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REVIEW PAPER

A Review on Architecture, Performance and Reliability of Hybrid Power System

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Abstract With rising demand of energy crisis, the extension of the grid, only with the non-renewable energy sources, has resulted to an end. As a result, the engineers from energy and power generation sector have become conscious for searching an alternate option, which includes the renewable source of energy like solar, wind, small hydro, geothermal, biomass, and ocean as economic, sustainable, and atmosphere pleasant alternative for the conventional source of energies. The inconsistencies in the accessibility of renewable sources every time throughout the year have led to a great expansion in the field of hybrid renewable energy system (HRES). In recent years, several researches have been reported on architecture, operation, and optimization of HRES in response to rising demands. This paper presents an analytical review of various issues related to HRES-based power generation. An overview of different architectures, performances, and reliabilities of hybrid energy system taking optimization into consideration has been presented. Reliability optimization adopted and reported in the studies which include sizing, cost, net present value, etc., of the system components is reviewed. Various software tools that enable evaluation and optimization of performance, reliability, and other parameters for hybrid system configurations are discussed in detail. The challenges, accessibility, and domain of future research in terms of optimization have also been identified.

Keywords Renewable energy · HRES · Optimization · Reliability

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Introduction

In the global energy scenario, India is presently the world's third-largest energy consumer and fourth-biggest economy in terms of purchasing power parity (PPP) [1, 2]. In the year 2017, the total primary energy supply meet by coal is 44.3% compared to 31.1% by oil and natural gas. Hydel and nuclear energy meet 1.4% and 1.1%, respectively. Natural gas meets up 5.8% of our energy needs in 2017 [3]. Researches are going on to find means and ways to reduce the level to a particular limit which the planet can afford. A study from world energy demand shows that the demand for energy will rise up to 62% by 2035 from 53% in 2011 [4, 5]. Nowadays, renewable energy projects are extended on large scale; hence, different renewable technologies are also suited to remote and rural areas and developing countries. To satisfy the increasing energy demand, the best use of resources available around us is the only possible option [6]. It is seen from various researches that renewable energy has the ability to uplift the poorest nations to high levels of prosperity. In addition to that, renewable energy is much more efficient which leads to a significant reduction in non-renewable energy requirements since most renewable energies do not require a steam cycle with high losses, whereas non-renewable energy like fossil power plants usually has losses of 40 to 65%. The sun the only one living source of energy irradiates estimated power of about 175,000TW approx. The rapid increase in renewable energy and its efficiency would result in economic benefit and significant energy security. It would reduce environmental pollution which was caused by the burning of fossil fuels and improve nature health and also reduce earth from global warming. Significant opportunities for renewable energy resources exist over wide geographical areas, in comparison with other energy sources.

High oil prices, scarcity of oil and increasing government support when combined with climatic change and global warming concerns increase the renewable energy demand. From various research studies, it is seen that solar energy may produce most of the world's electricity demand within the next 50 years, reducing the emissions of greenhouse gases which contribute to global warming that harm the environment [7]. Thus, solar energy acts as an attractive supplement for boosting green energy capacity to overcome the severe power constraints and cut pollution. Govt. of India launched a programme to generate 20,000 MW by 2020. India is first to start a solar park in Asia, planning to generate 72.4 GW from renewable sources or nearly 16% of total capacity by the year 2022, using methods of solar thermo-mechanical systems and solar photovoltaic (SPV). In the first case, the turbine runs with a working fluid heated by solar radiation, and in the second case, SPV directly converts the radiant energy to electric current [8]. Since the input to SPV is solar radiation, therefore, to capture the maximum amount of solar rays, the solar panels are placed at an incident angle which is identical to the latitude of the surface area considered for the SPV system. The power output of the solar PV system varies with beam radiation and diffuse radiation. Thus, power yield of the solar PV system is computed hourly, given as [9],

$$P_{\mathrm{SPV}} = \eta H_{\mathrm{T}} A \tag{1}$$

where η denotes conversion efficiency, A denotes the surface area in m^2, and H_T denotes hourly solar radiation in kWh/m^2. If the efficiency of a solar panel is 20 percent, it can convert 20 percent of the total sunshine hitting it into electricity. Solar panels can achieve maximum efficiency of almost 23%. Nevertheless, solar panels average efficiencies lie between 15 and 18%. Therefore, annual energy produced from SPV system is given as:

$$E_{\mathrm{SPV}} = \sum_{t=1}^{8760} P_{\mathrm{SPV}}(t) \tag{2}$$

Another form of energy that may reduce the world's electricity demand is wind energy since the total land area of earth generates approximately 1.67×10^5 kWh of wind energy annually. India is among the leading countries in generating power through wind energy. The present wind energy scenario in India is about 45000 MW out of which approximately 9000 MW is just installed in India. Most of the states in India are generating 5000 MW potential individually. These potentials can further be improved if various technologies are combined. The theoretical assessment of the potential of wind energy is restricted by physical, high altitude and high slant geographical areas, physical areas near cities, airports, protected regions, and spots used for agriculture constraints [10]. Wind speed varies from place to place depending on the area, weather, and installation height from the ground. The more the wind power captured, the more is the energy generated. Thus, from the survey, it is found that the Weibull probability density function gives the top result for variation of wind speed and is expressed as [11]

$$F(V,k,c) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{3}$$

where V represents the speed of wind (in m^3/s), c represents parameter scale, and k stands for shape parameter.

