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Using OPF for Smart Grids: From Concept to Reality - By Michael Liu, Luis (Nando) Ochoa, and Steven Low - Thanks to recent advances in computing power and alternative formulations, the solution time of large and complex AC Optimal Power Flow (OPF) problems has improved dramatically. This creates many opportunities in the context of future electricity distribution networks where the AC OPF can be used to orchestrate distributed energy resources (e.g., wind farms, solar PV systems, storage) and network assets (**e.g., on-load tap changers, capacitor banks**). In particular, the real-time application (i.e., **decisions needed within seconds or minutes**) of Smart Grid control schemes based on the AC OPF is becoming a more plausible concept that could soon be implemented in control rooms of distribution networks; and the R&D community is helping make this a reality.

The Need for Orchestration - The rapid adoption of Distributed Energy Resources (DER) over the last decade has significantly altered the characteristics of electricity distribution networks, introducing bi-directional power flows and higher degree of uncertainty, making its planning and operation more challenging. The traditional fit-and-forget approach might no longer be cost-effective nor adequate to meet the needs of future distribution networks. On the other hand, orchestrating the operation of these DER (as well as network assets) through advanced control schemes can become a key enabler to facilitate their adoption without incurring negative network impacts. Such an active approach also opens the door for distribution network operators to explore other opportunities to better meet network performance targets, and improve coordination with the transmission system, etc.

OPF for Smart Grids – The Concept - The design of control schemes (for smart distribution networks) comes in a variety of flavors, ranging from simple rules to advanced optimization, fully centralized to completely decentralized, and model-based to model-free. Among these approaches, the ones based on the AC OPF have shown great potential, due to key advantages: they inherently capture the power flows and constraints of the network, and allow control decisions to be included as optimization variables.

The classical AC OPF, a nonconvex optimization problem, has been widely used for offline purposes such as generator scheduling and network planning in transmission networks. However, its real-time usage, crucial to tackle the impacts due to DER variability, has been limited primarily due to the difficulty of solving it sufficiently quickly. Furthermore, in the context of distribution networks, this issue is exacerbated by the added complexity of size (many more nodes), unbalance operations (each phase needs to be modelled), and discrete control devices such as on-load tap changers and capacitor banks (mixed-integer formulations). Fortunately, in recent years, considerable effort has been invested to improve the solution time of OPF problems. This includes alternative formulations that are computationally easier to solve (e.g., the DistFlow equations – an equivalent formulation of the AC power flow equations for radial networks that has a more robust convex relaxation and simpler linear approximation), online techniques that exploit feedback from the network, and distributed algorithms that decompose a large optimization problem into more manageable parts. Particularly, recent works on centralized controllers utilizing the DistFlow equations and linear approximations have shown promising results for unbalanced distribution networks with several thousand nodes and discrete control devices. Indeed, as the challenge of quickly finding a feasible solution is gradually overcome, the real-time application of AC OPF-based control schemes to orchestrate DER and network assets is becoming a more plausible idea that could be implemented in control rooms of distribution networks.

Proof-of-Concept Using Hardware-in-the-Loop – Closer to Reality

In addition to developing adequate control schemes, demonstrating their technical feasibility is another key ingredient that will help make Smart Grid concepts a reality. This would entail going beyond offline, computer-based, time-series simulations and moving towards real-time, Hardware-In-the-Loop (HIL) simulations. HIL simulations are already widely used by many industries as it allows concepts to be demonstrated in an extremely realistic environment.

While the design of a HIL setup can vary, the use of Real-Time Simulators (RTSs) is often considered as the state-of-the-art in the context of Smart Grids. The RTS has two key advantages: it acts as a proxy of an actual distribution network and features commonly used interfaces, allowing external controllers to interact with the simulated network in real-time (such as collecting measurements and providing control set-points). This setup could even include power hardware through special interface devices (e.g., power amplifiers). In contrast, such functionalities are generally hard to achieve using PC-based simulations.

Leveraging the capabilities at The University of Melbourne, Australia (including two RTSs and a control-room-style laboratory), an HIL platform has been built to demonstrate advanced control schemes for smart distribution networks. Inside the control room, a network controller is implemented on a desktop computer using commercially available software, featuring a SCADA system and an OPF-based control scheme; a physical Ethernet connection is used to represent the communication infrastructure between the simulated network (inside the RTS) and the control room; and lastly, an interactive user interface is built to provide visual feedback and manual interactions with the HIL simulation. Tests carried out to date using this platform have shown that it is indeed possible to orchestrate DER and network assets using AC OPF in real time, providing a solid basis to expand the R&D in this area. Interested readers are invited to visit our website for a brief video demonstration showcasing the real-time operation of a smart distribution network.

What's Next? Despite receiving considerable attention in the R&D community, the adoption of real-time control schemes by industry is still limited. Nonetheless, as these concepts mature, researchers are encouraged to carry out similar demonstrations using HIL simulation. Ultimately, these demonstrations will help boost the industry’s confidence in adopting such concepts; and thus, making the real-time use of OPF for Smart Grids a reality.

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