21, rue d'Artois, F-75008 PARIS
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Trends for the Grid of the Future

B. DARYANIAN, H. ELAHI, E. LAROSE, R. WALLING
GE Energy
USA

SUMMARY

Changes in industry structure over the past few decades and more recent concerns over greenhouse gases have led to policies and regulations that cause a fundamental shift in the evolution of power grids. The many moving parts of policy, regulations, markets, and the cost and performance of new technologies demand fundamental departures from traditional planning and design disciplines. There are also major trends shaping the debate around the grid of the future. This article focuses on presenting key trends studied by GE Energy Consulting, and their potential impact on shaping the grid of the future, with emphasis on five trends that stand-out for transmission, distribution and smart grid applications. These trends are: energy storage, distributed generation in general, and distributed PV in particular, dynamic resources, and demand management.

KEYWORDS

Distributed generation, energy storage, reactive power sources, demand management

INTRODUCTION

For over a century, the principals of reliability, affordability, and efficiency have guided power system engineering. In the past few decades, the need to drive more operational efficiency in the developed countries and the need to attract greater capital investments in developing countries led to global re-structuring of our industry and the creation of various forms of energy markets. More recently, concerns over long term effects of greenhouse gases have led to development of a number of environmental policies and regulations with the promise of a fundamental shift in the evolution of future grids, and rapid growth of wind and solar generation. In parallel, concerns over aging infrastructure and advancements in new technologies present an unprecedented multitude of options to power system planners.

The many moving parts of policy, regulations, markets, cost and performance of new technologies demand fundamental departures from traditional planning and design disciplines. There are also major trends shaping the debate around the grid of the future. Among the key trends affecting the energy industry today, several directly impact the planning and operation of transmission and distribution systems, including the application of smart grid technology.

This paper will attempt to address key questions on five key T&D trends.

- Energy storage for niche applications: While widespread growth in energy storage is expected to face challenges since costs of alternative approaches are generally lower, a strong value proposition exists for the use of energy storage in certain niche applications, such as balancing in isolated or semi-isolated grids (e.g., islands) with high fuel prices. Storage may also become a competitive option for serving frequency regulation markets. What hurdles must be overcome to see more widespread storage projects?
- Distributed generation: Distributed generation (DG) growth is being driven strongly by policy; both policy implemented as subsidies and incentives (e.g., rooftop solar PV), and through

elizabeth.larose@ge.com

electric service tariff structures. Also, there is growth where DG can provide increased efficiency in combined heat and power and other related applications. Are we going to see DG displacing the need for a conventional grid?

- Management of distributed solar PV: Rapid growth in distributed solar PV could challenge the ability of the grid to manage voltage in the distribution system and will create opportunities for new distribution management and voltage control solutions. How will integration challenges stifle growth in PV and what types of solutions will emerge?
- Dynamic reactive power sources: Retirement of announced coal plants situated near loads, growth in wind and solar power coupled to the grid via asynchronous generator technology, and changing loads on the grid will challenge the grid's reactive power reserves and ability to maintain voltage stability. What would be the right mix of resources to maintain steady state and dynamic voltage supports in the grid of the future?
- Demand management: Generation resources were historically built to provide low cost electricity and ancillary services, and provide capacity to meet peak load. Today, demand management or demand response (DR) can provide these same services and is expected to play a more active role in the grid of the future. What is the right mix and types of policies, programs, technologies, and incentives that can maximize the benefits of DR? How should DR be integrated with the generation and transmission planning processes?

1. ENERGY STORAGE FOR NICHE APPLICATIONS

The grid is the ultimate "just-in-time" system; instantaneously serving customer load with generation that is precisely dispatched and controlled to match the load. Historically, the interconnected power system has been designed and controlled to manage variability in load by increasing or decreasing output of generation Even when a large industrial motor is started, this substantial load on the grid is masked by loads elsewhere on the grid that are shutting off, resulting in a natural load smoothing effect. Studies by the authors suggest that the variability of wind and solar power, when more than 30% of the annual energy is generated by these resources, can be managed by the grid [1]. In some instances, additional flexibility in generation is needed and additional regulation may be required, but the significant wind and solar variability smoothing effect observed over large areas (similar to that of the load smoothing effect of a neighborhood relative to that of a single home) does not necessitate the need for energy storage.

