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Monday, November 9

Monday, November 9 8:00 - 8:50

Keynote 1: Renewables and eMobility - Partners in Realizing the Energy Transition?

Dr. Rik De Doncker

Professor and Director at E.ON Energy Research Centre, ISEA at RWTH Aachen University, Germany.

Monday, November 9 8:55 - 9:35

Keynote 2: Monitoring the grid in transition

Dr. Ferdinanda Ponci

Professor at E.ON, Energy Research Centre, RWTH Aachen University, Germany

Monday, November 9 9:40 - 10:15

Keynote 3: The EU Approach to the Digitalization of the Energy System

Prof. Antonello Monti

Director of the Institute for Automation of Complex Power System at RWTH Aachen University, Germany

Monday, November 9 10:25 - 12:25

IP1: Industry Panel 1

Monday, November 9 12:25 - 12:55

Lunch 1: Lunch break - Monday

Monday, November 9 13:00 - 13:55

Keynote 4: Grid Modernization: Technological Advancements Beyond Smart Grid

John McDonald

Smart Grid Business Development Leader, GE

Monday, November 9 14:05 - 15:05

Tutorial 1: 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces

Dr. Babak Enayati

Technology Deployment Manager at Nation Grid, USA

Monday, November 9 15:30 - 16:25

Keynote 5: Taking a Value Chain Approach to Energy Transformation

Elizabeth Shirt

Managing Director at GLOBE Series

Monday, November 9 16:30 - 17:30

Paper Session 1: Paper Session 1

Chairs: Konstanitn Gerasimov (EPCOR, Canada), Gregory J Kish (University of Alberta, Canada)

16:30 ***Cost Optimized Load Allocation for Dual Radial Customers...1***

Matthew Yee and Vinson Kan (Toronto Hydro, Canada)

As load grows in areas of a distribution system, it can be difficult to find the capacity necessary to supply new customers. In order to accommodate new customers, large capital investments can be made, such as upgrading transformers and switchgear at transformer stations, or constructing entirely new transformer stations. However, these investments may be very costly and take many years to construct. It is proposed that existing infrastructure may be utilized more efficiently to make use of available capacity before opting for larger scale capital projects to add capacity to a system. It can be difficult to determine how to shift load within a distribution system in order to gain capacity in the areas required. This paper presents a method to optimally select a rearrangement strategy to accommodate new customer loads. Specifically, the optimization model aims to shift dual radial customers at the lowest cost and effort to make room for the emerging customers.

16:48 ***Analysis of Empirical Mode Decomposition-based Load and Renewable Time Series Forecasting...7***

Nima Safari and George Price (SaskPower, Canada); Chi Yung Chung (University of Saskatchewan, Canada)

The empirical mode decomposition (EMD) method and its variants have been extensively employed in the load and renewable forecasting literature. Using this multiresolution decomposition, time series (TS) related to the historical load and renewable generation are decomposed into several intrinsic mode functions (IMFs), which are less non-stationary and non-linear. As such, the prediction of the components can theoretically be carried out with notably higher precision. The EMD method is prone to several issues, including modal aliasing and boundary effect problems, but the TS decomposition-based load and renewable generation forecasting literature primarily focuses on comparing the performance of different decomposition approaches from the forecast accuracy standpoint; as a result, these problems have rarely been scrutinized. Underestimating these issues can lead to poor performance of the forecast model in real-time applications. This paper examines these issues and their importance in the model development stage. Using real-world data, EMD-based models are presented, and the impact of the boundary effect is illustrated.

17:06 ***Fast AI-Based Power Flow Analysis for High-Dimensional Electric Networks...13***

Ali R. Al-Roomi and Mohamed E. El-Hawary (Dalhousie University, Canada)

It is not revealing a secret to say that most of the power system studies highly depend on power flow (PF) analysis.This tool provides a frozen picture of dynamic electric network sunder certain conditions. Nowadays, many iterative techniques are available to solve PF problems. The most popular one is built based on the Newton-Raphson (NR) algorithm. Although NR can obtain highly accurate solutions, its processing speed significantly decreases as the problem dimension increases. Thus, a wise selection should be taken to compromise between the processing speed and the solution accuracy. For some critical studies, such as contingency analysis, the processing speed is a very important factor that forces some energy management systems (EMS) to apply DC and AC-DC approximations. This paper studies the processing speed when artificial neural networks (ANNs) are adopted to solve PF problems. First, the standard 9-bus test system is used. Then, the processing speed of ANNs is examined through a very large virtual network. This AI-based technique can hit multiple birds with one stone. Adding to the processing speed and the solution accuracy, it can also solve the uncertainty issue by feeding ANNs with actual PF readings measured from some mounted instrument devices.

17:24 ***Peak-Load Forecasting of Nova Scotia During Winter Using Support Vector Machine with Optimally Configured Hyperparameters...19***

Ali R. Al-Roomi and Mohamed E. El-Hawary (Dalhousie University, Canada)

Modern machine learning (ML) computing systems proved themselves as effective tools to forecast electric load demand. However, their internal learning optimization algorithms could trap into local optima. To tackle this issue, one of the practical ways is to optimize their hyper parameters. This paper presents a simple way to do that by using the most basic random search algorithm (RSA) as a global

optimizer. Support vector regression (SVR), which is a special type of support vector machine (SVM), is used. To do that, the total number of iterations is divided into multiple stages, and then RSA is sequentially executed where the search space is minimized at the end of each stage. The process ensures reaching a very rich area of near-optimal SVR settings, which can then be picked up as final candidate solutions. This technique is applied to forecast the peak-load of Nova Scotia - Canada during the winter of 2018-2019. The prediction accuracy of this effective simple technique can reach 99.89% and 97.17% for the training and test sets,respectively.

17:42 ***A Two-Stage Deep-Learning Based Detection Method for Pipeline Leakage and Transient Conditions...26***

Iman Amini, Yindi Jing and Tongwen Chen (University of Alberta, Canada); Amanda Colin and Gordon Meyer (Suncor Energy Logistics Corporation, Canada)

Nowadays, Leakage detection is of great importance as pipelines are the major means of transporting hydrocarbon fluids and gases. In this paper, a novel two-stage detection method is introduced to differentiate normal, leakage and transient conditions of pipelines. In this method, feature vectors are constructed from the flow difference and pressure using leakage characteristics, and are normalized with the modified hyperbolic-tangent estimator. An artificial neural network is used in the first stage of detection to differentiate normal and abnormal conditions with the feature vectors as the inputs. In the second detection stage, a simple logic is used to distinguish leakage and transient from abnormal time-windows. In addition, a pre-set leak-size tolerance is used to trigger alarms for detected leakage time-windows. The results for the cases of using different machine learning methods and varying leak-size tolerances are given. The method has been shown to have higher detection performance and less false alarms in comparison with the line balance and Kantorovich distance methods.

18:00 ***Smart Meters Tackling Energy Poverty Mitigation: Uses, Risks and Approaches...31***

Lluc Canals Casals (Universitat Politècnica de Catalunya & Catalonia Institute for Energy Research, Spain); Sergio Tirado (Universitat Autònoma de Barcelona, Spain); Mattia Barbero and Cristina Corchero (Catalonia Institute for Energy Research, Spain)

Big data analysis is becoming an increasing field of interest for research to analyse, identify and predict final user's behaviour. For this reason, in the energy sector, smart metering is generally used to find new business opportunities and, theoretically, it is said that it could also help to fight energy poverty issues. Nonetheless, when tackling social injustice issues, the deployment of massive technology might also bring other side effects. This study analyses the capability of smart metering to mitigate energy poverty in Europe according to the current approaches of projects and the risks it might bring to the more vulnerable layers of our society.

18:18 ***Artificial Bee Colony-Based Routing for Mobile Agents on the Internet of Things...37***

Shamim Yousefi and Farnaz Derakhshan (University of Tabriz, Iran); Hadis Karimipour (University of Guelph, Canada)

In the critical infrastructure of the Internet of Things (IoT), the most efficient approach for data collection is to employ the software Mobile Agents (MAs). In MA-based data collection, the energy exhaustion of wireless communications is much more than the data processing costs. Hence, a crucial challenge in IoT is to offer optimal routing for MAs to save the energy of devices. In this paper, we present a new routing method for MAs on IoT using the Artificial Bee Colony (ABC) algorithm. In our approach, the Euclidean distance between sensor/devices, residual energy, and data priority are considered to measure the appropriateness of the generated routing. Simulation analysis demonstrates that our proposed method improves the energy exhaustion, lifetime, transmission delay, and reliability of IoT.

18:36 ***A CPFL Energia Fraud Detection Model Based on Geographic Census Sectors Analysis...42***

Flavio Alceu, Lidia G Gusmão, Douglas Akassaka and Hugo Helito (CPFL Energia, Brazil)

Non-technical losses and irregular energy consumption severely jeopardize distribution utilities, and customers in general. Therefore, reducing them and pursuing revenue recovery stand for a crucial mechanism to secure companies financial health and quality in provided services. In such context, this work incorporates socioeconomic variables from demographic census into fraud detection models to improve the existing algorithms and enhance their performance. The inclusion of geographically sectioned explanatory characteristics reduces the existing models bias, preventing that only vulnerable areas are addressed in inspections, whereas others are unwisely left out. In order to achieve so, demographic census data are combined with historical inspection results and myriad predictive modeling tools to evaluate sectors fraud scores - i.e., the likeliness that an inspection will lead to the identification of a fraud within a given sector - and point out areas to which more inspections should be directed. The final proposed methodology applies Linear Regression, Spatial Auto-regressive Models, Geographically Weighted Regression and Logistic Regression techniques and the inclusion of sectors fraud scores has increased model accuracy to 72% (a 3 percentage points growth), improving success rates for fraud detection.

18:54 ***Contouring Method Considerations for Power Systems Applications...47***

Jessica L. Wert, Zeyu Mao, Hanyue Li and Thomas J. Overbye (Texas A&M University, USA)

Contouring can be used to enhance engineers' situational awareness during power system studies and events. This paper compares two contouring methods (Shepard and Delaunay-based) for power system applications. Power system case studies are presented to demonstrate and discuss contour choices in various steady-state and transient applications. Discussion is centralized around the following features: relative computation speed, realism, contour boundary, and smoothness.

19:12 ***Comparison of the Smith-Waterman and Needleman-Wunsch Algorithms for Online Similarity Analysis of Industrial Alarm Floods...52***

Md Rezwan Parvez (University of Alberta, Canada); Wenkai Hu (China University of Geosciences, China); Tongwen Chen (University of Alberta, Canada)

Alarm floods are considered to be the major obstacles that prevent the smooth process operations of large-scale industrial facilities. During an alarm flood situation, industrial operators often get confused by too many alarms and thus have difficulties in observing and handling critical alarms. In recent years, sequence alignment based similarity analysis has emerged as an effective way to handle alarm floods. Alarm floods caused by the same fault are very likely to consist of the same group of alarms in a certain sequential order. Conducting realtime sequence alignment of industrial alarm floods can help operators to quickly recall the root cause and make prompt corrective actions. This paper proposes the online similarity analysis of alarm floods based on the Smith-Waterman and Needleman-Wunsch algorithms, and compares their differences and application conditions. Case studies are provided to illustrate the proposed online similarity analysis methods and the differences of the two sequence alignment algorithms.

19:30 ***A Prediction Interval Based Cascading Failure Prediction Model for Power Systems...58***

Mohamed O Mahgoub (University of Saskatchewan, Canada); Seyed Mahdi Mazhari (University of Tehran, Iran); Chi Yung Chung and Sherif Faried (University of Saskatchewan, Canada)

Power system blackouts result in massive supply interruptions leading to significant financial and societal losses. Since the majority of blackouts begin as a cascading failure (CF), early detection of this event can help stop the propagation of a single incident into a large-scale blackout. In this paper, a real-time load-based model for CF prediction is proposed. The developed method feeds phasor measurement units (PMU) data into a prediction interval (PI) neural network (NN) model reinforced with a data-fusion-based self-correction algorithm. The main contribution of the paper is that the model provides load shedding locations and prediction intervals regarding the expected blackout size so that the operator, or the automatic controller, can better react to the CF situation. The simulation results indicate that the proposed method is fast and accurate in predicting the size of the resulting blackout or load shedding following a CF.

19:48 ***Multi-Unit Market-Based Mechanism Design in Cloud Secondary Markets...64***

Seyed Mohammad Reza Dibaj and Ali Miri (Ryerson University, Canada); Seyed Akbar Mostafavi (Yazd University, Iran)

The on-demand pricing mechanism, which is one of the most common pricing methods for cloud services, implements the pay-as-you-go model for cloud service users. Moreover, it provides the possibility of cost management and the flexibility of the service time for their service users. Since the on-demand mechanism does not provide all the providers' required information, it is not of interest to them. Thus, the service providers are more inclined to use futures contracts so they can accurately estimate the future needs of their users and plan for the requirements. To add the users' required flexibility to futures contracts, a new concept is introduced to cloud ecosystems, called the secondary market. In this secondary market, brokers and reseller buyers act as mediators to provide the required VMs for the service users. This paper provides a mechanism design that includes a market-based pricing model and a resource allocation mechanism in such environments. The proposed mechanism is based on dynamic double auction models and the suggested market price is computed based on the critical point that is obtained from the presence of the agents. Our experimental results prove that the proposed mechanism outperforms the other algorithms in terms of the overall utility, and the allocation efficiency.

20:06 ***A Reinforcement Learning Based Power System Stabilizer for a Grid Connected Wind Energy Conversion System..72***

Rahul Kosuru (Carleton University, Canada); Pengcheng Chen (Zhejiang univ of tech, China); Shichao Liu (Carleton University, Canada)

When connecting renewable sources wind turbines to a power grid, low frequency oscillations caused by wind turbines may threaten the stability of the entire electrical power system. Power system stabilizers (PSSs) are used to damp the low frequency oscillations. However, these PSSs are usually designed based on small-signal models around a fixed wind speed and their performances could be degraded when wind speed varies in a real-time pattern. In this paper, a reinforcement learning (RL) based power system stabilizer is designed for a grid-connected double-fed induction generator (DFIG) based wind system to enable the online optimization of control gains when wind speed varies. In specific, the Q-learning based PSS is designed in the rotor-side controller of the DFIG based wind system. In this method, the active power change is defined as the state, and the control output of the rotor side controller (RSC) is used as the action. A grid-connected DFIG based wind system is simulated and the results show that the Q-learning based PSS can quickly adjust the control parameters online and damp the low frequency oscillation under a time-varying wind speed condition.

20:24 ***Ensemble Learning for Charging Load Forecasting of Electric Vehicle Charging Stations...77***

Xingshuai Huang (McGill University, China); DI WU and Benoit Boulet (McGill University, Canada)

Electric vehicles (EVs) can help reduce the dependency on fossil oil and increasing concerns on environmental pollution problems. However, due to the complex charging behaviors and the large charging demand, EV charging has imposed a large burden on the power system. The forecasting of electric vehicle charging loads can help address the above issues by providing power systems with the future load as a reference for energy dispatching. Machine learning method shave demonstrated their effectiveness for short-term load forecasting. Different from previous works, this paper proposes a novel ensemble learning-based forecasting model by combining three base learners including the artificial neural network(ANN), recurrent neural network (RNN), and long short-term memory (LSTM) algorithms. Specifically, a linear regression(LR) algorithm is used to learn the weight of each base learner. The feasibility and advantage of our proposed model are demonstrated by experiments conducted on a real-world data set and comparisons with the other four baselines.

20:42 ***Deep Reinforcement Learning for Electric Transmission Voltage Control...82***

Brandon L Thayer (USA); Thomas J. Overbye (Texas A&M University, USA)

Today, human operators primarily perform voltage control of the electric transmission system. As the complexity of the grid increases, so does its operation, suggesting additional automation could be beneficial. A subset of machine learning known as deep reinforcement learning (DRL) has recently shown promise in performing tasks typically performed by humans. This paper applies DRL to the transmission

voltage control problem, presents open-source DRL environments for voltage control, proposes a novel modification to the "deep Q network" (DQN) algorithm, and performs experiments at scale with systems up to 500 buses. The promise of applying DRL to voltage control is demonstrated, though more research is needed to enable DRL-based techniques to consistently outperform conventional methods.

21:00 ***A Review of Recent Advances on Reinforcement Learning for Smart Home Energy Management...90***

Huiliang Zhang, DI WU and Benoit Boulet (McGill University, Canada)

Smart home energy management is one of the core problems in modern power grids. With the increasing adoption of different types of electric appliances and on-site intermittent renewable energy generation, it has been very challenging to use conventional control techniques for such energy management problems. Reinforcement Learning (RL) has attracted growing research interest recently; it also demonstrates its great potential to enhance smart home performance while addressing some limitations of other advanced control techniques, such as model predictive control. In this paper, we present a review of the recent advances on RL for smart home energy management. The problem of smart home energy management, the background for RL algorithms, and the survey of recent advances on RL for the smart home are presented. However, even though RL-based smart home controls have gained increasing research interest, it is in the beginning research stage. Several questions in this field are still not well-studied and worth further investigation, including data-efficient reinforcement learning, safety concerns, and how to include human behaviors in the loop of making control decisions. In this short survey, we also discuss the challenges and potential opportunities using RL in smart home control.

