Hybrid Optical and Wireless Communication Networks for Energy Community

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Energy communities are important components for realization of the smart grid. A robust communication network architecture, which consists of network components of Home Area Networks (HANs), Neighborhood Area Networks (NANs) and Wide Area Networks (WANs) is the touchstone to achieve the goal of community-based power balancing. To satisfy the reliability and scalability requirements of energy community, a hybrid communication network architecture utilizing using 802.15.4-based Wireless Sensor Networks (WSNs), 802.11s-based Wireless Mesh Networks (WMNs) and Ethernet Passive Optical Networks (EPONs) is presented.

Keywords: Energy Community, Prosumer, Wireless Sensor Networks (WSNs), Wireless Mesh Networks (WMNs), Ethernet Passive Optical Networks (EPONs).

1. Introduction

The existing power grid is a hierarchical system in which power plants are at the top of the chain and loads at the bottom, resulting in a unidirectional pipeline managed without any information about the exchange among sources and end points. This situation has severe drawbacks: the system is sensitive to voltage and frequency instabilities as well as to power security issues caused by load variations and dynamic networks reconfigurations, the implementation of demand-side management strategies, very useful for reducing the risk of failures and blackouts and for increasing system efficiency is not allowed; moreover, it is not suitable for integration of renewable energy sources [1].

The smart grid is expected to address the major shortcomings of the existing grid. In essence, the smart grid is defined as the modern infrastructure of the electric grid, which has the objective to improve efficiency, reliability, and security. This is achieved through the control automation of the transmission and distribution lines, the enhancement of consumption metering technologies, the implementation of new renewable energy sources, and the introduction of new energy management techniques [2].

The decreasing cost of renewable distributed energy resources motivates individuals to install small-scale units at their premises. By deploying a solar...
panel or a wind turbine, a household can minimize its dependence on the main grid and eventually reduce its electricity bill. In this context, each household is both an energy consumer and an energy producer, i.e. a prosumer [3].

This paper considers an neighborhood energy community comprising prosumer households that are connected to a low-voltage grid. An energy community aggregator coordinates the load profiles in the neighborhood energy community and also represents the energy community when trading power with the rest of the grid.

Finding the best communication technology for an energy community is not straight forward, as the communication network in the demand response applications has to support information exchange among a large number of smart meters, intelligent electronic devices, sensors and actors without or very limited human intervention. Hence, our main focus in this paper is to investigate the communication network architecture to support the energy community in the smart grid.

2. Overview of the Energy Community

Smart grid achieves bidirectional energy and information flow between the energy user and the utility grid, allowing energy users not only to consume energy, but also to generate the energy and share the excess energy with the utility grid or with other energy consumers. Therefore, classic power producers and consumers are supplemented by prosumers in the smart grid. In current society, there are a considerable number of prosumers who produce renewable energy in their residential environment and share the surplus with the main utility grid [4].

A set of prosumers can be attached to a smart grid through dedicated technical infrastructure facilitating accumulated energy sharing between the groups of prosumers and the utility grid. Such prosumer groups are generally implemented through one of the two well-known technical infrastructures: Virtual Power Plant (VPP) and micro-grid. As pointed out in [5], several deficiencies are involved with prosumer groups that are formed through dedicated technical infrastructure (VPPs and micro-grid). The key deficiency is that this type of fixed architecture may result in inflexibility, which makes it complex to add or remove new members to the VPP/micro-grid. For instance, some prosumers may offer whatever amount of energy they can contribute, or prefer to contribute, leading to an unreliable energy supply to the energy buyers in the long term, ultimately resulting in negative morale toward the entire VPP or micro-grid-enabled prosumer group. In order to address the aforementioned deficiencies of existing prosumer groups, as well as to promote sustainable social aspects with regard to the prosumer management in the long-term, the concept of energy community groups has emerged.
Figure 1. The hierarchical architecture of the energy community.

