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Operation and control of a hybrid microgrid containing unbalanced and nonlinear loads

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ABSTRACT

This paper shows how the power quality can be improved in a microgrid that is supplying a nonlinear and unbalanced load. The microgrid contains a hybrid combination of inertial and converter interfaced distributed generation units where a decentralized power sharing algorithm is used to control its power management. One of the distributed generators in the microgrid is used as a power quality compensator for the unbalanced and harmonic load. The current reference generation for power quality improvement takes into account the active and reactive power to be supplied by the micro-source which is connected to the compensator. Depending on the power requirement of the nonlinear load, the proposed control scheme can change modes of operation without any external communication interfaces. The compensator can operate in two modes depending on the entire power demand of the unbalanced nonlinear load. The proposed control scheme can even compensate system unbalance caused by the single-phase micro-sources and load changes. The efficacy of the proposed power quality improvement control and method in such a microgrid is validated through extensive simulation studies using PSCAD/EMTDC software with detailed dynamic models of the micro-sources and power electronic converters.

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1. Introduction

The ever increasing energy demand, along with the necessity of cost reduction and higher reliability requirements, are driving the modern power systems towards distributed generation (DG) as an alternative to the expansion of the current energy distribution systems [1]. In particular, small DG systems, typically with power levels ranging from 1 kW to 10 MW, located near the loads are gaining popularity due to their higher operating efficiencies. Fuel cells (FCs), photovoltaic cells (PVs), batteries, micro-turbines, etc. are nowadays the most available DGs for generation of power mostly in peak times or in rural areas [2].

A diesel generator set (genset) consists of an internal combustion engine, exciter and a synchronous generator coupled on the same shaft. Such systems are widely used as backup or emergency power in commercial as well as industrial installations. Diesel gensets are also extensively used in remote locations where no utility supply exists [3]. Over the last few decades, there is a growing interest in FC system for power generation and it has been identified as a suitable solution for distributed generation [4]. Other than FC, the use of new efficient PVs has emerged as an alternative measure of renewable green power, energy conservation and demand side management [5].

Microgrids are systems with clusters of loads and micro-sources. To deliver high quality and reliable power, the microgrid should appear as a single controllable unit that responds to changes in the system [6]. The high penetration of DGs, along with different types of loads, always raises concern about coordinated control and power quality issues. In microgrid, parallel DGs are controlled to deliver the desired active and reactive power to the system while local signals are used as feedback to control the converters. The power sharing among the DGs can be achieved by controlling two independent quantities—frequency and fundamental voltage magnitude [7–9].

General introduction on microgrid basics, including the architecture, protection and power management is given in [10]. A review of on going research projects on microgrid in US, Canada, Europe and Japan is presented in [11]. Different power management strategies and controlling algorithms for a microgrid is proposed in [12]. Refs. [13–16] have evaluated the feasibility for the operation of the microgrids during islanding and synchronisation. An algorithm was proposed in [17] and used for evaluation of dynamic analysis for grid connected and autonomous modes of the microgrid. In [18], it is shown that a proper control method of distributed resources can improve the power quality of the network. There are still many issues which are needed to be addressed to improve the power quality in a microgrid.

The power quality issues are important as the power electronic converters increase the harmonic levels in the network voltage and current. Unbalance loads can cause the current and hence

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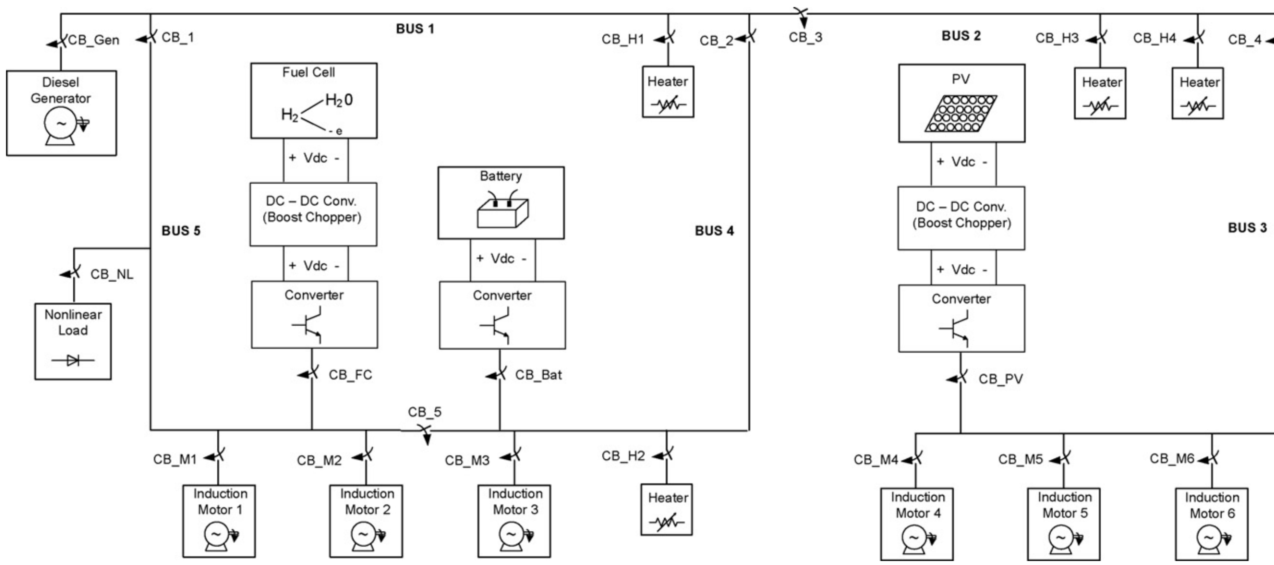