The output power of wind turbine can be evaluated in terms of density of air (ρ), swept area (A), wind speed (V) and power coefficient (C_p) as

$$P_{\mathrm{WT}} = \frac{1}{2} \rho A V^3 C_{\mathrm{p}} \tag{4}$$

Therefore, annual energy produced by a wind turbine is given as

$$E_{\mathrm{WT}} = \text{Time} \times \text{Power} = 8760 \times P_{\mathrm{WT}} \tag{5}$$

Hybrid power systems merge two or more means of electricity generation mutually and generally by means of renewable sources like SPV and wind turbines as shown in Fig. 1. The two energy sources used mutually provide better system efficiency, lower cost, and superior energy supply balance [12]. They offer high-level security in the techniques of employing energy generation and integrate storage systems usually battery or fuel cell in order to guarantee reliability and security in the utmost supply.

Power Sources

The usage of electricity in the world is growing at a rate double of demand in every 10 years. The energy generation is lagging behind this increasing demand due to several factors like inefficient generation, maintenance, and insufficient outlay of transmission lines. For social and economic development, power sources play an important role because the demand for energy is increasing remarkably. Different sources of renewable energy consist of solar, wind energy, hydroelectric, biomass, etc. Other forms of energy such as fuel cells are used for residential, industrial, and commercial primary and backup power generation and can achieve up to 99% reliability. The hydrogen used in fuel cells is obtained from several promising methods, such as solar power. Geothermal energy has the advantage of being accessible throughout the day and in every season. This type of energy can decrease the requirement for other energies to keep up agreeable temperatures in different constructions, but it cannot be utilized to create electrical energy [13]. Energy

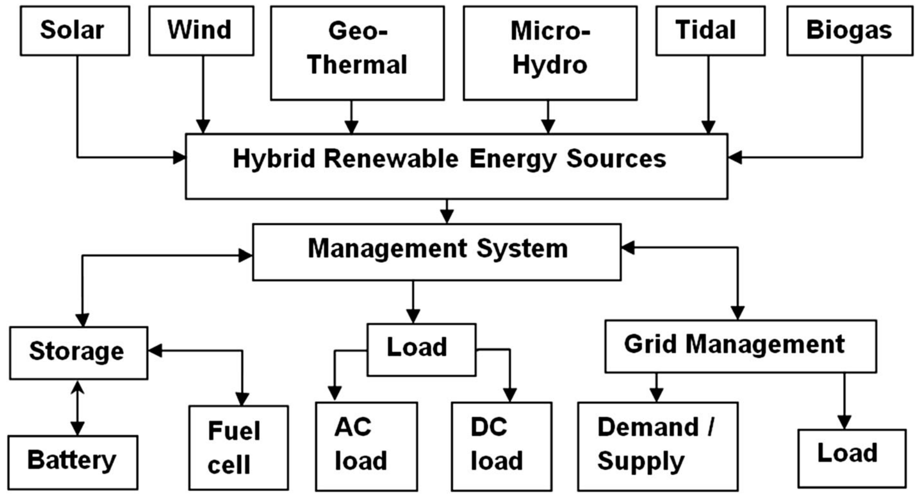

Fig. 1 Block diagram of hybrid power system

from tides, the seas, and hot hydrogen combination are different forms that can be utilized to generate electricity. The variations in earths' warming produce winds that exchange energy to produce waves since it ignores unblocked waterways. Waves move awesome separations with no critical loss and thus becomes an effective component for energy transport over a large number of kilometers [14].

A non-renewable resource is a resource of monetary worth that cannot be readily supplanted by characteristic means on a level equivalent to its utilization. There is a restricted supply of non-renewable energy resources, which will end in the long run. The study reveals that burning of fossil fuel discharges carbon dioxide, which adds to the greenhouse impact and increases an earth-wide temperature boost known as global warming. Of the three fossil fuels, coal creates the most carbon dioxide, for a given amount of energy discharged, while natural gas produces the slightest. The fuel requirement for nuclear power stations is generally cheap but installations of the nuclear plant and to destroy old stations or store radioactive waste are extremely costly.

Architecture of Power Sources Configuration

Every source of renewable energy posses its own particular operating descriptions, and it is important to formulate a benchmark method to integrate the energy sources in a hybrid system. In general, three types of possible configuration exist for integrating various sources of renewable energy such as hybrid-grid, hybrid-off-grid, and individual supply of grid configuration [15, 16].

