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Control, analysis and optimization of hybrid PV-Diesel-Battery systems for isolated rural city in Algeria

A. Yahiaoui [a,*], K. Benmansour [a], M. Tadjine [b]

[a] University of Medea, Electrical Engineering Department, Algeria
[b] Control Laboratory Processes, National Polytechnic School, 10 Avenue Hassen Badi, BP. 182, El-Harrach, Algiers, Algeria

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ABSTRACT

A power system consisting of a Photovoltaic (PV) array panel, diesel generator Battery banks and load is considered in this paper. A novel approach is proposed for optimal design of hybrid renewable energy systems. The particle swarm optimization (PSO) algorithm has been applied to minimize simultaneously the total cost of the system, loss of load probability (LLP) and CO_2 emission of the hybrid power generation system in isolated rural village in south Algeria named "Ilamane". These geographical data is as follows: Latitude: 23.12° N, Longitude: 5.27° E and Altitude: 1928 m. This study also reveals the Importance of PV and battery banks systems. Without their connections the annual cost of diesel generator becomes considerably high. Moreover, the proposed method is effectively used to deal with the cost reduction of a hybrid system under non-existence or unmet load condition, finally the results of our algorithm is compared with the software homer.

1. Introduction

Several projects in the field of renewable energy system (RES) are developed in the last two decades. Growing evidence of global warming phenomena, rapid depletion of fossil fuel resources and fast escalation in world's population caused widespread attention to seek energy from RES (Yazdanpanah, 2014). Among the renewable energy sources, solar energy is a suitable candidate as it allows direct conversion of this form of energy to the electrical energy by using photovoltaic (PV) systems (Reisi et al., 2013). In Algeria, steps have been drawn for a new national strategy for rural development, on a ten-year horizon (2005/2015), and rural revival plan. The part relating to renewable energy and the promotion of energy efficiency is an important focus in national energy policy. So, also storage and consumption of energy, particularly electricity. The hybrid combination of PV-battery-diesel systems is economically feasible in many cases for electric energy supply in isolated areas where the electric utility is not available. PV-Diesel system has greater reliability for electricity production than a PV only system or diesel only system. It means that hybrid power systems have greater flexibility, higher efficiency and lower costs for the same quantity of energy production (Ashari et al., 2001). In addition, the integration of PV system with battery storage and diesel unit as a backup system provides a reduction in the operational costs and emitted air pollutants to the atmosphere (Wies et al., 2004). Several methods can be found in literature for optimal design of hybrid PV-Diesel-Battery system (Ashari and Nayar, 1999; Ohsawa et al., 1993). But there are a few works that consider more than one objective in optimization problem of hybrid resources energy system (HRES) by using evolutionary algorithm (EA) (Niknam et al., 2011; Dufo-Lopez et al., 2011; Avril et al., 2010). El-Hefnawi (1998) presented an optimization method to design hybrid PV-Diesel-Battery system. The optimization method starts by modeling of diesel generator and then optimizing the PV and battery sizes in terms of minimum number of storage days and the minimum PV array area. Eke et al. (2005), developed a linear mathematical model to minimize total cost of an hybrid renewable energy system. They only considered solar panels and wind turbine and used a graphical method to solve the optimization problem. Dufo Lopez and Bernal-Agustin (2005) developed the hybrid optimization by genetic algorithms program that uses GA to determine the sizing and operation control of a PV-Diesel system.

This paper presents optimization of multi objectives problem and optimal sizing of PV-Diesel-Battery systems using PSO. Three objective functions are considered for minimizing the total cost of the system, the total CO_2 emission produced by diesel generators, and Loss of load probability LLP. PSO is an adequate and fast search technique for solving complex problems when other techniques are unable to reach the optimal solution (see Table 1).

* Corresponding author.
E-mail addresses: yahiaoui.industry@gmail.com (A. Yahiaoui), kh.benmansour@gmail.com (K. Benmansour), tadjine@yahoo.com (M. Tadjine).

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Table 1
Result of sizing PSO algorithm.

LP = 3% and FC ⩽ 250 l	
Number of photovoltaic modules	75
Number of battery banks	90
Number of diesel generators	3

2. Mathematical modeling

2.1. Photovoltaic system

The system configuration of PV-Diesel-Battery system in this study is shown in Fig. 1. The output power from PV panels is influenced by insolation condition shown in Fig. 2. Hence, choosing a suitable model for simulation is very essential. The simple model of PV panel as a function of the area, insolation condition and its efficiency is utilized in this research (Senjyu et al., 2007; Nelson et al., 2006) (see Fig. 3).

$$P_{pv}(t) = n \cdot A_p \cdot N_{pv} \cdot G(t) \quad (1)$$

where n energy conversion efficiency, (%). A_p is the area of single PV panels, (m^2). N_{pv} is the number of PV panel. $G(t)$ is the insolation data, (W/m^2).