21:18 ***BC Hydro's Methodology for Distribution Technical Loss Estimation Using Smart Technologies...96***

Jae Sung Park, Alice Cheung, James Profitt and Parvir Girn (BC Hydro, Canada)

The introduction of Smart Technologies such as Advanced Metering Infrastructure (AMI) and other distribution system metering (e.g. SCADA) has enabled BC Hydro to make advancements in its ability to estimate both technical and non-technical distribution losses on individual distribution assets. This report seeks to detail the logic for calculating such losses using this data and to demonstrate the improvements in distribution loss estimate accuracy that can be achieved as a result.

21:36 ***Computational Acquisition of Meteorological Data for Applications in Electric Power Systems...101***

Nigel J Woodhouse and Petr Musilek (University of Alberta, Canada)

Humans heavily rely on mother nature for hospitable living conditions, plentiful harvests, and energy generation, yet have no control. The best humans can do is plan and predict. Climatological statistics and forecasts provided by public weather services serve as traditional methods for obtaining meteorological information. However, through Numerical Weather Prediction models, one can simulate climate fluctuations with high spatial resolution over long periods. Uses for Numerical Weather Prediction models include analyzing the energy flux of smart homes, smart grid technology, impact on power transmission infrastructure, and energy production through wind and photovoltaic farms. The efficiency of these technologies is dependant on the surrounding weather phenomena. The optimization of these systems to the environment upon which they exist can both reduce wasted resources and the economic impact on consumers and organizations. This paper outlines the methods used for the acquisition of weather data through computer simulations at a spatial resolution of 1.2 km in 15-minute intervals with an accuracy of 2%.

21:54 ***GridKG: Knowledge Graph Representation of Distribution Grid Data...106***

Yashar Kor, Liang Tan, Marek Reformat and Petr Musilek (University of Alberta, Canada)

Distribution grid systems are complex networks containing multiple pieces of equipment. All of them interconnected, and all of them described a variety of pieces of information. A knowledge graph provides an interesting data format that allows us to represent information in a form of graphs, i.e., nodes and edges - relations between them. In this paper, we describe an application of a knowledge graph to represent information about a power grid. We show the main components of such a graph - called GridKG, a simple process of identifying electrical paths, and a few examples of grid analysis related to primary switches.

22:12 ***Representative Profiling of Prosumers with Local Distributed Energy Resources and Electric Vehicles Using Unsupervised Machine Learning...111***

Daniel Mabuggwe (Ontario Tech University, Canada); Walid Morsi (University of Ontario Institute of Technology, Canada)

In this paper, the representative profiles of residential prosumers owning local distributed energy resources (L-DERs) and plug-in electric vehicles (PEV) at different levels of generation and demand are identified. The Pecan Street household dataset is used in this work with high-granularity data of one second and it includes the roof-top solar photovoltaic (PV), home battery energy storage system (HBESS) and PEV profiles. Because of the large variance in the data due to such high granularity and different levels of generation/demand in the residential profiles, this study presents a systematic approach to identify a comprehensive list of representative profiles. The machine learning techniques such as principal component analysis (PCA), and the unsupervised K-means clustering and K-nearest neighbor are employed to identify the representative profiles. The study included 123 residential homes, which includes a set of different combinations of PVs, PEVs and HBESS and the results have shown that they can be represented by only 17 representative profiles. This reduction in the number of representative profiles at such high-granularity will lead to significant advances in accelerating the distribution system time-series analysis studies in particular when considering the presence of prosumers with L-DERs and PEVs.

22:30 ***Scenario Selection for Generation Expansion Planning with Demand and Wind Uncertainty...118***

Yasaman Mozafari and Bill Rosehart (University of Calgary, Canada)

In this paper, representative operating scenario selection for generation expansion planning with demand and wind uncertainty is addressed. Kmeans++ clustering technique is used to generate the operating scenarios and the results are compared with the commonly

used duration curve and kmeans clustering techniques in terms of cost and reliability. Furthermore, impact of data correlation on the scenario selection and investment results is investigated. The planning problem is simulated for the IEEE 24-bus test system.

22:48 ***Dependent Wind Speed Models: Copula Approach...124***

Md Amimul Ehsan and Amir Shahirinia (University of the District of Columbia, USA); Jeff Gill (American University, USA); Nian Zhang (University of the District of Columbia, USA)

Despite widespread availability, the nature of renewable energy resources is yet to understand fully to harness their optimum benefits. The aggregated portfolio and inter-play of geographically spread wind farms/resources is critical for intelligent extrapolation, yet less explored. In this paper, we focus on understanding the dependency structure of wind speeds. A multivariate cumulative distribution function- "Copula" is used to find the joint distribution of wind speed pairs. We have investigated copula family selection for varying wind speed pair distances ranging from 3 to 2700km. A case study for Joe-Frank (BB8) copula shows efficient joint distribution fit for a selected wind speed pair with a standard error of 0.0094.

23:06 ***A Comparative Analysis of Machine Learning Models for Prediction of Passing Bachelor Admission Test in Life-Science Faculty of a Public University in Bangladesh...130***

Md. Abul Ala Walid (Bangabandhu Sheikh Mujibur Rahman Science and Technology University (BSMRSTU), Bangladesh); S. M. Masum Ahmed (University of Mons (Umons)); S M Shibly Sadique (Bangabandhu Sheikh Mujibur Rahman Science and Technology University (BSMRSTU), Bangladesh)

The usage of neoteric technology like data mining and machine learning in the interest of the educational welfare of the students has been dramatically soared. In this work, we concentrate on the educational amelioration of university admission test candidates using state of the art data mining and machine learning methods. From the outset, a dataset has been prepared by analyzing and utilizing the limited features which are most relevant for prediction. In this regard, the data collection process is performed based on the vis-à-vis survey, and data are taken from the students who participated in the bachelor admission test exam of the Life-Science faculty of Bangabandhu Sheikh Mujibur Rahman Science and Technology University (BSMRSTU). The dataset includes 343 instances with 10 variables. As machine learning methods are robust on balanced datasets, we defined two balanced datasets generated from the original set on the basis of two mostly used re-sampling techniques. Using five selected supervised machine learning classification methods; Logistic Regression, Support Vector Machines (SVM), Artificial Neural Networks (ANN), Random Forest, and Adaboost the prediction has been performed. To evaluate our models as well as check generalization capability to previously unseen data, we specified the most significant method called Stratified K-fold cross-validation and to measure the performance mostly usable matric like AUC Score, Precision, Recall, F-Measure has been specified. By performing a comprehensive analysis, it can be included Adaboost performs best in both datasets contrariwise SVM shows second-highest performance and dataset equipped through oversampling approach become more representative.

23:24 ***An Efficient Method to Discover Association Rules of Mode-Dependent Alarms Based on the FP-Growth Algorithm...136***

Kai Ru Wang (University of Alberta, Canada); Wenkai Hu (China University of Geosciences, China); Tongwen Chen (University of Alberta, Canada)

State-based alarming is an advanced technique to reduce nuisance alarms and alarm floods by suppressing alarms associated with certain conditions or operating modes. To implement this technique, the key is to find the associations between operating modes and alarms. In practice, this is mainly done based on the experience of plant operators and expert knowledge of process engineers, and thus is very time consuming. Therefore, this paper proposes a data driven method to discover the association rules of mode-dependent alarms for both single and multiple operating modes from the historical Alarm and Event (A&E) logs in an efficient way based on a data mining approach named FP-Growth. The effectiveness of the proposed method is demonstrated by an industrial case study.

Tuesday, November 10

Tuesday, November 10 8:00 - 9:00

Keynote 6: Analytics-Driven Cyber-Physical Security for a Converged Smart Grid

Prof. Deepa Kundur

Chair, The Edward S. Rogers Sr. Department of Electrical and Computer Engineering at The University of Toronto, Canada

Tuesday, November 10 9:00 - 10:00

Paper Session 2: Paper Session 2

Chairs: Konstanitn Gerasimov (EPCOR, Canada), Gregory J Kish (University of Alberta, Canada)

9:00 ***Live Work Insulation Considerations on HVDC Lines…141***

Shan Jiang (& ATCO Electric, Canada); Peter Kuffel (& HVdc One, Canada); Ram Adapa (Electric Power Research Institute, USA)

Live work techniques can provide practical solutions for uninterrupted power flow maintenance on critical electrical infrastructures such as HVDC lines; however, there are potential risks including both electrical and mechanical aspects that need to be addressed. All transmission line components are designed to withstand maximum mechanical load under defined weather conditions; similarly, the insulation is selected to withstand normal operating overvoltage and meet defined reliability levels under various impulse or transient overvoltage such as switching, lightning, etc. Due to safety, live work is allowed under defined limited weather and electrical operating conditions only. Utilities are also mandated to comply with various relevant live work codes and standards based on national and local government regulations. Developing a HVDC line live work O&M plan is a comprehensive task and utilities often share their experience with each other. ATCO has contributed HVDC live work experience towards updating live work chapter in EPRI HVDC Reference Book. This paper provides practical support and reference to assess electrical insulation requirements on live work on HVDC lines.

9:18 ***Improvement of Input Current THD of Cascaded H-Bridge Multilevel Inverters Under Faulty Condition…146***

Sahar Tahzibi (Politecnico di Milano, Italy); Alireza Siadatan (University of Toronto, Canada); Reza Babaloo (Politecnico di Milano, Italy); Jacob Gotlieb (University of British Columbia, Canada)

This paper suggests a modified post-fault control method of Cascaded H-Bridge Multilevel Inverters (CHB-MLI). The proposed method focuses on improvement of the power quality by reduction in input current total harmonic distortion (THD) of the inverter under faulty condition. Initially, the algorithm of the proposed method is described to determine the optimal operation state which has less input current THD in comparison to the other possible post-fault states with the same output line to line voltages. This method yields the reduction in the input current THD in this case which the desired output line-line voltage is less than its maximum level. Then, the validity of the proposed method has been verified by the simulation of the symmetric 11-level CHB-MLI by MATLAB/SIMULINK. It is shown that by applying the proposed method in some faulty conditions, the THD of the input current has been reduced by 85%. Finally, it is concluded that the proposed method has been made less level of the input current THD in comparison with the existing control methods which results in reduction in electromagnetic interference (EMI), less transformer heat and improvement of the power quality.

9:36 ***Multi-FPGA Communication Interface for Electric Circuit Co-Simulation…152***

Michel Lemaire (Université du Québec à Trois-Rivières, Canada); Daniel Massicotte (Universite du Quebec a Trois-Rivieres, Canada); Jean Belanger (Opal-RT Technologies, Canada)

Real-time simulation of electric circuit is most often used to test real components connected to a real-time simulator. The increasing size and complexity of the simulation as well as the demand for better accuracy, lower time step, have pushed these simulations onto new hardware. For already more than a decade FPGA simulation is used by real-time simulation companies around the world to effectively simulate circuits under the µs. With the computation requirement growth, multi-FPGA simulation needs to be considered as a valuable asset but attention must be given to the latency between the simulations for accuracy and stability. In order to minimize the communication latency, a custom interface and communication architecture for co-FPGA simulation is proposed. This paper presents detailed work on this architecture and shows promising results.

9:54 ***Fourth-Order Minimum-Phase Boost Converters Using Reverse-Coupled Inductors…158***

Saman A. Gorji (Queensland University of Technology, Australia); Hosein G. Sahebi (Babol Noshirvani University of Technology, Iran); Mohammad Hosein Holakooie (Warsaw University of Technology, Poland)

This paper analyses three types of fourth-order boost dc-dc converters. In order to improve the dynamic response of uncoupled-inductor based topologies in continuous conduction mode (CCM), the magnetic coupling is used to shift the right-half-plane zeros (RHPZ) of the control-to-output transfer function to the left-half-plane (LHP). This has led to the proposal of two new types of coupled-inductor based fourth-order minimum-phase (MP) boost dc-dc converter topologies. The small-signal modelling, efficiency analysis and simulation results confirm that the proposed converters own several benefits such as no RHPZ and hence an MP behaviour, high efficiency, and continuous input/output current waveforms.

10:12 ***A Generalized Procedure to Develop DC Switchyard for MTDC Grids…166***

Vekhande Vishal (Sedemac Mechatronics Pvt. Ltd., India); J Sivaprasad (Hitachi ABB Power Grids, Sweden); Vinothkumar K (Hitachi ABB Power Grids); Sridhar Alapatti (NKT HV Cables AB, India); Jwala Rao (Hitachi ABB Power Grids, India); Saikat Karmakar (GE Health Care, India)

With the advent of Voltage Source Converter (VSC) based High Voltage Direct Current (HVDC) technology, Multi-Terminal DC (MTDC) grids are gaining popularity and becoming reality. Half-bridge based Modular Multilevel Converter (H-MMC) along with Hybrid HVDC Breaker (HHB) turns out to be a good combination for MTDC grids, which ensures minimum disturbance to the operation of ac-dc power system during dc faults, enhancing reliability and grid security. In MTDC grid, a dc switchyard is essential at each converter station, which acts as a transition point for various incoming and outgoing feeders. HHB can be designed as an internal equipment of such dc switchyard. The design of such dc switchyard is very important from the operational and cost perspective in achieving the required power system reliability and security. This paper utilizes the modular feature of Hybrid HVDC breaker (HHB) to design a N-feeder dc switchyard with reduced component count. A generalized procedure to develop an electrical layout of Nfeeder dc switchyard and its operation are proposed. Operation of a dc switchyard under failure of HHB components is also demonstrated.

10:30 ***Feasibility Study of Adding a Third VSC Based HVDC Terminal on an Existing Point-Point LCC Based HVDC Transmission System…173***

V Rakesh Reddy (Hitachi ABB Power Grids, India); Vinothkumar K (Hitachi ABB Power Grids); Hafner Ying-Jiang and Auddy Soubhik (Hitachi ABB Power Grids, Sweden)

Advantages of Voltage Source Converter (VSC's) over Line Commutated Converter (LCC's) urges to have at least one VSC based converter station in a multi terminal hybrid HVDC (MTDC) system. A hybrid HVDC system optimally combines the benefits of LCC (HVDC Classic) and VSC (HVDC Light). The resultant system offers advantages of bulk power transmission, independent control of active and reactive power, capability of interconnection with weak AC network and renewable energy sources, black start capability in absence of grid and no commutation failure issue at VSC inverter. This has made the hybrid HVDC ideally suitable for applications wherein the existing HVDC Classic needs an up gradation to dispatch higher power demands of the utilities. In this scenario, a third VSC terminal may be added to the existing point-to-point LCC HVDC transmission system to handle the large-capacity power transmission over long distances and to connect to the newer load centers or local power generation from distributed energy sources developed in its vicinity. Such a multi-terminal arrangement may renew the utilization of existing classic HVDC transmission link with additional operating flexibility, thus saving essential investment cost. In this paper, the study results for a hybrid HVDC system will be presented, where a half-bridge cell based modular multi-level converter (HBMMC) is added as a third station to an existing point to point LCC link with hybrid HVDC breaker (HHB) used as fault clearing or fault ride through technical solution (FRT device). The steady state and dynamic performance of this multi-terminal system is analyzed, and the simulation is performed in PSCAD/EMTDC. This paper will illustrate the advantages of the three-terminal hybrid HVDC. It will also address the new challenges due to addition of the third VSC terminal on the point to point LCC HVDC. Solution for mitigating the potential problems is presented. The proposed solutions are also verified by simulating AC and DC faults and the typical simulation results are presented in this paper. The results show that the multi-terminal hybrid HVDC system is able to handle different AC and DC faults with desired performances.

10:48 ***Fuzzy Based Energy Management System for a Micro-grid with a V2G Parking Lot…179***

Femina Mohammed Shakeel and Om P Malik (University of Calgary, Canada)

A fuzzy based intelligent energy management system (EMS) to utilize electric vehicle (EV) batteries for energy storage services in a micro-grid is proposed in this paper. A dc fast charging station is used to interconnect EVs to the micro-grid. The fuzzy logic controller determines the energy available with each EV to participate in vehicle-to-grid (V2G) and grid-to-vehicle (G2V) services, based on the battery state of charge, rated capacity and time remaining for departure of each EV. The EMS algorithm then allocates the balance power in the micro-grid to the available EV batteries without impairing the owner's driving needs. Different case studies have been simulated in MATLAB/SIMULINK environment by varying the load, generation and number of EVs available at the parking lot. The obtained results verify the effectiveness of the proposed approach in maintaining an optimal power balance in the system under different operating conditions.