Hybrid-Grid Configuration

The hybrid-grid configuration consists of solar–wind–hydro–battery integrated grid-connected system associated with the network along with a battery energy storage system shown in Fig. 2. In this plan, solar energy (DC sources) is attached with DC load through an appropriate affiliating circuit. DC source is generally supplied via DC interfacing circuits, if required by utilizing DC/DC converter. The power frequency AC coupled (PFAC) bus of 50–60 Hz provides energy to AC loads. In such configuration, PFAC sources of energy (wind, hydro, fuel cell, and so forth.) are associated with the grid that removes the utilization of converters and subsequently decreases transformation loss in the design. Hence, hybrid-grid configuration offers low system price and high efficiency of energy in comparison with AC coupled as well as DC-coupled plans individually. However, hybrid-grid configuration has generally complex administration of energy and control.

As an example, the 132 kV, 2500 MVA grid is attached to a typical hybrid solar–hydro system [17]. The solar array is made up of 8 strings of 5 series connected parallel PV modules. There are 96 PV cells in one PV module. At 1000 W/m^2 maximum power, the PV array provides up to 10 kW. A 10 kVA transformer increases the voltage produced from 260 V to 11 kV of the grid voltage level. The voltage of the hydro system is increased by 10 kVA three-phase two-wire transformers to link the hydro system to the grid from 415 V to 11 kV. In ideal conditions, the solar system generates about 10 kW of power, while 7.5 kW is produced by the hydroelectric system.

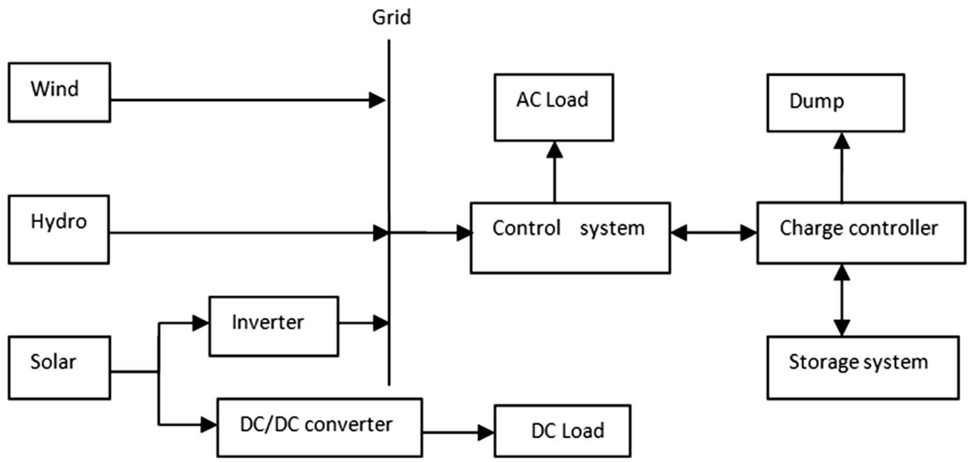

Fig. 2 Schematic diagram of integrated solar–wind–hydro–battery-based grid-connected system

Hybrid-Off-Grid Configuration

The hybrid-off grid configuration contains wind turbines, PV solar panels, small hydro system, a battery energy storage system, DC loads, and AC loads. In the first arrangement, all the sources of renewable energy are linked to the DC bus through a suitable affiliating circuit as shown in Fig. 3. Proper synchronization is a must among various system components. DC loads are coupled straightway to DC bus and supplied through DC/DC converter to the load end by properly maintaining constant DC voltage source. This configuration is capable of power supply to AC load via inverter provided inverter maintains its operation; otherwise, the entire system will experience a crisis of energy supply to AC load. The supply energy crisis may be eradicated by synchronizing numerous low rating inverters in parallel so as to deliver AC power.

In the second configuration as shown in Fig. 4, different sources of renewable energy, producing AC, are coupled to PFAC bus via proper interfacing circuit and sources of renewable energy producing DC are coupled straightway to DC bus along with an attached storage system via bidirectional converter. The AC loads are coupled straightway to AC bus, while DC loads can be interconnected to PFAC via AC/DC converter. The synchronization of different components of the system is no way necessary for power frequency AC-based coupled system [18].

Individual Supply of Grid

This particular system contains a grid, battery energy storage system, DC loads, and AC loads. For the individual supply of grid, one of the important components used is energy storage systems (ESS). Energy storage systems help in continuous power supply in any condition, to meet peak demand, smoothing out load fluctuations for certain areas.

