PV-wind hybrid system: A review with case study

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Abstract: Renewable energy systems are likely to become widespread in the future due to adverse environmental impacts and escalation in energy costs linked with the exercise of established energy sources. Solar and wind energy resources are alternative to each other which will have the actual potential to satisfy the load dilemma to some degree. However, such solutions any time researched independently are not entirely trustworthy because of their effect of unstable nature. In this context, autonomous photovoltaic and wind hybrid energy systems have been found to be more economically viable alternative to fulfill the energy demands of numerous isolated consumers worldwide. The aim of this paper is to give the idea of the hybrid system configuration, modeling, renewable energy sources, criteria for hybrid system optimization and control strategies, and software used for optimal sizing. A case study of comparative various standalone hybrid combinations for remote area Barwani, India also discussed and found PV–Wind–Battery–DG hybrid system is the most optimal solution regarding cost and emission among all various hybrid system combinations. This paper also features some of the near future improvements, which actually has the possibility to improve the actual monetary attraction connected with this sort of techniques and their endorsement by the consumer.

Subjects: Computer Science; Engineering & Technology; Urban Studies

Keywords: PV–wind-based hybrid systems; photovoltaic; wind turbine; modeling; optimization techniques

ABOUT THE AUTHORS
The key research area of authors is optimal sizing of renewable energy system. This paper information is very helpful for pre-analysis of hybrid renewable energy system design. This work analyzed the different combinations of hybrid renewable energy source model and compared each other on the basis of emission, fuel consumption, cost, and component used in the system. This study gives the hybrid system consisting of PV/Wind/Battery/Generator which is a feasible solution. The total net present cost, cost of energy, operating cost, and emission are very less for the presented hybrid renewable energy combination compared to the other. This paper addresses the issues related to the feasibility of the system, combination of renewable source and cost function for pre-analysis of any hybrid practical system and wider projects.

PUBLIC INTEREST STATEMENT
The aim of the paper is to electrify those remote locations where the utility supply is not available. In all over the world many remote location areas where the electricity supply is so costly due to the higher transportation cost, transmission losses, etc. to sort out all these problems renewable energy is the better option. Solar and wind energy resources are freely available in atmosphere thus utilizing these renewable energy sources to power generation is easy and economic. This type of hybrid system can be modeled near to the consumer, which reduces the transmission cost, losses, and transportation cost. Hybrid renewable energy system is environment friendly because it does not produce harmful gasses such as carbon dioxide, unburned hydrocarbons, sulfur dioxide, and nitrogen oxides.
1. Introduction

Many remote communities around the world cannot be physically or economically connected to an electric power grid. The electricity demand in these areas is conventionally supplied by small isolated diesel generators. The operating costs associated with these diesel generators may be unacceptably high due to discounted fossil fuel costs together with difficulties in fuel delivery and maintenance of generators. In such situations, renewable energy sources, such as solar photovoltaic (PV) and wind turbine generator provide a realistic alternative to supplement engine-driven generators for electricity generation in off-grid areas. It has been demonstrated that hybrid energy systems can significantly reduce the total life cycle cost of standalone power supplies in many off-grid situations, while at the same time providing a reliable supply of electricity using a combination of energy sources. Numerous hybrid systems have been installed across the world, and the expanding renewable energy industry has now developed reliable and cost competitive systems using a variety of technologies. In a report, India’s gross renewable energy potential (up to 2032) is estimated at 220 GW. It is likewise noted in the report that, with a renewable energy capacity of 14.8 GW (i.e. 9.7% of the total installed generation capacities of 150 GW as on 30 June 2009), India has barely scratched the surface of a huge opportunity. However, in the last couple of years itself, the share of renewable energy in installed capacity has grown from 5 to 9.7% (The Economic Times, 2009). This implies an enormous potential in energy generation, which can achieve several hundred GW with current renewable energy technologies. As the cost of building solar PV–wind capacity continues to fall over the next five to ten years; a significant scale-up of renewable generation is a very realistic possibility in the developing world. Thousands of villages across the globe are still being exiled from electricity and energizing these villages by extended grids or by diesel generators alone will be uneconomical. Moreover, with the current resource crunch with government, these villages receive low priority for grid extension because of lower economic return potential. Standalone solar PV–wind hybrid energy systems can provide economically viable and reliable electricity to such local needs. Solar and wind energy are non-depletable, site dependent, non-polluting, and possible sources of alternative energy choices. Many countries with an average wind speed in the range of 5–10 m/s and average solar insolation level in the range of 3–6 KWh/m² are pursuing the option of wind and PV system to minimize their dependence on fossil-based non-renewable fuels (Bellarmine & Urquhart, 1996; Nayar, Thomas, Phillips, & James, 1991). Autonomous wind systems (in spite of the maturity of state-of-the-art) do not produce usable energy for a considerable portion of time during the year. This is primarily due to relatively high cut-in wind speeds (the velocity at which wind turbine starts produces usable energy) which ranges from 3.5 to 4.5 m/s. In decree to overcome this downtime, the utilization of solar PV and wind hybrid system is urged. Such systems are usually equipped with diesel generators to meet the peak load during the short periods when there is a deficit of available energy to cover the load demand. Diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain, especially at low load levels (Nayar, Phillips, James, Pryor, & Remmer, 1993). In general, the variation of solar and wind energy does not match the time distribution of the demand. Thus, power generation system dictates the association of battery bank storage facilities to overcome/smoothen the time distribution-mismatch between the load and renewable (solar PV and wind) energy generation (Borowy & Salameh, 1996). A drawback common to wind and solar system is their unpredictable nature and dependence on weather and climatic change. Both of these (if used independently) would have to be oversized to make them completely reliable, resulting in an even higher total cost. However, a merging of solar and wind energy into a hybrid generating system can attenuate their individual fluctuations, increase overall energy output, and reduce energy storage requirement significantly. It has been shown that because of this arrangement, the overall expense for the autonomous renewable system may be reduced drastically (Bagul & Salameh, 1996). Nowadays, the integration of PV and wind system with battery storage and diesel backup system is becoming a viable, cost-effective approach for remote area electrification. Wind and solar systems are expandable, additional capacity may be added as the need arises. Moreover, the combination of wind and solar PV system shrinks the battery bank requirement and further reduces diesel consumption. The prospects of derivation of power from hybrid energy systems are proving to be very promising worldwide (Beyer & Langer, 1996; Erhard & Dieter, 1991; Seeling-Hochmuth, 1997). The use of hybrid energy systems also reduces combustion of fossil fuels and consequent CO₂ emission which
is the principle cause of greenhouse effect/global warming. The global warming is an international environmental concern which has become a decisive factor in energy planning. In wake of this problem and as a remedial measure, strong support is expected from renewables such as solar and winds (Diaf, Notton, Belhamel, Haddadi, & Louche, 2008). The smart grid readiness associate optimum resolution to the present-day power sector issues like environmental pollution caused by typical power generation, grid losses, as well as poor reliability and accessibility of power in rural areas (Zaheeruddin & Manas, 2015). The PV–wind hybrid energy system using battery bank and a diesel generator as a back-up can be provided to electrify the remotely located communities (that need an independent source of electrical power) where it is uneconomical to extend the conventional utility grid. All possible advantages of a hybrid energy system can be achieved only when the system is designed and operated appropriately (Gupta, Kumar, & Agnihotri, 2011). In these systems, sizing, control setting, and operating strategies are interdependent. In addition, some of the system components have non-trivial behavior characteristics. Thus, the task of assessing different design possibilities to plan a hybrid system for a specific location becomes quite difficult. The block diagram of a typical PV–wind hybrid system is depicted in Figure 1.

