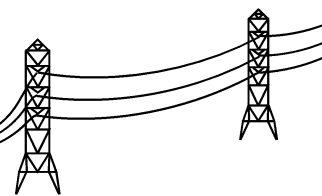


# NAPS-2006

Southern Illinois University Carbondale

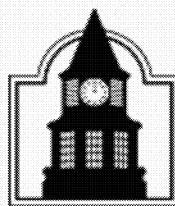


## *2006 38<sup>th</sup> Annual North American Power Symposium*

### *NAPS-2006 Proceedings*

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**September 17-19, 2006**



**Southern**  
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*Index Terms*— Animal-related failures, discrete wavelet transform, neural network, overhead distribution system

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*Index Terms*— Interruption duration distributions, microgrid, Monte Carlo simulation, reliability, storage.

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*Index Terms*—Capacitors, Economic capacitor placement, Graphical user interface, Load flow analysis.

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*Index Terms*— Battery, Fuel Cell, Hybrid Vehicle, Ultracapacitors
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*Index Terms*—Induction motor model, Load flow analysis, Parameter estimation, Quasi-steady-state analysis, Three-phase modeling

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*Index Terms*—Bangladesh, private sector, power generation.

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*Index Terms*—Electricity Restructuring, Economics of Power Systems, Turkey, Transmission Management, Transmission Expansion Planning

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*Index Terms*—Forward Markets for Electricity, Energy Capacity Markets, Investments, Stratum Electricity Market (SEM).

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	<i>Index Terms</i> —Availability Based Tariff (ABT), Indian Electricity Act 2003, Generation, Transmission, Distribution	
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*Index Terms*-- Electric Energy Market, Wyoming's Energy, and HVDC Transmission

## **ELECTRIC POWER MARKETS AND POWER PRICING**

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*Abstract*—Short-term price forecasting in competitive electricity markets is critical for consumers and producers in planning their operations and managing their price risk. This paper adopts artificial neural network (ANN) model based on similar days methodology in order to forecast weekly electricity prices in the PJM market. To demonstrate the superiority of the proposed model, extensive analysis is conducted using data from the PJM Interconnection. The factors impacting the electricity price forecasting, including time factors, load factors, and historical price factors are discussed. Comparison of forecasting performance of the proposed ANN model with that of forecasts obtained from similar days approach is discussed. The forecasting error is the major concern for forecaster; a lower error indicates a better result. Accumulative error depends on forecasting period (hourly, daily, weekly, monthly, etc.). It will increase for a longer time forecasts. In this paper, the test results obtained by using the proposed ANN provide reliable forecast for weekly price forecasting as the mean absolute percentage error (MAPE) values obtained for the first and last week of February 2006 are 7.66% and 8.88%, respectively. Similarly, MAPE for the second week of January 2006 is obtained as 12.92%. Forecast mean square error (FMSE) and MAPE results obtained through the simulation show that the proposed ANN model is capable of forecasting locational marginal price (LMP) in the PJM market efficiently.

*Index Terms*—Competitive power market, artificial neural network, price forecasting, similar days.

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*Index Terms*—Power Markets, Price Forecasting, Price Spikes, Neural Networks, System Identification.

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Prashanth Duvoor, Koteswar R Padamati, Sujatha Kotamarty, Anurag K Srivastava

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*Index Terms*— FACTS, UPFC, Loop flows, Transmission pricing, Deregulation

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*Index Terms*— power market; congestion management; optimal power flow; optimal resource allocation

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*Index Terms*—Game theory, Mathematical programming, Power system economics, Congestion management.



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*Index Terms*—Electricity Market, Market Equilibrium, Ologopolistic Competition.

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M. Soliman, A. K. Puppala, M. Safiuddin

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The proposed model uses a dc motor as the prime mover for a separately excited dc generator, which represents the fuel cell. The fuel cell current and voltage are measured using a National Instruments (NI) data acquisition card and the control signal is fed back to change the generator's field current.

*Index Terms*- Combined heat and power (CHP), Distributed Generation (DG), Fuel cell, Solid Oxide Fuel Cell (SOFC).

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Fabian M. Uriarte

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*Index Terms*— core, current, model, equation, hysteresis, loop, magnetizing, saturable, simpower, simulink, transformer, visual.

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F. Mişoc, M. M. Morcos, J. Lookadoo

*Abstract* -- The paper presents new models of DC–DC converters. The sub-circuit formed by the voltage source, switching transistor, and diode, is replaced by an independent square-pulse current source, while the rest of the circuit remains unchanged. Using Fourier series representation of current-pulse square wave, the current source is describe as a sum of sinusoidal currents, thus the system is considered linear. The system's state-space representations in the time domain and s-domain are derived. Comparison of the buck converter state-space representation of both models is

performed. Numerical validation of the buck converter is presented. The Fourier series models developed in the paper offer the benefits of large-signal models and small-signal models combined, without sacrificing accuracy, and is well suited for transient analysis of power systems incorporating DC-DC converters.

*Index Terms* -- Circuit modeling, DC-DC power conversion, Fourier series, linear systems.

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Fabian M. Uriarte, Karen L. Butler-Purpy

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*Index Terms*—bus, cable, diakoptics, hexagon, Kron, matlab, partition, power, ring, simpowersystems, system, simulation, shipboard, vtb.

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R. Arunachalam, R. Singh, B. A. Mork, L. J. Bohmann, and D. Ishchenko

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*Index Terms*—ATP-EMTP, Dynamic Reduction, Power System Stability, PSS/E.

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Marija D. Ilic

*Abstract*—This paper concerns a novel modeling and software framework in support of future electricity and energy services. A broad vision for one such possible framework named Energy-Temporal and Structural Kit (EN-TASK) is described. It is explained why is this needed, and how would such framework facilitate Dynamic Energy Control Protocols (DECPs) of the future. The emphasis is on a framework which zooms in and out to assess potential of candidate technology and/or organizational change at the level where it matters the most.

*Index Terms*—National Energy Model System (NEMS), Electric Power Grid Modernization, Performance Index, Dynamic Energy Control Protocols (DECPs), Distributed Generation (DG), Demand Side Response, Power Flow Control, Storage, Renewable Technologies, Electricity Service, Energy Service.

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Peda Medagam, Farzad Pourboghrat

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Chi-Seng Lam, Man-Chung Wong

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*Index Terms*—Power electronics, power quality.

