

Multi-Objective Optimization for Sizing of Solar-Wind Based Hybrid Power System: A Review

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ABSTRACT—In today's scenario Distributed Generation (DG) resources have gained a lot of attention due to their positive impact on distribution system. Multisource hybrid power generationsystem with the utilization of Renewable Energy Resources (RES) are of greater concern considering environmental aspects. The considered resources are photovoltaic panels, wind turbine and battery storage. In this review various optimization techniques are compared in terms of multi-objective criteria comprising of reliability and cost analysis.

KEYWORDS—RES, Hybridsolar-wind system, Multi-objective optimization, Optimization techniques.

I. INTRODUCTION

With the rapid depletion of fossil fuel resources and increasing concern for air pollution and global warming, the renewable energy resources (RES) based Distributed Generation (DG) are expected to play a significant role in order to meet future demand [1,2]. The primary object of power system is to provide a reliable and economic supply to their consumers [3].

There are various reasons for the rapid increasing in growth of Distributed Generation [3-7]:

1. Increased public support and government incentives for the utilization of RES based DGs .
2. DG units are closer to customer so that T&D investment are avoided or reduced.
3. DGs offer a low capital cost and high reliability.
4. Installation time of DG units is less and investment risk is not very high.

There are various renewable energy resources likes solar, wind, geothermal, bio-fuel, tidal etc.[1-16]. Among them wind and solar power are the two most widely used RES owing to their availability and ease in conversion [4,5,8,9]. Wind turbine generates no pollution and PV requires minimum maintenance to operate [4]. But the

main drawback with these resources is that, the power fluctuation will occur. This is because since both these sources are highly dependent on weather, they may not match with the time dependent demand [10].This problem can be overcome by integrating both the resources in the proper combination with energy storage battery (SBs) [6,11,17]. The hybrid system is usually defined "A way of working, organizing or doing something that is composed of element of two separate systems". A hybrid is the combination of two more different things, aimed to achieving particular objective or goal. The various advantages and disadvantages of hybrid system are summed up as follows [5,6,8,9,24] and have been given in table I as follows:

TABLE I

Advantages and disadvantage of hybrid system

S.NO.	ADVANTAGE	DISADVANTAGE
1.	The strength of one resource can overcome the weakness of other during a certain period of time.	Hybrid system is highly location dependent.
2.	Construction of this type of power plant do not required grid expansion.	The system becomes more complex by using multiple renewable resources than a single resource.
3.	Integration of two resources makes the system more stable and reliable throughout the year.	The limited experience exists with the operation of solar-wind hybrid energy system.

One resource can overcome the weakness of other, so that the system reliability improves[8]. The objective of hybrid system planning is to achieve minimum cost at maximum reliability [20,23]. The design of the system

aims at searching for the configuration that gives the lowest total cost throughout the useful life [25]. The following two objectives have been used in optimal planning of hybrid system: (i) Reliability (ii) Cost

Besides the fluctuation of time dependent sources, there are various uncertainties existing in operation of hybrid system such as component failure and stochastic nature of generation and load variation [13,19,26]. For reliability evaluation of hybrid power system adequacy evaluation theory [4], probabilistic indices [8,9,24,28], well being criteria [22,27] have been used in literature. Different cost evaluation criteria such as Annualized capital cost [4,8], Total life cycle cost [25], Levelised Cost of Energy [9,28] have been used by system planners for presenting a cost effective planning. In this review paper we study different optimization techniques to achieve an optimum combination for a hybrid system to meet the load demand, evaluation must be carried out on the basis of power reliability and life-cycle cost of the system.

II. SOLAR- WIND BASED HYBRID POWER SYSTEM

Hybrid system of different energy resources like solar, wind, diesel, tidal, biogas, geothermal etc. are the most suitable energy sources to generate electricity in some region of developing countries. A hybrid of solar-wind power generation system consists of a PV array, wind turbine, a battery bank and converters [5,6,8,9]. The hybrid of solar-wind system design is mainly dependent on the performance of individual component. In order to predict the system performance, individual components should be modeled first and then their combination can be evaluated to meet the demand reliability [8,32]. If the power output prediction from these individual component are accurate quite enough, the resultant combination will deliver power at the least cost.

III. COMPONENTS OF HYBRID MODEL

A. PV ARRAY:

The performance of PV module is a function of the physical variables of the PV cell material, one being the temperature of solar irradiance exposed on the solar cells [7,16]. The power generated by photovoltaic (PV) system is directly proportional to the solar energy received by the PV panels. The number of panels needed is decided by the required load demand.

B. WIND TURBINE:

The power generated from wind turbine mainly depends upon the wind speed at a selected site where the wind turbine is installed and wind tower height [9]. Wind speed changes with height and the available wind data is measured at the different level of the tower. The wind power law is a useful tool for the measurement of wind data at different level [8].