The paper is organized as follows: Section 2 describes hybrid renewable energy systems; Section 3 depicts a discussion on hybrid PV/wind energy system modeling; Section 4 provides criteria for PV–wind hybrid system optimization; Section 5 discusses control strategies; Section 6 provides an overview of software tool used for optimal sizing; Section 7 case study of standalone hybrid system; and Section 8 highlights the challenges and future scope and also discussed with a conclusion.

2. Description of hybrid renewable energy schemes
A hybrid renewable PV–wind energy system is a combination of solar PV, wind turbine, inverter, battery, and other addition components. A number of models are available in the literature of PV–wind combination as a PV hybrid system, wind hybrid system, and PV–wind hybrid system, which are employed to satisfy the load demand. Once the power resources (solar and wind flow energy) are sufficient excess generated power is fed to the battery until it is fully charged. Thus, the battery comes into play when the renewable energy sources (PV–wind) power is not able to satisfy the load demand until the storage is depleted. The operation of hybrid PV–wind system depends on the individual element. In order to evaluate the maximum output from each component, first the single component is modeled, thereafter which their combination can be evaluated to meet the require dependability. If the electric power production, though this type of individual element, is satisfactory the actual hybrid system will offer electrical power at the very least charge.
2.1. Hybrid photovoltaic system

Solar energy is one of the non-depletable, site-dependent, non-polluting energy sources, and is available in abundance. It is a potential source of alternative/renewable energy and utilization of solar radiation for power generation reduces the dependence on fossil fuel (Douglas, 1997; Erhard & Dieter, 1991; Mahmoud, 1990; Post & Thomas, 1988; Richard, 1989; Traca De Almeida, Martins, & Jesus, 1983). Solar PV power generation unit consists of PV generator, diesel generator, and inverter and battery system shown in Figure 2. For improved performance and better control, the role of battery storage is very important (Shaahid & Elhadidy, 2003, 2004a). The necessary condition for the design of the hybrid PV systems for maximum output power is hot climate. This type of system is cost effective and reliable, especially for those locations where the power supplies though the grid is not suitable and the cost of the transmission line is very high such as remote and isolated areas (Valente & de Almeida, 1998). Table 1 shows the summary of subjects based on PV hybrid system. In literature a number of methods are used to evaluate performance of the hybrid PV system as a combination of PV with battery, diesel generator, and PV without battery. Muselli, Notton, Poggi, and Louche (2000) in the hybrid system modeling of battery with respect to the state of charge and best possible sizing of the system can also be achieved. El-Hefnawi (1998) developed a technique for minimizing the PV area and evaluate of least number of storage days in a PV hybrid system. Syafaruddin, Narimatsu, and Miyauchi (2015) designed the real-time output power, PV system for calculating the accumulative energy and capacity factor. This information is used for evaluating the energy production model based on the capacity factor. Designed a system for computing production cost associated with hybrid PV battery method in which the size associated with PV method is calculated on such basis as electrical requirements not attained (Abouzahr & Ramakumar, 1991). For standalone hybrid PV system, analysis of reliability is determined in the term of loss of load (LOL) probability. A number of numerical and analytical models are employed for measuring the LOL probability (Egido & Lorenzo, 1992). Execution of hybrid PV system is assessed on the premise of the reliability of the power supply under broadly differing conditions (Marwali, Shahidehpour, & Daneshdoost, 1997).

2.2. Hybrid wind energy system

For the design of a reliable and economical hybrid wind system a location with a better wind energy potential must be chosen (Mathew, Pandey, & Anil Kumar, 2002). In addition, analysis has to be conducted for the feasibility, economic viability, and capacity meeting of the demands (Elhadidy & Shaahid, 2004; Nfouï, Buret, & Sayigh, 1996; Nfouï, Buret, Sayigh, & Dunn, 1994; Papadopoulos & Dermentzoglou, 2002; Rehman, Halawani, & Mohandes, 2003). The algorithm for calculating the size of wind turbines and optimal location of distributed energy system has to be developed by using a hybrid configuration of ant colony optimization (ACO), artificial bee colony (ABC) (Kefayat, Lashkar Ara, & Nabavi Niaki, 2015). Optimal sizing of a hybrid wind system and forecasting of a hybrid system based on regression analysis, neural network, Monte Carlo simulation technique, and genetic algorithm were described in the literature (Feijoo, Cidras, & Dornelas, 1999; Li, Wunsch, O’Hair, &
Salameh and Safari (1995) propose a methodology for identifying the wind turbine generator parameters as capacity factor, which relates to identically rated available wind turbine and capacity factor calculated on the basis of wind speed data at different hours of the day of many years. Hybrid wind system installation planning for a particular site and system control strategies have also been reported by researchers (Chedid, Karaki, & El-Chamali, 2000; Jangamshetti & Ran, 2001). For calculating the monthly performance of wind energy system without hourly wind data, a Weibull function is needed (Celik, 2003a). Hybrid wind system performance, reliability, and reduction in the cost of energy (COE) can be obtained by using a

