DISTRIBUTION SYSTEM OPERATIONS TRANSFORMATION FOR THE NEXT GENERATION ELECTRIC UTILITY BUSINESS

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ABSTRACT

Electric utilities globally face significant business and technical challenges with the growth of Distributed Energy Resources (DER), which are primarily deployed behind the meter. This has forced electric utilities to re-think and transform their traditional bundled, cost-based business model to align with emerging regulatory policies. These policies have also required electric utilities to focus intensely on customer engagement through energy efficiency and other DER programs. Regulators, electric utilities, customers and emerging stakeholders will have to work collaboratively to achieve the required industry transformation. Different paths will be taken, reflecting regional differences, but at the core will be the need to continue to maintain grid reliability. Only through transforming distribution system operations to enhance integration and management of DER reliably and economically will electric utilities be able to successfully transform and establish their future business models.

INTRODUCTION

The growing need for electric utility transformation has been led by different forces and challenges globally. Whilst there is a stark difference between what these are in the developed versus the developing world, the potential impact on electric utilities are heading in a similar trajectory led by DER and Microgrid deployment which is moving the operating paradigm towards a more active distribution network. DER and Microgrids hold the promise of revolutionizing how consumers value electricity services and reliability. Additionally DER and Microgrids provide new control variables for further optimization of not only the distribution grid, but also more critically the transmission grid and bulk generation dispatch.

In the developed world the need for transformation has been led by primarily the introduction of policies and regulations towards the reduction of greenhouse gases and environmental sustainability. However more recently the introduction of innovative financial leasing schemes by aggregators has led to exponential DER including solar photovoltaic and energy storage adoption. These schemes have significantly reduced the costs and complexities residential adoption, in sync with regulatory demands.

In the developing world the situation is very much different. The overall continued growth of population, from higher birth rates and improving medical access, and paltry rural electrification has led to significant migration and growth rates in the urban population. Unfortunately most of these migrants end up in large city slums where local electric utilities are unable to invest to meet their growing needs. More and more in the developing world the use of Microgrids with DER are being used electric utilities for electrification. The lower cost and development hurdles means that a rural village can now be partially electrified in just under 6 months.

Another force which is further impacting electric utilities is climate change as recently experienced through increased storms and natural disasters. Extended periods of dry weather in the Americas have led to extensive debates on how to use scarce resources for agriculture, wildlife, industry, residential consumption and energy generation. Hydro generation resources have been idled due to the need to maintain minimum levels for wildlife survival. Ever larger Atlantic and Pacific storms have submerged commercial capitals leading to fatalities, business interruption and significant loss of revenue. Growing climate threats are also forcing electric utilities to reconsider how to best provide grid resiliency. Recent grid restoration experiences from natural disasters and storms show the promise of DER and Microgrids to reduce outages, whilst providing critical emergency services.

These challenges and forces have led electric utilities globally to rethink their business as usual business models. Continuing to invest in electrical assets based on peak-load requirements is no longer a cost-effective and viable option. Electric utilities have begun to transform their business models from a purely cost-based bundled service to value based unbundled services. This was initially led by the introduction of wholesale markets and unbundling of generation and transmission over the last two decades. Electric distribution utilities were however largely unaffected by the bulk power transformation.

Electric distribution utilities now face similar needs to transform their business models. This is leading a paradigm shift in the classical business model of bundled and volumetric "KWH" centric services needs major overhaul to sustainably address the emerging challenges. Transformation will have to be implemented through an evolutionary and incremental phases. This paper will attempt to describe the salient operational and technical architecture principles that can help facilitate and provide solutions for electric distribution utility transformation through the introduction of a Distribution System Operator (DSO). The DSO will play a critical role in managing distribution grid reliability through economic participation and signals. The DSO concept is somewhat similar to how a Transmission System Operator (TSO) manages transmission grid reliability.

The authors envision a multi-level coordinated business operation framework based on electrical and/or commercial characteristics (e.g. TSO, DSO, Aggregators, Resources, and Devices). Each level in the multi-level framework, there are transactions of valued-based services between service provider, service consumers, and possible intermediaries. Depending on the nature of services, some will be exclusively provided by DSO (e.g. grid reliability), other by independent 3rd parties (e.g. energy supply). And there will be coordination between physical, commercial, and financial operations to ensure grid reliability, business viability, and environmental sustainability.

