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Real time implementation and optimal design of autonomous microgrids

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ABSTRACT

In this paper, an autonomous microgrid including current, voltage and power controllers, inverter-based distributed generation (DG) units, coupling inductance, LC filter, lines, and loads has been developed and implemented on real time digital simulator (RTDS). The optimal settings of the PI controllers and power sharing coefficients to enhance the autonomous microgrid stability have been also implemented. Non-linear time domain simulation is carried out to minimize the error in the measured power to improve the damping characteristics and to assess the effectiveness of the proposed controllers under over-loading condition, fault and step change disturbances. The results show satisfactory performance with efficient damping characteristics of the considered autonomous microgrid equipped with the proposed controllers. The considered autonomous microgrid with its controllers has been examined in real time using RTDS. The performance of three inverter-based DGs of the considered autonomous microgrid with the proposed controllers has been verified on RTDS. The experimental results confirm the effectiveness of the proposed controllers to enhance the stability of the microgrid considered.

1. Introduction

Nowadays with the fast growing concern over greenhouse gas emissions and other environmental issues, DG sources such as wind, photovoltaic (PV), micro turbines and fuel cells are being connected rapidly to the electricity network [1–4]. Most of DG units have been interfaced using power electronics to facilitate the operation and control of DGs [5]. Connecting multiple customers with multiple DG sources and storage units is defined as micro-grid [6]. Microgrid operates in autonomous mode as well as grid connected mode [7–11]. In the grid connected mode, the micro-grid is used to improve the dynamic response of the utility. For example, a grid connected PV is connected at the end of transmission line to improve the supply power quality and to stabilize line voltage [4]. On the other side, autonomous microgrid is used to support the loads which are far away from center stations to eliminate the cost of the long transmission lines [11]. Control and dynamics of DGs are the most important microgrids aspects as several control strategies have presented to control the inverter-based DGs in both modes [12–16]. In the autonomous mode, current, voltage and power controllers are generally used to control the DG. The voltage and current PI controllers are implemented to damp the output filter and reject high frequency disturbances to avoid resonance with the external network [11]. The droop power controller is utilized to share the powers between DGs. The behavior of the inverter of the DG is similar to the synchronous machine behavior where the voltage magnitude depends on reactive power, while the power angle depends mainly on real power. So the voltage magnitude of the microgrid can be obtained by adjusting active power while the frequency can be adjusted using the reactive power. The stability is affected by power sharing coefficients and PI controller parameters [7]. In general, selection of the power sharing coefficients and controller parameters carefully will promote the system performance against disturbances and load changes. Recently, this problem has been solved using trial and error methods where the researchers tried to study the effect of changing power sharing coefficients and the controller parameters on the microgrid stability [17,18]. Heuristic techniques such as genetic algorithm and particle swarm optimization (PSO) have been used to solve the trial problems [19]. PSO has been considered as one of the favorable optimization technique due to its robustness, computational efficiency and simplicity. Generally, PSO emulated the organisms' behavior

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such as bird flocking and fish schooling. It merges social psychology principles in socio-cognition human agents and evolutionary computations.

For dynamic analysis of the power system, using offline simulation usually is not enough especially if the system includes power inverter devices since the operation of these inverters depends mainly on a high switching frequency. Real time digital simulator (RTDS) is a well-established real time simulation tool for prototyping and hardware-in-loop testing. It also provides accurate, fast, reliable and cost effective study of complex power systems [20]. Optimal structures, unbalance problems and control strategies of the microgrids containing multi-energy generators have been studied using microgrid test beds built in the laboratory [20]. In particular, RTDS has been used for real-time tests for DGs and its controllers of microgrids [21–23]. A new unified controller for use with each DG system in the microgrid was proposed and implemented on RTDS [22].

In this paper, analysis and controller design of the autonomous microgrid on RTDS have been investigated. The dynamic model of an autonomous microgrid containing VSI, power, current, and voltage controllers, coupling inductance, LC filter, lines, and loads has been developed and implemented on RTDS small time-step environment to accommodate high switching frequency. With the aim of stability enhancement of the autonomous microgrid, a nonlinear time domain simulation-based objective function is employed and the controller design is formulated as an optimization problem where PSO is used to solve this design problem. The controller parameters and the power sharing coefficients are optimized to enhance the stability of the microgrid. The microgrid performance with the proposed optimal controllers has been examined under different disturbances using the nonlinear time domain simulations. The performance of the considered autonomous microgrid has been verified using RTDS.