A long list of potential applications for storage have been cited, ranging from price arbitrage from capturing lower cost energy to displace higher cost energy at a later time, or shifting energy from one time to another to avoid overloading equipment. In general, these applications do not offer strong value propositions as the cost of energy storage technologies is high relative to conventional approaches. It is the applications that demand sudden injection or removal of energy of short durations that seem to offer the greatest value. Niche applications already exist and more applications are emerging. Isolated systems with very high electricity costs may benefit by providing its relatively high regulation and reserve requirement with energy storage that eliminates the need for high cost fossil fuel generation to provide those services. In the 1990s, GE worked with GNB/Exide Technologies to build a battery storage system in Metlakatla, Alaska (Figure 1) to reduce the use of expensive diesel-fired generation. The roughly $2M battery system reduced the diesel fuel bill by more than $6M over its 12 years of operation [2].

Storage can provide an alternative means of providing regulation. At this time, the costs for storage to provide regulation ancillary services are beginning to approach the current prices for regulation in some energy markets. It remains to be seen if energy storage, without subsidies, can be truly competitive in the regulation application. More niche applications are also being observed. Urban centers experiencing line or transformer overloads, with no room available for new equipment, may benefit from storage located closer to the loads to avoid expanding the substation or reconfiguring the lines.

Figure 1. GE/GNB and Metlatkla Power and Light battery energy storage system in Alaska (Source: George Hunt, GNB/Exide).

2. DISTRIBUTED GENERATION

Electric power infrastructure originated over a century ago when isolated small generators, supplied nearby loads in isolation from other generators. As the infrastructure rapidly evolved, the benefits of a system based on centralized generation emerged: benefits of scale, diversification of loads, improved energy resource flexibility, and increased reliability. These outweighed the costs of the transmission and distribution infrastructure needed to connect the central generation with distributed loads and set a trend that evolved towards large interconnected grid. More recently, regulatory changes, technical advancements, and environmental impact have led to a significant increase in distributed generation (DG) applications.

The definition of DG is somewhat nebulous. There is presently no uniformly-accepted industry definition and definitions can vary from non-dispatchable solar PV located on the customer-side of the meter to hundred MW cogeneration facilities at large industrial sites. The drivers behind most customer-owned DG application can be tied to one or more of the following:

- Utilize a locally available energy source that cannot be easily transported, such as biogas or sun.
- Increase efficiency, by generating electricity and using exhaust for heating (combined heat and power).
- Provide lower cost electricity than that of the local utility. This may involve peak shaving in commercial facilities billed for demand charges.
- Exploit incentives for economic gains. Policy drives much DG application, with various incentives such as feed-in tariffs, net-metering rules, and rebates specific to distributed generation.
- Increased reliability to an individual facility. However, the reliability benefits of DG to the local grid are less certain and may actually detract from grid reliability in some situations.
- Fulfill non-technical and non-economic needs. This category includes the desire to be independent from the utility, to make a “green” statement, and other similar values that cannot be measured in a pro-forma analysis.

The value of DG in offsetting transmission and distribution capacity requirements, however, is much less, and more indirect, than commonly perceived by the public and the policy makers. To provide an effective substitute for T&D assets, DG output must be available at the time of system peak. This usually requires that the DG be dispatchable, and contractually obligated to provide support when needed. Also, because individual generation equipment has lower reliability and availability than utility service provided to customers, DG redundancy needs to be considered. Where only a few DG units are involved, the costs to provide reliable capacity could be sizeable.

While wind generation and hydro power are presently the largest renewable energy sources in the grid, solar photovoltaics (PV) represent the most rapidly growing DG segment. Growth in solar PV is strongly tied to policy as the cost for this generation is high relative to competing renewable and non-renewable alternatives. When PV is connected "behind the meter" on the roofs of customers, the electricity produced will displace the electricity typically provided by the utility. Where net metering tariffs are in place, the effective value of the generated energy is equal to the retail energy rate. Today, many utilities recover their fixed service costs through retail rates based entirely on the energy provided to the customer. Since the grid service will still be needed on the cloudy days when PV is unable to entirely displace the utility electricity supply, much of the fixed service costs remain unchanged. Thus, utilities may need to consider alternative tariff structures in order to adequately recover these fixed costs without placing undue burden on the customers who are not self-generating. These alternatives could include demand charges, similar to those experienced by industrial customers, or larger fixed service charges. Either will tend to decrease the energy-based electricity rates. While PV is approaching grid parity in some regions of the country, relative to conventional volumetric (kWh-based) retail electricity rates, the retail price of electricity may be a moving target and pricing mechanisms may change to ensure the true cost of electric service is best reflected in its price.

