A Survey of Networking Issues in Smart Grid

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Abstract

In this paper, a survey concerning different aspects of networking in Smart Grid is presented. An application-specific network architecture for Smart Grid is introduced including its physical connection and logical connections as well as its topology. Then, various networking technologies supporting Smart Grid are described according to different scales. Some special issues on networking that Smart Grid is facing are discussed. Additionally, some aspects about management of network in Smart Grid are referred.

Keywords: Smart Grid, Networking, SCADA, EMS, DMS, AMI, MDM, Smart Meters, Smart Grid management, Smart Grid security

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1. Introduction

The advent of the Smart Grid provides people with an efficient and intelligent method to manage power energy supply and consumption. Real time energy management provides the convenience, reliability and energy savings. One great advantage of Smart Grid is the implementation of two-way communication network between energy suppliers and consumers, which allows Smart Grid to be with an integrated data communication network having the collection and analysis of data in real time. This type of communication network will provide a number of new energy applications including real-time metering and pricing, intelligent load shedding, consumption management, cost savings from peak load reduction and energy efficiency, integration of plug-in hybrid electric vehicles for grid energy storage and the integration alternative and distributed generation sources including photovoltaic systems and wind turbines.[Liakopoulos12]

The paper is organized as follow: Section 2 introduces that network architecture for Smart Grid; Section 3 briefly presents the networking technologies used in Smart Grid; Section 4 describes some issues about Smart Grid that networking people are facing currently; Section 5 discusses the management of networking in Smart Grid; finally, Section 6 concludes the paper with a short summary.

2. Network Architecture for Smart Grid

The communication network enables communication between the sensors and actuators linked to the grid devices, and Smart Grid applications enforce power grid policies through these sensors and actuators based on these measurements. The integrated network supports other functionality needs including multimedia data transfer from substations to control centers as well as voice and data applications in addition to usual control applications. Besides, the network must connect to other Smart Grid entities such as independent system operators (ISOs) and regional transmission organizations (RTOs). The next part will talk about networking connections.

2.1 Networking Connections

A Smart Grid communication networking architecture is presented in this section including physical connections and logical connections. The next part will start with physical connections.[Zhou11]

Physical Connections

Figure 1 represents the networking architecture connecting most of the Smart Grid infrastructures. In this architecture, IP is the networking protocol for the integrated network. In addition, it may be prudent to implement Multiprotocol Label Switching (MPLS) for many utilities. Direct connections to the core network are over point-to-point connections. Concerning reliability and load sharing of the system, there might be multiple data and control center. Besides, the network must also connect to the networks of other regional Smart Grid. Connectivity is required to the utility's partner ISO/RTOs and corporate service providers.