Generally, an energy community is composed of networked prosumers located in a local geographic region. It is formed upon the agreement of participating prosumer household, with respect to local geographic, terrain, and zoning features [6]. Furthermore, the energy community may also be equipped with energy storage devices and distributed generation devices. The schematic diagram of the energy communities is shown in the Fig.1. The community level is the core of the energy community architecture, where a inter-home network is formed by prosumer household gateways and other metering gateways (represented by their smart meters). The role of the aggregator level is two-fold: i) to coordinate the load profiles in the energy community and ii) to represent the energy community when trading power with the rest of the grid.

3. **Smart Grid Communication Network**

The Smart Grid can be decomposed into the power system layer and communication layer. The power system layer is an integration of various electrical power generation systems, power transmission and distribution grids, substations, customers, and so on. The distinguishing feature of the smart grid, compared to the existing electrical grid, is the integration with a smart grid communication network, which is primarily responsible for monitoring, controlling, and automating the entire power grid. A variety of communication standards and technologies coexist in different communication networks of the smart grid. Basically, the smart grid network can be divided into three segments:
Home area networks (HANs), Neighborhood Area Networks (NANs) and Wide Area Networks (WANs).

HAN gathers sensor information from a variety of smart devices and DERs within the home and delivers control information to them for better energy consumption management. Due to the low-bandwidth requirements of HAN applications, it needs cost-effective communication technologies, such as Home-Plug, Wi-Fi, Bluetooth and ZigBee. Smart Meters (SMs) are installed in consumer sites and work as communication gateways that relay information between HANs and NANs.

NAN is established between data collectors and smart meters in a neighborhood area. To this end, short-range communication technologies, such as Wi-Fi and RF mesh technologies, can be used to collect the measured data from smart meters and transmit them to the data concentrator.

WAN aggregates data from multiple NANs and conveys it to service provider’s data center. It also enables the long-haul communications among different data aggregation points of power generation plants, distributed energy resource stations, substations, transmission and distribution grids, control centers, and so on. In general, the communication technology providing the best coverage with the lowest cost, such as LTE, cellular networks, fiber, power line communication networks, are widely adopted for WAN networks.

4. Hybrid Network Architecture for Energy Community

Energy Communities are important components for realization of the smart grid. In this article, our interest lies in the communication network architecture for energy community. To satisfy the reliability and scalability requirements of communication network, the combination of the HANs, the NAN and the WANs will be deployed for energy community. An illustrative communication architecture is shown in Fig. 2, where the HANs are constructed using 802.15.4 based wireless sensor networks (WSNs), the community NAN connecting the smart meters with aggregating gateway using 802.11s based Wireless Mesh Networks (WMNs), while the backhaul network are constructed using Ethernet Passive Optical Networks (EPONs).
IEEE 802.15.4 based WSNs are composed of a large number of low cost, low power and multifunctional sensor nodes that are small in size and communicate over short distances. As shown in the figure, the smart meter acts as the gateway of the HAN, it collects data from smart devices and invokes certain actions depending on the information it retrieves from the grid.

Community energy management usually concerns (i) load-shifting of energy consumption at different time points and/or (ii) load-adjustment by increasing or decreasing overall energy consumption. Community energy management system can be either centralized or decentralized. IEEE 802.11s is the standard for bringing multi-hopping capability to wireless LANs. This standard covers various functions, such as mesh discovery, peering, mesh path selection and forwarding. Hence, the IEEE 802.11s-based WMN is deployed for the community networking.

Due to its high bandwidth capacity and community characteristics, optical fibers will play an important role for the information network backbones in the smart grid. However, the installment cost of optical fibers such as SONET/SDH
may be expensive. In recent years, EPON has attracted a lot of interests from the communication community as optical fiber deployment and Ethernet technology make EPON very cost-effective. The EPON consists of one Optical Line Termination (OLT), multiple Optical Network Units (ONUs), and an Optical Distribution Network (ODN) with passive optical components. The backhaul communication network connecting community gateway with the utility’s backbone network is constructed using EPON. As shown in the figure, the star topology is adopted for the EPON.

5. Conclusion

This paper focuses on the communication network architecture of the energy community, where the network components of HAN, NAN and WAN communication systems are utilized. To satisfy the reliability and scalability requirements of energy community, a heterogeneous communication architecture using 802.15.4-based WSNs, 802.11s-based WMNs and EPONs is presented.

References