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Frequency deviation control by coordination control of FC and double-layer capacitor in an autonomous hybrid renewable energy power generation system

Majid Nayeripour*, Mohammad Hoseintabar, Taher Niknam

Department of Electrical and Electronics Engineering, Shiraz University of Technology, Shiraz, Iran

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ABSTRACT

In this paper, a novel control strategy for frequency control in stand-alone application based on coordination control of fuel cells (FCs) and double-layer capacitor (DLC) bank in an autonomous hybrid renewable energy power generation system is implemented. The proposed renewable energy power generation subsystems include wind turbine generator (WTG), photovoltaic system (PV), FC system and DLC bank as energy storage system. The system performance under different condition has been verified by using real weather data. Simulation results demonstrate the validity of proposed studied hybrid power generation system feeding isolated loads in power frequency balance condition.

1. Introduction

Stand-alone power generation systems are utilized by many communities and remote area around the world that have no access to grid electricity. The renewable energy in grid independent system is growing due to rising fuel prices and environmental warming and pollution [1,2].

Wind and solar power generation are two of the most attractive renewable power generation technologies. In order to integrate renewable energy into such systems and to prevent power fluctuation of wind and solar resources due to weather condition variation, some form of energy storage or additional generation such as FC and battery bank is generally needed [3–5].

FCs systems are one of the promising energy technologies for sustainable future due to their high energy efficiency, environment friendliness and modularity. The main drawback of FCs power generation system is slow dynamics because the FC current slope must be limited in order to prevent fuel starvation problems and to improve its performance and lifetime. The very fast power response, flexible and modular structure of DLC can complement the slower power output of the main source to satisfy load demand completely [6].

In order to prevent fuel starvation problem (over-use) and also to prevent fuel under-use conditions, the excess value of hydrogen fuel flow needs to be controlled rapidly by increasing and decreasing the mass flow into the FC stack, respectively. These operations are restricted by the inertia (dynamic respond) of the actuators. This problem can be controlled by restricting the dynamics of load changes. The different types of FC system have different duration of time delay. Due to this reason the FC system cannot change its power to the desire value.

Due to long duration time delay of FC system, DC link capacitor cannot compensate the variation of load demand and also the voltage variation of DC link capacitor is not in its allowable range for safe operation of inverters. So, DLCs are used to compensate the variation of load demand and FC system power [7,8].

A hybrid power system consists of a combination of two or more power generation technologies to enhance their operating characteristics and efficiencies than that could be obtained from a single power source [9]. The power for the load demand can be effectively delivered and supplied by the proposed hybrid power generation system with proper control and effective coordination among various subsystems.

Several practical arrangements of DLC are used in hybrid power generation. Each of the practical arrangements of double-layer capacitor in hybrid power generation has its advantages and disadvantages relative to operating conditions, control complexity, development cost and fuel economy potential. The usage of the DC/DC converter can maximize the utilization of DLC or batteries during acceleration and cruise and regenerative braking. This structure allows controlling the transient respond of fuel cell by applying different power split strategies such as power-assist or load-leveling control to mitigate the stress on the fuel cell stack [10,11].

* Corresponding author. Tel.: +98 9173114182; fax: +98 7117353502.
E-mail addresses: nayeri@sutech.ac.ir (M. Nayeripour), mohammad.hoseintabar@gmail.com (M. Hoseintabar), niknam@sutech.ac.ir (T. Niknam).

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List of symbols

P_{Total}	Total average power generation
P_{WTG}	Power of wind turbine generator
P_{Net}	Net power
K_{WTG}	Gain of wind turbine generator
T_{WTG}	Time constant of wind turbine generator
Δf	System frequency deviation
V_{Wind}	Wind speed
Φ	Solar irradiation
P_{PV}	Power of PV system
K_{PV}	Gain of PV system
T_{PV}	Time constant of PV system
P_{FC}	Power of FC system
K_{FC}	Gain of FC system
T_{FC}	Time constant of FC system
M	Equivalent inertia constant
D	Damping constant
P_W	Mechanical power of wind turbine

A number of literatures have been reported to investigate frequency deviation control and modeling of hybrid renewable energy systems. Among them, Dong Jing and Lee Wang reported the small signal stability analyzed results of a hybrid power generation/storage system connected to isolated load [12,13]. In [14], S. Doolla and T.S. Bhatti investigated the load frequency control of an isolated small-hydro power plant with reduced dump load technique. In [15], dynamic model of FC are simulated as first order lead lag to indicate the exact behavior of FC system in transient event based on experimental data. Output Power Control of Wind Turbine Generator by Pitch angle control is presented in [16] and [17].

