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TOOLS AND TECHNIQUES FOR OPTIMIZATION OF HYBRID RENEWABLE ENERGY SOURCES: A REVIEW

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Abstract: The world's energy consumption has risen drastically in the last few decades due to the fast-growing population, urbanization which lead to increased consumption in industrialization and domestic comfort. Most of the world's energy demand is fulfilled with conventional fuels to date, but these sources are not everlasting, it will exhaust in a few years. Nuclear fuels which are used for electricity generation are also on the verge of exhaustion and the recycling process of uranium fuel is a riskier process. The world is witnessing drastic climatic changes like global warming, an increase in sea level; that result in adverse health and environmental consequences. To get the better of these problems or at least limit them to a certain level, researchers all around the world have accepted renewable energy sources as the alternative source of energy. Again the renewable energy sources are uncertain or unpredictable in nature. It is better to use hybrid sources that can counterbalance the indiscriminate nature of each other. The hybridization of renewable sources is a complex non-linear problem. Researchers have adopted different optimization techniques to find the optimal size and cost of available resources. This chapter summarizes different optimization techniques used so far which helps researchers find suitable options out of many.
Keywords: Hybrid Renewable Energy sources (HRES), Optimization, Solar photovoltaic (PV), Wind, and Biomass Energy

1. INTRODUCTION

Electricity is the crucial factor for the sustainable development of any country. A growing country like India faces many challenges like exponential growth of population, increasing per capita energy consumption with optimum use of available energy resources. Currently, the majority of energy demands are met by conventional energy sources. The conventional fuels extracted from nature also have limited capacity; fossil fuels will not ever lasting. Nonetheless, India's per capita energy consumption stands at 30% of the world's average [1]. Harmful effects of using these conventional sources are also well-known. Therefore due to drastic climatic changes, depletion of fossil fuels, increased prices of oil and growing energy demand, worldwide attention has shifted towards renewable energy sources for clean electricity generation [2, 3]. There is a huge potential for renewable resources that can be exploited to reduce reliance on conventional energy sources. Alternative sources of energy are appropriate to implement micro-girds or distributed generation in an islanded area/remote area for local electricity generation. A large portion of India's population lives in remote non-urban regions. Also population is sparsely scattered in the vast geographical location, where government cannot provide electricity through the centralized national grid. Solar, wind, biomass, geothermal and hydropower are main renewable energy sources. These sources depend on weather conditions such as solar insolation, wind speeds, or availability of fuel in case of biomass [4]. Due to unpredictable weather conditions, the output power from these sources is fluctuating or uncertain. To overcome this problem of renewable energy sources, the best solution is hybridization. Hybridization occurs when two or more non-conventional energy sources are used which can counterbalance one another's weakness. A hybrid system draws on the power of more than one local resource to fulfil the demand of a remote area in a cost effective manner with the aim of providing continuous and carbon free energy [5].

2. HYBRID RENEWABLE ENERGY SYSTEMS

Hybrid renewable energy systems utilize the combination of at least two renewables or renewable sources including conventional sources and storage facilities such as wind and PV system or wind and hydro system or solar wind system with battery or solar wind system with diesel generator for round the clock generation of electrical power. It is commonly used as standalone mode for remote or islanded areas to utilize locally available resources to fulfil load demand of the area. This reduces transmission and distribution losses and hence reduces cost [6].

Wind, solar photovoltaics, biomass and hydroelectricity are the most widely used renewable sources. For proper prediction of output power from these sources, specific inputs are required like, wind speed for wind energy generation, solar insolation for generation from PV, biomass fuel for biomass generation. Solar system with battery, solar system with diesel generator, windmill with battery, windmill with diesel generator, solar system with windmill, diesel generator and battery, Biodiesel generator with diesel, PV-Biodiesel, wind-PV-

Biodiesel are commercial HRES combination as shown in Fig.1. In these combinations, different renewable sources have different generation characteristics like, flow of water changes in river according to season; solar radiation is higher in summer than in winter, just like the wind speed is higher in summer. Electricity generation from HRES is independent of fuel cost as renewable resources are free, abundant and infinite. However, for better performance of HRES, environmental factors and a proper combination of suitable renewable energy sources is very important. System reliability during various climatic conditions and overall cost of the system are serious concern in designing HRES [7].

Renewable sources	Conventional sources	Storage system
●Wind ●Solar PV ●Micro Hydro ●Biomass ●Tidal	●Diesel Generator ●Combustion turbine ●Gas turbine	●Flywheel ●Battery ●Fuel Cell ●SMES

Figure 1: Hybrid Renewable Energy Sources

3. OPTIMIZATION PROBLEM

Optimization of size, economic operation, controller design, real and reactive power control, voltage and frequency, reliability control are the main issues of optimization problem in the area of HRES [8]. The optimization problem include the knowledge of availability of renewable resources for power generation, hybrid system design, i.e. sizing and storage system options, interconnection of different sources with the help of converter, load curve of the area that has to be met, optimal operation, optimized cost, battery life, voltage and frequency regulation in case of grid connected system and overall effect on environment as shown in Fig.2 [9]. Numerous researches have been made for optimum economic design of HRES using intelligent techniques and algorithm [10-15]. Economic designing of HRES means to find the best combination of renewable or conventional generating sources (Size) with or without battery, which can securely fulfil the load demand. In this study, most commonly used optimization techniques are discussed from literature survey. Different soft computing techniques, heuristic and meta-heuristic techniques are observed in literature survey, namely, HOMER, HOGA, HYBRIDs, PVsyst, etc. [4, 12, 16] and artificial intelligent techniques using popular bio-inspired optimization algorithm, Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), Harmony Search (HS), Tabu Search (TS), Cuckoo Search (CS), neural network and fuzzy logic [17-20]. Some literature focused on comparative assessment of application of these optimization techniques for solution of optimization problems in hybrid renewable energy systems (HRES) [4, 10-20].