While DG growth will continue, the core drivers for a grid dominated by centralized generation will remain. The aforementioned drivers for DG will continue to increase its presence in the grid of the future. The dominant driver for DG will be policy, particularly policies that promote renewable generation. Distributed solar PV is likely to be the most pervasive form of DG in areas with good solar resources, or where incentives are strong.

3. MANAGING DISTRIBUTED SOLAR PV

Solar PV has historically been applied as a small-scale distributed resource. However, in recent years, there has been explosive growth in large utility-scale PV power plants, with some facilities currently planned to exceed several hundred MW of capacity. Unlike wind, solar PV does not suffer a large cost penalty when scaled to a small size. Thus, PV installations in the future are expected to be well divided between small, distributed applications and large utility-scale plants.

Integration of large-scale PV plants in the transmission system can follow the successful model already established by wind integration, with the consequential impact of variability treated in the same manner. At the distribution level, locally high penetrations of connected PV capacity can be very disruptive to operations. Power variability due to intermittent cloud shading of PV, in itself, is not of concern at the distribution level because energy balance is achieved on a much wider basis at the transmission level. However, the consequential impact of power variability is voltage variation which can cause premature failure of utility voltage regulating equipment, and power quality degradation for all customers served by the distribution system. While energy storage is often discussed as a mitigating approach, voltage variations can be much more economically addressed using reactive power. Dynamic reactive devices, such as static synchronous compensators (STATCOM) and static var compensators (SVC) can be applied to mitigate voltage variations at a cost that is large, relative to conventional distribution voltage regulation equipment, but still far less expensive than using energy storage. Advanced PV inverters can also use their reactive power capability to mitigate voltage variations. Intelligent distribution volt/VAR controls are needed to coordinate this capability, and such solutions are presently evolving.

4. DYNAMIC REACTIVE POWER SOURCES

Growth in wind and solar power, distributed generation and the retirement of coal plants and other large aging central-scale plants will have an unintended consequence on the performance of the transmission system. Today, many of the oldest thermal units are located near large urban load centers. Replacement of these retired units with generation situated further from the load centers not only changes the flows on the transmission lines, but also challenges the capability of the transmission system to maintain a strong and stable voltage. The disappearance of large power plants capable of providing dynamic reactive power (VArs) to nearby major load centers, could impact the stability of the grid. The retired or displaced generation often provided essential voltage support, or short circuit strength, through its dynamic reactive capability. These generating stations provided reactive power to help maintain a strong and stiff voltage that maintained the stability of the grid during and after disturbances such as the loss of a major transmission line or other unintended events.

Historically, nearly all electricity transmitted through the grid was delivered via synchronous generators equipped with excitation systems. In contrast, wind and solar use asynchronous generating technologies that have limited short-circuit strength. Wind and solar can provide the necessary VArs to the grid for normal operating conditions, but these asynchronous generators do not create the same level of voltage stiffness during deep grid disturbances as conventional synchronous generators. Added to loss of dynamic reactive capability, there is growing evidence that the aggregate load on the grid is becoming less “grid friendly”. Modern electronic loads, air conditioning loads and computers can all increase the requirement for dynamic reactive support. The retirement of conventional generators and the displacement of remaining generators with wind and solar power could alter the present systems’ capabilities to manage disturbances on the grid.

Solutions are available to address the changing need for reactive support, but many have significant political and regulatory obstacles. For example, new transmission is often a viable solution. However, building new transmission is typically a very long process, often taking many years from the initial planning stage to construction, if the project receives approval. Further, the timescale for building new transmission does not align with the retirement and replacement schedule for generation. Generation retirements are typically announced less than two years before the planned retirement date, making a transmission solution impractical.