11:06 ***Voltage Control of Islanded Hybrid Micro-grids Using AI Technique…184***

Hossam E Keshta (Schulich School of Engineering, Calgary University & Faculty of Engineering at Shoubra, Benha University, Canada); Ahmed Ayman Ali (Faculty of Engineering, Helwan University, Egypt); Om P Malik (University of Calgary, Canada); Ebtisam Saied and Fahmy Bendary (Faculty of Engieering at Shoubra, Benha University, Egypt)

A fuzzy logic proportional integral controller (Fuzzy-PI) is proposed as a voltage controller to control the voltage of islanded micro-grids and keep the system voltage within acceptable limits during disturbances such as load fluctuations and weather changes. Operating as a central controller for micro-grid, the aim is to optimize the operation of distributed generators. The controller parameters are tuned using self-global harmony search, an advanced optimization technique. Effectiveness of the proposed controller is investigated on two different islanded micro-grids under various operating conditions and performance is compared with that of a fuzzy controller and a classical PI controller. Results of simulation studies show that, compared to the conventional PI and fuzzy controllers, by using the proposed fuzzy-PI controller the system voltage profile is improved while still maintaining the technical constraints and economic operation.

11:24 ***An Analysis and Protection Scheme to Prevent Loss of Coordination Due to Microgrid Contributions: Part I - Short Circuit Predictions…190***

Keaton A. Wheeler and Sherif Faried (University of Saskatchewan, Canada)

This paper proposes a Polynomial Regression Analysis (PRA) technique to predict short circuit contributions from microgrids during utility distribution faults. Application of the proposed scheme at the point of common coupling (PCC), via an interconnecting block, allows the microgrid short circuit current to be predicted during a utility fault. A directional element within the scheme facilitates discrimination between utility and microgrid faults. The PRA utilizes the wind speed, solar irradiance and operating conditions of synchronous generators in conjunction with training data to determine short circuit contributions from the microgrid to the distribution network. Time domain simulations, conducted in the EMTP-RV software environment, confirm the efficacy of the proposed scheme by predicting the microgrid short circuit contributions during utility faults.

11:42 ***An Analysis and Protection Scheme to Prevent Loss of Coordination Due to Microgrid Contributions: Part II -Optimization and Mitigation…196***

Keaton A. Wheeler and Sherif Faried (University of Saskatchewan, Canada)

This paper proposes a smart protection scheme utilizing a previously presented Polynomial Regression Analysis (PRA) in conjunction with Particle Swarm Optimization (PSO). Combined with a directional element, the scheme limits short circuit current contributions

from microgrids during distribution network faults. Application of the proposed scheme at the point of common coupling (PCC), via an interconnecting block, allows the microgrid to maintain partial continual operation without the need for complete disconnection from the distribution network. A directional element within the scheme facilitates discrimination between utility and microgrid faults. The PRA utilizes the wind speed, solar irradiance and operating conditions of synchronous generators in conjunction with training data to determine short circuit contributions from the microgrid to the distribution network. The PSO algorithm utilizes predictions formulated by the PRA to determine the number of generation sources requiring mitigation following a grid fault. This ensures the original protection coordination in the distribution network is maintained. Time domain simulations, conducted in the EMTP-RV software environment, confirm the efficacy of the proposed scheme by mitigating the impact of the microgrid short circuit contributions on existing overcurrent protection infrastructure.

12:00 ***Mitigating Islanded Mode Small Scale Synchronous Generator Mechanical Oscillations Caused by Electrical Arc Furnace...202***

Yashar Kor (University of Alberta, Canada); Mahdi Davarpanah, Reza Bekhradian and Majid Sanaye-Pasand (University of Tehran, Iran)

Electrical arc furnace (EAF) is a nonlinear and time-varying load consuming low frequency fluctuating power. This results in mechanical fatigue in the nearby small scale synchronous generators (SSSGs), especially their corresponding turbines, that reduces their lifetime. Furthermore, to improve the power supply reliability and reduce electricity expenditures, utilizing SSSGs is inevitable. In this paper, an industrial EAF is modelled and verified based on the field measurement studies; moreover, an actual islanded microgrid including an EAF and an SSSG is studied to quantize the effect of EAF fluctuations on the SSSG mechanical parameters based on the introduced appropriate indices. In addition, the SSSG controller parameters are properly determined to alleviate the mechanical torque fluctuations. The use of the proposed practical and simple method without imposing any additional cost decreases the SSSG mechanical oscillation magnitude considerably.

12:18 ***Dynamic Performance Assessment of NG-MVDC Shipboard Power System with Distributed Electric Propulsions..210***

Zahra Shajari (Ferdowsi University of Mashhad, Iran); Mehdi Savaghebi and Josep M. Guerrero (Aalborg University, Denmark); Mohammad Hossein Javidi (Ferdowsi University of Mashhad, Iran)

In recent years, DC distribution system has been considered as an efficient solution in Shipboard Power Systems (SPS) to improve the system performance in several aspects such as overall efficiency, reliability, security and size. However, rising fuel price, its unpredictability, growing global demand for energy and the necessity to decrease environmental pollution have led to an ever-increasing trend for using Alternative Power Sources (APSs) and Energy Storage Systems (ESSs) into Next-Generation Shipboard Power Systems (NG-SPS). In this respect, the future SPSs provide great advantages but really complicate and introduce new challenges about system security and stability. Hence, exact evaluation of system dynamic performance has become a major concern and require an effective simulation-based modeling. This paper developed a modeling approach for Medium Voltage Direct Current (MVDC) of NG-SPS using Distributed Electric Propulsion (DEP) along with lithium ion battery and Solid Oxide Fuel Cell (SOFC) as an ESS and APS, respectively. The major objective is precise assessment of system dynamic behavior under various operating states in order to take full advantage of the system over dynamic events, effectively and keep the system secure. The proposed system has been simulated in MATLAB/Simulink and the results are presented for various operational modes.

12:36 ***Micro-Grid Dynamic Economic Dispatch with Renewable Energy Resources Using Equilibrium Optimizer...217***

Mohamed Ebeed (Sohag University, Egypt); Ahmed Rashad (Upper Egypt Electricity Distribution Company, Qena Rural Electrification Sector, Egypt); Ali S Alghamdi (Majmaah University, Saudi Arabia); Salah Kamel (Aswan University, Egypt)

Micro-grid is a small power system that consists of one or more generation sources managed by customers to satisfy their load demands for having the more economic and reliable state. Micro-grids may include conventional and renewable resources. Thus, the Economic Dispatch (ED) is utilized as an important tool for scheduling these resources to minimize the generation cost. In this paper, the economic dispatch of a Micro-grid (MG) is solved using one of the newest algorithms called Equilibrium Optimizer (EO). The aim of ED is assigning the optimal scheduling of the distributed generators in 24-h-ahead of a MG which includes two wind turbines, three fuel-cell units and two diesel generators. The simulation results reveal to that the EO is an efficient technique for solving the dynamic economic dispatch of the MG. Moreover, the proposed algorithm is superior compared with the other reported algorithm in terms of generation cost minimization.

12:54 ***Community Microgrid Energy Storage Sizing Considering EV Fleet Batteries as Supplemental Resource...222***

Qiyun Dang (Mcgill University, Canada); DI WU and Benoit Boulet (McGill University, Canada)

The penetration of electric vehicles (EVs) has been increasing very quickly in the last few years. EVs can help reduce the dependency on the fossil energy, greenhouse gas emission, and improve energy efficiency. Besides the aforementioned benefits, EVs could also provide extra benefits for the neighborhood level network. This paper present a case study to analyze the potential benefit of using an EV fleet as energy storage in order to cut off and save extra battery packs investments on energy storage. Particularly, the paper provides a Continuous Time Markov Chain (CTMC) based EV fleet total available battery capacity estimation framework dealing with cost savings oriented community energy storage sizing problem. The local fast charging station (FCS) queuing situation and the queuing theory are also considered. Experiment results show that the adoption of EVs could helo significantly reduce the investment on battery storage which could bring significant economic and social benefits.

13:12 ***Modelling Prime Diesel Electric Generator Fuel Consumption Across Genset Sizings...227***

Patrick T Giles and Michael Ross (Yukon University, Canada); Spencer R.D. Sumanik (Yukon College & Yukon Research

Centre, Canada)

This study investigates a general model for fuel consumption of prime diesel generators within a set range of loadings. The model is parametrized by the rated power output, or sizing, of a generator. This research gives insight into generator fuel consumption characteristics across a wider population of generators to provide a general estimate of fuel consumption for a given sizing. Manufacturer data sheets containing fuel consumption measurements are collected online and through electric power utilities in the Canadian territories for 40 unique diesel generator sizings. The sizing group effects are accounted for through a non-pooled and multilevel regression. Subsequent estimates of linear parameters across generator sizings are modelled through ordinary least squares to obtain the desired model for fuel consumption. The generality and adequacy of this model is investigated through simulation and selected fresh data sources. The general model for prime diesel generator fuel consumption serves as a useful estimate or approximation for subsequent work that requires a general fuel efficiency estimate.

13:30 ***Impact of Dead-Band Time on the Harmonic Spectrum of Power Converters...235***

Jigneshkumar Patel (UOIT, Canada); Vijay K. Sood (Ontario Tech University, Canada)

Power electronic (PE) converters suffer from a topological disadvantage as they often employ two series-connected switches within a common leg of a converter. These two switches have a complementary role i.e. when one switch is ON, the other must be OFF otherwise a short circuit will result with impending risks for the switches and power supply. This condition must be respected at all times - during steady-state and transient switching periods. Although modern PE switches are very fast switching, their speed is not infinite. And, in practice, a suitable dead-band time is required with any pulse width modulation (PWM) technique to prevent the occurrence of a short circuit between two switches in a common leg. A larger dead-band time enhances the security of operation of the switches (converter) but at the expense of additional harmonics and lower efficiency. This paper investigates the impact of dead-band time on the harmonic spectrum for a single-phase H-bridge converter for low/medium voltage applications and cascaded H-bridge (CHB) multilevel converter for medium/high voltage applications.

13:48 ***Robust H∞ Dynamic Output-Feedback Control of Power Oscillation Damped via VSC-HVDC Transmission Systems...242***

Yankai Xing and Elkhatib Kamal (Ecole Centrale de Nantes, LS2N-CNRS, France); Marinescu Bogdan (Ecole Centrale de Nantes, France); Xavier Florent (RTE-R&D, France)

This paper addresses the problem of a particular case of high-voltage direct current transmission inserted into a meshed AC grid, which has an inter-area oscillation mode with a higher frequency than the normal mode. The classic Power Oscillation Damping (POD) controller failure to deal with this situation and the other changing operation point cases . Moreover,Non-Minimum Phase Zeros (NMPZs) were systematically put into evidence. Combined with the system uncertainties, they present a serious challenge for the control. A same reduced-order model of High-Voltage Direct Current line (HVDC) and adjacent AC area as former research is used for control design in this paper. Based on the reference model, using the LMI optimization method, a Dynamic Output Feedback Controller(DOFC) is proposed to provide modulation of active and reactive power to damp the inter-area oscillations, enhance the damping of the other modes, eliminate some impacts of NMPZs in the system and achieve robustness against variation of the operation point. The linearization and nonlinear models of the system are studied to establish and verify the method. The efficiency and robustness of the proposed controller were tested on the same actual benchmark of 19 generators connected through the mesh AC grid.

14:06 ***EMT Implementation and Validation of MPC for VSC-HVDC Embedded in AC Meshed Grid...248***

Emile Thau and Elkhatib Kamal (Ecole Centrale de Nantes, LS2N-CNRS, France); Marinescu Bogdan (Ecole Centrale de Nantes, France); Guillaume Denis (RTE R&D Division, France)

This paper proposes a Model Predictive Control (MPC) for a High Voltage Direct Current (HVDC) inserted in an AC network, in order to improve the dynamic behavior performance under input and state non symmetrical constraints. To fully capture all range of grid and converter dynamics, an Electromagnetic Transients (EMT) modeling is done. For this, the well known New-England test case is enriched by adding a HVDC link. For the latter, a MPC is synthesized based on Linear Matrix Inequalities (LMIs) conditions for stabilization, in the sense of the Lyapunov theory. Constraints for converters currents are also integrated into the design in order to obtain a control implementable in practice. The proposed strategy is then compared with classic vector control to show the effectiveness of the strategy. Simulations are performed in EMT MATLAB/Simulink/Simpower/Simscape software environment.

14:24 ***Analysis of Symmetric and Asymmetric CHB-MLI Using MC Based SPWM and THI-PWM...254***

Jigneshkumar Patel (UOIT, Canada); Vijay K. Sood (Ontario Tech University, Canada)

Cascaded multilevel inverter (CHB-MLI) has the advantages of modularity and flexibility to generate any number of output voltage levels. It can be configured as a symmetrical or asymmetrical type. The CHB-MLI can be controlled with various modulation techniques, like multi-carrier PWM (MC-PWM), selective harmonics elimination PWM (SHE-PWM), and space vector PWM (SV-PWM). Among these PWM methods, MC-PWM is very well accepted for CHB-MLI topology. This paper investigates, using Matlab simulation, the performance of symmetric and asymmetric CHB-MLI incorporated with MC-PWM techniques, such as phase-shifted PWM (PS-PWM) and level-shifted PWM (LS-PWM). All MC-PWM methods are constructed using sinusoidal and third harmonic injected reference signals.

14:42 ***MMC Based PV Energy Integrated Multiterminal HVDC Transmission Network...261***

Md Ismail Hossain (King Fahd University of Petroleum & Minerals, Saudi Arabia); Mohammad A. Abido (KFUPM, Saudi Arabia); Ilius Pathan (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia)

This research presents the modeling and control of Modular Multilevel Converter (MMC) based multiterminal HVDC transmission system for solar energy integration. It includes detailed MMC model where circulating current of the arm and submodule capacitor voltage balancing are considered. The proposed network considers single PV unit with complete dynamics and follows the behavior of that PV

unit during scaling it's capacity. Furthermore, it optimally integrates solar energy using a modified incremental conductance method. The complete system has been implemented in RTDS. Performance of the MMC controller has been evaluated with severe balanced and unbalanced faults. The performance shows the improvement of low voltage ride through capability during faults at the common coupling point of AC grids.

15:00 ***PMSG Based Wind Energy Integration into MMC Based HVDC Transmission Network in RTDS...267***

Md Ismail Hossain (King Fahd University of Petroleum & Minerals, Saudi Arabia); Mohammad A. Abido (KFUPM, Saudi Arabia); Ilius Pathan (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia)

This research presents the modeling and control of Modular Multilevel Converter (MMC) based multiterminal HVDC network to integrate wind energy based on permanent magnet synchronous generator (PMSG). Submodule capacitor voltage balancing and arm circulating current control were considered in MMC detailed model. One complete unit of PMSG for wind energy generation using detailed model was considered in this work to preserve harmonics characteristics which is ignored in the simplified current source based conventional model. Without placing the capacitance on the high AC side voltage of MMC, it developed the constant AC grid voltage for wind farm connection employing PI controller. Wind energy was controlled through field oriented control. It analyzed MMC controller performance under unbalanced and balanced faults at the connection point of AC grid. The complete system has been implemented in RTDS for real time validation. Besides optimum wind energy tracking, the results showed reactive power support and enhancement of the ride through capability of low voltage during fault.

15:18 ***Optimal Demand Management for Smart Distribution Networks...273***

Mohamed Wagdy (Faculty of Engineering, Ain Shams University, Egypt); Amr Magdy (Faculty of Engineering Ain Shams University, Egypt); Walid El-Khattam (Faculty of Engineering, Ain Shams University, Egypt)

Smart Grid utilities have been considering the widespread integration of Renewable Energy Sources (RES),such as wind and solar systems, for power generation. However,the main obstacle that faces these kinds of resources is their intermittent nature of power generation. Therefore, this will affect the system's ability to safely cover the required load demand. One of the solutions to overcome this mismatching issue is to reshape the demand profiles to match the available source profiles. In this paper, we develop an algorithm for Demand Side Management (DSM) using the load shifting technique.The proposed algorithm aims to maximize the systems' Load Factor (LF) by reducing the peak load of the system. Additionally,the algorithm minimizes the cost of the energy consumption by shifting loads according to different Time of Use (ToU) tariffs. We demonstrate the effectiveness of our proposed algorithm by conducting the maximization of the LF and the minimization of energy consumption cost for different types of load profiles in a Microgrid incorporating RES power plants. In the meanwhile, two different ToU tariffs are implemented to show the capability of our developed model of carrying out various variables.

15:36 ***Small Signal Modeling of Interleaved Voltage Balancer with Coupled-Inductor...279***

Hyung-Jun Byun and Jung-Min Park (Sungkyunkwan University, Korea (South)); Bum-Jun Kim (Sungkyunkwan Univ, Korea (South)); Sung-hun Kim and Chung-Yuen Won (Sungkyunkwan University, Korea (South)); Jun-Shin Yi (Sungkyunkwan University, Korea (South), Korea (South))

In bipolar DC microgrid, the interleaved type voltage balancer(VB) based on the coupled-inductor has an advantage of reducing inductance by coupling effect. However, the equivalent inductance of coupled-inductor has a inconstant value due to the switching state and mutual inductance. It can adversely affects to interleaved inductor current magnitude, phase differences, and even the worst case the operation of VB. Therefore, it requires a highly regulated controller. To design the controller, this paper proposes the small signal modeling to a precise plant model that considering the coupling effect and the load variation through the coupling coefficient k and regarding load as the current source. Base on propose small signal modeling, the controller satisfies the interleaving operation and fast load follow. According to the modeling results, simulation is implemented to confirm the feasibility and effectiveness.

