ARTICLE IN PRESS

ISA Transactions xxx (2018) 1–8

Contents lists available at ScienceDirect

ISA Transactions

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

Research article

Coordinated control of micro-grid based on distributed moving horizon control

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ARTICLE INFO

Article history:
Received 27 September 2017
Revised 8 February 2018
Accepted 4 March 2018
Available online XXX

Keywords:
Distributed moving horizon control
Micro-grid
Wind energy
Solar energy
Power balance
Economic dispatch

ABSTRACT

This paper proposed the distributed moving horizon coordinated control scheme for the power balance and economic dispatch problems of micro-grid based on distributed generation. We design the power coordinated controller for each subsystem via moving horizon control by minimizing a suitable objective function. The objective function of distributed moving horizon coordinated controller is chosen based on the principle that wind power subsystem has the priority to generate electricity while photovoltaic power generation coordinates with wind power subsystem and the battery is only activated to meet the load demand when necessary. The simulation results illustrate that the proposed distributed moving horizon coordinated controller can allocate the output power of two generation subsystems reasonably under varying environment conditions, which not only can satisfy the load demand but also limit excessive fluctuations of output power to protect the power generation equipment.

1. Introduction

With the rapid development of energy storage and power electronic technology, micro-grid has been widely used in power system [1–3]. Micro-grid is a distributed system composed of the distributed generators (like wind power and solar power generations), inverters, energy storage system, loads and monitor devices. According to the need of the grid, the micro-grid has two operation modes, namely, grid-connected mode and islanded mode. Grid-connected mode can provide the excess power of micro-grid for the grid or obtain the power from the grid to complement the micro-grid in order to optimize the power allocation and improve the reliability of power supply [4,5]. While islanded mode means that the micro-grid disconnects from the power grid and can supply the load demand inside micro-grid when the regular grid breaks down. Therefore, the micro-grid can supply the power when the emergency or power shortage happens in the regular grid.

Power balance and economic dispatch problems are the bases of power system stability and economical operation. Power balance requires that the power supply of the micro-grid should match up with all load consumption [6,7]. Economic dispatch means that the power balance is realized with the minimum cost. Both issues mentioned above are achieved by coordinating the output power of various power generation units. Essentially, power balance and economic dispatch problems of the micro-grid can be considered as the coordinated control and optimization problems of distributed system [8–10]. Many scholars have proposed various control methods based on different theories to solve the power balance and economic dispatch problems of micro-grid, such as fuzzy control [11–13], robust control [14,15] and adaptive control [16,17], etc. But most of those concentrated on the independent wind generation system or solar generation system, rarely involved the micro-grid based on wind/solar hybrid generation [11,14,16,18]. For example, the control law adjusts the photovoltaic generation system to satisfy both the load and battery charge power requirements in [18], which takes the wind power generation as a distur-

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https://doi.org/10.1016/j.isatra.2018.03.005
0019-0578/

bance. Moreover, most research is based on the centralized control manner ([8,19,20] and the reference therein), which is impractical for the control of micro-grid based on distributed generation, since micro-grid is the geographically expansive system and involves enormous number of units [21,22]. On the other hand, some control schemes referred above are implemented in the decentralized manner [9], which assumes there are no information exchanges and may result in poor system performance. In order to achieve better system performance, it is necessary to establish the communication between the different subsystems, which reminds us of the distributed control of micro-grid based on distributed generation. In addition, some traditional control methods can not achieve satisfactory control performance since the physical constraints such as the limitations of the actual output power and the changing rate of output power were not explicitly considered in the controller design.

With solving the optimization problems online, distributed moving horizon control has become an efficient control strategy for many large scale systems in industry, since it can manage on-line the trade-off between disturbance rejection and system constraints [23]. In this paper, the distributed moving horizon coordinated control scheme is proposed for the power balance and economic dispatch problems of micro-grid based on distributed generation. In our scheme, each generation unit is considered as the subsystem of the micro-grid and is controlled by a local moving horizon controller. The subsystem-based moving horizon controllers communicate with each other by integrating the information in their control objectives. The objective function of distributed moving horizon coordinated controller is chosen based on the principle that wind power subsystem has the priority to generate electricity while photovoltaic power generation coordinates with wind power subsystem and the battery is only activated for satisfying the power demand when necessary. The simulation results demonstrate that the designed distributed moving horizon coordinated controller can allocate the output power of generation subsystems reasonably under varying environment conditions.