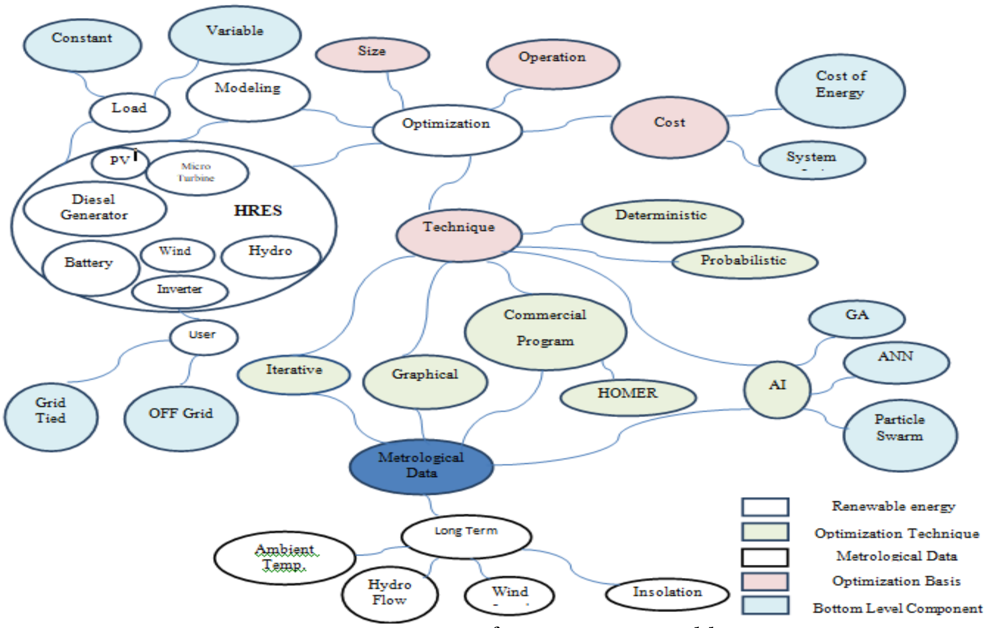

Figure 2. Components of Optimization Problem

4. VARIOUS OPTIMIZATION TECHNIQUES:

— Analytical techniques

Analytical techniques develops mathematical model of the system and solves the problem using direct numerical solution. It is an appropriate method for simple and linear problems, as computing time is very less. But the accuracy is compromised when the problem becomes complex or non-linear. Table 1 shows summary of analytical techniques used in different research.

a) Graphical Construction

In graphical construction method, optimization problem can be solved by plotting all constraint functions in one graph. This method can be used for two variable problems only, and the effect of change of one parameter with respect to other is observed graphically. Solution for such problem can be identified by finding feasible region of the objective function [8].

b) Probabilistic Approach

In probability approach, the randomness is shown in collected data; therefore the state variables in this method are described by the statistical tool instead of unique values.

c) Iterative Approach

Iterative approach is a mathematical method of optimization problem, that calculate approximate solution and a sequence of improvement of solution until the termination criteria is reached. For repetitive calculation of sequence of improvement, this method was performed using computer as computational time increases with increase in number of variables.

Table 1: Summary of Analytical Techniques

Approach	Objective	Method	Reference
Graphical Construction	Optimal sizing of solar photovoltaic system	Feasible solution of objective function	Markvart et al. [21]
Graphical Construction	Optimal sizing of hybrid wind/PV system for Wagan island of Hong Kong,	Graphical construction	Ai et al. [22]
Probabilistic Approach	Optimal size of battery in a PV/Wind hybrid system with minimum price	Annual average method, average of unfavorable month method and loss of power supply probability method (LPSP).	Kadda et al. [23]
Probabilistic Approach	Optimal designing of hybrid PV/wind energy system	Hourly average generation capacity method and most unfavourable month method	Z. Benhachani [24]
Iterative Approach	To find maximum reliability at minimum cost	Optimal size of the available sources Optimal capacity of Battery energy storage system (BESS)	Umer Akram 2017 [25]
Iterative Approach	Optimal sizing the number of PV panel and wind turbine for a stand –alone system	Number of wind turbines and number of solar panels starting from the minimum numbers until the possible maximum numbers which optimize the system	Sami Hamed Alalwani et al. [26]
Iterative Approach	Minimization of life cycle cost of hybrid wind-PV-battery system	Linear programming method	Li et al. [13]

