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Smart operations of smart grids integrated with distributed generation: A review

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ABSTRACT

In last few years, many countries in the world have shown huge interest in smart grid technology. They are facing many challenges in the process of deployment of this technology at ground level. Hence a planned research is required to meet those challenges within time. This paper provides a detailed description of progress in the field of demand side management, demand response programs, distributed generation, technical issues in the way of their progress and key advantages, which will be received after the final deployment of these programs. Renewable energy resources are also becoming a main part of distributed generation, which provides a solution for environmental problems caused by conventional power plants. Few countries are working on the deployment of the advanced metering system. Along with this, the scope of research in various programs of smart grid technology has been explored.

1. Introduction

Keeping in view today's consumer expectations and environmental concerns, it is necessary for the utilities to reduce the electricity bills of the consumers and to interconnect the green energy generation with the conventional energy generation at a large scale. Along with this, it is well known that day to day increasing demand is overloading the current electrical grids and conventional solution techniques are increasing the complexity of existing networks. These critical issues made the researchers to think about smart grid as an overall and better solution. To meet the distribution side consumer's expectations such as reduction in electricity bill, increasing comfort level, data security and reliability etc.; detailed study of smart grid components like demand side management, demand response, distributed generation, smart devices is required. Some technologies of the smart grid give direct exposure to the consumers thereby enabling them to check the current electricity price and in the response of the real-time price they are able to control their load. Thus the smart grid technology facilitates load shedding during the peak load time, as the price increases during the peak loads [1]. It can also make aware the consumers to reduce the electricity consumption. Some of the interfaces of smart grid technology are beyond the consumer's reach. Such interfaces are handled by the utilities for the sake of proper operation of the grid. Here proper operation means to maintain the balance in supply and demand. In the conventional power grids, with the integration of renewable generation, it is difficult to apply load following strategy [2]. Intermittent renewable energy resources like solar and wind generation can't be forecast with certainty [3]. Both solar and wind generation profile largely depend on weather conditions. These uncertainties create a problem in the calculation of bids necessary to take part in the day ahead unit commitment process. In [4], this problem is solved by using fuzzy optimization technique to limit the risk of uncertainty. In [5], the necessity of demand response programs and storage devices at a microgrid scale to overcome the problem of intermittency of wind and solar power generation is examined. Hence, as a solution to incorporate renewable energy resources (RERs) in the current power system, strategy of direct load control with the help of information technology can be used.

The remaining paper is organized as follows: motivation and objectives of the review are included in section 2. Smart grid technology and its role in the present electricity networks are discussed in section 3. Demand side management of electricity and its benefits for the consumers are discussed in section 4. Demand response, distributed generation and smart devices are discussed in detail in section 5, sections 6 and 7 respectively. Key points of the paper and observations from the review are included in section 8. The paper conclude in section 9.

2. Motivation and objective of the review

The review presented is inspired by the issue of continually increasing demand and price of electricity at the consumer end,

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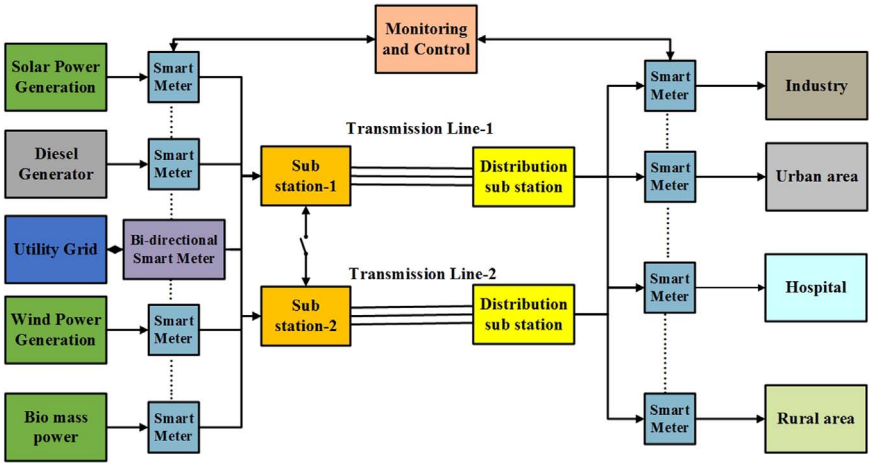

Fig. 1. Smart Grid model.

shortage of conventional energy sources, environmental problems caused by fossil fuel based energy generation plants and the issues related to the integration of renewable energy resources in the existing grid architecture. The objective of the review is to discuss in detail about the various smart grid components, their continuous development, technical challenges faced during their development, outcomes achieved and to find out the research scope in these areas.

