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Distributed generation system control strategies with PV and fuel cell in microgrid operation

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ABSTRACT

Control strategies of distributed generation (DG) are investigated for different combination of DG and storage units in a microgrid. In this paper the authors proposed a microgrid structure which consists of a detailed photovoltaic (PV) array model, a solid oxide fuel cell (SOFC) and various loads. Real and reactive power (PQ) control and droop control are developed for microgrid operation. In grid-connected mode, PQ control is developed by controlling the active and reactive power output of DGs in accordance with assigned references. Two PI controllers were used in the PQ controller, and a novel heuristic method, artificial bee colony (ABC), was adopted to tune the PI parameters. DGs can be controlled by droop control both under grid-connected and islanded modes. Droop control implements power reallocation between DGs based on predefined droop characteristics whenever load changes or the microgrid is connected/disconnected to the grid, while the microgrid voltage and frequency is maintained at appropriate levels. Through voltage, frequency, and power characteristics in the simulation under different scenarios, the proposed control strategies have demonstrated to work properly and effectively. The simulation results also show the effectiveness of tuning PI parameters by the ABC.

1. Introduction

A microgrid is a system that aggregates generators, consumers, energy storage devices and hybrid devices such as electric vehicles which are able to both produce and consume energy. In general, microgrid is considered as a localized grid where a cluster of distributed generators (DGs) are connected to the main utility grid, usually through voltage source converter (VSC) based interfaces (Cho et al., 2011). The key factor of microgrid is that it can be disconnected from the main grid, operating autonomously to enhance the resiliency of the power grid. Distributed generation (DG) technologies, such as photovoltaics (PV), wind energy, fuel cell, storage system, etc., are the main parts in microgrid (Puttgen, MacGregor & Lambert, 2003).

DGs encompass a wide range of technologies, such as wind power, micro turbines, internal combustion engines, gas turbines, photovaltaics (PV), fuel cells, and storage systems. However the challenges rise up at the same time in controlling a potentially huge number of DGs, and operating the network safely and efficiently (Hatziargyriou, Asano, Iravani & Marnay, 2007). This challenge can be partially addressed by the proper design and control of power electronic devices. (Ebad & Song, 2012). For example, if a PV system needs to be connected to the grid, a converter which converts the output voltage to a certain voltage level and an inverter which transfer the DC voltage to three-phase AC are needed. The interface between distributed generators and grid is called power conditioning system which places a vital role of regulating high quality power that injects to the grid (Wu, Lee & Yang, 2013). Microgrid can operate in two modes: grid-connected mode and islanded mode. In normal grid-connected mode power will be supplied to loads either though the main grid or the microgrid; however when there is a failure in the main grid, microgrid will disconnect itself from the grid and operate in an islanded mode.

Different from traditional utility grid, a microgrid contains DGs through VSC to interface with utility. The VSC have more controlled variables than the commonly used synchronous generators (Tan, So & Chu, 2010). Thus one of the key problems in microgrid operation is to determine control strategies. When load changes or disconnection occur, controllers need to coordinate DGs to guarantee power quality and meet the demand in the microgrid. In Cai and Mitra (2010), decentralized control using multi-agent systems approach is implemented by using only the local information of DGs. The decentralized architecture of the microgrid is equipped with power electronic devices and all the agents are working autonomously and equally. The agents only communicate with their neighbors to achieve power balancing to maintain voltage and frequency. However this method requires large amount

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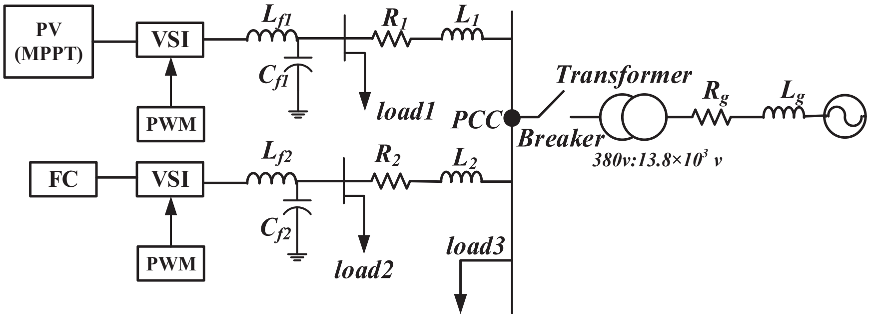

Fig. 1. Schematic of a microgrid, which is powered by a PV and FC and connected to the main power grid at PCC. The circuit breaker indicates the status of grid-connected mode and islanded mode of operation.

of communication, which increases the complexity when implemented for control.

