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Exploring the Challenging Issues with Synchrophasor Technology Deployments in Electric Power Grids

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***Abstract*—**Synchrophasor technology is fast being deployed in electric power grids all over the world and is fast changing the way the grids are managed. This trend is to continue until the entire power grids are fully connected so they can be monitored and controlled in real-time. Much achievement has been made in the synchrophasor technology development and deployment, and there are still much more to be achieved. For instance, real-time power grid control and protection potentials of synchrophasor are yet to be explored. It is of necessity that researchers keep in view the various challenges that still need to be overcome in expanding the frontiers of synchrophasor technology. This paper outlines the major challenges that should be dealt with in order to achieve the goal of total power grid visualization, monitoring, and control using synchrophasor technology.

***Keywords*—**Electric power grid, Grid Visualization, Phasor Measurement Unit, Synchrophasor Technology.

I. Introduction

FOR about a decade now, the August 14, 2003 blackout brought to the fore front the need for effective visualization, monitoring and control of electric power systems, and led to more interest being taken into the two-decade old synchrophasor technology. Many advances have been made in the development and application of synchrophasor technology in power grid visualization, monitoring and control. Many applications have been developed and tested while many others are still at various stages of development [1]-[3]. There is virtually no limit to what could be achieved in an electric power grid using synchrophasor technology especially in this era of renewable resources integrations into power grids. Renewable resources are characterized by their inherent variability and resultant instabilities caused to the power grid. Synchrophasor is expected to play leading roles in the future electric power grid: the smart grid. There are still many challenges that need to be addressed if the vision of achieving totally smart electric power grid is to be realized using synchrophasor or similar technologies. This paper tries to highlight these challenges to bring them to focus so that they could be addressed.

The paper is organized in sections; Section I is the introduction, Section II summarizes synchrophasor technology and architecture, Section III presents the major challenges.

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II. Synchrophasor Technology and Architecture

The time domain representation of steady state AC quantities are best presented through phasors. A sinusoidal function x(t) with magnitude X_m and phase angle δ can be expressed as a phasor $\bar{X}$ as:

$$x(t) = X_m Cos(wt + \delta) \quad (1)$$

The phasor representation of this sinusoid is given by

$$\bar{X} = \frac{X_m}{\sqrt{2}} e^{j\delta} = \frac{X_m}{\sqrt{2}} \angle \delta \quad (2)$$

The sinusoid and its corresponding phasor representation are given in Fig. 1. It is worth noting that the signal frequency w is not explicitly stated in the phasor representation. The angle δ is used to specify the value of x(t) at the reference time t=0.

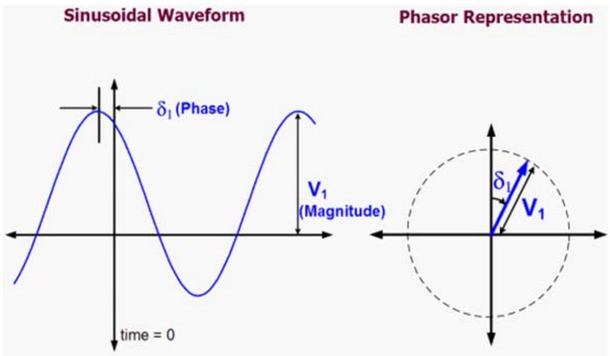

Fig. 1 Sinusoid and its corresponding phasor representation

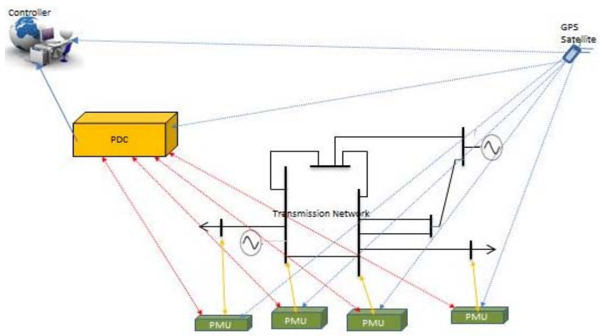

Fig. 2 Synchrophasor architecture

Phasor Measurement Units (PMUs) are power system devices that provide synchronized real-time measurements of phasors of voltages and currents [4]. Synchronization is achieved by time sampling of voltage and current waveforms using timing signals from the Global Positioning System Satellite (GPS) [5].

III. Major Challenges

It could be observed from Fig. 2 that synchrophasor system is a coordination of data acquisition, data storage, data transmission, data processing, and human-machine interface. A failure or malfunction in any of these subsystems results in malfunction of the whole system. It therefore becomes a grand challenge to ensure that each of the subsystems are designed and developed to handle the issues listed below.