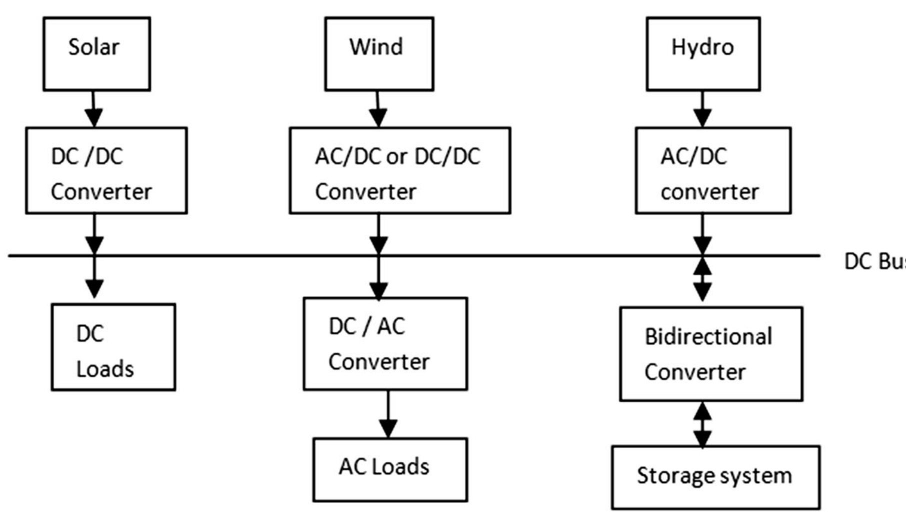

Fig. 3 Integrated system showing hybrid DC-coupled configuration of solar–wind–hydro

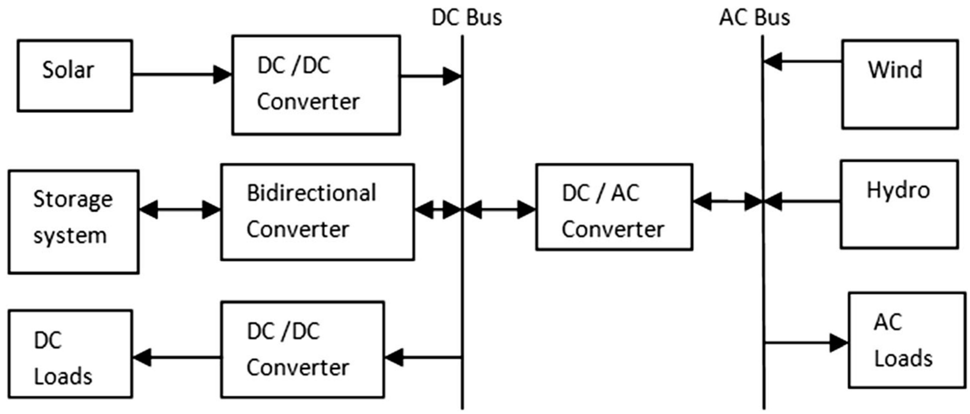

Fig. 4 Integrated system showing hybrid DC–AC coupled configuration of solar–wind–hydro

Criteria for Power System Reliability

Power system reliability under changing weather conditions is the major apprehension for scheming hybrid power generation systems. Gradually, the hybrid renewable energy systems (HRES) are getting to be trendy in applications of power development especially in the remote region because of advances in renewable energy innovations and consequent increase in the cost of petroleum items. Economic characteristics of such advances are adequately encouraging to incorporate them in generating power capacity limits for developing nations. Research and development of different types of renewable energies (solar, wind, and other renewable energy technologies) are essential to improve the overall performance, building up methods for precisely forecasting the output and dependably incorporating them with other conventional sources taking different constraints into consideration, such as sizing and control of system component, reliability, cost, efficiency, control, placement, and acceptable power quality. HRES reliability studies provide the necessary information regarding the production of energy whether capable to supply the desired demand load throughout. A literature survey shows that most of the researchers mainly consider parameters like unit sizing, expected energy not supplied (EENS), loss of power supply probability (LPSP), energy index ratio (EIR), level of autonomy (LA), etc. [19].

Sizing of Component

Unit sizing should be optimum which is crucial for proficient and cost-effective exploitation of the renewable sources of energy in HRES. Optimal sizing possess the most minimal net present cost (NPC) taking reliability of the system into consideration, which is a prerequisite for making the system work in an ideal environment. Appropriate synchronization of optimal resources in hybrid systems is crucial for achieving satisfactory reliability and cost of the system. Solar PV cell, PV module slope angle, number of wind turbines, battery banks, controller, inverter, cable, and additional accessories are considered as variables for optimal sizing [20].

Loss of Power Supply Probability (LPSP)

A reliable HRES is the one that ensures an uninterrupted supply of power in the system to feed the demand load, but sometimes, it has some amount of power loss which is measured as LPSP. This probability of inadequate power supply is defined as loss of power supply probability (LPSP), given by:

$$\mathrm{LPSP} = \frac{\sum_{t=0}^{T} \text{Power failure time}}{T} = \frac{\sum_{t=0}^{T} \mathrm{Time}(P_{\text{available}}(t) < P_{\text{needed}}(t))}{T} \tag{6}$$

where T denotes the number of hours for study with hourly data input, $P_{\text{needed}}(t)$ is the power needed by the load, and $P_{\text{available}}(t)$ is the overall power available from the system

Cost Analysis

To optimize the power reliability of HRES, an important aspect is its cost. Total cost of HRES is split into different cost constraints such as NPC, annualized cost of system (ACS), levelized cost of energy (LCE), internal rate of return (IRR), and payback period (PBP) which are to be evaluated as considered by the various authors. According to the research study, the different constraints of cost analysis are explained in the literature [21].

