Electrical Energy, Operational-Network Management

Introduction:

In vertically integrated systems the short term electrical network management is performed in an integrated fashion by the monopolist, whereas in those market based, this problem is responsibility of another entity usually called the Transmission System Operator (TSO). The transmission network is the nervous system of any EES and the network management poses very challenging issues. The list of the relevant problems in this field we will describe is as follows:

- **Load Flow**: LF is actually *not* an optimization problem, it is (just) a calculation of the power flowing along an electrical network where we have fixed the generation schedule and the load in the several nodes of the grid. While being not an optimization problem, it gives evidence on the networks operating points under different conditions.
- **Optimal Power Flow**: The first historical problem in network management is called Optimal Power Flow (OPF). The OPF problem deals with the optimization of the generating cost, and possibly hydro resources, considering the electricity grid. In considering the grid OPF takes into account the non linear Kirchhoff laws and the restrictions on power flow on each branch (transmission line) and voltage angles. Typically the generation cost optimization is performed considering all the units status (on or off) *fixed* to a feasible status otherwise found. To date there are many formulations of OPF from the first one appeared in the sixties, they basically fall into two broad classes:
    1. *The Direct Current (DC) model*: here the network structure is taken into account, including the capacity of the transmission links, but a simplified version of Kirchhoff laws is used so that the corresponding constraints are still linear.
    2. *The Alternative Current (AC) model:* here the full version of Kirchhoff laws is used, leading to highly nonlinear and nonconvex constraints. To cope with these difficulties a recent interesting avenue of research concerns the fact that the non-convex AC constraints can be written as quadratic relations. In particular quadratic relaxation approach have been proposed which builds upon the narrow bounds observed on decision variables (e.g. phase angle differences, voltage magnitudes) involved in power systems providing a formulation of the AC power flows equations that can be better incorporated into UC models with discrete variables (e.g. 3).
- **Security Constrained UC (SCUC):** SCUC is an integrated problem, say an integration of OPF and UC. So from one side one wants to consider a detailed set of constraints from power plants and from the other the physics of the grid itself as in an OPF. The inclusion of the status variables as in an ordinary UC further complicates the problem.
- **N-k OPF/SCUC/security:** This problem is an example of how things are decoupled in power systems. The issue here is to find a least cost schedule of production and flows that is also resistant to unpredictable fault of one of the component (power plant, network branch etc.). The n-1 security problem refers to a single fault. From a methodological standpoint one could consider n-k SCUC as an integrated problem, and some modeling proposal in this direction have been presented. In practice TSO tend to decouple OPF or SCUC from n-k, solving this latter problem by adding security requirements to an already *quasi*-fixed solution from SCUC (e.g. 4)**.**
- **Optimal Network Islanding (ONI):** When things go wrong and the schedule from n-k security arrangements fails to be sufficient, there is another *real time* issue: how to disconnect pieces (island) of the networks so that cascade failure is minimized**.** By isolating the faulty part of the network, the total load disconnected in the event of a cascading failure could be reduced. Controlled islanding or system splitting is therefore attracting an increasing amount of attention. The problem is how to efficiently split the network into islands that are balanced in load and generation, and have stable steady-state operating points. This is a considerable challenge, since the search space of line cutsets grows exponentially with the networks nodes number. The critical issue here is the time, since as a conseguence of a severe fault, few minutes or even seconds are available to perform actions aimed at triggering these spits.
- **Optimal Transmission Switching (OTS):** This problem recently emerged mostly because of the increasing penetration of renewables (solar or wind with virtually zero cost) power plants. Network must be designed with redundancies in order to cope with failure, but on considering a steady state operation these redundancies can result in bottleneck. OTS problem is an example of braess's paradox where removing some branch can actually be beneficial in terms of overall cost of supply (e.g. 5). From a technical point of view the reason here is that removing a branch also removes a potential-like constraint on the nodes voltage angle. In fact even if a simple DC model is considered the power flowing on a branch is subjected to be proportional to the differences of voltage angles at sending and receiving nodes (ultimately the kirchhoff's laws). Especially in fully (but not necessarely) renewable penetrated systems, the concentration of these power plant can be quite high (i.e. they are clustered where sun or wind is high), this in turn means that in these areas network conditions on some branch may easily became severe. Like in the SCUC problems, OTS could - and should - be considered as a single integrated problem together with SCUC/OPF itself. In practice, at the present time and knowledge, the complexity is too high for an optimization problem that can deal for a real sized grid with 1) a full AC representation of the grid, 2) a detailed representation of the power plant restrictions, 3) the degree of freedom of tripping some line out in order to reduce costs and possibly the inherent reduction of n-k like-security standard of the system. As a consequence, scientific literature has concentrated in the last years in simplified, PoC-like, models while from an industrial perspective some TSO uses some heuristic approach.
- **Smart grids operations:** The smart grid paradigm in the electricity contest has emerged in the last years as somehow natural evolution of the classical EES dating to more than an 100 years ago. There many similar definitions of smart grid but central points are 1) the smart capability of operating 2) interacting and 3) integrating customers into the system by means of more and more sophisticated IT facilities. Therefore some problems remain centralized but there is an active partecipation of the final users. Because of this interactions of decisions, coupled with a more and more penetration of renewables production, a broad class of optimization problems emerged. For instance, the distribution system in classic models has always been seen as a passive element. However with the increase of distributed production (mainly solar but also wind) and most importantly some form of distributed storage (batteries, compressed air storage, but also Plug in hybrid electric vehicle, PHEV) the fluxes of energy can be dynamically reversed creating opportunities for optimization and adding complexity to the operation of the whole system. Also, a partial load shifting from peak hours to off peak hours is now a reality at least in principle. However when we speak of Smart Grids the relevat portion of the network involved is at the distribution level (althought transmission one is of course involved as well). Also, as appears from the definition, the smart grid paradigm involves changes in many structural part of the distribution system as a whole. Many of the atomic problems explained before are still of interest (mainly LF, OPF, ONI and OTS) together with more specific problems such as optimal PHEV charging dynamics expecially when price elasticity is high (e.g. 6)**.**

References:

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