A. Data Storage

A synchrophasor system operation involves continuous gathering of data samples, on the operation parameters of the system, which is processed immediately for online applications and/or stored for off line applications. PMU that generates data at the rate of 30 data messages per second will generate 2.6million data message per day, which runs into several gigabytes of data depending on the nature of data being generated. An estimated 1040 networked PMUs are expected to be installed in the USA by 2015 largely due to the recent U.S. DOE grants [2]. The number of PMUs is expected to increase much more when synchrophasor applications are established at power distribution networks.

Though many data compression techniques have been developed [6], [7], and are being used currently in many areas of data handling, there is an urgent need for even more sophisticated techniques which can compress large amount of data with minimal loss of data quality to enhance utilization of data storage capacities.

B. Data Quality

Synchrophasor system operation is dictated by the data generated by the PMUs and transmitted to the control centers. This implies that the accuracy in the performance of synchrophasor applications is determined by the integrity of the data received at the control centers. Data quality is therefore a major issue in synchrophasor applications in power systems. NASPI Synchrophasor Network Data Flow shown in Fig. 3 points out eight different points in the system at which data quality threat can occur. Reports have shown that a reasonable percentage of the PMUs installed in the Eastern Interconnect and the Western Interconnect do not produce valid data up to 50% of the times. They either failed or are out of synchronization [8], [9].

Threat to the quality of synchrophasor data can occur at different points on the network as:

- **Point of measurement:** this point is characterized by analog to digital conversion. Faulty data recorder, faulty measurement or data processing, field maintenance, PMU failure, bad timing, etc. can constitute threats to the quality of data generated.
- **Network Transmission:** the network paths can constitute enormous threats to the data quality in the form of noise, GPS failure or failure of transmission protocol.
- **Data Processing:** faulty data processing and/or storage can cause a big threat to the system.

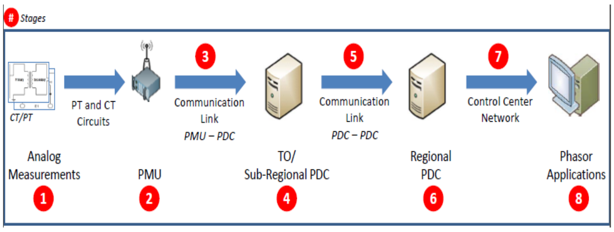

Fig. 3 NASPI Synchrophasor Network Data Flow. Synchrophasor errors can originate at any of 8 points in the data flow [8]

C. Data Transfer Rate (Data Transmission Channel Bandwidth)

An operational synchrophasor system network involves interconnection of thousands of PMUs, each generating very large amount of data and forwarding to the PDCs and to the control center. The data generated requires speedy processing and transmission to effect real time operations and control activities. Communication channel limitation definitely, becomes a major challenge in an all-synchrophasor controlled electric power grid. There is need for advanced data transmission channel bandwidth enhancement schemes on the existing transmission infrastructure to be ready to handle the forth coming data transmission explosion as thousands of PMUs are being installed on the power grids.

D. Cyber Security

An all-synchrophasor controlled power grid presents a veritable ground for cyber-attacks. Cyber security ranks first among the challenges of deploying synchrophasor systems in electric power grids. Synchrophasor system components continuously communicate across large geographical areas which may involve communication over untrusted channels [10], and transmit data among equipment owned by many different organizations as shown in Fig. 4.

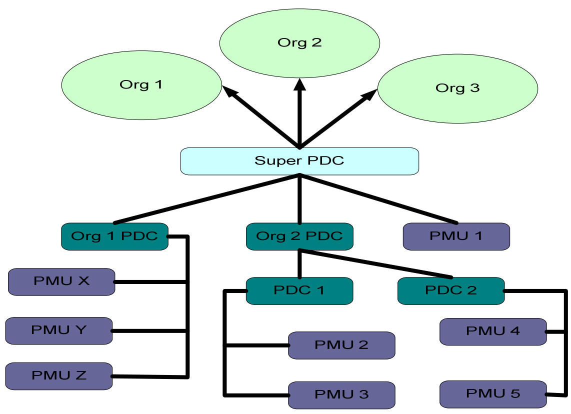

Fig. 4 Synchrophasor system sharing data among different organizations' equipment

Cyber security risk as relates to synchrophasor technology can be classified into the following:

- **Substation security:** this involves physical attack on the cyber assets within the substation. This kind of attack can cause big problems in terms of the systems operations and control, though; it is of less concern because it could easily be prevented by applying necessary security best practices.
- **Information security:** it is as important to be able to securely transport data as it is acquiring the data. An attack on synchrophasor data can be dangerous as the data is used in power system monitoring, operations and control. Three important security aspect of synchrophasor data are
- *Confidentiality*: ensuring that the data cannot be seen by any unauthorized entity. This serves for security and for market competition purposes.
- *Integrity:* received data should be identical with what is sent from the data source without modifications. Modification of data could among other things, causes automatic control applications to issue inappropriate control commands which could be harmful to the system.
- *Availability:* synchrophasor data are acquired and delivered to the entities that need them in a timely manner. An attacker may interfere with the process with the aim of causing an adverse effect on the system.