This paper will also present recent advances in control room technology including which includes next generation grid analytics and optimization technologies to manage active distribution networks.

ELECTRIC DISTRIBUTION UTILITY SERVICE ORIENTED TRANSFORMATION

Transformation of utility industry restructuring in transmission and centralized generation sectors, which started over two decades ago, set in motion major transformation of the power industry. It transformed classical vertically-integrated, cost-based utility business operation into a more open-access, transactive marketplace among participants in the bulk power markets. The transformation established energy-exchange framework for the bulk power wholesale business, that facilitated the creation of well-defined products (e.g. MWH Energy) and services (e.g. frequency regulation). Transactive exchanges of poducts and services comply with well defined protocols that ensure prudent commercial trading and physical operations. While significant improvements are still needed, tremendous progresses have been achieved towards enabling "choices" for consumers and providers of electricity products and services, to transact in the marketplace in accordance to their respective business requirements. Equally important to recognize is that the transformation could and did progress along different migration paths to reflect and accommodate technical and non-technical local regional differences, whilst preserving essential harmonization between commercial trading and physical operation.

Growth in DER, supported by policy and incentives, is driving industry transformation beyond bulk power grid to affect distribution grid and distribution customers. For example, continued proliferation of solar PV means more distribution customers will have choices to become prosumers, generating electricity for self-consumption or for supplying to others that can be reached via the distribution or transmission grid; similarly, technology improvements and price reductions of energy storage systems can provide customers with choices in customizable levels of energy security services. It is a step toward addressing concerns of distribution customers for reliable power supply following major disturbances such as major weather storms.

Customers' appetite for choices of energy services can be leveraged by distribution utilities and others to create a new business framework. In this new energy services framework, different types of services can be produced, delivered, and consumed in accordance to the nature of the services and comply with applicable service transaction protocols established within the reformed regulatory regime. Starting with a few relatively basic types of services to gain experiences, other services can be added incrementally as evolutionary migration over time. This is similar to bulk energy transactions in which basic energy products were implemented before other more advanced ancillary services were introduced.

Many existing distribution systems can be viewed in the service context as a distribution utility providing "classic" energy services to its customers, often denominated in KWH at a volumetric rate of $/KWH. Included in the "classic" energy service is an array of related services, such as power quality, resiliency, reserve, etc., that are frequently bundled together and simply represented, as a proxy, by the volumetric parameter KWH. This simple bundled service model introduces serious problems, such as when net-metering is used to settle behind-the-meter solar PV generation. The problems are caused by inability of the model to differentiate between the services associated with the classic composite energy services and the intermittent energy from solar PV. Advancing beyond the simple model of bundled services is critical to mitigate potentially severe consequences of net-metering of DG on distribution utilities. The following diagram illustrates a conceptual model of distribution services. It highlights the migration of services from (a) the classic bundled services by distribution utilities, to (b) incremental unbundling of selected services, to (c) continued evolution of additional services from further unbundling or new creations. Along with the introduction of new types of services, there can be a community of third party organizations and utilities providing specific types of authorized services in a vibrant energy business eco-system.

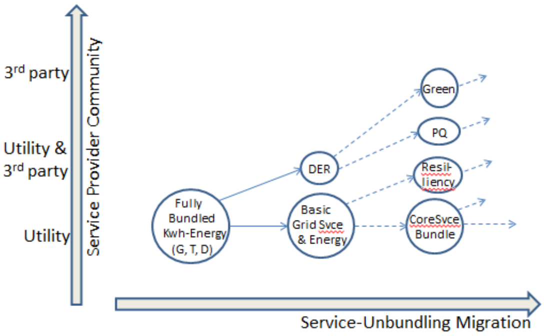

Figure 1: Distribution Service Transformation

There are several essential success criteria to be recognized in developing the transformational service business landscape, including:

a. Customer driven product and services
b. Incremental migration to ensure energy reliability and financial viability
c. Harmonized physical and commercial activities
d. Compliance to transparent business protocols

To enable the above business transformation, a robust and agile technology platform is required that can provided integrated operation across diverse organization boundaries. At the core of the technical platform are the functions to manage DER by the DSO, and will be described in the following section.

DER MANAGEMENT SOLUTIONS FOR DSO

The proposed multi-tier coordinated business and technical operation for integration and management of DER is envisioned to include some key actors interfacing with the DSO as described below.

