**Emerging Concepts and Techniques for Advanced Power System Operation and Control**

*Proposal for Invited Session at*

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**Organizers**:

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**Summary Statement:**

The U.S. electric power grid is currently facing the challenges of integrating large amounts of intermittent renewable generation and accommodating changes in load composition due to electrification of transportation. Due to growing environmental concerns, as well as economic and political requirements, the integration of renewable energy into the U.S. electric power grid becomes a growing trend, which could lead to significant reduction in fossil fuel consumption and CO2 emissions. Renewable generation is typically non-dispatchable because it is most often operated at the maximum output due to the low marginal cost of renewable energy. In addition, the available output of renewable generation is very variable and uncertain due to the intermittency of renewable energy. The vast integration of renewable energy into the electric power grid imposes daunting challenges to the traditional centralized management system. On the one hand, the variability and uncertainty of renewable generation will substantially increase the need for operational reserves to balance the power supply and demand instantaneously and continuously. On the other hand, the total system inertia as well as contingency reserve decreases as renewable generation displaces conventional generation. Therefore, it becomes extremely difficult for the system operator to maintain the stability and reliability of the power grid. If these additional reserves are still required to be provided by conventional generation, it will totally diminish the net carbon benefit from renewables, reduce generation efficiency, and become economically untenable. Therefore, the penetration of renewable generation is still limited due to the lack of the technologies that are able to reliably and affordably manage the dynamic variability introduced by renewable generation. Although the traditional hierarchical control paradigm with time scale separation was efficient for the conventional power grid, the way in which the power grid is controlled and operated should be revisited to resolve the challenges imposed by the future renewable integration. In order to increase system stability margin and maintain system reliability for the future highly variable power grid over very wide operating range, new technologies are greatly needed for advanced power system planning and operation. Furthermore, new communication and sensor technologies present unique opportunities to facilitate the development of new technologies. This invited session would like to bring leading researchers to present their recent results on emerging control concepts and techniques for the future power grid. It is expected to provide an overview of the state of the art in this emerging area. The topics to be covered include DER coordination, demand response, load modeling, damping control, wide area control and so on. These new technologies will also be examined to see if they have the desired attributes such as scalability, resilience and robustness that are important for future practical applications.

**Invited Papers:**

1. ***Title***: Consensus-based coordination of electric vehicle charging

***Authors***: Z. Ma, S. Zou and *I. Hiskens (University of Michigan)*

***Abstract***: This work considers coordinated charging of electric vehicles over a finite horizon, where the goal is to optimize the social welfare of the grid and the collection of EVs. Prior work established a coordination framework that facilitates the tradeoff between the total generation cost and local costs associated with overloading and battery degradation. A decentralized approach to solving the resulting optimization problem required all EVs to communicate with a central entity that managed price updates. This work develops an approach which eliminates the need for the central price update. Each EV computes a local price through an estimate of the total EV charging demand, and exchanges that information with its neighbours. A consensus algorithm is used to attain a common price which the EVs subsequently use to update their charging strategies. These new charging strategies are used to compute new price estimates and the process repeats. It is shown that this update procedure achieves exactly the same outcome as the central price update process. Furthermore, this iterative process converges to the unique and efficient solution.

1. ***Title***: Online Optimal Power Flow Problems

***Authors***: K. Dvijotham, Y. Tang and *S. Low (Caltech)*

***Abstract***: Optimal power flow (OPF) is a central problem because it underlies numerous power system operation and planning applications. The OPF literature focuses mainly on offline algorithms that are executed until they converge before the final solution is applied. In this paper, we build on recent work to develop a novel online algorithm for OPF, based on a gradient projection algorithm. Intermediate iterates of our algorithm are guaranteed to be feasible and can be applied to the network in real time. Under certain assumptions, the algorithm is guaranteed to produce a globally optimal solution, or a local solution with small sub-optimality. We study the convergence rate of the algorithm, and use results from online optimization theory to provide guarantees for drifting OPF problems, where the state of the network is slowly changing over time. Finally, we present numerical results on IEEE test networks.