15:54 ***A Bacterial Foraging Optimization Technique and Predictive Control Approach for Power Management in a Standalone Microgrid...285***

Félix Dubuisson (Ecole de Technologie Supérieure, Canada); Ambrish Chandra (Ecola de Technologie, Superieure, Canada); Rezkallah Miloud (ETS & Institut Technologique de Maintenance Industrielle (ITMI), Canada); Hussein Ibrahim (Cegep de Sept-Îles & Institut Technologique de Maintenance Industrielle, Canada)

In this paper, the Bacterial Foraging Optimization (BFO) algorithm is proposed for real-time calculation of active and reactive power references estimation. This method emulates the behavior of E.coli bacteria to find the global minimum of a cost function. Using this technique, one estimates the power references of the system to use as input parameters for the developed predictive control strategy for the three-phase inverter. The comportment of the BFO and the predictive control, are tested using Matlab/Simulink under load variation. In addition, a detailed comparison between the BFO method and Particle Swarm Optimization (PSO) is provided.

16:12 ***Demand Side Management Using Model-Free Fuzzy Controller in a Direct Load Control Program...292***

Pegah Yazdkhasti and Chris Diduch (University of New Brunswick, Canada)

Integrating renewable resources such as wind and solar into the electric power systems introduces new challenges to the grid due to fast fluctuations which reduces the reliability of the system. Demand side management (DSM) is one method to cope with the uncertainty and variability of the generation. Direct load control of thermostatically controlled appliances can play a significant role for this purpose; however, the system operator requires a reliable estimation about the magnitude of the load and how much it can be shifted, in order to produce attainable desired aggregated load. The focus of this paper is on designing a model-free controller to follow the system

operator's dispatch instructions. The main advantage of such controller is to eliminate the requirement for training or identifying the controllable loads' parameters; thus, it can be used as a plug & play component. The other advantage is that this system can dynamically cope with system changes. In this research, the controller changes the thermostat set points of the individual loads in a systematically manner so that the aggregated power consumptions of the loads would follow the desired aggregated load. To evaluate the performance of the proposed controller, a numerical simulator was developed, and the controller was applied over the simulation engine to follow arbitrary desired power profiles. It was observed that the system can follow the dispatch command in less than 10 minutes with a negligible steady state error (less than 5%).

Tuesday, November 10 10:00 - 12:00

Industry Panel 2: Industry Panel 2

Tuesday, November 10 12:00 - 12:30

Lunch 2: Lunch break - Tuesday

Tuesday, November 10 12:30 - 13:30

Keynote 7: Role of the Smart Grid in Facilitating the Integration of Renewables

Prof. Saifur Rahman

Director, Virginia Tech Advanced Research Institute, USA

Tuesday, November 10 13:30 - 15:30

Paper Session 3: Paper Session 3

Chairs: Konstanitn Gerasimov (EPCOR, Canada), Gregory J Kish (University of Alberta, Canada)

13:30 ***Improving Power Quality Using SPWM Control in Modular Multilevel Converters...297***

Djilali Hamza (University of Ottawa, Canada)

In Low Voltage (LV) and Medium Voltage (MV) networks, specific power converters, namely the modular multilevel converters (MMC), need to be in-place to aggregate the renewable energy sources and provide an interface to the distribution electric network (grid). In addition, these multilevel converters can also be used as point-to-point interface in HVDC transmission networks. This paper presents an overview of the evolution of the modular multilevel converters. It lists the control strategies used for these types of converters. It presents the merit of the selecting the Sub-harmonics SPWM technique as the preferred techniques base on the harmonics cancellations inherent in the control method. A complete analysis of a 9-level MMC has been conducted and simulation results have been provided to verify the effectiveness in choosing the voltage balancing control in conjunction with the SPWM technique.

13:48 ***Influence of Thickness of Solid Insulators on Creeping Discharges Propagating over Epoxy and Glass Insulators Immersed in Coconut Oil...304***

W. E. P. Sampath Ediriweera, K. L. I. M. Pramod B Jayarathna and Rasara Samarasinghe (University of Moratuwa, Sri Lanka); Joseph Rohan Lucas (University of Moratuwa & General Sir John Kothalawela Defence University, Sri Lanka)

This paper deals with the effect of thickness of the solid dielectrics on creeping discharges propagating over glass and epoxy dielectric materials immersed in coconut oil under AC voltage. A test setup based on a point plane electrode system with a HVAC transformer connected to it is used to study the discharges under a laboratory environment. Field values given by a three-dimensional simulated model are used to analyze the field distribution at the tip of the point electrode with different considered material samples and to explain experimental observations. Test results show that the thickness of the solid insulator changes the capacitance of it and electric field distribution at the tip of the point electrode on the solid material interface and the pattern propagation. The area of the discharge patterns follows an exponential variation with the applied voltage.

14:06 ***Determination of Magnetization Characteristics of a Three-Phase Transformer Using Inrush Current Waveform...310***

Dohitha B Yapa, Danuka Yasuranda Bentharavithana, Nirod Rathnaweera and Thushari Wimalarathna (University of Moratuwa, Sri Lanka); Joseph Rohan Lucas (University of Moratuwa & General Sir John Kothalawela Defence University, Sri Lanka); Rasara Samarasinghe (University of Moratuwa, Sri Lanka)

Transformer magnetization characteristics can change from their original conditions with the aging of the transformer, and hence, the actual characteristics may deviate from the manufacturers' data. This paper presents a method to derive the magnetization characteristics of a three-phase transformer, in the form of flux-current curve by analyzing the transformer inrush current and voltage waveforms. The method presented allows the derivation of magnetic characteristics without interrupting the transformer operation for a long period and avoids any complex procedures. The program is designed and validated for a star-star type transformer. The three-phase transformer was modeled mathematically, and the resulting system of equations was observed to be a set of second order, non-linear ordinary differential equations. A MATLAB Simulink transformer model was used to obtain the inrush current waveforms, since solving the system of equations was found to be a tedious task and the results from the Simulink model could be validated using a practical transformer. A MATLAB program was developed based on the mathematical model of the three phase transformer to derive magnetization characteristics of the transformer by analyzing the inrush current waveform. Magnetization characteristics derived from the developed MATLAB program were found to be in accordance with the input magnetization characteristics used to generate the inrush current waveform. Analysis of the results show that the program is more than 98% accurate.

14:24 ***Nine-Level Packed U-Cell Converter for Electric Spring Applications…316***

Amirabbas Kaymanesh (École de Technologie Supérieure, Canada); Rezkallah Miloud (ETS & Institut Technologique de Maintenance Industrielle (ITMI), Canada); Ambrish Chandra (Ecola de Technologie, Superieure, Canada); Claude Ziad El-Bayeh (Ecole de Technologie Superieure, Canada)

Inasmuch as various multifunctional applications have been proposed for electric spring (ES), there is a need for introducing new ES topologies suitable for industries. In this paper, a novel nine-level electric spring based on the nine-level packed U-Cell converter (PUC9-ES2) configuration is introduced considering its basic operation principles, configuration, and modulation technique. Since electric spring based on this topology has superior features such as improved efficiency and better power quality characteristics, it is appropriate for higher power/voltage implementations. A radial chordal decomposition-based external controller has been also applied for regulating the critical load voltage and adjusting the power factor of the smart load setup whereas balancing of the flying capacitors has been achieved in an open-loop manner integrated into the modulation method. Simulation results are presented to accredit the performance and viability of this topology even under severe transients.

14:42 ***Nonlinear Identification Approach for Black-Box Modeling of Voltage Source Converter Harmonic Characteristics…322***

Ahmed S. Abdelsamad (Bremen University, Germany); Johanna Myrzik (Technische Universität Dortmund, Germany); Elias Kaufhold and Jan Meyer (Technische Universität Dresden, Germany); Peter Schegner (TU Dresden, Germany)

The future of power grids is expected to face a surge in the number of power electronics devices connected to it. This increases the possibility of resonances occurring due to harmonic current injections which is known the harmonic instability. In order to further study this phenomenon, models which are both capable of capturing the harmonic characteristics of the power electronic devices and are computationally inexpensive need to be developed. In this paper a Hammerstein-Wiener identification approach is proposed to develop a black box model for a voltage source converter which is capable of meeting such requirements. The approach is implemented in a simulation environment and then tested on a commercial photo-voltaic inverter for validation.

15:00 ***Degradation Simulation for Non-Destructive Conditions of Power System Equipment…327***

Ming Dong (Alberta Electric System Operator, Canada); Alexandre B Nassif (ATCO Electric, Canada)

Power system reliability is largely affected by the conditions of power system equipment. Therefore, to accurately determine power system reliability and proper asset management strategies, it is important to understand the condition degradation processes of different equipment. When there is sufficient historical condition data, equipment degradation can be modeled based on such data; however, utility companies often face the situation where historical condition data is not properly recorded, tracked or stored for all the large amount of equipment utility companies have to manage. To solve this dilemma, this paper explored a solution from an unconventional angle - it investigated models for simulating the non-destructive condition degradation of power system equipment. Initial effort and results are presented in this paper along with future research suggestions identified.

15:18 ***Model Predictive Control with Active Damping Capability for Induction Machine Driver Based on Indirect Matrix Converter…331***

Mustafa Gokdag and Ozan Gulbudak (Karabuk University, Turkey)

In this paper, a model predictive control approach with active damping capability for input filter is presented for an indirect matrix converter-based induction machine driver. The indirect matrix converter is a two-stage converter without using an intermediate bulky energy storage component between the rectifier side and the inverter side. An induction machine is connected to the inverter side and model predictive based indirect field-oriented control is adopted. To control the rectifier side with the unity input power factor, a current-controlled predictive approach in the dq-frame is used. To mitigate the unwanted harmonics in grid current, an active damping technique without requiring the selection of optimum value for fictitious damping resistor is also included in the proposed control scheme. The cost function just employs current terms for controlling input and output, and no weighting factor is required since all the terms are in the same nature and identical ranges. The presented control technique provides a good driving for the induction machine and unity input power factor with low THD for the grid side.

15:36 ***Reliability Analysis of Large-Scale Electric Bus Depots Based on Different Failure Scenarios…337***

Mina Eskander, Amra Jahic and Detlef Schulz (Helmut Schmidt University, Germany)

In order to decrease the harmful emissions of carbon monoxide, the senate of Hamburg has decided to buy only emission free buses by 2020. The two transportation companies in Hamburg; the Hamburger HOCHBAHN AG and Verkehrsbetriebe Hamburg-Holstein GmbH

(VHH) are therefore converting their diesel bus depots to electric ones. Total of eight electrical bus depots are planned to be built during the upcoming years in Hamburg. Those bus depots should be able to serve approximately a total of 1500 buses by 2030. The transportation field is critical for every city due its daily usage. This paper analyzes the cases of having different failure scenarios in the components of the charging infrastructure and their effect on the charging processes of the buses. Additionally the contribution of this paper is to show the effects of the failure scenarios on the routes assigned to the concerned buses. A second-life battery is also implemented to the system as well as a 5 MW emergency connection in order to decrease the se-verity of the situation. For this purpose many charging scenarios are considered to simulate these effects at diverse operational conditions. As a conclusion, the degree of severity of each case is presented based on the failures consequences.

15:54 ***A Reactive Power Compensation Scheme Using Distribution STATCOMs to Manage Voltage in Rural Distribution Systems…343***

Alexandre B Nassif and Dawit Teshome (ATCO Electric, Canada)

Flexible ac transmission system (FACTS) devices are often a recommended option for improving power quality. The most common shunt-connected FACTS device, namely the STATCOM, has become a viable option for distribution systems and has been employed for mitigating instances of voltage fluctuation, voltage unbalance, and in some cases harmonic distortion. As a distribution application, it has been termed D-STATCOM. D-STATCOMs also aid reducing the amount of reactive power drawn from the distribution system, reducing overall ampacity and aiding voltage management. However, it is well known that the degree of compensation provided by a D-STATCOM is a direct relationship with the system X/R ratio. For typical distribution systems, this results in large reactive power rating to perform appropriately. Unless an optimized reactive power scheme is developed, this will translate into large equipment rating near its installation site. This paper proposes a distributed reactive power management scheme, where reactive power is provided by one or more D-STATCOMs. The scheme is intended to boost low steady-state voltages and its output prescribes the instantaneous reactive power output of each participating D-STATCOM. For system boundary conditions, it also dictates the device rating. The proposed method is supported by an analytical development that estimates the amount of outputted reactive power to manage the voltage with a planning-specified voltage rise. Case studies representing real rural distribution systems applications are presented to demonstrate the proposed scheme.

16:12 ***How to Estimate Temperature Coefficients of Series and Shunt Parameters of Transmission Lines with Sag…348***

Ali R. Al-Roomi and Mohamed E. El-Hawary (Dalhousie University, Canada)

For line distributed resistance, it is easy to know its temperature coefficient. The literature has different approaches to express that distributed parameter as a temperature-dependent quantity. For line distributed inductance, capacitance, and conductance, the literature still lacks any methodology to express them as temperature-dependent quantities. This study is the first trial to express these temperature coefficients. Two possible approaches are provided. The first one assumes that the conductor temperature is known, while the other offers temperature-free estimations by regressing some variables correlated with the conductor temperature. The formulas provided in this study can be considered as a foundation to develop more advanced methods.

16:30 ***A Novel Approach to Precisely Calculate Lumped Parameters for Transmission Lines with Sag Using the M-Model Equivalent Circuit…354***

Ali R. Al-Roomi and Mohamed E. El-Hawary (Dalhousie University, Canada)

Real transmission lines are exposed to dynamic weather conditions and operated under different system states.These changes force power cables to sag, and thus the values of their distributed series and shunt parameters vary as well. This study is an attempt to account for the variations in these parameters by using a new highly precise medium-length transmission line model called the M-model. This lumped circuit represents the changes in the shunt parameters by a variable slack admittance placed in the middle of the circuit and the changes in the series parameters by two variable series impedances. Two approaches are proposed in this paper to realize the lumped shunt admittance. The first one divides the line into three ideal parts and then calculates the shunt admittance of the middle part at an equivalent height. The second one takes the ratio of the area below the line before and after sag. These methods can directly solve the inherent weaknesses associated with temperature-dependent studies without the necessity to know any temperature coefficient.

16:48 ***Optimal Coordination of Directional Overcurrent Relays Using BBO When Electromechanical, Static, Digital, and Numerical Relays All Exist…360***

Ali R. Al-Roomi and Mohamed E. El-Hawary (Dalhousie University, Canada)

Nowadays, the literature is very rich with many techniques proposed especially for optimal relay coordination (ORC) problems of directional over current relays (DOCRs).Many approaches have been applied to solve this stiff problem by considering different scenarios on protective relays and their network. However, the literature lacks a realistic model to deal with the inevitable fact that modern electric power networks have different relay technologies. Protection engineers could face elec-tromechanical, static, digital "hardware-based", and numerical "software-based" relays all together in the same network. Thus,existing ORC solvers are inapplicable to optimally coordinate such realistic networks. This paper presents a corrected model to deal with different relay technologies where the original problem dimension increases by 1.5× to indicate the relay types.To validate its correctness, the biogeography-based optimization(BBO) algorithm is used with the IEEE 6-bus, 15-bus, and 42-bustest systems. The results show that this realistic ORC problem can be solved, which means that it is possible to coordinate DOCRs that come with different speeds, coordination time intervals(CT I), and resolutions of time multiplier settings (T MS) and pickup settings (P S).

17:06 ***Real-Time Monitoring Applications for the Power Grid Under Geomagnetic Disturbances…368***

Cecilia Klauber and Komal S Shetye (Texas A&M University, USA); Jennifer Gannon and Michael Henderson (Computational

Physics Inc, USA); Zeyu Mao and Thomas J. Overbye (Texas A&M University, USA)

Prior research on the impact of geomagnetic disturbances (GMD) on the electric grid has mainly focused on improving GMD modeling for off-line analyses. Given the recent industry emphasis on monitoring the earth's magnetic field and geomagnetically induced currents (GIC), this paper describes a real-time GMD monitoring system. The real-time magnetic field measurements come from a network of six magnetometers installed in the US State of Texas. The paper focuses on the real-time GIC monitoring application implemented in a simulation environment, which could be extended to the real grid. The magnetic field measurements are coupled with ground conductivity models to calculate real-time electric fields, which are passed to a grid model to estimate and visualize GICs in real-time. Results are demonstrated on a synthetic but realistic and publicly available model of the Texas grid. The simulation environment is interactive with communication capabilities, making operational control and GMD mitigation possible in the near future.

