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POSTER ABSTRACTS

SMART INVERTER VOLTAGE CONTROL ON DISTRIBUTION FEEDERS

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Smart inverters are studied in both the dynamic/transient and steady state in a simulation environment. Using EPRI OpenDSS, five real California feeders are simulated over a 95 day period while the PV penetration and smart inverter fraction are varied. From the simulations, it is shown that smart inverters operating under different Volt/VAr based control schemes improve feeder conditions. The improvement is shown with regards to voltage maxima and minima, tap operations, and variability. Feeder total line losses increase due to the presence of smart inverters, as a result of increased current in the lines associated with reduced bus voltages. Increasing the smart inverter fraction and removing the deadband from the Volt/VAr control curve produces the largest improvements in these quantities. On one feeder, using smart inverters alone reduced the number of tap operations to zero, showing potential for the inverters to be used as primary voltage regulators (assuming proper PV penetration and placement). Finally, based on the results, sizing of the inverter was shown to be important in ensuring smart inverter effectiveness, and is recommended for future work.

In the dynamic domain, smart inverters behave according to the same Volt/VAr control, but are also subject to recommended ride-through constraints for tripping. The focus of the dynamic simulations are to show how an inverter responds to anomalous behavior in the feeder operations. To explore this, various fault situations are applied to the feeder. The inverters can successfully ride through small faults on the feeder. Furthermore, we demonstrate the importance of the decrease to energize requirement for UVR3 range voltages ($V<0.5$ pu) in preventing frequency increases resulting in unnecessary tripping of the inverter. Finally, we show that for a large range of voltages values, power system instabilities caused by competing inverters is not observed.

As a result of this work, we have designed a comprehensive testbed for use in both the dynamic and steady state simulations which can be used to study a large number of scenarios regarding advanced inverter functionalities.

ECONOMIC MODELING OF MICROGRID BUSINESS CASES CONSIDERING RELIABILITY

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Technology, policy, and market forces are combining to make microgrids economically viable within some modern electric grids. Industry forecasts point to significant future growth which may be led by private investors seeking
private benefits like lower energy costs and/or greater reliability

Though benefits are well-known theory, the evidentiary basis for understanding when and where microgrids are cost-effective remains highly contested. One of the central missing elements is a robust understanding of where and how enterprises will actually invest in these systems. Models that quantify such business cases using realistic technology models and optimization techniques are essential. In our work we are building such a microgrid model.

OPTIMAL ON-LOAD TAP CHANGER CONTROL FOR HIGHER PV HOSTING CAPACITY OF DISTRIBUTION FEEDERS

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High Solar Photovoltaic (PV) penetration on distribution systems causes over-voltages near the end of the feeder. Given that voltage regulators are typically not at the end of the feeder, conventional local tap control does not consider the highest feeder voltages limiting the feeder PV hosting capacity.

An optimal tap control (OTC) method is proposed to regulate on-load tap changers (OLTC) using a feeder-wide multi-horizon control which minimizes the maximum deviation of the voltage profile from 1 p.u. on the entire feeder during the optimization horizon. To reduce maintenance cost of OLTCs, the number of tap operations is also considered in the objective function. In order to reduce the computational cost, linearization techniques are introduced to transform the optimization problem to mixed-integer convex programming.

The efficiency of the control algorithm is tested against two real feeders in California. The case studies show that OTC improves the voltage condition such that the PV hosting capacities on the test feeders increase by 40% and 24%. Although OTC increases the number of tap operations on the feeders, the increase does not lead to increased operations and maintenance needs from the grid, compared to the no-battery case. Furthermore, we show that we have a high tolerance to forecast errors for 3 actual buildings from the UCSD campus.

A COMPUTATIONAL MODELING APPROACH OF USERBEHAVIOR FOR SWARM CONTROL APPLICATIONS

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As increasing number of household appliances are connecting to Internet we can leverage their sensing, monitoring and actuation capabilities to predict user behavior. Such contextual user behavior can be utilized to schedule household appliances to minimize energy requirements, maximize cost savings and improve user satisfaction. In this poster we present a system which combines demographic based user behavior models, household appliance energy and indoor user localization data to create an optimized appliance schedule. It is also used to produce various house profiles with different energy demand characteristics in a reproducible manner. Comparison with real data shows that our model captures the power demand differences between different family types and accurately follows the trends seen in real data. For different families, generated power trace matches the peak power times and obtains 38% absolute mean error, with minimum 0.25% error.