1. ***Title***: A Linearized Power Flow Model for Optimization in Unbalanced Distribution Systems

***Authors***: D. Arnold (LBNL) and *D. Callaway (UC Berkeley)*

***Abstract***: Optimal Power Flow (OPF) is an important tool used to coordinate assets in electric power systems to ensure customer voltages are within pre-defined tolerances and to improve distribution system operations. While convex relaxations of Optimal Power Flow (OPF) problems have been proposed for both balanced and unbalanced networks, these approaches do not provide universal convexity guarantees and scale inefficiently as network size and the number of constraints increase. To address these issues, we have recently explored a novel linearized OPF formulation for unbalanced distribution systems. In this work, an extension of the previous formulation is proposed to reduce errors introduced by the linearization. Furthermore, we continue the analysis of the linearized OPF via comparison to results obtained through convex relaxations and Semi-Definite Programming (SDP). Simulation results of the IEEE 37 node test feeder show that the linearized OPF produces control decisions that closely approximate those obtained via SDP relaxations. In a specific case, we show that the linearized OPF is capable of solving certain problems which cannot be formulated as SPDs.

1. ***Title***: Design of Distributed Controllers Seeking Optimal Power Flow Solutions Under Communication Constraints

***Authors***: *E. Dall'Anese (National Renewable Energy Laboratory)*, A. Simonetto, and S. Dhople

***Abstract***: This paper focuses on power distribution networks featuring inverter-interfaced distributed energy resources (DERs), and develops feedback controllers that drive the DER output powers to solutions of time-varying AC optimal power flow (OPF) problems. Control synthesis is grounded on primal-dual-type methods for regularized Lagrangian functions, as well as linear approximations of the AC power-flow equations. Convergence and OPF-target-tracking capabilities are established while acknowledging: i) communication-packet losses, and 2) partial updates of control signals. The latter case is particularly relevant since it enables asynchronous operation of the controllers where DER setpoints are updated at a fast time scale based on local voltage measurements, and information on the network state is utilized if and when available, based on communication constraints. As an application, the paper considers distribution systems with high photovoltaic integration, and demonstrates that the proposed framework provides fast voltage-regulation capabilities, while enabling the near real-time pursuit of solutions of OPF problems.

1. ***Title***: A Lyapunov approach to control of microgrids with a network-preserved model

***Authors***: C. D. Persis, N. Monshizadeh, J. Schiffer and *F. Dorfler (ETH Zurich)*

***Abstract***: In this work, we consider microgrids with a network preserved model consisting of inverters and constant active power as well as constant reactive power loads. We avoid the simplifying yet restrictive decoupling assumption, and explicitly consider the coupling between the frequency and voltage dynamics. By leveraging incremental Lyapunov functions and the implicit function theorem, we treat the analysis of the resulting coupled nonlinear differential algebraic system. We show that under suitable conditions, a distributed averaging proportional integral control regulates the frequency to the nominal one, stabilizes the voltages, and allocates the resources in an optimal fashion at steady-state.

1. ***Title***: On Resilience Analysis and Quantification for Wide-Area Control of Power Systems

***Authors***: Y. Lu, C.-Y. Chang, *W. Zhang (The OSU)*, A. Conejo and L. Marinovici

***Abstract***: Wide-area control is an effective means to reduce inter-area oscillations of bulk power systems. Its dependence on communication of remote measurement signals makes the closed-loop system vulnerable to cyber attacks. This paper develops a framework to analyze and quantify resilience of a given wide-area controller under disruptive attacks on certain communication links. Resilience of a given controller is measured in terms of closed-loop eigenvalues under the worst possible attack strategy. The computation of such a resilience index is challenging especially for large-scale power systems due to the discrete nature of the attack strategies. We propose an equivalent optimization-based formulation in terms of Lyapunov conditions and a convex relaxation approach to facilitate the computation. Conditions under which the proposed relaxation is exact are derived and an efficient algorithm with guaranteed convergence is also developed. The proposed framework and the algorithm allows us to quantify resilience for given wide-area controllers and also provide sufficient conditions to guarantee closed-loop stability under the worst communication attack. Simulations are performed on IEEE 39-bus system to illustrate the proposed resilience analysis and computation framework.