2. Autonomous microgrid controller

The autonomous microgrid with its controllers is shown in Fig. 1. The power, voltage and current controllers are used to control the output powers of the DG units as well as to maintain the voltage and frequency of this autonomous microgrid system [13].

2.1. Power controller

In the autonomous microgrid, the DG units are controlled to share the load demands between them. The conventional droop method shown in Fig. 2 is a common control method used to share the loads between these DGs. The power sharing concept is shown in Fig. 3. It emulates the synchronous generator where the active power depends on the power angle, while the reactive power mostly depends on the output-voltage amplitude. Firstly, the measured output current and voltage are used to determine the instantaneous measured active and reactive powers. Then these measured powers are filtered through low pass filter to obtain the real power "P_c" and reactive power "Q_c". Finally, the frequency ω corresponding to the active power and the d-component of the output voltage reference v^*_{od} corresponding to the reactive power can be determined as follows [13].

$$\omega = \omega_n - m_p P_c, \quad \dot{\theta} = \omega \tag{1}$$

$$v^*_{od} = V_n - n_q Q_c, \quad v^*_{oq} = 0 \tag{2}$$

where ω_n and V_n are the nominal values of DG angular frequency and DG voltage magnitude, P_c and Q_c are the measured real and reactive powers after the low-pass filtering, m_p and n_q are the droop

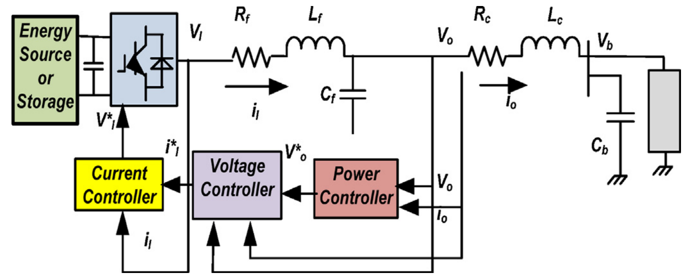

Fig. 1. Autonomous microgrid controllers.

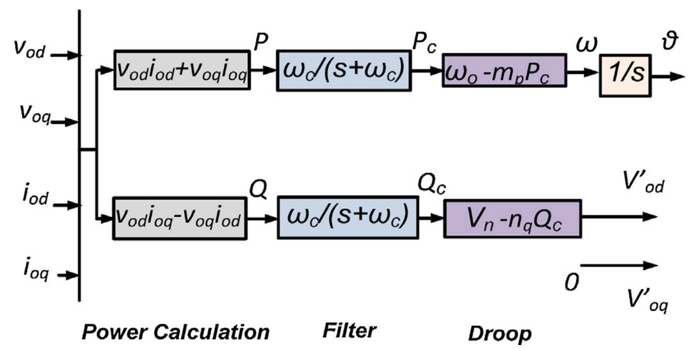

Fig. 2. Power controller.

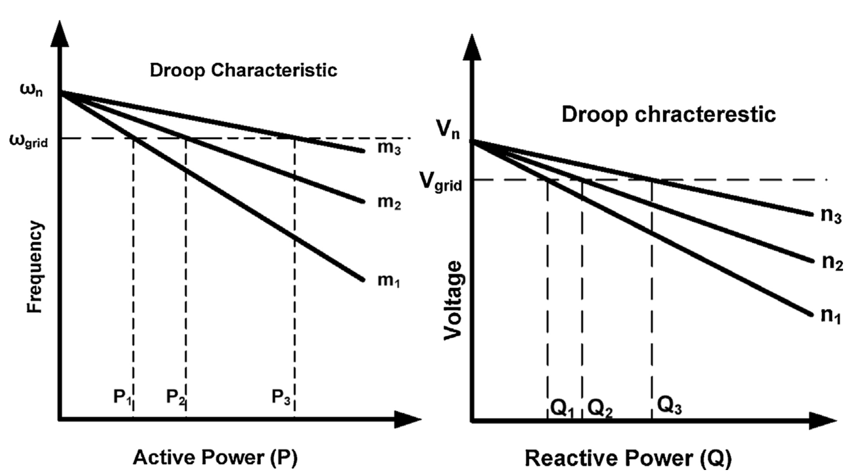

Fig. 3. Droop characteristics.