### Table 1. Summary of studies based on PV hybrid system

| Author | Indicator optimized | SA/GC | Location | Load type | Outcome | Algorithm used |
|--------|---------------------|-------|----------|-----------|---------|----------------|
| Mahmoud (1990) | Reliability and economic feasibility study | SA | Jordan | Water pumping motor | The report exemplifies the invention and testing of water pumping systems powered by PV generators | Matlab |
| Post and Thomas (1988) | Cost | SA/GC | – | – | Study on PV systems for present and upcoming relevancies | – |
| Richard (1989) | Systems with a fixed tilt array, product or energy storage | SA | US | – | Built up the correlations for optimal sizing which give storage capacity and array size as a function of horizontal insolation and the long-term load-of-load probability, respectively | LLP |
| Traca De Almeida et al. (1983) | Reliability | GC | Portugal | Grid connected | Design an optimal hybrid system which reduce system cost and give higher reliability | Monte Carlo simulation |
| Shaahid and Elhadidy (2003) | Potential of utilizing hybrid system | SA | Dhahran, Saudi Arabia | Residential buildings | An attempt has been made to address monthly average daily energy generated by the PV systems or different situations while meeting the load allocation | Matlab |
| S. M. Shaahid et al. (2004) | Feasibility of hybrid system | SA | Saudi Arabia | Commercial | 1. System load can be satisfied in the optimal way <br> 2. Diesel efficiency can be maximized <br> 3. Diesel maintenance can be minimized <br> 4. A reduction in the capacities of diesel and battery can occur | Matlab |
| L. Carlos et al. (1998) | Costs and the reliability | SA | Northern, Brazil | Residential | 1. Software has been developed to optimize the generation starting from a given load curve <br> 2. The PV/diesel option is more reliable and economical than the diesel system | Matlab |
| M. Muselli et al. (2000) | Lower kilowatt-hour cost | SA | Corsica island | Residential | The design hybrid system for remote location to fulfill load requirement | – |
| Tahrir Street et al. (1998) | Minimum number of storage days and the minimum PV array area | SA | Egyptian Eastern Desert | Farm | 1. The sized hybrid system is reliable and can absorb any load disturbances <br> 2. The hybrid system is more economic than the standalone system | A program has been designed using FORTRAN language |
| R. Ramakumar et al. (1991) | Energy storage and the loss of power supply probability | SA | – | Residential | Evaluate relationships between the amount of energy storage and the loss of power supply probability under various operating conditions can be investigated using the results | LPSP |
| M. Egido et al. (1992) | Reliability | SA | Spain | Residential | Developed a new model which is more accurate and simple as compare to analytical and numerical models | LLP |
| M. K. C. Marwali et al. (1997) | Production cost | GC | – | Utility systems | Examine valuable method for generation expectation, production assessment and EENS in a PV-utility with battery storage | Probabilistic approach |

Giesselmann, 2001; Papaefthymiou & Stavros, 2014. Salameh and Safari (1995) propose a methodology for identifying the wind turbine generator parameters as capacity factor which relates to identically rated available wind turbine and capacity factor calculated on the basis of wind speed data at different hours of the day of many years. Hybrid wind system installation planning for a particular site and system control strategies have also been reported by researchers (Chedid, Karaki, & El-Chamali, 2000; Jangamshetti & Ran, 2001). For calculating the monthly performance of wind energy system without hourly wind data, a Weibull function is needed (Celik, 2003a). Hybrid wind system performance, reliability, and reduction in the cost of energy (COE) can be obtained by using a
battery backup system. When the hybrid system generated power is in surplus, this power is used for loading the batteries for backup security and this charge battery power is used when the load requirement is not supplied by design hybrid system (Elhadidy & Shaahid, 2000). Figure 3 shows the architecture of wind hybrid energy system and Table 2 shows the summary of studies based on wind hybrid system.

2.3. Hybrid photovoltaic/wind energy system

PV and wind system, both depending on weather condition, individual hybrid PV and hybrid wind system does not produce usable energy throughout the year. For better performance of the standalone individual PV combination or wind combination need battery backup unit and diesel generator set, which increase the hybrid system cost (Elhadidy & Shaahid, 2004; Giraud & Salameh, 2001; McGowan, Manwell, Avelar, & Warner, 1996) for proper operation and better reliability, and lower cost of the system, studies are reported by researchers regarding the combination of hybrid PV–wind system. The current report offers a new strategy determined by the iterative approach, to accomplish the suitable sizing of any standalone hybrid PV/wind/hydrogen method, supplying a desalination unit which feeds the area’s inhabitants with fresh water (Smaoui, Abdelkafi, & Krichen, 2015).