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*Index Terms*— Soft switching PWM; Three-phase PFC; Zero-current switching

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B. Chatham, M. M. Morcos

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*Index Terms*—Fast Fourier transform, power quality, S-Transform, Short Time Fourier Transform, time-varying waveform distortions, Wavelet Transform

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*Index Terms* -- Anechoic chambers, electromagnetic compatibility, electromagnetic interference.

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- 1 PSO-Based Multi-Criteria Economic Dispatch Considering Wind Power Penetration Subject To Dispatcher's Attitude** **269**  
Lingfeng Wang, Chanan Singh

*Abstract*—Significant attention has been paid to the renewable energy resources such as wind power in recent years. It has potential benefits in curbing emissions and reducing the consumption of irreplaceable fuel reserves. However, the penetration of wind power into traditional fuel-based generation systems will also have some implications such as security concerns due to its unpredictable nature. Thus, in economic power dispatch with wind power penetration, a reasonable tradeoff between system risk and operational cost is desired. In this paper, a biobjective economic dispatch problem considering wind penetration is formulated, which treats economic and security impacts as conflicting objectives. Different fuzzy membership functions are used to reflect the dispatcher's attitude toward the wind power penetration. A modified multi-objective particle swarm optimization (MOPSO) algorithm is adopted to develop a power dispatch scheme which is able to achieve compromise between economic and security requirements. Numerical simulations including sensitivity analysis are reported based on a typical IEEE test power system to show the validity and applicability of the proposed approach.

- 2 Transmission Corridor Analysis Using PTDFS** **277**  
David J. Maggio, Thomas J. Overbye, Minghai Liu

*Abstract*—Subsection 1221(a) of the Energy Policy Act of 2005 calls for a study to determine national interest electric transmission corridors. These corridors are defined as “any geographic area experiencing electric transmission capacity constraints or congestion that adversely affects consumers.” This paper presents a method to define a “direct flow” between two hubs using the power transfer distribution factors (PTDFs). With these hubs properly defined, the hope is to be

able to assess where these transmission corridors of national significance exist.

*Index Terms*—Transmission corridors, Power Transfer Distribution Factors

### **3 SVC And TCSC Implemented Into A Newton-Type Harmonic Power Flow Algorithm** **283**

J.J. Chavez, A. Ramirez

*Abstract*—The methodology for including generators as *PV* buses in a Newton-Type Harmonic Power Flow (HPF) program presented in a previous paper is extended here to include electronic devices. Application examples including a Static VAR Compensator (SVC) and a Thyristor Controlled Series Compensator (TCSC) are presented. Although the calculation of the firing angles for such devices needs an internal iterative procedure, in the overall the HPF methodology does not require an iterative procedure for satisfying the generator constraints and, as a consequence, it nearly preserves the quadratic convergence characteristics of the Newton approach.

*Index Terms*—Harmonic analysis, Harmonic Power Flow, Newton-Raphson method, Static VAR compensator, and Thyristor Controlled Series Compensator.

### **4 Approximate Prediction Of Generator Dynamic Coupling Using Load Flow Data** **289**

Jason A. Taylor, Kent A. Sayler, S. Mark Halpin

*Abstract*—Dynamic coupling occurs when multiple groups of strongly connected generators are tied together through weak or strained transmission lines. Establishing which machines in a system are dynamically coupled has shown to be helpful in identifying coherent area for aggregation, providing insights into system stability, as well as indications of potential stability limits. One of the most significant factors influencing dynamic coupling is the value of the transfer impedance between the machines. Therefore, this paper proposes that a strong indicator of which machines are likely to be electrically coupled can be derived from direct evaluation of the off-diagonal entries of the system impedance matrix. Estimation of the dynamic coupling in this manner not only has the benefit of only requiring readily available machine and load flow data but being computationally simple.

*Index Terms*—Power system dynamic stability, power systems, power transmission planning.

### **5 Highly Available Distributed RAM (HADRAM) For Data Exchange Between Power Utilities** **295**

Damian Cieslicki, Stefan Schäckeler, Thomas Schwarz

*Abstract*—Power Control Centers need to model their systems in real-time to support the necessary control and security functions. Neighboring independent system operators and regional transmission organizations also need to exchange system data. In the USA, a data exchange structure based on EPRI's common information model and XML is evolving. Currently, this data exchange is implemented by providing each local provider with an agent that mediates between data exchange messages and the local database. We propose here a different technology for data exchange built of main memory of commodity computers at different independent system operators to provide a universally accessible database. While distributed memory offers scalability and excellent access times (compared to disk based systems), it is also vulnerable to node outages. Our proposal, Highly Available Distributed RAM (HADRAM) is highly reliable and has the speed and bandwidth advantages of distributed memory. This enables it to be used as a standard for the timely exchange of system models and real time SCADA data between power utilities.

*Index Terms*—data communication, data management, distributed random access memory, erasure correcting codes, in-memory-databases, network data exchange, power system control, power system modeling, scalable distributed data structure, transmission control.

**6 Laplacian Structure In Power Network Constraints And Inherent Zonal Price Regions 303**  
Daniel Chéverez-González, Christopher L. DeMarco

*Abstract*—Standard computations reveal that locational marginal prices (LMPs), being Lagrange multipliers in an optimization problem, must lie in the null space of a Jacobian matrix associated with power flow and line flow limit constraints in a power network. When no line limits are active, the matrix in question has a nearly Laplacian structure, and must admit a vector of all equal elements in its null space (verifying the well-known equal incremental cost condition – that all LMPs must be equal in a lossless, unconstrained system). When line flow limits are active, the null space grows in dimension, and admissible LMP vectors can show patterns in which buses partition into regions of approximately equal LMPs. We claim that this phenomena arises from the same near-Laplacian structure in the power flow Jacobian that gives rise to coherency in electromechanical dynamics. For coherency problems, Fiedler vector computations have been previously exploited for graph partitioning to identify coherent buses. Using similar concepts, this paper will explore a new computational approach to identifying network partitions in LMP computations, giving rise to “inherent” zonal price regions.

*Index Terms*—Locational Marginal Prices (LMPs), Zonal Prices, Fiedler vector, coherency.

