# ASSESSMENT OF SMART GRID COMMUNICATION INFRASTRUCTURES: REQUIREMENTS AND CHALLENGES

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## ABSTRACT

*One of the requirements for achieving active distribution network management and Smart Grid will be Telecommunication and data management. The cornerstone of a active distribution network is the ability for multiple entities (e.g. intelligent devices, dedicated software, processes, control center, etc) to interact via a communication infrastructure. In this paper, we present the background of communication infrastructures in smart grid systems and also summarize major requirements that smart grid communications must meet.*

## INTRODUCTION

The future power system will indeed be quite different from the present one and distribution systems are at the center of the changes such as: high penetration of Distributed Resources(decentralized generation/storage) connected to distribution networks, constitution of mobile customers for example Electric Vehicles. Therefore the future distribution system will be active system that will imply reviewing the role of the customer in the system. One of the important topics discussed in the active distribution network can be the concept of Smart Grid. All the visions of the smart grid share one common, critical need: communications. Telecommunication and data management ; requirements and options for safe telecommunication infrastructures, and solutions for data exchange between all the players.

A smart grid delivers electricity between suppliers and consumers using two-way digital technologies. It controls intelligent appliances at consumers' home or building to save energy, reduce cost and increase reliability, efficiency and transparency. It provides monitoring, protecting and optimizing automatically to operation of the interconnected elements. It covers from traditional central generator and/or emerging renewal distributed generator through transmission network and distribution system to industrial consumer and/or home users with their thermostats, electric vehicles, intelligent appliances. A smart grid is characterized by the bidirectional connection of electricity and information flows to create an automated, widely distributed delivery network.

The appropriate telecommunication infrastructure can be including : wireless (VHF, UHF, microwave, satellite and variety of wireless technologies i.e. data communications in cellular networks such as GSM/GPRS/WIMAX/), wired (cooper trunk cable, telephone twisted pairs, and Ethernet coaxial cables), Fibre Optic, and Power Line Carrier.

The smart grid could thus be thought of as a combination of the electric power infrastructure and the communications infrastructure. Many smart grid applications could be developed simply using the existing infrastructures for both. A consumer connected to the existing distribution system, for example, can use their existing telephone and internet systems to communicate with the utility or anyone else involved in the application. In many cases, this may be all that is needed. In an integrated approach where the energy and communications infrastructures are considered as one system, a more efficient, reliable, and resilient solution is possible. Existing and evolving communications systems, when integrated, are all candidates for smart grid communications uses. Figure.1 illustrates the main subject discussed to assess the communications needs for the smart grid through study of overlaps, possible aggregation, and the use of common communication paths, all to reduce bandwidth and channel requirements and implement new smart grid Applications. Figure.1 illustrates how far the existing solutions are from what is needed in the smart grid environment.

This approach enables far more extensive applications than what is feasible by simply looking at the two systems separately. By studying the characteristics of the applications that will allow the smart grid to be realized, this paper establishes the communications needs and requirements specification for the smart grid development and integration of renewables, microgrids and advanced energy technologies such as plug-in hybrid electric vehicles represent quite new experience to take place. Existing, and evolving communications systems that can best meet the needs of the smart grid, both for consumers and utilities, are identified.