A STUDY OF A NEW RECOMBINATION PROCESS OF D2 PLASMA MEDIATED BY ND3 MOLECULES

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In future tokamak fusion devices, nitrogen(N2) is the most probable candidate of the impurity seeding to protect the tungsten divertor from the heat loads. It has been reported, nitrogen forms compounds with hydrogen, i.e. ammonia, in H2-N2 plasmas. In this research, a new recombination process of deuterium atomic/molecular ions Dx+(x=1-3) supported by ammonia is suggested. The process is initiated with neutralization processes of Dx+ by exchanging charge/D+ with ND3 molecules. After the reactions, the formed NDy+ (y = 3 or 4) ions are recombined with electrons. The electron-ion recombination rate of NDy+ is much higher than one of Dx+. Therefore, ND3 catalyzes recombination of hydrogen plasmas throughout those two steps. The initial step of the ND3-enhanced recombination process is studied by experimental and simulation methods in this research. The Etcher plasma machine is used to make low density plasmas (Ne=10^16m-3, Te=4eV) with D2 and N2 gas feeding. Total pressure is kept constant as 3.0 mTorr while partial gas pressure fraction is changed. A rate equation model is used to understand the production and loss reactions for 20 species (10 ions and 10 neutrals), and solutions give densities of those 20 species. To check applicability of the model to our experimental configuration, calculation results are compared with experimental density fractions, which is measured by a mass spectrometer combined with ion energy analyzer. The comparison shows qualitative agreement, so that the model seems to capture important processes in the plasma. The model shows that dominant neutralization channel of Dx+ in the volume are the creation process of NDy+ throughout the charge/D+ exchange reactions with ND3. This process is the initial step of the ND3-enhanced recombination process as predicted. Thus, the ammonia would strongly enhance neutralization of Dx+ in the divertor plasmas.

BLOBS AND DRIFT WAVE DYNAMICS

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Blobs, high plasma density coherent filamentary structures propagating in tokamak edge toward outer wall with speed ~1 km/s, play an important role in the scrape-off layer plasma transport in both L-mode and H-mode in between ELMs. Although the blobs are studied for about 15 years, the mechanism(-s) of blob formation is still under debates. Meanwhile blobs are often observed inside the separatrix where they move mainly in poloidal direction and once in a while cross the separatrix and appear in the SOL. Recently, the Hasegawa-Mima equation was generalized by considering Boltzmann electrons and keeping all nonlinearities, which illustrated that the traveling wave solution F(x,y,t)=F(y-Ut) at large amplitude resembles blob-like structure. Based on this work, two conservative integrals, which are different from the generalized energy and enstrophy, were generated and discussed. From the first conservative integral, it follows that the amplitude of wave-packet propagating in the direction of decreasing background plasma density will increase exponentially with the distance travelled, which agrees with the linear analysis in 2-D case, until nonlinear effects become important. The numerical results of one-dimensional (1-D) and two-dimensional (2-D) nonlinear evolutions of normalized electrostatic potential support such analytic results and are validated by keeping the conservation of the two integrals. In 1-D case (neglecting radial-dependence) the amplitude of normalized electrostatic potential is limited by the second integral, while, in 2-D case, it growing exponentially and then saturates at the level ~1 by nonlinear effects. At this stage, density bursts reaching factor ~3 against the background, which is close to experimental observations of blob plasma density in the vicinity of the separatrix.

OPTIMAL DISTRIBUTED NONLINEAR BATTERY CONTROL

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Energy storage plays a more important role than ever before, due to the transition to smart grid along with higher penetration of renewable resources. In this paper, we describe our optimal nonlinear battery control algorithm that can handle multiple batteries connected to the grid in a distributed and costoptimal fashion, while maintaining low complexity of O(N^2). In contrast to the state-of-the-art, we use a high accuracy nonlinear battery model with 2% error. We present three distributed solutions: 1) Circular negotiation ring, providing convergence rates independent of number of batteries, 2) Mean circular negotiation ring, converging very quickly for a low number of batteries, 3) Bisection method has a convergence rate independent of battery capacities. We compare our algorithm to the state-ofthe-art and show that we can decrease the utility cost of an actual building by up to 50% compared to the batteryless case, by 30% over the load-following heuristic and by 60% over a state-of-theart optimal control algorithm designed using a linear battery model. For a constant load profile, optimal linear control incurs
costs higher by 150% for MPC.

