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An optimized Fuzzy Logic Controller by Water Cycle Algorithm for power management of Stand-alone Hybrid Green Power generation

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ABSTRACT

This paper aims to improve the power management system of a Stand-alone Hybrid Green Power generation based on the Fuzzy Logic Controller optimized by the Water Cycle Algorithm. The proposed Stand-alone Hybrid Green Power consists of wind energy conversion and photovoltaic systems as primary power sources and a battery, fuel cell, and Electrolyzer as energy storage systems. Hydrogen is produced from surplus power generated by the wind energy conversion and photovoltaic systems of Stand-alone Hybrid Green Power and stored in the hydrogen storage tank for fuel cell later using when the power generated by primary sources is lower than load demand. The proposed optimized Fuzzy Logic Controller based power management system determines the power that is generated by fuel cell or use by Electrolyzer. In a hybrid system, operation and maintenance cost and reliability of the system are the important issues that should be considered in studies. In this regard, Water Cycle Algorithm is used to optimize membership functions in order to simultaneously minimize the Loss of Power Supply Probability and operation and maintenance. The results are compared with the particle swarm optimization and the un-optimized Fuzzy Logic Controller power management system to prove that the proposed method is robust and effective. Reduction in Loss of Power Supply Probability and operation and maintenance, are the most advantages of the proposed method. Moreover the level of the State of Charge of the battery in the proposed method is higher than other mentioned methods which leads to increase battery lifetime.

1. Introduction

Nowadays, according to increase the fuel consumption and decline the fossil fuel sources, economic and political trends toward using the renewable a clean energy sources are getting more attention. In this case, some energy sources such as solar energy, wind are in top priority because of their accessibility and abundance. Stand-alone Hybrid Green Power generation (SHGP) system is a power system including two or more power generation units to produce power at lower costs and/or higher reliability than a singular power system unit. In countries, where rural electrification is difficult and extending the power grid from centralized sources to remote areas is not economically reasonable, SHGP can be used to produce electrical energy [1] also low level of fossil fuels reserves has led to increase attention to SHGP [2]. Renewable energy sources provide clean energy; it is an environmentally friendly resource and also it can be used almost anywhere in remote areas, so it is suitable for Stand-alone autonomous hybrid systems [3]. According to these advantages, hybrid systems have a highly promising future for energy generation and also the maintenance and operating costs of the hybrid systems are lower than the power generation units based on the fossil fuels. So it could be considered as the best alternative for both urban and remote areas. The other advantage of the hybrid system is easy installation without any interference. In addition to the SHGP, it is well known that energy storage like battery and super capacitor used as an auxiliary power resource provides additional advantages such as stability, power quality and reliability. There are several configurations of SHGP described in the literature, such as photovoltaic (PV)/diesel generator power systems [4], PV/battery and diesel [5–7], PV/wind turbine and diesel [8], PV/wind only [9], and PV/wind/diesel/micro hydroelectric turbine [10]. Optimization of a hybrid system consists of two parts: first, the component sizing and second, the energy dispatch strategy. The first one defines that how much electricity is available to be utilized by the load and the second one specifies the set points of electricity producer units and load shedding. Both aspects of these parts are important in minimizing overall cost of hybrid system.

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Ref. [11] presents a new ANFIS-based energy management system for a hybrid renewable energy and an ANFIS-based control for the three-phase inverter, which its main novelty is the application of ANFIS. A ramping current reference is presented by Hajizadeh et al. [12]. It presents a novel controller to control hybrid renewable energy systems. The aim of [13] is to maximize the output energy and reducing the output power fluctuations. As it is seen in [14], a general method for optimal power management strategy combined with optimal design of system components is presented. In this work, the differential evolution algorithm is used to solve none linear problems. This optimization algorithm is combined with the fuzzy technique to solve the multi-objective optimization problem. In this regard, a novel method involved in the size optimization of system components, is proposed. In [15], a method has been introduced, in which a Fuzzy Logic Controller (FLC) is utilized to assign priority to the installed system loads to get a higher priority than the non-critical loads and also this controller optimizes the higher battery charge. Ref. [16] has taken the overall cost of hybrid system into account to minimize it. Three new power management strategies and their effect on the battery bank and fuel cell (FC) life span were investigated by Dursun and Kilic [17]. In many investigations, the fuzzy system is optimized to enhance the energy system for example, [18] uses genetic algorithm for dynamic energy system and in [19] genetic algorithm uses to FLC optimization for maximum power point tracking (MPPT). In [20,21] particle swarm optimization and cuckoo algorithm have been used for optimization of FLC for power management of a hybrid system.

In this paper, it is focused on the optimized FLC to introduce the new optimized FLC based on the Water Cycle Algorithm (WCA). The studied system consists of a wind turbine, a photovoltaic, a fuel cell, a battery and, an Electrolyzer (Elec). The proposed approach entitled WCA_FLC power management system (PMS) uses some signals as the inputs to make a decision, so the net power flow, hydrogen tank level and the State-Of-Charge (SOC) of the battery are the FLC inputs, and the power rate of FC and Elec are determined by FLC as output. So it sends a command as the output to the DC–DC convertors and defines the operating point of FC and Elec. The proposed method is compared with the Particle Swarm Optimization (PSO) and un-optimized FLC method. In comparison with other studies, for example [20,21], in the field of power management system based on optimized FLC, using the new optimization algorithm adaptive with fuzzy controller and three inputs for FLC are the novelty of this article. In this paper, the hydrogen tank level and SOC are used as inputs together which lead to better results. Hourly solar irradiation, ambient temperature, wind speed and load profile are used to tune and evaluate of proposed controller of the SHGP for a month.

