Smart Grid and Electric Power Informatization

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Abstract. This paper introduces various concepts that relate to information technology and the development of energy transmission and distribution. Key challenges need to be addressed in relation to energy consumption, such as the need to be responsive to current demand, which have been addressed through information technology systems. With the increased connectedness of energy systems, there has also been an increased need to ensure the information security of these systems. The Internet of Things (IoT) concept will be reviewed in relation to the connection of objects in energy systems as well as the concepts of Big Data and Cloud Computing. The former has developed in response to the need to predict energy usage more accurately and the latter offers the advantages of increased failover potential as well as much faster provisioning of enhanced capacity in IT systems to meet consumer demand.

1. Introduction
Electronic power systems need to be able to address demand for electricity and have become automated in order more efficiently to manage transmission and distribution. The introduction of Smart Grid systems has introduced the capacity for bi-directional communication between electricity suppliers and consumers so that real-time demand can be better anticipated. The increasing interconnectedness of energy systems has, however, exposed them to the potential for cyber-attacks, which create a risk to the energy supply with potentially life-threatening consequences. The Smart Grid has also incorporated the IoT concept into energy systems as well as Big Data concepts, in which vast amounts of data is now used, partially through the use of Smart Meters, in order to better estimate customer demand for electricity. These concepts will be addressed in three main parts: first, the automation of electric power systems; second, the issues of information security in power systems; the third part evaluates the use of IoT, Big Data and Cloud Computing in electric power systems.

2. Automatic Operation of Electric Power System
Electronic power systems are comprised of several generating stations, where electricity is generated in response to demand from consumers. The objective of this system is to generate sufficient electrical energy at the best-suited locations and to transmit it to the various load centers and then distribute it to consumers while maintaining quality and reliability (Sivanagaraju, 2009). An important characteristic of electric energy is that it should be used as it is generated; due to the varied demands of consumers (e.g. domestic, industrial, agricultural), the load on the system varies over time. The generating station must, however, be in a state or readiness to meet demand, thus establishing a ‘variable load problem’ (Sivanagaraju, 2009). Since electric energy cannot be cheaply stored on a large scale, it must be generated to meet demand; it is imperative therefore for electric power utilities to be able estimate load in advance. Load forecasting in electric power systems is critical for the correct planning of power systems and transmission and distribution facilities for the operation, financing, grid formation, personnel requirements and sales of electricity (Sivanagaraju, 2009).
Various technologies have been created over the past decades in order to better enable the automation of the ability to forecast load in electric power systems and predict the amount of electrical energy that is required over a given time period. As the global economy becomes more reliant on the sustainable development of energy, a series of problems, such as energy shortages, disconnection and climate change need to be addressed, as well as the need to maximize economies to the consumer (Naveen, Ing, Danquah, Sidhu, & Abu-Siada, 2016). In particular, a recent development which seeks to address some of these current imperatives is the Smart Electrical Power Grid or Smart Grid. A Smart Grid is an electrical network that utilizes both digital and other information technologies to monitor and manage the transport of electricity from the various sources to meet the varying and competing demands of consumers (Naveen et al., 2016). It has been developed to improve mechanisms to increase the information available to predict the need for energy and in turn improve efficiency and sustainability in relation to the use of electrical energy.

3. Information Security of Electric Power System

The introduction of ‘Smart Grid’ solutions to electricity supply has led to various challenges in relation to cyber security and power system communication systems. While physical threats to electronic power systems are commonly understood, the increasing threats of cyber-attacks to electricity systems need to be addressed (Ericsson, 2010). Power system communication (PSC) systems, supervisory control and data acquisition (SCADA) systems and substations are now interconnected with other systems, leaving them vulnerable to attack through computer networks (Ericsson, 2010). The use of standard products for SCADA and energy management systems (EMS) opens up new possibilities for threats to security. Furthermore increased security threats come from the increasing integration of IT infrastructures at power utilities, including public infrastructures (Dán, Sandberg, Björkman, & Ekstedt, 2012). Increased threats require increased security measures such as Firewalls, and encryption systems that protect information as it is sent across the network. Physical security measures should also be in place to prevent attacks (Kizza, 2017).

