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Review of Optimization Techniques for Sizing Renewable Energy Systems

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ABSTRACT

The growing evidence of the global warning phenomena and the rapid depletion of fossil fuels have drawn the world attention to the exploitation of renewable energy sources (RES). However standalone RES has been proven to be very expensive and unreliable in nature owing to the stochastic nature of the energy sources. Hybrid energy system is an excellent solution for electrification of areas where the grid extension is difficult and not economical. One of the main attributes of hybridising is to be able to optimally size each RES including storages with the aim of minimizing operation costs while efficiently and reliably responding to load demand. Hybrid RES emerges as a trend born out of the need to fully utilize and solve problems associated with the reliability of RES. This paper presents a review of techniques used in recent optimal sizing of hybrid RES. It discusses several methodologies and criteria for optimization of hybrid RES. The recent trend in optimization in the field of hybrid RES shows that bio-inspired techniques may provide good optimization of system without extensive long weather data.

Keywords: Mapping, GPS, Python, GIS, Nasiriyah

1. INTRODUCTION

Now are days, energy-related aspects are becoming extremely important. They involve, for instance, a rational use of resources, the environmental impact related to the pollutants emission and the consumption of non-renewable resources [1]. For these reasons there is an increasing worldwide interest in sustainable energy production and energy saving. Among the technologies that could play a role in the generation of sustainable and widespread energy, interesting solutions are represented by photovoltaic (PV) cells, wind generators, biomass plants and fuel cells. In particular, photovoltaic and wind systems can be considered as the most widespread solution with significant margins of improvement while ensuring the generation of energy with low environmental impact. However a drawback common to wind and solar system is that their optimization depends on many factors from which the dominant [2] being geographical (latitude, longitude, solar intensity, wind speed), environmental (temperature, wind, humidity, pollution, dust, rain, etc.).

Fortunately, the problems caused by the variable nature of these resources can be partially overcome by integrating the two resources in proper combination, using the strengths of one source to overcome the weakness of the other [3]. The hybrid systems that combined solar and wind generating units with battery backup can attenuate their individual fluctuations and reduce energy storage requirements significantly. However, some problems stem from the increased complexity of the system in comparison with single energy systems especially when it is backed by and efficient storage system [4]. This complexity, brought about by the use of two different resources combined, makes an analysis of hybrid systems more difficult. In order to efficiently and economically utilize the renewable energy resources, one optimum match design sizing method is necessary. The sizing optimization method can help to guarantee the lowest investment with adequate and full use of the solar system, wind system and battery bank, so that the hybrid system can work at optimum conditions in terms of investment and system power reliability requirement [5].

2. NEED FOR METHOD TO OPTIMALLY SIZE A RES

In the world, a significant number of villages may never be connected to the national grid due to their remoteness, or communities are far from the conventional electrical grid due to natural obstacles and environmental constraints. It becomes necessary to take up electrification of remote villages through non-conventional energy sources such as solar, micro-hydro and wind systems[6]. Isolated operation of these power units may not be effective in terms of cost, efficiency and reliability. A viable alternative solution is by combining these different renewable energy sources to form a hybrid energy system. In order to efficiently and economically utilize the renewable energy resources, one optimum sizing

method considering system reliability and economic benefit for the hybrid generation system is necessary[7]. The sizing optimization method consists in the identification of the optimal system (or near optimal) generating a reasonable amount of renewable energy that match the distribution of the load demand with the lowest cost [8].

3. RES OPTIMAL SIZING APPROACHES

3.1 CONVENTIONAL APPROACHES OF RENEWABLE

Many practical hybrid system design and implementations[9], [10] and [11] are often based on progressive experience including trial and error. These methods of sizing a RES often report unanticipated problems such as, premature battery degradation requiring design correction after installation. This can be very costly, especially for remote application in developing country.