The rest of this paper is organized as follows: Section 2 presents a short explanation about SHGP. A brief description about the FLC PMS is represented in Section 3. In Section 4, the results have been addressed and discussed. The conclusions are presented in Section 5.

2. Stand-alone Hybrid Green Power generation model

Fig. 1 shows a schematic of the SHGP. The SHGP, used in this paper consists of a Wind and a PV as primary power sources, a FC, an Elec, and a battery as auxiliary source and energy storage system. Elec has been used for hydrogen generation from surplus power to provide the required hydrogen to feed the FC. The FC generates power when the primary source power is unable to meet the load demand. In this paper, the FC and Elec are controlled by boost and buck converters in which the power set point of the controllers are determined by the PMS based on the optimized FLC. Also a battery is discharged when the primary sources and the FC are not able to satisfy the load demand and charged when surplus power is excess after feeding the load and Elec. Since the Depth of Discharge (DOD) in the battery lifetime is one of the most effective parameters, so this parameter must be kept in the optimal DOD value. In this regard, the aim of this paper is to keep the optimal DOD as well as reducing the operation and maintenance (O&M) cost and Loss of Power Supply Probability (LPSP). In this study, in order to make a balance between the generated power and the consumed power, a dump load is considered to absorb the excess power by means of the resistor bank. All these elements are connected to DC bus that it sends generated power to the AC load. In the studied system, an inverter makes connection between the DC bus and the AC load. Fig. 2 shows the flowchart of operating strategy of the hybrid power system. Hourly data for load power for 1 month is shown in Fig. 3. The mentioned SHGP is simulated in MATLAB/simulation environment to evaluate and analyze its dynamic behavior. For a month analysis, Hourly data for wind speed, ambient temperature, and solar irradiation are shown in Fig. 4.

2.1. PV

PV system consists of many cells in parallel (N_P) and series (N_S) which provide the desired output power. The power generated by PV is given as following [20]:

$$P_{PV}(t) = N_p \cdot N_s \cdot \frac{\frac{V_{oc}}{n_{MPP}\cdot KT/q} - \ln\left(\frac{V_{oc}}{n_{MPP}\cdot KT/q} + 0.72\right)}{1 + \frac{V_{oc}}{n_{MPP}\cdot KT/q}} \cdot \left(1 - \frac{R_s}{V_{oc}/I_{sc}}\right) \cdot I_{SC0}\left(\frac{G}{G_0}\right)^{\alpha} \cdot \frac{V_{oc0}}{1 + \beta \ln \frac{G_0}{G}} \cdot \left(\frac{T_0}{T}\right)^{\gamma} \cdot \eta_{MPPT} \cdot \eta_{oth} \quad (1)$$

where (V_{oc},I_{sc}) and (V_{oc0},I_{sc0}) are open circuit voltage and short circuit current under two different solar irradiation (in W/m^2) and PV temperature (in K) ((G,T) and (G_0,T_0), respectively), K is the Boltzmann constant (1.38×10^{-23} J/K), q is the magnitude of the electron charge (1.6×10^{-19} C), R_s is the series resistance (Ω), α is the non-liner effect that PV depends on, β is a dimensionless coefficient parameter for PV module technology, γ is the non-liner temperature–voltage effects. n_{MPP} is the ideality factor, η_{MPPT}, η_{oth} are the effects of maximum power point tracking and other losses such as cables resistance (0.05) [20]. Table 1 represents the parametric value of PV. The generated power by PV is shown in Fig. 5.

2.2. Wind turbine

There are many mathematical model of wind turbine power. One of liner simple model has been brought in [20,22]:

$$P_{wind}(t) = \begin{cases} P_n \cdot \frac{V_{wind}(t) - V_{start}}{V_n - V_{start}} & \text{if} \quad V_{start} \leqslant V_{wind}(t) \leqslant V_n \\ P_n & \text{if} \quad V_n \leqslant V_{wind}(t) \leqslant V_{brake} \\ 0 & \text{if} \quad \text{other } V_{wind}(t) \end{cases} \quad (2)$$

where $V_{wind}(t)$ (in m/s) is the wind speed at time t, P_n is the power rating of the wind turbine (in kW), V_{start}, V_n and V_{brake} are the characteristic parameters determined by the wind turbine power curve provided by the manufacturer (in m/s), The wind turbine starts producing power at a wind speed of 5 m/s and reaches rated power at the wind speed of 8.5 m/s. At the wind speeds higher than 25 m/s, the controller puts the wind turbine on the brake. Fig. 6 shows the power curve of wind turbine power versus wind speed. The generated power by wind turbine is shown in Fig. 7.