**7 Basic Frequency and Time Domain Least Squares Methods for System Identification 311**  
Ashish Subramanian, John W. Pierre

*Abstract*—This paper investigates the feasibility of applying least squares (LS) techniques for estimating the low-frequency electromechanical modes of a power system. The performance of time domain least squares (TDLS) and frequency domain least squares (FDLS) system identification algorithms is studied. These algorithms use measured input and output signals to estimate system models. Simulation studies are performed. These simulations include using a test system model developed based on a series of tests performed on the Western North American Power Grid (WNA PG) in June, 2000.

*Index Terms*—Least squares, Estimation, System identification, Power system modeling.

**8 Modified Methodology for Tracing Power Flow 317**  
Ashutosh Tiwari, V. Ajjarapu

*Abstract*— Due to continuing trend towards deregulation and unbundling of transmission services, usage allocation has become critical. It is important to determine load being supplied from a particular generator. We need to know in a transmission line, the proportion of power going to a given load and the loads contribution to overall system losses. Thus, tracing method is used to trace the flow of electricity in a meshed electrical network. In this paper a modified methodology is proposed for tracing reactive power flow without adding fictitious nodes on system lines. Also, in this paper a modified methodology is proposed to break down the total real and reactive power loss in a transmission line into components to be allocated to individual loads.

*Index Terms*— Electricity tracing, Loss allocation

## POWER SYSTEM CONTROLS

**1 Neural-Based Predictive Control Applied To FACTS Devices 325**  
Ruben Tapia O., Pavel Zuñiga H., Juan M. Ramirez

*Abstract*-- In this paper applications are presented employing the neural-based predictive control (NPC) for controlling Flexible AC Transmission Systems (FACTS) devices with the purpose of regulating bus voltage magnitudes through the use of a Static Compensator (STATCOM), and the active power flow on a transmission line where a Static Synchronous Series Compensator (SSSC) is embedded. Contrary to a Proportional-Integral (PI) conventional control with its trial-and error

tuning, once trained a neural net able to predict the firing angle, simple calculations are required to achieve the wanted regulation. Thus, the NPC is a convenient tool to execute the power system adaptive control, with the possibility of carrying out such tasks considering non-linearities. The controller's design simplicity and its performance compared with the conventional PI controller are shown, especially those related with overshoots and control signals quality, impacting directly into the controlled variable response and having softer behavior than that of the PI control. The applicability of the proposition is studied by digital simulation.

*Index Terms*-- Neuro-controller; Power electronic; Predictive control.

## **2 An Overview Of Fuzzy Logic Based Power System Stabilizers 335** Mohamed M. Osman

*Abstract* - Fuzzy logic has emerged as a promising tool for several power system applications. A large body of the literature in this area is concerned with the stability of the electric power system, and considerable effort has been directed to the development of a fuzzy logic based power system stabilizer (FLPSS). The purpose of this paper is to present an overview of the FLPSS, based on published literature from 1989 to the present.

*Index Terms* - fuzzy logic, power system stabilizer, power system stability.

## **3 A Comparison Between The UPFC And The IPFC In Optimal Power Flow Control And Power Flow Regulation 339** Jun Zhang, Akihiko Yokoyama

*Abstract*—This paper presents a comparison study between the applications of the unified power flow controller (UPFC) and the interline power flow controller (IPFC) in optimal power flow (OPF) control. The power injection models of the flexible AC transmission systems (FACTS) devices are reviewed and incorporated in the OPF problem without active power generation redispatching, which minimizes the overall generating cost. The FACTS devices are planned for power flow regulation and their additional degrees of freedom act as additional potential in optimizing the power system. The performance of the UPFC and the IPFC is compared from the viewpoint of the total active power losses and their necessary capacities through numerical examples. The feasibility of a gradient-based algorithm, namely sequential quadratic programming (SQP), is tested, and the importance and some techniques of proper selection of the initial optimization conditions are also presented.

*Index Terms*—FACTS, IPFC, OPF, UPFC

## **4 ADALINE Network Based Adaptive Controller For STATCOM 347** A. Albakkar, O.P. Malik, W. Rosehart

*Abstract*— In this paper, an adaptive controller for Static Synchronous Compensator (STATCOM) is developed to damp oscillations and enhance the stability of power systems. The adaptive controller consists of an on-line identified system model and a Pole-Shift (PS) feedback controller. Adaptive Linear Element Neuron (ADALINE) is used for on-line model identification to obtain a dynamic equivalent model of the system. The PS controller is then adapted using the identified model. The proposed technique is tested on a single machine infinite bus system. The results obtained demonstrate improvement in the overall system damping characteristics applying the proposed adaptive controller and enhancing the stability of the power system in comparison to the conventional controller.

*Index Terms*—ADALINE Network, Adaptive PS Controller, STATCOM.

## **5 Nonlinear Robust Adaptive Control Design For DC Power Modulation In Multi-Area AC/DC Power Systems 353** Kenny K.Y. Poon, H.J. Zhu, Z.X. Cai, Z. Lan, D.Q. Gan, Y.X. Ni

*Abstract*—A nonlinear robust adaptive controller for dc power modulation of interconnected ac/dc power systems is proposed and is used to damp tie line power oscillations in interconnected power systems. The design idea is to drive the centers of inertia (COI) of various interconnected areas to a

stable equilibrium point such that the oscillations in the system can be damped out. Genetic algorithm is applied to optimize the parameters of the proposed controller, and computer test results illustrate that the proposed controller is superior to the conventional linear dc power modulation controller..

*Index Terms*—Center of Inertia, Genetic Algorithm, HVDC transmission, Nonlinear robust adaptive control, Power system.

## **6 Damping Control By Fusion Of Reinforcement Learning And Control Lyapunov** **361**

Mevludin Glavic, Damien Ernst, Louis Wehenkel

*Abstract*—The main idea behind the concept, proposed in the paper, is the opportunity to make control systems with increased capabilities by synergetic fusion of the domain-specific knowledge and the methodologies from control theory and artificial intelligence. The particular approach considered combines Control Lyapunov Functions (CLF), a constructive control technique, and Reinforcement Learning (RL) in attempt to optimize a mix of system stability and performance. Two control schemes are proposed and the capabilities of the resulting controllers are illustrated on a control problem involving a Thyristor Controlled Series Capacitor (TCSC) for damping oscillations in a four-machine power system.

*Index Terms* — Reinforcement learning, Control Lyapunov functions, Power system damping control.