— **Software based approach**

Renewable energy sources are abundant in nature but due to lack of proper designing and optimization, HRE systems are over-sized or unreliable, which makes renewable sources rare choice and higher cost system. Therefore, in order to design a steady-going and low-cost system, a technical and economic analysis is required for effective use of HRES. Random availability of renewable sources makes designing process more complicated. For proper designing, analysis, optimization and economical planning, numerous software models have been developed. These software streamline the hybrid system design process and allows a better use of renewable resources. In this section, commonly used software for HRES optimization, are discussed along with literature review. Some of the software tools used include HYBRID, RETscreen, TRYNS, iHOGA, and Hybrid Multi-Power Resource Optimization (HOMER), etc. [12-13]. Table 3 shows literature review of different software used by the researcher.

a) HYBRID2

HYBRID 1 was developed in 1994 by the University of Massachusetts USA with support from National Renewable Energy Laboratory. Later HYBRID 2 was designed in 1996 and now 1.3b is the latest version of HYBRID which is freely available for download and use, with a password for installation on Windows XP version. It uses Microsoft Visual BASIC platform for programming and Microsoft Access Database. HYBRID 2 uses statistical method for calculations and performs detailed analysis of system economics, long term evaluation, and prediction for various HRES. It has higher control strategies for precise simulation [27].

It is simulation software that can model solar photovoltaic array, wind turbines, diesel generators, and other components of HRES. Fuel cells with hydrogen tanks and electrolyzers can be also be designed in this software. The HYBRID2 software has four components, i.e. the Graphical User Interface (GUI), simulation Module, economic Module and Graphical Results Interface (GRI). The software has data files for various resources but software lacks flexibility as it has limited access to parameters. Although HOMER is most recommended software by NREL for optimization and further improvement can be done in design by using HYBRID2 [28].

b) RETScreen

RETScreen is feasibility calculation tool was developed by the Ministry of Natural Resources, Canada in 1998 for on-grid applications. It can evaluate cost and emission calculations for various combinations of renewable sources [29].

PV model of RETScreen also have grid connected applications, stand-alone, and hybrid systems. Its database contains global climatic data of 6000 land stations, yearly temperature data, wind energy resources maps, hydrology data etc. NASA climatic database can also be accessed with a link in it. RETScreen 4 and RETScreen Plus are two version of RETscreen. RETScreen 4 is project analysis software on Microsoft excel techno-financial evaluation [30].

RETScreen Plus is used for performance analysis with the help of energy management tool. Due to excel based software, it is easy to use for techno-economical evaluation but the main drawback of the system is that, it cannot import the data or files, no visualization feature, less number of options for search and problem in data sharing. It does not support more advanced calculations [12, 31].

c) PVSyst

PVsyst is freely available software for detailed analysis of sizing and data collection of PV systems. This software is customized with complete set of tools for the designers, engineers and researchers for absolute and accurate study of PV system. It can also be used for educational training purpose. It is multi-lingual software available in English, and other 7 languages. PVsyst 7.0 runs under all Windows operating systems; with minimum screen resolution is 1280x720 at 100% text size. Latest version PVSyst 7.1 is available. It can perform techno-economic analysis of PV system that is either grid connected or stand-alone system equipped with battery. This software provides multiple objects to elucidate effect of shading and simulation of PV system with varied directions. It displays output in graphical form for the functioning of PV components and performance of PV array under shading [31-33].

d) HOGA

HOGA is a GA based optimization program for hybrid systems developed by the Electric Engineering Department of the University of Zaragoza (Spain). iHOGA is the new version of HOGA. Genetic Algorithm is used for optimization. It can also be used for multi-objective optimization problems. It works on Windows XP or Vista platform. Two versions of iHOGA are available, EDU version and PRO version. EDU version is educational software for training which is freely available with some limitations. PRO version is used for research activity and it is paid version. This software allows optimization of solar photovoltaic system, wind, battery, Diesel generator, biomass generator. [34].

Advantages of iHOGA software were summarized by [15]; it uses genetic algorithm for optimization of HRES. It designs renewable energy sources accurately for economic and probability analysis. Carbon emission for life cycle of the project is also calculated. Data can be easily exported from this software. Grid connected system with net-metering can also be simulated by iHOGA [11-12, 35].

Main drawback of EDU version of HOGA is that it needs internet connection for activation of license.

e) TRNSYS

TRNSYS was developed in 1975 by the University of Wisconsin and the University of Colorado, USA. It is basically Transient Energy System Simulation Program that simulates program in FORTRAN language and it does not carry out optimization. Initially it was used for simulation of thermal system, later it was used for simulation of hybrid (PV/thermal) system. TRNSYS library comprises many commonly used components of renewable and thermal system. Its simulation is very precise and gives output in the form of graphics with great details and accuracy. This software is not freely available [14, 36]

f) iGRHYSO

iGRHYSO (improved Grid-connected Renewable Hybrid Systems Optimization) is a Spanish language program. This software can simulate and optimize solar PV, wind, small hydro, hydrogen storage batteries etc. Resource data like solar irradiation, wind speed or temperature data can be imported in the software from the NASA website, connected to the software. The effects of variation of these resources like wind speed or temperature can be studied. This tool calculates Internal Rate of Return (IRR) and considers various sales/purchase of electricity from grid. Results obtained from simulation can be exported in excel sheet format. This tool is only available in Spanish language, that's the only drawback of this tool [37-38].

i) HOMER

HOMER is very popular and commercial software developed by National Renewable Energy Laboratory (NREL)/USA, used for designing and planning HRES. It evaluates technical and financially feasible options for stand-alone and grid connected power systems. A variety of HRES components can be modeled in HOMER such as wind turbines, solar photovoltaic networks, fuel cells, small hydro power plants, biomass, converter, storage system, batteries and diesel/conventional generators.

