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Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system

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ABSTRACT

Renewable energy systems are proving to be promising and environment friendly sources of electricity generation, particularly, in countries with inadequate fossil fuel resources. In recent years, wind, solar photovoltaic (PV) and biomass based systems have been drawing more attention to provide electricity to isolated or energy deficient regions. This paper presents a hybrid PV-wind generation system along with biomass and storage to fulfill the electrical load demand of a small area. For optimal sizing of components, a recently introduced swarm based artificial bee colony (ABC) algorithm is applied. To verify the strength of the proposed technique, the results are compared with the results obtained from the standard software tool, hybrid optimization model for electric renewable (HOMER) and particle swarm optimization (PSO) algorithm. It has been verified from the results that the ABC algorithm has good convergence property and ability to provide good quality results. Further, for critical case such as the failure of any source, the behavior of the proposed system has been observed. It is evident from the results that the proposed scheme is able to manage a smooth power flow with the same optimal configuration.

1. Introduction

In the last few years, renewable based hybrid energy system has found attention due to increasing environmental concerns, energy demand, fuel prices and depletion of fossil fuels. In particular, solar and wind based generation systems have become sustainable and environmentally friendly options to supply power in isolated or off grid locations [1]. Solar photovoltaic (PV) energy conversion systems along with storage system have proved to be a very attractive method to provide electricity to the places like remote or off grid locations [2], residential households [3], off-grid location [4] and commercial buildings [5,6]. However, PV generation has a low energy conversion efficiency and cost of electricity per kWh is high. This led to a substantial growth in wind based power generation. Numerous researches focus on feasibility and optimum sizing of the wind based systems [7–9]. However, the major drawbacks for both wind and solar energy sources are their stochastic nature which raises concern about the reliability of power to the user. Therefore, to enhance the reliability, hybridization of both wind and solar energy is a suitable alternative. One's weakness can be compensated by the strengths of another. However, it increases the complexity of the system [10]. Stand alone solar-wind based hybrid energy systems have been analyzed in various researches in terms of cost effectiveness [11–13].

The biggest drawback of a stand alone solar-wind based energy system is its dependency on power back-up due to the irregular nature of both wind and solar resources. In case of a stand-alone hybrid system generally back-up is provided by diesel generator or energy storage devices such as batteries or ultra-capacitors. Usage of a diesel generator in hybrid system raises cost and environmental concerns. Fortunately, continuous advancement in technology, other renewable options such as biomass, bio-gas, mini hydro and fuel cell have been integrated along with solar and wind sources [14]. In the aforementioned renewable energy options, biomass seems to be a more viable option, especially in the case of agriculture rich countries. Biomass can be converted into many forms such as heat, electricity and bio-fuels [15]. Due to advancement in biomass gasification technology, electricity generated by biomass gasifiers is becoming popular especially in the rural areas. Biomass power generation plants have high load factor and cost effective [16]. Biomass power generation has been integrated along with PV, wind and other renewable energy sources. Stand alone and grid connected PV-biomass with or without storage is seen as a viable and cost effective option for electricity, particularly in developing countries [17,18].

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Thus, utilizing locally available renewable energy sources for generation of electricity can be a possible option at off grid or electricity deficient places. In case of rural areas enough biomass, wind and solar resources are available. Therefore, electricity demands of such areas can be met by intelligently harnessing these resources. Moreover, in the case of renewable hybrid energy system, the power generated needs to be stored in a large battery bank [19]. A typical self-sustainable hybrid energy system could be designed by incorporating renewable energy sources and storage systems. In case of such hybrid systems, various factors such as total cost of system, size and capacity of renewable energy sources plays a crucial role. Optimal power flow between different components of a hybrid system is required due to the intermittent nature of renewable energy sources. Two major parameters such as price of generating energy and reliability of the system are major challenges in hybrid systems. An optimal designed system should have the best selection of components while assuring the reliability of the system [20].

In the existing literature, limited work has been found in PV, wind and biomass based hybrid systems with energy storage. For instance, Balamurgun et al. [21] proposed a PV-biomass-wind hybrid system for rural areas of India. The authors performed economic analysis and component selection with the help of the standard software tool hybrid optimization model for electric renewable (HOMER). Rehman et al. [22] proposed a PV-biomass-wind based hybrid system for a location in Bangladesh. The system sizing was obtained with the help of HOMER. Dhass and Harikrishnan [23] evaluated a PV-wind-biomass hybrid system for rural electrification on the basis of life cycle cost. Ho et al. [24] integrated solar and biomass resources to make a small village self sustainable. To design hybrid system a mixed integer linear programming based model has been developed. Garrido et al. [25] presented techno-economic analysis of hybrid PV-biomass energy system for an off grid location in Mozambique using tool HOMER. It is inferred from the results that agricultural and food processing wastes could play an important role in energy generation, particularly in rural areas.