## **POWER SYSTEM EDUCATION**

### **1 Basics Of Energy Systems Through Games** **371**

Varano M., Patel M., Asnani D., TsyKalyuk A., Idowu P.

*Abstract*—Energy topics have remained dominant in the political arena in the United States since September 11, 2001 and various energy policy statements have been focused on the need for research and development. To effectively engage and attract undergraduate students to studies in energy however, the structure of presentation of energy information and learning must be expanded. This paper presents two learning games - “Who Wants to be an Engineer?” and “Energy Jeopardy” that are designed to capture the interest of undergraduates as they are introduced to various topics on electric energy systems.

*Index Terms*—Engineering education, Energy, Games.

### **2 Electrical Safety Education In An Undergraduate Engineering Program: Curriculum Development And Assessment** **375**

Ravel F. Ammerman, P.K. Sen

*Abstract*—In an effort to develop increased safety awareness related to the electric power industry, Colorado School of Mines (CSM), electrical specialty students are required to take a one-week intensive electrical safety training course. Though safety training should start with young people, it is also an important part of the education for experienced electrical technical personnel too. Engineers, designers, and operators continue to develop insights about electrical safety throughout their careers. This paper discusses the Electrical Safety Training course curriculum developed at CSM and provides an assessment of the effectiveness of the program. Based on the success of the program this has become a permanent part of the Field Session curriculum.

*Index Terms*—Curriculum development and assessment, electrical safety awareness, engineering standards, power engineering education.



- 3 On VA's, VAR's, And Other Traditions In Electric Power Engineering 383**  
Charles A. Gross

*ABSTRACT*—The author presents a commentary on traditionally accepted power concepts in classical electric power engineering. A revision of traditional terminology is proposed.

- 4 Enhancement Of Undergraduate Electric Power Courses Via 389**  
**Commercial Electromagnetic Simulation Software**  
Walter L. Collett

*Abstract*—The electric power courses at Western Kentucky University emphasize proficiency in both electric machines and the integration of these machines into complex systems via transmission lines. The electric machines considered are electromagnetic devices governed by abstract principles. Recently, the courses have been enhanced by the use of commercial finite element method (FEM) software, which calculates approximate solutions to the governing differential equations and permits visualization and animation to assist in the understanding and design of the devices. This paper will describe how the technology is being used to improve an evolving project-based electric power curriculum.

*Index Terms*—finite element method, electromagnetic, machines

## **POWER SYSTEM MEASUREMENTS AND STATE ESTIMATION**

- 1 Innovative Sensory Concepts For Power Systems 397**  
Jonathan W. Stahlhut, Gerald T. Heydt, Elias Kyriakides

*Abstract:* This paper addresses the use of innovative and unconventional instrumentation technologies for power systems. The main focus is on giant magnetoresistance, Faraday and Poockels and other optical effect devices, Hall effect devices, satellite measurement technologies, mechanical measurements, lab on a chip / chemical sensing, and video technologies. It is suggested to utilize overhead conductor mechanical and thermal measurements to provide corrections for state estimation applications.

*Index Terms:* sensors, instrumentation, power system measurements, voltage, current, power.

- 2 On-Line Monitoring Of Sag In Overhead Transmission Lines With 405**  
**Leveled Spans**  
Poorani Ramachandran, Vijay Vittal

*Abstract*—A method for real time monitoring of overhead transmission line sags has been proposed. Mechanical state estimation is used to determine the sag value of each span of the transmission line using real time data. Use of separate tension sensors for critical spans enhances the sag estimation process. The estimated sag values can be used to calculate the clearance values to check for compliance with the national electric safety code (NESC).

*Index Terms*—Conductor sag, state estimation, overhead conductor, available transfer capacity, tension, ruling span.

- 3 State Estimation Of Power System With UPFC Using Interior Point WLAV Method** **411**  
C. Rakpenthai, S. Premrudeepreechacharn, S. Uatrongjit, N.R. Watson

*Abstract*—This paper presents a robust state estimator for power system containing unified power flow controller. The state estimation problem is formulated as an optimization problem using weighted least absolute value criteria, with a set of equality and inequality constraints. The interior point optimization method is applied to primal and dual formulation in order to solve this problem. The modified IEEE 14-bus system is used to demonstrate the effectiveness of the proposed algorithm. The simulation results indicate that the method yields good estimation of the system states for a power system with UPFC.

*Index Terms*—Flexible ac transmission system devices, interior point method, state estimation, unified power flow controllers.

- 4 A Kalman Filter Approach To Quasi-Static State Estimation In Power Systems** **417**  
Ellery A. Blood, Marija D. Ilić, Jovan Ilić, Bruce H. Krogh

*Abstract*—Static state estimation in electric power systems is normally accomplished without the use of time-history data. This paper presents preliminary work on the use of the discrete-time Kalman filter to incorporate time history into the state estimators. Transitional state equations are derived via linearization of the power flow equations. A simplified example using a decoupled real power flow solution demonstrates this technique.

*Index Terms*—Kalman Filter, Electric Power System, Static State Estimation, Time History

## POWER SYSTEM OPERATIONS AND SCHEDULING

- 1 A Genetic Algorithm Approach To Price-Based Unit Commitment** **425**  
Jignesh Solanki, Sarika Khushalani, Anurag Srivastava

*Abstract* – Deregulation creates competition amongst generator companies. The generator company objectives are to maximize their profit and to place proper bids in the market. In order to do this they need to determine the schedule and operating points based on the load and price forecasts. The traditional unit commitment problem aims at minimizing the cost of operation subject to fulfillment of demand. However in a deregulated environment the traditional unit commitment objective needs to be changed to maximization of profit with relaxation of the demand fulfillment constraint. This paper applies a genetic algorithm technique to price based unit commitment (PBUC) for GENCO with 3 generators and compares the solution with that obtained by dynamic programming. Proposed algorithm can be extended to ‘n’ number of generators.

*Index Terms* - Price based unit commitment, genetic algorithm, deregulation, dynamic programming.