2.2. Battery banks

The charge and discharge mechanism of battery banks depends on the condition of generated power in the hybrid system. Meanwhile, the power generated by hybrid system at any time t can be expressed by the following equation (Suryoatmojo et al., 2014):

$$P_G(t) = P_{pv}(t) + P_{DG}(t) \quad (2)$$

where $P_{DG}(t)$ is output power from diesel generators. During charging process, if the total output of PV panels and DG_s exceeds the load demand, the available battery banks capacity at hour t can be described by the following equation (Borrowy and Salameh, 1997):

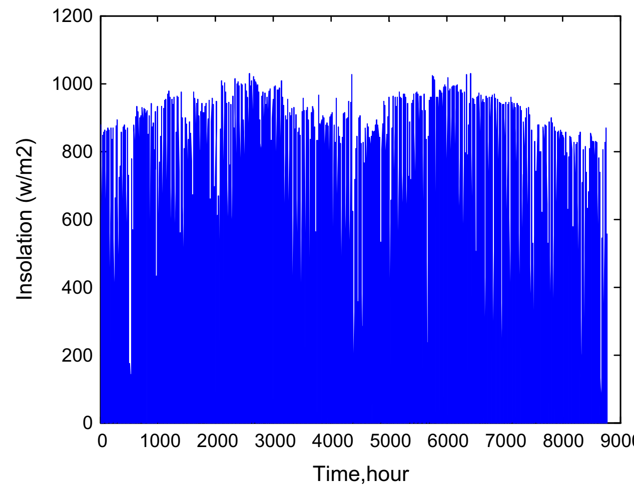

Fig. 2. Annual insolation data.

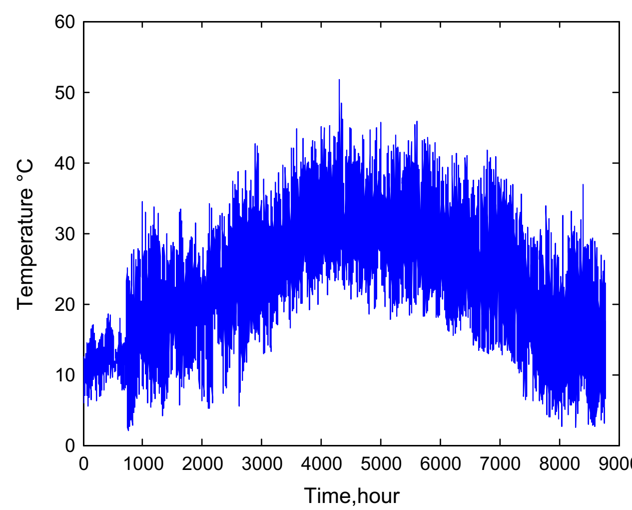

Fig. 3. Annual temperature data.

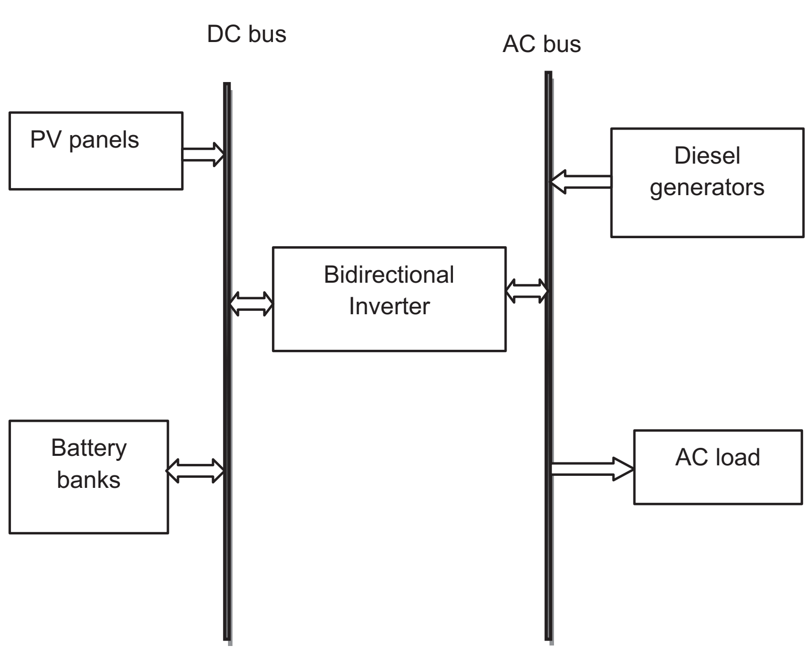

Fig. 1. Configuration of the system.