Table 2: Literature survey for software approach

Software	Renewable Energy System	Site/ Location	Parameters considered	Reference
HOMER and PSO	PV/Wind/DG system with converter and battery	Madhya Pradesh India	Sensitivity analysis, Total Net Present Cost and carbon emission	Yashwant Sawle et al. [11]
PVSyst	PV station for self consumption	Unknown	Techno-financial analysis	Tazarine et al. [18]
TRNSYS	hybrid biomass generator with solar thermal system	Taberei District of the Odorheiu Secuiesc City	payback period	Adrian Ilie et al. [19]
HOMER and RETscreen	Wind/PV/ DG and battery system	Bhilwara Rajasthan	NPC	Norat Mal Swarnkar et al.[40]
RETscreen	grid-connected rooftop solar PV system	University of Surabaya, Indonesia.	Greenhouse gas emission reduction	Tarigan Elieser et al. [41]
HOMER and RETscreen	off-grid solar PV battery system	Residential load in Sohag city	Optimal sizing, cost effective PV configuration	Khairy Kassem et al. [42]
PVsyst	stand-alone PV system and thermal energy system	Ghardala site	Optimal design	Abdelmadjid Kaddour et al.[43]
PVSyst and HOMER	Mobile Power Pack Module (MHPS) PV/Generator with Gasoline Fuel, Battery, and Inverter	Sei Bening, Kalimantan Island, Indonesia	PVSyst and HOMER	Naftalin Winanti et al. [44]
TRNSYS	Windmill system	30 states of India	Wind Energy potential	Vishakha Tank et al. [45]
TRNSYS	Solar thermal system	Baghdad, Iraq	Annual solar fraction	M.N.Mohammed [46]
HOMER	Various combination PV/Battery PV/Hydro/Battery PV/Wind/Fuelcell PV/Wind/Grid tied	Unknown	NPC	Tom Lambert 2006[47]
HOMER	Wind/PV	Western Himalayan Indian state of Himachal Pradesh	COE	Rahul Rawat 2013[48]
HOMER	PV system/Battery	Renewable energy lab, Sohar-Oman	NPC/COE	Majid Alabdul Salam, Ali H Al-Waeli 2013 [49]
HOMER	Photovoltaic (PV)/Wind turbine	Sirte City, Libya	COE), total net present cost (NPC), and size	Faisal Alkarrami 2016 [50]
HOMER	Different combination of HRES in both modes of operation with and without storage system	Aligarh Muslim University (AMU)	Net Present Cost (NPC),	Furkan Ahmad 2017 [51]
HOMER	PV/Biomass/ Fuel cell	Academic research building Bhopal MP India	COE/NPC	Anand Singh 2017[52]
HOMER	MG1 (PV/Wind/DG/Battery) MG2 (PV/Wind/Battery/Grid)	Real building located in Medellín.	Optimal size best possible configuration	David Restrepo 2018 [53]
HOMER	PV/Wind/Grid connected	Khulna University of Engineering & Technology in Bangladesh	Optimum inverter size Optimum PV-wind ratio Optimum size of the plant	Md. Nurunnabi,2019 [54]
HOMER	Wind/PV/battery	commercial classroom complex Potheri, Thailavaram, Tamil Nadu	NPC/COE	J. Divya Navamani 2019 [55]
HOMER	Grid-connected PV/Wind/battery system	Residential community located in the eastern region of KSA, Kingdom of Saudi Arabia	LCOE	Ammar H. A. Dehwah 2019 [56]
HOMER	wind generator, a solar panel, and an inverter	A building at the University of Al-Marj (MARJU).	Most feasible economical design	Peter Jenkins 2019 [57]
HOMER and GA	Biogas/Biomass/PV/fuel cell with battery	A group of three villages in Kollegal block of Chamarajanagar district, Karnataka State in India	Total System Net Preset Cost (TNPC), Cost of Energy (COE), unmet load, CO2 emissions	Vendoti Suresh 2020 [58]
HOMER	Six different standard wind turbines	Oman	COE	Yassine Charabi 2020 [59]

Inputs to the HOMER software are meteorological data, load profile of the area, technical details of components, and economics of components, controls and dispatch strategy. HOMER can perform simulation, optimization and sensitivity analysis of the HRES [39]. For simulation, HOMER carries out energy balance calculations for different configurations of HRES including various components of different sizes to find out most practical solution. Optimization process starts after completion of simulation. In this process HRES components are optimized with the sizes specified in search space to find lowest NPC and output provides each combination of HRES that can fulfill the load demand. Sensitivity analysis is performed with the multiple values of a particular input given by the designer. It repeats the optimization process for each value of the variable and the output shows the effect of the sensitivity parameter that is displayed as a table or graph. HOMER is easy to use and freely accessible software. It gives output in form of graph and tables that can be exported [40].

