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Design of intelligent control for stabilization of microgrid system

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ABSTRACT

This paper proposes a design of robust intelligent control for stabilization of grid-connected microgrid (MG) system, consisting of photovoltaic (PV), wind power (WP), and fuel cell (FC). Since intermittent power generations from WP and PV sources are unpredictable and variable, these result in power fluctuations in a MG. To stabilize power fluctuations, an intelligent controller was proposed, which consists of the modified general regression neural network (GRNN) and the radial basis function network-sliding mode (RBFNSM) for stabilization control of microgrids incorporating PV and wind generation. With proper control, a distribution static var compensator (SVC) integrated with MG is able to significantly enhance the dynamic security of the power system. Simulation studies have been done to verify the performance and robustness of the proposed method against various loading conditions and it is found that the designed control scheme enhances the stability.

Introduction

Presently, there are many remote areas around the world which are not still connected with the main utility grid due to the environment and investment. Therefore, the microgrid (MG) system is an essential choice to solve this problem. The MG is group of the distributed generation units, distributed storage units and loads. The grid-connected hybrid system consisting of a wind generator and PV panels to extract the maximum power from wind and solar energy sources and balanced by a diesel electric generator [1]. A stand-alone PV and FC-wind hybrid generation system can quickly and accurately track the maximum power output for the high performance [2]. Furthermore, the MG can be operated independently in a stand-alone mode and also interconnected to the utility grid [3]. Microgrids are operated in two modes: grid-connected and islanded. In normal conditions, a MG is connected to and operates in parallel with a utility grid, and power is exchanged between the two grids based on supply and demand in the MG. However, a MG can disconnect from the utility grid and work in the islanded mode when a fault occurs in the upstream power grid. The balance between power supply and demand is one of the most important criteria in MG management in both operation modes. In the grid-connected mode, the utility grid is required to meet the balance. On the other hand, in the islanded mode the MG needs to do this, via increases in generation or load shedding [4,5].

A direct building algorithm for MG distribution ground fault (MGDGF) analysis is proposed in [6]. Two relationship matrices: B_I and Z_{V-BC}, the bus injection to branch current matrix and the branch current to bus voltage mismatch matrix, respectively, which are built from the topological characteristics of MG distribution networks, are used to achieve the MGDGF solution. Through Z-Matrix building algorithm, B_I and Z_{V-BC} can be derived directly and stored no matter how the network expands, and fault current analysis [7] can be conducted effectively. In [8,9], the proposed control and monitoring system (CMS) is applied to suppress the fluctuations of frequency and tie line power in MG via controllable power outputs of micro-turbine (MT) and electrolyzer (ES). However, the controller parameters of MT and ES are separately tuned for islanding and interconnected utility grid operations. As a result, the CMS cannot guarantee the well coordinated control effect. Besides, these works do not take system uncertainties such as the variation of system parameters into consideration. Accordingly, the robustness of CMS against system uncertainties cannot be guaranteed. To improve the coordinated control effect and robustness against system uncertainties of MG system, the modified GRNN and RBFNSM control are applied.

The radial basis function network (RBFN) not only has the abilities to carry out parallel computing, learning and fault tolerance, but is also be able to approximate any complicated nonlinearity to an infinite degree. It thus has enormous potential for dealing with problems that include high nonlinearity and significant uncertainty. Sliding mode variable structure control is a special discontinuous nonlinear control strategy, which has strong robustness against parameter variations, load disturbances and system

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uncertainty, with the advantages of fast and easy realization. However, the control precision and stability of such systems are adversely affected by chattering. The normal method to minimize chattering is to replace the switch control with continued saturated nonlinear control to smooth the discontinuous variables. While this method can eliminate chattering, it also minimizes the robustness of the sliding mode structure control system. In contrast, combining a neural network approach with sliding mode variable control can not only increase robustness, the enabling the system to resist perturbation and external interference, but also eliminate buffeting [10,11]. GRNN has been applied in a number of applications for system control and identification, and there have also been some comparative studies which demonstrate the modeling capability of the GRNN model with respect to other types of neural networks. Although some studies present adaptive GRNN methods, the assignment of sigmas in these is usually based on the overall results of statistical calculations carried out on a pre-collected batch of training data. However, few studies have reported on the use of adaptive GRNN for the modeling of dynamic systems, especially for online applications. Furthermore, investigations into the adaptive aspects of the GRNN parameters in dynamic process modeling are still in their infancy, and much more work is needed here [12,13].

