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Hybrid diesel-wind system with battery storage operating in standalone mode: Control and energy management – Experimental investigation

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ABSTRACT

In this work, an experimental Hybrid diesel-wind system with battery storage operating in standalone mode, is presented. The system is comprised of a small scale wind turbine based on 1 kW PMSG, storage batteries, a charge controller, an inverter, a diesel generator, a weather station, a data logger, an electrical load prototype realized and developed such as to simulate a typical house consumption, the controller and the current and voltage sensor.

The main task of the proposed scheme was confirmed under three considered scenarios corresponding respectively to low wind speed and high state of charge of batteries, high wind speed and moderate state of charge of batteries and moderate wind speed and low state of charge of batteries while the extensive measurement results demonstrate the system ability to run as expected each of these modes. On the other hand, the data logger via the realized current and voltage sensor as well as the different software and computer tools used and exploited in the present experimental study allowed the permanent supervision and follow-up of the whole system which enabled also to intervene at any time in order to improve the behavior of the whole system.

1. Introduction

Energy is a critical enabler and is becoming more important to economic growth. Each progressive economy requires safe access to modern sources of energy to fortify its economic growth and development. Hence, ensuring access to affordable, reliable, sustainable and modern energy is fundamental for jobs, security, climate change and food production, enhancing competitiveness and promoting economic growth. Research proves that there is a significant relationship between socio-economic growth and electricity consumption [1].

Electricity is an energy carrier. It is produced by transforming primary energy sources, such as fossil fuels (coal, oil, natural gas, etc.) or nuclear fission, into electrical power. An important disadvantage of generating electricity by these latter sources is the adverse environmental impact, such as the greenhouse effect due to the CO_2 increases and the nuclear wastes problem. Therefore, the interest is to replace these sources by less harmful other ones for producing electricity. It seems that renewable energy sources are among the most efficient and consistent solutions for sustainable and suitable energy [2–4]. However, the fluctuating and stochastic nature of the wind and solar power generation may not be effective in terms of costs, efficiency and reliability. A viable replacement solution is to combine these renewable energy sources to the conventional generator (diesel) to form hybrid energy production systems. Hybrid systems can produce continuous high quality electric power. Therefore, the key design goals for hybrid power generation systems are fossil fuel consumption and diesel run time reduction.

Hence, there are many topologies of hybrid power systems. In the literature, several hybrid systems are described, such as: PV/Wind Turbine/Battery [5–14] PV/Wind only [15–17], PV/Wind Turbine/Battery/Diesel [18–22], PV/Battery/Diesel [23–27], PV/Diesel generator power systems without storage [28–31], PV/Wind/Diesel without storage [32], PV/Wind/Diesel/Micro

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hydroelectric turbine [33–35] PV/Wind/Fuel cell [36–38].

The hybrid energy sources are generally selected for a specific site based on a combination of various factors including the seasonal availability and sustainability of energy sources, the load demand, site topography, the cost of storage and energy distribution, and seasonal energy needs [39].

Yang, Hongxing et al. [5] reported that the research and monitoring results of the hybrid project showed good complementary characteristics between the solar and wind energy, and the hybrid system turned out to be able to perform very well as expected throughout the year with the battery over-discharge situations seldom occurred.

In Ref. [6] an optimal sizing method of the configurations of a hybrid solar–wind system employing battery banks based on a genetic algorithm has been applied to the analysis of a hybrid system which supplies power for a telecommunication relay station with good optimization performance obtained.

In Ref. [7] the hybrid system analysis showed that for a small community consuming 53,317 kWh/year the cost of energy is 0.47USD/kWh with 10% annual capacity of shortage and produces 89,15 kWh/year of which 53% electricity originate from wind and the remaining part from solar energy.

The work of Nandi, Sanjoy Kumar, and Himangshu Ranjan Ghosh [8] showed that the least cost of energy (COE) is about USD 0.363/kWh for a community using 169 kWh/day with 61 kW peak and having minimum amount of access or unused energy.

The results published by Ma, Tao et al. [9] demonstrate the techno-economic feasibility of implementing the solar–wind–battery system to supply power to the remote island.

The Kaabeche, A. et al. [10] paper recommends an optimal sizing model based on an iterative technique, to optimize the capacity sizes of different components of the hybrid photovoltaic/wind power generation system using a battery bank.

In Ref. [11] research it is deducted that the power produced employing PV panels and wind turbine generators is based on weather conditions. As a result, this system is unreliable. The hybridization of this system with another source such as batteries or diesel generator increases significantly the reliability of the whole system.