— **Artificial intelligent techniques:**

Artificial intelligent techniques are alternative methods to classical techniques to design and model environmental systems. Artificial intelligence (AI) is the branch that studies science of making machines intelligent or developing algorithms and software that can emulate human intelligence. AI enables machines to learn, think, execute and solve problem like human being. Different intelligent techniques of AIT are artificial neural networks, genetic algorithms (GA), particle swarm optimization (PSO) and fuzzy logic (FL) [60].

Heuristic approach of solving problem uses algorithm to find optimal solution of a problem that may or may not be correct. It uses trial and error method for determining a solution in a reasonable time. Heuristic methods are simple, deterministic and easy to implement but it does not guarantee the best or correct solution. Genetic Algorithm is a heuristic approach of solving optimization problem [61].

Metaheuristics are iterative methods to find an optimal or almost optimal solution by exploring the search space in an efficient way to solve the optimization problem with certain supporting heuristics. Heuristics and Metaheuristic methods are slightly different; meta heuristic methods are used for optimization problems with few changes made in heuristics methods for a particular problem. Meta heuristics may combine one or more heuristic methods, ranging from simple local search to complex learning process to solve highly complex non-linear problems. Tabu Search, Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization etc. are meta-heuristic methods of solving optimization problem [62].

a) Genetic Algorithms (GA):

Genetic algorithm is a optimization technique used to find solutions of complex optimization problems with or without constrained parameters. It is a search based technique, inspired from principles of genetics and natural selection such as inheritance, mutation, selection and recombination. GA was developed by John Holland at University of Michigan. David E. Goldberg worked further on GA and popularized GA for various optimization problems. It is a heuristic approach of global search. GA can be applied to any branch of engineering and sciences to solve optimization problem. GA is suitable for complex problems where traditional hill climbing methods fail [63].

The algorithm generates a pool or a population of possible solution randomly. These set of individual act as initial set of individual, undergoes recombination and mutation and produces new generation. The process is iterative and repeated over generations. The fitness value is assigned to each individual during iteration, most fit individual get the chance to mate and produce fitter individual. Selection, crossover and mutation are three important steps of algorithm [14]. Major steps involved in GA are shown in Fig.3

Select a set of individual as initial population
Fitness value is assigned to each individual
Generate offspring until termination criteria is met
Choose the fittest individual for reproduction
Generate new individual by crossing and mutation
Calculate fitness of new individual

Figure 3: Steps involved in Genetic Algorithm [14]

Mahsa Zarrini Farahmand et al. investigated hybrid PV-wind-diesel system taking into account battery energy storage to minimize the total cost. To optimize the HRES, GA was used. The simulation results presented two PV technologies and for acceptable LOLP index, diesel generator and battery system were found necessary [64]. Paul Okunade et al. proposed a modified fuzzy logic design in the structure of GA. It was a parallel computation methodology that was used to forecasting the day ahead scheduling of HRES based distribution market. he simulation results of the fuzzy-based GA parallel calculation confirmed the superior performance relative to similar methods used for total energy cost, voltage drop and convergence velocity [65]. S. Rajanna et al. worked for optimal sizing of an integrated RES for electricity supply of a outside area in Karnataka. GA was used to find minimum NPC and COE of IRES [66]. Alaaeldin M. Abdelshafy et al. proposed modified GA, namely multi-objective genetic algorithm (MOGA) for optimizing a grid connected HRES. Different configurations of HRES were designed and result shown PV/WT/battery/diesel hybrid system was most feasible in terms of cost and emission as compared to other configurations [67]. Vivek Kumar Soni et al. worked on designing a HRES for rural areas in Bhopal India. HOMER software was used for designing an optimal system and to validate results obtained from HOMER, GA was used. Results of GA were found satisfactory for multi-objective optimization problem [68]. K. J. Gurubel et al. presented the modeling, neural prediction and optimal sizing for HRES in order to reduce the total cost and the use share of conventional sources. Firstly, to predict load variations of the site, an extended Kalman filter, a high order neural network was used. Later, Clonal selection and GA was for optimal sizing [69].

b) Particle Swarm Optimization (PSO):

Particle swarm optimization was invented by Dr. Eberhart and Dr. Kennedy in 1995. It a meta-heuristic algorithm, inspired by the nature and swarm intelligence shown by bird flocking, fish schooling, etc. PSO is a commonly used optimization algorithm as it has simple theory, easy to apply and find appropriate good solution quickly. In PSO algorithm, a particle is the each possible solution of the problem. In this algorithm, a cluster of particles or a swarm moves in a well-defined or limited search space to look for the best velocity and overall position in the swarm. For each swarm particle, the position and velocity are calculated in each stage iteratively to reach the global optimized value [70]. PSO algorithm for general optimization problem is shown in Figure 4.