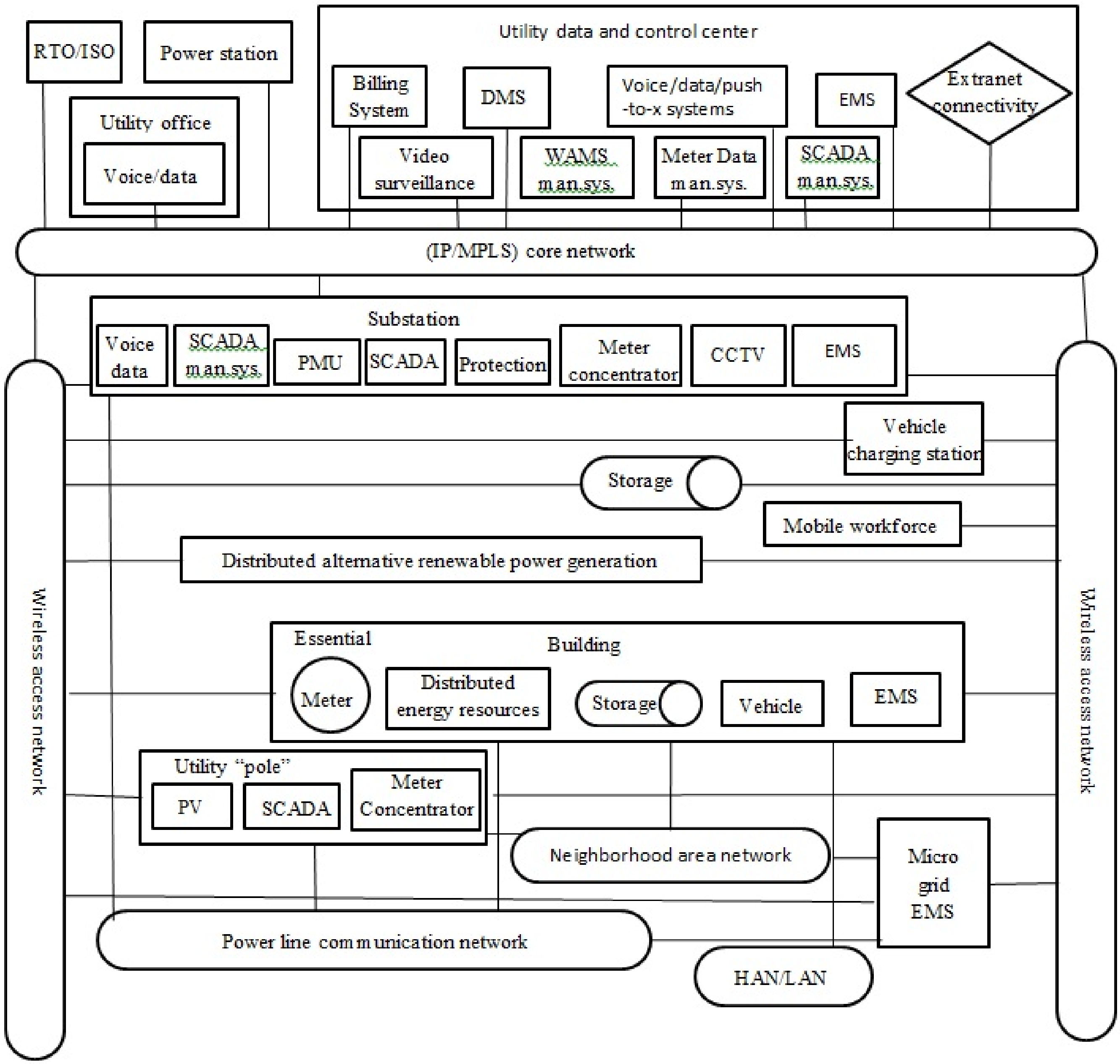

Figure 1: Physical connectivity architecture[Budka10]

Every consumer location has a smart grid device which is connected to the network. A consumer building may have DERs (Distributed Energy Resource) located in or close to consumer building, energy storage elements, and electric vehicles. DERs, storage, vehicles and meters may be connected over a HAN (Home Area Network) or a LAN (Local Area Network), which is linked to the communication network.

The grid infrastructures at distribution points are connected to the network over one or more of the connections. Standalone and large scale renewable energy sources and storage elements are connected to the wireless or wireline access networks. Each micro grid has its own communication network as shown in Figure 1.

It is expected that Voice over Internet Protocol (VoIP) can be used for peer-to-peer (P2P) voice and push-to-talk (PTT) communication of the mobile work tasks, and that mobile wireless data applications will adjust according to broadband. Therefore, all needs can be satisfied by mobile access terminal connecting to the wireless broadband access network. Gateways are going to be needed to connect legacy voice systems to the communication network till VoIP communication is setup. [Silva13]

A substation may contain many Smart Grids and other systems that require communication with other endpoints because of its location and size. The substation automation LAN can be implemented as a hierarchy of Ethernet LANs. The substation may have a separate LAN for applications that have nothing to do with automation and thus the substation router may need to connect to multiple networks from the set of networks. Network access adapters or gateways may be needed according to the network technology. Over time, different networking technologies have been used with network-specific gateways supporting these connections. Further, if latency objectives can be met, tunneling Ethernet over an IP connection through the router is a method to support communication between substations. The next part will talk about logical connections.[Gharavi11]