Fig. 1. Schematic diagram of the microgrid structure under consideration.

the voltage of the network suffering from high values of negative sequence which can be a problem for all induction motor loads in the network. Nonlinear loads (NL) can increase the harmonic level of the network current and voltage, which will increase the loss and reduce the efficiency of the network [19,20]. On the other hand, a power electronic converter can mitigate harmonic and unbalanced load or source problems. In [20] a series-shunt compensator is added in microgrid to achieve an enhancement of both the quality of power within the microgrid and the utility grid. The compensator has a series element as well as a shunt element. The series element can compensate for the unwanted positive, negative, and zero sequence voltage during any utility grid voltage unbalance, while the shunt element is controlled to ensure balanced voltages within the microgrid and to regulate power sharing among the parallel-connected DG systems. The proposed method in [20] requires adding other converters, while the same power quality improvement objectives can be achieved by one of the existing converters in the microgrid as proposed and validated in this paper.

To investigate the operation of all the micro-sources together, a microgrid test bed is planned to be established at Queensland University of Technology (QUT) where issues such as decentralized power sharing and enhanced power quality operation will be tested. The QUT conceptual system with the technical parameters of its micro-sources will be used as the test system in this paper.

One of the main contributions of the paper is the formulation of the compensator reference both when the compensator is able to supply the entire nonlinear load and when it is not. Furthermore, the compensator not only compensates the nonlinearity in the system but also shares power with other sources in the microgrid. In addition, inclusion of dynamics of the micro-sources validates the feasibility of power sharing among inertial and converter interfaced micro-sources. Finally, the paper demonstrates how to compensate the single-phase residential loads that maybe connected to the microgrid.

In this paper, the power quality enhanced decentralized power sharing is investigated in an autonomous microgrid with inertial and converter interfaced micro-sources. To investigate the system response with the dynamics of the DGs, the micro-sources and all the power electronic interfaces are modelled in detail. One of the converter interfaced sources is used as the compensator of the nonlinear and unbalanced load while the other DGs share the system load proportional to their rating based on droop control. The compensating DG can work in different operational modes depending on the power requirement of the local nonlinear load from just supplying a part of the nonlinear load to sharing some power of the microgrid loads while functioning as a compensator. Also, the compensation principle is tested on a low voltage residential distribution network that is connected to the microgrid. It is assumed that this low voltage network supplies single-phase residential loads with few installed PVs, connected at different phases. The efficacy of the proposed control scheme is validated through PSCAD/EMTDC simulation studies.

2. Microgrid structure

The schematic diagram of the microgrid system under consideration is shown in Fig. 1. There are four DGs as shown; one of them is an inertial DG (diesel generator) while others are converter interfaced DGs (PV, FC and battery). There are four resistive heater loads and six induction motor loads. A nonlinear load, which is a combination of unbalance and harmonic load, is also connected to BUS 5 in the microgrid. The FC will be used as the compensating DG for power quality improvement in this structure since it is the closest among all the converter interfaced DGs to the nonlinear load and connected to the same bus. If the nonlinear load was connected to BUS 3 or 4, the PV or battery should be used as the compensating DG. A discussion on the compensator location and the criteria for its placement is given in Appendix A. The parameters of the microgrid, loads, DGs and their converters are given in Appendix B. In this paper, the autonomous operation mode of the microgrid is studied.

3. Droop control method in microgrid

In this section, the power sharing method in the microgrid is discussed. The decentralized power sharing among the DGs is achieved by the use of conventional droop control [7,8] as

$$\begin{aligned} \omega &= \omega_s - m(P - P_{rated}) \\ V &= V^* - n(Q - Q_{rated}) \end{aligned} \tag{1}$$

where m and n are the droop coefficients taken proportional to rated power of DGs for power sharing among them, ω_s is the synchronous frequency, V^* is the nominal magnitude of the network voltage, V is the magnitude of the converter output voltage and ω is its frequency, while P and Q respectively denote the active

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