Gupta, Kumar, and Agnihotri (2011) designed a Matlab software tool for evaluating the economic cost and loss of power supply probability (LPSP) technique is used as a key system constraint to assess the reliability and net present cost (NPC) of the system. González, Riba, Rius, and Puig (2015) suggested a system which is able to seek the sizing leading into a minimum life cycle cost of the system while matching the electrical supply with the local requirement. In the present post, the system is examined through a case study that precise by the hour electrical energy store and also current market rates are actually implemented for getting practical estimations of life cycle costs and also benefits. Design an off-grid hybrid PV–wind battery system with high reliability and minimum production cost of the system. The main objective of the design is to obtain a cost-effective solution (Cano, Jurado, Sánchez, Fernández, & Castañeda, 2014; Sawle & Gupta, 2014, 2015). Maleki and Askarzadeh (2014) use different artificial techniques for the optimal size of the hybrid system to minimize total annual cost. For this aspire sizing is formulated in four different techniques such as particle swarm optimization (PSO), tabu search (TS), simulated annealing (SA), and harmony search (HS). Shang, Srinivasan, and Reindl (2016) this specific paper will take the actual dispatch-coupled sizing approach through adding the actual battery to the procedure on the generation unit inside a process, and formulates this particular program issue employing optimum control. A couple of renewable energy sources——PV panels and wind turbines——are viewed as, together with traditional diesel generators. Shin, Koo, Kim, Jung, and Kim (2015) in order to optimally design ability as well as functioning, preparing of the hybrid system, per hour electricity demand data should be applied more than 8,760 h of 12 months. An optimization that matches hourly supply and demand problem had been resolved to have sparse matrices and also the linear programming algorithm. Lingfeng Wang and Singh (2009) study on techno-economic and environmental for hybrid system PV–wind, and battery banks and optimized for total cost, energy index of reliability, and pollutant emissions (PEs) and evaluate. A set of trade-off solution is obtained using multi-criteria meta-heuristic method.
| Author | Indicator optimized | SA/GC | Location | Load type | Outcome | Algorithm used |
|--------|---------------------|-------|----------|-----------|---------|----------------|
| Mathew et al. (2002) | Distribution of wind velocity | SA | Kerala, India | Water pumping | A method to calculate the energy potential of a wind regime is suggested | Matlab |
| Rehman et al. (2003) | Cost calculation of three different wind turbine capacities | SA | Saudi Arabia | Residential | The wind duration curves have been formulated in addition to employed to estimate the cost every kWh involving power created coming from several decided on the wind machines | Matlab |
| Nfouzi et al. (1996) | Cost of electricity generated and fuel saving | SA | Morocco | Residential | Develop an optimum hybrid system which reduces the cost energy generation | - |
| Elhadidy and Shaahid (2004b) | Role of hybrid power systems | SA | Saudi Arabia | Commercial | Design an optimal system which capable to minimize the overall cost of generation and maximized the efficiency | Matlab |
| Papadopoulos and Dermontzoglou (2002) | Economic viability | GC | Greece | Utility system | Developed software which analysis the economic viability for two different cases in this study | Software developed |
| Kefayat et al. (2015) | Optimal location and sizing of distributed energy resources (DERs) on distribution systems | GC | Utility system | In this study found to minimize power loss, emission, cost of energy and increase the voltage stability | Hybrid ACO-ABC |
| Papaefthymiou and Stavros (2014) | Two alternative perspectives regarding the optimization targets: | SA | Greece | Residential | Enhance the penetration of green power technique plus decrease in levelized price of energy | Genetic algorithms |
| 1. The investor’s perspective, profit | | | | | |
| 2. The system perspective | | | | | |
| Li et al. (2001) | Compares regression and artificial neural network models | GC | Fort Davis, Texas | Utility system | The neural network model is found to own far better effectiveness than the regression model pertaining to wind generator energy curve evaluation within challenging have an effect on components. | Regression and artificial neural |
| Feijoo et al. (1999) | Optimization based on two methods | GC | – | – | Two methods have been proposed to calculate the probability of occurrence of wind speed in several wind farms simultaneously | Monte Carlo simulation |
| 1. Wind speed distribution, assumed to be Rayleigh | | | | | |
| 2. Application of the simulation to the wind speed series | | | | | |
| Salameh and Safari (1995) | Finding the capacity factors (CF) | – | Irbid-Jordan | – | Time calculation and selection of windmill is done capacity factor. | - |
| Chedid et al. (2000) | To generate fuzzy membership functions and control rules for the controller. | GC | – | Motor load | Develop a adaptive fuzzy control for wind-diesel weak power systems | Fuzzy logy |
| Celik (2003a) | Estimate the monthly performance of autonomous hybrid system with battery storage | SA | Athens | – | Design a model for estimating the monthly performance of autonomous wind energy systems | ARES |
| Elhadidy and Shaahid (2000) | Identified the viability of hybrid system in Dhahran | SA | Saudi Arabia | Commercial | Parametric study of hybrid generating systems | Matlab |
that offers many design alternatives to decision-maker. Bilal, Sambou, Ndiaye, Kébé, and Ndongo (2013) developed a methodology to size and to optimize a hybrid PV–wind system minimizing the levelized COE and the carbon emission using a multi-objective genetic algorithm approach. Kamel and Dahl (2005) study on standalone hybrid PV–wind–diesel generate-battery system for economic analysis and evaluated annualized cost LPSP optimization results show that hybrid systems are less costly than diesel generation from a NPC perspective. Dufo-López, Bernal-Agustín, and Mendoza (2009) design a grid connected hybrid PV–wind system, taking constraints of land surface acquired by system and initial installation cost and evaluated that system is economical if the selling price of the electric energy is roughly 10 €/kg. Katsigiannis, Georgilakis, and Karapidakis (2010) work on economic and environmental study of a standalone hybrid system, the main aim of the work is to calculate the greenhouse gas emission based on life cycle cost of each component of the hybrid system. Bernal-Agustín, Dufo-López, and Rivas-Ascaso (2006) design is posed as a possible optimization problem whose solution allows having the configuration of the system as well as the control strategy that simultaneously minimizes the total cost through the particular useful life of system plus the PEs. Tina and Gagliano (2010) study on the probabilistic method for standalone hybrid system on the basis of the energy index of the reliability, internal rate of return and expected energy not supplied, evaluate the inform at the design of a pre-processing stage for the input of an algorithm that probabilistically optimized the design of hybrid power systems. In literature various types of method are used for most feasible solution, high reliability, and minimizing the COE such as (Yang, Lu, & Burnett, 2003) probabilistic method (Diaf, Notton, et al., 2008; Dufo-López et al., 2009; Kamel & Dahl, 2005), analytical method (Khatod, Pant, & Sharma, 2010), iterative method (Ekren & Ekren, 2009; Yang, Wei, & Chengzhi, 2009), hybrid method (Bernal-Agustín et al., 2006; Katsigiannis et al., 2010; Lingfeng Wang & Singh, 2009). Figure 4 shows the architecture of PV–wind hybrid energy system and Table 3 shows the summary of studies based on PV–wind hybrid system.

3. Modeling of hybrid renewable energy system components

Different modeling techniques are suggested by researches for modeling the component of a hybrid renewable energy system. The modeling of hybrid system component is discussed below.

3.1. Modeling of photovoltaic system

The outputs of the PV fully depend on solar radiation. Hourly solar radiation on a fixed inclined surface ($I_T$) can be evaluated as (Onar, Uzunoglu, & Alam, 2006).

\[ I_T = I_{b}R_{b} + I_{d}R_{d} + (I_{b} + I_{d})R_{r} \]  

where $I_T$ = solar radiation on an incident surface; $I_{b}$ = direct normal and diffuse; $I_{d}$ = solar radiations; $R_{b}$ = the tilt factors for the beam; $R_{d}$ = the tilt factors for the diffuse; and $R_{r}$ = reflected part of the solar radiations.