Logical Connections

It is important to determine endpoints of an application in the network regardless of their physical network connections. Logical connection focuses on the interdependence of applications including ADR (Automated Demand Response), SCADA (Supervisory Control and Data Acquisition) management, and distribution management. [Zaballos11]

Smart meters that play a core role in many applications have been replicated. Newer distribution automation applications like the Volt, VAR, Watt control (VVWC) application will gradually use periodic and on-demand smart meter measurements. In addition, the smart meter is a central component of ADR applications and home energy management. The next part will refer to network topology.[Zhang11]

2.2 Network Topology

A good choice for network topology is a tree structure, which is shown in Figure 2. A substation router is the main component of traffic aggregation in addition to the centralized destination of the utility data and control center for a tremendous amount of applications traffic. Traffic from multiple smaller substations may be gathered at another large substation. The metering traffic may be aggregated at the meter concentrators at substations or the meters and concentrators may be connected to the core network. At last, other Smart Grid endpoints including energy sources and storage units connect to the substations or to the core network routers directly.

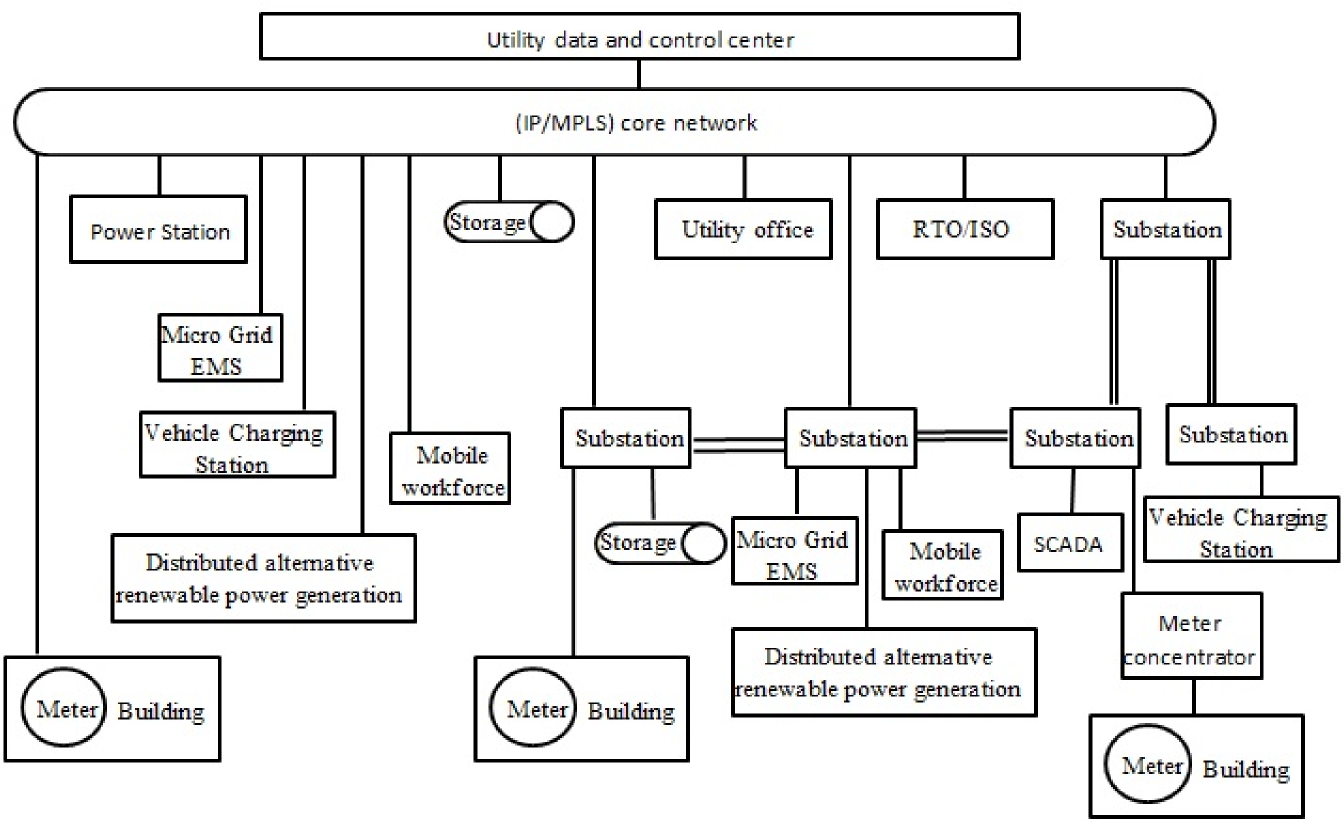

Figure 2: Network Topology [Budka10]

Tree topology can support peer-to-peer applications because connectivity is available through the core routers. However, this may lead to latency of some applications. Many applications with low-latency have endpoints in adjoining substations. Direct inter-substation links may provide the possibility of a better path for P2P traffic.

The topology design is affected by the fact that it is expected to cover a large number of endpoints than to maximize the traffic volume. Because the upload traffic volume is greater than the download traffic for most centralized applications, special design is required. The next part will talk about networking technologies.

3. Networking Technologies

Two-way communications is one of the major technology requirements in the Smart Grid because it makes it possible to dynamically monitor electrical use and to schedule automated electricity use. The basic concept of Smart Grid is that all components of the Smart Grid can communicate and support applications including distant control of user and real-time energy consumption. Different subsystems making up the power grid need to have the ability to communicate with each other within a communication network. The research and use of standard networking technology offers numerous opportunities to the development of Smart Grid. They allow products from different vendors to be integrated into electric utilities. Besides, integration of utilities from multiple technology vendors is possible due to international, regional and national standards. The next part will talk about WAN technologies.[García-Hernández11]