Annualized Cost of System (ACS)

The metric ACS is the summation of the annual capital cost of each of the components of HRES, the annual cost for replacement of battery, and annual cost for maintenance of each of the component of HRES. Considering the sources of the HRES, the ACS can be expressed as:

$$\begin{aligned}\text{ACS} = {} & C_{\text{acap}}(\text{Component 1} + \text{Component 2} + \text{Bat} \\ & + \text{Other sources}) + C_{\text{arep}}(\text{Bat}) \\ & + C_{\text{amain}}(\text{Component 1} + \text{Component 2} \\ & + \text{Bat} + \text{Other sources})\end{aligned} \tag{7}$$

where C_{acap}, C_{arep}, and C_{amain} represent annualized capital cost, annualized replacement cost, and annualized maintenance cost, respectively.

Levelized Cost of Energy (LCE)

LCE is represented as the net present value of the unit cost of energy production in a hybrid system over the lifetime of a generating system. It is seen that LCE is defined as the fraction of annualized cost of the system to the total electricity produced (E_T) annually by the system given as:

$$\text{LCE} = \frac{\text{ACS}}{E_T} \tag{8}$$

Another way of expressing LCE in terms of the average cost of generation for t number of year is:

$$\text{LCE} = \frac{\text{Sum of costs over life time}}{\text{Sum of electrical energy produced over life time}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{9}$$

where I_t is the investment expenditures, M_t is the maintenance and operations expenditure, F_t is the fuel expenditure, E_t is the electrical energy generated, r is the rate of discount, and n represents the expected lifetime of system or power station.

Net Present Cost (NPC)

NPC represents the total cost comprising income and expenditure of a hybrid renewable energy system over its life cycle. Thus, NPC [22] can be expressed as:

$$\text{NPC} = \frac{\text{Total annualized cost}}{\text{Capital recovery factor}} \tag{10}$$

Net present cost can also be expressed in terms of total capital outlay (TCO) as:

$$\text{NPC} = \frac{\text{TCO}(1+i)^n}{1+r} \tag{11}$$

where i is the annual inflation rate with r being rate of discount and n represents the expected lifetime of system or power station.

Economic Analysis to Implement Distributed Generation System

Distributed generation (DG) system is an approach that uses various technologies like solar panels and combined heat and power to generate electricity close to where it will be used and efficiently distribute it with minimum losses. It may supply a single structure like home, or it could be a component of a microgrid fixed to a larger electricity delivery system intended for an industrial facility. It offers the advantages of reducing electricity losses along transmission and distribution lines, reduces voltage fluctuation, reduces energy cost, and improves reliability and power quality. There are numerous objectives to promote DG system such as

1. Decreasing the release of greenhouse gas
2. Liberty from imported fuels
3. Improvement of certain technologies
4. Setting up the latest industries through employment scope.

An economic analysis to implement DG using distributed renewable energy resources with optimal power operation was carried out for minimum energy cost [23]. Gravitation search algorithm (GSA) was used to solve this optimization problem which achieved better results compared to particle swarm optimization (PSO).

Expected Energy not Supplied (EENS)

Whenever the normal demand for load supply exceeds beyond the energy generation of an HRES, there arises a situation called expected energy not supplied. EENS in kWh can be evaluated in terms of average annual demand (W) in kW and duration for which load is not met (T) in hr [24] as

$$\text{EENS} = \sum_{i=1}^{8760} W(i) * T \tag{12}$$

Level of Autonomy (LA)

LA can be expressed as the proportion of time that satisfies the desired load demand. It is dependent on time duration, when usual energy is not furnished or loss of load occurs, and actual duration of operation in hours. Mathematically, LA can be modeled as: [25]

$$\text{LA} = 1 - \frac{\textit{Loss of load}}{\textit{Actual duration of operation}} \tag{13}$$

Renewable Energy Source Intermittency

Intermittency is the amount to which a power source is inadvertently unavailable or blocked due to which the power source reveals transformations in output and produces irregular or interrupted patterns. In renewable energy systems, intermittency is one of the foremost hindrances in large-scale deployment that illustrates the inconsistency of the energy output from sources. Solar or wind energy-based power systems produce power intermittently since they entirely rely on climatic conditions. Power generation from solar panels depends on the availability of sunlight and the absence of cloud coverage, while wind turbines entail a fixed wind speed to produce power. This intermittency can be compensated by backing up the source through an alternative means of energy supply like storage battery or dispatchable renewable energy sources that have the capability to control the output like geothermal, hydropower, biomass, or sector coupling by electric heating. But this form of intermittency arises issues like pollution and economic infeasibility. In terms of intermittency, renewable energy sources remain in a disadvantageous position over non-renewable ones.

Reliability Optimization

In HRES-based power generation discipline, several techniques and strategies are available for optimization of system reliability using commercially available computer tools, artificial intelligence techniques, multi-objective design strategy, analytical and statistical approaches, etc.