In another study, Kaabache et al. [12] performed technically and economically the optimal size of a PV/wind hybrid energy conversion system using a battery bank designed to supply a small residential household situated in the area of the Center for Renewable Energy Development (CDER) localized in Bouzaréah, Algeria (36°48′N, 3°1′E, 345 m).

Zaibi, Malek, et al. [13] developed and tested, using a dynamic simulator, a hybrid system with its Power Management System.

Ekren, Banu Y., and Orhan Ekren [14]. presented the optimum sizes of PV, wind turbine and battery capacity obtained under various auxiliary energy unit costs and two different loads. The optimal results were confirmed using the Loss of Load Probability (LLP) and autonomy analysis.

The paper developed by Nehrir, M. Hashem et al. [15] reported the development of a computer approach for evaluating the general performance of stand-alone wind/photovoltaic generating systems.

The paper [16] aimed to optimally harness the wind resource with the support of solar energy through hybrid technology for a north-east Indian state Tripura (low wind topography).

Based on the fact that the potential of wind and solar energy is not evenly distributed in Oman, the paper [17] discussed the optimal sizing process of two proposed hybrid PV–Wind plants in Oman.

Chen, Yaow-Ming et al. [18] proposed a novel multi-input inverter for the grid-connected hybrid photovoltaic (PV)/wind power system in order to simplify the power system and reduce the costs.

Saheb-Koussa, D. et al. [19] revealed that the energy cost of photovoltaic/wind/batteries/diesel hybrid system depends largely on the renewable energy potential quality.

The obtained results by Al-Badi, A. H., et al. [20] showed that the PV energy utilization is an attractive option with an energy cost of the selected PV ranging between 0.128 and 0.144 $/kWh at 7.55% discount rate compared to an operating cost of 0.128–0.558 $\kWh for diesel generation.

Khelif, A., et al. [21] in their paper investigated the feasibility of hybridization of AFRA diesel power plant with a photovoltaic (PV) system whereby the performances of each part were simulated. The simulation results confirmed that the hybrid configuration is truly feasible even though the levelized electricity cost is very sensible to fossil fuel cost.

Abidi, Mohamed Ghaieth et al. [22] presented a new control strategy for optimal energy consumption in microgrids based on forecasting and load shedding method. The obtained results showed clearly a high improvement of degree of availability of electrical power distribution in microgrids.

Shaahid, S. M., and M. A. Elhadidy [23] showed in their paper that for photovoltaic–diesel–battery hybrid system configurations, the operational hours of diesel generators decrease with the increase in PV capacity.

In the paper [24], the economic analysis of utilization of hybrid PV–diesel-battery power systems to meet the load of a typical residential building in different provinces/zones of K.S.A. was performed by analyzing long-term solar radiation data. For a given hybrid system, the obtained results showed that the PV penetration is higher in Southern and Northern Province as compared to other provinces.

Park, Jae-Shik et al. [25] proposed an operation control of a photovoltaic/diesel hybrid generating system for a small ship in consideration of the fluctuating photovoltaic power due to solar radiation. The validity of the proposed control method is shown by the numerical simulation based on the experimental data of a photovoltaic system.

In Schmid, Aloısio et al. [26] paper the simulations showed that PV systems with energy storage connected to existing diesel generators, allowing for them to be turned off during day time, provide the lowest energy costs.

In the paper [27] Ashari, Mochamad, and C. V. Nayar presented dispatch strategies for the operation of a solar photovoltaic (PV)–diesel–battery hybrid power system using ‘set points’. A computer program for a typical dispatch strategy was developed to predict the long-term energy performance and the lifecycle cost of the system.

Ruther, R., et al. [28] demonstrated that hybrid diesel/PV systems without storage can be the most competitive option, if the introduction of PV in this sector is intended.

In the paper [29] the authors presented the results of an experimental study of a PV/diesel hybrid system without storage. Experimental results have showed that the sizing of a PV/diesel hybrid system by taking into account the solar radiation and the load/demand profile of a typical area may lead the diesel generator to operate near its optimal point (70–80% of its nominal power).

Dufo-López, Rodolfo, and José L. Bernal-Agustín [30]. showed the economic advantages of the PV-hybrid system. On the other hand, Lau, KYMFM Yousof et al. [31] showed that the suitability of utilizing the hybrid PV/diesel energy system over the standalone diesel system was based on different solar irradiances and diesel prices.

In the study [31] the authors found that a wind- PV–diesel hybrid power system with 35% renewable energy penetration (26% wind and 9% solar PV) is a feasible system with a cost of energy of