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Physics Procedia 24 (2012) 443 – 449
Physics Procedia

2012 International Conference on Applied Physics and Industrial Engineering

Smart Operations in Distributed Energy Resources System

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Abstract

Smart grid capabilities are being proposed to help solve the challenges concerning system operations due to that the trade-offs between energy and environmental needs will be constantly negotiated while a reliable supply of electricity needs even greater assurance in case of that threats of disruption have risen. This paper mainly explores models for distributed energy resources system (DG, storage, and load)，and also reviews the evolving nature of electricity markets to deal with this complexity and a change of emphasis on signals from these markets to affect power system control. Smart grid capabilities will also impact reliable operations, while cyber security issues must be solved as a culture change that influences all system design, implementation, and maintenance. Lastly, the paper explores significant questions for further research and the need for a simulation environment that supports such investigation and informs deployments to mitigate operational issues as they arise.

Keywords—system modeling, demand response, market systems, distributed generation, communication system .

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1. Introduction

The common idea smart grid brings to mind is the application of technology in the form of computational hardware and software and pervasive communications to more effectively operate and maintain the electric system. Considering the scope of the electric system to include generation, electricity delivery, and end-use systems, to effectively discuss the impact that a smart grid can have on system operations we must identify the capabilities or functions of a smart grid. In its efforts to promote electricity system modernization, the United States Department of Energy (DOE) has engaged electricity stakeholders and developed material introducing smart grid concepts and characteristics [1][2]. The functional areas include

- Capacity

doi:10.1016/j.phpro.2012.02.065

- Energy Efficiency
- Power Quality & Reliability
- Operational Efficiency

All of these four areas are subject to a set of fundamental concerns that must be solved by all functions. Examples include economic sustainability subject to the business and regulatory environment, cyber security, and safety.

The involvement of end-use resources as participants in system operations is truly transformational. As automation and communications are able to be cost effectively deployed, distributed energy resources (DER – including generation, storage, and load) can dramatically change system operations. A more collaborative paradigm can involve end-use systems so that the overall system may be run more effectively. In addition, these resources can also provide flexibility to solve emerging operational issues, such as the integration of variable renewable generation. This paper discusses system operation impacts of DER participation and the automation advances in the transmission and distribution infrastructure. It also explores the use of electricity markets to effectively engage these resources. While smart grid capabilities will also impact system planning [3].

2. DER Models

A. DER Models for Transmission Operations

DER can be viewed, at the bulk system level, as an aggregated set of resources. The location-based characteristics become aggregated to the distribution feeder level of the system. Understanding the response of DER to wholesale market or emergency signals requires significant changes to the way transmission system operators consider load today. If one tries to comprehensively model individual end-use systems at the transmission level, the exercise becomes overwhelming, particularly when one considers the maintenance of such models. To solve this scalability issue, transmission operation will need to rely upon advanced load forecasts that take into account the active response characteristics of DER to bulk system signals.

We have seen DER engaged in the bulk markets in ISO NE [4] and the PJM ISO. In these cases, DER aggregators can provide capacity services and compete with bulk generators. Additional services can be provided by DER, including spinning reserve and regulation [5]. Forecasting the behavior of these resources to transmission operation signals will become critical.

B. DER Models for Distribution Operations

Traditionally, distribution system design relatively depends upon crude representations of end-use systems used by system planners. The models reflect the aggregated behavior of the load with voltage and frequency characteristics to accommodate levels of resistive and other load behaviors. Sufficient capacity is designed into the distribution feeders to withstand peak load conditions and growth projections. Distribution operation has evolved to depend upon the random nature of end-use systems for anticipating peak usage. Lastly, distribution system protection expects one-way power flow from the feeder to the end-user.

New models are required as DER begins to participate in system operation,. Depending upon the size of the DER devices, some behavior may modeled explicitly; however, given the large number of DER, predicting the time and level of participation at the feeder level needs estimation techniques. Just as load forecasting has been perfected to a relatively high degree, DER response to operating signals, such as a real-time price or emergency signals, will be forecasted without explicit modeling of every participating system. In some situations, distribution operation may depend upon a third-party aggregator who provides a location-based response to operation needs. These aggregators will likely have their own form of forecasting. They may also have relatively detailed DER models and sensing, particularly if they provide other services, such as facility energy optimization and diagnostics.

Also, new models will be necessary to solve the flow of energy from the end-use system into the distribution system. Relay coordination and other safety concerns of a bi-directional system must be met. In addition, a cost recovery model must be developed that compensates the builders, operators, and maintainers of the distribution system.

