My research interests are in the areas of power system optimization and control, grid integration of distributed energy resources including renewables and energy storage systems (ESS), distribution system optimal voltage regulation, and power markets and power system economics. I conduct fundamental and applied research on efficient grid integration of distributed energy resources from both technical and economic aspects as well as development of distributed optimal power flow algorithms and optimal feeder-wide voltage control to increase hosting capacity of distribution feeders.

1. Research Experience

During my postdoctoral experience at University of California San Diego, my research has been focused on grid integration of distributed energy resources (DER) from both technical and economic aspects. I have led several tasks of various research projects funded by California Energy Commission (CEC) and U.S. Department of Energy (DOE) for a total of $6.8M since August 2015. Meanwhile, I have also co-advised five Ph.D. students with Dr. Jan Kleissl at UC San Diego and have co-authored several papers from the students' dissertation works as the principal advisor in different research areas in power systems. In my Ph.D. study at University of South Florida, I conducted research on optimal operation of microgrids equipped with various DER and developed several optimization and control algorithms for microgrids and power electronic converters. A full list of my research projects is provided in my CV; however, the following three projects are detailed here since they highly motivate my future research plans.

Research project 1: Voltage control for distribution feeders

Spatio-temporal photovoltaic (PV) forecast using sky-imagers is one of unique capabilities in the Center of Energy Research (CER) at UC San Diego. Using such PV forecast data, we have shown that high intermittency of solar energy resources causes significant voltage excursions ([25] in my CV). Voltage variability most significantly affects the ability for distribution systems to host high penetration of PV and results in increasing number of tap operations and O&M costs. To reduce the number of tap operations, I have developed a model predictive control method to use spatio-temporal PV forecast data to identify and eliminate unnecessary tap operations. In this research, the solution proposed to seek the optimal tap position of a specific transformer is presented as the following optimization problem,

$$t_1^* = \{\text{argmin}\ |t_1 - t_0|, \text{s.t. } \ t_1 \in \{t_0\} \cup T\}$$

where $T = \{t_i^{sim\,(\tau)} \,|\, \tau \in \mathbb{Z}, 1 \le \tau \le 11\}$ is the vector of simulated tap positions in the time interval $[T_s, T_s + 5\text{min}]$ based on 11 quasi-steady state power flow simulations. Tap operations of different voltage regulators are coordinated to minimize the voltage deviations. This research has shown that 54% of the imposed tap operations due to PV variability can be avoided without any adverse effect on the voltage profile [13, 24]. Fig. 1 illustrates a 3-hour tap operation results for one of the test feeders on Jan 15, 2015. In another CEC-funded project (PON 14-303), I have studied the long-term and transient impacts of smart inverters through quasi-static time series (QSTS) and dynamic simulations on five real California feeders [11]. I have shown that replacing conventional PV inverters with smart inverters reduces the voltage variability by up to 70% and significantly increases their PV hosting capacity. For the dynamic simulations for this grant, I developed a multi-phase distribution feeder reduction algorithm which significantly reduces the computation expenses of QSTS simulations for PV grid integration studies and makes the dynamic studies feasible [9].

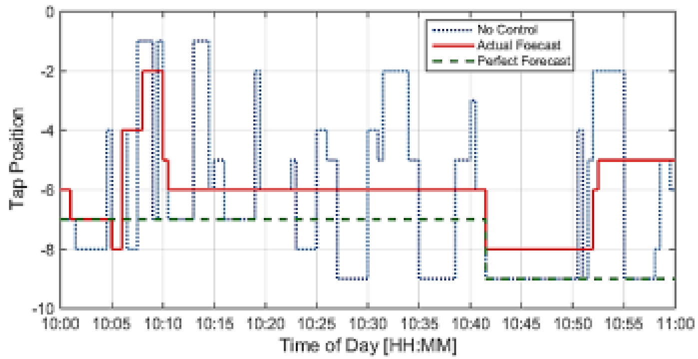

Fig. 1. Tap position sequences of transformer 3 at 10am-1pm on Jan 19, 2015 for three different scenarios. Originally the number of TO was 135. Using the actual and perfect forecast that is reduced to 17 and 2, respectively.