In the grid-connected MG system, power electronic inverters are needed to realize the power conversion, grid connection, and control optimization [14,15]. Grid-connected pulse width modulation (PWM) voltage source inverters (VSIs) are widely applied in PV and wind power systems, which have at least two functions because of the unique features of PV modules. First, the dc-bus voltage of the inverter should be fixed to a specific value since the output voltage of the PV modules varies with temperature, irradiance, and the effect of MPPT [16]. Second, the energy should be fed from the PV modules into the utility grid by converting the dc current into a sinusoidal waveform synchronized with the utility grid. It is obvious for the inverter-based PV system that the conversion power quality including the low total harmonic distortion (THD), high power factor, and fast dynamic response, largely depends on the control strategy adopted by the grid-connected inverters [17,18].

System overview and model description

Dynamic models of the main components in the proposed hybrid system were developed using MATLAB/Simulink. The hybrid MG system shown in Fig. 1 consists of the

(1) wind energy conversion systems (WECS),
(2) fuel cell stack system,
(3) PV generation systems, and
(4) static var compensator (SVC).

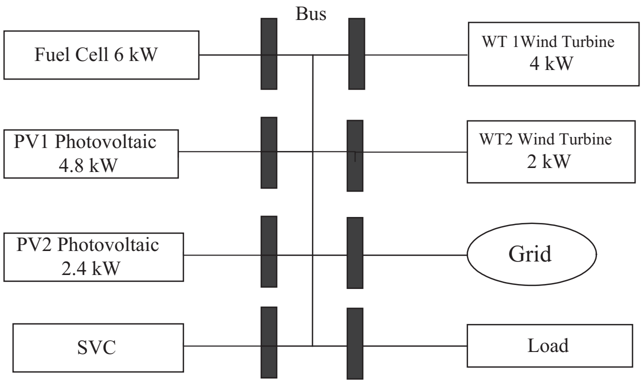

Fig. 1. Proposed hybrid microgrid power system.

WECS

In order to capture the maximal wind energy, it is necessary to install the power electronic devices between the wind turbine generator (WTG) and the grid where the frequency is constant. The input of a wind turbine is the wind and the output is the mechanical power turning the generator rotor [19]. For a variable speed wind turbine, the output mechanical power available from a wind turbine could be expressed as

$$P_m = \frac{1}{2}\rho A C_p(\lambda, \beta) V_\omega^3 \tag{1}$$

where ρ is the air density, and A is the area swept by blades. V_ω is the wind velocity (m/s), and C_p is called the power coefficient, and is given as a nonlinear function of the tip speed ratio (TSR) λ defined by

$$\lambda = \frac{\omega_r r}{V_\omega} \tag{2}$$

where r is wind turbine blade radius, and ω_r is the turbine speed. C_p is a function of λ and the blade pitch angle β.

A variable-speed pitch-regulated wind turbine is considered in this paper, where the pitch angle controller plays an important role. Fig. 2 shows the groups of C_p–λ curves of the wind turbine used in this study with different pitch angles [20]. It is noted from the figure that the value of C_p can be changed by changing the pitch angle (β). In other words, the output power of the wind turbine can be regulated by pitch angle control.

Fuel cell

The proton exchange membrane FC (PEMFC) model is based on the validated dynamic model for a PEMFC stack reported in Jung et al. [21]. It is an autonomous model operated under constant channel pressure with no control on the input fuel flow into the FC. Fig. 3 shows a generalized polarization curve which shows the typical voltage losses in a PEMFC versus current density. This characteristic curve can be divided into three regions. The drop in voltage across the FC associated with low currents is due to the activation loss inside the FC, while the drop in voltage in the middle of the curve is due to the ohmic loss in the FC stack. As a

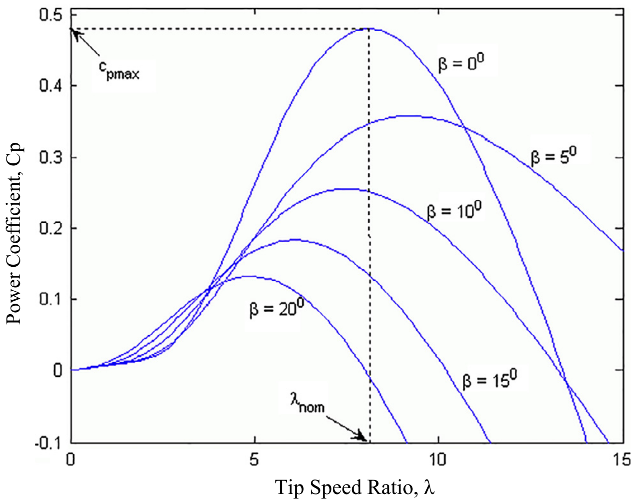

Fig. 2. C_p–λ characteristics of the WECS at different pitch angles.