Available Software Tools

The simulation programs are the popular method or tool for evaluating the operation of HRES. Several software programs are available from various researches, using which performance, reliability, and other parameters can be found for hybrid system configurations. Talking about sizing programs, it is seen that HOMER is among the prominent tool for sizing which is developed by National Renewable Energy Laboratory (NREL), USA. In the literature survey, it is seen that HOMER is commonly used in several case studies for renewable energy systems. HOMER software possess many energy component modules, like solar PV, wind, hydro, batteries, diesel, and other fuel generators, electrolysis units, fuel cells, etc., and assess them in regard to their cost and resource accessibility. Grid connection can also be considered in this software; hence, both stand-alone and grid-connected configurations have been studied. The architecture of the HOMER [26–34] and other major software is shown in Fig. 5. Several other software programs applicable for HRES, like The Hybrid Power System Simulation Model (HYBRID2), Improved Hybrid Optimization by Genetic Algorithm (iHOGA), TRANSYS, RETScreen, The General Algebraic Modelling System (GAMS), optimization, and control system on single or multi-objective problems resolved by means of genetic algorithm, ORIENTE, Opt Quest, LINDO, WDILOG2, DIRECT, DOIRES, SimPhoSys, GSPEIS, GRHYSO, etc., were successfully utilized for optimization considering several constraints [35–41]. A comparison of a different software of reliability optimization is presented in Table 1 [42].

Different Approaches

For the power reliability, analysis of HRES to be formulated is done by determining the optimization of the hybrid system along with its most favorable type, location, and sizing of different components of the generation units placed in particular places, so that the HRES confirms the desired load demand at low cost and high efficiency. From the literature survey, the design of HRES can be assessed by sizing of different components, supply probability constraints cost of the system, etc. A comparison of optimization in terms of different parameters using various artificial intelligence-based approaches is tabulated in Table 2, while Table 3 represents the comparison using different multi-objective design, analytical and statistical modeling approaches in terms of sources, objective of design and results.

For optimization of reliability in HRES, many of the researchers concentrated on the sizing of components, LPSP, net present cost, the annualized cost of the system, cost of energy, EENS, LA, etc., taking different types of constraints into consideration. So to optimize, different methodologies as AI (artificial neural network, genetic algorithm, PSO, etc.), multi-objective design, analytical, statistical approaches are used. Along with that, commercially available software tools (HOMER, iHOGA, HYBRID2, TRANSYS, RETScreen) have also been used. In the present paper, a comparative study of the different methodologies is summarized. After the comparative study, this paper proposes the need for a different methodology to improve the convergence rate and quality of the solution. Hybrid algorithms or ensemble models are presently popular for optimization problems and provide enhanced results [64].

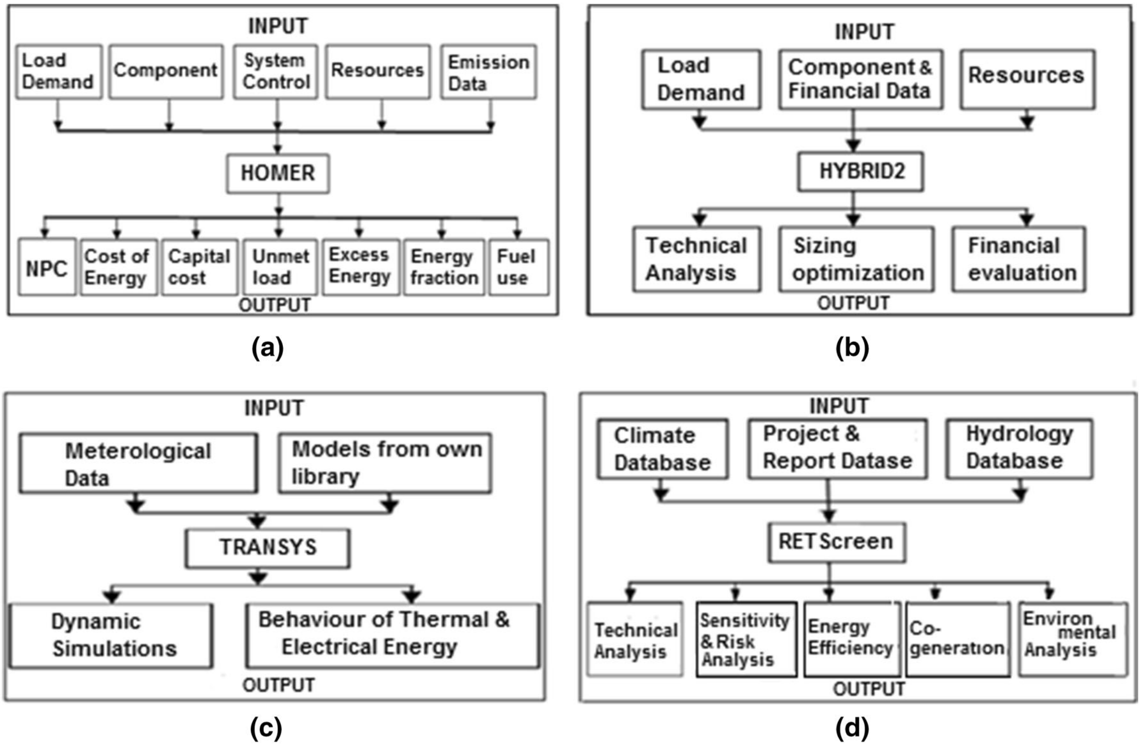

Fig. 5 Architecture of various software **a** HOMER, **b** HYBRID2, **c** TRANSYS, **d** RETScreen