3.1.1 AMPERE HOUR METHOD

This section describes the paper based ampere hour method for sizing pv/diesel systems. Table 1 summarises the main steps carried out during a hybrid system design using this method. The ampere hour method is useful in that it is relatively simple. It lends itself to being implemented in spread sheets. With the ampere hour

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method all the loads are compiled with their power ratings in watt which multiplied by the hours of operation in a day and the losses incurred through power conversion and battery cycling. The storage capacity is determined by number of autonomous days (number of continuous days that the battery can cover the load without sunshine), which is arbitrary selected by designer (typically 3–7 days)[12].

In [13] the decision to hybridise is based on whether more than a certain percentage of the given loads per day in watt hours is required to be covered by the output power of the pv array. For "hybridise if 60%-80% of the load", for load under 2000wh/day, or if 40%-60% for loads between 2000 and 5000wh/day or if 20%-40% for loads between 5000 and 10000wh/day, need coverage from pv. This method is used in [14] and [15] to size the standalone PV systems. This type of method however requires a lot of time and can easily leads to system components oversizing and suboptimal results. Changing weather conditions or different daily, weekly or seasonal demands patterns, environmental concerns are not incorporated or only through an arbitrary weighting system. In addition other RES such as wind turbines cannot be included.

TABLE 1.

Ampere hour design method[13]

Design	AH method
Load profile estimate	Compile load in wh/day
Battery	Select battery type and number of days of storage
	Number of battery in series obtained through dividing system voltage with battery voltage
	Number of parallel battery strings obtained through matching AH load current with the maximum discharge
PV	Divide the load in AH/DAY by peak sun hours per day
	Number of panels in series obtained through dividing system voltage with panel voltage
	Number of panels in parallel obtained through dividing DC bus current with panel output current
Hybridise (yes or no)	Follow decision guide
Battery Redefine storage size	In case smaller battery storage is desired in the hybrid system configuration, redo the calculation on number of batteries required with the new number of days of storage.
Diesel: choose KW size	Choose diesel generator size to cover peak demand plus maximum charging rate simultaneously
Redefine the panels in series and parallel	Redo PV calculation taking account of battery and diesel generator sizing
Round off	Choose inverter size, wiring sizes and determine LCC

3.1.2 TRADE-OFF METHOD

The trade-off method is introduced by [16]for multi-objective planning under uncertainty. The idea is intended for use in the design of standalone systems with renewable energy sources. This is done first by developing a database that contains all possible combinations of PV plants, wind generator, and battery, given ranges and steps of component sizes. Next, all possible planes are simulated over all possible futures, i.e. ±1 m/s variation in the wind velocity, ±10% variation in the global solar insolation. The author then creates a trade-off curve by plotting investment cost and loss of load probability (LOLP) for all possible scenarios, eliminating options with LOLP greater than 10%, and identifying the knee-sets. Robust plans are then identified by the frequency of the occurrence of discrete option values in the conditional decision set. This method yields a small set of robust designs that are expected to work well under most foreseeable conditions. The final decision for the selection of the unique design is left to the decision-makers.

However, current optimization problems in sustainable energy systems become more complex, especially when they include the integration of renewable sources in coherent energy systems. This is because most of such problems are nonlinear, non-convex, with multiple local optima, and included in the category of NP-hard problems [17]. In consequence, the above mentioned classical methods although being effective are highly inefficient due to the calculation of every single point which makes it cumbersome and time-consuming. Hence, when problems are complex and large in space, classical optimization techniques are not suitable [18].

3.2 CLASSICAL TECHNIQUES

Classical optimization algorithms use differential calculus to find optimum solutions for differentiable and continuous functions. This methods of optimization techniques have been extensively used in hybrids systems sizing and are broadly classified as: Linear programming model (LPM), dynamic programming (DP) and nonlinear programming (NLP), are examples of classical algorithms widely in use for optimizing HRESs [19].