C. BATTERY BANK:

To enhance the system reliability, a battery bank is added in the hybrid model. The selection of proper size of battery bank for a particular application that requires the analysis of battery charging and discharging [11,15,33]. If the renewable sources produces power more than the demand, this surplus power is used to charge the batteries. If in case these renewable resources are unable to meet the load demand, than deficit power is provided by the batteries [4,17,18]. The system efficiency is largely dependent on battery ageing and thus batteries need to be replaced as and when required [8,17].

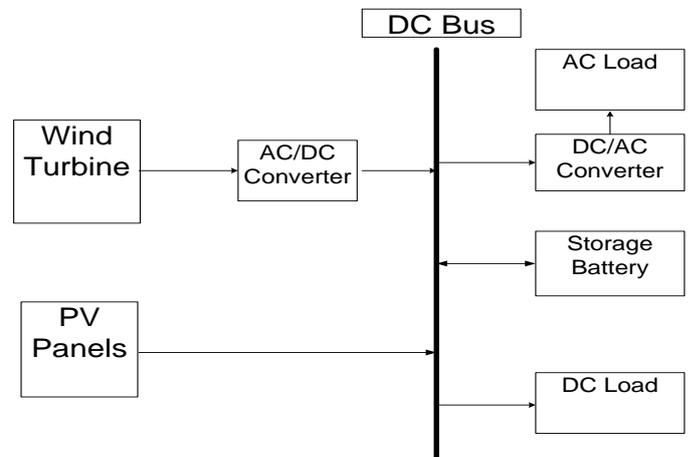


Fig.1. Block Diagram of Hybrid Solar-Wind System [4]

IV. OBJECTIVE IN PLANNING

The objective of the power system is to supply electricity to its customers in an economical and reliable manner. In order to select an optimum combination for hybrid system to meet the load demand, evaluation must be carried out on the basis of power reliability, system life-cycle cost and environmental aspect.

A. Power Reliability analysis

With increasing interest of utilities worldwide in RES based technologies, it is essential to analyze the impact of RES based hybrid system along with storage on reliability benefits for efficient and effective system planning [20,23,26,33]. A reliable electrical power system means a system has sufficient power to feed the load demand during a certain period of time or a small loss of power supply [9]. Because of the intermittent solar radiation and wind speed characteristics, which highly influence the energy production from the hybrid system, power reliability analysis is usually considered as an important step in any such system design process [19]. The reliability of power supply is increasing by the integration of DGs to distribution system [28].

There are a number of methods used to calculate the reliability of the hybrid systems. The most popular method is the loss of power supply probability (LPSP) method [8]. The LPSP is the probability that an insufficient power supply results when the hybrid system (PV, wind power and energy storage) is not able to satisfy

the load demand. The energy index of reliability (EIR) is used to measure the reliability of hybrid system design [4].

$$EIR = 1 - \frac{EENS}{E} \quad (1)$$

Where EENS(KWh/year) is the expected energy not served and E is the yearly energy demand.

B. System Cost Analysis

The economic evaluation plays a critical role in selecting a hybrid system component [2]. In solar-wind based hybrid system both the components have zero operating cost due to no fuel usage and maintenance cost is required in wind turbine and storage battery. On the contrary, diesel generators have high operating cost and maintenance cost. Economics has been one of the most important criteria in system planning [20,23]. Several economic evaluation criteria such as the Annualized Cost of System [8], Levelised Cost of Energy [9,28] and life-cycle cost [25]. The Annualized Cost of system (ACS) is composed of the annualized capital cost, the annualized replacement cost and the annualized maintenance cost. The ACS can be calculated based on these five components: PV array, Wind Turbine, Battery, Wind Turbine Tower and converters as follow [8]

$$ACS = C_{acap}(PV + Wind + Bat + Tower + Converter) + C_{arep}(Bat) + C_{amaint}(PV + Wind + Bat + Tower + Converter) \quad (2)$$

Here C_{acap} is the annualized capital cost, C_{arep} is the annualized replacement cost and C_{amaint} is the annualized maintenance cost are in Rs/kW.

The system lifetime is usually considered to be the life of the PV modules, which are the elements that have a longer lifespan. The Levelised Cost of Energy is defined as the ratio of the total annualized cost of the system to the annual electricity delivered by the system and the discount rate. The discount rate generally in the range of 5-10% for generation of electricity [30].

C. Environmental Aspect of Hybrid System

During the design of any system, the objective is that system is environment friendly which means that the total greenhouse gas emissions of the system during its lifetime is very less [2,21]. Environmental benefits encourage the uses of renewable based hybrid system such as wind turbine, solar photovoltaic panel and hydroelectric turbines since they consume no fossil fuels and reduces the greenhouse gas [3,4]. With the increase penetration of renewable, the system is utilized more effectively and efficiently through proper planning [26]. Katsigiannis et al.[2] the calculation of greenhouse gas emission on the bases of life cycle analysis (LCA) of each components.

