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Microgrid: Architecture, policy and future trends

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ABSTRACT

Future electricity network must be flexible, accessible, reliable and economically viable to realise the aims of the smart grid initiative. In order to achieve these objectives and to reduce greenhouse gas (GHG) emissions, research on various configurations or architectures of microgrid (μGrid) systems is gaining greater attention. This is occurring in step with increasing penetration of Renewable Energy Sources (RES) such as solar, wind and other micro-sources. Energy storage can also be a part of the μGrid architecture to ensure more stable and sustainable operation. The techno-economic viability of the μGrid system is also a point of concern. Again, the variable and uncontrollable behaviour of RES can also introduce power quality problems. To improve the systems reliability, efficiency and power quality, different μGrid architectures are introduced. Complex control of the μGrid controller is helping to overcome these conditions. In that case, integration of Custom Power Devices is also playing an important role. Therefore, μGrid policies should also deal with these issues in the light of future trends towards the Smart Grid. This paper presents a literature review, based on various existing and/or simulated μGrid architectures. In relation to the reliability, efficiency and power quality issues, different distribution systems have been introduced. The advantages and disadvantages of these configurations are discussed here. The benefits of RES and its associated power quality problems have been identified. The benefits of energy storage systems and the development of communication systems towards the stable, flexible and efficient operation of smart grids are also reviewed. Findings have been outlined and then the policies with future trends of μGrid are also discussed.

Contents

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1. Introduction

Most of the large power generation systems rely on conventional energy sources such as coal, natural gas and oil, each of which have a more or less negative impact on the environment. Furthermore, as long-distance, high-voltage transmission lines carry power to the customers from centralized generation sources, transmission losses are unavoidable. The increasing demand for clean, reliable and affordable electrical energy is changing the existing scenario for electricity generation. The realization of the concept of the μGrid has the potential to deliver an innovative, economic and environmentally friendly solution. One of the major aims of the μGrid is to combine the benefits of non-conventional/renewable, low carbon generation technologies and high efficiency combined heat and power (CHP) systems. The choice of a DG technology mainly depends on the climate and topology of the region.

The μGrid embodies the concept of a single organized power subsystem comprising a number of distributed generation (DG) systems, both renewable (such as photovoltaic, wind power, hydro and fuel-cell devices) and/or conventional generation (such as internal combustion engines, micro-turbines and diesel generators) and a cluster of loads [1]. The application of an individual DG system is also possible, which is termed micro-generation (μGen). This can cause a number of problems such as local voltage rise, the potential to exceed thermal limits of certain lines and transformers, islanding problems and high capital costs. μGrid can be a better solution for those problems. Some of the benefits of μGrid, including enhanced local reliability, reduced feeder loss, better local voltage support, increased efficiency, voltage sag correction or uninterruptible power supply function are also reviewed in [2,3]. In μGrid, the DG system must be equipped with proper power electronic interfaces (PEIs) and control to ensure the flexibility to operate as a single aggregated system maintaining the power quality and energy output. μGrid central controller takes the leading role for satisfactory automated operation and control of μgrid while working in grid connected and islanded modes. Detailed of controller types and advancement in control technologies has been reviewed in [4]. From the grid point of view, the main advantage of the μGrid is that it is treated as a controlled entity within the power system which can operate as a single load. From the customer point of view, this μGrid can meet their electrical and heat requirement locally, can supply uninterruptible power, improve local reliability, improve PQ, reduce feeder losses and provide voltage support [5]. Furthermore the μGrid can reduce environmental pollution and global warming through utilizing low-carbon technologies.

Large scale penetration of distributed generation systems may cause also instability and thus it introduces a negative impact on the distribution grid or μGrid [6]. The aspects of stability in μGrid are also revised in [7]. Therefore control and operational strategies for individual and integrated distributed generation systems are highly important and these also have been studied in [8]. On the other hand, to avoid the grid voltage fluctuation or black outs at any time instant, the electric grid should be able to balance the power between the production and consumption. The power adjustment ensured by the excess capacity in stand-by mode, could be reduced if the peak consumption is shifted. Strategies for power management are being developed for a robust and reliable utility grid which can assist power balancing and avoid undesired injection and can perform peak shaving during peak hours [9]. To achieve this configuration, Smart Grid has been created that employs intelligent monitoring, control communication and self-healing technologies. Smart grid has mainly the following features: bidirectional power flow, bidirectional communication and reduces mismatch between production and demand [10]. As the concept of μGrid is for better penetration of RE in the existing grid that can help in energy management in more controlled way, can help in peak shaving and can reduce energy cost, it (μGrid) is considered as one of the possible approaches to develop a Smart Grid system [11]. This also depends on the design architecture of μGrid systems. In that case, understanding and predicting the impact of geographical location, resource availability and load demand on μGrid design is a must [12].

In recent years, emphasis has been placed on renewable energy based μGrid systems because of their advantages over μGen systems in terms of stability, reliability and economics. Different types of architectures and control strategies have been practiced (in real scale, test-bed or simulating platform) worldwide to achieve some specific goals. However, the commercial development of the μGrid system has not yet progressed significantly. The most common barriers were identified and grouped into four categories: technical, regulatory, financial and stakeholder [13]. Another obstacle is that these are not included properly in the national energy policy. Along with these, the policies relating to the implementation of μGrids differ from country to country. Most countries have not developed policies as yet and thus the goals for introducing μGrids as part of the existing electrical distribution network are not established. Power quality issues related to DG connected grid network are also a matter of concern. Reviews have already been done in different literatures and published papers with a focus on a specified part of the μGrid system. These include AC and DC technologies in μGrid systems, hybrid structures, islanding techniques, detailed in control with hierarchy approach and progress in protection. These are referred in the relevant sections of this paper.

Therefore, for integrating μGrid into the existing grid or to the future Smart Grid Network, this paper starts with the review of existing and simulated μGrid architectures that have been developed and studied to date. This study helps to identify the (i) basic structure and architecture of μGrid systems including the types of DG sources and storage, controller, power quality improvement and communication systems that have been used, (ii) operating policies and (iii) goals that have been achieved. Section 2 summarize this study by formatting a table for existing μGrid test-beds available in the literature together with their operating policies and goals. Based on the study, the basic μGrid architecture is divided into four parts (distribution systems, DG sources, storage, control and communication) that have been presented in Section 3. A brief overview along with the advantages and disadvantages of different distribution systems, DG sources including their power quality issues, storage systems and communication technologies