INNOVATIVE, VERSATILE AND COST-COMPETITIVE SOLID OXIDE FUEL CELL STACK CONCEPT

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An innovative, versatile and cost-competitive solid oxide fuel cell (SOFC) stack design concept suitable for a broad range of power generation applications is being developed at UCSD. This SOFC stack concept, based on a novel prime-surface interconnect design, has several attractive features including reduced weight and volume, minimal stacking performance losses, improved sealing, flexibility in gas flow configuration, and versatility in incorporating different types of cell construction (e.g., conventional sintered cells such as sintered anode-supported cells, metal-supported cells, etc.). These features lead to lower cost, better performance, and enhanced reliability for the stack. Current efforts at UCSD focus on developing the prime-surface interconnect design and fabrication, evaluating and demonstrating operation of stacks combining prime-surface interconnects and conventional sintered cells and in parallel, advancing the stack concept to incorporate metal-supported cells for further improvements. Preliminary results on the development of metal-supported cells (thin-film SOFC cells on metal substrates) fabricated by sputtering and prime-surface interconnect design are presented.

OPTIMAL CONTROL TECHNIQUES FOR MHD STABILITY

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The DIII-D tokamak can excite strong, locked or nearly locked kink modes whose rotation frequencies do not evolve quickly and are slow compared to their growth rates. To control these Resistive Wall Modes (RWMs), DIII-D and Columbia University have installed a GPU-based feedback control system in a low-latency architecture based on a system developed on the HBT-EP tokamak [1]. This system is capable of handling up to 96 inputs and 32 analog outputs with microsecond latency. Simulations have predicted that mod-
ern control techniques like Linear Quadratic Gaussian (LQG) control will perform better than classical control techniques when using control coils external to the vacuum vessel. The VALEN RWM model [2] has been used to gauge the eectiveness of RWM control algorithms in tokamaks. VALEN models the perturbed magnetic field from a single MHD instability and its interaction with surrounding conducting structures as a series of coupled circuit equations. An LQG control algorithm based on VALEN has been developed and tested on this GPU based system. An overview of the control hardware, VALEN model, control algorithm and results of experiments to develop control of a rotating n=1 perturbation using external coils will be presented. Results from high N experiments also suggest that advanced feedback techniques using external control coils may be as effective as internal control coil feedback using classical control techniques. Work supported by the U.S. DOE under DE-FC02-04ER54698 and DE-FG02-04ER54761.

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MECHANISTIC STUDIES FOR THE DEVELOPMENT OF THIN SI MICROWIRE SOLAR CELLS FOR WEARABLE ELECTRONICS

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Si nanowire and microwire solar cells promise thin, flexible, and efficient powering strategies for wearable electronics due to their short optical absorption lengths and radial charge separation over short distances. However, owing to large surface to volume ratio, recombination of carriers at surfaces is a crucial factor that affects the performance of Si nano/microwire solar cell. Controlling the nanowire facets on crystal planes that are known to have low interface state densities may help in reducing surface recombination and recovering the promised performance of nanowire solar cells. Moreover, optimal design of wire array is needed as the size and number of wires also contribute to surface recombination. In this work, we performed a systematic study to minimize the surface recombination effect by fabricating microwires with various structural designs that are based on 10 Î¼m tall Si microwire (SiMW) solar cells with a radial p-n junction. The optimal design resulted in power conversion efficiencies that exceeded 15%.The SiMW cells were then transferred and characterized on parylene C substrates. We will report on the latest performance metrics in these endeavors and the performance analysis on a flexible substrate.

