Renewable Energy 81 (2015) 123–135

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Demand side management of household appliances in stand-alone hybrid photovoltaic system

Randa Kallel, Ghada Boukettaya*, Lotfi Krichen

University of Sfax National School of Engineering, Department of Electrical Engineering, Bp w, 3038 Sfax, Tunisia

ARTICLE INFO

Article history:
Received 10 July 2014
Accepted 10 March 2015
Available online 28 March 2015

Keywords:
Isolated hybrid system
PV
Battery
DSM
Load modes

ABSTRACT

In this paper, a demand side management control (DSM) acting on the load profile for an isolated hybrid photovoltaic/diesel/battery system for residential application was investigated. This control is a new strategy that compensates the global power flow of a distributed generation system. In fact, using the DSM strategy, the renewable energy can be used effectively to satisfy the demand and reduce the size of the system components. It leads to satisfy customers' continuous requirements to minimize the loss of power supply propability (*LPSP*), to extend the battery life time minimizing the storage system charge cycle, and to reduce fuel consumption and CO_2 emission together with the diesel generator operation rate (*DGOR*). Consequently, the DSM strategy is implemented to ensure the minimum system cost. The DSM algorithm relies on the customer's energy consumption record, the instantaneous available PV energy and the state of charge (*SOC*) of the battery storage system. This could be achieved through switching between two action modes on the consumption profile: time shifting load mode, amplitude modulation load mode. To prove the effectiveness of the proposed control strategy, two scenarios were investigated. The first one describes the system's simulation for two typical days. The second scenario is performed using annual profiles of photovoltaic and load powers. To highlight the benefits of the proposed strategy for the residential hybrid system applications under various conditions, a comparative study between the power management strategies without and with DSM was presented.

1. Introduction

Global energy consumption continues to grow rapidly causing too much stress on the fossil fuel energy resources and increasing the amount of greenhouse gas emissions that lead to the global warming phenomenon [1]. During the last few decades, it has been estimated that 60% of the electricity in the world is consumed by the residential electrification causing an increase in the greenhouse gas emissions [2]. Therefore, the use of the renewable resources particularly in the residential sector is one of the most efficient and reliable solutions for a proper sustainable energy [3]. Thanks to suitable energy management strategies, such systems will significantly reduce the cost of energy consumption [4]. Nowadays, wind and photovoltaic sources are the most commonly used energy sources all over the world mainly in rural areas where access to electricity is almost impossible [5].

In domestic applications, PV systems are more commonly used than wind energy systems, due to their quiet operation, low maintenance and reliability [6], particulary in African regions [7].

Because of the random nature of renewable generation, it is difficult to implement renewable sources in an autonomous system without a storage element and a backup source [8,9]. The justification of the auxiliary source use, in the isolated system, is made with the hybrid indicator which is the most widely used method [10]. So, the choice of the diesel generator (DG) as an auxiliary source is considered as the most efficient and economical solution [11]. In addition, the most universally prevalent means for the storage implied by such operations is the electrochemical Lead Acid battery thanks to its technical maturity and low investment cost [12,13].

A good sizing of these system components (PV, battery and DG) is needed to meet the load demand, in order to minimize the system cost, the diesel generator fuel consumption and consequently the greenhouse gas emissions [14]. Several authors have therefore developed some optimization methods mainly based on evolutionary algorithms to determine the optimal combination of photovoltaic modules and a number of needed batteries. For example, Ref. [15,16] present a methodology for the optimal design

* Corresponding author.
E-mail addresses: randa.kallel@hotmail.fr (R. Kallel), boukettayaghada@yahoo.fr (G. Boukettaya), lotfi.krichen@enis.rnu.tn (L. Krichen).

http://dx.doi.org/10.1016/j.renene.2015.03.024
0960-1481/

of the hybrid power system using a genetic algorithm to ensure the minimum system cost.

A power management strategy (PMS) is necessarily developed for a renewable hybrid system. It includes an auxiliary source and storage system to control the power flow between the different energy sources, according to the available renewable power and the state of charge of the storage system. In Ref. [5], a PMS is developed of an isolated hybrid micro-system for residential electricity supply, comprising of a variable speed wind turbine (WT) and a PV panel. Ref. [9] develops a PMS based on fuzzy logic to control an autonomous hybrid WT/PV/battery/Fuel Cell system supplying a constant demand in the studied city. In Ref. [17], an overall PMS is proposed for stand-alone PV/FC energy system.