Linear programming is a mathematical optimization method which deals with minimization or maximization of linear functions subject to linear constraints. The general linear programming problem can be stated in the following standard matrix form [20]:

$$\min_{x}(f^T x) \qquad (1)$$

Subject to the constraints as follows: $\begin{cases} A \cdot x \leq b \\ A_{eq} \cdot x = b_{eq} \\ lb \leq x \leq ub \end{cases}$

where, f, x, b, b_{eq} , lb, ub are vectors and A and A_{eq} are matrices.

When all or some of the decision variables are restricted to discrete integer values, for example, where the discrete values are restricted to zero and one only, that is, yes or no decisions, or binary decision variables. The problem can be formulated as a mixed integer programming (MIP) and it is generally structured as according to [21]:

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$$\text{Maximize } p(x) = \sum_{j=1}^{n} c_j x_i \quad (2)$$

Subject to the following constraints:

$$\sum_{i=1}^{n}\left(\sum_{i=1}^{n} a_{ij} x_j \leq b_i\right)$$

$x_j \geq 0 \quad \forall j \in \{1, n\}$ and x_j is an integer $\forall i \in \{1, I\}$

When the objective function or any of the problem constraint contains non-linear terms, in this case, the system is formulated using non-linear programming technique (NLP). The main issue with these types of problems is that they might give rise to non-convexity, meaning that there might exist several local minima. Nonlinear programming (NLP) typically employs Lagrangian or Newtonian techniques for constrained and unconstrained optimization problems. According to [22] the general structure of NLP methods can be written as follow:

$$Min\ f(x) \quad (3)$$

Subject to:

$g_i(x) \leq b_i \qquad \forall i \in \{1, 2, ------, N\}$

where some terms in the constraints $g_i(x)$ or *f(x)* are non-linear.

Variants of the linear programming method have been used for the optimal sizing of components of a hybrid renewable energy system. Chen dan Gooi proposed a new method for optimal sizing of an energy storage system. The ESS was to be used for storage of energy at times of surplus and for re-dispatch later when needed. They considered the Unit commitment problem with spinning reserve for micro grids. They formulated the main method as a mixed nonlinear integer problem (MNIP) which was solved in AMPL (A mathematical programming language). Results indicated that a properly sized ESS not only stored and re-dispatched renewable energy appropriately but also reduced the total cost of the micro grid. In a paper described in [24] the author formulated a method of selecting, and sizing different power generation technologies and storage devices for a micro-grid as a MIP (Mixed Integer Programming) problem. [25] propose a classical method to design a cost-optimized micro-grid architectures subject to reliability constraints. The method is based on DP (dynamic programming) and consists on determining the optimal power line layout between micro-sources and load points, given their locations and the rights of way for possible interconnections. Both Cooling and Heating Power model of a rural micro-grid is built in [26] and optimized by using a MINLP(mix integer linear programming) optimization process to improve system efficiency of energy utilization. Also, in [27] MINLP is used to minimize the fuel consumption rate for a two-generation unit micro-grid, while constraining it to fulfil the local energy demand (both electrical and thermal) and provide a certain minimum power reserve. [28] use DP and defines a dynamic optimal schedule management method for an isolated or grid-connected microgrid system, considering forecast errors with uncertainties of solar radiation, wind speed and local user demand. Using the same optimization technique, [29] try to maximize the profit that owner might achieve from energy trading in a day, either in isolated or grid-connected micro-grids. [30] used LP to model a micro-grid including a mix of renewable generation technologies, energy storage and DR, based on real world data of residential energy consumption and weather variables. [31] introduced two LP techniques to plan and design an electrical power system. The first is an optimization that minimizes the deviation from the electric load requirements. The procedure includes variable generators, conventional generators, transmission, and storage, along with their most salient engineering requirements. In addition, the optimization includes some basic electric power system requirements. The second optimization is one that minimizes the overall system costs per annum while taking into consideration all the aspects of the first optimization. In recent years, biological optimization techniques, which are stochastic search methods inspired by the concepts and principles of artificial intelligence, have gained popularity in the optimization of sustainable energy systems.