V. OPTIMIZATION TECHNIQUES

Various optimization methods are classified based on the type of the search space and objective function. The

various optimization techniques are discussed in following subsections.

A. Analytical Techniques

Analytical technique is a mathematical model based optimization technique. The system is represented by a mathematical model and produces an algebraic expression that can be analyzed for optimization [3]. Analytical technique require a short computing time. During a complex problem accuracy of the solution is override. Gozel et al. [34] have considered the effect of static load in determining the optimal size and site of DG unit as well on the minimization of losses. Wang and Nehir et al. [35] have presented analytical technique to determine the optimal location for placing DG in both radial and networked system for minimization of power losses subjected to voltage constrained. Acharya et al. [38] have presented a approach which is based on loss sensitivity factor that gives less computation and faster result.

B. Particle Swarm Optimization

PSO is a population based optimization technique and it is an evolutionary based computation techniques, where the system is initialized with a population of random particle, which is developed by Dr. Kennedy and Dr. Eberhart in 1995[39,40]. PSO algorithm is initialized with a swarm of particle randomly placed on the search space. Each particle in a search space is initializing with velocity and position. The velocity of the particles updates by the particle previous best performances and by the previous best performances of the particle neighbors.

In n-dimension search space, let the position and velocity of the i^{th} individual be represented by $x_i = (x_{i1}, x_{i2}, \dots, x_{in})$ and $v_i = (v_{i1}, v_{i2}, \dots, v_{in})$ respectively. Each particle i^{th} known its best value record and represented by $Pbest_i = (Pbest_{i1}, Pbest_{i2}, \dots, Pbest_{in})$ and the global best position of the swarm found so far is denoted by $Gbest_i = (Gbest_{i1}, Gbest_{i2}, \dots, Gbest_{in})$.

The modified velocity of each particle can be first calculated regarding the personal initial velocity. The distance from local best position and the distance from global best position expressed by the following equation:

$$v_{id}^{(t+1)} = w \cdot v_{id}^{(t)} + c_1 \cdot rand_1(0) \cdot (Pbest_{id} - x_{id}^{(t)}) + c_2 \cdot rand_2(0) \cdot (Gbest_{id} - x_{id}^{(t)}) \quad (3)$$

$$x_{id}^{(t+1)} = x_{id}^{(t)} + v_{id}^{(t+1)} \quad (4)$$

Eq.(3) determines the direction in which the i^{th} particle should be taken along. Therefore, the new position of that particle can be determined by applying Eq. (4) [39,40].

In these equations $i = 1, 2, \dots, m$ is the index of each particle, t is the iteration number, $rand_1(0)$ and $rand_2(0)$ are the random numbers between 0 and 1. The constants c_1 and c_2 are the weight factors of the stochastic

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acceleration terms, which pull each particle toward P_{best} and G_{best} positions. Low values allow particles to roam far from the target region before being toggled back. On the other hand, high values result in abrupt movements toward, or backward the target region. Hence, the learning factors c_1 and c_2 are often set to 2.0 according to early experiences. We bear in mind that the PSO has been found to be robust and fast in solving nonlinear, non-

differentiable, multi-objective problems. Shi and Eberharthave introduced the parameter w into the PSO's equation to improve its performance. The appropriate selection of inertia weight w , provides a balance between global and local explorations, requiring less iteration on average to find a sufficiently optimal solution.

TABLE II
COMPARISON OF VARIOUS OPTIMIZATION TECHNIQUES

S.No.	Optimization Technique	Objective Function	Merit	Demerit
1	Analytical Technique	1.Minimization of average power losses [35,38] 2.Minimization of power and Feeder losses [34,36] 3.Feeder loss minimization [37]	1. Easy to implement. 2. Computation time is short.	1. Difficult to use when problem becomes complex.
2	Particle Swarm Optimization	1.Improving voltage profile and reduced THD and losses [41,42] 2.Reduction of power loss [43] 3.Optimal sizing of AHPS [26] 4.Multicriteria design of HPGS [4]	1. No overlapping and mutation. 2. Memory capability is more effective. 3. Calculation is simplified.	1.Create difficulty to find out the problem of scattering and optimization.
3	Genetic Algorithm	1.Power loss minimization [44] 2.Minimizing the system cost while achieving the reliability [45] 3.To obtain a compromised non-inferior solution[46]	1.Very useful for complex problem. 2. It can rapidly locate good solutions, even for difficult search space. 3.No derivative needed	1. Operating on dynamic data set is difficult. 2. Not efficient in determining the absolute optimum.
4	Tabu Search	1.Minimizing losses line loading and total reactive power required [47] 2. Loss minimization [48] 3.Minimizing of DG size [54]	1. Has explicit memory. 2.Applied to both discrete and continuous solution.	1. Number of iteration is very large. 2. Many parameter to be determine.
5	Ant Colony Optimization	1.DG investment and operating cost minimization [49] 2.Derive the optimal recloser [50]	1. Inherent parallelism.	1. Tough in theoretical analysis. 2. Uncertain in time convergence, but convergence is absolute.