PV power output with respect to area is calculated by

Figure 4. Architecture of PV–wind hybrid system.
| Author                  | Indicator optimized                                      | SA/GC | Location         | Load type       | Outcome                                                                                           | Algorithm used                      |
|------------------------|----------------------------------------------------------|-------|------------------|-----------------|---------------------------------------------------------------------------------------------------|-------------------------------------|
| McGowan et al. (1996)  | Life cycle cost                                          | SA    | Brazil           | Telecom         | The major performance parameters for the design and sizing of renewable energy systems can be set up | HYBRID 2 and SOME                   |
| Francois Giraud et al. (2001) | Reliability, power quality, loss of supply | GC    | England          | Residential     | Evaluate performance of hybrid system regarding cost, reliability                                  | LPSP                                |
| Elhady et al. (2004)   | Load distribution and power generation                   | GC    | Saudi Arabia     | Commercial      | Investigate the potential of utilizing hybrid energy conversion systems to meet the load requirements | Matlab                              |
| Mariem Smaou et al. (2010) | Economic                                                | SA    | South of Tunisia | Residential     | Evaluate a hybrid system, which is designed to supply sea water desalination                       | Iterative technique                 |
| Arnao Gonzalez et al. (2015) | Minimum life cycle cost                                 | GC    | Catalonia Spain  | Residential     | Design a hybrid system to meet the load demand at minimum life cycle cost on the basis of net present cost | GA and PSO                           |
| Antonio Cano et al. (2014) | Unit-sizing and the total net present cost             | SA    | Malaga Spain     | Residential     | Investigate a hybrid system by dissimilar methods and examine hybrid off-grid system is more reliable and cost effective | HOMER, HOGA, MATLAB                |
| Akbar Maleki et al. (2014) | Annual cost                                             | SA    | -                | Residential     | Evaluate an optimal system by using PSO tool which result at minimum cost while comparing to other artificial intelligence techniques | PSO, HS, TS, SA                     |
| Ce Shang et al. (2016) | Economic, levelized cost                                 | SA    | Singapore        | Residential     | The author describes the sizing optimization in the dispatch-coupled way, and derives the optimal size of battery for systems with different penetration levels of renewable | PSO                                 |
| Younggy Shin et al. (2015) | Capacity design and operation planning                   | SA    | South Korea      | Building load   | It observes the hybrid renewable energy system is more reliable as compare to diesel generator system for island location. | Pareto optimal front               |
| Lingfeng Wang et al. (2009) | Cost, reliability, and emissions                        | GC    | -                | Utility system  | A set of trade-off clarifications is obtained by way of the multi-criteria meta-heuristic scheme that provides numerous design substitutes to the decision-maker | PSO                                 |
| Ould. Bilal et al. (2013) | Levelized cost of energy (LCE) and the CO₂ emission    | SA    | North-western of Senegal | Three different loads | Author takes variation of three dissimilar load profile for hybrid system and minimized LCE and the CO₂ emission | Genetic Algorithm                 |
| Sami Kamel et al. (2005) | Economic                                                | SA    | Egypt            | Agricultural load | Hybrid renewable energy system is more cost valuable and environmentally pleasant as compare to diesel generator scheme | HOMER                              |
| Rodolfo Dufo-López et al. (2009) | Net present value                                       | GC    | Spain            | Utility system  | Design in addition to cost-effective analysis connected with hybrid techniques connected to the grid for the irregular generation connected with hydrogen | GRHYSO                             |
| Banu Y. Ekren et al. (2009) | Economic                                                | SA    | Urla, Turkey     | Institute load  | Evaluate optimal sizing at different loads and auxiliary energy positions and output shown by loss of load probability and autonomy analysis | ARENA                              |
| Katsigiannis et al. (2009) | Cost of energy and greenhouse gas (GHG) emissions      | SA    | Crete, Greece    | Residential     | The main uniqueness of the anticipated methodology is the thought of LCA results for the estimate of CO₂ emissions | Genetic Algorithm                 |
| Yang Hongxing et al. (2010) | Economic                                                | SA    | China            | Telecommunication station | Design an optimal hybrid system which annualized cost is least while load demand is satisfied on the basis of loss of power supply probability | Genetic algorithm                 |
| Bernal-Agustin et al. (2006) | Pollutant emissions, cost                              | SA    | -                | Farm Load       | Developed a software tool which objective is to reduce cost of energy and co₂ emission             | Pareto Evolutionary               |
| Yang et al. (2003)     | Reliability, and probability of power supply            | SA    | Hong Kong        | Telecommunication | Study on weather data and probability analysis of hybrid power generation systems                  | Matlab                              |
| Khatod et al. (2010)   | Well-being assessment and production cost               | SA    | Gujarat, India   | -               | Design a technique which has high accuracy and taking less calculating time as compare to Monte Carlo method | Monte Carlo simulation            |
| Tina et al. (2010)     | Probability distribution function                        | -     | Italy            | -               | Developed a algorithm which results gives information about more reliable and optimal configurations for design of hybrid system | Matlab                             |
A$_{PV}$ and $\eta_{PV}$ are PV system area and PV system efficiency, respectively.

The PV system efficiency is defined as

$$\eta_{PV} = \eta_M \eta_{PC} \left[ 1 - \beta \left( T_C - T_R \right) \right]$$

(3)

where $\eta_M$ = module efficiency; $\eta_{PC}$ = power conditioning efficiency; $T_C$ = monthly average cell temperature; $T_R$ = reference temperature; and $\beta$ = array efficiency temperature coefficient.

In the ideal equivalent circuit of PV cell a current source is connected in parallel with diode. Onar et al. (2006) connected PV cell with load, voltage, and current equation of cell which is calculated by

$$I_{PV} = I_{PH} - I \left( e^{QV_{PV}/kT} - 1 \right)$$

(4)

where $I_{PV}$ = is the PV current (A); $I = \text{the diode reverse saturation current (A)}$; $Q = \text{the electron charge} = 1.6 \times 10^{-19} \text{ (C)}$; $k = \text{the Boltzman Constant} = 1.38 \times 10^{-23} \text{ (J/K)}$; and $T = \text{the cell temperature (K)}$.

### 3.2. Modeling of wind energy system

The actual mathematical modeling of wind energy conversion process comprises wind turbine dynamics as well as generator modeling. Borowy and Salameh (1997) took a three blade, horizontal axis and repair free wind generator is installed for modeling. Power generation through the wind turbine can be calculated by wind power equation. The turbine is characterized by non-dimensional performance as a function of tip the speed quantitative relation. Bhave (1999) estimates the generated output power and torque by the wind turbine by giving the formula.

$$P_T = \left( \frac{C_P \lambda^2 AV^3}{2} \right)$$

(5)

Torque developed by wind turbine given as

$$T_T = \frac{P_T}{\omega M}$$

(6)

$$\lambda = \frac{\omega R}{V}$$

(7)

where $P_T = \text{output power}$; $T_T = \text{the torque developed by wind turbine}$; $C_p = \text{the power co-efficient}$; $\lambda = \text{the tip speed ratio}$; $\rho = \text{the air density in kg/mg}^3$; $A = \text{the frontal area of wind turbine}$; and $V = \text{the wind speed}$.

Many researchers work on different mathematical modeling for wind energy conversion. Arifujjaman, Iqbal, Quaicoe, and Khan (2005) has worked on small wind turbine by controlling horizontal furling scheme. This furling scheme is used to control aerodynamic, power extraction through the wind. The system is designed in Matlab/Simulink for evaluating appropriate control approach. Two controllers are designed and simulated. For the first scheme, a controller uses rotor speed and wind speed information and controls the load in order to operate the wind turbine at optimal tip speed ratio. In the second scheme, controller compares the output power of the turbine with the previous power and based on this comparison it controls the load.
3.3. Modeling of diesel generator

Hybrid PV–wind system's operation and power generation depends on weather conditions. If poor sunshine and low wind speeds then hybrid PV–wind system's operation and efficiency are affected and the load requirement is not satisfied by either hybrid system or by batteries. All this issue can be resolved by using a diesel generator in hybrid PV–wind system. The application of diesel generator depends on the type and nature of load demand. Notton, Muselli, and Louche (1996) present two essential conditions for calculating the rated capacity of the generator to be installed. The first condition, if the diesel generator is directly connected to the load then the rated capacity of the generator must be at least equal to the maximum load. Second condition, if the diesel generator is used as a battery charger then the current produced by the generator should not be greater than CAh/5 A, where CAh is the ampere-hour capacity of the battery. The efficiency of a diesel generator is specified by the formula (Kaldellis & Th, 2005; Nag, 2001).

\[ \eta_T = \eta_B + \eta_G \]  

where \( \eta_T \) total efficiency and \( \eta_B, \eta_G \) are the thermal and generator efficiency. In hybrid system, a generator is used to maintain the reliability and load requirement. To obtain the lowest cost of system generator should work between the ranges of 70–90% of full load (El-Hefnawi, 1998; Valenciaga & Puleston, 2005). Generator fulfills the load demand and battery charging if peak load is not available.

