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Optimal design of hybrid power generation system and its integration in the distribution network

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ABSTRACT

The inability of conventional energy sources to fully meet the rapidly increasing energy demands in today's world has led to the growing importance of hybrid power generation systems that incorporate renewable energy sources. This work proposes an optimally designed multi-source standalone hybrid generation system comprising of photovoltaic panels, wind turbine generators, batteries and diesel generator. This design aims at minimizing emissions and cost, expressed in the form of the Net Present Value (NPV) of the system, while simultaneously maximizing its Energy Index of Reliability (EIR). The designed hybrid power generation system is further integrated into the distribution system as a Distributed Generation (DG); this is to optimally improve the performance of the distribution system by minimizing the total losses and the total voltage deviation of the distribution system. The combined cost and emissions incurred due to the energy purchased from the grid and the energy generated by DG are also reduced. For this purpose an improvised Multi-Objective Particle Swarm Optimization (MOPSO) algorithm is developed taking care of contradicting objectives. The proposed optimization algorithms are implemented using MATLAB for a standard IEEE 69-bus distribution system, using an hour-wise annual data of Spain. The location and size of DGs and the type and number of each generating source of the hybrid system are considered as decision variables. The effectiveness of the proposed optimal design using the improvised MOPSO algorithm is established in comparison with Improved Hybrid Optimization by Genetic Algorithm (i-HOGA) results.

Introduction

Hybrid power generation systems, especially those including renewable sources of energy, are preferred in the modern context, as conventional sources of energy struggle to cope up with rapidly increasing demand of electricity. These hybrid generation systems are designed to function either as a standalone system – a system which supplies a set of loads without being connected to the electricity grid; or as a grid-connected system – a system which is integrated to the electricity grid in the transmission or distribution level.

In the recent past, the use of hybrid power generation systems has garnered extensive research and publication. Dalton et al. [1] concluded that multi-source hybrid energy systems provide better quality and reliability than single source systems. Luna-Rubio et al. [2] stated that efficient and economical employment of renewable energy sources in a hybrid system would necessitate the need for their optimal sizing. Koutroulis et al. [3] proposed a genetic algorithm (GA) based cost minimization of a stand-alone hybrid solar-wind system in order to determine the optimal number and type of each energy source. Dufo-Lopez and Bernal Agustin [4] put forward a dispatch strategy to obtain the optimal configuration of the PV/Diesel system by simultaneously minimizing the total cost, pollutant emissions and the total not met load using multi-objective evolutionary algorithm and genetic algorithm.

Recent literature has focussed on the various ways of integrating hybrid renewable based DGs in the distribution system. Singh and Parida [5] have considered minimization of cost to optimally place solar, wind and fuel cell based DGs using Analytic Hierarchy Process. Atwa et al. [6] proposed a new method for optimally allocating different types of renewable DG units. The problem is formulated as MINLP, with an objective of minimizing the system's annualized energy losses. Kayal and Chanda [7] introduced a multi-objective constrained PSO based approach to place, wind and solar based DG units for optimal power loss reduction and voltage stability improvement of the distribution network. In most

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of the literature, different optimization algorithms [8] were proposed to separately solve the hybrid energy system and the integration of renewable DG's into the distribution system. Each of these algorithms either aims at reducing the power loss and improving the voltage stability of distribution network or minimizing the total cost and improving the reliability of stand-alone hybrid energy system.

This paper proposes a new methodology to integrate the hybrid DG's into the distribution system while simultaneously optimizing the type and size of energy sources allied with the size and location of DG's in the distribution system. This is done considering many contradicting objectives in both hybrid energy system and distribution system. The suggested algorithm finds an optimal combination of type, number of PV and wind, battery, diesel hybrid energy sources to increase the reliability and to minimize the cost and emission. Different combinations of these sources are considered to meet the sample energy demand for a day of 9.22 kW h which is repeated for 365 days. The best combination is being selected as the hybrid DG for integration. This algorithm, then attempts to integrate the hybrid renewable DG's into the IEEE-69 bus distribution system with an aim of minimizing the distribution losses, voltage deviation, cost and emission which is due to the energy generated by the DG and that purchased from the grid. The optimization algorithm considers three hybrid renewable DG's optimally placed at multiple locations, taking the location and size of DG's as variables. The size of DG's thus obtained are considered as the load for the hybrid energy system optimization problem. As the radiation data, wind data, state of charge (SOC) of the battery varies for 8760 h, the load (DG size) thus obtained by the above optimization problem should also be converted to 8760 h. The load (DG size) thus obtained is converted to hour-wise data by matching the assumed sample load pattern of 9.22 kW h data. Taking this as the load, the optimal size of hybrid energy system to minimize the cost and to maximize the reliability of PV/Wind/Battery hybrid energy system is obtained. With this obtained reliability and size of DG (hybrid energy system), the Forward Backward sweep Power flow algorithm for the distribution network is used to obtain the voltage of different buses. Thus, this paper attempts to find the size and location of DG with the type, number of PV panels, Wind turbines and batteries. The total cost, emission, voltage deviation and the total losses in the distribution and hybrid energy system are simultaneously minimized. To solve both these multi-objective optimization problems, an improvised multi-objective particle swarm optimization (MOPSO) algorithm is formulated which includes Pareto optimality to arrive at multiple optimal solutions, sigma method and crowding distance to maintain the diversity among the non-dominated set of solutions obtained, and fuzzy set theory to arrive at a best compromised solution. The steps for the proposed methodology is as shown in Fig. 1.

