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A survey on the contributions of power electronics to smart grid systems

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ABSTRACT

The smart grid (SG) as a research area is advancing dealing with a wider range of topics such as power systems, energy generation and telecommunication. The conventional utility grid is used to operate in a passive mode absorbing energy from the substations and delivering it to the customers. This approach is well developed but the needs of the state-of-the-art technology require a bidirectional flow of power and data. Nevertheless, smart grid systems provide more flexible, reliable, sustainable, secure and two-way communication service. Especially, integration of renewable energy sources, electrical vehicles and distributed generations (DG) into network can be achieved in an efficient way in smart grid systems. Moreover, control and monitoring capabilities, automatic configuration of the grid, and active involvement of consumers in energy production extend the importance of smart grids. All these positive aspects of smart grids have been attained by integration of power electronics and telecommunication technologies with the grid. This study deals with contributions of power electronics to SG in the context of generation, conversion, distribution, and control of power. The recent power electronic devices and systems adapted to SG are also introduced in detail with several power control methods.

Moreover, the renewable energy sources (RESs), which are an extensively studied topic of power engineering and their integration to smart grid, are also surveyed in terms of DG units, control and management features. Thus, a particular section is dedicated to RES utilization in SG covering almost all aspects of a monotype and hybrid energy plants. Finally, the survey is carried on by reviewing the most recent and comprehensive articles to highlight the importance of power electronics in a logical way in the smart grids for readers.

Contents

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1. Introduction

Smart grid (SG) is regarded as the next generation of conventional grids based on the fact of its two-way power and information flow capabilities. The term grid is used to define the energy facilities that manage all or some of the generation, transmission, distribution, control, and metering processes of the electricity. The main components of a conventional grid can be classified into five topics: electricity generation plants, transmission grid, distribution grid, control center, and end-users. The conventional grid is also required to be improved due to the technology development in the energy generation and distribution. Although the conventional grid has area for improvement such as voltage sags, blackouts, and overloads, the novel technologies are being researched in order to improve the performance of the current grid technology [1,2].

On the other hand, the SG is intended to perform these duties but also to facilitate the bidirectional operation of the distribution system. Furthermore, the modern communication technologies improved the SG by adding medium or high-speed data transfer specifications that are widely used in Internet and voice data transfer operations. Besides that, telecommunication infrastructures make the SG capable to perform remote metering and monitoring operations [2,3]. One of the SG definitions has been done by the Smart Grids European Technology Platform as “an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supply” [4]. In addition to this, the US Congress assigned several obligations to SG concept via Energy Independence and Security Act in 2007. Besides the precautions to be followed, there are several requirements of a modern SG that are also announced in the 10 mark list with this Act [5]. Moreover, Joint Research Centre (JRC) of European Commission announced a number of research and guidelines for smart grid projects. Members of the Smart Grids Task Force (SGTF) that was set up by the Commission at the end of 2009 have become expert on SG researches. It is noted in a report of JRC that the SG employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies [6]. The future demands directed to SG are

- creating a grid that is more efficient secure, reliable, and controllable to enhance the communication abilities,
- instant control capabilities and self-healing resources,
- easy integration of individual micro-generation units,
- fast distribution of smart technologies such as remote control, autonomous operating, sustainable and interactive communication, and
- integration of smart appliances and consumer devices [5,6].

Some other governmental regulations about SG are also announced all around the World. The SGTF of JRC defines a regulatory package named The Third Energy Package that aims to encourage the long-term modernization of the European grids across Europe through the introduction of smart meters and SGs. The initial efforts among regulatory authorities, regulated companies, end users and technology providers are intended to be coordinated at European level to establish harmonized and cost-efficient policies and regulations to avoid duplication of work and exploit synergies among them. These regulations are basically focused on generation, transmission, distribution, control, metering and communication subjects in order to obtain more reliable, self-healing, efficient and secure grid infrastructures [1,6–9]. Almost all aspects of the SG that are mentioned above are aimed to be reviewed by constructing hierarchical and logical relations through the subjects in this survey study. Furthermore, the study is focused on the review of distributed generation with renewable and their integration to SG, utilization of power electronics in smart metering and monitoring stages, and alternative communication applications performed in smart monitoring infrastructure. Although there are several surveys on existing SG studies, this paper focuses on power electronics and renewable energy sources (RESs) integrated to SGs.

The organization of the survey contains overview of SG concept with detailed introduction in Section 2. Power electronics, device technologies and their involvements in to SG are comprehensively introduced in Section 3. Section 4covers the RES integration into SG with generation, storage, control, smart measurement and monitoring facilities.

2. Overview of smart grid concept

One of the greenhouse gas emissions' reduction tools is the increased utilization of production from renewable energy sources (RESs) fed to the grid. However, the integration of RES brings several challenges such as dynamic stability issues, the need of more complicated operating processes, and additional remote control together. Since the conventional grid has an infrastructure not ready to accommodate the RES, it is difficult to meet these requirements where this situation caused to construct smarter grid structures [1,10,11]. The modernizing requirements of the actual grid are not only focused to the renewable energy sources but also to the different types of distributed generation sources (DGS) that are connected to the current grid and other technologies such as plug-in hybrid electrical vehicles (PHEV) that would cause load profiles modifications [12–14]. According to the current situation, the primary idea of a SG concept is going to be met with advanced metering infrastructure (AMI) with the aim to provide an efficient energy management technology. Although the most widely used remote control and metering interface on the Transmission level is *Supervisory Control and Data Acquisition* (SCADA) system, there are going to be more widely applied information and communication technologies (ICT), which are based on wired and wireless mediums, proposed and installed under the AMI coverage [15,16].

A comprehensive outlook of a smart grid infrastructure is illustrated in Fig. 1 that is reproduced from [17]. The distributed generation (DG) units are represented such as offshore wind farm, solar plants, fossil fuel based power plants, and power-heat coupling units that may be usually found in any extended grid scenario. The SG infrastructure manages the generation parts of this scenario by remote monitoring and control subsystems that are considered as an “intelligent node” where the AMI or SCADA-like operations are executed. A dedicated data center is usually operated to supervise the transmission and distribution networks. Another constituent of SG scheme involves smart homes and intelligent buildings through smart metering with their microgrids and several loads such as household electronics and electric vehicles (EVs) [18]. All these components require an accurately