The aforementioned literature reveals that researchers have used either software tools or conventional optimization methods for performance analysis. However, software tools possess some serious disadvantages such as black box coding, single function minimization and require more computational time as compared to existing optimization techniques. However, many works have been identified in hybrid systems where the different researchers have proposed different conventional and evolutionary algorithms to achieve the optimal size of the components used in hybrid systems. Different research activities have been carried out using conventional techniques such as graphical construction method [26], iterative method [27], trade off method [29] and linear programming [28]. The problem with conventional techniques is that they often trap in local minima. To overcome these shortcoming numerous meta-heuristic evolutionary algorithms, i.e., genetic algorithm [30], particle swarm optimization [31], ant and bee colony algorithm [18], harmony search [32], bio-geography based optimization [33], etc. have been implemented in different hybrid systems. In recent years, a new trend has been observed where researchers are applying widely these evolutionary algorithms for optimal sizing of the hybrid energy system. To the best of authors knowledge, a very limited work is found, where the optimization of hybrid PV-wind-biomass along with the energy storage system has been explored.

From the above mentioned literature, it has been observed that there is a need of a hybrid system which consists of PV, wind and biomass along with an energy storage system especially in isolated or off-grid locations. The sizing of each equipment in any hybrid system is a challenging work. Despite of works in literature under different perspectives, the proposed work focuses on the hybrid energy system which is a combination of PV, wind, biomass and energy storage. The optimal sizing of components for all the above hybrid systems have been identified by using either software tools or by conventional and evolutionary algorithms. But none of the researchers have worked on the optimal sizing of PV-wind-biomass with battery bank as storage using evolutionary algorithms. The biomass resources can be harnessed along with wind and solar sources to enhance the reliability of the hybrid system. Therefore, in this paper, an autonomous hybrid PV-wind-biomass with battery system is proposed to fulfill the electrical demand of a typical village. A swarm based meta-heuristic, artificial bee colony (ABC) algorithm has been applied to realize optimal configurations of the proposed system. The major factor which differentiates ABC algorithm from other algorithms (such as GA and PSO) is that it employs a lesser number of control parameters. Also, it has a good convergence accuracy and potential to provide optimal results, like other evolutionary algorithms [34]. To compare the performance of the applied technique, the results achieved by the ABC algorithm have been compared with PSO and HOMER. A brief comparison is performed on the basis of the levelized cost of energy (LCOE). The configuration with least LCOE is considered the optimal one. The main objectives of this work are outlined as follows.

- To develop a mathematical model of an autonomous PV-wind-biomass energy system with battery bank to provide electricity for an off-grid location.
- To deduce the optimal size of the components used in the proposed system with the least LCOE by minimizing the net present cost (NPC) of the system by applying swarm based ABC algorithm.
- To compare results achieved from the ABC algorithm to results obtained with HOMER and PSO.
- To observe the performance of the hybrid system in the critical cases such as failure of any generating unit.

The major contribution of this paper is to design a cost effective and reliable hybrid PV-wind-biomass energy system with battery storage to meet the electrical load demand of small area which has enough natural resources. The mathematical modeling of various components and operational strategy in the proposed system have been discussed in detail. The detail cost analysis of the proposed hybrid system is performed by applying two evolutionary algorithms and one software tool. For optimal sizing and scheduling, results obtained by applying these different methods have been compared. Moreover, a critical case such as failure of one generating unit has also been performed to test the reliability of the hybrid energy system.

2. Mathematical modeling of proposed hybrid system

This work emphasizes on the formulation of a new hybrid system to supply the reliable power to off-grid or isolated location. Fig. 1 shows the different components of the proposed microgrid. The power generated by wind, solar and biomass is managed with the help of storage devices. As shown in Fig. 1, load, wind turbines and biomass gasifier are connected to AC bus. Moreover, solar PV panels and batteries are connected to the AC bus via converters. A charge controller is also deployed to maintain the smooth flow of power and limit the charging and discharging rate of batteries.

The proposed system is most suitable for off grid locations and agriculture based villages in developing countries where energy crisis is a major concern. However, the proposed system can be integrated to the grid. This system will be helpful in reducing