Table 1: Networking Technologies used in Smart Grid

WAN	LAN	HAN	Access	Multimedia
SONET/SDH	Ethernet	ZigBee	PSTN	MPLS
WDM/DWDM	Wireless Ethernet	HomePlug	xDSL	
Digital trunked radio	GbE/10GbE	6LoWPAN	Cable Modem	
RoIP		OpenHAN	FTTH	

3.1 Wide Area Networking Technologies

SONET/SDH

SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy) are critical digital transport networks that allow the combination of high-speed data services. A common number of aggregate transmission rates, especially at higher rates, are both defined in them. However, they are quite different at lower multiplexing levels. SDH is widely used in electric utilities as the backbone of transmission networks in Smart Grid as well as in carriers. It provides carrier-level reliability with short restoration time in case of path failures. SDH also has been put into use by many electric utilities for fibre and microwave systems throughout the world.

WDM/DWDM

WDM (Wavelength Division Multiplexing) is a technology which enables a number of optical carrier signals being integrated onto a single optical fiber by using different wavelength of laser light. In the power grid, WDM can be used to update current SDH devices. DWDM (Dense WDM) allows data transmits at more than one wavelength on each fiber pair of an optical fiber channel and allows data transmits in different formats including IP, ATM, SONET/SDH and Ethernet. Thus, DWDM-based networks can carry multiple types of data at different rate on an optical fiber channel.

Digital trunked radio

Digital trunked radio uses unguided electromagnetic waves to transmit information as well as wireless transport of data. A trunked radio system is a complex type of computer-controlled two-way radio system that allows sharing of relatively few radio frequency channels among a large group of users. Efficiency is the main object of this kind of system, and it can provide Smart Grid with electric utility network with disaster management.

RoIP

Radio over IP (RoIP) is a new generation technology focusing on data transmission over microwave radio, which is with IP addressing. RoIP networks can use all types of IP infrastructure including public Internet, private network, or local network. RoIP is a new way to improve the efficiency of two-way radio technology and allows it to communicate with desk and mobile phones. Besides, RoIP can also improve the stability of Smart Grid when disaster occurs.

3.2 Local Area Networking Technologies

Ethernet

Ethernet is a LAN technology which has lots of advantages including superior versatility, speed and compatibility which make it a good choice for substation automation system. A trend to create LANs in substations appears due to the increased number of intelligent electronic devices (IEDs).