- 2 A Two-Stage Stochastic Unit Commitment With Electricity Derivatives** **431**  
V. Siriariyaporn, F. T. Sparrow, D. J. Gotham

*Abstract* – A unit commitment problem has long been known in the class of short-term functions and decisions, inherited from vertically integrated utility. In the competitive environment, the problem has become more complicated due to the fact that any action taken will now influence profitability of decision maker such as generation companies, load serving entities, and so forth. Thus, not only do economic agents face operational risks, but they also need to procure their operations against financial risks from volatility in fuel, contract, and electricity prices. This leads to the evolution of stochastic unit commitment in this paper integrating risk management tools, i.e.,

electricity derivatives, so as to reduce the impacts from both operational and financial risks in the short run. The planning model is structured of stochastic mixed-integer program with recourse cost. A case study will be addressed with preliminary result presenting an improved solution.

*Index Terms* – stochastic programming, mixed-integer programming, unit commitment, risk management, power portfolio optimization, and power system planning and operation.

### **3 Reactive Power Reserve Issues**

**439**

Pablo A. Ruiz, Peter W. Sauer

*Abstract*—The lack of investments in transmission and the inductive nature of the network make reactive power of key importance in system operations and planning. Moreover, the many sources of uncertainty require reserves for the reliable operation of the power system. Reactive reserves can be viewed from the load's and the generation's perspective. From the load's perspective, the focus is on the margins to collapse, a key metric in voltage stability studies. From the generation's perspective, the focus is on the amount and value of reserves, a key need in system operations and planning, and in electricity markets. This paper defines reactive reserves as seen from the load's and generation's perspectives. The computational methods available for reactive reserves are discussed and compared. The heavy nonlinear dependence of reactive reserves on the network's and the generators' physical characteristics, the plausible contingencies, the direction of load growth and the generation dispatch is shown using numerical examples.

*Index Terms*—Reactive power, reserves, VQ curves, contingencies, capability curves.

## **POWER SYSTEM PROTECTION**

### **1 The Effect Of Inrush Current On Transformer Protection**

**449**

Li-Cheng Wu, Chih-Wen Liu, Shih-En Chien, Ching-Shan Chen

*Abstract*—Transformers are key components for electrical energy transfer in power system. Stability and security of transformer protection are important to system operation; we found that many mal-trip cases of transformer protection are caused by inrush current problems. The phenomenon of transformer inrush current has been discussed in many papers since 1958 [1-5]. Therefore, this paper will only discuss and analyze inrush current problems. Finally, this paper will also present two cases that were analyzed with the use of digital simulation technique to make COMTRADE files, to provide over-current protection and differential protection tests and the analysis of the effect of inrush current on transformer protection.

*Index Terms*—Over-current protection, Differential Protection, Inrush Current, COMTRADE files.

### **2 Imbedding Smart Relays In Large Electric Power Networks: The Scalability Problem And A Possible Solution**

**457**

Yi Zhang, Marija D. Ilić, Marija Prica, Ozan Tonguz

*Abstract*—As the need to meet the high security and reliability requirements of the electric power grids intensify, it is essential to make the existing relays smarter and more adaptive to changing system conditions. A successful implementation of enhanced relay performance requires both improved logic and the ability to manage computing and communications in near-real time. In this paper, we first summarize our recently introduced hypothesis-testing-based improved logic for over-current relays. The new contribution concerns the computational and communications problem associated with the large combinatorial burden of decision making underlying this new logic when relays are embedded in large electric power networks. We refer to this problem as the scalability problem. In this paper, a possible approach to solving the scalability problem is presented. In particular, this approach leads to: 1) Shorter simulation and training time prior to installing new relays; 2) Less data requirement for training and updating each relay; and 3) Faster dynamic

updating with lower communication traffic load. These features are essential for a physical cyber system (PCS) to effectively meet the goals of secure and reliable critical infrastructures, such as a large electric power system.

*Index Terms*—Large electric power systems, Hypothesis testing, Smart relays, Scalability, Monte Carlo simulations, Cyber Physical Systems (CPS), Critical network infrastructures.

### **3 Extension of Power Line Fault Location Techniques to Pressurized Line Diagnostics 465**

Kang Lin, Keith E. Holbert

*Abstract*—Researchers in power systems have investigated fault location methods for many years and have developed mature techniques. Analogies between hydraulic systems and electrical circuits are long established, and are useful for pipeline system analysis. Based on an electric model of the pressurized lines, this paper provides a feasibility study of extending power line fault location techniques to pressurized line leakage diagnostics. Theoretical derivations are presented in the paper.

*Index Terms*—pressurized systems, hydraulic-electric analogy, acoustic-electric analogy, fault location, traveling wave, impedance measurement, noise analysis.

### **4 Evaluation Of Position Of A Fault Current Limiter With Regard To The Circuit Breaker 475**

Anthony Frantz Alcidas, Moreau Jr. Saint Paul, Evenson Calixte

*Abstract*— Calculations were performed to examine the optimum location of a fault current limiter (FCL) with regard to the circuit breaker. The series-connected FCL was assumed to be associated with the circuit breaker in two positions: upstream and downstream from the circuit breaker. In both cases, the characteristics of the transient recovery voltage (TRV) appearing across the circuit breaker with FCL were studied under several fault locations. For both locations of FCL, the presence of the FCL reduces the severity of the circuit breaker duty. Whereas the difference in location of the FCL leads to no variation in the TRV characteristics and the fault current, locating the FCL downstream proved to lessen the voltage at the source-side terminal of the FCL, compared with the FCL located upstream from the circuit breaker. In other words, a gain in the device safety can be obtained by locating the FCL downstream from the circuit breaker.

*Index Terms*—Rate of rise of recovery voltage, location of FCL, circuit breaker, source-side voltage of FCL.

## **POWER SYSTEM SECURITY ASSESSMENT AND CONTROL**

### **1 SCADA Cyber Security Testbed Development 483**

C. M. Davis, J. E. Tate, H. Okhravi, C. Grier, T. J. Overbye, D. Nicol

*Abstract*—New technologies are increasing the vulnerability of the power system to cyber security threats. Dealing with these threats and determining vulnerabilities is an important task for utilities. This paper presents the development of a testbed designed to assess the vulnerabilities introduced by using public networks for communication.

### **2 Algorithm To Determine Minimum Contingency Set In Voltage Collapse Scenario 489**

Jeremiah D. Smith, Peter W. Sauer

*Abstract*—This investigation explores how many system elements must be outaged in order to cause system-wide voltage collapse. The IEEE 118-bus case was used to conduct simulations which implemented continuous steady-state load flows and power-voltage curves as indicators. The base

case maintained constant power factor load throughout, and applied given generator capability curve data and automatic generation control data to each unit. Using the  $n - 1$  contingency list, sensitivities were found for the system with respect to increased system load given a unique  $n - 1$  topology. The minimum number of system elements can be found by systematically repeating this process while outaging the most sensitive element at each step.