17:24 ***Political Optimization Algorithm for Optimal Coordination of Directional Overcurrent Relays…373***

Mohammed Abdelhamid and Salah Kamel (Aswan University, Egypt); Mohamed A. Mohamed (Minia University, Egypt); Mansour AlJohani (YIC, Saudi Arabia); Claudia Rahmann (Universidad de Chile, Chile); Mohammed I. Mosaad (Yanbu Industrial College, Saudi Arabia)

In this paper, the political optimization (PO) algorithm is applied to coordinate the directional overcurrent relays (DOCRs). Optimal coordination of DOCRs that used for protecting electrical networks is a nonlinear constrained optimization problem. The PO algorithm is duplicating five main phases of politics from the population which is divided into parties and constituencies until updating their position depending on the party leader addition to the constituency winner. The primary target of this paper is to apply PO algorithm to coordinate DOCRs to minimize the total uptime utilized in four test systems including eight-Bus, nine-Bus, and fifteen-Bus systems. The results of the proposed algorithm have been contrasted with other well-known algorithms. The simulation outcomes exhibited the significance and viability of the proposed algorithm in finding the ideal coordination of DOCRs by minimizing the overall operating time of the relays.

17:42 ***Application of Circuit-Breaker Standards in Short-Circuit Current Calculation for Generator Circuit-Breakers…380***

Priyanka Gugale and Mirko Palazzo (Hitachi ABB Power Grids, Switzerland)

Interruption of fault current with delayed current zeros (DCZ) is one of the peculiarities of generator circuit-breaker (GCB) that differentiates it from other medium-voltage and high-voltage circuit-breakers. This paper aims to provide a guideline for precise calculation of short-circuit current requirements for GCB. The methods described in IEEE and IEC standards are analyzed and their impact on the selection of GCB is investigated. In particular, the standard IEC 60909, IEEE C37.010 and standards specific for GCB application IEEE C37.013 which is superseded by new dual logo standard IEC/IEEE 62271-37-013 are the scope of this paper. Calculation of two main interrupting duties of GCB are addressed: 1) generator-source short-circuit currents and 2) out-of-phase fault currents. Analytical results are verified with the simulation results obtained from ATP-EMTP. In conclusion, the question of which standard shall be used to accurately evaluate the short-circuit current requirements for the selection of a GCB is well-answered.

18:00 ***Probablistic Assessment of the Impact of Integrating Large-Scale High-Power Fast Charging Stations on the Power Quality in the Distribution Systems…388***

Bishoy Basta and Walid Morsi (University of Ontario Institute of Technology, Canada)

In this paper, the impact of integrating large-scale high-power fast charging stations for electric vehicles on the power quality in the distribution system is probabilistically evaluated in terms of harmonics, supraharmonics and voltage fluctuation. The Monte Carlo method is proposed to probabilistically estimate the power demand of clusters of electric vehicles when charging at the fast charging stations. Different types of electrical vehicles along with chargers from different manufacturers are used in this study to quantify the effect of chargers from different manufacturers on the harmonics and the supraharmonic distortion. The IEEE 34-bus standard test distribution feeder is used to study the harmonic and supraharmonic distortion propagation at the system level as well as the voltage fluctuations and light flicker when integrating the large-scale high-power fast charging stations. The results have been presented and the conclusions are drawn.

18:18 ***Event Tree Reliability Analysis of Electrical Power Generation Network Using Formal Techniques…394***

Mohamed Abdelghany, Waqar Ahmad and Sofiene Tahar (Concordia University, Canada)

In recent years, there has been a significant proliferation in the use of Renewable Energy Sources (RES),such as wind/solar systems, for power generation. However, the main obstacle that these resources face is their intermittent nature, which greatly affects their ability to deliver constant power to the power network. This raises several reliability-related concerns and existing sampling-based simulation tools,such as the Monte-Carlo approach, cannot guarantee absolute accuracy of the reliability analysis results due to their inherent incompleteness. In this paper, we propose to use formal techniques based on theorem proving to conduct the reliability analysis of electric grids as an accurate alternate approach.In particular, we use the HOL4 theorem prover, which is a computer-based mathematical reasoning tool. We demonstrate the effectiveness of our proposed approach by analyzing the reliability of the IEEE 39-bus power grid incorporating RES power plants and and also determine its reliability indices, such as System Average Interruption Frequency and Duration (SAIFIandSAIDI). To assess the accuracy of our proposed approach, we compare our results with the commercial reliability analysis tool Isograph and the MATLAB toolbox based on Monte-Carlo approach.

18:36 ***Localizing Hotspot in an Oil Immersed Distribution Transformer Using Finite Element Analysis…401***

Gevindu Ediriweera, Kalpa Wickramasinghe, Irupa Sithmini, Anupa Ekanayaka and Rasara Samarasinghe (University of Moratuwa, Sri Lanka); Joseph Rohan Lucas (University of Moratuwa & General Sir John Kothalawela Defence University, Sri

Lanka)

In the electric power system the health of the distribution transformer is essential in maintaining a healthy power system. An overheated transformer leads to reduction in its life. Heat generation caused in the core and in the conductor due to losses, affect the performance. Monitoring the hotspot temperature, where the temperature is the highest within the transformer, leads to many benefits, such as the reduction of transformer aging due to partial discharges and permitting optimum loading to be carried out. In this paper, a Finite Element Method based thermal model has been developed considering the conjugate heat transfer and fluid dynamics mechanisms, to determine the temperature distribution of a distribution transformer. Using the manufacturer provided data for a 160 kVA distribution transformer, the top-oil temperature has been validated and found to be within 10C. Based on the temperature profiles determined, the location of the hot spot has been accurately predicted to permit insertion of sensitive temperature monitoring fiber-optic sensors during distribution transformer manufacture.

18:54 ***Electric Power Load Forecasting Based on Multivariate LSTM Neural Network Using Bayesian Optimization…407***

Mohammad Munem and T. M. Rubaith Bashar (Rajshahi University of Engineering & Technology, Bangladesh); Mehedi Roni, Munem Shahriar and Tasnim Shawkat (Rajshahi University of Engineering and Technology, Bangladesh); Md. Habibur Rahaman (Memorial University of Newfoundland, Canada)

With rapid growth and development around the world, electricity consumption is increasing day by day. As the production and consumption of electricity is simultaneous, an electric power load forecasting technique with higher accuracy can play a pivotal role in a stable and effective power supply system. In this paper, a multivariate Bayesian optimization based Long short-term memory (LSTM) neural network is proposed to forecast the residential electric power load for the upcoming hour. Bayesian optimization algorithm is conducted to select the best-fitted hyperparameter values since deep learning networks are associated with different hyperparameters which play a vital role in the performance of a network architecture. Our proposed Bayesian optimized LSTM neural network has obtained almost perfect prediction performance and it surpasses the other established model such as convolutional neural network (CNN), artificial neural network (ANN) and support vector machine (SVM) where mean absolute error (MAE), root mean squared error (RMSE) and mean squared error (MSE) are found 0.39, 0.54 and 0.29 respectively for the individual household power consumption dataset.

19:12 ***Review of Protection Strategies for Wind Turbines Against Lightning…413***

Choudhury Naser and Vijay K. Sood (Ontario Tech University, Canada)

Protection of modern wind turbines (WTs) / wind turbine generators (WTGs) against lightning presents numerous challenges due to geometrical, electrical and mechanical characteristics of the turbines. The importance of the subject is increasing as the number of WT installations are trending more towards offshore applications where access for maintenance is increasingly more difficult than that for land-based wind farms. The objective of this paper is to collate, in an easily comprehensive manner, known information about the present protection of WTs, and make recommendations/suggestions that may contribute towards the future protection of WTs against catastrophic damage by lightning.

19:30 ***The Impact of Cybersecurity on Siting Distributed Generation Units in AC Power Systems…421***

Jay Nayak and Irfan S. Al-Anbagi (Faculty of Engineering and Applied Science, University of Regina, Canada)

The vulnerabilities of the smart grid to cyberattacks can pose dangerous threats to the assets connected to the power network. It is important to identify cyber vulnerabilities in power systems and implement effective defense mechanisms to prevent cyber threats on these assets. Existing research works have not shown effective techniques for the vulnerability assessment and countermeasures against cyberattacks for the AC power systems. In this paper, we emphasize the impact of cybersecurity on siting distributed generation (DG) units in the AC power grid. We present an AC-based false data injection (FDI) attack model to analyze the cyber vulnerabilities of the system and propose an optimal defense strategy to prevent cyber incidents on these units. We perform experiments on the SaskPower network of Saskatchewan, Canada, to demonstrate the optimal siting for DG units under the cybersecurity constraint. Our simulation results obtained for the SaskPower grid show the effectiveness of our proposed approaches to analyze the cyber vulnerabilities of the power grid and find secure sites for the DG units in Saskatchewan.

19:48 ***Decoy-Based Moving Target Defense Against Cyber-Physical Attacks on Smart Grid…427***

Ahmed Abdelwahab, Walter Lucia and Amr Youssef (Concordia University, Canada)

The design of successful covert cyber-physical attacks against smart grids requires a good level of knowledge about the dynamics of the target power system. Consequently, in the reconnaissance phase of a cyber-physical attack on a power system, the attacker usually needs to perform an accurate identification of the dynamics of the underlying control system. To degrade the accuracy of the system identification process, artificial noise can be added to the system measurements sent from the plant to the controller. While this approach might be effective in degrading the accuracy of recovering the parameters of the underlying target system, it comes at the expense of degrading the control system performance. In this paper, and inspired by the concept of decoy flare in air defense, a moving target defense mechanism is developed by leveraging an auxiliary set of virtual state-based decoy systems. More precisely, in this approach, the plant maintains and simulates a set of several decoy system models, designed to be indistinguishable from actual system models. At each time step, the plant sends a randomly permuted version of the corresponding measurements, of both the decoys and real system, to the controller which then evaluates and sends the corresponding optimal control of each system. The plant applies the received control inputs to the corresponding decoy models and the real system, respectively. The indistinguishability of the deployed decoy models, combined with the time-varying nature of the utilized permutation and system parameters, hinders the attacker's ability to perform an accurate system identification process. The effectiveness of the proposed approach is confirmed by considering an application example of an Automatic Generation Control (AGC) system. Based on our simulation results, the proposed decoy-based approach degrades the attacker's ability to correctly identify the underlying state-space model of the considered system from the intercepted control inputs and

sensor measurements. It also does not impose any penalty on the control performance of the underlying system.

20:06 ***Load Sharing Strategy Incorporating Power Limits in Islanded Inverter-Based Microgrids...432***

Chiebuka Eyisi and Guanyu Tian (University of Central Florida, USA); Petr Vorobev (Skolkovo Institute of Science & Technology, Russia); Qifeng Li (University of Central Florida, USA)

Microgrids (MGs) comprising multiple interconnected distributed energy resources (DERs) with coordinated control strategies can operate in both grid-connected and islanded modes. In the grid-connected mode, the frequency and bus voltages are maintained by the utility grid. In the islanded mode, the DERs maintain the frequency and bus voltages in the MG. This paper presents a load demand sharing strategy in an islanded voltage source inverter-based microgrid (VSI-MG). The survivability of the interconnected MG in the presence of a single fully loaded VSI in an islanded VSI-MG is investigated. The concept of virtual synchronous machines (VSM) that enables the modeling of the VSI to emulate the inertia effect of synchronous machines is applied and then a Jacobian-based approach is formulated that takes into account, the capacity of the VSI. Simulation results are presented to verify the effectiveness of the approach.

20:24 ***Smart Inverters for Seamless Reconnection of Isolated Residential Microgrids to Utility Grid...438***

Mohsen S. Pilehvar and Behrooz Mirafzal (Kansas State University, USA)

This paper proposes an approach to achieve seamless reconnection of isolated residential microgrids to utility grid. Any abnormal condition on the grid side results in isolating the residential microgrid from utility grid, and giving the full responsibility of supplying household loads to local distributed generation (DG) units. However, after resolving the abnormal condition on the grid side, the residential microgrid needs to seamlessly reconnect to the main grid. To this end, a seamless transition algorithm is presented which monitors the system condition in real time, and coordinates the operation of all inverter-based DG units in residential microgrid before reconnection to the main grid. A modified control scheme is proposed for single-phase inverters which turns them into smart inverters enable to interact with seamless transition algorithm. The proposed approach synchronizes each phase voltage with its respective grid-side voltage in order to seamlessly reconnect the residential microgrid to the main grid. Case study results are carried out in PSCAD/EMTDC environment to verify the validity of proposed method.

20:42 ***Energy-Storage Fed Smart Inverters for Mitigation of Voltage Fluctuations in Islanded Microgrids...444***

Mohsen S. Pilehvar and Behrooz Mirafzal (Kansas State University, USA)

The continuous integration of intermittent low-carbon energy resources makes islanded microgrids vulnerable to voltage fluctuations. Besides, different dynamic response of synchronous-based and inverter-based distributed generation (DG) units can result in an instantaneous power imbalance between supply and demand during transients. As a result, the ac-bus voltage of microgrid starts oscillating which might have severe consequences such as blackouts. This paper modifies the conventional control scheme of battery energy storage systems (BESSs) to participate in improving the dynamic behavior of islanded microgrids by mitigating the voltage fluctuations. A piecewise linear-elliptic (PLE) droop is proposed and employed in BESS to achieve an enhanced voltage profile by injecting/absorbing reactive power during transients. In this way, the conventional inverter implemented in BESS turns into a smart inverter to cope with fast transients. Using the proposed approach in this paper, any linear droop curve with a specified coefficient can be replaced by a PLE droop curve. Compared with linear droop, an enhanced dynamic response is achieved by utilizing the proposed PLE droop. Case study results are presented using PSCAD/EMTDC to demonstrate the superiority of the proposed approach in improving the dynamic behavior of islanded microgrids.

Tuesday, November 10 15:30 - 16:25

Keynote 8: How Long can Lithium-ion Batteries last for Grid Energy Storage and Vehicle to Grid Applications

Dr. Jeff Dahn

Professor, at Dalhousie University and NSERC/Tesla Canada Industrial Research Chair, Canada

Tuesday, November 10 16:30 - 17:30

Paper Session 4: Paper Session 4

Chairs: Konstanitn Gerasimov (EPCOR, Canada), Gregory J Kish (University of Alberta, Canada)

16:30 ***Comparing Technical Criteria of Various Lithium-Ion Battery Cell Formats for Deriving Respective Market Potentials...450***

Johannes Full and Johannes Wanner (Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Germany); Steffen Kiemel (Fraunhofer IPA, Germany); Robert Miehe (Fraunhofer-Society, Germany); Max Weeber (Fraunhofer Institute

for for Manufacturing Engineering and Automation IPA, Germany); Alexander Sauer (Fraunhoder IPA, Germany)

In this paper, the three most common formats for lithium-ion batteries (pouch, cylindrical and prismatic) are compared in terms of 19 defined technical criteria. Furthermore, the importance of the respective criteria for different fields of application is determined, which in turn can be used to evaluate the suitability of the three formats for market-specific use. Therefore, an evaluation method was developed and carried out with the help of numerous experts from German research institutions and industry. As results, requirement profiles for the fields of application as well as performance profiles for the cell formats could be assigned.

16:48 ***Evaluation of the Sustainability of Decentralised Energy Systems for Domestic Applications…456***

Franz Teske and Adrian Fehrle (FAU Erlangen-Nürnberg, Germany); Jörg Franke (FAU Erlangen-Nuremberg, Germany)

17:06 ***Evaluation of a Stochastic Vehicle Travel Pattern Generation Model with Real-World Travel Data…463***

Anand MP, Athula Rajapakse and Saman Muthukumarana (University of Manitoba, Canada); Bagen Bagen (Manitoba Hydro, Canada)

Higher electric vehicle penetration and associated grid charging will have significant reliability impacts on electric power systems. Therefore, distribution network planning studies need suitable models to capture spatial and temporal distribution of vehicle charging demand. When making expensive planning decisions, it is important to have high confidence in the models used. This paper proposes a systematic method and metrics to evaluate a stochastic model that generate random vehicle travel patterns in an urban area. The particular model considered consists of a collection of Hidden Markov Models, and its efficacy is evaluated using a database of actual vehicle travel data from Winnipeg, Manitoba, Canada. The probabilities associated with the model were extracted from the actual data. The evaluation approach involves comparison of actual and simulated values of model outputs representing the spatial-temporal distributions and use of Euclidean distances to measure the similarity of probability distributions produced by actual and simulated data.

17:24 ***Gaussian Mixture Model for Estimating Solar Irradiance Probability Density…469***

Maisam Wahbah (Khalifa University, United Arab Emirates); Tarek EL-Fouly (Khalifa University of Science and Technology, United Arab Emirates); Bashar Zahawi (Khalifa University, United Arab Emirates)

The increasing penetration of photovoltaic generation resources make it imperative for power network designers to assess the available resources by obtaining accurate estimates of solar irradiance at a given site/geographical area. The parametric Beta distribution has long been a popular choice in such studies; however, the use of parametric functions for probability density estimation (such as the Beta distribution) can be problematic and may lead to model mis-specification. The Gaussian Mixture Model (GMM) is proposed in this paper to provide a more robust estimation of solar irradiance probability density at a certain site. Multi-year solar data from eight locations in the United States is utilized to evaluate the accuracy of the GMM estimate and compare its performance with the popular Beta distribution. Assessments are carried out using three standard measures of error, coefficient of determination, and the Kolmogorov-Smirnov goodness-of-fit test for distributional adequacy. Results demonstrate that the GMM estimate produces a more robust estimation with better performance metrics when compared with the Beta distribution.