Wireless Ethernet

Wireless Ethernet, also known as wireless LAN technologies provide stable, high speed point-to-point and point-to-multipoint communication. 802.11 standard defines three non-interoperable technologies: Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) and Infrared (IR). It is beneficial to implement wireless LANs over wired LAN because it is easy to setup, its cost-efficiency and it provides mobility of devices. Wireless Ethernet is able to be chosen for multiple applications in Smart Grid like distribution substation automation and protection system.

GbE/10GbE

Gigabit Ethernet (GbE) is an extension of the IEEE 802.3 Ethernet standard. It can be used in high-speed local area network backbones and server connectivity with its lower cost of ownership because applications do not need to change and re-training of technical support people will not be necessary. The need to interconnect Ethernet LANs to SONET/SDH wide area networks is growing as the increasing deployment of Ethernet in the LAN. The next part will talk about HAN technologies.

3.3 Home Area Networking Technologies

ZigBee

ZigBee is designed to emphasize the unique needs of low-cost, low-power wireless sensor and control network. ZigBee is a specification for a suite of high-level communication protocols using small digital radio for wireless personal area networks. The ZigBee allows networking using multiple topologies, like star, tree and mesh. The technology is intended to be simpler and cheaper. Its open standard platform that integrates multiple products and systems is ZigBee’s main advantage. ZigBee now has a Smart Energy Application Profile that is specifically designed for utility application within HAN.

HomePlug

HomePlug is a union name for various power line communications specifications that support networking over existing home electrical wiring. Some specifications exist under the HomePlug moniker, each offering unique performance capabilities and coexistence or capability with other HomePlug specifications. The HomePlug applications are based on PLC (Programmable

Logic Controller) or BPL (Broadband-Over-Powerline) technology. PLC/BPL brings new interest to Smart Grid technology. For example, the energy consumer can control plug-in electric vehicle charging or other smart energy devices they are using.

6LoWPAN

6LowPAN (IPV6 over LoW Power wireless Area Network) is the name of the working group in the Internet area of the IETF (Internet Engineering Task Force). 6LoWPAN is an international open standard that allows in-home wireless Internet. 6LoWPAN has defined encapsulation and header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks, which means IP protocol is a stable technology supporting various applications and communication technologies.

OpenHAN

OpenHAN (Home Area Network) is a proposed standard for home area network and home grids that is aimed to standardize powerline networking interoperation from a utility point of view and ensure reliable communications co-extant with AC power outlets. OpenHAN enables utility control of standards, customer coordination and operational states. OpenHAN is the basis of automated demand response in which there is a link between the customer's smart meters and the appliances. And residents are able to let the appliances run the system during time when electricity is cheap or expensive.

3.4 Access Technologies

PSTN

PSTN (Public Switched Telephone Network) is the union of the world's circuit-switched telephone networks that are operated by national, regional, or local telephone operators and provides infrastructure and services for public telecommunications. PSTN consists of telephone line, fiber optical cables, microwave transmission networks, cellular networks, communication satellites, and undersea telephone cables interconnected by switching centers which allows any telephone in the world to communicate with any other. The core of PSTN now is digital and it includes mobile phones as well as fixed telephones.

xDSL

DSL (Digital Subscriber Line) is an aggregate of technologies that provide Internet access by transmitting digital data over the wires of a local telephone network. xDSL includes a series of DSL technologies, ADSL (Asymmetric Digital Subscriber Line), SDSL (Symmetric Digital Subscriber Line), SHDSL (Symmetric High-speed Digital Subscriber Line), G.SHDSL (Group of Single-pair High-speed Digital Subscriber Line), IDSL (Internet Digital Subscriber Line) and VDSL (Very-high-data-rate Digital Subscriber Line).

Cable Modem

Cable Modem is a type of network bridge and modem that provides two-way data communication via radio frequency channels on a hybrid fiber-coaxial (HFC) and RFoG (Radio Frequency over Glass). Cable Modem is mainly used to deliver broadband Internet access in the form of cable Internet by taking the advantage of the high bandwidth of a HFC and RFoG network.