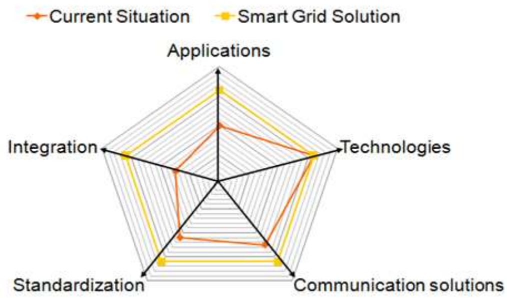


Fig.1 issue overview of Smart Grid communications

## REQUIREMENTS

Monitoring/sensing, communication and control are the three fundamental building blocks that will convert a power distribution system into a smart grid. Monitoring/sensing will have the ability to detect malfunctions or deviations from normal operational ranges that would warrant actions. Further, since in a smart grid, a point of electricity consumption can also become a point of generation, the sensing process will be closely linked with the metering process. Communications will allow inputs from sensors to be conveyed to the control elements in the smart grid which will generate control messages for transmission to various points in the smart grid resulting in appropriate actions. The communication infrastructure has to be robust enough to accept inputs from a user and make it an integral part of the process. By the same token, the user must be capable of getting the appropriate level of information from the smart grid. The major requirements for smart grid communication infrastructures are discussed in the rest of this section.
Reliable communications at the distribution level has high importance for the Smart Grid. There has already been significant work done on power system communication needs and applications. IEC 61850 and DNP3 standardize the communication within the substation. ANSI C12.22 networking standards apply to advanced metering infrastructure. Even though 80% of consumer interruptions are attributed to distribution component failures at the feeder level, getting reliable information is currently a challenging task. Because of this, only limited monitoring is done on components in the distribution system and the associated communication infrastructure. Due to these difficulties, distribution failure/abnormality analysis is done by harvesting information from the components at substation level. There has been a significant amount of work to analyze such data, but even analyzing the whole feeder using information from substations will not capture all the necessary information. Accurate prediction and location of distribution failures are still in an early stage of development. If the communication infrastructure is improved a more reliable approach could be taken and this would also aid better asset management strategies. This work considers wireless communication as a medium for feeder level communication. Leon, et al, have proposed a two-layer wireless sensor network for transmission towers, mainly to reduce the cost of operation while overcoming the limitations of wireless communication range [1]. Muthukumar, et al, proposed a wireless sensor network for distribution level automation. Motivated from these, this work identifies the requirements for communication for distribution feeders and explores the feasibility of wireless communication. Traditional system control and data acquisition (SCADA) level communication has limited bandwidth, 75 bits/s to 2400 bits/s. Greater bandwidth is necessary if the information from the components is going to be used not only for monitoring (abnormality detection), but also for control and asset management tasks. Intra-substation communication is moving from binary or analog communication to Ethernet and TCP/IP based wide area network. IEC61850 standardizes the communication network within a substation. IEC 61850 could be extended to distributed sources. Smart meter technologies are capable of using TCP/IP based communication to/from the control center. The emerging standard ANSI C12.22 standardizes the communication network for smart meters [2]. Based on the above discussion, this paper recommends a similar approach for the entire distribution system. The proposed communication network with different levels of communication is presented in Figure.2.

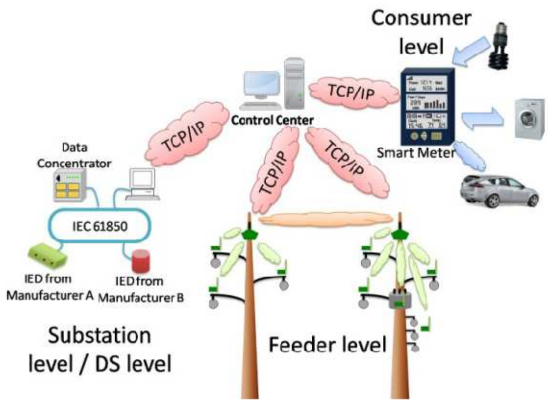


Fig.2 Communication Network for Distribution System

Figure.2 shows three levels of communication. Each of these networks would have two states of communication. The higher priority state would be the abnormal event state, where a detected event with estimated location would be transmitted to the control center for further action. The low priority state will transmit component condition data for asset management tasks. Substation level communication will have higher priority than the feeder level and consumer level communication, which will be operated with lower priority. Data (packets) traffic in the communication network can be prioritized using IEEE 802.1Q standards similar to priority tagging in IEC 61850. Except for substation level communication, other parts of the distribution system currently lack standards, which are needed for efficient use of equipment from multiple vendors/manufacturers. It is also necessary to increase security of transmitted data to mitigate the effect of hacking and modifying data. Security and connectivity of components should be given a higher priority at the consumer level. Utilities have the burden of ensuring all components used are connected to the appropriate smart meter. These will all have significant impacts on choosing the medium of communication.