Acts of cyber-war or cyber-terrorism can include attacks on critical infrastructures such as electricity power stations. A cyber-attack was carried out in December 2015 which led to service outages to customers in the Ukraine. The cause of the attack was a third party’s illegal entry into the Ukrainian Kyivoblenenergo, a regional electricity distribution company’s computer and SCADA systems. As a result, seven 110 kV and twenty-three 35 kV substations were disconnected for three hours (E-ISAC, 2016). The Ukrainian government claimed that the Russian security services were responsible for the cyber-attack, making it an act of cyber warfare (BBC News, 2017). The attacks were directed at the regional distribution system, as illustrated in figure 1 (Oblenergos are distribution companies) (E-ISAC, 2016).

![Figure 1: Electrical System Overview Diagram (E-ISAC, 2016)](image)

Cyber-attacks on electricity control systems therefore carry significant risks to a country’s power infrastructure, hence the information security of power stations is of increasing importance. However, as the sophistication and interconnectedness of technology increases, attackers gain greater...
opportunities to do increasing amounts of damage as more and more components of the system are interconnected and controlled through automation.

4. Smart Grid Technology and Information Security

Figure 2: Smart grid landscape and its characteristics (Kayastha, Niyato, Hossain, & Han, 2014)

The smart grid is an innovative energy network (see figure 2) which aims to improve the reliability, cooperation, responsiveness and economy of the conventional grid network. According to NIST, a Smart Grid is “a modernised grid that enables bidirectional flows of energy and used two-way communication and control capabilities that will lead to an array of new functionalities and applications” (Locke & Gallagher, 2010, p. 33). The smart grid includes two-way electrical and data networks through the introduction of advanced metering infrastructure (AMI). The key advantage of the AMI is to provide near real-time metering data, including fault and outage information, which is communicated directly to the utility center (Kayastha et al., 2014).

Smart meters are electric meters that record real time energy consumption and voltage quality, and are installed in the domestic residences (see figure 2) (Naveen et al., 2016). They communicate via the AMI directly to the utility company, thus providing much more detailed and accurate power consumption information than was previously provided through conventional monitoring and billing mechanisms (Kayastha et al., 2014). The advantage of the use of Smart Meters is that they help address the issues of demand response and variable demand discussed above, which are critical to manage predictions and transmission of energy.

5. Cloud computing and IoT with Big Data of Electric Power System

Cloud computing constitutes a model which enables convenient, ubiquitous, on-demand services to a pool of computer resources (Naveen et al., 2016). Cloud computing is a disruptive computing paradigm, and as such it has required some significant changes in many areas of computer systems engineering including data storage, computer architecture, networking, computer security and resource management. Due to its reliance on high speed computer networks, cloud computing has been enabled through the creation of the Internet (Marinescu, 2018).
Figure 3: Cloud computing, delivery models, deployment models, infrastructure, attributes, resources (Marinescu, 2018)

Figure 3 illustrates the 4 delivery models of Cloud infrastructure, the 4 deployment models, the three infrastructure options, the resources required to implement cloud and the defining attributes of Cloud computing which distinguishes it from traditional infrastructures where each company or organization hosts their software, platform, infrastructure and database services in-house (Marinescu, 2018).

One of Smart Grid’s major concerns is energy management, or the process of monitoring, controlling and conserving energy (Naveen et al., 2016). Cloud Applications have introduced benefits over the conventional Server-Client architectures and thus providing advantages for the Smart Grid. The conventional Master-Slave architecture can be vulnerable to cyber-attacks such as Distributed Denial of Service attacks; it can also suffer from a single point of failure. Cloud allows for load balancing to prevent these problems (Naveen et al., 2016). Traditional infrastructures also are limited to the number of users that can be supported without need to introduce additional hardware: through the use of virtualization, additional services can be added within the Cloud paradigm more seamlessly (Naveen et al., 2016). These advantages thus allow the expansion of the Smart Grid systems to address changes in electrical use by end-use customers in response to price fluctuations (Demand Response) (Naveen et al., 2016).

5.1. Smart Grid Energy System and the Internet of Things
The RFID group has defined the Internet IoT as “the worldwide network of interconnected objects uniquely addressable based on standard communications protocols” (Riggins & Wamba, 2015). The IoT is therefore connected with technologies such as RFID, sensors, actuators, GPS and mobile devices; the integration of these components therefore establishes the basis of the IoT. ‘Things’ can be sensors, databases, and other devices or software. Sensors include location identifiers such as global positioning system (GPS) and individual identification devices such as radio frequency identification (RFID) tags (Wang & Alexander, 2016). In the Smart Grid environment, multiple devices are implemented such as smart meters, sub-stations, home appliances, sensor notes and communication network devices which are integrated to encompass elements of the IoT (Naveen et al., 2016).