The position and velocity of the swarm is updated as [71]:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{1}$$

$$v_i^{k+1} = wv_i^k + c_1 r_1 P_{besti} + c_2 r_2 g_{besti} \tag{2}$$

where: c1, c2 - position constants

r1, r2 - random represent random numbers in the range of (0,1)

v_i^{k+1} - swarm velocity of ith particle at k+1th iteration

P_{besti}- particle best value

g_{besti} -global best value

w- learning rate

1. Generate a population randomly.
2. Assign a initial velocity to each particle in the population.
3. Calculate objective function for each particle.
4. Select P_{best} as initial position of each particle and G_{best} is the best particle among the population.
5. Update new positions of particles using eqution (1) and (2).
6. Check the allowed range for particles, if it goes beyond, replace it with its previous position.
7. Calculate objective function for each particle.
8. Update P_{best} and G_{best}.
9. The algorithm is terminated if stopping criteria is met, and the optimal solution is G_{best}. Otherwise iteratethe steps 5 to 8.

Figure 4: General PSO Algorithm

Motaz Amer et al. designed a small HRES to fulfill load demand of a house. The PSO (Particle Swarm Optimization Technique) optimization technique was used as optimal search algorithm and the MATLAB software was used to construct the algorithm structure. Results proved high intensity and sensitivity of PSO in solving optimization problem [72]. Vikas Khare et al. studied optimization of RES for the police control room at Sagar, Central India. The results obtained from simulation and optimization in HOMER was further compared with two algorithms, namely particle swarm optimization and chaotic particle swarm optimization. Results of those two algorithms found the stand-alone hybrid solar-wind system to be feasible solution for replacing conventional diesel generator [16]. Soumia Khenfous et al. used cuckoo search algorithm and accelerated particle optimization algorithm for optimization problem and sizing of HRES. The results of CS algorithm were compared with APSO [73].

c) Cuckoo Search Algorithm

Cuckoo search is also one of the meta-heuristic algorithms, inspired by nature and invented by Xin-She-Yang and Suash Deb in 2009. This algorithm is derived from brood parasitism strategy of cuckoo birds for reproduction. In this reproductive behaviour, cuckoo bird laid their eggs in the nest of other birds of the same/different species. There are chances that the host birds identify the alien eggs and it may kill the eggs or leave the nest. The cuckoo bird tries different tricks like mimic in colours and host species egg pattern, to reduce chances of abandoning and increase the likelihood of having cuckoo offspring. The behaviour of cuckoos is used with Levy flights in cuckoo search algorithm to find new nest. Levy flights are a random walk pattern identified by their specific lengths of steps that follows a power-law distribution. Brood parasitism adopted by cuckoo bird can be outlined as: the cuckoo bird lays egg and put down into the nest of other bird randomly. Here, there are chances that the host bird identifies the egg dropped by cuckoo bird and it discard it or build a new nest. Only the best nest with high-grade eggs will be brought to the next generation [74]. Steps involved in optimization of HRES using Cuckoo search algorithm is shown in Fig.5.

Sarangthem Sanajaoba et al. proposed cuckoo search algorithm for PV-Battery, wind-battery and Hybrid wind PV system. The objective was to determine appropriate size of the HRES with minimum system cost for a site in Uttarakhand, India. Compared to GA and PSO, the performance of cuckoo search for solving designing of HRES was found effective [74]. Mohamed A. Mohamed et al. used cuckoo search algorithm for optimization of hybrid PV/wind/ diesel/battery energy system. The aim of the programme was to find an optimal size of autonomous HRES that is technically and economically achievable. Compared to other techniques, the time of convergence off cuckoo search was less and the results provided highly accurate the optimal size of the system [76].

Step 1 Initialization
- → Collect site specific meteorological data (speed of wind and solar insolation)
- → Load curve of the site
- → Characteristics of components available
- → Economic data

Step 2 Define Cuckoo algorithm parameters
- → Set the constraints Number of nest
  Number of iterations (N)
  Fraction of Abandoned eggs Fraction (Pa)
  Fraction of High quality eggs (Pc)
- → Develop a initial generation of n nest randomly and check the constraints.
- → Calculate the solution for the objective function and come up with the best nest.

Step 3 Evaluate the smart cuckoos out of the fraction of the population (pc), update the best nest.
Step 4 Use Levy flight algorithm to perform the global search, compute new nests and refresh the best nest.
Step 5 The fraction of worse nests (pa) is replaced by new ones, compute the new nests and the best nest updated.
Step 6 Renew the optimum solution and expand the iteration number.
Step 7 If the number of iterations is greater than the maximum number specified, stop, otherwise proceed to step 3.

Figure 5: Cuckoo algorithm for HRES optimization was given by [75]

d) Tabu Search

Tabu search is a meta-heuristic method of optimization that has ability to escape the local optima by using local search methods and was developed by Fred Glover in 1986. This method uses neighbourhood search of any given solution to determine the optimal solution with intelligent mechanisms. Tabu search have an adaptive forms of memory, intelligent mechanisms and responsive exploration which helps it to perforate complexities that are often found in alternative methods. This method is an iterative technique that uses greatest-descent algorithm to find a group of solutions by moving in search space iteratively. To reach the goal, a list of prohibited moves extracted from the previous search. This list is called tabu moves. The tabu list of restrictions and the aspiration criteria are two main components of tabu search. Tabu list is prepared by recording the moves earlier made in the order in which they are made. The number of elements in the tabu list is very important for the success of the algorithm. It may happen that a move is restricted but it satisfies the aspiration criteria, in that case aspiration criteria can overrule tabu restrictions and reactivate that move [77-78]. Fig.6 shows TS algorithm for optimization of HRES.