System modelling

The designed hybrid power generation system consists of photovoltaic cells, wind turbine generators, batteries and diesel generators. Each generating unit is first mathematically modelled. For simplicity, current modelling is used, in which the output and input of each generating unit is expressed in terms of current. The schematic representation of the hybrid power system [4] is shown in Fig. 2.

The demand considered is an AC load. Output from solar and wind energy sources together is called renewable energy generation. Batteries get charged by and also discharge DC currents, with the help of a charge regulator in accordance with the considered dispatch strategy. All the DC current outputs are converted into AC by an inverter before supplying the load. The diesel generator on the other hand generates AC current, which is either directly supplied to the load or is used to charge batteries through a battery charger and the charge regulator.

PV panel model

PV generator is one of the renewable source generators which provides DC current at a voltage level of 48 V. The rating of each PV module is mentioned in the latter sections. As mentioned earlier, current modelling [4,22,23,25] is used to represent the output of a PV generator. The efficiency of a PV panel is low compared to other conventional sources. The maximum output, and hence the maximum efficiency, is obtained at the maximum power point. At any instant of time the power output of each PV panel is given by

$$P_{PV_i} = N_P \cdot N_s \cdot V_{PV} \cdot I_{PV_i} \tag{1}$$

where N_p is the number of PV panels connected in parallel, N_s is the number of PV panels connected in series, V_{PV} is the final DC voltage of the PV panel, I_{PV_i} is the current supplied by the PV panel during the ith hour which is given by:

$$I_{PV_i} = G_i \cdot I_p \tag{2}$$

where G_i is the ith hour irradiation of Zaragoza, Spain and i ranges from 1 to 8760 h. I_p is the final constant peak current of the panel, assuming that the necessary physical changes including losses are already made.

Wind turbine model

Wind turbine generator is the other type of renewable energy source generator used in the considered hybrid system. To maintain a constant base of voltage type among the renewable sources, the DC wind turbine is considered in this design [24,26,28]. The output of each wind turbine is modelled as a DC current, I_{wind}, given by

$$I_{wind} = P_{wind}/V_{wind} \tag{3}$$

where, V_{wind} is the voltage rating of the wind turbine and P_{wind} is the power from wind turbine [26,29], calculated as

$$P_{wind} = \begin{cases} P_{rated} \cdot (v - v_{in})/(v_r - v_{in}) & v_{in} \leqslant v \leqslant v_r \\ P_{rated} & v_r \leqslant v \leqslant v_{out} \\ 0 & v < v_{in} \text{ or } v > v_{out} \end{cases} \tag{4}$$

where, P_{rated} is the rated power of a wind turbine, v_r is the rated wind velocity, v_{in} and v_{out} are the cut-in and cut-out wind velocities and v is the net hourly wind velocity. Wind velocity changes with hub height and available wind data. The net hourly wind velocity is given by

$$v = v_{ref} \cdot \left(\frac{H_{wt}}{H_{ref}}\right)^{\alpha} \tag{5}$$

where, H_{wt} is the hub height of the wind turbine and H_{ref} is the reference hub height considered to obtain the wind velocity data, v_{ref},v is the wind speed at the hub height H_{wt}, α is the power law exponent which varies with parameters such as elevation, time of day, season, nature of terrain, wind speed and temperature.

Battery model

Battery banks serve as a backup storage and are either charged or discharged according to the dispatch strategy [4,27]. The maximum value of the State of Charge (SOC) of a battery is equivalent to