3.3 BIOLOGICAL BASED APPROACHES

Biological approaches of RES can be roughly group those methods into three categories which are [32]: which are artificial neural networks (ANNs), evolutionary algorithms (EAs), and swarm intelligence.

3.3.1 GENETIC ALGORITH(GA)

Genetic Algorithm(GA)is a search process that mimics the process of natural selection and was developed by John Holland in 1960–1970 [33]. GA generates solutions to optimization problems using techniques inspired by natural evolution such as inheritance, mutation, selection, and crossover. A basic GA has five main components: a random number generator, a fitness evaluation unit, a reproduction process, a crossover process, and a mutation operation. Reproduction selects the fittest candidates of the population, while

Crossover is the procedure of combining the fittest chromosomes and passing superior genes to the next generation, and mutation alters some of the genes in a chromosome [34]. Figure: 1 shows the general standard structure of a genetic algorithm. A number of researches have used the application of GA for the optimal design and operation of RES based hybrid energy systems.

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Genetic Algorithm

Begin (1)
t = 0 [start with an initial time]
Initialize Population P(t) [initialize a usually random population of individuals]
Evaluate fitness of Population P(t) [evaluate fitness of all individuals in population]
While (Generations < Total Number) do begin (2)
t = t + 1 [increase the time counter]
Select Population P(t) out of Population P(t-1) [select sub-population for offspring production]
Apply Crossover on Population P(t)
Apply Mutation on Population P(t)
Evaluate fitness of Population P(t) [evaluate new fitness of population]

End (2)
end (1)

FIGURE 1. The structure of a standard genetic algorithm [35]

Using genetic algorithms, [36] calculated the optimal number and type of each component of the stand-alone PV/wind system to minimize the 20-year round total system cost. The load power requirement was considered as constraint condition of the optimization problem and must be completely met. The same method has been applied to analyze a hybrid power system that supplies power for a telecommunication relay station on a remote island[37][38] studied the behaviour of GA applied to the design of PV-wind-diesel-batteries-hydrogen systems. First, the global solution was found by applying an exhaustive enumerative method. Consequently, the GA technique was used and the influence of the number of generations, population size, and crossing and mutation rates on the behaviour of the algorithm was studied in order to find the very parameters to reach a global optimal solution with nearly 100% probability [39]. Developed an optimal sizing method based on GA to calculate the optimum stand-alone system configuration that can achieve the customers required LPSP with a minimum annualised cost and total capital cost of the system, respectively. The author have brought into picture two optimisation variables that are rarely used, namely PV array slope angle and wind turbine installation height. In [40] Pareto-based multi-objective GA optimisation method was used to optimize hybrid solar-wind systems with battery storage are optimised by simultaneously minimising the annualised cost of system (ACS) as well as the LPSP. In [41] a method was develop to optimally size hybrid power generation systems comprising PV, wind, diesel and battery devices. The authors again made use of multi-objective GA minimising the LCE as well as the CO2 emissions. An applied a multi-objective Pareto-based GA was used in [42] to the design of an isolated hybrid RES-diesel systems minimising the total cost throughout the useful life of the installation as well as the CO2 emissions using two different load profiles. [43] employed a controlled elitist GA based on a triple multi-objective optimisation which minimised life cycle cost, LPSP and an ecological objective for the design of a hybrid PV-wind-battery system in order to find the best compromise between them. The decision variables include the swept area of the wind turbine, PV array area as well as battery capacity. [44] employed an optimisation method based on GA which aims at minimising the total water cost while at the same time the desalinated water demand of a community is completely covered.