FTTH

FTTH (Fiber to the home) is a technology that offers a broadband optical fiber connection to consumer sites. It has been a decade since FTTH became a better solution of the telecommunication industry and it provides nearly unlimited bandwidth to the home users. Passive Optical Network (PON), which permits a single optical fiber to be separated into 128 times without active electronic repeaters, is the key to FTTH. This kind of point-to-multipoint network does not require any electronics between the consumers and the central office.

3.5 Multimedia Networking Technologies

MPLS

MPLS is a mechanism in high-performance telecommunications networks that directs data from one network node to the next based on short path labels rather than long network addresses to avoid complicated search in a routing table. MPLS technology provides some new capabilities in IP networks including the support of VPN (Virtual Private Networks), the support of IP routing on network switches and traffic engineering. The next part will talk about some special issues in Smart Grid.

4. Special Issues on Networking in Smart Grid

Smart Grid, the next generation power grid, is expected to be reliable, scalable, efficient, and secure and support the deployment of renewable and distribution energy systems. Modern communications and networking technology will be an important part of Smart Grid because they support bi-direction energy and information flow and enable better monitoring, control and optimization of various power functionalities and Smart Grid infrastructures. As the development of communications and networking technology brings much more convenience to traditional power grid, new challenges for communications and networking research field have been raised with the emerging of Smart Grid. Inter-disciplinary research opportunities and chances for collaborations among researchers in different fields including communicating network, signal processing, security and power grid are created as well. The next part will talk about security of Smart Grid networking.

4.1 Security of Smart Grid Networking

Smart Grid requires developing and deploying powerful computer and communication networking infrastructures that are able to support significantly increased situational awareness and finer-grained commands and control, which is necessary to enable major applications and systems including demand-response wide-area measurement and electricity control, generation, storage and transportation, and distribution automation.

Smart Grid has vulnerabilities and challenges just as any other system does. The integration of cyber and physical systems and factors like human behaviors, commercial interests, regulatory policy and political factors may lead to lots of challenges to Smart Grid. Some challenges will be similar to those of traditional networks but with more complex interactions.[Khurana10]

The supervisory control and data acquisition system is regarded as the “brain” of traditional power grid. But the traditional SCADA system must be designed and produced to work in a more distributed way and supply new services in a secured manner in a wide-are communication environment as the conventional power system is developing towards Smart Grid. To make a contribution to this issue, an architecture and a security framework of such a distributed SCADA system based on a concept named distributed event-based systems (DEBS) are presented. In this SCADA networking architecture, a set of broker nodes, which makes up a network on top of the physical network, connects the publisher and subscriber nodes. These broker nodes require security control policy for end-to-end access protection, which has also been proposed.

As a core component in Smart Grid, the advanced metering infrastructure (AMI) includes meter data management servers (MDMS), data control units (DCUs), and smart meters (SMs). These parts communicate with each other using an IP-based network for control of power and efficient usage. Mutual authentication in the devices will be required in order to have secured communications and prevent data leakage. Two mutual authentication protocols have been developed between an SM and an MDMS so that they can authenticate each other and build a secure communication channel. A matrix-based homomorphic hash to limit the computations in a resource-constrained smart meter is used by these protocols. The next part will talk about communication issues in Smart Grid.

4.2 Communication Issues

Traditional power grid communications networking relied on serial communication environments to provide monitoring and control. Serial communication is reliable, predictable, and based on the nature of the communications and provides containment. But Smart Grid usually uses Internet technologies, broadband communication networks, and nondeterministic communication environment. This issue results from the rapid deployment of Smart Grid systems without adequate security and planning. Here are two aspects of communication issues concerning Smart Grid.[Hossain12]

Wireless technologies such as IEEE 802.11-based WLANs and IEEE 802.15.4-based WPANs would be the core technologies for Smart Grid communications networks. Particularly, IEEE 802.11 based wireless network is used to build the neighborhood area network (NAN) infrastructure for reliable and high-speed data communication for Smart Grid. And IEEE 802.11s takes into use the hybrid wireless mesh protocol (HWMP) at the routing layer. However, because the inaccurate link cost metric calculation and mishandling of quality of service (QoS)-sensitive Smart Grid data, the conventional HWMP may not work well in Smart Grid.