Research project 2: Optimization and control for microgrid operation

Optimal power flow (OPF) is a non-convex optimization problem which seeks the best operation point for the power system. A comprehensive set of constraints including generation and network limits must also be taken into account. The integration of microgrids operated by non-utility agents adds more computational expense to the OPF problem since they may host various DERs such as energy storage systems and electric vehicles (EV) with additional and different types of constraints and these microgrids do not share their data for optimization purposes due to privacy and economic concerns. I proposed an optimal operation and management system for microgrids with high penetration of renewable energy and energy storage systems as well as several multi-agent OPF solutions which guarantee the optimal operation of distribution systems with only limited data sharing and less computation expenses [6, 17]. The multi-agent algorithms essentially decomposes the entire OPF problem, i.e.

$$\min \sum_{i\in A} C_i(P_{g_i}) + \sum_{i\in N-A} C_i(P_{g_i}) \qquad s.t. \;\; P_{imp_i} = P_{exp_i}, Q_{imp_i} = Q_{exp_i} \;\; \forall i \in A$$

into two sub-problems (Fig. 2): 1) $\min \sum_{i\in N-A} C_i(P_{g_i}) + \sum_{i\in A}[\lambda_i^p P_{imp_i} + \lambda_i^q Q_{imp_i}]$ solved by the Distribution System Operator (DSO) or utility, and 2) $\min C_i(P_{g_i}) - \lambda_i^p P_{exp} - \lambda_i^q Q_{exp_i}$ which is solved by any microgrid or community $i \in A$. I have developed two iterative solutions named Modified Subgradient and Lower-Upper-Bound-Switching (LUBS) to realize the optimal solution of the original problem. Expanding these multi-agent optimization platforms to consider other DERs (such as wind, demand response, and electric vehicles) is an attractive research path that I plan to pursue in the future.

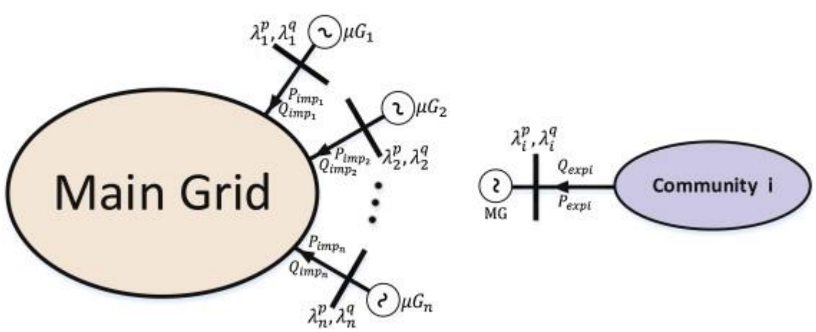

Fig. 2. Power networks in utility and community optimization sub-problems. Utility and communities appear as constant price generators in each other's sub-problems.

Research project 3: Market Participation of variable renewable energy (VRE)

Integration of more renewable energy resources to the power grid will soon cause the electricity price on the open market to decrease. Such a price depression reduces the value of renewable energy and finally will threaten the business case for renewable energy. I developed a game-theoretical approach to study how aggregation and market participation of VRE could mitigate declines in the economic value of VRE [14]. I proved mathematically that, 1) in an N-aggregator scenario, the optimal bid for all aggregators are equivalent if all have enough available power; 2) the equilibrium point $P_r^* = \{P_{r_1}^*, \dots, P_{r_N}^*\}$ sought by my proposed algorithm is Nash Equilibrium, i.e. $\phi_i\left(P_{r_i}^*, P_{r_{\mathcal{N}/i}}^*\right) = \max \phi_i\left(P_{r_i}, P_{r_{\mathcal{N}/i}}^*\right)$ for all $i \in \mathcal{N}$; and 3) VREs earn the highest revenue if they completely cooperate with one another and participate in the market via one aggregator even though they offer less power to the market.

My analytical results provide three important conclusions for VRE operators, policymakers, and system operators alike: 1) there are periods when VRE operators can increase revenue by curtailing power output and not offering their entire available power; 2) such market outcomes occur with only moderate increases in California's renewables penetration (from present-day 20% to 26%); and 3) VRE operators can earn 70% more revenue at 60% VRE penetration level by forming aggregations, i.e. coupling bids between multiple merchant VRE.