PSO has been widely used for DG placement problem. Paliwal et al. [26] have employed PSO to determine optimal component sizing for each of the configuration. Wang et al. [33] have used a PSO for multi criteria design of hybrid power generation. Jain et al. [30] have used a multi objective PSO for DG placement targeting multiple objectives viz. improvement in voltage profile, reduction in environmental emissions and line losses, minimization of investment cost associated with DG units.

C. Genetic Algorithm

A genetic algorithm (GA) is an advanced search and optimization technique. Genetic algorithms belongs to the large class of evolutionary algorithms(EA), which generate solutions to optimization problems using technique inspired by natural evolutionary biology such as inheritance, selection, crossover, mutation [3,12].

In genetic algorithm, a population of string (called chromosomes) which encoded candidates solution for an optimizing problem toward better solution [44]. The evolution is start from the population of randomly generated individual in generation. The fitness value of every individual in the population is evaluated. Some the individuals are selected from the current population on

the basis of their fitness value. After those crossover and mutation processes are done and generate a new population. The new population is used in the next iteration of algorithm. Afsari et al. [45] has proposed a multi-objective optimization model simultaneously minimizing the system cost while achieving the reliability. Teng et al. [50] have proposed a value based DG placement for overall improvement in service quality obtained through GA. GA has been found to be very effective in area of DG allocation but it is not very efficient in determining the absolute optimum.

Therefore it is not the obvious choice when the high quality solutions are desired. To overcome this drawback, GA is hybridized with other techniques in order to improve efficiency. Gandomkar et al. [52] combined the simulated annealing in the production phase of GA to avoid the major drawback of simple genetic algorithm. The problem formulated with GA has no need of transform the non-linear problem into a linear modal. This approach is more beneficial for solving multi-objective problem.

D. Tabu Search

This meta-heuristics approach has dramatically changed the way we solve a host of optimization problem. It can be as an iterative technique that explores a set of problem solutions by repeatedly making moves from one solution to another [53]. Tabu search was created by Fred Glover in 1986, employing local search methods. It allows local search methods to overcome the local optima and escape from the occurrence of cycles, which usually cause even simple algorithms to terminate. In cases where many solutions are equally fit, these techniques have a tendency to become stuck. Tabu search is a very powerful optimization tool, and has the ability to avoid entrapment in local minima by using a flexible memory system. The memory system is a distinguishing feature of this meta-heuristic technique, which equips it to solve the optimization problem even for a complex system.

Tabu Search is also employed by Nara et al [47], Golshan and Arefifar [48] to optimize DG size and location. In their proposed methodology they have extensively made use of the memory structures to effectively and economically direct the search to attractive regions in the solution space.

E. Ant Colony Optimization

ACO was first proposed by Marco Dorigo in 1992 in his PhD thesis; with an aim to find an optimal path in a graph. This optimization technique is based on the behavior of ants. It is a well-known fact that ants have the exceptional ability to find the shortest path from the nest to the food source; this fact is also used to find the optimal solution. This method uses a population to collectively solve the optimization problem under consideration. This technique gives better quality of

results compared to other techniques. Though, it may take a considerable amount of time to give those results.

Lingfeng Wang et al. [50] have used ant colony system for radial distribution networks, to find the optimal location of DG placement. While keeping in mind that ACS can handle discrete optimization problem efficiently, the author has employed this technique to solve the problem in which a composite reliability index is used as the objective function. It was observed that the proposed ACS method gives solutions that are more accurate than the solutions obtained from GA method. It was also observed that the computational efficiency of ACO method was significantly higher than that of GA. However, it should be noted that, ACO may take a longer time to converge because a large number of potential solutions are to be evaluated. But the extra time needed is not as significant as that in analytical methods, since its computational efficiency is relatively insensitive to system complexity and size.

VI. CONCLUSION

In this review multi-objective optimization for sizing of solar-wind based hybrid power system is considered, with two main objectives viz. minimization of cost and maximization of the system reliability. There are several techniques, as studied above, which can provide an optimal solution to the problem. Since, PSO is easier to implement for a complex system and there are fewer parameter to adjust hence it can be used for a wide variety of hybrid power systems. It can significantly improve the obtained results, while not increasing the computing time significantly. Whenever a hybrid power system is to be installed on a large scale, system planners finds PSO as an extremely helpful optimization tool, as it very helpful in providing near-optimal solutions for complex systems.

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