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Renewable energy management through microgrid central controller design: An approach to integrate solar, wind and biomass with battery

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ABSTRACT

In this study, an isolated microgrid comprising of renewable energy (RE) sources like wind, solar, biogas and battery is considered. Provision of utility grid insertion is also given if total microgrid sources falls short of supplying the total load. To establish an efficient energy management strategy, a central controller takes the decision based on the status of the loads and sources. The status is obtained with the assistance of multi-agent concept (treating each source and load as an agent). The data acquisition system of these renewable sources and loads consists of multiple sensors interconnected through Low Power Radio over one of many GPRS communication. The Microgrid Central Controller (MGCC) would use an embedded energy management algorithm to take decisions, which are then transmitted to the controllable RE systems to manage the utilization of their power outputs as per the load-supply power balance. A control strategy is adopted to regulate the power output from the battery in case of supply shortage, which results in a floating battery scheme in steady state.

1. Introduction

In today's world, the reduction of greenhouse gas emission from the conventional thermal power plants is quite necessary. For the reduction of greenhouse gases from the electrical power sources, the power producers are now marching towards usage of renewable energy sources (RESs) (Bull, 2001). A study on the US power system suggests that a conservative approach could reduce annual CO_2 emissions by 5% by 2030 (Hledik, 2009). Also, if the national electricity market were to function properly, the renewable energy technologies would offer the cheapest forms of power generation (Sovacool, 2008). In general, these sources are small in capacity and thus are mostly connected at distribution voltage level and are known as distributed generation (DG). This localized grouping of electricity generation, storage, and loads that normally operate connected to a centralized utility grid is called as a microgrid (Mishra et al., 2012). In reality there are technical limits on the degree to which distributed generation can be connected, especially for some intermittent forms of renewable generation (Arulampalam et al., 2004).

In this study a microgrid comprising of controllable renewable sources like wind, solar, biogas and battery is considered for supplying the load. In a microgrid (Valenciaga and Puleston, 2005) the power output from controllable sources changes, thus they have to be regulated. The solution is to have a battery with state of charge (SOC) greater than 20% to bridge the gap between the power produced by the RESs and loads. As per SOC of battery and real power needs of the microgrid, the battery is either charged or discharged (Xu et al., 2012). If the SOC of battery is less than 20% then utility grid has to be inserted as the last resort to meet the deficit load. The battery control mechanism should also consider its SOC to avoid any damage due to overcharging (Miao et al., 2014). Thus, in line with the literature review of State of charge of the batteries used for microgrid integration, the SOC limit for operation has been kept between 20% and 80% (Prajapati et al., 2011). Here, we are managing the output power available from different microgrid energy sources to maintain microgrid load–source power balance. The battery used for supplying the deficit power (in case renewable energy sources are insufficient to meet the load) is integrated here. Even though a battery is a highly reliable power source, it cannot be used under steady state for power exchange with the microgrid. Thus, a battery power control mechanism for handling load fluctuations is implemented (Bragard et al., 2010; Vazquez et al., 2010).

The microgrid has a larger power capacity and more control flexibilities to fulfill system reliability and power quality requirements (Gaonkar, 2010). The features of the microgrid can improve the reliability of the power supply but it also creates specific problems like transient dynamics, Intermittency of renewables, load

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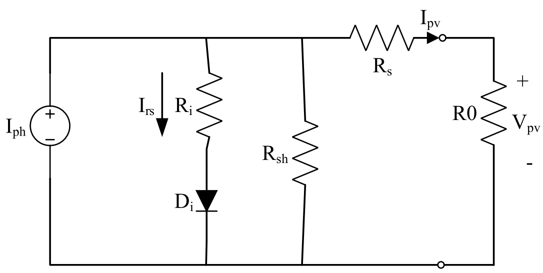

Fig. 1. Solar PV panel equivalent circuit.

management, reliability issues etc. The problem of transient dynamics is fundamentally important because it concerns the protection configuration, control strategy formulation, and transient stability assessment of the whole power system (Xiong and Ouyang, 2011). In this study, we are considering how to improve the transient dynamics by designing a microgrid central controller.

The exact objective of this study is to formulate and implement an energy management algorithm for supplying reliable power to the connected load in a microgrid, by designing a microgrid central controller (MGCC). Such a controller finds its usefulness in managing intermittency of power supply from renewable energy sources in a microgrid set up and is of immense use to the distribution utility and microgrid energy management sector. Due to higher sampling rate of MGCC, it can handle both primary as well as secondary controllers. For effective resource utilization and control of microgrid power sources a smart MGCC is developed based on multi agent system (MAS) concept. The renewable energy sources considered for this study are solar photovoltaic (PV), wind energy, and biogas internal combustion engine. The data acquisition system of these renewable sources and loads consists of multiple sensors interconnected through Low Power Radio (LPR) (http://www.fi-ppp-finseny.eu/wp-content/uploads/2013/04/FINSENY_D3\T1\ndash3_Microgrid_Functional_Architecturev1_0_March_2013.pdf). The data thus received will be utilized by MGCC for deciding the control actions. The microgrid proposed in this study is with the following installed capacities: (a) Wind Gen.—40 kW, (b) Solar photovoltaic Generation.—13 kW_p, (c) Biogas Generation—25 kW, (d) Total Load—80 kW, (e) Battery I.C.—200 kWh.