3. Electricity Market

Economic markets are widely used to achieve a distributed optimization that efficiently takes into account costs and benefits to the extent that they are revealed through the value propositions offered. Markets also allow adaption to changing economic conditions. However, experience has shown that adequate regulation and contingency plans are still required since their markets can also be unstable.

A. Wholesale Markets

Electric energy markets can allow aggregated DER to compete with bulk generation in markets such as day-ahead or hour-ahead scheduled energy. Also, mechanisms to hedge against market volatility can also be provided to suppliers and consumers by bilateral contracts and other risk mitigation products, and thus wholesale markets affect bulk system level operations.

Additionally, smart grid capabilities can enable DER to participate in ancillary service markets. Such capabilities can include spinning reserve and voltage support markets that can help with the integration of variable renewable generation. Secondly, DER may be more efficient for control area balancing than having bulk generators on automatic generation control. Lastly, end-use devices, such as water heaters, can be equipped with sensors and actuators that allow them to respond to frequency fluctuations, especially during system stress.

B. Retail Markets

At the retail level, the majority of end-use DER will be engaged. Dynamic pricing pilots show good potential for engaging demand response participation [6]. Some load serving entities and aggregators are experimenting with various retail products mainly to solve the peak times of system operation (i.e., peak shaving), and to solve asset utilization issues, such as feeder capacity constraints or voltage control. Micro-grid projects are looking at the use of local markets to balance distributed generation and storage with demand as well as energy supplied through the distribution supplier.

4. Transactive Control

A. Communications and Security

New instrumentation and control in the distribution end of a smart grid system needs new communications. It is thought to be that the condition that the application of distribution automation was constrained by bandwidth has changed since the more widespread adoption of broadband communications, i.e., the Internet. However, still, the limitation exists because the traditional inclination of the utilities to own the communication infrastructure continues and thus to implement a satisfactory communication system for the distribution-oriented smart grid functions deserves serious attention. The data rate, the latency and the reliability of the communications link must all be estimated, as well as the security of the connection.

While the physical isolation of the company-owned channel was viewed as providing sufficient resistance to attack, utility communication systems arose. But the things have changed. The increased communication capacity of smart grid is considered to be exposed to attack as never before. To hack the system at connection points to obtain private data and otherwise introduce bad behavior, the profit motive for computer hackers arises.

It is beyond the purview of most utilities to design, build and maintain company-owned communications that are proof against attack, but is routine for broadband providers. To provide high throughput-3G and 4G cellular, WiMax and WiFi, DSL, and cable, any one of those could be nice option. There are many companies that offer these services, with valuable lessons on how to secure their networks and to mitigate sorts of the problems coming from highly exposed networks.

B. Price Sensitivity

A rational decision about whether or not and when to make use of the electricity or could be made if the producer and the user could, somehow in real time, communicate the price. A simple example can be that peaks in the daily load curve would automatically disappear because the price signal would remind users of the higher cost of peak energy. Troughs in the curve would be filled because of the lower price. This was the idea of MIT Professor Fred Schweppe [7] long before deregulation. Dr. Schweppe imagined that the whole power system would operate in a condition he called homeostasis, a sort of self-regulating stability which is based on the notion that the supplier and the user have decision-making roles. Overall costs would be driven lower if they behave as cooperating users of a limited resource, as well as the system performance will benefit. Several options for deriving the price signal were contemplated, such as the use of λ, the incremental cost of production.

By allowing the nodes between the producer and the user to modify a basic price signal in recognition of local conditions, transactive control starts with homeostasis and goes further. While the producer and the user are still the decision makers, the intermediate nodes, acting as brokers in the negotiation, are adding their own biases, and thus the details of the price signal can be different from location to location and local nodes can play a role in system operation by discouraging the overloading of distribution lines. Imagine a system that autonomously solves concerns, such as overload constraints, without the need for a complicated command and control infrastructure. A scalable means of distributed operation has much appeal. In the negotiations, the producer and the user are still the decision makers, but the limited resource may be the distribution circuit, not just the system capacity. These have been demonstrated in the Olympic Peninsula project [5].

While market-based control systems show great promise, we are just beginning to understand how they behave under stress and the types of market regulation that can be established to ensure proper operation. Like other markets and control systems, they have stable and unstable operating regions. For example, market signals can encourage demand to synchronize their behavior. This loss of diversity can cause power peaking problems once prices fall after a high price period, unless a diversification strategy is implemented to spread the load pick up.

