International Journal of Advanced Engineering and Nano Technology (IJAENT)
ISSN: 2347-6389, Volume-2 Issue-9, August 2015

Challenges in Smart Grid of Future

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Abstract- Our nation's infrastructure for generating, transmitting, and distributing electricity – "The Grid" – is a relic based in many respects on century-old technology. It consists of expensive, centralized generation via large plants, and a massive transmission and distribution system. It strives to deliver high-quality power to all subscribers simultaneously – no matter what their demand – and must therefore be sized to the peak aggregate demand at each distribution point. In this paper we describe what the electricity grid could look like in 10 years, and specifically how Federal investment in data analytics approaches is critical to realizing this vision.

Keywords: - nation's, generating, electricity, Grid, power, paper, system

I. INTRODUCTION

Power is transmitted via high voltage lines over long distances, with associated inefficiencies, power losses, and right-of-way costs; and local distribution, via step-down transformers, is expensive in cost and efficiency, and is a single point of failure for an entire neighborhood. Ultimately, the system demands end-to-end synchronization, and it lacks a mechanism for storing ("buffering") energy, thus complicating sharing among grids or independent operation during an "upstream" outage. Recent blackouts demonstrate the existing grid's problems – failures are rare but spectacular. Average demand per consumer is a small fraction of the peak – a 25 kWhr/day home draws on average less than five percent of its 100-amp service. Consumption correlations, e.g., air conditioners on a hot day, drive demand beyond estimated aggregates, which can result in huge spikes in supply cost and may trigger blackouts. Moreover, the structure cannot accommodate the highly variable nature of renewable energy sources such as solar (generating power only during the day) and wind (generating power only when the wind is strong enough). Meanwhile, consumers are provided little information about their energy usage (just a monthly total) and even fewer opportunities or incentives to adapt their usage to better align their demands to the capabilities of the utility companies.

Many people are pinning their hopes on the "smart grid" – i.e., a more distributed, adaptive, and market-based infrastructure for the generation, distribution, and consumption of electrical energy. This new approach is designed to yield greater efficiency and resilience, while reducing environmental impact, compared to the existing electricity distribution system.[1] Already, the U.S. government is investing billions of dollars in deploying aspects of smart grid technology,

II. The Smart Grid in 2025

A critical step in enhancing our nation's electricity infrastructure involves smartly extending it into homes, offices, and factories. Consider the following vision for how electricity may be served to a home in 2025:

The Rams family, of Mainpuri, Uttar Prades, lives in a house with state-of-the art sensing and control capabilities. Their home management computer has collected data on the habits and preferences of the family in order to create a model of their electricity use. The management computer uses this model to inform its decisions and interactions with the electric utility's computer system. While the ideas of using pricing incentives and household automation have been proposed as part of the system for achieving more balanced loads and better efficiencies in the smart grid, the above scenario includes aspects that go much further than other existing plans for smart grid technology:

- The home management computer serves as the "energy czar" for the home. It uses sensors to "learn" the usage patterns and characteristics of the household appliances and lighting (e.g., power draw, ramp-up time), as well as the occupants' habits, needs, and preferences beyond default settings. It can selectively control devices, such as the household thermostat. It can diagnose anomalies (e.g., defective fluorescent lighting ballasts or refrigerator doors left ajar) and report these to the homeowners. It has access to the homeowners' calendar programs and is able to determine when they will be away. Unlike some smart grid proposals that require humans to continually monitor and adjust their energy usage, this example illustrates how the home management computer could function much like a good butler — it would automatically learn the occupants' preferences and make the right choices in the background.
- The home management computer negotiates with the utility company, engaging in complex transactions involving bundled combinations of current and future quotas and prices, as both a consumer and a provider of electricity.
- The utility company's system must perform these negotiations with hundreds of thousands of households, as well as with hundreds of other entities such as power generators, transmission line operators, other utility companies, etc. The system has at its disposal data about weather and seasonal patterns, but it must also consider possible statistical variations and unexpected demands and outages.
- Although we described the above scenario as involving a single negotiation per day, it is likely that utility companies and home computer systems will be engaging in these exchanges more frequently (e.g., hourly).

Revised Version Manuscript Received on August 18, 2015.