This paper is organized in the following manner. Section 2 describes the modeling of renewable energy sources. Section 3 presents the formulation of energy management algorithm. Section 4 illustrates the modeling and design of Microgrid Central Controller (MGCC). Section 5 demonstrates the simulation results and analysis. Section 6 presents the conclusion.

2. Modeling and simulation of renewable energy sources and the battery

In order to verify the correct functioning of the designed Microgrid Central Controller, a dynamic model of the proposed microgrid system is necessary. The modeling of dc microgrid's renewable energy sources and the energy storage component (the battery) was mainly built by LabVIEW mathematical modules (labVIEW Software Signal Express, 2012, National Instruments, Texas, USA 2012), based on equivalent circuits of the components. The detailed description of the model of each subsystem is given below.

2.1. Modeling of solar photovoltaic (PV) module

Solar PV panel equivalent circuit is shown in Fig. 1.

The output power from the solar PV panel at a specified output voltage is given as follows

$$P_{SOLAR} = V_{pv} I_{pv}. \quad (1)$$

The current supplied by the solar PV panel I_{pv} is given as follows

$$I_{pv} = \eta_p I_{ph} - \eta_p I_{rs} \left[\exp\left(\frac{q}{kTA} \frac{V_{pv}}{\eta_s} \right) - 1 \right] \quad (2)$$

where V_{pv} is output voltage of solar panels, I_{pv} is output current of solar panels, η_s is the number of solar panels in series, η_p is the number of solar panels in parallel, k is the Boltzmann constant, q is the electron charge, A is the ideality factor (ranges from 1 to 2), T is surface temperature of the solar panels (Kelvin), and I_{rs} is reverse saturation current, I_{ph} is the solar PV phase current expressed in Amp. (A) (Chen et al., 2013).

In (1), the characteristic of reverse saturation current I_{rs} varies with temperature as

$$I_{rs} = I_{rr} \left[\frac{T}{T_r} \right]^3 \exp\left(\frac{qE_q}{kA} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right) \quad (3)$$

where T_r is the reference temperature of the solar panels (Kelvin), I_{rr} (A) is reverse saturation current of the solar panels at temperature T_r (Kelvin), and E_q is energy band gap of semiconductor material.

$$I_{ph} = [I_{scr} + \alpha (T - T_r)] \frac{S}{100} \quad (4)$$

where I_{scr} is the short circuit current at reference temperature T_r (Kelvin) and solar insolation specified at 0.85 kW/m^2, α is the short circuit current temperature coefficient of the solar panels, and S is the solar insolation (kW/m^2). The hourly values of input variables for modeling all the renewable energy sources are taken from smart grid pilot project commissioned at Mysore, India (http://indiasmartgrid.org/en/Lists/SmartGrid_Project/Attachments/9/14%20Smart%20Grid%20Pilots%20-%20Updates.pdf).

For this study we used Panasonic HIT-240S-BL solar modules each with a power rating of 240 W as the photovoltaic device of the microgrid system. This study used a solar system of 13 kW_p at M.P.P.T. (maximum power point tracking) generated by twenty photovoltaic arrays in parallel, where each array was built with twenty eight solar panels in series. This study used solar insolation of 0.85 kW/m^2 and constant temperature with varying V_{pv} for simulation verification.

2.2. Wind turbine modeling

The power generated by wind turbine is expressed as

$$P_{WIND} = 0.5 \rho A V^3 C_P (\tau_i, \theta) \quad (5)$$

where P_W is the power generated by the wind turbine W, ρ is the density of air in atmosphere (kg/m^3), A is cross-sectional area of a wind turbine blade (m^2), V is wind velocity (m/s), and C_P is the wind turbine energy conversion coefficient (Zhengming and Mingzong, 2010).

The density of air ρ (kg/m^3) and energy conversion coefficient C_P in (4) is expressed as

$$\rho = \left(\frac{353.05}{T} \right) \exp^{-0.034 \frac{Z}{T}} \quad (6)$$

$$C_P (\tau_i, \theta) = \left(\frac{116}{\tau_i} - 0.4 \times \theta - 5 \right) 0.5 \exp^{\frac{-16.3}{\tau_i}} \quad (7)$$

where Z is the altitude, T is the atmospheric temperature, τ_i is the tip speed ratio and θ is the blade tilt angle.