*Index Terms*—continuous load flow, p-v curve, p-v study, static bifurcation, voltage stability.

### **3 The Statistical Law Of Power System Blackouts** **495**

Bei Gou, Hui Zheng, Weibiao Wu, Xingbin Yu

*Abstract*—This paper proposes a statistical distribution of blackouts for power systems through the employment of statistical theory. Two groups of factors involved in the cascading events leading to blackouts are explored and explained. The mechanism of blackouts is proposed based on these two factors so that the statistical law of blackouts can be derived by using statistical and probability theory. The theoretical proofs are given in obtaining the statistical law of blackouts. Sequential Monte Carlo simulation method is utilized to perform the numerical tests on different power systems to justify the proposed law for blackouts.

*Index Terms*—Deterministic factors, probabilistic factors, Sequential Monte Carlo simulation, blackout analysis, hidden failure.

### **4 Power System Extreme Event Screening Using Graph Partitioning** **503**

Bernard

C. Lesieutre, Sandip Roy, Vaibhav Donde, Ali Pinar

*Abstract*— We propose a partitioning problem in a power system context that weighs the two objectives of minimizing cuts between partitions and maximizing the power imbalance between partitions. We then pose the problem in a purely graph theoretic sense. We offer an approximate solution through relaxation of the integer problem and suggest refinement using stochastic methods. Results are presented for the IEEE 30-bus and 118-bus electric power systems.

*Index Terms*—Graph Partitioning, Extreme Events

### **5 Multi-Area Security Assessment: Results Using Efficient Bounding Method** **511**

Louis Wehenkel, Mevludin Glavic, Damien Ernst

*Abstract*— We present our recent results on using previously introduced framework for multi-area security assessment in large interconnections. The basic idea of the framework is exchanging just enough information so that each operator can evaluate the impact in his control area of contingencies both internal and external to his area. We provide illustrations based on a localization concept known as efficient bounding method and recently introduced approximate DC model of the European interconnected system. In this paper we focus on four transmission system operators (within the approximate DC model): Belgium, France, Germany, and Netherlands (for both Summer and Winter-peak load conditions).

*Index Terms*— Security assessment, information exchange, multi-area large interconnection, black-box equivalent.

### **6 Effects Of Protection System Hidden Failures On Bulk Power System Reliability** **517**

Fang Yang, A. P. Sakis Meliopoulos, George J. Cokkinides, Q. Binh Dam

*Abstract* – Protection System hidden failures have been recognized as a contributing factor to power system cascading outages. However, in the current bulk power system reliability assessment practice, protection systems are generally assumed to be perfect, and the effects of hidden failures in protection systems are not taken into account. In this paper, the impact of protection system hidden failures on bulk power system reliability is investigated. A breaker-oriented bulk power system network model is developed to include detailed system substation configurations and associated

protection system schemes. Protection system constituents, such as transducers, relays, circuit breakers, may suffer from hidden failures. Hidden failures existing in transducers and relays can be detected by the advanced system real time monitoring and analysis technologies. Thus, the major concern of this work focuses on the analysis of hidden failures in circuit breakers. The hidden failure effects analysis shows that some initial system disturbances can result in the unnecessary outages of intact power system equipment because of hidden failures in circuit breaker trip mechanisms. Contingencies resulting from hidden failure outages are further evaluated by a security-constrained adequacy evaluation methodology to obtain their influence on system reliability. The proposed analysis procedure is demonstrated with a breaker-oriented 24-substation reliability test system, which is developed based on the IEEE 24-bus reliability test system and integrates explicit substation and protection system models in the network model. Evaluation results show that protection system hidden failures downgrade the system reliability level because they lead to the outages of undamaged equipment following initial system disturbances.

*Index Terms* – Hidden failure, protection system, circuit breaker- oriented substation model, bulk power system reliability assessment, advanced real time power system monitoring and analysis, security-constrained adequacy evaluation.

## **7 Cost Of Adequacy And Reliability Of Electric Power**

**525**

Roy Rietz, P.K. Sen

*Abstract*—Placing a dollar value on electric service reliability causing the disruption of critical social services and the inconveniences to businesses and individuals is nothing new to the electric power industry. The value the customers place on electric service reliability has been studied by utilities and others. This paper provides an overview and reviews the findings of a few such studies and compares the results.

*Index Terms*—Cost of Electricity, Reliability of Electrical Power.

## **8 Critical Voltage Monitoring Using Sensitivity And Optimal Information Machine**

**531**

Jovan Ilić, Le Xie, Marija D. Ilić

*Abstract*—This paper is motivated by the basic need to develop methods for on-line detection of abnormal conditions in large electric power systems. In order to implement truly effective near-automated tools for this purpose, it is necessary to overcome several problems such as: (1) excessive computational complexity; (b) unacceptable approximations; and, (3) dependence on full state measurements. In an attempt to overcome these major roadblocks, we combine tools capable of producing accurate results over broad ranges of conditions, such as off-line data mining and machine learning, with the approximate, well-understood deterministic methods, such as sensitivity-based methods. The resulting approach indirectly overcomes the dependence on full state measurements; the actual choice of the most relevant measurements becomes a result of such a combined approach. The proposed approach is illustrated on an example of detecting a given voltage threshold violation.

*Index Terms*—Sensitivity analysis, information theory, decision trees, electrical distance, event monitoring, abnormal conditions.

## **9 Towards Grid Modernization Through Enhanced Communications And Computing: Novel Performance Index And Information Structure For Monitoring Voltage Problems**

**537**

Le Xie, Jovan Ilić, Marija D. Ilić

*Abstract*—In this paper we observe that recent voltage problems, including August 2003 blackout, are often caused by the lack of adequate and timely information. We study the type of information essential to avoiding such problems in the future. The needed information concerns (a) choice of a performance index characterizing problems of interest; (b) information structure necessary to monitor the performance index with acceptable accuracy; and, (c) the interdependence between (a) and (b). We propose a novel performance index and corresponding information structure. This information structure requires very little or no communications between decomposed subsystems. Illustrations of proposed concepts in multi control area systems are presented. These findings form a

basis for grid modernization through communications and computing for improved voltage support in multi control area system.