17:42 ***Smart Meter Data to Optimize Roof-top Solar and Battery Size…475***

Emon Chatterji (USA)

This paper presents results from a co-optimization model of solar panels and battery capacity for a household using smart meter data-minimizing total energy supply costs. The model undertakes a customer-centric optimization taking into consideration net metering policy, time-of-use grid pricing and inter-annual variability of solar irradiance. It is tested for real household data to assess load and policy parameters that can influence sizing of the combined solar plus battery system. Two case studies are presented for a single-family residential house and a larger community institution. The model's ability to combine solar + battery optimization, together with smart meter data proves useful in deciding the best mix of solar, battery, and electricity purchase or export.

18:00 ***Adaptive Capacity Determination for Critical Load in Power Systems…481***

Hanyue Li and Jessica L. Wert (Texas A&M University, USA); Phylicia Cicilio (University of Alaska Fairbanks, USA)

Resilience metrics are the cornerstone of implementing resilience-based improvements to the electric utility sector. There is a recognized need in power systems for increased resilience and there are numerous power system devices and methods that aim to improve resilience. These methods and devices need to be evaluated for their actual resilience value for each system they aim to improve to determine their worth for each system. This work presents the resilience metric called adaptive capacity calculated using the available transfer capability (ATC) method. Adaptive capacity determines the maximum incremental amount of power that can be transferred to critical loads in the aftermath of an event. The use of this metric is demonstrated by comparing the adaptive capacity of eight seasonal scenarios of the 2000-bus synthetic transmission network on the footprint of Texas with and without the integration of distributed energy resources (DERs). This work highlights how adaptive capacity can help determine where the integration of DERs in the system will and will not provide a resilience benefit.

18:18 ***Optimal Allocation of Shunt Compensators in Distribution Systems Using Turbulent Flow of Water-Based Optimization Algorithm…487***

Ahmad Eid (Aswan University & Faculty of Engineering, Egypt); Salah Kamel (Aswan University, Egypt)

Three different reactive power compensators (RPCs) are typically used with distribution systems to enhance their performance. The RPC includes a shunt capacitor (C), Static Var Compensator (SVC), and Distribution Static Compensator (DSTATCOM). For a small amount of RPC, the capacitors are typically used for their simplicity and low cost of maintenance. On the other hand, the SVC and DSTATCOM are

applied for medium and large RPCs. In this work, the new algorithm of the Turbulent Flow Water-based Optimization (TFWO) algorithm is used to identify the type and amount of RPC in order to reduce the total power loss of the system. The Particle Swarm Optimization (PSO) algorithm is used to verify and compare the results obtained from the TFWO algorithms. The TFWO algorithm is more effective and faster than the PSO algorithm. Moreover, the results verify the effectiveness of the TFWO algorithm in power loss reduction, enhancing the voltage profile, and determining the suitable RPC type, size, and site.

18:36 ***Wind Turbine Productivity and Wind Energy Assessment: An Ontario Case Study...492***

Omid Beik (McMaster University, Canada); Ahmad S. Al-Adsani (Public Authority for Applied Education and Training, Kuwait)

This paper discusses wind energy assessment for the largest wind farm in Ontario to-date, Henvey Inlet wind farm (HIWF), which began in 2017 and reached commercial operation in October 2019. The study includes analysis of wind turbine conversion system, wind velocity using measurement towers, wind turbine and wind farm power and energy prosecution. Characteristics of Vestas V136-3.45 that are used in the HIWF are extracted and implemented in the analysis to achieve real-world results. Two analyses approaches are considered, (i) a definite method based on mathematical modelling of wind velocity, power, and energy, and (ii) a statistic analysis based on Rayleigh probability function. Comparison of the results from the definite and probability approach presents a difference of up to 50%. Therefore, although a probability approach may be used for initial analyses of wind energy when choosing a candidate wind farm, the energy output from a wind farm needs to be calculated based on measured and manufacturers data using a definite approach.

18:54 ***Proposed Wind Turbine Limited- and High-Speed Operation...497***

Omid Beik (McMaster University, Canada); Ahmad S. Al-Adsani (Public Authority for Applied Education and Training, Kuwait)

This paper proposes a high-speed operation (HSO) scheme for wind turbines. In the HSO the turbine can exceed the rated rotor speed while it maintains its output power. The HSO is compared with the existing industry standard for wind turbine control, here referred to as limited speed operation (LSO) where the turbine rotor speed is controlled below the rated speed. Compared to LSO the HSO results in reduced torque for the turbine generator. The paper presents analytical models for the turbine power coefficient, which is used to estimate the turbine power and torque characteristics. The developed models are examined on a commercial wind turbine, Enercon E-82 2 MW, which confirm the effectiveness and accuracy of the methods. Analyses of blade pitch angle and its effect on the turbine characteristics are presented and compared in LSO and HSO schemes.

19:12 ***Optimal Value-Based Prices Placement of DER and V2G Using Planet Search Algorithm...503***

Harold Chamorro (KU Leuven, Belgium); Vijay K. Sood (Ontario Tech University, Canada)

This paper presents a novel approaches for optimal simultaneous placement of distributed generations and V2G parking lots based on value-based prices method which is neglected in previous researches. In this regard, the technical issues of the network, such as reducing losses and improving the voltage profile, are considered by locating and determining the optimal capacity of scattered production resources and electric vehicles parking lots by considering value-based prices to encourage investors in the network. In the other words the presented method in this paper calculates the actual value of each DG in the active loss reduction and according to this value, determines DG energy price, which is named value based pricing. Therefore consideration of value-based prices of DGs and V2Gs during their optimal placement and proposed optimal search algorithm (PSA)are the main contribution of the paper. In this way, the interests of the operator and the investor are secured simultaneously. To solve the optimization problem, the two algorithms of bird assembly and genetics are compared. The proposed method has been tested on standard IEEE33 bus distribution systems. The simulation results show that the proposed method is effective in terms of network benefits and incentive packages to attract investors.

19:30 ***Investigation of Effects of Increasing EV Penetration on Distribution Transformers in Modi Ganpati Area, Pune...509***

Sunil Gaikwad (P. V. G C. O. E. T, University of Pune, India); Hrishikesh Mehta (Savitribai Phule Pune University & Aethertec Innovative Solutions, India)

Electric vehicle (EV) charging loads expected to be geographically-clustered in residential areas than in in industrial or commercial space. This can drive the distribution system to be overloaded, even if the overall supply system may have surplus power and can fulfill the EV charging requirements. The EV charging has negative influence on the grid as it can affect secondary distribution transformer (DT) to be overloaded, especially during EV peak charging periods. In this paper, a model is developed to study the effect of EV on transformers' life considering real-life data of DTs from Modi Ganpati area, Pune. Energy required to charge is calculated considering random state-of-charge (SOC) of battery and charging time instants. Different EV penetration scenarios are considered to study the effect of EV on loss-of-life (LOL) of DT.

19:48 ***Comparison of Halbach, Radial and Axial Magnet Arrangement for Single Phase Tubular Permanent Magnet Linear Alternators...514***

Jayaram Subramanian, Parviz Famouri and Fereshteh Mahmudzadeh (West Virginia University, USA); Mehar Bade (Enginuity Power Systems, USA)

Linear alternators converts linear motion directly into electricity. Linear alternators can be used in applications such as hybrid electric vehicles, Stirling engines, free piston engines, and renewable energy applications. This paper compares halbach, radial and axial magnet arrangement for single phase tubular permanent magnet linear alternator. Modeling has been done using FEMM and the electrical parameters such as power, open circuit voltage, load voltage and current have been compared. It was seen that the halbach arrangement provides best power output in comparison with radial and axial arrangement for the chosen configuration. Furthermore, the advantages

and disadvantages associated with the three magnet arrangements have been discussed in detail.

20:06 ***Optimal Design of a Grid-Connected Hybrid Photovoltaic/Wind/Fuel Cell System…519***

Hamdy M. Sultan and Ahmed S. Menesy (Minia University, Egypt); Salah Kamel (Aswan University, Egypt); Ali S Alghamdi (Majmaah University, Saudi Arabia); Claudia Rahmann (Universidad de Chile, Chile)

In this paper, the optimal design and operation of a hybrid renewable power system is investigated using Invasive Weed Optimization (IWO) technique. The developed algorithm is validated on three different configurations of the grid-connected PV/Wind/Fuel cell system for supplying the load demand in Ataka region in Egypt. The IWO algorithm is adapted for generating the optimal capacities of the generating units while minimizing the cost of energy (COE) generated from the proposed system. In this study, the reliability index is taken as the loss of power supply probability (LPSP). The optimal design of the system is obtained under an acceptable energy fluctuation level and utilization of the renewable resources. In addition, statistical analysis of the results obtained in different system configurations are performed for validating the accuracy and stability of IWO algorithm.

20:24 ***Combining Volt/Var & Volt/Watt Modes to Increase PV Hosting Capacity in LV Distribution Networks…525***

Muhammad Rashid and Andrew M Knight (University of Calgary, Canada)

The PV hosting capacity of a LV distribution feeder is directly affected by how much deterioration happens to the feeder power quality as a result of increased PV resources penetration. This paper focuses on the feeder voltage regulation and the use of local voltage control algorithms to improve the issue. Test simulations have been performed on a typical LV distribution feeder with a heavy load demand scenario and another for light load demand. Firstly, no voltage control is being implemented to demonstrate the full extent of voltage limit violation. Then, Volt/Var and Volt/Watt are used individually and afterwards, combining both algorithms is implemented. The results show that overvoltage violation occurs when the feeder is lightly loaded. Volt/Var control lowers the feeder voltage but it does not prevent limit violation. Volt/Watt prevents limit violation but it reduces the hosting capacity considerably. Combing both Volt/Var and Volt/Watt prevents overvoltage violation and improves the PV hosting capacity of the feeder.

20:42 ***Frequency Control for a High Penetration Wind-Based Energy Storage System in the Power Network…530***

Md Jahidur Rahman and Tafticht Tahar (University of Québec in Abitibi-Témiscamingue (UQAT), Canada); Mamadou Lamine Doumbia (Universite du Quebec à Trois-Rivieres, Canada)

Distributed Generation (DG) becomes a very impressive and renowned power generation system in the presence of the power engineering industry. It has economical as well as environmental benefits in respect of conventional power generation systems and develops new ideas to build up the system more effectively and reduce pollution in the environment. Due to the fluctuating behavior of Renewable Energy Sources (RES), balancing, demand and generation are not an easy task to control the power system. It is impossible to have a continuous power production from the RES because of natural situations. That's why control of frequency in a power generation system makes it more challenging due to the increasing penetration of RES. In this paper, a control technique has been developed with two cases for a hybrid diesel / high-penetration wind-based energy storage system to control the frequency in the overall power system. The results show that without throwing the large amount of power in a secondary/dump load to maintain the desired level of frequency, a storage system (battery) can be charged when power from renewable energy sources is higher than load demand and discharged when power from renewable energy sources is less than total load demand. To investigate the fluctuation behavior of overall system a PID Controller has been used.

21:00 ***Review of Studies and Operational Experiences of PV Hosting Capacity Improvement by Smart Inverters…536***

Rajiv K. Varma (University of Western Ontario, Canada); Vatandeep Singh (The University of Western Ontario, Canada)

This paper presents a review of case studies and operational experiences of smart inverters in increasing hosting capacity in real distribution systems, worldwide. The phenomenal increase in penetration of solar PV systems has caused several grid integration challenges. Overvoltage due to active power injection by solar PV systems is a prominent factor that restricts hosting capacity of PV systems in distribution networks. Smart inverter functions on PV inverters have been shown to obviate this challenge and enhance hosting capacity. This paper presents a comparative evaluation of different smart inverter functions such as constant power factor, volt-var, and volt-watt in improving hosting capacity. Key takeaways from various simulation studies and operating experiences of smart inverters in actual distribution systems across the world are described. This paper provides useful insights to utilities in understanding the impact of smart inverters for improving PV hosting capacity in their distribution systems.

21:18 ***Hybrid Fuzzy Control for Mitigating the Partial Shading Effects in a Seven-Level Grid Connected Photovoltaic Inverter…542***

Mateus Batista Pinto (Federal University of Mato Grosso do Sul, Brazil); Ruben Barros Godoy (Federal University of Mato Grosso do Sul); Moacyr Aureliano de Brito and Tiago Henrique Mateus (Federal University of Mato Grosso do Sul, Brazil)

This work presents comparative analysis, obtained through MATLAB/Simulink® platform, of a proposed Hybrid Fuzzy Logic controller and a classic Proportional-Integral (PI) controller, intended for mitigating the effects of partial shading in photovoltaic generation systems connected to a low voltage distribution grid. In this analysis, a seven-level cascaded Half-Bridge multi-level converter, modulated by phase shifted sinusoidal pulse width modulation, with a robust Droop Control strategy, was adopted as power stage. The system was subjected to several scenarios of solar irradiation changes, comparing its dynamic behavior using both control methodologies. In such scenarios, the proposed Hybrid Fuzzy Logic presented superior performance supporting its applicability.

21:36 ***Optimal Sizing of a Hybrid Power System for Driving a Passenger Boat in Bangladesh…548***

Mohammad Abu Abdullah Al Mehedi and Mohammad Tariq Iqbal (Memorial University of Newfoundland, Canada)

Bangladesh is a land of rivers, canals, and lakes where water transportation is an essential means of transport. The country use boats as one of the leading resources of transportation in its widespread inland waterways. Most of the currently used boats use only diesel for fuel. Appropriate use of renewable energy sources, particularly solar energy with diesel generators, could reduce diesel consumption. In this paper, a typical boat energy requirement was calculated to be 42.10kWh/day. A boat could be driven by a DC motor using electrical power generated using an onboard PV system, battery, and small-sized generator. The size of the vessel is length 12m, width 4.8m, depth 0.5m, and draft height 0.04m with a carrying capacity of 20passenger for 8hours a day. The designed system consists of a 10.6 kW PV, 1.6kW rated small generator, onboard battery storage consists of 16 batteries, each rated 6V, 240Ah, and a 48V DC motor rated 5kW 300rpm with a speed controller. The paper includes system design details and sizing using HOMER Pro.

21:54 ***Dual Use Solar Surfaces for Local Grids and Net Zero Development…554***

Andrew Csinger (Taktikai Consulting Corp., Canada); Douglas Matthews (Solar Earth Technologies, Canada)

Legacy approaches to energy management and distribution are ill suited to solar power. The history of hydro, nuclear and coal offer little to guide contemporary photovoltaics infrastructure deployment. Putting gigawatts of solar panels on the cheapest available real estate will have lasting negative consequences: new approaches are needed to avoid unnecessary, undesirable and both predictable and unpredictable environmental, social and economic side effects. Rather than taking over productive farmers' fields with gigawatt scale solar plantations that unbalance grids and introduce new transmission needs, the many sunny surfaces proximal to load should be pressed into dual-use: efficient pavement integrated photovoltaics (PIPV) avoid misappropriation of real-estate, do not affect current use or aesthetics of surfaces and require no transmission lines. We call this dual-use of high value real estate surface solar, and demonstrate the opportunity for superior IRR over traditional deployment.

22:12 ***Novel Six-Phase DFIG Suitable for Three-Phase and Six-Phase Grid-Connected Disperse Generation…559***

Neeraj Kumar Mishra (NIT Hamirpur, India); Zakir Husain (National Institute of Technology Hamirpur, India); Arvind Mukhraiya (India)

The motivation of this paper is inspired through the question that "if, in 21 centuries, the 6-phase grid system becomes commercially available, then which type of DFIG will provide electricity to the 6-phase grid system." this manuscript proposes the modelling and simulation of novel six-Phase DFIG (6-Φ-DFIG) for providing electricity to the 6-phase and 3-phase grid system. Along with 6-Φ-DFIG, the modelling of the wind energy conversion system (WECS) also presented in this paper. The utility, advantages, and future scope of the 6-Φ-DFIG show the viability of the proposed novel area.

22:30 ***The Profitability and Affordability of Smart Renewable Microgrid in Sub-Saharan Africa…565***

Hendrika Kuffar (RIKACHI, Canada)

Sadly, in the twenty-first century, approximately 55% of the people living in sub-Saharan Africa do not have access to electricity. According to the International Energy Agency (IEA), the number of people without access to electricity in the world was 860 million by 2017, and 600 million of those people were from sub-Saharan Africa. Lack of access to electricity and shortage of electricity has negative impacts on the economy, environment, as well as the quality of healthcare and education of people in sub-Saharan Africa. This paper seeks to examine the factors that influence the profitability and affordability of smart renewable micro grid. Eliminating or reducing the barriers to profitability from an investor's perspective and consumer affordability will help to accelerate implementation to achieve the UN Sustainable Development Goal 7 (SDG7) to ensure access to renewable, reliable, and affordable electricity to most people in sub-Saharan Africa and elsewhere by 2030. As a result, a significant improvement in the economic livelihoods of people in these regions.

