaluation," *Power Systems, IEEE Transactions*, vol. 16, no. 1, pp. 44–55, 2001.

[3] S. A. Soliman, *Electrical load forecasting modeling and model construction*. Burlington, MA: Butterworth-Heinemann, 2010.

Acknowledgement

This work is supported by the Eaton Corporation and the City of Fort Collins through the FortZED project, as well as the US National Science Foundation Award # 0931748. The authors acknowledge the cooperation of the Colorado State University facilities department; Dr. Chuck Andersen, Professor of Computer Science at Colorado State University for his valuable input on ANNs. Thanks to my advisors, Professor Dan Zimmerle and Dr. Sid Suryanarayanan for their invaluable help on this research.

Impact of wind penetration on conventional transmission line fault location algorithms

Chaoqi Ji
Electrical and Computer Engineering Department
Clemson University, Clemson, SC USA
cji@clemson.edu

Abstract—*With an increasing capacity of wind power installed in the world, the impact of wind penetration has been studied in many areas. In this poster, some widely-used conventional fault location algorithms for transmission system are applied to a simple equivalent system during fault condition. The system is connected to a wind farm equipped with doubly fed induction generator (DFIG). Real time simulation with relay hardware in loop (HIP) is performed to compare the validity of fault location algorithms. Comparisons are made for different fault types and fault locations with various fault resistance value. Possible reasons are then discussed based on the fault location results.*

Keywords – wind penetration; fault location algorithm; DFIG; real time simulation; HIP

A Novel Optimization Approach to Solve Power Flow Problem Using Complementarity

Mehrdad Pirnia, Kankar Bhattacharya, Claudio Canizares
Power and Energy Systems Group, Department of Electrical and Computer Engineering, University of Waterloo, Ontario, Canada, N2L 3G1,
Email: mpirnia@uwaterloo.ca , Kankar@uwaterloo.ca , ccanizares@uwaterloo.ca

***Abstract*—A novel optimization based solution to the power flow problem, using complementarity conditions which tracks the generator bus voltage level changes when its minimum or maximum reactive power limits have been attained is proposed. In order to test the accuracy of the model, this has been tested on IEEE 14-bus, 30-bus, 57-bus, 118-bus and 300-bus test systems, using GAMS PATHNLP solver, and has been benchmarked against the standard Newton-Raphson method, which is the most well-known power flow solution methodology today. The proposed model converges in a few iterations, with the same results as the Newton-Raphson solver, using UWPflow [1]. To investigate the robustness of this approach, the proposed model has been tested on a large 1200-bus real system, which can be classified as an ill-conditioned power flow problem when using a flat start. Using the proposed complementarity method, the problem converges from a flat start in a few iterations, while Newton-Raphson method diverges.**

I. Key Equations

The proposed optimization model for power flow problem with complementarity conditions can be written as [2]:

$$\min \quad \sum_i \Delta P^2{}_i + \Delta Q^2{}_i \qquad (1)$$

s.t.

$$\Delta P_i(\delta, V, P_i) = P_i - \sum_i P_{ij}(\delta, V) \qquad \forall i \qquad (2)$$

$$\Delta Q_i(\delta, V, Q_i) = Q_i - \sum_i Q_{ij}(\delta, V) \qquad \forall i \qquad (3)$$

$$0 \le \left(Q_{gen_i} - Q_{gen_i}^{Min}\right) \perp V_{a_i} \ge 0 \quad \forall i \in \{gen, slack\} \ (4)$$

$$0 \le \left(Q_{gen_i}^{Max} - Q_{gen_i}\right) \perp V_{b_i} \ge 0 \quad \forall i \in \{gen, slack\} (5)$$

$$V_{gen_i} = V_{i_0} + V_{a_i} - V_{b_i} \qquad \forall i \in \{gen, slack\} \ (6)$$

$$V_{gen_i}, V_{a_i}, V_{b_i} \ge 0 \qquad \forall i \in \{gen, slack\} \ (7)$$

II. Key Results

Proposed Model (Flat Start)		
System	Major Iterations	Total time (Seconds)
IEEE 14bus	7	0.046
IEEE 30bus	3	0.047
IEEE 57bus	5	0.109
IEEE 118bus	9	0.375
IEEE 300bus	9	0.515
Real 1211bus	11	12.281

Table 1. Performance Evaluation for PF-CC with Flat Start

Newton-Raphson (Flat Start)	
System	Major Iterations
IEEE 14bus	5
IEEE 30bus	6
IEEE 57bus	4
IEEE 118bus	5
IEEE 300bus	12
Real 1211bus	Doesn't converge

Table 2. Performance Evaluation for Newtone-Raphson Method with Flat start

References

[1] "UWPFLOW: Continuation and Direct Methods to Locate Fold Bifurcations in AC/DC/FACTS Power Systems". Available: http://www.power.uwaterloo.ca.

