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Multi input-output fuzzy logic smart controller for a residential hybrid solar-wind-storage energy system

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ABSTRACT

This study concerns the conception and development of an efficient multi input-output fuzzy logic smart controller, to manage the energy flux of a sustainable hybrid power system, based on renewable power sources, integrating solar panels and a wind turbine associated with storage, applied to a typical residential habitat. In the suggested topology, the energy surplus is redirected to an electrolysis system to produce hydrogen suitable for household utilities. To assume a constant access to electricity in case of consumption peak, connection to the grid is also considered as an exceptional rescue resource. The objective of the presented controller is to exploit instantaneously the produced renewable electric energy and insure savings of electric grid energy. The proposed multi input-output fuzzy logic smart controller has been achieved and verified, outcome switches command signals are discussed and the renewable energy system integration ratio is highlighted.

1. Introduction

Increasing environmental awareness, conservation of natural resources, rising cost of fossil fuels and the continuous search for lowering energy dependency on fossil fuels, have motivated the development of national legislations enabling the deployment of alternative energy technologies [1]. To improve the nation's energy independence and security, the best solution is to efficiently use renewable energy resources including solar, wind, hydro, geothermal, and tidal energy [2]. In order to optimize the use of the renewable energy source, wide-scale distributed renewable energy systems (DRERs) are more widespread than the large-scale centralized installations [3]. The environment could be protected from further deterioration if the renewable energy sources are used more intensively for the production of energy. Furthermore, the solar and wind energy are free and clean, although available at variable levels related to the local environment parameters (insolation, wind speed and temperature), their long life-time and low maintenance requirements make them attractive [4]. As shown by Tascikaraoglu et al. [5] and Onur et al. [6], the combinations of PV and WT systems with energy storage source to respond to the lack of power under load peaks, have a widespread use, to insure a continuous and reliable energy source for consumers. Zhang et al. [7] and Tudu et al. [8] consider the integration of solar and wind energy as a hybrid energy generation system mainly focusing on sizing and optimization. Other studies center the energy management system designed on minimizing the micro-grid operating costs [9,10], or maximizing the revenues according to the distributed generation bids and the market price of energy [11]. To avoid time wasting and insure accurate measurements of PV panels, before sizing hybrid energy system, Zegaoui et al. [12] proposed a universal real-time device simulator based on transistor. Moreover, Khatib et al. [13] studied both sizing configuration and methodologies for PV and storage system, where challenges and limitations for PV and storage of standalone systems where highlighted. In order to handle simultaneously the uncertainty of the load demand, the wind and solar energies, Ahmadian et al. in Ref. [14] propose a new approach, based on Point Estimate Method (PEM) and intuitively compared with Monte Carlo Simulation (MCS) as well as conventional PEM for a case study in Iran. An optimal scheduling of batteries, associated to wind turbines generators for grid distribution grid is presented in Ref. [15], in which the point estimate method PEM and Tabu search/particle swarm optimization are used for optimal energy flow. The same authors, in Ref. [16] have considered the storage and distributed generation

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(DGs) planning, dealing with Plug-in electrical vehicles (PEV) uncertainty problems; The latters being fixed by using Tabu Search (TS) and Simulated Annealing (SA) algorithms, respectively.

Sizing and management technics of renewable energy based micro-grid for green buildings has been presented by Pavan et al. [17]; with the support of HOMER software, the authors studied technical feasibility and optimal economy by the use of renewable energies sources so as wind and solar, focusing on the integration percentage of these clean energies and the CO_2 emission reduction. In this brief review of existing hybrid systems, we note an interesting approach done by Adouane et al. [18] who proposed a photovoltaic system associated with a GPL generator driven by a microcontroller adopting classic "ON/OFF" electronic switch control. Additionally, an adaptive power smoothing fuzzy logic controller is proposed by Nahidul et al. [19] to manage battery storage state of charge SOC through a DC-DC buck control scheme converter and a frequency resynchronization technique command between the AC and DC buses for islanded and grid connected micro-grid systems. Zhou et al. [20] have presented a smart feedback home energy management strategy between the energy suppliers and the end-user under a continuous monitoring of the home energy consumption, reminding by that the customers have to activate or disable flexible appliances taking into account the limits of available energy.