3.3.2 PARTICLE SWARM OPTIMIZATION (PSO)

Particle Swarm Optimization (PSO) is one recent technique that has been used with great success in the Computational Intelligence arena. PSO applies the concept of social interaction to problem solving[45]. PSO algorithm was originally proposed by Kennedy and Eberhart in 1995 [46].

The key attractive feature of PSO is its simplicity as it involves only two models. In PSO, the coordinates of each particle represents a possible solution called particles associated with position and velocity vector. At each iteration, particle move towards and optimal solution, through it presents velocity, personal best solution obtained by themselves so far and global best solution obtained by all particles in a physical dimensional search space. The position and velocity of the particle i are represented as the vectors of

$$v_{i,j}{}^{k+1} = v_{i,j}{}^{k} + c_1 r_1\left(xbest_{i,j}{}^{k} - x_{i,j}{}^{k}\right) + c_2 r_2\left(xgbest_{j}{}^{k} - x_{i,j}{}^{k}\right) \quad (4)$$

$$x_{i,j}{}^{k+1} = x_{i,j}{}^{k} + v_{i,j}{}^{k+1} \quad (5)$$

where $x_{i,j}{}^{k}$ and $v_{i,j}{}^{k}$ are the j^{th} compoenents of the i^{th} pericle`s position and veleocity vector respectively, c_1 and c_1 are the acceleration coefficients, r_1 and r_2 are uniformly distributed random numbers between 0 and 1, *xbest*(i) best position of particle i until iteration *k*, *gbest* best position of the group until iteration *k*, *k* is the constriction factor.

However despite of its simplicity and speed of optimization, this algorithm suffers from a premature convergence. The modified velocity and position of each particle can be calculated using the current velocity and the distance [47].

$$v_{i,j}{}^{k+1} = wv_{i,j}{}^{k} + c_1 r_1\left(xlbest_{i,j}{}^{k} - x_{i,j}{}^{k}\right) + c_2 r_2\left(xgbest_{j}{}^{k} - x_{i,j}{}^{k}\right) \quad (6)$$

In addition, in order to ensure convergence of the PSO, an alternative formulation is proposed for velocity vector that is;

$$v_{i,j}{}^{k+1} = \chi\left[v_{i,j}{}^{k} + c_1 r_1\left(xlbest_{i,j}{}^{k} - x_{i,j}{}^{k}\right) + c_2 r_2\left(xgbest_{j}{}^{k} - x_{i,j}{}^{k}\right)\right] \quad (7)$$

$$\chi = \frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4c}\right|} \quad (8)$$

$$\varphi = c_1 + c_2,\ \varphi > 4 \quad (9)$$

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where *w* is the inertia weight factor
In this velocity updating process, the value of the parameters such as: w, C_1, C_2 and k should be determine in advanced. The weight of inertia w can be a positive constant or a positive linear or nonlinear function of time; and usually in the range 0 and 1.4.

Using PSO, [48] presented a simple approach of optimal power generation from multi sources in HRES to minimize the levelized cost of energy (LCE). At which the PSO proved its high intensity and sensitivity in solving such optimization problems. [49] Presented a method for optimum sizing of stand-alone hybrid PV/wind/battery/diesel energy systems utilizing PSO. The optimization goal was to minimize the system cost with the state of insuring the load demand and satisfying a set of optimization constraints. The authors also confirmed in their work that parallel implementation PSO can save more time during the optimization process compared to the serial implementation of PSO. [50] presented a paper in which a hybrid for a practical standalone renewable energy generation system was proposed. They employed wind, pv, battery banks and diesel generator in their hybridization. The wind, pv battery system was intended as the primary system with the diesel generator provided as a back-up system. The goal of their optimization was to minimize investment cost and fuel cost while ensuring availability of the energy needed by the customers and sufficiency to meet peak demand. The design was based on solar radiation data, wind speed data and load curves and PSO was for the optimal sizing. (Navaerfard & al, 2010) argued that capacity sizing was important to fully meet demand due to uncertainty of wind and solar pv. They proposed a method of determining capacity for hybrid pv , wind with battery storage. Their proposed method considered uncertainty in generation of wind energy and solar energy. They formulated the algorithm for determining the capacity of wind, pv and battery ESS as an optimization problem with the objective of minimizing the system cost while constrained to having a given reliability for a given load. This was solved using PSO algorithm. [52] also presented a paper in which they considered a hybrid system of wind, pv, and tidal with battery storage. In this paper they highlight the benefits of tidal energy which is harnessed from rising and falling of ocean water levels as being highly predictable compared to wind and solar. They consider a 20 years plant life and optimize the design with the objective of minimizing the annualized cost of generated energy of the life of the plant, with the constraint of having a specific reliability index. PSO was used for the optimization.