Key Actors Interfacing with DSO

DER Market Systems/Exchanges
Emerging regulatory policies synergized with higher penetration of DER and Microgrid deployments will lead to a diverse set of structured (potentially both regulated and unregulated) DER market places / DER Market Systems. Examples will range from new ancillary services in existing RTO/TSO markets to new distribution service markets similar to currently being discussed by regulators in the European Union [1] and USA [2] . DSO will play a critical role in such evolving DER market system.

DER Service Providers
The authors envision that a number of new players will emerge as DER service providers in response to opportunities created by different scenarios including evolving DER market systems as described above. We expect that various business model innovations will create a wide spectrum of opportunities to develop DER service providers. A sound DSO strategy will require a close coordination with emerging DER service providers.

DER Owners/Customers
DSO will be required to manage the DER Assets owned by different parties including:

a. Electric utilities
b. End-use customers
c. 3rd party owners/aggregators

Distribution Control Rooms
The author's envision that the DSO will be a new desk on the utility distribution control room. One of the key goals of the DSO desk is to manage and/or assist in reliability and security functions of distribution grid operation by simplifying the complexities due to impact of DERs. For example, the DSO desk will perform solar-swing and reactive power (or volt-var) management for a given DER integrated network circuit.

Until very recent years, most of the distribution grid operations activities have been primarily focused on distribution grid protection and field services for outage management. The notion of controls (unlike what has been prevalent in the transmission grid) in distribution grid operation has been fairly limited. Until very recently distribution networks included primarily passive (static) load models that did not necessitate control interactions either within distribution control room or between transmission control room and distribution control room. Consequently, current paradigm of wholesale power (transmission power flows) – retail power (distribution power flows) integration is fairly de-coupled.

With the advent of DERs, the new paradigm requires DSO to provide necessary monitoring and control capability for DER integrated transmission control room operation described later in this paper. The proposed business and technical operation framework for integration and management of DER is depicted in the Figure 2. Electric utilities have begun to investigate some of these future framework and roles through pilot Smart Grid programs [3], [4], [5].

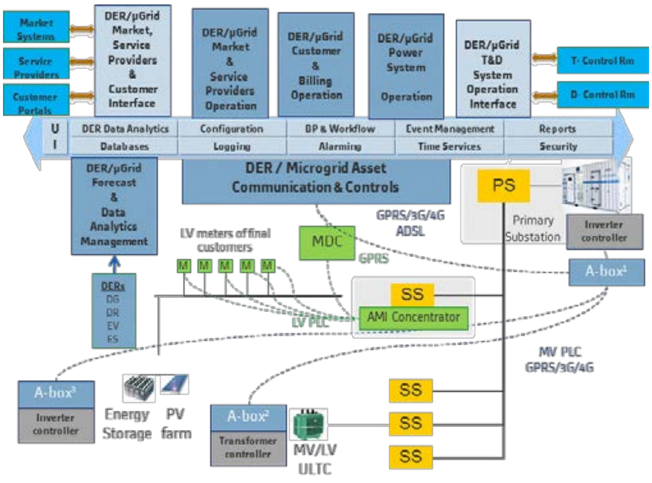

Figure 2: DSO - Business and Technical Operation Framework

The DSO operation framework is envisioned to have three transaction and control components supported by two operation infrastructure components as follows:

Transaction & Control Operation

Customer and Billing Operations

This component will manage commercial relationships between customers, service-provider aggregators, and the distribution utilities. The evolution towards customers becoming 'prosumers' of both energy and grid services implies some type of contractual agreement that covers the term, services, incentives, constraints, and performance criteria for each party. Ultimately, transactions must be settled financially as an integrated billing function.

Market and Service Provider Operations

This component will provide operational scheduling and dispatch instructions to the service providers to meet the expected demands of the service consumers. A key element of this operational component is that the service requests and service offers from multiple organizations, and across different types or inter-related services, are coordinated holistically via formal systematic analysis. The analysis will use optimization methodology to facilitate transparent process, secure grid operation, and maximized business merits. An example of using optimization for DER scheduling is described later in the paper.