This work concerned the development of an efficient and low cost hybrid energy system built with standard components for renewable energy harvesting and storage which are solar panels, small wind turbine, lead acid batteries and converters/inverters. A smart controller based on fuzzy logic assumes the management of this hybrid system. To size the hybrid renewable energy system, a normal integration in grid- rural or urban housing was considered. To increase the global efficiency of the system, a novel configuration with smart management is presented here where the load state is considered as an additional input of the controller insuring in real time the tracking of climatic changes and load demands. Generally, in standard systems, energy excesses generated by the various renewable sources are dissipated as pure losses in dump loads. Here, the high efficiency of the hybrid system is achieved by an original recovering of these excesses to produce hydrogen through an electrolyzer system for air or water heating and for cooking. We have discussed the savings of this solution compared to standard grid-connected installations without renewable and/or hybrid energy system under the same environmental conditions.

The suggested hybrid power system has been sized according to the electrical energy needs for a housing load considering its instantaneous and average daily maximum value over one year. Within this starting principle for the sizing of the installation, we have considered a typical house for a family with two children. No electric heater or cooler is considered in this type of housing. The current contribution is dedicated to installation on the northern Mediterranean coast of Algeria, and more generally in locations of the Mediterranean coast. Nevertheless, if we consider typical countries of the south coast of Mediterranean sea, they are vast and the temperature differences between the North and the South are very important. For example considering Algeria, Dabou et al. [21] experimentally showed that in the South PV panels efficiency and performance decrease to 10.29% and 76.5%, respectively, during summer, when measured temperature is about 41.1 °C in clear sky day. Thus, we have considered the performance based on a comparative study of four types of PV generators done in the same location's area [22]. In this area, weather conditions are quite mild, and the temperature rarely excesses 36 °C even during summer.

Due to the specific location of the geographic site chosen for this study, we have favored a solar source instead of other renewables sources.

It is to be noted that this work constitutes the first fundamental and indispensable step for a more global development of an efficient renewable energy system based on new topology of energy system hardware and control. Thus, this contribution focuses on the presentation of all the concerned theoretical formulated concepts, then followed by important phases of modeling and simulation validating the ability of the system to be efficient.

2. The hybrid power system

The hybrid power system shown in Fig. 1 is based on the integration of a photovoltaic array, a wind turbine generator, a storage battery bank, a full bridge single-phase DC/AC inverter and an electrolysis system for the production of hydrogen. The voltage of the input intermediary bus is chosen at 24 Vdc to avoid expensive additional DC/DC converter for sources and storage.

The domestic equipment operates at 220 V–50 Hz with an optimal use of the energy thanks to economic lighting lamps and zenithal daylight. Table 1 shows the standard set of load parameters related to the housing. The standard equipment found in this

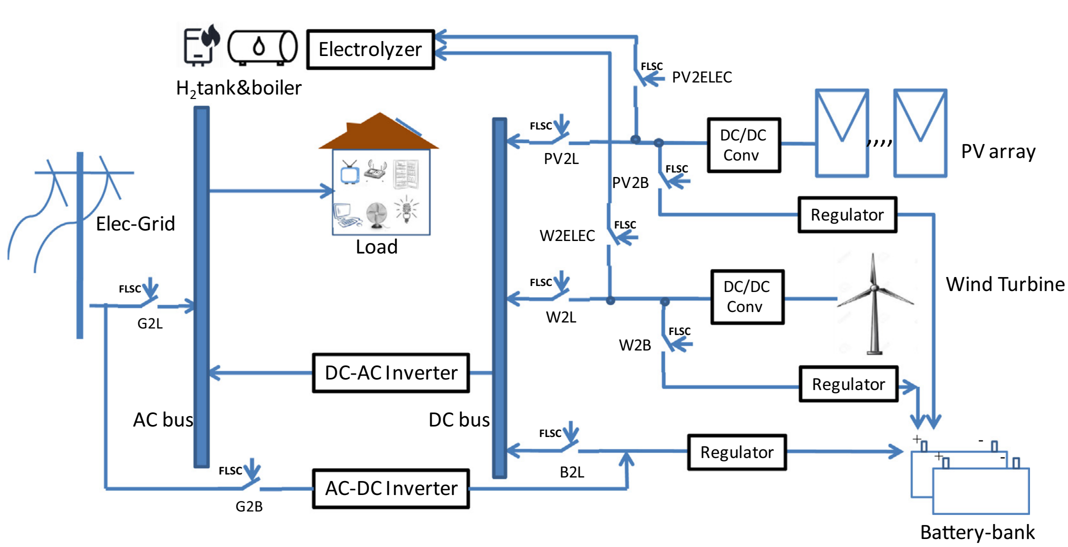

Fig. 1. Synoptic of the proposed HPS.