*Index Terms*—Voltage monitoring, grid modernization, communications in electric power system, performance index, system decomposition, multi-control area operations.

## DISTRIBUTED GENERATION AND RENEWABLE ENERGY

### **1 Alternative Energy Distributed Generation: Need For Multi-Source Operation** **547**

M. Hashem Nehrir, Caisheng Wang, S.R. Guda

*Abstract*—Power deregulation, which resulted in restructuring of the power industry, and shortage of transmission line capacities have led to increased interest in the use of distributed generation (DG) sources, mainly at the distribution level near load centers, for support of the utility grid. Moreover, technological advances in renewable (wind, solar) and other alternative energy DG (AEDG) sources, e.g. microturbines and fuel cells, coupled with environmental concerns over the use of conventional steam power plants have developed especial interest in their use. However, because of the non-dispatchable nature of renewable energy and slow nature of some alternative energy power generation sources, e.g. fuel cells, multi-source operation of these sources and/or their parallel operation with a storage device is necessary to make their operation more reliable. This paper discusses the need for multi-source operation of AEDGs. It reviews four different AEDG sources - wind, solar photovoltaic (PV), microturbine, and fuel cells – and discusses their multi-source operation for better power management and reliability.

*Index Terms* – Alternative energy, distributed generation, multi-source operation

### **2 SOFC-Based Fuel Cells For Load Following Stationary Applications** **553**

Nagasmitha Akkinapragada, Badrul H. Chowdhury

*Abstract*— This paper presents a dynamic model of SOFC and the response of the fuel cell for sudden load changes. Slow response of the fuel cell prevents it from following the load. Hence connection with the DC/DC buck-boost converter is required. The models are developed in PSCAD with and without a feedback control system. Power characteristics obtained in order to validate the need of the DC/DC converter which allows the SOFC system to be used for load following applications.

*Index Terms*— Dynamic model, Solid Oxide fuel cell, DC/DC converter, load following.

### **3 A Fuzzy Optimization Approach To PV/Battery Scheduling With Uncertainty In PV** **561**

Michael Urbina, Zuyi Li

*Abstract*—With new developments in technologies, grid-connected photovoltaic (PV) systems are becoming increasingly attractive as a generation technology, due to many factors, including environmental concerns and transmission congestion management. Additionally, PV generators are often paired with energy storage elements, such as batteries, to store excess power generated during off-peak hours to be returned to the system when generation is more expensive. For system economic operation, the PV/Battery commitment and dispatch must be optimal. However, the generation is not known in advance, as it is dependant on weather factors that are not completely predictable. This paper presents a unit commitment and economic dispatch solution for the PV/Battery system using fuzzy optimization to model the uncertainty in PV generation based on mixed-integer programming.

*Index Terms*— Day-Ahead Scheduling, Fuzzy Optimization, Photovoltaic

- 4 Electrolysis: Opportunities For Electric Power Utilities In A Hydrogen Economy** **567**  
Benjamin Kroposki, Johanna Levene, Kevin Harrison, P.K. Sen, Frank Novachek
- Abstract*—As the demand for energy, both in the form of electricity and transportation fuel, increase around the world, a renewed focus on converting to a *hydrogen economy* has emerged. Recent advancements in hydrogen technologies and renewable energy applications show the promise of converting to a hydrogen-based economy should become economically feasible in the near- to mid-term. As the shift from a fossil fuel to a hydrogen based economy unfolds, electric power utilities should be in a position to understand the potential benefits and impacts. This paper provides a historical perspective of hydrogen, discusses the process of electrolysis for hydrogen production especially from solar and wind technologies and describes the opportunities for electric power utilities.
- Index Terms*—Hydrogen, Electrolysis, Renewable Energy, Wind, Solar
- 5 Providing Renewable Energy For The Wolf Researchers At Windigo, Isle Royale** **577**  
David A. Meyer, Eric D. Welch, Patric Rinckey, Leonard Bohmann
- Abstract*— The use of renewable energy (RE) requires a complicated design when meeting complex needs in National Parks. The design of a renewable energy system for the wolf researchers at Isle Royale National Park, Michigan provided many challenges due to location and also limitations to weather data. The paper provides and design for a RE system to meet the needs of the researchers.
- Index Terms*— Isle Royale, Net Present Cost, Renewable Energy, Wolf Research
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H. Louie, K. Strunz
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- Index Terms*—Energy storage, hydrogen economy, optimization methods, wind energy.
- 7 Analysis Of The Dynamic Operation Of Experimental Wind Farms In Mexico** **591**  
J.A. Huerta-Balcazar, A. Medina
- Abstract*— In this contribution, the dynamic operation of two pilot Mexican wind farms is analyzed. These wind farms are located in La Venta, Oaxaca and Guerrero Negro, Baja California México, respectively. Results are shown for the dynamic behaviour of the wind farms operating in isolated mode and connected to the Mexican grid. The Electromagnetic Transient simulator PSCAD/EMTDC V 4.0 has been used to carry-out the reported case studies.
- Index Terms* — Dynamic operation, wind farms, Electromagnetic Transient, PSCAD/EMTDC.



**8 Design Of An Offshore Wind Farm On Lake Michigan: Part 1** 597  
Whitney J. Wilson, M. M. Morcos

*Abstract* -- The potential of offshore wind is among the newest technologies in renewable energy. Utilizing a 10% wind speed increase over open waters, an increase in power production can be seen of approximately 30%. In the present study, a location on Lake Michigan is determined based on the wind resources, lakebed depth, and ease of access to existing onshore substations and transmission lines. An analysis of the wind resources at the site will be used to determine if the development of the site is feasible. A turbine review and park layout analysis is completed to give the base for Part 2 (the design phase). Part 2 outline is presented.

*Index Terms* -- Offshore wind, Lake Michigan, Wind Speed Analysis.

**9 Interfacing An Avista SR-12 Hydrogen Fuel Cell To An Analog** 603  
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Chris Cockrell, Daniel Hubbard, Adam Lint, Herbert L. Hess, Brian K. Johnson

*Abstract*—Alternative energy sources are becoming a focus in the energy industry as the world realizes that its dependency on fossil fuels must diminish because of pollution, oil prices, and other factors. For this reason, it's important that students do have exposure to some of the alternative energy sources available in the 21<sup>st</sup> century. The analog model power system provides students with the opportunity to explore and understand a typical power transmission system. Course instructors wish to expand and improve this system to include alternative energy sources. This project facilitates the learning experience for students and enables them to experiment with fuel cells as distributed generation sources.

