

please give me any final changes by tomorrow morning if possible:

Holistic Assessment for Enterprise Control of the Future Electricity Grid

Written by Amro M. Farid

Because of many compelling trends in electrical power, the overall dispatchability of the generation fleet is decreasing while the overall dispatchability of demand is increasing. The future electrical grid will benefit from enterprise control techniques that deliver holistic dynamic properties.

Traditional power systems have often been built on the basis of an electrical energy value chain which consists of relatively few centralized and actively controlled thermal power generation facilities serving a relatively large number of distributed passive electrical loads. It does not appear that this status quo is destined to last.

Instead, five drivers are set to dramatically challenge the basic assumptions upon which the electrical power grid was built, [as the IEEE Control Systems Society has outlined](#). These are:

1. Decarbonization of electric power generation.
2. Continued yearly growth of electricity demand especially in developing economies.
3. Electrification of the transportation sector.
4. Trends towards electric power deregulation.
5. Trends towards empowered consumers responsive to the grid's physical and economic conditions.

Taken together, those drivers virtually require a steadily increasing penetration of the grid by variable energy resources (VERs). They include not only solar and wind generation but also evolving capabilities to support demand side management of the tremendously diverse loads connecting to the grid. As a result, the conventional generation and demand portfolio is expanding to include non-dispatchable generation units, on the one hand, and dispatchable demand-side resources and electric vehicles, on the other.

In other words, the overall dispatchability of the generation fleet is decreasing while the overall dispatchability of demand is increasing. Naturally, power system assessment techniques should correspondingly evolve so that controls operate on either the generation or demand side, wherever the disturbance originates.

The introduction of variable energy resources is bound to have a big impact on the power grid's structure. The clear dichotomy of bi-directional meshed transmission networks and radial uni-directional distribution networks will fade and make way for distribution systems to more closely resemble transmission's meshed bidirectional characteristics. Such structural changes call for joint study of transmission and distribution networks and suggest corresponding development of assessment methods.

Greater VER penetration also changes power grid dynamics. Traditionally, grid flows have been handled in three well-separated control layers: primary, secondary and tertiary. VER integration affects all time-scales of these power system-balancing operations. Accordingly, [the Federal Energy Regulatory Commission \(FERC\)](#) has recently required that tertiary dispatch be every 15 instead of every 60 minutes, with individual ISOs dispatching every 5 minutes.

Manual operator actions are also facing downward pressure as operators are increasingly taking more frequent manual operations actions, especially in regard to curtailment. In the meantime, with the introduction of grid-scale storage, smart buildings and fast ramping generation facilities, the scope of transient stability studies expands to include slower time scales dominated by hydraulic and thermal energy phenomena.

In short, the traditional dichotomy of primary, secondary and tertiary control is increasingly blurred with the penetration of VERs. Mathematically, the now overlapping control techniques can be viewed as a convolution of actions, requiring holistic assessment methods.

The introduction of meshed networks in the distribution system can also bring about new power grid dynamics when the system, is operated to have a variable rather than static network topology. In such a situation, the continuous-time transient stability dynamics are superimposed on the discrete-event network switching. Such hybrid dynamic systems have an interesting and important property: While each network topology configuration may be dynamically stable in its own right, the meta-system that allows switching between configurations may not be so.

Therefore, dynamically reconfigured power grids further motivate the need for holistic assessment approaches. The promise of such work is a resilient, self-healing power grid that responds to disturbances and contingencies. In contrast, [the San Diego blackout of September 8, 2011](#) was a reminder of the importance of even routine switching decisions.

To address these emerging challenges, we propose the concept of [grid enterprise control](#). Originally, the concept of enterprise control emerged from the manufacturing sector out of the need for greater agility and flexibility in response to increased competition, mass-customization and short

product life cycles. Thus, enterprise control came to be viewed as a technology to not just manage the fast dynamics of manufacturing processes but also to integrate control with economic objectives. The recent smart grid initiatives towards interoperability can be viewed as nascent steps towards advanced enterprise control of the grid that simultaneously empowers the diversity and number of stakeholders all across the energy-value chain.

To that effect, the future electricity grid with all of its millions of supply and demand side resources must holistically enable its dynamic properties. These include dispatchability, flexibility, forecastability and voltage control.

Addressed holistically, different components of the power generation and demand have differing levels of dispatchability. While thermal generation has traditionally fulfilled the dispatch role, it is not unlikely that electricity-intensive industrial production will be able to take a counterpart role on the demand side. A medium level of dispatchability can be achieved with hydro, concentrated solar power and commercial buildings. Wind, photovoltaics, run-of-river hydro and lighting have the least dispatchability.

This taxonomy of generation and demand resources effectively introduces a pareto analysis in regards to system dispatchability, which of course is required to cover the stochastic elements in the future grid. More concretely, existing power grids can generally accommodate modest levels of VEs because of a certain level of existing dispatchability. If this penetration were to grow, however, the system dispatchability may not be sufficient to meet reliability standards.

System flexibility, or resource ramping, complements system dispatchability and may also be addressed holistically by Pareto analysis, to optimize decision-making. Interestingly, ramping capabilities are often very much tied to the ratio of stored thermal energy to mechanical work. Facilities with a very large ratio such as nuclear, coal, chemicals and metals have relatively low ramping capabilities. In contrast, facilities with a high ratio such as hydroelectric, gas turbines, internal combustion engines, heaters and kettles can easily ramp. The integration of VEs is a challenge not just because of their lack of dispatchability but also because their stochastic nature can cause ramps of various *speeds* and not just magnitude.

Since the stochastic elements on the power grid are not perfectly forecastable, they introduce uncertainties that significantly decrease the effectiveness of the scheduling process, increasing the potential for system imbalances. Such imbalances create a volatile situation in which frequent and costly manual actions are required in concert with automatic generation/demand control. Again, power supply and demand have better forecasted components such as dispatchable generation and industrial production as well as less predictable components such as solar and wind generation and use of air conditioning and lighting.

Finally, this more dynamic mode of operation must also not affect voltage stability adversely. To maintain this control objective, many types of generation and demand resources can potentially contribute to voltage support. Recent literature advocates a highly decentralized approach that relies upon power electronics on both synchronous and induction motors and generators.

In conclusion, the concept of grid enterprise control provides a working framework upon which to build holistic approaches to assessment and control. Such an approach can facilitate methods that directly address the four holistic dynamic properties discussed: dispatchability, flexibility, forecastability and voltage stability. These properties then become the guiding principles upon which to implement control technologies. Otherwise, solutions may be unwisely adopted that are overlapping in function, over-built and costly. Holistic assessment can help a transition from the existing technology-push scheme to one which is much more requirements driven.