Ethernet networks are used widely for communication networking in Smart Grid. The high-availability seamless redundancy (HSR), a redundancy protocol at layer 2 transmitting duplicate frames for each frame sent and thus doubling the traffic, is used for fault tolerance in Ethernet networks, and it may cause congestion and therefore degrade the network performance. Some researchers have proposed two approaches, the quick removing (QR) and the virtual ring (VRing), to mitigate this problem. The first one removes the duplicate frame from the network after all nodes have received one copy of the frame. The second separates any closed-loop HSR network into several virtual rings. The next part will talk about demand side management issue in Smart Grid.

4.3 Demand Side Management

The development of power system technology is the main power that pushes the whole power engineering field moving forward. Besides, the demand side requirement also spurs the developing trend of power systems. The plug-in hybrid electric vehicles (PHEV) are typical example of demand-side requirement that affects the adjustment of electric power. PHEV will tremendously increase the demand for electric energy because they will be widely used in the future transportation systems. The combination of PHEVs and Smart Grid will require intelligent techniques for their charging and discharging so to optimize the energy consumption for the PHEV owners, and the supply and demand ends in the power system will be balanced.

Actually, there are two approaches that have been raised to schedule charging of PHEVs to avoid the negative effects on the power distribution grid that the additional load because of PHEVs may have. First uses quadratic programming and discusses three algorithms. The second approach is based on a single-shot multi-auction market mechanism that the power grid is regarded as a market and agents that act as transformer and households. The target of both approaches is to minimize the peak load and load profiles variability that charging the PHEVs leads. Although the second method is more flexible, requires less knowledge of the load profiles, and involves very limited information exchange, the performance evaluation results show that the method based on quadratic programming performs better in terms of peak load and load profile variance reduction. The next part will talk about networking management issues in Smart Grid.

5. Management of Network in Smart Grid

Traditional power networks were managed by operations centers to ensure adequate power supplies in spite of peaks and troughs in demand. An operation center existing in each section of the power grid conducts various functions including system supervisory, control, crew administration and dispatch and it has been viewed as "the brain" of the power system. [Nakayama10]

The operation centers are becoming to play new roles to conduct the power system because distribution systems are evolving towards smart distribution systems. The networking systems in these operation centers are developing to communicate seamlessly to provide an integrated monitoring and management system. The control systems make the power grid smarter and help to improve support for decision makers responsible for operations, maintenance and planning and thus help distribution organizations satisfy their needs regarding the increasing challenges. The next part will talk about automation systems in Smart Grid.

5.1 Automation Systems

Automation systems are becoming more and more common with smart infrastructures and applications appearing in a home network. System integration contains three important areas: distribution management system (DMS) integration with SCADA, AMI integration with the DMS, and the integration of data from substation gateways.[Gharavi11]

With the development of Smart Grid driving installation of additional SCADA on the distribution system, available properties include the transformation of status points from SCADA to DMS, supervisory control and manual override commands from DMS to SCADA system, and an implemented user system operating on the same PC operator monitor between two systems.

Integrating SCADA with DMS brings benefits including:

1. Increased operations by close integration of DMS applications with distribution SCADA

2. Improved the efficiency of operator within one system to avoid the necessity to scan multiple systems which may bring different data

3. Integrated analysis of security for substation and circuit operations to check for tags in one area affecting the other operations

4. Stable login and authority certification management within one system

5. Integrated system supporting DMS, OMS and distribution SCADA

The interfaces between AMI/MDM (Meter Data Management) and SCADA/DMS are going to support meter status queries, outage notifications and restoration notifications. The use of other AMI data in DMS applications is being researched such as interval demand data and voltage violations, which would provide improved knowledge of system loading and system's better voltage profiles.