3.4. Modeling of battery system

Sinha (2015) mentions that battery is used to store surplus generated energy, regulate system voltage and supply load in case of insufficient power generation from the hybrid system. Battery sizing depends on the maximum depth of discharge (DD), temperature, and battery life. A battery's state of charge \( \left( S_C \right) \) is expressed as follows:

During charging process

\[ S_C(t + 1) = S_C(t) \left[ 1 - \sigma(t) \right] + \left[ I_B(t) \Delta t \eta_C(t)/C_B \right] \]  

During discharging process

\[ S_C(t + 1) = S_C(t) \left[ 1 - \sigma(t) \right] - \left[ I_B(t) \Delta t \eta_D(t)/C_B \right] \]

where \( S_C \) = state of charge; \( \sigma(t) \) = hourly self-discharge rate depending on the battery; \( I_B \) = battery current; \( C_B \) = nominal capacity of the battery (Ah); \( \eta_C \) = charge efficiency (depends on the \( S_C \) and the charging current and has a value between 0.65 and 0.85); and \( \eta_D \) = discharge efficiency (generally taken equal to one)

and

\[ |1 - DD| \leq S_C(t) \leq 1 \]

where \( DD \) = depth of discharge.

4. Criteria for PV–wind hybrid system optimization

In literature, optimal and reliable solutions of hybrid PV–wind system, different techniques are employed such as battery to load ratio, non-availability of energy, and energy to load ratio. The two main criteria for any hybrid system design are reliability and cost of the system. The different methods used for these criteria are given below.

4.1. Reliability analysis

Hybrid PV–wind system performance, production, and reliability depend on weather conditions. Hybrid system is said to be reliable if it fulfills the electrical load demand. A power reliability study is
important for hybrid system design and optimization process. In literature, several methods are used to determine the reliability of the hybrid system. Al-Ashwal (1997) has developed, LOL risk method for reliability analysis. LOL risk evaluation is performed using a probabilistic model. LOLR is defined as the probability of the generating system failure to meet the daily electrical energy demand due to the deficient energy of the renewable energy sources used (Planning & installing PV system: A guide for installers, architects & engineers, 2005). LOLR can be represented as \( \text{LOLR} = 1 - P \) or \( \text{LORL} = Q \), where \( P \) is the cumulative probability of meteorological status which corresponds to electrical energy generation and \( Q \) is the probability of failure. Maghraby, Shwehdi, and Al-Bassam (2002) worked on system performance level. System performance level is defined as the probability of unsatisfied load. Shrestha and Goel’s Shrestha & Goel, (1998) reliability calculated on the basis of LOL hours. LOL hours is the summation of LOL expectation in hours over a specified time (usually one year) that the power system is unable to meet load requirements due to lack of power at an instant excluding the effects of component breakdown or maintenance time. \( LA \) is defined as one minus the ratio between the total number of hours in which LOL occurs and the total hours of operation (Celik, 2003b).

\[
LA = 1 - \frac{H_{\text{LOL}}}{H_{\text{TOT}}}
\]  
(12)

where \( H_{\text{LOL}} \) hours which LOL occurs (h) and \( H_{\text{TOT}} \) total hours operation system (h). Kaldellis (2010) uses different methods for analysis of hybrid system reliability as LPSP, LOL probability (LOLP), unmet load (UL). LPSP is the most widely used method on condition when power supplies do not fulfill the required load demand. LLP is the ratio of power supply deficits to the electric load demand during a certain period. As for the LOL probability (LLP), it is defined as the power failure time period divided by the total working time of the hybrid system. Lastly, UL can be defined as the load which cannot be served divided by a total load of a time period (normally one year).

4.2. Cost analysis

NPC or net present worth (NPW) is defined as the total present cost of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. The basis of NPC analysis is to be an ability to express a series of yearly costs in constant currency taking into account the changing value of money as well as cost escalation due to inflation (Dufo-López et al., 2009; Gupta et al., 2011). Therefore, the NPC means the present value of the cost of installing and operating the hybrid system over the lifetime of the project. It is calculated as follows:

\[
\text{NPC} = \frac{C_{\text{ANN}}}{CRF(i, T_{\text{PLT}})}
\]  
(12)

where \( C_{\text{ANN}} \) = total annualized cost; \( CRF \) = capital recovery factor; \( i \) = interest rate; and \( T_{\text{PLT}} \) = project lifetime. Life cycle costs (LCC) are the sum of all the hybrid system component costs and discounted operational costs arising during the project until the end of the project horizon, which is usually set between 20 and 30 years (Bhuiyan, Asgar, Mazumder, & Hussain, 2000). The component costs are the capital cost incurred at the beginning of hybrid system project; operational costs include system running costs, maintenance, and replacement costs. The COE reflects the cost of energy or electricity generation and is expressed as the ratio of total annualized cost of the system to the annual electricity delivered by the system. Total annualized cost includes all the costs over the system’s lifetime from initial investment and capital costs to operations and maintenance (e.g. fuel) and financing costs (Zhou, Lou, Li, Lu, & Yang, 2010).

