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Parameter optimization via cuckoo optimization algorithm of fuzzy controller for energy management of a hybrid power system

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ABSTRACT

This paper presents the development of an optimized fuzzy logic controller (FLC) for operating a stand-alone hybrid power system based on cuckoo search algorithm. The FLC inputs are batteries state of charge (SOC) and net power flow, FLC outputs are the power rate of batteries, photovoltaic and diesel generator. Data for weekly solar irradiation, ambient temperature and load profile are used to tune the proposed controller by using cuckoo search algorithm. The optimized FLC is able to minimize loss of power supply probability (LPSP), excess energy (EE) and levelized energy cost (LEC). Moreover, the results of CS optimization are better than of particle swarm optimization PSO for fuzzy system controller.

1. Introduction

In last decade, the application of alternative energy sources such as wind, solar, biomass, and hydro has become more widespread mainly due to needs for better reliability, higher power quality, more flexibility, less cost and smaller environmental foot-prints [1]. Many studies have shown the importance of renewable energy systems in rural electrification and reduction of the emission of greenhouse gases [2]. However, their applications are limited by their optimal placement, design and control with low cost, high reliability and acceptable power quality. Thus making the optimal control of renewable energy source is unique way to make the overall system more economical and serve higher power quality [3–5].

Application of artificial intelligence technologies to deal with the problems of the power source which uses multiple sources has been an active area due to their robustness and ability to deal with complex systems easily [6]. However, the traditional approaches cannot solve the problems of Hybrid Power System (HPS) in which the information is often incomplete and qualitative in nature with multiple conflicting objectives must be satisfied. In this environment, artificial intelligence such as neural networks, fuzzy logic and bio-inspired algorithms can enhance the performance of HPS for accurate results.

A analysis of the literature on the hybrid power system problem reveals that many optimization methods have been proposed for solving the energy management system problem [7–13]. Some researchers have developed methods based on artificial neural network for the optimum operation and forecasting meteorological data for local energy performance, scheduling the tasks demanded by the user and maximizing the use of local generation [14–17]. Previous works by other researchers have reported on the development of un-optimized fuzzy logic controllers for optimal power flow [18–22]. Others, developed optimal FLC by using the Hopfield neural network [23], HNN is utilized to automatically tune the FLC membership functions instead of adopting the trial-and-error approach, but this method needs historical data to be efficient. In another studies, optimal FLC using evolutionary programming has been utilized, for example, the genetic algorithm (GA) is applied for the simultaneous design of membership functions and rule sets for maximum-power-point tracker for a stand-alone PV system [24,25].

The hybrid genetic algorithm–simulated annealing algorithm is used in [26] to search the optimal linguistic hedge combination in the linguistic hedge module. The results showed that the optimized FLC is better than un-optimized FLC or PI controller.

The particle swarm optimization (PSO) algorithm is used in [27] for tuning a FLC that tracks maximum power point in a grid-connected photovoltaic (PV) inverter. In another studies, particle swarm optimization is adopted for solving the optimal power flow (OPF) problem with uncertainties by forecasting load demand and wind speed to prevent errors [28]. Optimal energy management using FLC-PSO is discussed in [29,30] for operating an autonomous hybrid power system. From the simulation results, it is observed

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that the fuzzy controller reduces error and gives rapid response to environmental changes.

The objective of this paper is to propose an optimized fuzzy logic controller which is developed for operating a standalone hybrid power system based on cuckoo search (CS) algorithm, while satisfying the underlying capacity and operational constraints. The CS is used to adjust the shape of the system membership functions of FLC to achieve a better performance comparatively with conventional FLC or optimized FLC based on PSO algorithm. Actually data for weekly solar irradiation, ambient temperature and load profile are used to simulate a real hybrid power system. The costs of installation, operation and maintenance are used to evaluate the cost of energy delivered.

This paper is organized as following: the mathematical model used for the hourly simulation of the system is detailed in Section 2, including the economic calculations performed. In Section 3, the power reliability model based on loss of power supply probability is developed. The Fuzzy logic controller design used to control HPS is given in Section 4. This FLC optimized using cuckoo search algorithm is given in Section 5 with giving the detailed description of algorithm used. The simulation results and discussions are given in Section 6.

2. System structure and modeling

A hybrid power system consists of PV array, diesel generator, battery bank, inverter, charge controller, and other accessory devices and cables. A schematic diagram of the basic hybrid power system is shown in Fig. 1. The PV array produces energy from solar irradiation to satisfy the load demand. When energy array of PV is abundant, the generated power, after satisfying the load demand, will be supplied to feed the battery bank for next use. On the contrary, when energy sources are poor, the battery will release energy to assist the PV array to cover the load requirements until the storage is depleted. In this case, the DG produces the energy to satisfy the load demand and the excess energy will be supplied to feed the battery bank. The differential power flow of the system is given as following:

$$dP = P_{pv} - P_{load} \quad (1)$$

The differential power flow represents the difference between available solar power and the power demand.