[2] W. Rosehart, C. Roman, and A. Schellenberg, "Optimal Power Flow With Complementarity Constraints," *IEEE Transactions On Power Systems*, vol. 20, no. 2, 2005.

Off-grid Power Quality: Impacts, Analysis and Solutions

Arjun Gautam and Dr. Allison Kipple
Department of Electrical Engineering & Computer Science
Northern Arizona University
Flagstaff, Arizona 86011, USA
Email: ag786@nau.edu and Allison.Kipple@nau.edu

***Abstract*—Power quality data were obtained in two off-grid homes near Flagstaff, Arizona, a region with a large off-grid population including thousands of Native Americans. Voltage and current waveforms, RMS values, transients, and harmonics were captured as various electronic devices were operated in each home. The devices which caused the greatest power quality concerns, along with the devices most susceptible to power quality issues, were determined. Potential solutions to the most significant problems were proposed and tested, with price playing a major role due to the economic distress of many off-grid residents. The findings will be useful to off-grid communities worldwide.**

Keywords-power quality; off-grid; stand-alone; renewable energy; electronics failure; harmonic distortion; filters

I. Introduction

Thousands of off-grid homes near Flagstaff, Arizona depend upon photovoltaic solar panels, wind turbines, batteries, etc. to operate their household devices. Unfortunately, many of these systems suffer equipment damage due to poor power quality, including transients and noise. In this project, we sought to investigate the reasons and possible solutions for these off-grid equipment failures.

II. Methods and Results

A Fluke 43B power quality analyzer was used to record the voltage and current characteristics at two off-grid homes, one using a modified sine wave inverter and another containing a pure sine wave inverter. Data were obtained while various electrical devices were running independently or in combination, including CFLs, refrigerators, vacuums, water pumps, washing machines, microwaves and more.

The Total Harmonic Distortion (THD) produced by the modified sine wave inverter was around 50%, even without any electronic devices being turned on. These inverters are therefore not compatible for use with sensitive or specialized equipment. In the off-grid house containing the pure sine wave inverter, the refrigerator, washing machine, water pump, vacuum and CFLs were the sources of current harmonics that exceeded the IEEE 519-1992 standards. However, in many cases the Total Demand Distortion (TDD) at the inverter connection could be below the IEEE limit and may not pose a threat to the system. For example, the current harmonics produced by the CFLs may cause a negligible overall effect because of their low current draw compared to greater linear loads. In other cases, where both the current magnitude and the current harmonics produced by the device were large, harmonic filters and isolation transformers were implemented to improve the power quality experienced by other devices in the home.

III. Key Figures

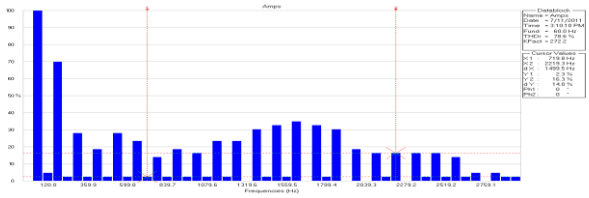

Figure 1. Current harmonics produced by a CFL lamp.

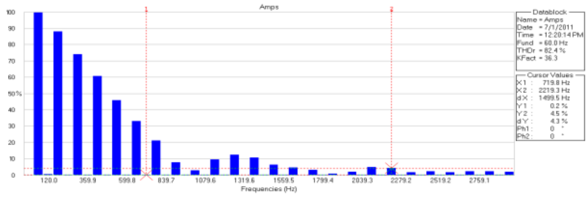

Figure 2. Current harmonics produced by a refrigerator.

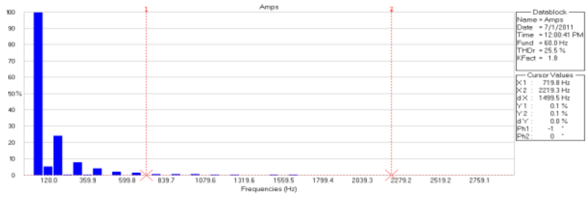

Figure 3. Current harmonics produced by a microwave.

This work was supported through Arizona Public Service (APS) and Hooper Sustainability Award Program at Northern Arizona University