## Communications Medium

Potential communication media for distribution system networking include power line carrier (PLC), wireless, and dedicated wired. When the substation is considered due to the confined physical space, a dedicated wired medium such as Ethernet is the best choice. Substation communication networks use the well-established IEC 61850 and thus this paper will not discuss the requirements for substation level/distributed source level communication and medium. When feeders are considered, PLC is well-suited, because it is a medium that is available throughout the distribution system. PLC has potential to transmit data at a maximum rate of 11 kbit/s; when the PLC has sufficient robustness and reliability, this maximum data rate can be achieved only in a narrow frequency range of 9-95 kHz. This low rate of communication is not ideal for secure communication. Therefore, if more information has to be sent from all the components in a feeder, higher bandwidth is required. Current developments in broadband over power line (BPL) technologies suggest that it is a promising technology. The distribution system will be affected by unpredictable voltage transients and harmonics, and these affect the reliability and speed of BPL. High frequency BPL signals need to bypass transformers to avoid high attenuation. BPL signals may also be blocked by voltage regulators, reclosers and shunt capacitors which are common for long radial feeders. The attenuation in a radial distribution feeder is high and this would increase the number of regenerators needed. It is expected that a typical 20-mile rural feeder would need 30-110 regenerators. This shows that even though the medium is free, BPL costs are significant. Further, when a pole fails the PLC/BPL communication link fails as well. This would be a major concern when the communication is used for automatic fault location and system restoration. For Smart Grid applications highly reliable communications is necessary. Prior work recommends having 99.995% availability of communication [4] for a reliable Smart Grid system. The 99.995% requirement would result in unavailability of communication to less than 44 hours per year. This would further initiate the discussion on performance indices for the communication network as an additional measure for Smart Grid performance. All these concerns develop a case to explore other options for the communication medium at the feeder level. Another option is dedicated wired communication. One of the problems with copper wire connections is interference and attenuation. Fiber optic cables are a solution for interference but increase the cost. It should be noted that investment for a fiber optic network would be $10-100 million for 100 nodes [5]. Newly developing communities could install a fiber optic communications network close to the feeders, so that this infrastructure could be shared for both Smart Grid and consumer communication needs. One of the advantages of this medium is that the utility has to bear only the terminal equipment cost and costs associated with leasing the line. This will reduce the overhead for the utility while improving communications. On the other hand the utility will not have control over the medium as it will not own the dedicated wired medium in most cases. This will require physical connections and will reduce the flexibility. Further when a pole goes down, the communication link will be broken and may result in poor performance. Wireless communication is another promising alternative for distribution level communication. One of the important characteristics of wireless communication is the feasibility of communication without a physical connection between two nodes. This would ensure the continued communication even with a few poles down. In other words redundant paths for communication are possible without additional cost. According to Huertas et al, discharges between the line components which arise in power lines under 70 kV and the corona effect which arise in power lines over 110 kV have the dominating frequency spectrum in the range of 10 – 30 MHz [10]. Selection of medium with communication frequency spectrum above these limits would minimize the interference. Wireless Fidelity (WiFi / IEEE Standard 802.11), ZigBee (IEEE Standard 802.15.4) or Worldwide Interoperability for Microwave Access (WiMAX / IEEE Standard 802.16) could be utilized in the distribution system with minimal interference. Another advantage of using wireless communication is that the utility has to own only the terminal units, which are relatively cheap and could be integrated with cost effective local processors. When multi-hopping is used in wireless communication, especially in WiFi and ZigBee, the range of communication can be extended and the nodes located in the feeder could be able to communicate with the control center. Disadvantages of wireless communication would be interference in the presence of buildings and trees which could result in multi-path; this can be avoided with improved receivers and directional antennas, which will increase the cost. Another major concern with wireless medium is easy accessibility, which could result in security issues. This can be avoided by using secure protocols. Rural feeder sections would be long and range of communication could become a concern; however, directional antennas could mitigate this issue. Both PLC and wireless communication are promising in the distribution level communication. Based on the need and the availability of the technology a combination of both could be used for improved communication infrastructure.