It seems that the most energy efficient solution in a PMS, is to try to generate a synchronous consumption profile with the production one. In fact, loads can be controlled to obtain a yield management by including the DSM strategy [18]. Acting on the load profile has lately become a control lever used in the new architectures for energy production system in rural areas [14]. The DSM strategy is used in this study to guide the consumers towards an economical choice [19]. Indeed, it attempts to modify the consumer profile in order to maximize consumption when the renewable resource is available and decrease it when production is low [19]. Then, this strategy consists in regulating energy consumption time and quantity in order to reduce the stress on the electrical system and make use of more efficient energy resources. Besides the DSM strategy reduces the size of the system components and the use of fossil energies derived from the operation of the conventional source. It also minimizes the excessive use of the storage system to increase the battery life span which mainly depends on the number of charge–discharge cycles [16], and consequently reduces the system cost [20,21].

Several authors have focused about modifying the load profile in order to optimize the electrical system from production to delivery to the consumer. Therefore, they proposed various processes to control the DSM strategy taking into account some predictive information. Ref. [22] develops this control strategy to improve the energy performance of the PV energy system, plan tasks requested by the consumer and maximize the utilization of the generated power using neural networks. Ref. [21] develops a Binary Particle Swarm Optimization (BPSO) algorithm for the optimization of DSM strategy in a household application leading to system cost savings. Ref. [23] proposes an intelligent DSM strategy based on Grey Prediction algorithms which can address the system design principles successfully and guarantee the effective operation of an autonomous polygeneration microgrid in remote areas. Ref. [14] develops a sizing algorithm for an hybrid renewable energy system in remote area through the addition of a DSM strategy.

In this paper, a new control strategy was developed in an isolated PV/battery/diesel system based on domestic consumption control of a house in remote area. Indeed, according to the available renewable energy and a typical consumer profile which were previously defined, a DSM strategy was developed to guide consumers towards an economical choice. Indeed, the power system components can be reduced in size and the available PV energy can be used in appropriate ways, which leads to a reduction of the system cost, to the extension of the storage system life time and reduce fuel consumption and CO_2 emission coming from diesel generator operation. In fact, the DSM strategy has an effect on the time pattern and power magnitude for each household appliance in order to minimize resorting to the storage system and the diesel engine operation.

The studied system uses PV panels associated with a DC–DC converter ensuring a maximum power extraction with the P&O algorithm [24]. In order to regulate the DC bus, a lead acid battery bank is associated to the renewable source to absorb or supply the power difference, for that it is linked to a buck boost converter to control the exchange when the *SOC*has not reached its limit values yet. On the AC side, the load and the diesel generator are connected to the DC bus through a bidirectional inverter as shown in Fig. 1. The PV inverter is synchronized with the DG when they supply the household with electrical power simultaneously. To improve the effectiveness of the proposed DSM strategy, a comparative study through simulation was achieved between the traditional power flow control with and without DSM under various conditions. The proposed system was tested and simulated in two scenarios: a daily tracking over 24 h in summer and winter seasons and a monthly monitoring.

The remainder of this article was organized as follows. Section 2 described the autonomous hybrid studied system. In Section 3, the

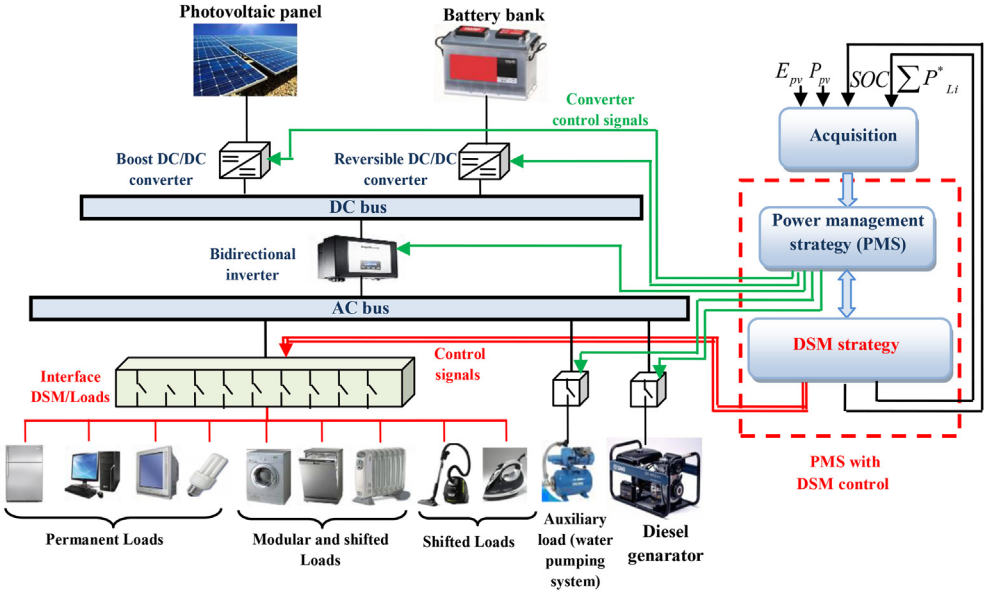

Fig. 1. Architecture of the studied system.