The increasing amount of substation automation and substation gateways supplies growing access to data in IEDs installed in substations and distribution systems. Integrating these systems with DMS enable decentralizing local control at substation level and provide system optimization through the DMS. Integration of SCADA and DMS with other systems provides an alternative way to integrate control center to manage the Smart Grid. The next part will talk about SCADA systems in Smart Grid.

5.2 Supervisory Control and Data Acquisition Systems

As technology and business needs have changed, many SCADA systems have extended from transmission system to include monitoring. The primary part of the integrated distribution system is the integration of different IT systems, which contains the SCADA system as a key element of data collection and system control. The developing trend of distribution system is to expand SCADA systems past the distribution substation, providing aware control system of distribution systems. The architecture defining the transmission of data between infrastructure and the integrated operations center may vary according to distribution organizations.

Advanced applications take the network model and the monitoring of the network operation conditions into use to provide recommendations for optimal network operation. In many cases, distribution systems tend to leave the operator in the decision circuit so that the operator can oversee the system. However, as smart grids evolve, the eager to minimize human control will favor an automated approach. In the future, the level to which the system is automated will be an important decision for every distribution company. The next part will summarize the whole paper.

6. Conclusion

There exists a wide variety of networking architectures that pay attention to different fields of Smart Grid. The networking architecture including physical and logical connections and topology is based on the particular utility that people are expected the most when design it. The development of networking technologies spurs the Smart Grid to become a more efficient, more robust and more reliable power system and plays an important role to support the communication within Smart Grid. Some problems about network security, communication and power demand in Smart Grid still need to be solved, though a few solutions have been come up with. The management of networking in Smart Grid is a key part to ensure the whole network work properly.

7. List of Acronyms

- 6LowPAN - IPV6 over LoW Power wireless Area Network
- ADR - Automated Demand Response
- ADSL - Asymmetric Digital Subscriber Line
- AMI - Advanced Metering Infrastructure
- BPL – Broadband over Powerline
- DCU - Data Control Units
- DEBS - Distributed Event-Based Systems
- DER - Distributed Energy
- DMS - Distribution Management System
- DSL - Digital Subscriber Line
- DSSS - Direct Sequence Spread Spectrum
- FHSS - Frequency Hopping Spread Spectrum
- FTTH - Fiber to the Home
- G.SHDSL - Group of Single-pair High-speed Digital Subscriber Line
- GbE - Gigabit Ethernet
- HAN - Home Area Network
- HFC - Hybrid Fiber-Coaxial
- HSR - High-Availability Seamless Redundancy
- HWMP - Hybrid Wireless Mesh Protocol
- IDSL - Internet Digital Subscriber Line
- IED - Intelligent Electronic Device
- IETF - Internet Engineering Task Force
- IR - Infrared
- ISO - Independent System Operators
- LAN - Local Area Network
- MDM - Meter Data Management
- MDMS - Meter Data Management Server
- MPLS - Multiprotocol Label Switching
- NAN - Neighborhood Area Network
- OSHAN - Open Source for Home Area Network
- OSI - Open Systems Interconnection
- P2P - peer-to-peer
- PHEV - Plug-In Hybrid Electric Vehicles
- PLC - Programmable Logic Controller
- PON - Passive Optical Network
- PSTN - Public Switched Telephone Network
- PTT - push-to-talk
- QR - Quick Removing
- RFoG - Radio Frequency over Glass
- RoIP - Radio over IP
- RTO - Regional Transmission Organizations
- SCADA - Supervisory Control and Data Acquisition
- SDH - Synchronous Digital Hierarchy
- SDSL - Symmetric Digital Subscriber Line
- SHDSL - Symmetric High-speed Digital Subscriber Line
- SM - Smart Meters
- SMS - Short Message Services
- SONET - Synchronous Optical Network
- TCP - Transmission Control Protocol
- VDSL - Very-high-data-rate Digital Subscriber Line
- VoIP - Voice over Internet Protocol
- VPN - Virtual Private Networks

- VRing - Virtual Ring
- VSAT - Very Small Aperture Terminal
- VVWC - Volt, VAR, Watt Control
- WDM - Wavelength Division Multiplexing

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