5.2. Big Data and Electronic Power Systems
The application and methodologies applied to very large data sets were developed many years ago in order to forecast electricity load consumption. Recently, developments in monitoring, sensor networks and advance metering infrastructure (AMI) have led to a significant increase in the variety, volume and velocity of available data in relation to electricity distribution and transmission networks (Arghandeh &
To become data driven, it requires a culture shift in organizational and business processes and a holistic approach, and views the transmission and distribution of electricity as a single integrated entity (Arghandeh & Zhou, 2017). Furthermore, while sensors, processing and the visibility they produce have been applied to the transmission system for some time, the real growth they can produce is in the distribution system, where intelligent electronic devices (IED) are proliferating (Arghandeh & Zhou, 2017).

In comparison to conventional grids, the advantages of Smart Grid are manifold. These include its self-healing and recovery functionality, its ability to better incorporate renewable energies, situational awareness and transient stability. These features have been implemented in reliance upon the deployment of smart meter devices and Big Data analytics (Tu, He, Shuai, & Jiang, 2017). The Big Data in Smart Grid is generated from a number of sources. The proliferation of Phasor Measurement Units (PMUs), the advanced meter read (AMR) and other advanced measurement devices such as the Digital Fault Recorder (DFR), the Sequence of Event Recorder (SER) and Intelligent Electronic Devices (IEDs) have introduced vast amounts of data relating to power systems for storage, curation, mining, sharing and visualization (Depuru, Wang, Devabhaktuni, & Gudi, 2011).

Big Data produces both opportunities and challenges for Smart Grid and electronic power systems (Miao, 2014). It has already brought many tangible benefits to electricity users, including increased system stability and reliability, increased asset utilization and efficiency, improved customer experience and satisfaction. This latter effect is considered to have been a result of the implementation of smart meters that enable easier billing, fraud detection, demand response and efficient utilization of energy (Tu et al., 2017). Table 1 (below) illustrates a number of practical applications that have been developed using Big Data analytics to facilitate features of Smart Grid that have been applied by private research groups and corporations.

| Applications                        | Software            | Developer                  | Description                                                                 | Reference |
|-------------------------------------|---------------------|----------------------------|----------------------------------------------------------------------------|-----------|
| Situational Awareness System        | FNET/GridEye       | Yilu Liu (Lead)            | Real-time event detection, location estimation, oscillation detection       | (Chai et al., 2016; Liu, 2016) |
| Wide Area Situational Awareness     | SMDA (ver5.0)       | Hydro-Quebec               | Collects wide area Phasor data in real time and monitors inter-area oscillations | (Basu et al., 2014) |
| Event Detection and Alarm Management| e-terra 3.0         | Alstom                     | Presents and visualizes disturbances and navigates to the relevant diagnostic data | (ALSTROM, 2012) |
| Oscillation, Detection and Mitigation| Grid 3P platform   | Electric Power Group       | Oscillations are observable by fine granular PMU data                      | (US Department of Energy, 2016) |
| Power Plant Models Validation       | CERTS               | BPA & CERTS                | BPA engineers calibrate the Colombia Generating Station model without off-line generators | (Overholt, Kosterev, Eto, Yang, & Lesieutre, 2014) |
| Renewable Resource Integration      | DEMS                | Siemens                    | A data-driven system which monitors, manages and intergrades distributed generation and renewable energy in a bulk power system | (Siemens, 2013) |
At the same time as these advantages, there are various challenges that have been introduced through the use of Big Data for energy systems. Social power consumption is closely related to Big Data analytics, and the development of Big Data has in itself led to significant growth in systems that require vast energy consumption (Miao, 2014). Smart Grids themselves significantly increase the need for energy consumption; thus, although energy efficiencies may be achieved through the implementation of technology, in another sense electric power consumption is positively correlated with growth in the volume of Big Data (Miao, 2014). Furthermore, the collection and analysis of vast amounts of consumer data lead to Data Protection, security and privacy challenges (Miao, 2014).

6. Conclusion
This paper has reviewed the introduction of a number of information technology systems to electrical energy systems. Due to the increased interconnectedness of systems, there is now an increased need for information security to prevent attacks against vulnerable power supply services. Furthermore, the IoT signifies the way in which the energy grid system is now an interconnected set of components which interoperate to create the Smart Grid system. This Smart Grid system now relies upon concept of Cloud Computing to produce failover and faster provisioning capacity for expansion. Furthermore, Big Data analytics have been used to address the need to better predict demand for energy as well as to improve energy sustainability. Paradoxically, Big Data systems themselves increase the demand for energy.

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