Electrical Power and Energy Systems 65 (2015) 70–75

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A novel three-phase four-leg inverter based load unbalance compensator for stand-alone microgrid

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ARTICLE INFO

Article history:
Received 27 September 2013
Received in revised form 16 September 2014
Accepted 22 September 2014
Available online 11 October 2014

Keywords:
Microgrid
Power quality
Load unbalance
Three-phase four-leg inverter

ABSTRACT

This paper proposes a three-phase four-leg voltage sourced inverter (VSI) based load unbalance compensator (LUC) including its control algorithm, which is a component of a microgrid. The purpose of proposed three-phase four-leg VSI based LUC is to improve power quality of the standalone microgrid. Power quality of the microgrid which was installed in Mara-island, Korea is analyzed using a real operational data. In this work, the microgrid in Mara-island which includes a photovoltaic power generation system, a diesel generator, a battery energy storage system, and a power management system is modeled in PSCAD/EMTDC, and proposed three-phase four-leg VSI based LUC is also modeled and applies to the modeled microgrid. Power flow and stability of the modeled microgrid with the LUC is analyzed under variable irradiance and unbalance loads. The results show that the proposed LUC helps to improve stability of the stand-alone microgrid. The proposed three-phase four-leg VSI based LUC and its control algorithm can be effectively utilized to the stand alone microgrid which has large unbalance loads.

Introduction

A distributed generator (DG) such as photovoltaic, wind power, and geothermal is one solution to the energy demand growth and limitation caused by global warming and fossil fuels shortage. However, the power system have encountered with many problems such as increasing of complexity and changing protection rules caused by the increase of DGs. To overcome these problems, a microgrid concept was introduced which is defined as a cluster of DGs [1,2]. The microgrid consists of diesel generators, micro-turbines, wind generators, photovoltaic (PV) generation systems, local loads, and so on [3]. These DGs are managed by a power and energy management systems, which offers many advantages such as peak load shaving, reliability against the utility faults, and high power quality [4,5].

There are two different types of microgrids: grid-connected microgrid and stand-alone microgrid [6]. The grid-connected microgrid can operate either a grid-connected mode or an islanding mode. The efficient operation is the key control issue in the grid-connected mode, and the voltage and frequency control is main issue in the islanding mode when the microgrid disconnects from the utility under abnormal condition [3]. In the case of the stand-alone microgrid, it is always operates in the islanding mode without the grid-connected mode, because it is usually installed in the remote country from the city such as mountainous areas or island without power grid [7].

The stand-alone microgrid for the remote country may be small scale, and has a low voltage distribution network, in which there is the increased likelihood of significant load imbalance between phases. It causes voltage imbalance which can be problem for equipment of the microgrid such as motors [8–10]. Moreover, imbalance current of microgrid causes unclearness of power management system (PMS) because components of microgrid are three-phase three-leg voltage sourced inverter (VSI).

The imbalance compensation method is proposed using three phase three leg VSI for the islanding network in [11]. The negative-sequence conductance is controlled to compensate for the voltage unbalance in [12]. The control methods well compensate voltage unbalance using the three phase three wire VSI in [11,12]. However, it does not solve the unclearness problem of the PMS.

The control strategy for an islanded microgrid under unbalance conditions is presented in [13], a negative-sequence output impedance controller is adapted to the three wire DG. The control method for power quality enhancement using the three-phase four-leg VSI is presented in [14]. However, two inverters are necessary for the power injection and unbalance compensation.

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http://dx.doi.org/10.1016/j.ijepes.2014.09.035
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A hierarchical control scheme for unbalance voltage compensation is adapted in [15]. The reference signals for compensation are transmitted to DGs through low bandwidth communication link. The scheme in [15] which uses each DG in microgrid can solve the voltage unbalance problem in islanded mode. However, it is also difficult to solve the unclearness problem of the PMS when the line impedance is small, especially in the case of the small-sized stand-alone microgrid.

This paper proposes a novel load unbalance compensator (LUC) for the stand-alone microgrid using three-phase four-leg VSI, which is connected in parallel with a diesel generator. The concept of the proposed compensator approaches the unbalance currents as opposed to the unbalance voltage. In the case of the existed microgrid, the unbalance currents of the loads is usually supplied by the diesel generator, because the three-phase three-wire based DGs are impossible to inject unbalance current. The proposed system directly compensates unbalance currents of the diesel generator under unbalanced conditions. For verifying effectiveness of the proposed system, the Mara-island's microgrid in Korea including three-phase four-leg VSI based LUC is modeled and analyzed in PSCAD/EMTDC. The microgrid includes a photovoltaic (PV) power generation system, a diesel generator, a battery energy storage system (BESS), and power management system (PMS).

