Electrical Energy, Strategic-Network Management

Mathematical models

In vertically integrated systems the strategic 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 strategic network management poses very challenging issues. Basically in the long term perspective, the main goal are:

- Reinforce the networks itself by constructing new branches and possibly dismissing old ones. Additionally the decision of installing network technologies, together with their siting, can be considered in the grid reinforcement process. These technologies could enhance the operation/controllability of the grid and include: Phasor Measurement Units (*PMUs*), Wide-Area Measurement Systems (*WAMS*), and *notably* Flexible Alternating Current Transmission Systems (*FACTS*). It is in fact known that power flowing on individual lines cannot be controlled, though these devices are improving the ability of system operators to do so (possibly in conjunction with OTS related operations).
- Energy Storage System siting and sizing, say deciding where locate and the size of an ESS (e.g. 2).
- Smart grids design. The actual design of a smart grid in a certain local area is another universe of related (optimization) problems, and surely includes also previous two class of problems.

In order to approach the three above-mentioned classes of problems, many tools described in the short term management are obsviously used. Their usage is somehow differently oriented however:

- **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. Under strategic perspective LF can be used integrated in a what if analysis tool.
- **Optimal Power Flow**: 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. As for the LF, also OPF under strategic perspective can be used integrated in a what if analysis tool.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. Again in the long term, the level of details of the OPF models can be adjusted depending on the goals.
- **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. 1)

Differently from the short term management, in the strategic view, these problems are solved in models equipped with an upper lever set of decision variables, that indicate the virtual presence (or dismission) or a certain set of new branches, special devices and some representation of their costs. Additionally in recent times, due to the increasing capability of storage mainly at the distribution level, also the size, types and siting of such storage equipment contributes to the set of the decision variables. From a methodological standpoint, very often these prescriptive problems are tackled in a what if analysis fashion, or with approaches that fall in the broad definition of *optimization with costly function*. In other words the upper level decision variables are seen as a set on which the decision maker does sensitivity or in a more sophisticated approaches as a set of variables whose change on cascade produces another optimization problem with other - more operating - variables. However especially in the scientific literature there are attempts to model the whole problem with all variables at the same level.

Indeed, it is very important to consider the operation and scheduling of generation and storage units already at design phase to determine the most convenient combination (i.e. minimum objective function) of technology selection and size. This is especially true when dealing with selection, sizing and unit commitment of long-term, or seasonal, energy storage. Long-term storage systems have recently caught much attention due to their ability to compensate the seasonal intermittency of renewable energy sources. However, compensating renewable fluctuations at the seasonal scale is particularly challenging: on the one hand, a few systems, such as hydro storage, hydrogen storage and large thermal storage can be used to this purpose; on the other hand, the optimization problem is complicated due to the different periodicities of the involved operation cycles, i.e. from daily to yearly. This implies long time horizons with fine resolution which, in its turn, translates into very large optimization problems. Furthermore, such systems often require the integration of different energy carriers, e.g. electricity, heat and hydrogen. Exploiting the interaction between different energy infrastructure, in the so-called multi-energy systems (MES), allows to improve the technical, economic and environmental performance of the overall system [3].

In this framework, including the unit commitment problem already at design phase implies taking into account the expected profiles of electricity and gas prices, weather conditions, and electricity and thermal demands along entire years. Moreover, the technical features of conversion and storage units should be accurately described. The resulting optimization problem can be described through a mixed integer nonlinear program (MINLP), which is often simplified in a mixed integer linear problem (MILP) due to the global optimality guarantees and the effectiveness of the available commercial solvers (e.g. CPLEX, Gurobi, Mosek, etc.). In this context, integer variables are generally implemented to describe the number of installed units for a given unit, whereas binary variables are typically used to describe the on/off status of a certain technology. Furthermore, decomposition approaches relying on meta-heuristic algorithms for unit selection and sizing have been proposed. A comprehensive review of MINLP, MILP and decomposition approaches for the design of MES including storage technologies has been carried out by [4]. However, independently of the implemented approach, significant model simplifications are required to maintain the tractability of the problem. Such simplifications include limiting the number of considered technologies, restricting technology installation to a subset of locations, analyzing entire years based on seasonal design days or weeks, or aggregating the hours of each day into a few periods.

References:

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