In the previous works, the authors used the diesel generators and battery bank to control frequency deviation control with different control strategy. The main contribution of this research is that a novel control strategy for frequency deviation control of stand-alone autonomous hybrid power generation based on coordination of FC and DLC is proposed to enhance power quality. Also studied hybrid power generation is investigated under real weather data to analysis the effective of proposed control strategy. The simulation results show the validity of the proposed control strategy.

This paper is organized as follows: in Section 2, system descriptions and methodology are explained, power management and proposed control strategy is described in Section 3. Simulation and results discussion are presented in Section 4 and the research will be concluded in Section 5.

2. System configuration and description

The generalized block diagram of the proposed hybrid power generation/energy storage system is shown in Fig. 1. The power generation subsystems include a WTG, a PV, an FC system and DLC bank is employed as energy storage system. DLC is assumed to have enough capacity to store surplus energy generated subsystem. In the proposed system a PV and a WTG system are used as primary energy power generation and have priority to produce power to satisfy load demand.

To detailed study of proposed hybrid power generation/storage system precisely, should employ high order mathematical models with nonlinearity. In this case to simulate and investigate all part of such systems with this complexity, simplified model as linear first order transfer function are generally employed. Therefore, the system nonlinearities have not been taken into account and the system simulated in simplified model. The mathematical models of the different components are presented in sub-section.

2.1. Wind power generation model

The output power of wind turbine generators depends upon the wind speed. The mechanical power of the wind turbine is given by [16]

$$P_{Wind} = \frac{1}{2}\rho A v^3 C_p(\lambda, \theta) \quad (1)$$

where ρA, C_p are the air density, swept area of blades and power coefficient which is a function of tip speed ratio.

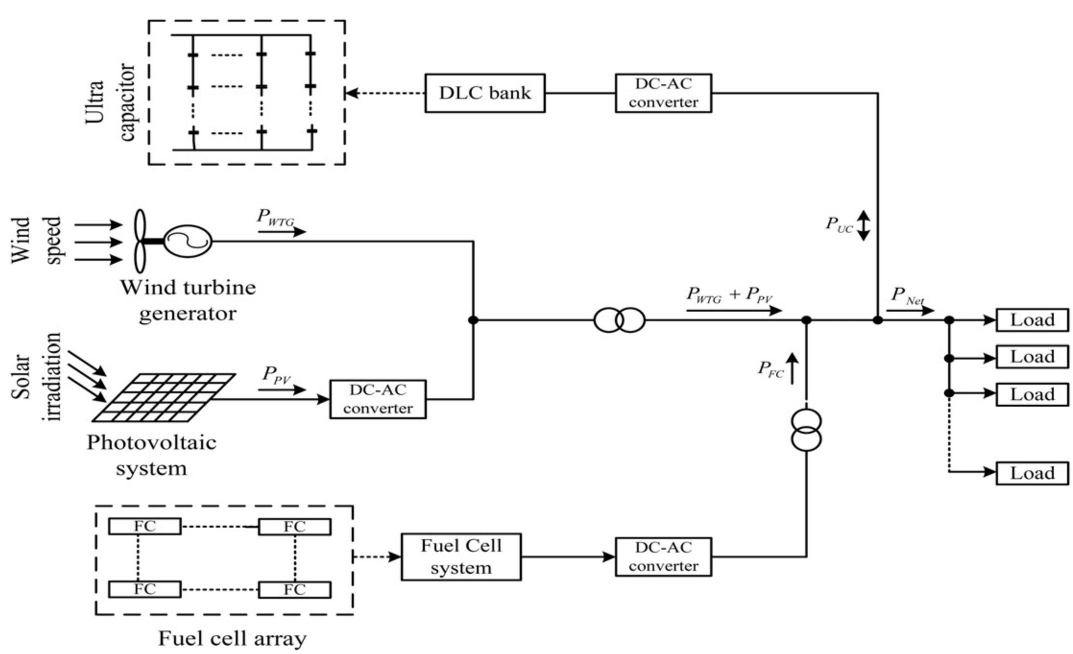

Fig. 1 Overall system configuration of the hybrid power generation and energy storage system.