22:48 ***Implications of Microgrids, Economic Autonomy and Renewable Energy Systems for Remote Indigenous Communities…569***

Alyssa Schatz and Petr Musilek (University of Alberta, Canada)

Indigenous knowledge has the capacity to facilitate the utilization of microgrids within Indigenous energy systems to spur reconciliation and self-determination. Since Indigenous ways of knowing can be conceptually related to renewable energy systems, ecological economic ideology and various forms of innovation, there is an organic opportunity for microgrids, amongst other decentralized energy technologies, to work in concert with Indigenous communities. The natural eclipse of theory and practice has the potential to uplift Indigenous communities across Canada and has already done so. Renewable energy systems enable Indigenous people to address local issues and promote autonomy. Additionally, through Indigenous ownership and the fundamental comprehension of the complexities that Indigenous people face, there is great potential to uplift these communities as forerunners within the renewable energy sector. By analyzing how microgrids can capture renewable generation, co-generation and Indigenous ownership, specifically though islanded microgrids, there is a great potential for further impact.

23:06 ***A Novel Smart Gas Stove with Gas Leakage Detection and Multistage Prevention System Using IoT LoRa Technology…573***

Md. Rakibul Islam (Rajshahi University of Engineering and Technology); Abdul Matin, Md. Saifullah Siddiquee and Fahim Md. Sifnatul Hasnain (Rajshahi University of Engineering and Technology, Bangladesh); Md. Habibur Rahaman (Memorial University of Newfoundland, Canada); Tonmoy Hasan (Rajshahi University of Engineering & Technology (RUET), Bangladesh)

The outline and implementation of a low power real-time gas leakage detection and LoRa wireless communication technology-based notification system are accompanied by the multistage safety features in the kitchen as well as in the house have been inaugurated in this paper. The proposed system comprises a LoRa client and a LoRa gateway. LoRa client was made by the RFM69HW LoRa module, Arduino Uno,and some sensing devices, which were installed in the kitchen.Primarily a LoRa gateway was installed in our community. This LoRa gateway was associated with a cloud server (Ubidots) by employing Wi-Fi networks as transmission media. When gas leakage was detected, liquid crystal display (LCD), and the buzzer were activated, thereupon a GPS sensor identified the geographical position of the affected area, and LoRa client stored the measured data to Ubidots IoT platform, afterword data was sent to the user and police station, and eventually, the main power circuit at home was tripped off, and the exhaust fan was activated for avoiding further accidents. Here, for the efficient use of heat from a conventional gas stove in Bangladesh, and subsequently, for the secure power supply to the whole system,power was generated from the unused heat during cooking using the see back concept of thermo electric power generation(TEG)module.

23:24 ***Cyber-Attacks Against Voltage Profile in Smart Distribution Grids with Highly-Dispersed PV Generators: Detection and Protection...578***

Nour Ghalib Abuaysheh (Doha, Qatar); Tamer Khattab and Ahmed Massoud (Qatar University, Qatar)

In this work, we study the effect of cyber-attacks on voltage regulation in smart grids with highly dispersed photovoltaic (PV) power generators. We picture how the cyber-attacks in the distribution network with the existence of PV generators can cause induced voltage violations of overvoltage or undervoltage. It is demonstrated that if an attacker falsifies measurements, voltage violations may occur in the system. A proposed algorithm using a PV perturbation method to check the response of the nodes in the network is applied to detect the cyber-attacks and protect against destructive reactions as a second detection and protection layer in addition to classical cyber protection at the communication network layer. We establish a primary distribution network model that incorporates attacks that penetrate the communication network and inject falsified data. We project the proposed basic model into a distribution network example to show the effect of such attacks. We further use the extended model to evaluate the ability of the proposed algorithms to detect and hence protect from these attacks.

23:42 ***Design and Analysis of a Stand-Alone DC Hybrid Microgrid for a Rural Base Transceiver Station in Nigeria...584***

Cyprian Oton and Mohammad Tariq Iqbal (Memorial University of Newfoundland, Canada)

The proliferation of mobile base transceiver station sites in Nigeria comes with a growing need to address those sites' source of power. Sustainability and mitigating harmful environmental impact caused by the diesel-only method of power generation is of great concern. This article examines the optimal sizing of a small DC microgrid to power an outdoor base station site in Agbaja, a rural settlement in Kogi State, Nigeria. A DC system has better performance because multiple energy conversion experienced in the AC system is eliminated. HOMER pro is used to size the system based on the measured load and available renewable resources. The PV/Diesel/Battery configuration resulted in the least Net Present Cost (NPC), Cost of Energy (COE), and unmet energy. A comparison between this proposed system and the current system shows a reduction in operating expenditure (OPEX) by 75% with zero unmet energy.

24:00 ***Adaptive Q(U) Control Using Combined Genetic Algorithm and Artificial Neural Network...590***

Desmond Okwabi Ampofo (University of Bremen, Germany); Ahmed S. Abdelsamad (Bremen University, Germany); Johanna Myrzik (University of Bremen, Germany); Marilyn Asmah (TU Dortmund, Germany)

The increasing penetration of distributed generation on power grids will increase the number of voltage violations because of voltage rise phenomenon. Thus, there is a need for efficient utilization of reactive power resources available on the grid including using local voltage control of DGs for voltage regulation. One of such is Q(U) control. However, the question is how to tune its control parameters to guarantee good performances as the grid condition keeps changing. This paper proposes a two stage offline methodology based on genetic algorithm (GA) optimization and artificial neural network (ANN) to adapt the control parameters. The objective of the ANN is to develop a fitting function correlating the Thevenin impedance seen at the point of common coupling and optimal control parameters obtained from the GA optimization. This scheme is implemented on 16 United Kingdom generic test distribution network. Results demonstrated the effectiveness of this method in regulating the voltage as compared to the base where the control parameters of the Q(U) control are fixed.

Tuesday, November 10 17:30 - 18:30

Paper Session 5: Paper Session 5

Chairs: Konstanitn Gerasimov (EPCOR, Canada), Gregory J Kish (University of Alberta, Canada)

17:30 ***Steady State Accuracy of Second-Order Generator Dynamic Models in Generator Parameter Validation Testing...596***

Quincy Wang (BC Hydro, Canada); Song Wang (PacifiCorp, USA)

This article analyzes and compares existing second-order generator dynamic models including two new models under development. Model structures and saturation methods are reviewed for existing popular second-order generator models. Analyses on the steady state accuracy of the dynamic models and their applications in generator model parameter validation testing using stator current interruption method are discussed. Theoretical background of the new GENQEC model is provided and the advantage of the GENQEC in parameter validation is proven through mathematically derived equations from the structure of all the models analyzed.

17:48 ***Non-Synchronous Generation Impact on Frequency Response - A Case from Albania...602***

Harold Chamorro (KU Leuven, Belgium); Wilfredo Flores (Technologyc University UNITEC, HONDURAS & UNITEC, Honduras)

Albanian electric power generation has been almost totally dependent on hydropower since its system inception. Within the past decade, although modest, there has been some share of power produced from Renewable Energy Sources (RES), mostly from Solar Power Plants. Going forward, the Albanian government has promoted renewable energy as an important part of its energy mix and is planning to increase the share of injected RES composed of hydro, Photovoltaic (PV) and Wind. Among these, wind energy is one of the most promising sources. This paper gives an overview of the studies performed regarding System Frequency Response (SFR) by replacing hydro inertia with non-synchronous generation. A study of frequency behavior under several penetration levels of non-synchronous generation is presented with cases which show how system frequency is affected when replacing hydro-power inertia with wind turbine converter inertia

18:06 ***Exhaustive Modal Analysis of Interconnected European Power System...608***

Kouki Mohamed and Marinescu Bogdan (Ecole Centrale de Nantes, France); Xavier Florent (RTE-R&D, France)

The interconnected European power system is evolving due to the new extensions and to the systematic integration of Power Park Modules, i.e., unit or ensemble of units generation electricity (Renewable Energy (RE), Distributed Generation (DG), etc), which is connected to the grid by power electronics and FACTS (STATCOM, HVDC,...). As a consequence, the increase of the size and the emergence of the new oscillatory modes which involve distant dynamic devices, i.e., of coupling modes (modes associated to generator/ turbine inertia, and modes associated to Power Park Modules), and of modes related to various regulations. In this paper, a full scan of European power system is given. An exhaustive method that determines all oscillatory modes independently of the system's order, of the topology and without a priori knowledge about the system, is used. The exhaustive method is fully analytic. Indeed, it is based only on the state-space realisation of any given power system and does not require operator manipulation like dynamic simulations. To this end, we quantify and analyse the interaction between the different inputs/outputs of a given system. This leads to the identification of classes of coupled dynamic devices of the power system. Next, starting from a reduced number of classes, a selective modal analysis method is applied to each class to put into evidence a good approximation of all oscillatory modes. Finally, a complete classification of the oscillatory modes found at the previous stage is provided in terms of the types (interarea, electrical, ...) and their characteristics (oscillation frequency, damping, participation, ...). 2900 oscillatory modes were found for the studied model of the European system.

18:24 ***Saturation of Current Transformer in a Coordinated Substation Towards Optimal Power Flow...614***

A B M Shafiul Azam (Lansing Board of Water and Light, USA)

Power systems optimization problems are very difficult to implement because these systems are very large, complex, widely distributed, and are influenced by many unexpected events. The utility industry employs the most reliable optimization methods to take full advantage of simplifying the formulation and implementation of the problem. For the utility, high voltage substation modernization is getting essential to enable the connection of the new loads and diverse generation customers and to ensure that electricity supplied is of acceptable quality, reliable, and affordable. In light of that, the protection scheme must act perfectly to protect the substation as a whole and its equipment from any possible fault. However, relay used in the high voltage substation for protection purposes acts differently when the current transformer is saturated. Here, we present consideration of the maximum loading capacity of a substation along with its CT saturation, of a coordinated substation at the very early phase of design. The substation is comprised of 138 kV transmission and 13.2 kV distribution networks. Power flow and fault current data, along with protection schemes for line, bus, transformer, and switchgear and availability of key equipment in the market are investigated to explore the most suitable substation design. A procedure is developed based on the steps required to plan and design a modern substation. Step-by-step iterative simulation is performed at the planning phase based on generation and transmission sources' fault current data, X/R ratio of the 138 kV incoming lines to the substation end, and the continuous and emergency loads for present and future. A design decision to construct a substation is made to select a network configuration to maximize redundancy and reliability to ensure optimal power flow through the substation. Additionally, the presented planning process ensures proper coordination between the transmission and distribution systems.

18:42 ***Inertial Response of Electrical Power Systems...620***

Berardino Porretta (Ergosum Inc, Canada)

Following loss of generation events and during the period prior to the deployment of automatic generation control, the stabilization of system frequency above load shedding levels rests solely on the system inertia, self regulation, and governor response. This paper focuses on system inertia. The physics of inertia is reviewed and it is shown that increased amounts of inertia, and thus increased amounts of inertial response, can be provided only by increasing the mass of the machines rotating on the system or by redistributing it farther away from its axis of rotation. It is shown that controls that inject power into the system, such as synthetic inertia controls, do not provide inertial response. These controls only change the generation minus load imbalance. A one machine equivalent of a power system is developed and the calculation of equivalent system values for inertia, self regulation, and governor droop is discussed. Results of simulations that illustrate the impacts of different values of inertia on frequency recovery are presented. These results demonstrate that governor controls become unstable at some critical low value of inertia.

19:00 ***Medium Range Resonant Inductive Wireless Power Transfer...626***

Shahbaz Tahir (Technical University Munich, Germany); Muhammad Azmat Ali Rathore (Altran, Germany)

In this paper basic principles of wireless power transfer and QI standards are discussed and measurements of various coil characteristics like mutual coupling and resonant frequencies are presented. After measurements, various simulations were performed on LT-Spice for the design of a mid-range Wireless Power Transfer prototype. Afterwards, the circuit is fabricated according to the simulated parameters.

A simplified Moving Field Inductive Power Transfer prototype is simulated to analyze its behavior. Finally, investigations on various design parameters for prototype development with respect to challenges and future state of the art for Wireless Power Transfer have been done.

19:18 ***Instability Prediction in Smart Cyber-Physical Grids Using Feedforward Neural Networks…633***

Amir Jafari (University of Tabriz, Iran); Farzad Darbandi (University of Tabriz, Canada); Hadis Karimipour (University of Guelph, Canada)

Due to the use of huge number of sensors and the increasing use of communication networks, cyber-physical systems (CPS) are becoming vulnerable to cyber-attacks. The ever-increasing complexity of CPS bring up the need for data-driven machine learning applications to fill in the need of model creation to describe the system behavior. In this paper, a novel stability condition predictor based on cascaded feedforward neural network is proposed. The proposed method aims to identify anomaly due to cyber or physical disturbances as an early sign of instability. The proposed neural network utilizes cascaded connections in order to increase accuracy of the prediction. The conjugate gradient backpropagation and Polak-Ribière formula are utilized for training process. This method also can predict the critical generators to mitigate the effect of the cascading failure and consequent blackout in the system. Simulations results on the IEEE 39-bus system indicate the superiority of the proposed method in terms of accuracy, speed, and robustness.

19:36 ***Multi-Core Platform of Admittance Matrix Formation of Power Systems: Computational Time Assessment…639***

Harold Chamorro (KU Leuven, Belgium); Vijay K. Sood (Ontario Tech University, Canada)

This paper presents a comparison of computational time required to build the admittance matrix of five test systems (ranging from 200 to 70,000 nodes) considering two formation approaches: element-by-element and matrix approach. The algorithms have been implemented in MATLABTM and tested in four multi-core platforms. Implementations include sparse and dense matrix representation and parallel/ non-parallel computing. Results show the matrix approach considering sparse representation and parallel computing is the best approach in computing time.

19:54 ***Performance Evaluation of GMR and TMR Sensors to Estimate Current Phasors in Smart Grids…645***

Prasad Shrawane and Tarlochan Sidhu (University of Ontario Institute of Technology, Canada)

This paper gives results of the performance evaluation of noninvasive sensors that are used to estimate current by sensing the magnetic field produced surrounding the overhead power conductors in transmission and distribution of power generated by smart grids. The objective of the research is to replace the conventional instrument transformers to bring more ease of operation and maintenance in addition to save the space in the switchgear as well as substation. The experiment is performed in the laboratory on an alternating current. The sensors work on the principle of Giant Magnetoresistance (GMR) and Tunnel Magnetoresistance (TMR) effect.

20:12 ***Self-Secure Inverters Against Malicious Setpoints…650***

Tareq Hossen, Fahmid Sadeque and Behrooz Mirafzal (Kansas State University, USA)

The next generation of grid-interactive inverters is a cyber-physical device, which can receive set points in real-time from a utility operator or a third-party aggregator. This feature enhances the control ability of grid-interactive inverters to provide services beyond just pumping power to the grid. Being a cyber-physical device makes an inverter vulnerable to cyber attacks. In this paper, a model/knowledge-based technique is proposed for developing self-secure smart inverters. The reference model/knowledge is built based on the normal operating region of the inverter and its reduced-order dynamic model. The inverter can autonomously examine the incoming set points before engaging them to the local controller. The inverter must learn about the input and output circuits to determine its normal operating region through estimating system parameters. The estimation of the grid parameters is accomplished by injecting current at a different frequency than the power frequency. In this paper, the feasibility of realizing self-secure inverters is examined using a laboratory setup including a Powerflex 755 three-phase inverter and a 12 kW NHR 9410 power grid emulator. The results confirm that inverters can be programmed to autonomously accept or reject the incoming commands and protect themselves from malicious set points.

20:30 ***Distributed Ledger Technologies for Peer-To-Peer Energy Trading…656***

Olamide Jogunola and Mohammad Hammoudeh (Manchester Metropolitan University, United Kingdom (Great Britain)); Kelvin Anoh (University of Bolton, United Kingdom (Great Britain)); Bamidele Adebisi (Manchester Metropolitan University, United Kingdom (Great Britain))

The increasing integration of prosumers and smart metering devices into the energy distribution network, is transforming the traditional energy market to a community energy trading that requires peer-to-peer (P2P) interactions.Such P2P interactions result in complex data exchanges among prosumers, utility grid, and market operators. This inevitably introduces control complexity, security, and privacy challenges in the existing power system. The application of distributed ledger technology (DLT) has seen an increase in solving security challenges in the power network, specifically, in P2P energy exchanges. Thus, this study explores different DLT structures including blockchain and IOTA usage in energy P2P trading. A smart contract for managing trust and transactions is designed and implemented on IBM hyper ledger fabric platform. In addition, we evaluated the performance of interconnected internet of things devices for energy transactions with IOTA protocol,which uses the directed a cyclic graph as its DLT structure, against the Ethereum-based blockchain structure. It is shown that -to-end transaction delay with the IOTA DLT is lower than the Ethereum-based DLT implementation.