Akbar Maleki et al. analysed various artificial intelligence techniques to determine appropriate size of PV/wind/FC HRES. The sizing problem was solved using particle swarm optimization (PSO), tabu search (TS), simulated annealing (SA), and harmony search (HS), and the results obtained in all four cases were compared in terms of the total cost [77]. Yiannis A. Katsigiannis et al. proposed a hybrid Simulated Annealing-Tabu Search method to minimize the cost of energy of various combinations of wind/PV/diesel/biodiesel/FC HRES in Chania, Greece. A large number of possible combinations were evaluated in terms of performance and sensitivity and the result proved the proposed hybrid SA-TS method provided better quality and convergence [78].

Step 1 Define the size of tabu list
Step 2 Generate a random solution and calculate its COE.
Step 3 Assign the current solution equals to global best solution.
Step 4 Find a list of possible solutions around the current solution and arrange them in increasing order of COE.
Step 5 Check the first trial solution, if it belong to tabu list:
IF
The solution belongs to tabu list but aspiration criteria is not met, then select next solution from trial list
Otherwise
The solution is accepted and updated to the tabu list by moving the current solution to the past move.
Step 6 check for the aspiration criteria: An aspiration criterion is fulfilled if the move gives a superior solution than the finest obtained yet.
Step 7 Refresh the global best solution that has a lowest COE value.
Step 8 Stopping criteria: the search is ended if iteration number reaches the limit of iterations. Otherwise repeat step 4 to 7

Figure 6: TS algorithm for optimization of HRES

e) Ant Colony Optimization

The ant colony algorithm is also a nature-inspired algorithm which is based on ant behaviour. Ant uses a chemical substance called pheromone, to find the shortest routes from nest to food sources [79]. Weiqiang Dong et al. used an ant colony optimization algorithm for an autonomous hybrid PV/wind/battery/hydrogen system with the aim of obtaining the lowest annual system cost and maximum reliability. The results demonstrated the advantage of the HS-BS system in obtaining a reliable system (LPSP) and optimal system size [80]. Wang Deshun et al. achieved optimal multi-objective planning of an energy storage system using an enhanced ant colony algorithm based on a stratified sequencing method. The results confirmed that the algorithm was efficient and feasible for optimal planning and configuration of the energy storage system [81].

f) Simulated Annealing

Simulated Annealing was discovered by Scott Kirkpatrick. Gelatt and Vecchi in 1983, later by Vlado Černý in 1985. SA is a meta-heuristic approach used for optimization problem. This method is commonly used for the problem having a discrete search space since it may find a estimation of the global optima for a given problem in a wide spread search space. The process of annealing, used in metallurgy is the main inspiration of SA. Annealing is a process that heats and cools a metal in a controlled manner to maximize crystal size and reduce defects. The process of optimization using SA is similar to annealing (Slow cooling of metals), which provide crystalline structure of the metal. Therefore, cooling criteria are essential in order to achieve a good solution using SA. The search starts from a large temperature and moves downhill using steepest descent method, and terminates the search at a low temperature by gradually decreasing temperature in each iteration.[82]

C. Nayanatara proposed a hybrid simulated annealing method for optimizing the location and size of distributed generation (DG) devices. to improve system stability, reduce losses and cost of energy generation. The outcome was compared with other optimisation methods such as Genetic Algorithm(GA), Fuzzy Simulated Annealing (FSA) and Micro Genetic Algorithm(MGA). The proposed method was found appropriate and beneficial for solving optimization problem of DG devices [88]. Sutthibun and Bhasaputra used SA to solve multi-objective problem of sizing and optimal allocation of DGs. The results were found to provide better result in less computing time compare to GA and TS [83].

g) Neural Network

ANN are made up of simple processing units called neurons, based on the structure and functions of biological neural networks. These neurons are highly interconnected to solve specific problem. Neural networks are non-linear, self-learning, fault tolerant and robust that can perform parallel processing. ANN maps the relationship between input and output data with the help of data given during training. ANN techniques are easy to implement for real world problems as it does not need system model for calculations. It has powerful pattern recognition quality that makes it flexible and attractive for optimization problems. ANN needs enough data and training for solving any problem. Several authors have presented an in-depth understanding of suitability of various ANN algorithms for solving optimization problems of hybrid renewable energy sources [84].