In [53] applied PSO in order to optimise three different hybrid systems including PV, wind and a storage system in the form of battery or hydrogen tank or a combination of both. The optimisation was undertaken by minimising the net present value (NPV) considering a reliability constraint. PSO technique was employed by [54] in order to optimise a hybrid wind-PV system with the use of a fuel cell in terms of ACS and under the condition that the load is fully met at all times. Outage probabilities of the wind turbine, the PV array as well as the converter are taken into account for reliability assessment. In [55] a simulation based triple-objective PSO algorithm and the ε-constraint method was used to solved the problem in [43]. After comparing the results, an improvement in the total cost is obtained while achieving the same fuel emission and reliability. A study to determine the optimum dimensions of hybrid photovoltaic systems, wind power, and storage battery bank has been carried out by [56] in the remote regions of the South, North-West and North-East of Iran. Authors studied the performance of five different PSO variants and three more algorithms namely tabu search, simulated annealing and harmony search (HS).PSO, modified PSO (MPSO),PSO based on repulsion factor (PSO-RF),PSO with constriction factor(PSO-CF),and PSO with adaptive inertia weight (PSO-W) these are the variants used in the study. It has been concluded by the authors that PSO-CF is more favourable than the other PSO variants and PV–battery based hybrid systems are suitable for most areas of the country due to the good solar radiation availability and low windy nature.

3.3.3 ARTIFICIAL NEURAL NETWORK (ANN)

Given solar and wind power's variable, intermittent, and non-dispatchable nature, considerable effort has been made to develop accurate forecasts that meet the needs of macrogrid power providers. Forecasting the production of large solar arrays and wind farms allows power providers the time necessary to make changes to base load power plant production to minimize peak power plant use. These forecasts often use artificial neural networks (ANNs) which access multiple and varied data sources to estimate power changes hours or days in advance[57]. ANN as described by figure:2, is able to handle noisy and incomplete data, and once trained, allow performing as complex tasks as prediction, modelling, identification, optimization, forecasting and control [58].

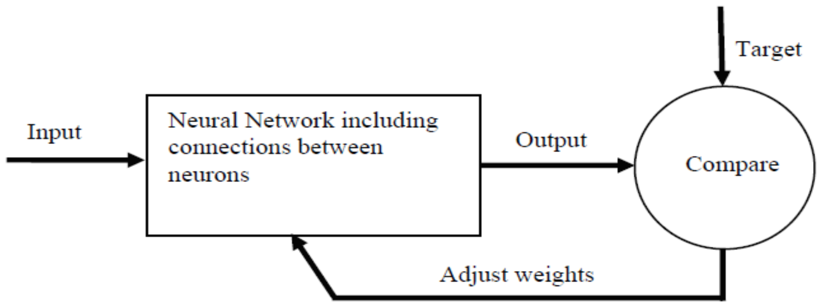

FIGURE 2. Basic Principles of Artificial Neural Networks [35]