*Index Terms*—Hydrogen Fuel Cell, Alternative Energy, Synchronization, Analog Model Power System.

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Juan Miguel González, Juan M. Ramirez

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*Index Terms*— ac-ac power conversion, power electronics, power control.

**2 Dynamic Simulations Of Cascading Failures** 619  
Hong Tao Ma, Badrul H. Chowdhury

*Abstract*—Steady state analysis cannot provide the details of how system evolves in cascading failure. Dynamic response of generator plays an important role in power system operation and blackout events. In this paper, classical generator and detail generator models are integrated into system model for cascading dynamic simulations.. The cascading scenarios are compared using both steady state and dynamic simulations. Classical models are simpler; however, the detailed generator model is more accurate. Generator performance of speed deviation and angle deviations as well as the bus voltage profile are investigated for various scenarios. The IEEE 118-bus, 20-generator test case is used as the test system.

*Index Terms*—Blackout, generator modeling, power system dynamic performance, transient stability.

- 3 Some Reflections On Model Predictive Control Of Transmission Voltages** 625  
Mevludin Glavic, Thierry Van Cutsem
- Abstract*— This paper deals with the application of algorithms inspired by Model Predictive Control to solve voltage-related power system control problems in both normal and emergency operating conditions. In the first part of the paper, we identify critical issues for a practical implementation of this methodology, and analyze how far these requirements have been met so far. In the second part, we outline a voltage control scheme that hopefully addresses the above issues. The central idea of this scheme is a static optimization to determine target control values, followed by a dynamic optimization to produce a feasible transition, both carried out in the closed-loop mode of Model Predictive Control.
- Index Terms*— Model predictive control, quasi steady-state model, optimization, voltage control, secondary voltage control.
- 4 The Effect Of Various UPFC Operating Points On Transient Stability** 633  
Mahyar Zarghami, Mariesa. L. Crow
- Abstract*—In this paper, it is shown that using the power injection model for a UPFC, there exists a set of operating points for which the same amount of ac bus voltage and active/reactive series power injections can be evaluated. These various operating points are designated by different dc bus voltages ( $V_{dc}$ ) and modulation amplitudes ( $k_1, k_2$ ) and phases ( $\alpha_1, \alpha_2$ ).
- Simulations show that the dynamic behavior of a UPFC could be related to its pre-fault operating situations. The question to be answered is to verify which operating point would be the best candidate from a network stability point of view. A linear approach based on the eigenvalue problem has been used to answer the question and satisfactory results have been outlined.
- Index Terms*—UPFC, Transient Stability
- 5 Electromechanical Modal Behavior During A 48 Hour Interval Using Nonparametric Methods** 641  
Francis K. Tuffner, John W. Pierre
- Abstract*—In this paper, the behavior of dominant electromechanical modes is investigated. Forty eight hours of Western Electricity Coordinating Council (WECC) power grid data from June 13, 2005 to June 15, 2005 is analyzed using fundamental nonparametric techniques. The analysis included taking the mean and variance of 10 minute data frames and a modification of the short-time Fourier transform (STFT) on 15 minute overlapping segments of data. These analyses provide information into how the electromechanical modes in the western power grid behave over a normal day and provide insight needed for more advanced analysis techniques.
- Index Terms*— WECC data, power system monitoring, nonparametric analysis, electromechanical mode behavior.
- 6 Mitigation Of Voltage Sags With Phase Jump Using A Dynamic Voltage Restorer** 647  
Brice J. Quirl, Brian K. Johnson, Herb L. Hess
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Two control methods are analyzed with simulations performed in SIMULINK.

*Index Terms*—Control, dynamic voltage restorer (DVR), power quality, phase jump, voltage sag mitigation.

## POWER LINE INSULATORS AND CIRCUIT BREAKERS

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Ali Zolfaghari, Andres Moreira, Walter Collett

*Abstract*—The contact dynamics in a low-voltage circuit breaker contact assembly have been modeled using a multiphysics approach. The approach considered the effects of current constriction and Lorentz forces acting to separate the contacts, while incorporating the presence of the arc established between the open contacts in providing a path for continued current flow. Contact movement, due to these forces as well as additional tripping mechanism action, was determined. The results compare well with high-speed x-ray video images captured during an actual short circuit test.

*Index Terms*—circuit breaker, electromagnetic, finite element, multiphysics

- 2** **Non Linear Regression Model To Predict Flashover Of Nonceramic Insulators** **663**  
S. Venkataraman, R. S. Gorur

*Abstract*-- This work is based on the application of non-linear regression analysis technique to develop a model for prediction of flashover voltage of non-ceramic insulators (NCIs). The superiority of nonlinear model over a linear model is demonstrated. Surface resistance measurement and flashover experiments were performed with field aged samples. This work finds applications in distribution class insulators and can be extended for higher voltage class of insulators.

*Index Terms*— Flashover, Gauss Newton iteration, Regressor variable, Response variable, Surface resistance

- 3** **Failure Probability Methodology For Overdutied Circuit Breakers** **667**  
Q. Binh Dam, A. P. Sakis Meliopoulos

*Abstract*—With the expansion of the grid, fault current levels increase and circuit breakers are subject to increasing duties and stresses, and are more prone to failures. Because the performance of breakers is critically affecting the operation and protection of the power grid, it is important to quantify the probability of failure of the circuit breakers to assess the risks, prioritize maintenance and replace the equipment. This paper describes a methodology to compute the absolute, stress-induced failure probability for a given circuit breaker of a power system. We compute the breaker probability of failure that accounts for all the characteristics of the network in which the circuit breaker operates, including the physical properties of the system. The knowledge of this result is of paramount importance for utilities to pinpoint the circuit breakers that may become overdutied (underrated) as a result of increased fault currents due to generation capacity expansions. As a side benefit, appropriate actions can be defined to prepare the protective equipment to handle constraints imposed by higher fault currents.

*Index Terms*—Circuit breaker rating, DC offset, fault current distribution, overduty, probability of failure.

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