Smart grids operations

The smart grid paradigm improves upon the controllability and control of existing power systems. With the increased penetration of distributed production (solar, wind), energy storage (pumped storage, batteries, compressed air storage, and plug-in hybrid electric vehicles), transmission switching and controllable elements called FACTS (see below), power flows can be and need to be dynamically adjusted in order to improve reliability and efficiency. Also, a partial load shifting from peak hours to off peak hours is possible. Such opportunities also increase the complexity of the design and operations of the power system. A broad class of novel optimization problems hence emerges, with the focus varying power system to power system.

In power systems, where peak demand occurs in one season, while the peak generation from renewables occurs in another season [1], the focus has largely been on the improvements to the efficiency of power generation and reliability of power transmission under stress due to peak demand or peak generation from renewables. The improvements are made possible by the so called flexible alternating current transmission system (FACTS) devices [1], which are now routinely installed at generators, at the interconnection of one national transmission system (TS) with others, and elsewhere, such that the national transmission system operators (TSO) gain more control over the power flows in their TS [5,6]. FACTS devices intended for steady-state operations include:

- load tap changer (LTC), thyristor-controlled load tap changers, which make it possibly to vary the tap ratio rapidly
- phase-shifters (PS), e.g. thyristor-controlled phase shifters, which make it possibly to vary the phase angle rapidly
- series capacitor (SC), e.g., thyristor-controlled series capacitor coupled in parallel with a thyristor-controlled reactor (TCR), makes it possible to smooth the output of the reactor with varying reactance
- interphase power controller (IPC), which makes it possible to control reactive and active power independently
- static VAR compensator (SVC), which is a source or sink of reactive power
- static compensator (STATCOM), which allows to control either the nodal voltage magnitude or the reactive power injected at the bus.

The availability of such devices underlies the corrective actions available in response to stress. To summarize the book-length treatment of [3]:

- when voltages are too low, one supplies reactive power (using STATCOM, SVC)
- when the voltages are too high, reactive power is absorbed (using STATCOM, SVC)
- when thermal limits are exceeded, load is reduced (using SC, IPC),
- when loop flows appear, series reactance is adjusted (using IPC, SC, PS),
- when power flow direction is reversed, phase angles are adjusted (using IPC, SC, PS).

It is hence believed that wider availability of FACTS devices will lead to an increased stability of power systems. The non-convex optimization problems combining efficiency and reliability objectives, decisions as to FACTS settings, and constraints of the alternating-current power flows remain a major challenge.

Especially in power systems, where peak demand and peak renewable generation occur within the same season, there is an additional focus on energy storage and demand response management. A 2006 report [4] estimates that the potential demand response capability was about 20,500 megawatts (MW) in the US, or 3% of total peak demand. This is obtained by combining a variety of readily deferrable loads, comprising:

- pumped energy storage, which has been introduced into a number of power systems since 1950s and remains an important feature to the present day
- large industrial customers, e.g., in refrigeration, who are being converted to flexible contracts, allowing for load shedding
- charging of electric cars which could become a major load, eventually while many other loads may become deferrable, should the regulatory environment change such that retail prices vary over time and load control switches (e.g., remotely controlled relays or relays relying on price data, such as learning thermostats connected to domestic air conditioning) become widespread.

while many other loads may become deferrable, should the regulatory environment change such that retail prices vary over time and load control switches (e.g., remotely controlled relays or relays relying on price data, such as learning thermostats connected to domestic air conditioning) become widespread. In some regions, such as California, where the photo-voltaic generation facilities are widespread and the peak demand is due to the use of air conditioning, the resulting savings can be considerable. Notice, however, that a number of challenges remain. First, there is the issue of information provision: in many markets with dynamic pricing, customers do not have access to data on current prices. The immediate announcement of prices may lead to swings in the demand, whereas no announcement may make it impossible to reach the best possible efficiency. Second, the regulatory framework has to be compatible with the free markets. Third, if the decision making is to remain centralised, one needs to model the behaviour of the users. Because of the numerous difficulties of doing so, a number of mechanism design studies and distributed decision making schemes have been proposed.

Overall, smart grids require both changes to the power systems' infrastructure, as well as changes to their control mechanisms, which require the generation, distribution, transmission, and consumption to be modelled jointly. Although much innovative thinking is required, any progress on solving the underlying problems (mainly LF, OPF, ONI and OTS) is still relevant.

References

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