20:48 ***Key Performance Indicator Based Design Guidelines for Local Electricity Markets…662***

Mukund Wadhwa (Albert-Ludwigs-Universität Freiburg & Oli Systems GmbH, Stuttgart, Germany); Godwin Chidiebube Okwuibe (Oli Systems GmbH, Stuttgart & Chair of Renewable and Sustainable Energy Systems, Technical University of Munich, Germany); Thomas Brenner (Oli Systems GmbH, Stuttgart, Germany); Peter Tzscheutschler (Technical University of

Munich, Germany); Thomas Hamacher (Technische Universität München, Germany)

Local electricity markets (LEMs) are investigated as a solution to provide the residential and small commercial consumers, and prosumers the opportunity to have control over their electricity-related choices and make more profit from the electricity trading. This work analysis the market design factors such as update intervals in a time step, production to consumption (PtC) ratio and pricing scenarios, influencing the performance of an LEM run on the Decentralized Autonomous Area Agent (D3A) simulation framework. Comparing the results using performance indicators such as self sufficiency, share of market savings (SMS), and average buying rate (ABR) reveals that the performance of LEMs is highly dependent on the market design factors. The level of savings or profits made by participants also changes significantly with these market design factors. Furthermore, the results imply that LEM can provide better incentives for prosumers by providing them with the opportunity to trade their PV generated electricity at a price higher than the feed-in tariff. With only 20% reduction in average buying rate, it is also evident that LEMs provide a great opportunity for keeping the small scale PV systems active after their 20 years of fixed remuneration under Renewable Energy Source Act (EEG) in Germany.

21:06 ***A Blockchain-Based Double-Sided Auction Peer-To-Peer Electricity Market Framework...668***

Godwin Chidiebube Okwuibe (Oli Systems GmbH, Stuttgart & Chair of Renewable and Sustainable Energy Systems, Technical University of Munich, Germany); Michel Zade and Peter Tzscheutschler (Technical University of Munich, Germany); Thomas Hamacher (Technische Universität München, Germany); Ulrich Wagner (Chair of Energy Economy and Application Technology, Germany)

The framework presented provides an open-source,blockchain-based, peer-to-peer energy market platform which can be used for testing different setups or for creating a micro-grid peer-to-peer trading platform. The framework offers the following possibilities: •variations of the trading horizon, metering intervals; •simulations within a fraction of the real time; •variations of the number of participants; •multiple operated micro-grids within one smart contract; •clearing mechanisms with discriminative prices or a market clearing price; •functionality to log data exchanged with the blockchain; production and consumption data of each participant, electricity exchanged within the micro-grid and the main grid, token balances of all participants, •variation of the price ranges.

21:24 ***Intelligent Bidding Strategies in Local Electricity Markets: A Simulation-Based Analysis...676***

Godwin Chidiebube Okwuibe (Oli Systems GmbH, Stuttgart & Chair of Renewable and Sustainable Energy Systems, Technical University of Munich, Germany); Mukund Wadhwa (Albert-Ludwigs-Universität Freiburg & Oli Systems GmbH, Stuttgart, Germany); Thomas Brenner (Oli Systems GmbH, Stuttgart, Germany); Peter Tzscheutschler (Technical University of Munich, Germany); Thomas Hamacher (Technische Universität München, Germany)

The integration of PV-generated electricity from households and commercial buildings into the electricity mix offers opportunity to reduce the greenhouse gas emissions released in the Earth's atmosphere. The rising quantity of these distributed energy resources (DER) and their fluctuating energy production makes it challenging for the grid operators to manage the grids. This in turn leads to an increase in retail electricity prices due to the rising grid fee. Local electricity markets (LEMs) have proven to be an effective and efficient tool to manage the local generated electricity and ensure that electricity is traded and consumed close to its point of production. The market design factors influencing the performance of an LEM are analysed using a decentralized autonomous area agent (D3A) simulation framework. The market design factors investigated are prosumers-to-consumers ratio(nPC), pricing scenarios and bidding strategies. The results were compared using performance indicators such as self sufficiency, share of individual savings (SIS) of the participants, share of market savings (SMS) and average buying rate. The simulation results show that the performance of an LEM on addition of new participant depends upon the type of participants added to the market. Furthermore, using intelligent bidding strategy like Q-learning increases the self sufficiency of the local community close to their threshold value without the addition of flexibility or storage options.

21:42 ***Investigating the Flexibilization of Hydraulic Storage Power Plants in the Nordics...683***

Marius Siemonsmeier, Peter Wirtz and Maik Schönefeld (RWTH Aachen University, Germany)

The increase in supply-dependent renewable energy sources and the decommissioning of thermal power plants leads to an increasing need for flexibility in the future European electricity supply system. In this context, hydraulic power plants represent a mature and renewable flexibility option. The EU Horizon 2020 project "HydroFlex" aims to increase the value of hydropower through increased flexibility. To this end, the project aims to develop a flexible turbine capable of very flexible operation and in particular several start/stop cycles per day. In this paper, different types of flexibility are first analyzed as they are required in the future European power system. Subsequently, the paper presents a method simulating the operation of highly complex hydraulic power plant parks, which is essential to investigate future operational requirements and to evaluate the turbine technology developed within the "HydroFlex" project from a systemic perspective. The focus is, in particular, on the future operation of hydraulic power plants in the Nordics in order to meet the increasing flexibility demands in the European power system.

22:00 ***An Active Damping Method for the Bipolar DC System Connected with Constant Power Loads...689***

Xiaoyao You, Heping Liu, Jianquan Liao and Yuansheng Huang (Chongqing University, China)

The constant power loads (CPLs) in direct current (DC) power system have the potential to degrade the stability of the whole system. This paper proposed a virtual resistance damping method that improves the stability of the bipolar DC system connected with CPLs. At first, a stability criterion for the bipolar system is given. After that, a bipolar DC system based on a half-bridge voltage balancer (HBVB) is introduced and its small-signal model is derived. On this basis, a virtual resistance damping method, Inductor-Series-Damping-Resistance (ISDR), is proposed and analyzed. Moreover, the Lyapunov stability theory is adopted to investigate the impact of unbalanced load on the system stability. It turns out that system stability is determined by the sum of the system output power. This conclusion can significantly reduce the complexity of the bipolar system stability analysis and control loop design. Finally, the simulations and experiments are

performed to verify the proposed idea in this paper.

22:18 ***Robust Integral Sliding Mode Control of Non-Minimum Phase DC-DC Converters…695***

Youssef El Haj (Ontario Tech University, Canada); Ahmed Sheir and Ruth Milman (UOIT, Canada); Vijay K. Sood (Ontario Tech University, Canada)

In this paper, a modified integral sliding mode controller (ISMC) is proposed for non-minimum phase dc-dc converters. A boost dc-dc converter operating in continuous conduction mode (CCM) is chosen as a representative case study. The converter's bilinear model and its effect on the controller design necessitate the need for a nonlinear controller. Unlike a recently introduced ISMC, the proposed controller does not need a priori knowledge of initial conditions such as inductor current or capacitor voltage, nor does it implement a sign function to ensure a fast response or reachability. A novel modified sliding surface which ensures reachability, stability and reduces chattering at the steady-state operation point is proposed. Moreover, the proposed controller in conjunction with a disturbance observer (DO) enables the converter to maintain stable operation under disturbances and uncertainties. The system's robustness against drastic, discontinuous, autonomous, or non-zero derivative disturbances are enhanced by including an invariant saturation function. The performance of the proposed ISMC is tested and compared with a well-established linear controller to prove its validity under different types and levels of disturbances and uncertainties.

22:36 ***Robust H∞ Decentralized Control Design for HVDC Link Embedded in a Large-Scale AC Grid…702***

Hoang-Trung Ngo (École Centrale de Nantes, France); Elkhatib Kamal (Ecole Centrale de Nantes, LS2N-CNRS, France); Marinescu Bogdan (Ecole Centrale de Nantes, France); Xavier Florent (RTE-R&D, France)

This paper proposes a static decentralized controller design method for an HVDC link embedded in a large-scale AC grid based on the Linear Matrix Inequalities (LMIs) technique. The considered studied system is treated as composed by two overlapping subsystems. The interconnection between the two subsystems is nonlinear and is treated by increasing disturbance rejection and robustness against norm-bounded parametric uncertainties of the closed-loop. Indeed, the overall robustness and tracking ability of the entire closed-loop is significantly improved with the proposed controller. This is both analytically ensured in the synthesis of the gains of the regulators and, next proven by validation simulations.The overall robustness and tracking ability of the entire closed loop system can be significantly improved. It is shown that this control can deal with HVDC link with different lengths, including the short ones for each the coupling between the two converters is strong. Another advantage of the proposed decoupling control is the resilience: as no communication is used between the two stations,in case of failure of one converter or loss of measures as control, the control of the other converter is not affected. Moreover, it guarantees the stability of the overall system. Finally, the efficiency and robustness of the proposed controllers are tested and compared with each others, to illustrate the control synthesis and its effectiveness.

22:54 ***Robust Constrained Controller Design for HVDC Link Embedded in a Large-Scale AC Grid…708***

Elkhatib Kamal and Emile Thau (Ecole Centrale de Nantes, LS2N-CNRS, France); Marinescu Bogdan (Ecole Centrale de Nantes, France); Guillaume Denis (RTE R&D Division, France)

In this paper, a robust control strategy, able to improve the dynamic behavior performance of High Voltage Direct Current (HVDC) under diverse operating conditions, is proposed. The design of the control proposed in this paper is based on the coordination of the control actions of the HVDC converters and the use of a simplified control model which takes into account not only the HVDC but also its AC neighbor zone.As consequence, stability is ensured for the HVDC and transient stability margin of its AC neighbor zone is improved. From the computational point of view, Linear Matrix Inequalities (LMIs)are solved to compute the gains of regulator which is of standard Proportional-Integral (PI) type. Constrained on both control and the states are also taken into account. This new methodology was validated on a realistic scale model of the France-Spain interconnection in Euro stag. Compared with the standard vector control, Linear Quadratic (LQ) and H∞approaches, the new proposed controller gives higher critical clearing time (CCT). In addition, the proposed controller improves the dynamic behavior performance under wide range of operating conditions and minimize the tracking reference error with respect to saturations on both control and the states.

23:12 ***Stability Enhancement of High Frequency DC Distribution Network by Incorporating Wide Bandgap β-Ga2O3 Power MOSFET as Switching Element…714***

Sudipta Mukherjee (Indian Institute of Technology, Bombay, India); Swaroop Ganguly (IIT Bombay, India)

We propose stability enhancement of a high frequency (1.2MHz) DC distribution network comprising numerous feedback-controlled buck converters by replacing their conventional electro-mechanical switches with β-polymorphic Gallium Oxide (β-Ga2O3) power MOSFETs operated on soft switching. The performance anomaly in terms of output voltage oscillations and poor overall stability resulting from negative incremental impedances have been successfully addressed with the help of the Middlebrook Criterion. Having the highest Johnson's Figure of Merit (2844) among all studied Wide Band Gap (WBG) materials, β-Ga2O3promises the best Power-Frequency operation. In our simulations here, it leads to substantial performance improvement compared to the conventional system design in terms of output voltage oscillation and overall stability of the DC-distribution network. Losses have been calculated and analyzed, with regard to the Minimum System Efficiency Degradation versus Maximum Stability Enhancement trade-off. Further, we demonstrate the dominance of a solid-state switch at the converter input, over a feedback loop at the back-end,in securing a system with higher stability.

23:30 ***Matrix Inverter: A Multilevel Inverter Based on Matrix Converter Switch Matrix…720***

Ahmad Syukri Mohamad (Universiti Kuala Lumpur, Malaysia)

This paper presents a new concept of matrix converter application as an inverter. A matrix converter is commonly used as an AC-to-AC conversion device. Hypothetically the AC sources of the matrix converter can be replaced with DC sources. By using a switching strategy similar to a multilevel inverter switching strategy, and some modification on the matrix converter topology, the matrix converter is able

to produce a stepped output waveform similar to a multilevel inverter output. The proposed matrix inverter is fundamentally built on the basis of the combination of matrix converter topology with the DC-to-AC conversion technique of a multilevel inverter. The number of rows in the switches matrix represents the number of output voltage level, while the number of columns represents the number of output phases. The matrix inverter topology version variations can be synthesized for single-phase, two-phase, three-phase, four-phase, five-phase, six-phase and up to any number of output phases - not limited by the number of the input sources, with each output phase frequency can be set independently. A 41-level, three-phase matrix inverter has been constructed and tested in order to validate the matrix inverter concept.

23:48 ***State-Space Dynamic Model of Unified MMC Structure for Hybrid AC/DC Grids…725***

Abraham Rojas Tarango and Gregory J Kish (University of Alberta, Canada)

The state-space modelling process and validation of a generalized DC/DC/AC MMC structure is presented. This structure can be used to represent two different MMC topologies that are capable of performing simultaneous AC/DC and DC/DC conversions. The DC/DC/AC models enable controlled power exchanges between two DC systems and an AC system. The time-averaged model is developed in the αβ0-frame, and includes all dynamics in the converter structure, barring switching harmonics. The resulting model is validated against a switched converter model implemented in PLECS. The model can be used to perform time-domain studies of the multiport converters, at a much-reduced simulation time than its switched model counterpart.

24:06 ***Electrochemical Optimization Model for Parameters Identification of PEM Electrolyzer…733***

Abdulrahman Mohamed Abomazid, Nader El-Taweel and Hany Farag (York University, Canada)

This paper proposes an optimization model that identifies the parameters of a detailed electro chemical model for a Proton Exchange Membrane (PEM) electrolyzer. The identification procedure is based on current-voltage (I-V)measurements. The proposed model aims to identify the values of seven modelling parameters of the electrolyzer electro chemical model. These parameters include: change in Gibbs free energy,exchange current density for anode and cathode, charge transfer coefficient of both anode and cathode, conductivity of the membrane, and limiting current density. The parameter identification problem is formulated based on a nonlinear least-squares objective function. The optimization problem is solved using the MATLAB optimization toolbox. Comparisons of results and analysis between experimental and estimated data are presented for different operating conditions of temperature and pressure. The results provide a Root Mean Square Error(RMSE) in the range of10−6which demonstrates the accuracy of the proposed model. To affirm the model's superiority, the proposed model is compared with other electrolyzer parameter identification models found in existing literature.

24:24 ***Electric Vehicle User Behavior Prediction Using Learning-Based Approaches…738***

Sara Khan (University of Saarland, Germany); Boris Brandherm (Deutsche Forschungszentrum für Künstliche Intelligenz GmbH, Germany); Anilkumar Swamy (University of Saarland, Germany)

One of the main barrier for electric vehicles to be successful in real world is the need for expensive charging infrastructures. The key aspect of EV is time required to charge the battery to full capacity is far less than the time duration for which the car remains available for charging. Smart charging system can leverage this aspect to efficiently manage the load demand, which in turn alleviates the need for more than necessary number of expensive charging infrastructures. EV user behaviour prediction is vital for building EV Adaptive Charging System. In the past there have been several statistical and ML methods that tries to predict EV user behavior. But with the influx of huge amount of EV user data and deep learning's (DL) ability to perform well on such large data enables us to build DL based methods to predict EV user behavior. In this paper, we predict EV user behavior using ML and DL methods and compare the results and infer the insights for difference in performance. By comparing at various settings between machine learning (ML) and DL methods, we found that K-Nearest Neighbours outperforms Neural Networks with a very minute difference of 0.031 in Mean Absolute Error metric.

24:42 ***Bayesian Optimization Based ANN Model for Short Term Wind Speed Forecasting in Newfoundland, Canada…743***

Md. Habibur Rahaman (Memorial University of Newfoundland, Canada); T. M. Rubaith Bashar, Mohammad Munem and Md. Hasibul Hasan Hasib (Rajshahi University of Engineering & Technology, Bangladesh); Hasan Mahmud (University of Dhaka, Bangladesh); Arifin Nur Alif (Bangladesh University of Engineering & Technology, Bangladesh)

Wind power capacity around the world is increasing day by day, but the production of wind energy greatly depends on the wind speed, where the wind speed has stochastic nature over time. In this paper, an artificial neural network (ANN) technique to forecast wind speed for the next hour in Newfoundland, Canada is proposed. As, deep learning models are combined with different hyperparameters, in our study, the selection of important hyperparameters are conducted by applying the Bayesian optimization algorithm. The wind speed forecasting performance of the proposed model is compared with other recognized models like support vector machine (SVM), random forest (R.F.) and decision tree (D.T.), where it is observed that our proposed model performs better than the other models in terms of mean absolute error (M.A.E.) and root mean squared error (R.M.S.E.). The proposed Bayesian optimized artificial neural network is fed with five input features and delivers M.A.E. and R.M.S.E. of 1.09 and 1.45.

1:00 ***Impacts of Frequency Containment Reserve on the Optimal Coordinated Hydropower Scheduling in Three-Settlement Markets…748***

Abolfazl Khodadadi (KTH Royal Institute of Technology, Sweden); Lennart Söder (Royal Institute of Technology, Sweden)

This paper investigates the coordinated scheduling of hydropower plants in a river participating in a day-ahead,regulation and reserve markets. The gains in participating in the multiple sequential electricity markets are formulated through the linear programming. In the reserve market, the possibility of proposing an unsymmetrical frequency containment reserve(FCR) is considered for two scenarios in the winter and summer.Furthermore, the impacts of active time of regulation bids are investigated. The results show a moderate revenue increase by participating in the reserve market. Also, it states that providing the unsymmetrical FCR market will even increase revenue as

an incentive for the owners to participate.