2. Micro-grid system model

The micro-grid system discussed in this paper includes three mutually independent subsystems [16]: wind power subsystem, solar power subsystem, and a battery bank which is used to complement the shortage of electricity in an emergency. The schematic diagram of micro-grid is illustrated in Fig. 1. The energy which is generated by both wind power subsystem and solar power subsystems is collected by the DC bus and transferred to the load and, if needed, to the battery. When the wind and solar subsystems can not fulfill the load requirement, the battery will discharge and provide extra energy to meet the load requirement.

2.1. Wind power subsystem model

The wind power subsystem comprises a windmill, a multipolar permanent-magnet synchronous generator (PMSG), a rectifier, and a DC/DC converter which is connected to the generation via the DC bus. As shown in Fig. 1, the DC/DC converter commands the PMSG terminal voltage to regulate the power output of wind turbine.

The windmill can convert the wind energy to the mechanical energy of wind wheel and drive the engine to generate electric energy by gear transmission system. The mechanical power generated by the wind turbine is described as [24]:

$$P_m = \frac{1}{2} C_p(\lambda) A \rho v^3 \tag{1}$$

where v is wind speed; A is the area swept by the turbine; ρ is the air density; $C_p(\lambda)$ is the actual wind energy utilization coefficient which is related to the tip speed ratio $\lambda = R\omega_m / v$ and ω_m is the angular shaft speed. In addition, the torque of wind turbine can be computed as:

$$T_t = \frac{1}{2} C_t(\lambda) \rho A R v^2 \tag{2}$$

where $C_t(\lambda) = C_p(\lambda)/\lambda$ is the nonlinear torque coefficient, and R is the turbine radius. In a rotor reference frame, the dynamic model of the wind subsystem can be described as follows [24]:

$$\dot{x}_w = \begin{bmatrix} \dot{i}_q \\ \dot{i}_d \\ \dot{\omega}_e \end{bmatrix} = \begin{bmatrix} -\frac{r_s}{L} i_q - \omega_e i_d + \frac{\omega_e \phi_m}{L} \\ -\frac{r_s}{L} i_d + \omega_e i_q \\ \frac{P}{2J}(T_t - \frac{3}{2}\frac{P}{2}\phi_m i_q) \end{bmatrix} + \begin{bmatrix} -\frac{\pi v_b i_q}{3\sqrt{3} L \sqrt{i_q^2 + i_d^2}} \\ -\frac{\pi v_b i_d}{3\sqrt{3} L \sqrt{i_q^2 + i_d^2}} \\ 0 \end{bmatrix} \tag{3}$$

$$u_w = f_w(x_w) + g_w(x_w) u_w$$

$$i_w = \frac{\pi}{2\sqrt{3}} \sqrt{i_q^2 + i_d^2}\, u_w$$

where i_q and i_d are the quadrature current and the direct current in the rotor reference frame, respectively; $\omega_e = (P/2)\omega_m$ is the electrical angular speed; r_s and L are the per phase resistance and inductance of the stator windings, respectively; J is the inertial of the rotating parts; P is the PMSG number of poles; v_b is defined as the voltage of the battery bank terminals; ϕ_m is the flux linked by the stator windings and u_w is the control signal [duty cycle of the DC/DC converter in Fig. 1].

Based on (3), the power generated by the wind turbine can be computed as [19]:

$$P_w = \frac{\pi v_b}{2\sqrt{3}} \sqrt{i_q^2 + i_d^2}\, u_w. \tag{4}$$

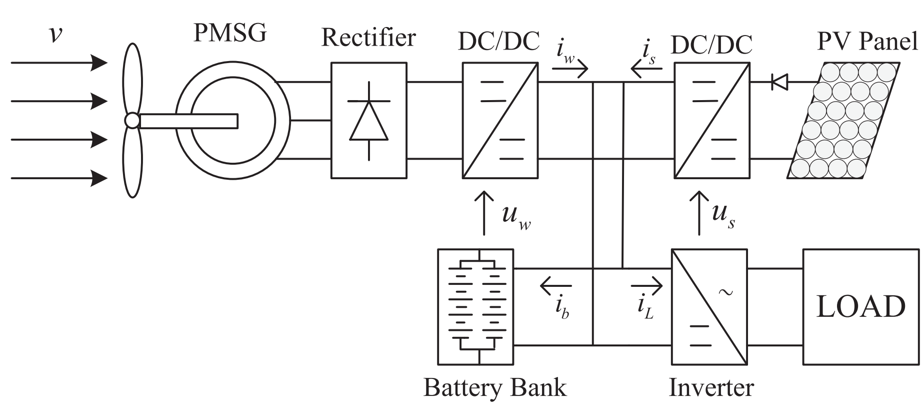

Fig. 1. Schematic diagram of micro-grid.