## CHALLENGES

The proliferation of wireless/wired sensors and communication devices and the emergence of embedded computing represents an opportunity to develop applications for connected environments in general, and especially management systems that address urgent challenges facing the smart grid communication infrastructure. The challenges include the deployment of large-scale embedded computing, legacy power grids, intelligent appliances, and next-generation communications and collaborations that will provide the foundation for a post-carbon society. In this section, we discuss the context that gives these challenges urgency as well as the technical challenges that need to be addressed by smart grid communication infrastructures.

**Complexity**

A smart grid communication infrastructure is a system of systems and it is extremely complex. As a consequence, modeling, analysis and design a suitable communication infrastructure meet many new challenges. The models to be used must be capable of accounting for uncertainty as a way to simulate emerging behavior. The numerical tools to perform the analysis must be capable of solving very large scale problems. In fact, the power system is tightly coupled and non-linear and does not benefit from the sparsity that typically characterized this problem. The control system and particularly communication infrastructure must be designed to manage uncertainty and inconsistencies to be resilient or gracefully degrade when necessary. Finally the performance metric must be adjusted to the new nature of the power system. The challenges in modeling the complexity of a smart grid communication infrastructure are summarized in the following [7,8].

1) Need to support multi-physics approach, 2) Need to support multidisciplinary approach, 3) Need to support dynamic and reconfigurable model level definition, 4) Need to provide high-level graphic visualization to support system, 5) Need to provide support for uncertainty propagation

**Efficiency**

Realization of the future smart grid requires meeting the ever increasing efficiency challenges by harnessing modern communication and information technologies to enable a communication infrastructure that provides grid-wide coordinated monitoring and control capabilities. Such communication infrastructure should be capable of providing fail proof and nearly instantaneous bidirectional communications among all devices ranging from individual loads to the grid wide control centers including all important equipment at the electricity distribution and transmission system. This involves processing vast number of data transactions for analysis and automation. It requires a high performance communication infrastructure capable of providing fast intelligent local subsecond responses coordinated with a higher level global analysis in order to prevent or contain rapidly evolving adverse events. It needs to meet the challenges in the following.

1) Better Telemetry, 2) Faster Controls, 3) More Robust Controls, 4)Embedded Intelligent Device Communications, 5)Integrated and Secure Communications, 6) Enhanced Computing Capabilities, 7) Internet Technology

**Reliability**

A framework for cohesive integration of reliability technologies facilitate convergence of the needed standards and protocols, and implementation of necessary analytical capabilities. This subsection reviews the impact of a communication infrastructure to the reliability of a smart grid. An ideal mix of the current communication and control techniques are expected to lead a flatter net demand that eventually accentuates many reliability issues further. A grid-wide communication architectural framework to meet these reliability challenges are discussed in the following.