3. Smart grid technology

A technology which is developed to maximize the benefits of utilities and its consumers and to provide the economic and reliable electricity services by efficiently using the available sources and smart tools is called smart grid technology. A smart grid is an intelligent network, which combines information technology with the current power system network [6]. Hence, it is possible for utilities to collect various electrical information from the electrical network using intelligent sensors and fast communication system which helps in balancing demand and supply [7]. A model of a smart grid is shown in Fig. 1.

The potential of smart grid network is very high as power grid is becoming complex and overloaded day by day. The infrastructure is getting old to support current energy requirement [8]. Demand during peak load hours is generally more than the supply from the grids. It causes power cuts, which is really a subject of worry. Power grids have different problems at different levels say generation, transmission and distribution [9]. Today, most of the power plants are using fossil fuel for the electricity generation. Therefore, environmental and economic challenges are also present in the power grids [10,11]. Authors in [12] have analyzed the economic and environmental impact of smart grid in detail. They presented their findings on the variation of cost estimation in this area. According to the author's findings, the definition of a smart grid is not still clear in the research papers in various journals. They found a common part in most of the definitions which help to get a clear definition of smart grid. The common part is application of digital processing and communication to the grid, making continuous data flow and information management control to the smart grid. They also found that if the analysis gap of the uncertainties related to estimates of environmental impacts and cost can be reduced, then more accurate results can be achieved. Coordination of latest technology with advance equipments converts a power grid to a smart grid. Smart grid technology is considered the best solution for the various problems of the power grids [13,14]. Smart grids enhance the use of renewable energy giving a solution to the environmental problems caused by electrical power plants [15,16]. The development process of smart grid technology has been discussed in [17]. This technology ensures high energy efficiency, continuity in energy flow, security and stability of the power system [17–21]. Various models are proposed for smart grids and the most suitable and reliable model is selected for the advancement of the power network [22]. Smart grid technology enhances the automation of distribution network, which is necessary to ensure the balance in supply and demand [23]. This contribution of smart grids helps in load shedding during peak load hours and results in an efficient electrical network. Thus, smart grid technology is the technology developed to meet the current energy expectations of the world efficiently and economically. Implementation of smart grid technology is also not an easy task. There are many challenges which occur during implementation. Authors in [24] presented some critical challenges in smart grid. Various issues related to measurement, sensing, information and communication technology, control and automation technologies, energy storage, power electronics have been discussed and a solution has been proposed. This paper has been also discussed about smart grid projects in Europe.

4. Demand side management

Every utility wants to avoid extra expenditure by installing more capacity to meet the daily increasing electricity demand. One way to achieve this goal is to use existing energy efficiently. Hence, utilities implement demand side management (DSM) programs to manage the energy consumption of the consumers [25]. So the main aims of DSM implementation can be listed as, to reduce the cost of electricity by managing energy consumption, social and environmental improvement, to increase reliability and to reduce the network issues. Energy management steps at different level of the power system are shown in Fig. 2.

DSM programs include different strategies such as demand response strategy, consumers (residential or commercial) load management strategy, energy efficiency strategy [26–28]. In the consumer load management strategy (mainly for the residential consumers) utility aims to reduce the consumption of electricity and to shift the peak hours demand to off peak hours [29]. Different load shape techniques can be seen in Fig. 3.

Consumption of electricity can be reduced by directly controlling the load by utility. When utility apply this approach to a residential consumer, there is always a concern of user's privacy. This acts as a barrier in implementation of this approach [31–35]. Other barriers in the way of implementing DSM programs are listed in [36]. These barriers can be omitted by using an alternative approach for consumer load control. In this approach, utility does not force a consumer to cut the load, rather it gives them options to reduce their electricity bill by managing their demand at different time of the day [37–39]. Utility uses changing price approach based on demand variation. It regularly conveys the electricity price information to the consumer through