2. Future Research Plans

I plan to conduct research in the area of power systems especially grid integration of DERs and advise graduate and undergraduate students. Besides being able to conduct research independently, I believe collaborating as a team in a research group strengthens the students' research capabilities and enhances their productivity. It is obvious that funding is the key element to establish a successful research program. Due to the recent national interest in the United States in clean energy and their integration to power grids, there are numerous funding opportunities provided by DOE and states' energy commissions such as CEC in California. I have already submitted research proposals to DOE and CEC and have additional concrete plans to submit strong proposals to obtain extramural funding. I believe that the support from other faculty members, especially my future colleagues, and industry partners will make my future proposals competitive. An increasing push by DOE and CEC to ensure commercialization of research results has recently shifted the funding priorities towards the private sector. Fortunately, I have had a unique chance at UC San Diego to lead three research proposals to CEC and DOE, where I have been able to establish relationships with industry partners such as San Diego Gas & Electric, Power Analytics, SolarCity, Electric Power Research Institute (EPRI), KnGrid, SunSpec Alliance, and eMotorWerks.

Further, my colleagues at the Center of Energy Research (CER) at UC San Diego including Professors Kleissl, de Callafon, and Victor as well as Director of Energy Storage Mr. Torre and Director of Strategic Energy Initiatives Byron Washom will be great asset as collaborators in my future proposals. I believe my ideas and proposal writing skills along with their great experiences in winning prestigious funding awards will make my future research lab very successful in attracting extramural funding. Additionally, I have plan to submit proposals for the funding opportunities provided by National Science Foundation (NSF) such as Energy, Power, Control and Networks (EPCN) and Faculty Early Career Development (CAREER) as well as Defense Advanced Research Projects Agency (DARPA) Young Faculty Award (YFA). Finally, when it comes to management of the grants which I will lead as PI or co-PI, my experience of simultaneously co-advising Ph.D.

student and leading award management and reporting at UC San Diego gives me the confidence and experience to successfully manage the projects with the highest standards.

Here, I am outlining three research ideas which I would like to conduct during my academic career. These directions further develop prior research work listed above:

Research plan 1: Real-time optimal power flow control for power systems

The future structure of power systems equipped with advanced metering and communication systems, known as smart grid, is grounded on a paradigm of pervasive data availability, which will resolve the possible stability issues and inefficiency of the current decentralized control schemes. My research goal is 1) to employ and extend my previous research on power system state estimation [23] to improve the situational awareness of the power system operator and 2) to develop central optimal power flow control algorithms for all types of DER including EVs, ESS, and demand response (DR) based on the state estimation results. This research is expected to increase DER hosting capacity of power grids.

Research plan 2: Distributed optimization and control of DERs

My previous research experience in multi-agent optimization and control algorithms will enable my future research group to tackle data privacy and cybersecurity challenges by developing computationally efficient distributed optimal control designs. This research plan will expand my previous research achievements to include all DERs with their different operation objectives and constraints. In these optimization problem and control designs I will address the uncertainty associated with the availability of DERs. My access to PV forecast algorithms and EV charging data from UCSD will allow demonstrating the efficiency of the developed algorithms using real world scenarios.

Research plan 3: The future of power markets with distributed energy resources

I expect market participation of DERs to be a hot topic in the near future, especially after the technical challenges of grid integration of DER are ameliorated. Following my research work where I studied how VRE market participation will change the wholesale electricity markets, I would like to extend the scope to study the aggregation and market participation of all types of DER. I would also like to conduct research on how to pave the path for DERs to actively participate in the power markets and how their participation will affect the market performance and the market behavior of the other participants. As I showed in [14], the number of aggregators participating in the market on behalf of individual small DERs has significant effects on their market behavior, I will develop game-theoretical approaches to define the equilibrium number and structure of aggregators and how DERs would decide whether to join an aggregator or participate directly in the power market. Finally, I will study how to regulate the market participants including DER aggregators to prevent using their market power to manipulate the market. I believe my knowledge on electricity markets and game theory will help my future research group to carry out pioneering research projects on these topics.

3. References

Please refer to the list of publications in my Curriculum Vitae.