When a transmission line cannot be built, shunt capacitors are a relatively inexpensive approach and can be installed quickly, however shunt capacitors cannot regulate voltage dynamically, due to the discrete switching necessary for operation. Power electronics, such as static VAr controllers (SVC) have been used successfully for many years to meet dynamic voltage regulation requirements, but require a stiff grid voltage that is created by nearby generation. More advanced power electronic devices such as static synchronous compensators (STATCOM) can provide improved performance in a weaker grid but still have limited ability to stabilize voltage during a disturbance. A third option is synchronous condensers, which replicate the dynamic reactive power capability of a conventional power plant without the capability of generating power for the grid. An installation is shown in Figure 2. An emerging trend in North America is the conversion of retired generation to synchronous condensers. This involves removing the turbine and operating the synchronous generator to produce only reactive power. This is often a very attractive approach from both a system performance and economic perspective.

As load become less grid friendly, more wind, solar and other asynchronous forms of power generation displace conventional power plants, older plants are retired, and coal plants are retired, the grid will need local dynamic reactive power sources. Synchronous condensers are expected to be one tried and tested approach to maintaining a stiff grid voltage for stable operation of the grid of the future, which is a grid with more power electronic controlled resources (wind, solar, batteries, etc.) and ensure the grid performs well through disturbances.

5. DEMAND MANAGEMENT

Demand Management or Demand Response (DR) covers the whole range of demand side resources from direct load control (operators disconnect load on demand) to responsive demand based on dynamic pricing and other control signals (price schedules or signals are passed to customers to incent load reduction). The advent of new technology is enabling more sophisticated and engaging demand response options that, coupled with dynamic pricing, are making possible more flexible and robust customer response behavior. Smart Grid innovations in AMI, communications, HAN, IHD, EMS, and Smart Appliances are making DR both technologically feasible and economically viable and are enabling wider deployment.

Despite the relatively slow economy, utility and retail DR programs are being driven by state regulatory commissions and by utilities’ need of managing their peak demand and reducing long-term capacity costs. Furthermore, FERC orders #719 and #745 are expected to open up opportunities for participation of demand resources in the wholesale market, with DR to be paid ISO locational marginal prices and to be treated similar to supply side resources in energy, capacity, and ancillary services markets.

DR benefits utilities, customers, and the power system in a number of ways, including:

a. Direct and indirect benefits to customers in addition to opportunities for customer choice, control and contribution to their energy equation;
b. Reduced need for future investments in generation and transmission;
c. Increased economic efficiency by price responsive (and price-elastic) demand; and
d. Increased system reliability due to peak load curtailment or as an ancillary services provider.

Figure 2. New synchronous condenser project in New England (Source: GE/VELCO/IEEE)

Indeed, we foresee a greater need for DR as an ancillary service in a world with more wind and solar power, where DR can act as reserve to cover the forecast errors and provide a very low cost approach for providing reserves. This becomes particularly important for the inevitable worst-case wind or solar forecast error scenario that leaves an operator short many GW of generation without much time to deploy reserves.

FERC estimates that, if the current level of demand response is preserved through the next decade, DR would shave 38 GW off U.S. peak demand in the year 2019 and, with dynamic pricing, the total potential could range between 14% and 20% of peak demand or 138 to 188 GW depending on whether dynamic pricing is deployed on an opt-in basis or opt-out basis [3]. The Brattle Group estimates $65B in costs avoidance in US through 2030 from DR [4]. Hence, under the proper alignment of technology, pricing, and incentives, DR is expected to play a key role in the value proposition for smart grid and a key part of the grid of the future. DR has been a largely untapped resource with significant potential. The idea of addressing a grid challenge by deploying software and minimal hardware—without building large power plants or new T&D equipment—is simply too valuable to overlook.

CONCLUSIONS

New technologies, changing market conditions, and new regulations and policies all shape the future of the grid. This is true for both the emerging and developed economies of the world. The many moving parts of policy, regulations, market conditions, and the cost and performance of new and existing technology makes it difficult to place bets as a product vendor, utility planner or investor. While many factors will shape the future of the grid and many other factors can alter the course, the five key trends described in this article are some of the key drivers that the authors believe will significantly shape the grid over the next decade.

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