This paper is divided into five sections. 'Modeling of Mara-island's microgrid in Korea' describes the Mara-island's microgrid and how to modeling it using PSCAD/EMTDC. In 'Three-phase four-leg inverter based load unbalance compensator', the control strategy of the three-phase four-leg VSI based LUC is explained. The simulation results are shown and discussed in 'Simulation results and discussion and Conclusions' is the conclusion.

Modeling of Mara-island's microgrid in Korea

Fig. 1 shows configuration of the Mara-island's microgrid in Korea, which is used for case studied. The microgrid is composed of a 380 V, one-feeder distribution subsystem, which is the stand-alone system far away from utility network. It consists of a diesel generator, a PV generation system, a BESS, a PMS, and unbalance loads. These systems are connected to 380 V low voltage line. The parameters of each component in the microgrid are shown in Table 1. The loads of the microgrid usually vary from 40 kW to 120 kW.

The microgrid is modeled in PSCAD/EMTDC, which has a control problem of power management caused by unbalance load. The purpose of simulation model is to reenact the actual case using real operation data. In the case of the modeled 150 kW PV generation system as illustrated in Fig. 2, the current source is used. The power of the current source is controlled to actual output power data. A d–q transformation control is used for enabling independent control of the active and reactive power. A typical synchronous generator model in PSCAD/EMTDC library is used to represent diesel generator, which is equipped with a simplified 1st-order model of exciter and governor [16]. The BESS is also modeled by using the current source. The power reference of the BESS is calculated by PMS as depicted in Fig. 1.

The purpose of PMS is a high efficient operation of diesel generators and stability of the microgrid. Diesel generators are inherently inefficient when operated at light load, and which can also shorten their lifetime and result in high maintenance costs [17]. The PMS calculates the power reference of BESS in order to maintain the active power of the diesel generator between minimum and maximum value. As shown in Fig. 3, the droop control is applied to the PMS for avoiding power oscillation, and the droop gain is set to $k_p = 2$.

Three-phase four-leg inverter based load unbalance compensator

The structure of three-phase four-leg VSI for the proposed LUC is shown in Fig. 4, which is composed of a dc-link capacitor, a four-leg inverter, and LC filters. The output of the proposed LUC is connected to the microgrid. The operation scheme for the LUC consists of three main blocks, namely control algorithm for determining current reference, current controller, and strategy to generating PWM. The following subsections describe the functionality of each block in more detail.

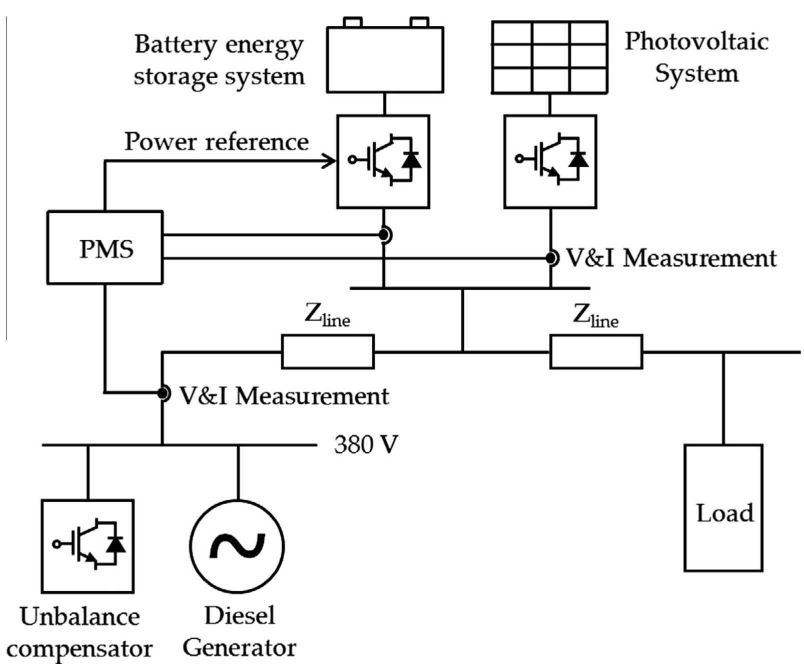

Fig. 1. Configuration of the Mara-island's microgrid in Korea.