There are many optimization problems related to energy in general which deal with optimization techniques, such as the prediction of energy demands using ANN. [59] presented a simulator of a renewable energy system in both grid-connect and stand-alone modes, containing wind, solar, energy storage and stand-by plants, which is able to calculate energy flows and optimize the scheduling of the stand-by plant or grid connection. In [60] a recurrent neural network is used for the control of a battery energy storage system accounting state of charge (SOC) and terminal voltage. Neural networks in wind energy systems is illustrated in [61] where a hybrid neural network approach, comprising a Self-Organizing Map (SOM) and a Radial Basis Function (RBF) neural network, is used to predict wind speed automatically. The approach enables wind speed prediction with fewer errors. [62] studied possibility of using an adaptive ANN to find a suitable model for sizing stand-alone PV systems, based on a minimum of input data.

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In [63], the optimal battery size for stand-alone PV system is analysed using ANN model. The results obtained from their analysis shows that sizing a battery bank to meet the demand with 99% availability, the cost of batteries can be about three times more than the one meeting demand of 95% availability. [64] develop a novel EMS (energy management system) that uses a Multi-Layer Perceptron Neural Network for the optimal scheduling of generators in an industrial park. They train the Neural Network by using information about energy price, weather conditions and the forecasts on the energy and thermal load demand. In [65] an analytical method is used to obtain a large data set of PV system optimum sizes at different LLPs then this data set is used to train an ANN to predict the optimum size of the PV array in terms of the optimum storage battery, LLP (loss of load probability) and yearly cleanses index. ANFIS is used in [66] for size optimization of the hybrid PV-wind-battery system with the objective to reduce the production cost; also, the performance is compared with the hybrid optimization model for electric renewables (HOMER) and hybrid optimization (HO)-GA (ANFIS achieve better performance).[67] implemented BPNN(back propagation neural network) method for power prediction of hybrid RE systems and FLC for energy management. ANN and fuzzy logic based controller is developed as a hybrid AI approach to control the flow of power between the hybrid RE system and the energy storage unit, resulting, a high storage of charge (SOC) [68]

4. RELIABILITY INDICES

In [69] defines reliability as the probability that a system, product or service operates properly for a specific period of time under operating conditions without failures. It is a broad field subdivided into system adequacy and system security. System security relates to the ability of the system to withstand credible contingencies without violating the normal operating limits and is generally in the context of the system's reaction to perturbations. System adequacy on the other hand is the existence of sufficient capacity within the system to meet demand[70]. In most studies to optimize the sizing components of a hybrid renewable energy power system, Generation adequacy is measured using a reliability index which quantifies the system reliability. These indices are helpful in assessing reliability performance of a generation system against some predetermined minimum requirements or reliability standards, comparing alternative designs, identifying weak spots and determining ways of improvement and in cost / performance considerations for decision making[71]. Some of the methods that appear in recent published literature are described in the following section.

4.1 LOSS OF POWER SUPPLY PROBABILITY (LPSP)

Loss of power supply probability (LPSP) is defined as the percentage of power supply that it is not able to satisfy the load demand. It indicates the reliability of power supply to load. LPSP is given by the ratio of summation of all loss power supply, LPS (t) at a specific time period (t) over the summation of load demand, D (t) at the same time period (t). mathematically LPSP is expressed as [72]:

$$LPSP = \frac{\sum_{t=1}^{N} LPS(t)}{\sum_{t=1}^{N} D(t)} \quad (7)$$

$$LPS(t)=D(t)-E_T(t) \quad (8)$$

where, E_T (t) is the total energy generated by the source.

Meanwhile, if LPSP is equal to 0, it means that the load demand is totally satisfied at a specific time period (t). On the other hand, if LPSP is not equal 0, it means that the load demand is not totally satisfied. For LPSP between 0 and 1, it means that the supplied power cannot fully cover the load demand because of insufficient solar radiation and wind speed (in case of wind/pv system) and the battery storage capacity. A review of works implementing LPSP is provided below.