The internet is not very secure for synchrophasor data transportation considering the data sharing structures (Fig. 4) among the different stakeholders involved in the power grid management, and the roles of electrical energy in nation's economy. Dedicated utility owned optical fiber links could be a more secure way to enhance data transport safety but the question becomes: can the utility companies run optic fiber cables that can go round the power transmission network for data transmission? This is not feasible for economic purposes. Even when this becomes possible, the link itself will be exposed to the risk of physical attacks that cannot be prevented as easily as the substations cyber asset attacks.

Forms of Cyber Attack

- **Reconnaissance attack:** This allows a cyber attacker to reconnoiter a system before attacking. Attackers use this form of attack to identify connected systems and then finger-print the connected systems. Fingerprinting allows attackers to learn which ports are open, the identity and the versions of the remote operating systems, and then the identity and versions of the remote network stack daemons. The attacker uses this information to plan an effective attack.
- **Packet-injection attack:** this is when malicious data packets are injected into the transmitted data and it comes in three forms:
- *Sensor measurement injection*: when attacker injects false sensor measurement data into the control system.
- *Command injection attack*: when the attacker injects false control commands into the control system.
- *Denial of service (DOS) attack*: Attackers attempt to disrupt the communication link between the remote terminals or human-machine interface.

E. Cost and Optimal Placement

Deployment of synchrophasor into a power grid network is a capital intensive project. Reports show that it costs an average of $43,400.00 to install one PMU unit, and an average of $107,000.00 to install one PDC unit [2],[11]. For complete observability, every bus in the system must be monitored directly or have at least one connecting link with a bus that is monitored. Report [4] has shown that about one-third the number of buses (along with all the connected lines) in the system need to be monitored in order to achieve complete observability of the power grid. The above concept leads to the development of formulations for optimal placement of PMUs in electric power grids [12]. Ideally, utility companies would like to have the devices installed at every bus on the grid [3] but in reality, that is not economically feasible considering the cost of the equipment and its operations requirements. Installing phasor monitoring equipment at all buses in the network enhances reliability of the synchrophasor system through redundancy and direct data acquisition and processing.

Deployment of synchrophasor technology into the distribution level of power grids definitely requires many times more the number of PMUs being installed at the transmission level. It therefore becomes a daunting challenge to develop effective ways of deploying synchrophasor technology at an optimal economy.

F. Technology Adaptation

As a technology that is being built on an existing technology, SCADA/EMS, and which is also manufactured by many different vendors, synchrophasor technology has to develop and get standardized to achieve effective interoperability among products from different vendors and to integrate smoothly with the existing SCADA technology. This challenge of adaptation is further heightened by the fact that performance in the present stage of synchrophasor implementation is driven by need-base rather than being followed. This has caused standardization to be made more difficult reducing the guarantee for interoperability among products from different vendors.

G. Manpower Training

Report in [8] pointed out lack of adequate understanding of synchrophasor system among the operators of the system as one of the possible obstacles to synchrophasor data quality and availability. This has brought to the fore front the need for adequate manpower development in synchrophasor systems development and applications. Areas of manpower training needs include but are not limited to:

- *Applications personnel who could make use of the system*: Synchrophasor technology adds a new parameter, phase angle, which has never been seen on a wide area monitoring and control system before. This therefore introduces a new challenge in the area of training of engineers and operators that control the power grids.

- *Maintenance personnel who can carry out repair in case of faults:* The components of the synchrophasor system, being electronic, are susceptible to getting damaged either by wear and tear or accidental damages. Servicing personnel are therefore required to be at hand to bring up any failed system in order to keep the whole system in good condition. System manufacturers' service personnel alone would not be enough to cover the service needs for nationwide synchrophasor system especially during the rainy season. There is need for adequate training of utility based system components service personnel to stand up for any urgent service need.
- *Calibration and testing for reliability of measurement:* The systems have to be routinely calibrated and tested against standard measurements to ensure measurement reliability.
- *University and college students who will take over in future:* The era of synchrophasor technology has brought a new dawn into power system operations, which hitherto was not experiencing fast evolution. This therefore comes with a challenge of training the future power system engineers at the time interface between traditional power systems and data driven electric power grid networks. The engineers are being trained by those who are also actively learning the emerging system, resulting in a dynamic learning environment. There is need for enhanced simulation tools for training and experimentations in this study area.

IV. Conclusion

The electric power grid is evolving to a 100% data driven network. In such a state of the network, much data is going to be generated and utilized. The challenges of data storage, data transmission, data quality, and cyber security therefore become imminent because any alteration in the working data of the network can change the network operation and cause unprecedented damage. There is therefore urgent need for concerted research efforts into ways of conquering these challenges towards actualizing the dream of a smart electric power grid.

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