In (Barsali, Ceraolo, Pelacchi & Poli, 2002) voltage and frequency (*V*/*f*) control was implemented to control DGs in an islanded mode by maintaining voltage and frequency at references. However pure *V*/*f* controller for DGs in islanded mode is not able to respond to load changes, thus in Chen, Wang and Wang (2013), a master–slave control configuration of a microgrid is built. In grid-connected mode all DGs are equipped with PQ controllers, and under islanded mode only the master inverter switches to *V*/*f* control to maintain the microgrid voltage level and frequency. The drawback of master–slave method is that it also takes large amount of communication. In practical microgrid operation, controllers for different types of DGs vary extensively. For example, micro turbines and fuel cell can be equipped with either PQ controller to follow real and reactive power references or *V*/*f* controller to maintain stability of microgrid's voltage and frequency; however for renewable energy DGs such as wind turbine and PV, due to their intermittency, PQ controller will have to be used to maximize renewable energy.

The use of droop characteristics concepts is commonly used in controlling generating units in power system (Kundur, 1993). In terms of the interfacing a microgrid to the utility grid, DGs should achieve proper load sharing. By retrieving the grid parameters such as the voltage, frequency, grid impedance, the inverters based on droop control method are able to inject real and reactive power to the grid (Vasquez, Guerrero, Luna, Rodriguez & Teodorescu, 2009). A detailed hierarchical droop control strategy has been proposed to manage power between distributed generation and grid (Guerrero, Vasquez, Matas, Vicuna & Castilla, 2011). In order to enhance dynamic performance of parallel inverters, researchers have developed a novel droop control method by utilizing the locally measureable feedback signals (Guerrero, Vicuna, Matas, Castilla & Miret, 2004). We want to implement a load sharing with minimal communication because of the complexity of network system and thus droop control method is adopted in this paper. Both PV and DG were carried out with PQ control in grid-connection mode, while they were switched into droop control once disconnected from the grid.

In order to operate microgrid under both modes effectively by satisfying the load demand and voltage/frequency stability, while minimizing the communication between DGs in microgrid control, a PQ controller and droop controller are adopted in this paper. The control strategies presented here is to overcome the drawback of pure *V*/*f* control which leads to the failure of responding to load changes while requiring less communication compared to the master–slave control. PI controllers are the most common solution in industry (Sun, Li & Lee, 2015), and they were used in both PQ and droop controllers. However, the tuning process, in many cases, is made by extensive trial and error approaches, which is very time-consuming (Kishnani, Pareek & Gupta, 2014). To tackle the problem, we proposed a novel heuristic method, artificial bee colony (ABC), to find the optimal PI parameters. The main advantage of heuristic method is that without the complete information of system and the knowledge of tuning parameters it is able to find optimal parameters by intelligent search process.

The paper is organized as follows: Section 2 describes the proposed architecture of the microgrid, and PV model, the solid oxide fuel cell (SOFC) and controller design process was described in Section 3. In Section 4, ABC is introduced first and the implementation of ABC to PI parameters tuning is presented. The performance of the proposed controller is tested and results are shown in simulation in Section 5. Finally the conclusion is drawn in Section 6 with recommendation for future works.

2. Microgrid architecture

In order to test the effectiveness and efficiency of controllers, a microgrid structure is developed as shown in Fig. 1. The microgrid contains one PV array and one SOFC. The PV provides DC voltage, and MPPT was implemented to obtain the maximum power reference for PV.

In Fig. 1, PV and FC are connected to voltage source inverters (VSI) controlled by pulse width modulation (PWM) controller. The VSI converts DC voltage to AC voltage and then the power go through a low pass LC filter to filter high frequency noise. Load 1 and load 2 are connected to PV and FC after filters, respectively, and load 3 is connected at the point of common coupling (PCC). DGs are connected to the main grid through transmission line, circuit breakers and transformers. The voltage ratio of transformer is $380{:}13.8 \times 10^3$ (v). Note that both PV and SOFC implements PQ controller under grid-connected mode and droop controller can be implemented under either grid-connected or islanded mode. In this paper the PV was modeled as a current source in parallel with an ideal diode. The SOFC is a dynamic model characterizing relationship between the input fuel and output voltage.

3. PV model and controller design

3.1. PV model

The main component of a solar panel is a solar cell. A single solar cell can be modeled as a current source connected with one diode and two resistors (Fig. 2). A photovoltaic (PV) module is built by simply connecting many solar cells in series and parallel.

The characteristic equation for a single solar cell can be found in the paper of Villalva, Gazoli and Ruppert (2009):