Table 1 Comparison of a different software of reliability optimization

Sl. no	Software	Platform	Used for	Type of analysis	Advantages
1	HOMER	Visual CPP	Feasibility, optimization, and sensitivity analysis Both on-grid and off-grid systems	Technical, economical, and emission analysis	1. Freely available and user-friendly interface with efficient graphical demonstration of results 2. Handle hourly data 3. Includes SPV temperature effect 4. Compute overload power generation 5. Illustrates the computational time of the simulation
2	HYBRID2	Visual Basic, MS Access	Simulations and input error checking	Technical, economical analysis	1. User-friendly interface 2. Includes option for multiple power load transmission
3	iHOGA	CPP	Hybrid system optimization, sensitivity, and probability analysis	Technical	1. Allows both mono- and multi-objective optimization 2. low computational complexity
3	RETScreen	C, Visual Basic	Feasibility study, Assessment of financial, and environmental costs	Financial, environmental analysis	1. EXCEL-based product: hence, simple and accessible 2. Includes financial analysis option. 3. Powerful dataset (NASA meteorological data)
4	TRANSYS	Fortran, CPP	System simulation (also for hybrid system)	Simulation of the stochastic system	1. Allows hybrid simulation 2. Flexibility 3. GUI-based risk analysis and emission analysis

Table 2 Outline of applications using artificial intelligence approach

Author	Algorithm used	Source	Objectives	Design constraint	Result
Mellit et al. [43]	ANN	Solar, battery	Sizing	LPSP	A method developed through minimal data input for best sizing of the component
Lujano-Rojas et al. [44]	ANN	Solar, wind, battery, generator	Cost	Incident solar ray, speed of wind cost of fuel and batteries	Proposed a model considering the irregularity of solar radiation, speed of the wind, cost of fuel, and battery durability and found EENS and NPC for the proposed model under numerous constraints
Rezvani et al. [45]	ANN and GA	Solar, wind	MPPT	MPPT	2 percent improved efficiency in tacking fast and accurate maximum power output
Merei et al. [46]	GA	PV, diesel, wind	Net present value	Sources capacity, tilt angle	Combination of lithium ion, lead–acid, vanadium redox flow battery is used to optimize the hybrid system
Kumar et al. 2013 [47]	GA, PSO,	Solar, wind, battery	Net present value, cost	No. of generator, battery capacity, energy balance	Designed a new algorithm for converging to simplicity and also compared with other algorithms
Paliwal et al. [48]	PSO	PV, diesel, wind, battery	Cost	No. of generators, battery	Optimized the levelized cost of energy of a hybrid system to met economic criterion taking different constraints
Jiang et al. [49]	PSO	Wind and hydrogen	Maximize the social benefit and rate of smoothing the instability of wind	Cost and wind instability	An example of wind volatility with the likelihood of constraint and the cost of production of hydrogen and fuel cells has been studied in detail and stated that the overall system provides additional social benefits if the expenses of fuel cell and hydrogen fabrication system fall down and the probability of smoothing fluctuations improves even if wind differs uncontrollably
Askarzadeh [50]	DHSSA, HS, SA	PV, wind, battery	Annual cost	No. of solar panel, wind turbine, battery	Minimized annual cost using DHSSA and analyzed it with HS and HSSA
Kumar et al. 2019 [51]	Satin Bowerbird optimization method	Solar, Wind, Battery	Cost and Sizing	Energy generation and storage system	Obtained the optimal sizing and power management with the usual saving of NPC by 19.7%/day in annual cost

Challenges and Discussion

Electrical energy generation using various renewable energy sources like solar, wind, hydro, geothermal, biogas, fuel cell, etc., is sustainable and environment friendly. However, day to day we are facing new challenges from hybrid renewable energy system-based power generation. Some of the challenges are discussed as:

- Improvement of reliability at an optimum operating cost as renewable energies are dependent on the weather like rain, wind, sunshine, etc.
- Improvement of the convergence rate and quality of the optimized solution.
- Improvement of efficiency of solar panel and wind turbine as these are the greatest source of renewable energy.
- Minimization of the capital cost of renewable energy which is very high compared to conventional energy.
- Reduction in energy losses in the conversion process using power converters.
- System stability and reliability in case of a stand-alone hybrid renewable energy system, grid-connected, and offshore onshore power systems.
- Improvement of the durability and performance of battery storage at a minimum cost.