In order to simulate the performance of the hybrid plant, mathematical models have been taken for all components based on electrical models to simulate their real behavior.

2.1. PV generator model

Photovoltaic conversion of the sun irradiation implies conversion of the energy of solar irradiation into the electrical energy. The power produced by the PV system is estimated by the following equation [31]:

$$P_{pv} = \eta_{pv} A_{pv} G \quad (2)$$

where A_{pv} is PV array area (m^2), G is solar irradiation (kW h/m^2) and η_{pv} represents the PV generator efficiency and is given by:

$$\eta_{pv} = \eta_{pv\_ref}\eta_{\mathrm{MPPT}}[1 - \beta(T_c - T_{c\_ref})] \quad P_{pv} = \eta_{pv} A_{pv} G \quad (3)$$

where η_{pv_ref} is the reference module efficiency evaluated at solar radiation flux of 1000 W/m and at the reference temperature T_{c_ref} which is usual taken as 25 °C [9,32], η_{MPPT} is the power conditioning efficiency which equals to 1 if a perfect maximum power tracker (MPPT) is used. β is the generator efficiency temperature coefficient, it is assumed to be a constant and for silicon cells the range of β is 0.004–0.006 per °C, T_c is the cell temperature (°C) and can be calculated as follows:

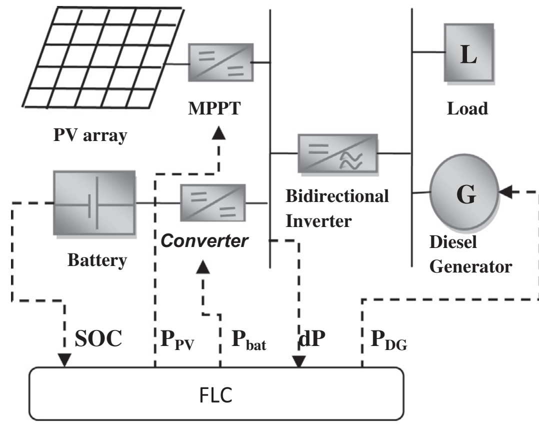

Fig. 1. Schematic diagram of the hybrid power system.

$$T_c = T_a + [(\mathrm{NCOT} - 20)/800]G \quad (4)$$

where T_a is the ambient temperature (°C) and NCOT is the nominal cell operating temperature (°C).

2.2. Battery model

Currently, battery technology is being considered in research and development. The CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) developed a model to predict charge and discharge for lead-acid battery based on work of Copetti and Chenlo [33]. This model presents a good performance to represent dynamic and complex battery operation [34]. The equations are normalized with respect to the total ampere-hours that may be charged or discharged in 10 h at 25 °C (C_{10} capacity), and it considers the low current operation and temperature effects of the battery capacity. Eqs. (4) and (5) show the capacity equation [35].

$$C_T = 1.67C_{10}(1 + 0.005\Delta T_a) \quad (5)$$

$$C = \frac{C_T}{1 + 0.67\left(\frac{|I|}{I_{10}}\right)^{0.9}} \quad (6)$$

where $\Delta T_a = T_a - 25$ is the temperature variation from the reference of 25 °C, and T_a is the ambient temperature in °C, C_T is the maximum capacity of the battery (A h), and C is the ampere-hours capacity at the charge or discharge constant current $I(A)$, I_{10} is the current of fully discharges of battery from its nominal capacity, C_n, in 10 h, we have taken the battery current as absolute value $|I|$ because in simulation, we assumed that the battery current is negative in discharging and positive in charging, however the capacity is always positive.

The state of charge (SOC) of the battery in charging is calculated using the following equation:

$$\mathrm{SOC}(t+1) = \mathrm{SOC}(t) \cdot (1 - \delta(t)) + (I_{Bat}(t)\Delta t \eta_{ch}(t))/C_{Bat} \quad (7)$$

The state of charge (SOC) of the battery in discharging is calculated using the following equation:

$$\mathrm{SOC}(t+1) = \mathrm{SOC}(t) \cdot (1 - \delta(t)) + (I_{Bat}(t)\Delta t)/C_{Bat} \quad (8)$$

where $\delta(t)$ is self discharge.

The maximum electrical current delivered by battery bank is depend by current SOC