In [73] the authors provided a new method for finding an optimal combination of a hybrid system including renewable energies with the aim of reducing the investment costs in designing hybrid systems. The results show that for LPSP=0.05, the number and the size of hybrid system equipment are less than other scenarios where LPSP is less than 0.05, which reduce the net present cost (NPC) of the system. [74] Postulate that power supply reliability depended on optimum sizing of solar pv , wind and battery storage in a hybrid renewable energy system. They LPSP as reliability index and design a system for a case study in Shengyang region. [51] appreciated the importance of capacity sizing in order to fully meet demand due to uncertainty of wind and solar resources. As a measure of reliability they also make use of LPSP. [75] recognized the uncertainty in maintaining a high quality of supply as the main challenge in standalone hybrid renewable energy systems. They considered the Loss of Power Supply Probability as a reliability measure for their optimization. [76]used the Loss of Power Supply probability as reliability criteria. In designing a hybrid power system to supply a remote telecommunications relay station their objective was to achieve a required loss of power supply probability (LPSP) at a minimum annualized cost of the System (ACS). [77] developed a software based on Loss of power supply probability algorithms for techno-economic analysis and optimization of hybrid systems. [78] desired to minimize the cost of their system whilst ensuring it was reliable enough. They used LPSP as reliability index alongside the annualized cost of the system which was to be maximized. Other authors aimed at reducing the cost of electricity generated by their system whilst meeting the required reliability index. For a Loss of Power Supply Probability (LPSP) of 0,[79] found that in order to obtain a total renewable contribution of an autonomous hybrid PV/wind system, more than 30% of the energy production was unused unless the battery capacity was very large.

4.2 LOSS OF LOAD PROBABILITY(LLP)

Loss of load occurs when the system load exceeds the generating capacity available for use. Loss of Load Probability (LLP) is a projected value of how much time, in the long run, the load on a power system is expected to be greater than the capacity of the available generating resources. LLP is based on combining the

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probability of generation capacity states with the daily peak probability so as to assess the number of days during the year in which the generation system may be unable to meet the daily peak [80]. LLP can be calculated considering the daily peak loads for 1 year duration or sometimes on each hour's load for a 24 hours day. The mathematical representation of LLP is given by equation (9) [80].

$$LLP = \sum_j p[C_A = C_j].p[L > C_j] = \sum_j \frac{p_j \cdot t_j}{100} \tag{9}$$

where

L is the expected load, C_A is available generation capacity C_j is remaining generation capacity, P_j is probability of capacity outage P probability, t_j is percentage of time when the load exceeds C_j

In [81], the loss of load probability for stand-alone photovoltaic (SAPV) power system was determined for an ICT Center with total daily energy demand of 346480 Wh/day. In the paper the authors classified the electrical appliances into four (4) different load priority levels depending on the acceptable loss of load probability of the appliance in the data center. A cubic regression model is derived to enable the load scheduler to determine the possible LLP for any give load level. [82] applied loss of load probability and autonomy analysis to determine the validity of their optimal sizing. In a later paper with a different optimization approach [83] they again used LLP to validate the reliability of their system.

5. CONCLUSION

The instability in prices and scarcity reserves of foil oils have in the last decade significally increase the interest in renewable energy sources. However reliable transformation of these energy sources into electrical energy and at a minimum cost still remains a challenge in designing RES. The size coordination of any hybrid system components is very crucial for such a system in terms of cost and reliability. So in other to obtain the best performance from the renewable energy sources, hybridizing two or more sources with complementary characteristic has emerged as an important technique for improving reliability while reducing the cost in spite of the fluctuation of the individual sources. This paper presents in detail a comprehensive review of optimization of hybrid power system consisting of renewable energy sources. Several optimization methods and optimization design criteria are explained with their strength. Also bio-inspired methods of sizing hybrid system have been review in this paper. With the great potential of AI (artificial intelligent methods), there is a need for their proper utilization in RES especially for hybrid system. Their application in RES will impact the performance of RES for the world prosperity.

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