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III. Data analytics as a driver

Much of the technology underlying such a system requires advances in the area of data analytics, including:

- ***Machine learning/data mining*** can readily detect usage patterns and preferences automatically. For example, researchers at Georgia Tech and the University of Washington have shown that instrumenting a home with just three sensors — for electric power, water, and gas — makes it possible to determine the resource usage of individual appliances, lights controlled by individual switches, and the HVAC and plumbing systems — simply by analyzing patterns in the data. The sensor and control system can apply machine learning to continually improve energy efficiency, reliability, and comfort by monitoring operations and algorithmically tuning parameters and behaviors, largely eliminating the need for users to manually set configuration parameters. Realizing this potential requires that sensors and the control system work reliably in all environments and at sufficiently low cost for a consumer marketplace.
- ***Agent-based (auction) systems*** can negotiate complex contracts on a massive scale. For example, Google performs automated auctions millions of times per day to place paid advertisements within its search result pages. But it's one thing to sell space on Web pages; it's a much more serious proposition to operate a market-based system at this scale that controls critical infrastructure.
- ***Advanced optimization*** can guide the adoption of renewable energy sources, such as wind and solar, based on projected macro-scale demand, grid capacity with anticipated upgrades, and consideration of the inherent intermittency of renewable power sources. For instance, the optimal location in terms of wind-energy density may not be as desirable as a slightly suboptimal location where projections indicate maximal need; two smaller wind farms on opposite sides of a geographical barrier (e.g., a mountain range) may prove most efficient due to offsetting intermittency, reasonable grid access, and consistency with planned grid upgrades.

IV. Challenges in Future

Fully realizing a future in which millions, perhaps billions, of computerized agents manage our energy production, distribution and consumption requires many capabilities well beyond those of current data analytics tools and consequently of any system relying upon them. Indeed, moving to the smart grid of the future presents many fundamental challenges that we have yet to address:

- ***The systems must adapt to unexpected events.*** What if the Jones' return home early, or their car returns with less charge in its batteries than was anticipated? Many other events can undo the careful planning made by the utility company: new usage patterns, unexpected weather conditions, failures of components or subsystems, etc. The systems must operate with sufficient capacity margins to avoid failures. The agents must be able to dynamically renegotiate contracts, with appropriate pricing mechanisms to avoid abuse.
- ***The system components must be able to cooperate with one another.*** For example, shouldn't the Jones' home computer be able to remotely query the Jones' car during the course of the day to assess the precise level of charge anticipated upon the Jones' return, and could the Jones' home computer in turn use this information to renegotiate contracts in "real-time"? This high degree of connectivity and coordination could make the system more reliable; however, if poorly designed, the system could also be more vulnerable to cascading failures leading to large-scale blackouts.
- ***The system must guarantee sufficient privacy.*** The Jones family might not want the utility company (or a malicious eavesdropper) to know things like when the house is vacant or when the teenage daughter is home alone. Unlike scenarios where utility companies are provided direct control over household appliances, we envision that the home management computer will serve as an "information firewall" to the outside world. It will act on behalf of the homeowners while restricting the flow of information to the outside world. It may even choose to obfuscate externally visible usage patterns, e.g., by having some form of energy storage within the house that can be charged or utilized at different times of day. (As with many other real-world systems, there may be a benefit-cost tradeoff between privacy and efficiency.) Ultimately, these technologies will require computer scientists interfacing with policymakers directly.
- ***The system must be resilient to abuse or attack.*** Experience with the California energy market in 2000 demonstrated the possibility for companies to "game the system," creating havoc while reaping huge monetary benefits by exploiting flaws in the computerized marketplace. Given the rise in the amount and sophistication of Internet-/cybercrime, there are justifiable fears that malicious agents will target any network-based smart grid both for monetary gain and to disrupt the U.S. economy. An effectively designed, agent-based system can potentially be less vulnerable to manipulation or attack than a centralized, monolithic one, but a bad design could yield just the opposite effect.
- ***The system must learn and improve over time.*** As new electrical devices become available, how should they be incorporated into the power optimization equation most efficiently? As usage patterns evolve with households becoming more energy conscious, or as families evolve (e.g., children are born, or children go off to college) and so do their energy consumption patterns, the underlying machine learning must track and adapt, both to long-term lifestyle changes and to transient ones (e.g., a family goes on a two-week vacation, or workmen remodel a home and their power tools draw substantial electricity for a short time).

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V. Conclusion

We as a nation need to change course with fierce urgency." Achieving a truly smart energy infrastructure – for energy generation, distribution, and consumption – inherently requires basic and advanced computing research, as outlined above. Today, computer scientists are well-equipped to collaborate with other scientists and engineers, enabling the current concepts for the smart grid to be realized and then taking the vision to entirely new levels, yielding fundamental improvements in efficiency, reliability, and security, all the while reducing environmental impact. We can no longer afford to wait for this work to get underway.

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