Interplay Between Computation, Control, and Communications

From the dynamical perspective, a power system can be modeled as a large-scale interconnected system composed of thousands of interacting subsystems. A detailed modeling of the system amounts to a set of nonlinear differential equations subject to a set of algebraic equality and inequality constraints. To be able to achieve an efficient and reliable real-time performance for the network, this dynamical system needs a distributed controller, which consists of a collection of local controllers together with a communication layer responsible for data transfer among the local controllers. Traditionally, the communication architecture has had a minimal role, i.e. the local controllers have been prohibited from exchanging data with one another. To operate a power network, three important questions should be answered: (i) how to design the reference of each local controller to guarantee a global performance in steady state? (ii) how to design each local controller to guarantee the global stability? and (iii) what communication architecture to use?.

The first problem to be addressed is concerned with the design of the reference of the controller. This needs solving a large-scale nonlinear unit-commitment security-constrained optimal power flow in the ideal case. However, a very simplified version of this problem is currently solved in practice, which may put the system in jeopardy. The reference under design aims to find an equilibrium point of the network that is optimal with respect to some economic, security and reliability indices. The main challenge is how to solve a large-scale non-convex mixed-integer problem in a reasonable amount of time and perhaps in a distributed way (due to the inability to collect all necessary information in a single location).

The second problem to be addressed is concerned with the design of a distributed controller that is able to guarantee the stability of the grid and the quality of the important signals in presence of small and large disturbances, especially those coming from renewable resources. From the operation point of view, maintaining stability has the highest priority since the system cannot work safely otherwise. The design of an optimal distributed controller has been long known to be computational hard to solve. However, the recent results in the literature witness that the problem becomes tractable for highly structured systems. Since power networks are structured in many ways, they may fall into the category of "easy-to-handle systems".

The third problem to be addressed is concerned with the design of communication architecture for the controller. In comparison with a fully decentralized controller, it is believed that a distributed controller with a sufficient number of communication links is significantly better in terms of both performance and the design complexity (the computation required to find the optimal parameters of the controller). Since wireless devices and sensors are becoming widespread in power systems, it is essential to understand what communication architecture should be used in the control layer and how reliable the communication links should be (in terms of delays, transmission rates, etc.).

Although three separate problems were introduced above, the solution to each of them affects the other two. In fact, an integrated approach is needed for the design of the references, the local controllers, and the communication layer. This unified approach should study optimization problems such as state estimation, unit commitment and optimal power flow, stability problems such as voltage stability and frequency stability, and the role of networking through a single framework. The recent advances in the areas of convex optimization and convex relaxation may allow us to develop a rigorous technique for the above-mentioned problem.