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Dynamic operation and control of microgrid hybrid power systems

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ABSTRACT

This paper examines dynamic operation and control strategies for a microgrid hybrid wind–PV (photovoltaic)–FC (fuel cell) based power supply system. The system consists of the PV power, wind power, FC power, SVC (static var compensator) and an intelligent power controller. A simulation model for this hybrid energy system was developed using MATLAB/Simulink. An SVC was used to supply reactive power and regulate the voltage of the hybrid system. A GRNN (General Regression Neural Network) with an Improved PSO (Particle Swarm Optimization) algorithm, which has a non-linear characteristic, was applied to analyze the performance of the PV generation system. A high-performance on-line training RBFNSM (radial basis function network-sliding mode) algorithm was designed to derive the optimal turbine speed to extract maximum power from the wind. To achieve a fast and stable response for real power control, the intelligent controller consists of an RBFNSM and a GRNN for MPPT (maximum power point tracking) control. As a result, the validity of this paper was demonstrated through simulation of proposed algorithm.

1. Introduction

A microgrid is a small-scale power grid composed of DG (distributed generation), DS (distributed storage), and loads [1]. There is now growing interest in microgrids in many countries, because of their relatively low environmental impact, ability to meet the diverse needs of end users for higher quality power supplies, the restructuring of the electric power industry, and restrictions on the extension of power transmission and distribution facilities.

Microgrids are operated in two modes: grid-connected and islanded. In normal conditions, a microgrid 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 microgrid. However, a microgrid 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 microgrid 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 microgrid needs to do this, via increases in generation or load sharing [2,3].

Most applications of microgrids are for stand-alone operations, where the main control target is to balance local loads. A few grid-connected systems consider the utility as just a back-up system to use when there is insufficient supply from renewable sources to power to the microgrid. Such systems were originally designed to meet local load demands when there is likely to be a loss of the main power-supply during certain times. These hybrid systems, which focus on providing sustainable power to meet their loads, do not pay much attention to the quality or flexibility of the power delivered to the grid. From the perspective of utility, however, a hybrid system with less fluctuating power injection or with the capability of flexibly regulating its power is more desirable. In addition, users will prefer a system that can provide multiple options for power transfer, since this can benefit system operations and management. The control strategies used for such a hybrid system should be quite different from those of conventional systems, and it is this issue that the current work examines.

A number of studies of hybrid systems have been published. For example, Bakic et al. (2012) [4] analyzed the dynamic performance of a stand-alone wind-solar system with battery storage, in which a wind turbine system model was developed and compared with a real system [5,6]. Methodologies for the optimal design or unit

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sizing of stand-alone or grid-connected hybrid systems have been proposed using steady-state analysis, in which the steady-state of a microturbine and a battery energy storage system was analyzed [7,8]. However, most applications in the literature are for stand-alone operations, where the main control target is to balance local load, and only a few grid-connected systems consider the grid as a back-up for use when there is insufficient supply from renewable sources [2].

FCs (Fuel cells) may utilize traditional fossil fuels, such as coal, petroleum and natural gas, or various forms of recycled energy, such as marsh gas, methyl alcohol, and so on, but the method of power generation used by FC is quite different to that seen with traditional thermal plants. In addition, FC can produce electricity with the advantages of high efficiency, low pollution, onsite installation, reusability of exhaust heat and water, and the ability to use a wide range of fuels [9,10]. The research and development of the PV (photovoltaic) cells can be traced back to the 1970s, and since then they have become much cheaper and more efficient, leading to a dramatic growth in the installed capacity in recent years. However, PV cells have relatively low energy conversion efficiency, lower power density, and higher cost compared with wind turbines.

A RBFN (radial basis function network) 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 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.

The general requirements of MPPT (maximum power point tracking) are that it should enable simple, low cost, and rapid tracking when conditions change and there are small fluctuations in output power [11,12]. The traditional methods used to achieve this, such as hill climbing, P&O (Perturbation and Observation), and incremental conductance, are simple and low cost, but do not have good tracking performance. A number of novel methods have been developed that have greater accuracy but are also more complex, such as the optimum gradient method, FLC (fuzzy logic control) and NNs (neural networks). These techniques can be costly, difficult to implement, and may not be stable enough [11]. GRNN with Improved PSO (Particle Swarm Optimization) 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.

2. System component characteristic

The proposed wind and PV–FC hybrid system is shown in Fig. 1. Dynamic models of the main components were developed using MATLAB/Simulink is shown in Fig. 2, consisting of

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

2.1. Wind turbine

In order to capture the maximal wind energy, it is necessary to install the power electronic devices between the WTG (wind turbine generator) 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. For a variable speed wind turbine, the output mechanical power available from a wind turbine can be expressed as

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

where ρ and A are the air density and area swept by blades, respectively. 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 TSR (tip speed ratio) 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. 3 shows C_p–λ curves of the wind turbine used in this study at different pitch angles [13]. It is noted from the figure that C_p can be changed by adjusting the pitch angle (β). In other words, the output power of the wind turbine can be regulated by pitch angle control.

2.2. Fuel cell

The FC model is based on the validated dynamic model for an FC stack [14,15]. It is an autonomous model operated under constant channel pressure with no control on the input fuel flow into the FC. Fig. 4 shows a generalized polarization curve which shows the

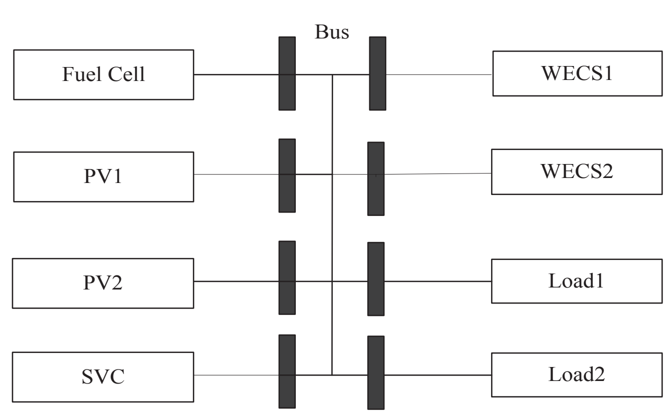

Fig. 1. Proposed hybrid micro-grid power system.