STRATOCUMULUS DISSIPATION DEPENDENCE ON INITIAL AND BOUNDARY CONDITIONS PARAMETERS FOR A MIXED LAYER MODEL

Zamora, Manica; Norris, Joel; Ghonima, Mohamed; Kleissl, Jan
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Sky imagers are a well-accepted technology for producing short-term forecasts of solar energy availability. Here, we present three recent developments at UCSD that we anticipate will improve accuracy of sky imager forecasts in the future.

Increasing renewable energy penetration goals has led to a need of improved forecasting tools of renewable resources. In the the case of some coastal cities like San Diego, the main factor affecting the solar resource are stratocumulus clouds. These clouds are common in summertime, covering large parts of the land during nighttime, and usually dissipating during the morning as the cloud thins due to solar heating.

A single column Mixed Layer Model (MLM) that was developed to study the evolution of stratocumulus clouds (Ghonima et al., 2016) is used to predict their dissipation time. In this work we are interested in determining which parameters in the initial and boundary conditions used by the MLM are the most important ones affecting the predicted cloud lifetime. The ranges of studied parameters are derived from observations and Numerical Weather Prediction models results in the summer season of the past 3 years for the MCAS Miramar station in San Diego, CA.

The set of parameters for the initial conditions include temperature and moisture profiles fitted to a mixed layer assumption, a daily wind profile, expected solar irradiance, large scale divergence, and Bowen ratio. We study the effect of each parameter by varying them in pairs around the median of all the observations. For the studied range, temperature above the cloud, expected solar irradiance and mean wind speed don't impact dissipation time as much as the rest of the parameters.

SOLAR FORECASTING FOR LARGE-SCALE SOLAR PLANTS

Pedro, Hugo; Larson, David; Li, Mengying; Coimbra, Carlos
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Accurate and reliable generation forecasts are very important for the operation of large-scale solar plants. Good forecasts can reduce plant operation costs associated with intra-day variability, reduce imbalance charges incurred by solar plants due to inaccurate forecasts, reduce utility costs associated with day-ahead scheduling (thereby reducing overall solar O&M costs), and assist the grid operator to balance load demand schedules.

In this poster we present our experience in creating solar irradiance and solar generation forecasts for two large solar farms in California: California Valley Solar Ranch (250 MW PV), and Ivanpah Solar Electric Generating System (377 MW CSP).
We present some typical results that can be obtained by applying the latest research models in a real-case scenario. We also highlight the major hurdles that must be addressed to improve the forecast accuracy. Finally we describe some tools under development to overcome these hurdles.

IMPROVING CLOUD CLASSIFICATION AND FORECASTING FROM SATELLITE IMAGES

Pedro, Hugo; Coimbra, Carlos
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The accuracy of the irradiance forecast at a given location depends primarily on the accuracy of predicting the optical depth of clouds that block the solar disk. For this reason, cloud tracking models from satellite images are key components in solar forecasts for horizons that range from 1 to 8 hours. In general, those models operate in two stages: first, pixels in the image are classified as cloud or no cloud; second, the clouds are advected into the future according to some cloud motion estimation.
Despite considerable recent progress in cloud identification and forecasting, there is still large room for improvement. For instance, thin clouds are often not captured by the cloud classification algorithms although they can attenuate the solar beam substantially.

Furthermore, even when clouds are correctly identified it is difficult to estimate properly the correct optical depth and their impact in irradiance.

In this work we address the issues identified above by considering numerical weather prediction (NWP) data (e.g. NAM and NDFD) together with the cloud maps obtained from satellite images. By overlaying NWP data over the cloud identification maps we can improve the optical depth estimation. The accuracy of all data (NWP data and satellite-derived data) will be validated against ground telemetry obtained in the Mojave desert, CA.

LOW-COST, WIRELESS SENSOR NETWORKS FOR DISTRIBUTED SOLAR POWER PLANT MONITORING

Larson, David P. and Orosco, Jeremy and Pedro, Hugo T. C. and Coimbra, Carlos F. M.
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We detail the development of a low-cost, wireless sensor network (WSN) for distributed monitoring of large scale (> 1 MWp and > 1 km^2) solar power plants. The WSN provides a solution to the need for high-density ground telemetry at low cost, with each unit priced at under $500. Each node in the network is solar powered and communicates wireless, thereby eliminating the need for invasive changes to pre-existing network and power infrastructure at potential sites. Additionally, the wireless network topology enables rapid reconfiguration of the sensor deployment, e.g., subtraction or addition of nodes. A prototype WSN has been deployed to an operational 250 MWp photovoltaic power plant in California and is undergoing validation.