Grid Operations

This component will manage/assist in reliability and security functions of DER/Microgrid integrated grid operation. This operation must be designed to support distribution as well as transmission control rooms by hiding complexities due to impact of distributed energy resources (defined to include DG, DR, EV and storage) on grid operation. Examples of activities include voltage and frequency management (maintain voltage profile, optimize volt-var management, perform voltage reduction, maintain voltage and frequency of Microgrids), power flow based grid circuit level network analysis functions for DER integrated grid operation (energy storage operations and controls, solar swing management, integrated solar and energy storage portfolio operation), outage and restoration functions (fault location, isolation and service restoration) .

Operation Infrastructure

Forecasting and Data Analytics

This component will provide dis-aggregate system level net load forecasting is into more localized views of load and DER contributions. This information is needed by transmission and distribution operation systems to predict network congestion and/or plan schedules of controllable assets. Data analytics are a critical part of identifying what forecasts to produce, developing forecast models, calculating forecasts, and measuring the accuracy of methodologies against observations.

Communication and Control

This component will integrate DER assets into the operational control loop and will include mechanisms for communication and control. This will be similar in function to SCADA, but will likely trade-off security and reliability for scalability and cost-effectiveness. This component will manage communications and control of DER assets using secure open protocols including OpenADR or XMPP over the Internet, or Automated Metering Infrastructure (AMI) network.

UTILIZING OPTIMIZATION TECHNOLOGY FOR DSO BUSINESS PROCESSES

This section illustrates capabilities of optimization technology for scheduling DER and other energy resources to meet grid operational requirements. This is a critical task for the DSO to manage services offers/requests with precision and transparency, and in compliance with business transaction protocols.

A high level optimization formulation for DER fleet scheduling problem can be expressed as follows:

Min $\Sigma_t \Sigma_r C_r(X_{t,r})$,
r, t: indices for resource and time
C: cost function of resource r
X: Status/output of resource r in time t

Subject to constraints:
$X_{min} \le X \le X_{max}$
$H_{min} \le H(X_{t,r}) \le H_{max}$,

H: broad set of operational and commercial constraints (e.g. power balance, reserve, energy conservation, grid security).

Sample results of the DER fleet optimization function is summarized below.

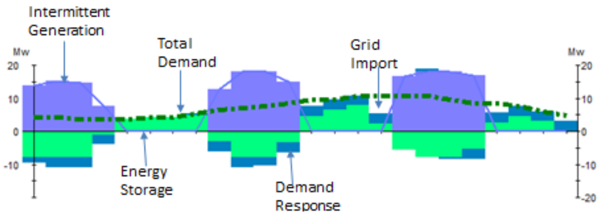

Figure 3: Grid-Connected Microgrid

Figure 3 shows a grid-connected Microgrid meeting its total demand by optimally scheduling Energy Storage (ES) and Demand Response (DR) to leverage Intermittent Generation (IG), and to import from the grid to meet energy shortfall.

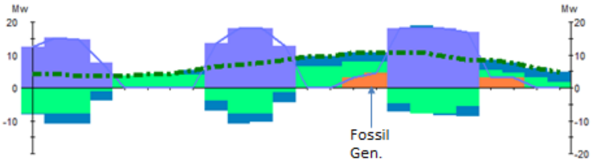

Figure 4: Islanded Microgrid with Fossil Generation

Figure 4 shows the Microgrid in island mode. Fossil generation was needed to make-up for the energy it could no longer import from the grid. Unit commitment constraints such as minimum up/down times have to be satisfied, which led to the fossil unit having to operate for longer time duration than the import duration in Figure 3.

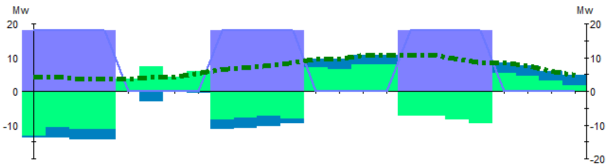

Figure 5: Islanded Microgrid with Extra Energy Storage

Figure 5 shows that, with additional energy storage capacity, the Microgrid can fully capture energy from IG and thus no longer needs to rely on fossil generation.

SUMMARY

This paper has provided the background on current challenges on traditional electric utility business models driven primarily through the introduction of DER and Microgrids. The authors have proposed a multi-level coordinated business operations framework which could potentially include transactions of valued-based services between service provider, service consumers, and intermediaries. Electric utilities will have to transform distribution system operations by enhancing integration and management of DER and Microgrids to successfully establish their future business models. These models are capable of providing enhanced grid reliability economically, whilst meeting future customer needs and regulatory requirements.

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