S.Rameshwar used artificial neutral network (ANN) control the real and reactive power, power factor and total harmonic distortion of renewable hybrid systems at the common coupling point and network. The current from the point of coupling is compared with the reference signal and output power fed into the network is modified to maintain the real power. Results proved that proposed system make use of artificial neural network (ANN) to provide intelligent control by automatically varying the power produced according to the demand [85]. Vikram Puri et al. offered a system based on the Internet of Things (IoT) to generate electric power from multiple sensors for household appliances and industrial areas. Artificial Neural Network (ANN) and Adaptive Network based Fuzzy Inference System (ANFIS) was used for evaluation. The outcome of the system showed better performance by ANN than ANFIS [86]. N. Chettibi et al. developed a novel ANN-based system for controlling the hybrid micro-grid. In the proposed methodology, Adaptive neuron networks were used to monitor the maximum power point of renewable energy generators and an energy management system with fuzzy logic was used to lower the energy purchased from the power grid. The findings demonstrated the efficacy and self-adaptability of the proposed control system [87]. K. J. Gurubel et al. used an expanded Kalman filter to forecast load demand, whereas the clonal selection algorithm and genetic algorithm were used for modelling, neural prediction and optimal sizing of hybrid energy systems. The effectiveness of using neural prediction data was demonstrated by a simulation, with the results demonstrating the efficiency of the two optimization algorithms for the computation of an optimal hybrid system sizing [69]. Md Mijanur Rahman et al. reviewed different machine learning methods for HRES. This research studied different models of ANN to predict the accurate value of power generated by renewable sources. A variety of neural network architectures, including multi-layer perceptron, recurrent neural network, convolution neural network, and long-term memory models, were used to predict power generation by renewable energy. These models have proven to be an effective predictor of short-term time series [88].

h) Fuzzy Logic

Fuzzy logic is a method of reasoning just like human reasoning. It is used for complex and non-linear systems that have incomplete, ambiguous, distorted or inaccurate input. FL approach makes decision emulating human behaviour that involves all possibilities between YES or NO and TRUE or FALSE. Therefore FL have multiple logical states between zero and one. Fuzzy logic controller has three processing stages: fuzzification, fuzzy inference stage, and defuzzification. Fuzzification is the process of changing the net value input into fuzzy values using different membership functions. Next stage of processing is fuzzy inference system where fuzzy rule base are generated depending upon the problem. The result obtained from a fuzzy inference system consists of fuzzy variables that are again changed into net values by the defuzzification process. The fuzzy logic controller calculates the error and the error change between the reference inputs and the real outputs [89-90].

Mohammed J. Wadi Yildiz et al. used HOMER software to find optimal design of a distributed generation system, and evaluate financial and technical feasibility if the grid-connected and stand-alone system. To choose optimal value of power source according to various load demand, available power sources, and distance between the power sources and the load, fuzzy based approach was used in this study. The results obtained with these two techniques provided an optimal system with low cost, higher efficiency and long life-time of the system [91]. Imene Yahyaoui et al. proposed the fuzzy algorithm for energy management of a HRES installed in rural area. The fuzzy logic controller provided control decision for switching of installed components according to non-controllable power demands. The total cost of the system was optimized using GA. The results showed effectiveness of the fuzzy logic controller in energy management, providing system autonomy, ensured continuous load supply and safe functioning of battery bank [92]. Sujata Huddar et al. proposed fuzzy logic method for optimal location and sizing of distributed generation. The method includes a fuzzy inference system (FIS) that helps in deciding the DG placement. The results obtained have proper location and size of DG that improved system reliability and stability, also the proposed method was verified on IEEE33 bus system data [93]. M. Mosbah et al. proposed a hybrid technology using NSGA-II and a fuzzy logic controller for multi-target optimization of DG location and size. The Pareto-optimal front was figured by using NSGA-II technique and fuzzy controller was used to find finest solution. The objective functions of the proposed study were to minimize active power losses and optimize the voltage stability index. The proposed methodology was tested on distribution networks of different sizes (10 bus, 33 bus, 85 bus) and validated on the Algerian distribution network (116 bus) [94]. Guoqing Weng et al. summarized different artificial intelligent techniques like, genetic algorithm and fuzzy logic for distributed generation system. Methodology of AI techniques to solve problems were discussed along with the drawbacks and result concluded that hybrid AI techniques have better problem solving capability and may overcome drawbacks of single AI technique [95].

5. CONCLUSIONS

There is existential threat to human race if pollution keeps on increasing with the same rate as today. World has witnessed drastic climatic changes due to pollution and greenhouse gases. Fossil fuels are also at the verge of its extinction, which causes high prices of coal and oil. All the developed and developing countries are looking for carbon free, green energy sources for fulfilment of energy demand. Hybrid renewable energy systems are more preferred choice of the researchers and scientists as compared to single renewable energy source. HRES can be used for rural/remote electrification, charging station for electric vehicles and for other energy demands reliably. To use HRES, it should be properly designed with optimal size and cost for better utilization of renewable sources. Researchers and scientists around the globe have been working and worked for multi-objective optimization of HRES that yields economic, reliable and secure system. This study includes review of different software tools and techniques used by the researchers for this optimization problem. Some authors used traditional methods like linear-programming, graphical construction and probabilistic methods for optimal designing of HRES considering the linear problem. Some authors suggested heuristic and meta-heuristic methods for non-linear optimization problem. The various optimization software has also been developed and used by numerous researchers. There is continuous on-going research in this field. Some authors used artificial intelligent techniques, fuzzy logic controllers and hybrid models for simulation and optimization of HRES. This study provides a concise and good idea of the tools and techniques used for optimizing the HRES. The review will be useful to researchers in order to address the complexity and challenges of research on hybrid systems based on renewable energy. This article included the most pertinent literature on the design, simulation, control and optimisation of hybrid systems.

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