5. Reliability and availability

5.1 Availability

Technology can be deployed to better target high end availability requirements which are usually socialized to some minimum level by the electricity regulator or service provider policy, smart grid systems can offer higher availability to those who are willing to pay while not burdening others with higher rates when their needs are less demanding.

By using market-based techniques, system operations technique is prioritized electricity under stressed conditions. The extreme case could be that high availability users, such as hospitals can be offered service first while others run in degraded mode until the emergency has passed.

The load can be adjusted to meet the supply in a prioritized way with more sensors and intelligence in the delivery infrastructure and the engagement of DER. The need to drop entire neighborhoods should be reduced.

5.2 Reliability

The required the addition of electronics to power systems introduces new failure modes, which can impact system reliability. The reliability mentioned here is referred to the probability of a device or component being able to perform its job adequately under the conditions it will be used in for the life of the project. Therefore, a decrease in reliability does not necessarily mean that the availability of power to the customer will be lower. Actually, smart-grid-related deployments are often advocated based on improving power system availability.

Provided that the electronics parts may not be adequately qualified for their application, it seems likely that if the level of reliability achieved does not exceed that of (for example) Internet routers, the overall power availability may suffer. This will affect the spares policy of the service providers: they may have to get accustomed to replacing parts much more frequently, and it may also affect the operation of the power system: unanticipated power outages may occur.

While most of the computers in control of different functions throughout the power delivery system will be operating autonomously, some of them will be involved in communications with their neighbors and with the utility control system. The communication could fail for a number of different reasons such as hardware problems, software problems, or even deliberate attack.

To solve the question, discipline needs to be instilled. Typical ways are to enter what is called a safe mode, and a sequence of operation designed to restore communications. By engaging DER that is under the control of another party the discipline to articulate safe mode agreements becomes even more apparent. Serious ramifications for proper operation occurs when it comes to whether a distributed generator that loses communications remains connected at its scheduled level or disconnects from the system has. To collaborate with autonomous devices or systems, part of the power delivery infrastructure, the corresponding safe mode action might be to switch in any redundant communication hardware, or to attempt to communicate over a different path.

Some general guidelines can be offered while the safe-mode actions must be thought through on a case-by-case basis. First, with automation elements in safe mode, the behavior of the power system should be about the same or even broadly similar to the old grid. Merely shutting everyone off does not guarantee the “safe” in safe mode! Second, whatever the system checks are, the set of questions during system startup must be answered first for safe mode.

6. Emergency Response

An improved view of the grid situation could prove useful in some emergencies: reducing the response time for reconnection, and rationing the power to priority users– depending on the nature of the emergency.

A distributed energy resources allowing the formation and operation of electrical islands within a blacked-out region could not only keep priority users energized, but also could speed up the reconnection of conventional generators by supplying their auxiliaries.

7. Simulating System Operations

While smart grid related technology is supposed to bring significant benefits, the operating behavior of the devices and systems deployed are just beginning to be understood. As smart grid concepts have been imagined, simulation tools have been used, altered, and created to model and test smart grid operations functions (e.g., [8]).

Some important areas where simulation can help solve many operations related questions follow:

- Data Management
- Power and Communications System Interaction
- Market System Interaction
- Probabilistic Characteristics and Risk Management
- End-user and Human Behavior Acceptance of Smart Grid Capabilities

8. Conclusion

The engagement of DER as a full participant in system operations transforms the paradigm managing the electricity. With greater flexibility and efficiency, the level of sensing and coordination imagined in the delivery infrastructure provides system operations with many more options to enhance efficiency and better respond to disturbances.

Considering that not all regions face the same electricity operations issues, smart grid ideas must be reviewed through analysis, simulation, and controlled tests. Especially, failure scenarios must be studied and remediation plans put in place. From an operations point of view, moving in smart grid directions needs to be done incrementally. Over time, the power systems in industrialized nations have evolved in a tractable way in response to many social-economic and security pressures. Also, we need to see those steps respect the complexity of the technical, economic, and regulatory policy problem before us due to the economic and environmental pressures.

Acknowledgement

The authors are grateful for the financial support from Knowledge Innovation Program of The Chinese Academy of Sciences (No. KGCX2-YW-399+8); The Science and Technology Project of Guangdong Province and Ministry of Education of China (No. 2010A090200065); The Guangdong-Hong Kong Technology Cooperation Funding Project (No. 2009A011603003).

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