Conclusion and Future Scope

Hybrid renewable energy system has been playing a great role for energy supply in case of stand-alone applications along with the increase in global energy demand and scarcity of conventional energies. It has been increasingly

Table 3 Summary of studies based on multi-objective design, analytical and statistical modeling approaches

Authors	Source	Objective	Design constraint	Result
Abbes et al. [52]	PV, wind, battery	LCC, LPSP	No. of generators, SOC	Designed 120 Pareto optimal set and found a solution that satisfied 95% of the housing power requirement
Ippolito et al. [53]	Solar, battery	Overall cost, energy loss, emission of greenhouse gas	Active and reactive power limit, power transfer and voltage limit	Studied three scenarios and found that for the intermediate values of objective functions, the development of voltage profile was very appropriate functions
Maheri et al. [54]	PV, wind diesel	LCE for cost, unmet load for reliability	LCE and reliability	Developed two algorithms and in one algorithm, the most reliable system was built taking cost constraint and in the second one, the most cost-effective system was built taking reliability constraint
Abedi et al. [55]	PV, wind, fuel cell, battery, and diesel	NPC, fuel emission, LLP	Storage energy level, tilt angle	Optimized total system cost, unmet load, and fuel emission using fuzzy techniques. Also, designed energy source uncertainty related to Weibull and Beta pdf
Kaldellis et al. [56]	PV, lead–acid battery	Energy payback	Generation-demand balance, individual power capacity	Compared stand-alone system with grid-connected configurations and found that the battery component crosses 27% of the required life cycle energy demand of the system
Tina et al. [57]	Solar and wind	Annual total cost	Internal rate of return, EENS	Optimized the hybrid system probabilistically by designing a preprocessing stage for the input of an algorithm
Yang et al. [58]	Wind, solar and battery	LPSP	SOC	Designed battery storage using probabilistic approach which has a charge for 3–5 days was appropriate for the required LPSP of 1% and 2% for this case
Ali et al. [59]	Solar, wind generator and battery	VCVSI and CCVSI	Cost and efficiency	Designed a power processing unit which is able to supply uninterruptible power, voltage stabilization, better efficiency, unity power factor operation
Borowy et al. [60]	Wind, solar, and battery	Total system cost	LPSP	Taking long-term data for irradiance and wind speed a method is developed to optimize the size by correlating between the no. of PV modules and the number of batteries from which the minimum cost was attained at the tangent of the curve
Vick et al. [61]	Solar and wind	Efficiency	Size of PV array	Developed a most efficient hybrid system and improvement of the hybrid water pumping system taking an additional controller
Li et al. [62]	PV and hydro	Energy generation and consumption	Fluctuant photovoltaic (PV)	Designed a multi-objective optimization model by non-dominated sorting genetic algorithms-II (NSGA–II) to maximize the energy generation and minimize the gap between energy generation and consumption
Yin et al. [63]	PV, wind, hydro	Annual power generation and smooth output power variations	Solar and wind instability	A modified NSWOA is proposed and revealed through the proposed algorithm that a collection of optimal solutions may be provided to decision-makers and the hydropower by its great adaptive capacity will compensate for the PV and wind power

accepted for distant and rural electrification in recent years because of the lower cost of PV and wind generators. As a substitute for lone power generation systems such as solar PV or wind, hybrid system can produce energy even if the availability of one form is limited, thereby enhancing the power reliability. A hybrid system combined with the conventional energy sources crafts an appropriate solution to the challenges that the world is facing today regarding reliability, sustainability issues of energy generation, and transmission. Different sources used in hybrid systems mutually provide better system efficiency, lower cost, and superior energy supply balance. They offer high-level security in the techniques of employing energy generation and integrate storage systems usually battery or fuel cell in order to guarantee reliability and security in the utmost supply. Taking different constraints into consideration, the hybrid energy systems can be modeled and optimized according to the load demand for any particular area. A comprehensive review covering all the relevant optimization techniques of configurations, reliability, and sizing of components of the hybrid system is discussed and summarized in this work. A brief model of the architecture of power source configuration has been presented. A review of the criteria for power system reliability is also explained in detail. Several reliability optimization tools and approaches are explained with objective and design constraints. The review carried out in this paper presents an idea about the architecture, performance, and reliability of the hybrid power system. In order to find global optimum systems architectures, it was found that artificial intelligence (AI) approaches give relative computational versatility. The most successful algorithms for sizing in the current scenario are GA and PSO. In terms of reliability, the probabilistic behavior of solar or wind energy can also be addressed by these techniques. However, from research, it is found that a lot of works has been carried out in this area; still, more research and efforts are required to make a hybrid renewable energy system more reliable and perform better. The future direction of research requires initiative focusing on cost reduction through maximizing battery life and efficiency. The convergence rate and quality of the optimized solution are another area that requires substantial improvement. In addition to stand-alone HRES, system stability and reliability for both grid-connected and offshore onshore power systems are required. Analysis of hardware-specific tools and their specifications like RAM, ROM, processor, etc., are to be carried out.

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