CURRENT AND CHARGE DEMAND SCHEDULING OF PARALLEL PLACED (SECOND-LIFE) BATTERIES

Jiang, Joe; Habib, Abdulelah; Zhao, Xin; Shrinkle, Lou; de Callafon, Raymond
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This poster presents a centralized recursive optimal scheduling method for a battery system of parallel connected battery modules by applying buck regulators in the battery management system (BMS) to adjust individual module currents. Our proposed method can robustly compute an optimal current scheduling that balances (equals) each module current and maximize total bus current without violating a batteryâ€™s operating constraints. In order to demonstrate the capability of this method in real battery system, an experiment setup of 3 parallel placed battery modules is built. The experimental results validate the feasibility and show the advantages of this current scheduling method in a real battery application despite the fact that battery operating parameters change as the battery pack ages or is imbalanced in energy storage and deliver system (EEDS).

OPTIMAL HYBRID POWER DISPATCH FOR DISTRIBUTED ENERGY RESOURCES WITH DYNAMIC CONSTRAINTS

Konakalla, Sai Akhil Reddy; de Callafon, Raymond
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Consider a microgrid with a hybrid collection of distributed energy resources (DERs) that include fossil, renewables and energy storage battery systems. Given the dynamic variability of the DERs in terms of power production, this paper presents an optimization approach for the optimal power dispatch in such a hybrid microgrid by taking into account amplitude and rate constraints on each DER. The constrained multi-objective power dispatch problem is solved by formulating a weighted convex optimization with penalty terms imposed to take both power dynamics and allowable energy levels of each DER into account. The paper also analyzes the weighting used in the optimization as a trade-off between the use of renewable energy, energy storage and the cost of fossil fuel to achieve power dispatch demands. The optimization approach is illustrated on the combination of a fossil and a (multi-)battery system where the State of Charge (SoC) levels of the batteries are required to stay close to each other while minimizing frequent power switching (chattering) and battery round-trip losses. Simulations results demonstrate how economic incentives can be used to formulate the optimal hybrid power dispatching between fossil and renewable resources, while battery SoCs can be balanced (converge to the same mean value) by sharing power optimally among different batteries.

PMU-BASED MICROGRID POWER CONTROL OVER THE INTERNET WITH REAL-TIME GRID SIMULATION

Valibeygi, Amir; de Callafon, Raymond
UC San Diego

As part of microgrid research activities at Synchrophasor Grid Monitoring and Automation (SyGMA) lab, a microgrid controller is being developed and tested on a real-time simulation of a microgrid in RTDS. The real-time simulator models loads, PV generation, battery, and several PMUs for measurements across the microgrid. The microgrid together with the PMUs and the central controller constitute a Cyber-Physical System (CPS) and suffer inherent communication, coordination, computation, and safety challenges as is typical of CPS. The objective is to control power flow between the microgrid and the main grid and also control the State of Charge of the battery in the microgrid. The communication between the controller and the simulator is performed in real-time over the Internet as they are located at distant locations.

ADVANCED ENERGY STORAGE MODELING, PERFORMANCE EVALUATION, AND TESTING

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In recent years, there has been increased attention on electrochemical grid-scale energy storage solutions. For accurate market valuation, there is a pressing need for careful modeling of the activities of energy storage systems providing services to the grid. The current economic analyses lack essential experimental results of energy storage systems undergoing such activities. This study combines economic analysis with electrochemical testing to provide detailed information of possible grid-scale duty-cycles and their relationship with different battery chemistries. The work includes the generation of five different economically driven duty cycles with which to test batteries. In addition, it demonstrates protocol for assessing the performance of batteries during the duty cycles and an assessment of the effects that the duty cycles have on the performance and the health of the batteries. The results show that specific battery chemistries exhibit unique performances during different grid-scale applications, suggesting that more than one type of battery may be suited for optimal use of energy storage on the grid, each having unique roles. The work demonstrates the need for a multi-disciplinary approach to modeling, designing, and selecting batteries for grid-scale use.