5. Control strategies

As the hybrid renewable energy system is the combination of different renewable energy sources, diesel generator–conventional sources, and energy storage system it is very difficult to get output at maximum efficiency and reliability without applying any proper control strategy (Dimeas & Hatziargyriou, 2005). In hybrid renewable energy system, for a variable, monitoring and power supply load for the requirement is done by the controller. Controller also keeps the output voltage, frequency and determines the active and reactive power from different energy sources. Different types of controller are applied in a hybrid renewable energy system according to the requirement of different energy sources, output power, and control strategy. Controller, predominantly are of four types as centralized, distributed, hybrid (combination of centralized and distributed) control, and multiple
control system. In each one of the cases, every source is expected to have its own controller that can focus on ideal operation of the relating unit taking into account current data. In the centralized control arrangement, the entire energy source’s signals and storage system are controlled by centralized (master controller) arrangement. Multi-objective energy unit framework can accomplish global optimization in view of all accessible data (Abido, 2003; Azmy & Erlich, 2005; Lagorse, Simoes, & Miraoui, 2009; Miettinen, 1998; Sawle & Gupta, 2014). The disadvantage of this centralized unit is that it suffers from heavy computation load and is subjected to single-point failures. The second control unit is the distributed control unit; in this, unit single energy source is connected to individual to local control unit and thus control units are connected to each other for communicating measurement signals and take a suitable assessment for global optimization. This control unit more advantageous as compared to the centralized control unit because it calls for a minimum computational load without any failure (Hajizadeh & Golkar, 2009; Huang, Cartes, & Srivastava, 2007; Kelash, Faheem, & Amoon, 2007; Ko & Jatskevich, 2007; Lagorse et al., 2009; Nagata & Sasaki, 2002; Nehir et al., 2011; Torozckai & Eubank, 2005; Weiss, 1999; Yang et al., 2006). With this control structure has the shortcoming of multi-faceted communication systems among local controllers. This problem of distributed control unit can be solved by artificial algorithm techniques. Multi-agent system is a standout among the most encouraging methodologies for a distributed control unit. The third control arrangement is a hybrid control unit (Ko & Jatskevich, 2007; Torreglosa, García, Fernández, & Jurado, 2014; Torres-Hernandez, 2007). Hybrid control unit is the arrangement of centralized and distributed control units. In hybrid control unit, renewable sources are assembled within the integrated system. In this hybrid control unit, local optimization in a group and global optimization with different groups are obtained by centralized control unit and distributed control unit, respectively. This hybrid control unit is more advantageous and suitability over other control units because it takes less computation burden which reduces the failure problem of the system. The main drawback of the system is the potential complexity of its communication system. The fourth control is a multi-level control unit. The working operation of this control unit is almost the same as the hybrid control unit but the advantage is it has supervisor control which takes care about real-time operation of each energy unit on the basis of control objective within millisecond range. It also facilitates with the two-way communication existing among diverse levels to execute choices (Torreglosa et al., 2014; Upadhyay & Sharma, 2014). The drawback of this control unit is the potential complexity of its communication system. Figure 5 shows the energy flow and data communication information.

![Figure 5. The energy flow and data communication information.](image-url)
6. Software based on optimization of hybrid system

There are many software tools that are capable to assess the renewable energy system performance for pre-defined system configurations. These include HYBRID 2, PVSYST, INSEL, SOLSIM, WATSUN-PV, PV-DESIGNPRO, RAPSIM, PHOTO, SOMES, HOMER, RAPSYS, RETScreen, ARES, and PVF-chart. Out of all these software tools only two (SOMES and HOMER) are exactly relevant to this investigation, because these two software are capable of providing optimal design of hybrid system. A brief description of each tool is given below sections.

6.1. Software tools for pre-defined system configurations

6.1.1. HYBRID 2

HYBRID 2 (http://www.ceere.org/rel/projects/software/hybrid2/index) is a simulation tool that aims to provide a versatile model for the technical and economical analysis of renewable hybrid energy system. The tool was developed in NREL, Canada in the year 1993. This programming model utilizes both the time series and a statistical approach to evaluate the operation of renewable hybrid system. This allows the model to determine long-term performance while still taking into account the effect of short-term variability of solar and wind data. A range of system components, control and dispatch option can be modeled with users specified time steps. HYBRID 2 comprises all kinds of energy dispatch strategies researched by Barley (1995). HYBRID 2 is an extensively validated model. Though the technical accuracy of the model is very high but the model is incapable to optimize the energy system. The HYBRID 2 code employs a user-friendly graphical user interface (GUI) and a glossary of terms commonly associated with hybrid power systems. HYBRID 2 is also packaged with a library of equipment to assist the user in designing hybrid power systems. Each piece of equipment is commercially available and uses the manufacturer’s specifications. In addition the library includes sample power systems and projects that the user can use as a template. Two levels of output are provided, a summary and a detailed time step by time step description of power flows. A graphical results interface (GRI) allows for easy and in-depth review of the detailed simulation results.

6.1.2. PVSYST

PVSYS 4.35 (2009) developed by Geneva University in Switzerland is a software package for the study sizing, simulation, and data analysis of complete PV systems. It allows determination of PV size and battery capacity, given a user’s load profile and the acceptable duration that load cannot be satisfied. The software offers a large database of PV components, metrological sites, an expert system, and a 3-D tool for near shading detailed studies. This software is oriented toward architects, engineers, and researchers, and holds very helpful tools for education. It includes an extensive contextual help, which explains in detail the procedures and the models used. Tool performs the database meteo and components management. It provides also a wide choice of general solar tools (solar geometry, meteo on tilted planes, etc.), as well as a powerful mean of importing real data measured on existing PV systems for close comparisons with simulated values.

6.1.3. INSEL

Integrated simulation environment and a graphical performing language (INSEL) is software developed by University of Oldenburg, Germany, in which simulation models can be created from existing blocks in the graphic editor HP VEE with a few mouse clicks (Swift & Holder, 1988). The simulation of systems like on-grid PV generators with MPP tracker and inverter, for instance, becomes practically a drawing exercise. This software supports the designer with database for PV modules, inverters, thermal collectors, and meteorological parameters. Even more, INSEL offers a programming interface for the extension of the block library. The main advantage of this model is the flexibility in creating system model and configuration compared to simulation tools with fixed layouts. A disadvantage is that INSEL does not perform system optimization, though it completes or even replaces the experimental laboratory for renewable energy system, since components can be interconnected like in reality.
6.1.4. SOLSIM
Simulation and optimization model for renewable Energy Systems (SOLSIM) (Schaffrin, 1998) is developed at Fachhochschule Konstanz, Germany. SOLSIM is a simulation tool that enables users to design, analyze, and optimize off-grid, grid connected hybrid solar energy systems. It has detailed technical models for PV, wind turbine, diesel generator, and battery components as well as for biogas and biomass modeling. SOLSIM software package consists of different tools: the main simulation program called SOLSIM; the unit to optimize the tilting angle of PV module called SolOpti; the unit to calculate life cycle cost called SolCal; and the unit to simulate wind generators called SolWind. This program is also incapable to find the optimal size of hybrid system for any location on technoeconomical ground.

6.1.5. WATSUN-PV
WATSUN-PV 6.0 (Tiba & Barbosa, 2002) developed by University of Waterloo, Canada, is a program intended for hourly simulation of various PV systems: standalone battery back-up, PV/diesel hybrid, utility grid-connected system, and PV water pumping system simulations. The modules standalone battery back-up and PV/diesel hybrid system simulation modules are very complete; on the other hand, the module that deals with PV water pumping systems only allows the analysis of configurations using DC electric motors, which is not a configuration very frequently used nowadays. The modeling systems for solar radiation, PV arrangement, and the battery are quite detailed and updated. The model used for DC motors is a simple relationship between the voltage and current supplied by the array and the torque and angular speed of the motor. WATSUN-PV 6.0 has a library containing information on PV modules, batteries, inverters, and diesel and gasoline generators. The database does not include information on motors or pumps.