1)Renewable Resources: Renewable resources generally have adverse challenges on smart grid reliability due to the following factors: variability and low capacity, factors making the net demand profile steeper, low correlation with the load profile especially in the case of wind resource, relatively high forecast errors especially for longer horizons, congestion issues at transmission level due to large installations and at distribution level due to dispersed resources. Operational performance issues such as voltage and regulation. To address the variability of the net demand, as renewable resources growing over the long run, efficient communication infrastructure for information exchange among demand response, storage devices and utilization of plug-in electric vehicles (PEVs)/plug-in hybrid electric vehicles (PHEV) will complement the remedies [9]. 2)Demand Response: Demand response allows consumer load reduction in response to emergency and high price conditions on the smart grid. Such conditions are more prevalent during peak load or congested operation as illustrated in Figure.9. Non-emergency demand response in the range of 5% to 15% of system peak load can provide substantial benefits in reducing the need for additional resources and lowering real-time electricity prices. Demand response does not substantially change the total energy consumption since a large fraction of the energy saved during the load curtailment period is consumed at a more opportune time - thus a flatter load. 3) Load Management: Load rejection as an emergency resource to protect the smart grid from disruption is well understood and is implemented to operate either by system operator command or through under-frequency and/or undervoltage relays. In a smart grid, the load rejection schemes can be enhanced to act more intelligently and based on customer participation. 4) Storage Devices: Most of the existing storage resources are hydro and pumped storage. However, growth potential for these resources is much smaller than the need for storage necessary to counter growing net demand variability presented by new wind and solar resources. Various storage technologies are emerging to

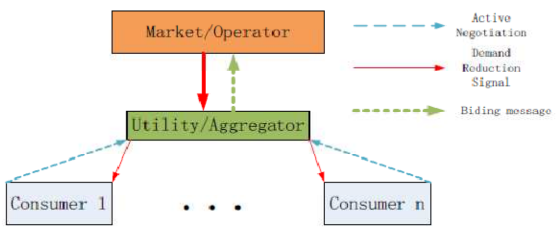

Fig.3 Communications for Demand Response

fill the gap. Battery storage appears to be most promising due to improvements in technology as well as economies of scale. 5) Electric Transportation: Plug-in electric vehicles (PEV, PHEV, etc.) continue to become more popular as environmental concerns increase. They are a significant means to reduce green house gases and reliance on fossil fuels. From reliability viewpoint, electric transportation has features similar to both demand response resources and storage resources. As PHEVs present a significant factor of load growth, this can also aggravate the demand variability and associated reliability problems depending on the charging schemes and consumer behavioral patterns.

**Security**

Based on the evolution of power system communication infrastructures and the concern of cyber security, many new issues have arisen in the context of smart grid.

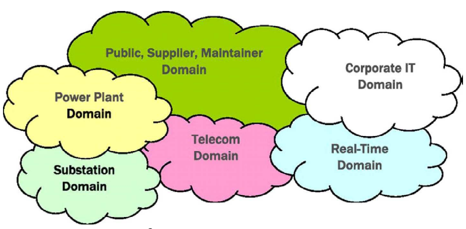

Fig. 4 Information Security Domains

1) Information Security Domains: Since the SCADA/EMS systems have become increasingly integrated, it becomes more difficult to treat the system structure in terms of parts or subsystems. The physical realization of various functions is less evident from a user perspective. Instead, it becomes more natural to study a SCADA/EMS system in terms of domains. A domain is a specific area, wherein specific activities/ business operations are going on and they can be grouped together. The security domains are introduced in Figure.4. When communicating across power utilities, different organizations and companies, using communication networks, the security domains should be recognized. 2) Threats: The fact that SCADA/EMS systems are now being interconnected and integrated with external systems creates new possibilities and threats in cyber security.

## CONCLUSION

In this paper, we presented the background for smart grid communication infrastructures. We showed that a smart grid built on the technologies of sensing, communications, and control technologies offer a very promising future for utilities and users. Through studies of example Smart Grid applications on distribution, the communication needs for the Smart Grid are defined and protocols for communications are recommended. Distribution applications are optimized electric vehicle charging and condition assessment and optimized maintenance of distribution system components. For distribution, the protocol proposed is a wireless (WiFi) mesh architecture. In addition, a wireless-based home area network for advanced metering infrastructure is proposed. The home area network protocol addresses the unique security issues associated with the advanced metering infrastructure application. Efficiency, reliability and security of interconnected devices and systems are critical to enabling smart grid communication infrastructures. Based on the above survey, we can focus on those challenges to smart grid communication infrastructures in both system design and operations to make it more efficient and secure.

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