6.1.6. PV-DESIGN PRO
The PV-design pro simulation program (Planning & installing PV system: A guide for installers, architects & engineers, 2005) comprises three variants for simulating standalone system, grid-connected system, and PV pump system. For standalone systems, a reserve generator and a wind generator can be integrated into the PV system, and a shading analysis can be carried out. The system can be optimized by varying the individual parameters. Detailed calculations are performed for operating data and characteristics curves. The module and climate database are very comprehensive. This program is recommended for the PV systems that have battery storage. Simulation is carried out on hourly basis. An advantage of PV-design pro is that its database already includes most information needed for PV system design.

6.1.7. RAPSIM
RAPSIM (Pryor, Gray, & Cheok, 1999) or remote area power supply simulator is a computer modeling program developed at the Murdoch University Energy Research Institute, Australia. It is designed to simulate alternative power supply options, including PV, wind turbine, battery, and diesel system. The user selects a system and operating strategy from a few pre-defined options and optimization is sought by varying component sizes and by experimenting with the control variables that determine on-off cycles of the diesel generator. Battery aging effect is not considered in this model.

6.1.8. RETScreen
RETScreen is developed and maintained by the Government of Canada through Natural Resources Canada’s Canmet Energy research centre in 1996. RETScreen software is capable to calculate the energy efficiency, renewable energy, and risk for various types of renewable-energy, energy-efficient technologies and also analyze the cost function of the design system and hybrid system feasibility (RETScreen, 2009). RETScreen working is based on Microsoft excel software tool. The main characteristics of this software are to minimize the green house gas emission, life cycle cost, and energy generation (Sinha & Chandel, 2014).
6.1.9. PHOTO

The computer code PHOTO (Manninen, Lund, & Vikkula, 1990) developed at the Helsinki University of Technology in Finland simulates the performance of renewable energy systems, including PV–wind hybrid configurations. A backup diesel generator can also be included in the system configuration. The dynamic method developed uses accurate system component models accounting for component interactions and losses in wiring and diodes. The PV array can operate in a maximum power mode with the other subsystems. Various control strategies can also be considered. Individual subsystem models can be verified against real measurements. The model can be used to simulate various system configurations accurately and evaluate system performance, such as energy flows and power losses in PV array, wind generator, backup generator, wiring, diodes, and maximum power point tracking device, inverter, and battery. A cost analysis can be carried out by PHOTO. This code has the facility to create a stochastic weather generation database in the cases where hourly data are not available. The simulation results compare well with the measured performance of a PV test plant.

6.1.10. SOMES

The computer model SOMES (Simulation and Optimization Model for Renewable Energy Systems) developed at the University of Utrecht, Netherlands (RETScreen, 2009) can simulate the performance of renewable energy systems. The energy system can comprise renewable energy sources (PV arrays, wind turbines), diesel generator, a grid, battery storage, and several types of converters. An analysis of the results gives technical and economical performance of the system and the reliability of power supply. The simulation is carried out on an hourly basis for the simulation period of, for example, one year. Hourly average electricity produced by solar and wind systems is determined. Hourly results are accumulated for the simulation period. The accumulated values are used to evaluate technical and economical performance of the system. The model contains an optimization routine to search for the system with lowest electricity cost, given the customer’s desired reliability level.

6.1.11. HOMER

HOMER (https://analysis.nrel.gov/homer/includes/downloads/HOMERBrochure_English.pdf) is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, standalone, and distributed generation (DG) applications. HOMER is developed by the National Renewable Energy Laboratory (NREL, USA), HOMER’s optimization and sensitivity analysis algorithms allow us to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. HOMER models both conventional and renewable energy technologies: such as PV, wind turbine, run-of-river hydropower, diesel or biogas generator, fuel cell, utility grid, battery bank, micro turbine, and hydrogen storage. HOMER performs simulation for all of the possible system configurations to determine whether a configuration is feasible. Then, HOMER estimates the cost of installing and operating the system, and displays a list of configurations sorted by their life cycle cost. This tool offers a powerful user interface and accurate sizing with detail analysis of the system.

6.1.12. RAPSYS

RAPSYS (version 1.3) was developed in the University of New South Wales, Australia in the year 1987 (RAPSYS, www.upress.uni-kassel.de/online/frei/978-3-933146-19-9). This software can simulate a wide range of renewable system components that may be included in a hybrid system configuration. The software can be used only by those who are experts in remote area power supply systems. RAPSYS does not optimize the size of components. The user is required to pre-define the system configuration. The simulation recommends the switch ON and OFF timings of diesel generator. RAPSYS does not calculate the life cycle COE system, though it is capable to provide detailed information about the operating cost of the system.
6.1.13. ARES
A refined simulation program for sizing and optimization of autonomous hybrid energy systems (ARES) developed at University of Cardiff, UK determines whether a system meets the desired reliability level while meeting the project budget based on user specified cost data (Morgan, Marshall, & Brinkworth, 1995; Morgan, Marshall, & Brinkworth, 1997). This program, unlike the majority of other hybrid simulation program, predicts the battery state of voltage (SOV) rather than its state of charge (SOC). LOL occurs when the battery voltage drops below the low voltage cut-off limit. Given the load and weather profiles, ARES is able to predict the occurrence of LOL thus giving a direct measure of the system autonomy. The model predicts electrical quantities measured at the terminals of battery bank and do not describe the electro-chemical phenomena occurring within the individual cells. The simulation code has been validated by comparison with measured data obtained from a 200 W wind and PV system. Accurate prediction of battery voltage requires a fairly extensive knowledge of the descriptive parameters of system components. These details are rarely found in manufacturing data sheets. The lack of data concerning charge characteristics and temperature effects is even more blatant. It would be advantageous if a data bank with such parameters were to be made available. The battery aging and its effects on system performance has not been addressed as part of this program. The precision and reliability of the simulation results obtained by this software depend mostly on the accuracy of the descriptive parameters.

6.1.14. PVF-CHART
The computer program PVF-chart (Klein & Beckman, 1993; Planning & installing PV system: A guide for installers, architects & engineers, 2005) developed by F-chart software is suitable for prediction of long-term average performance of PV utility interface system, battery storage system, and system without interface or battery storage. It is a comprehensive PV system analysis and design program. The program provides monthly-average performance estimates for each hour of the day. The calculations are based upon methods developed at the University of Wisconsin which use solar radiation utilizability to account for statistical variation of radiation and the load. The PVF-Chart method consists of combination of correlation and fundamental expression for hourly calculation of solar radiation at given location.

6.2. Search methodology based on optimization of hybrid system
In addition to the software tool stated above, other search methods for the design of hybrid energy system are described in various technical publications. These methods, which are described below, include amp-hour (AH) method, knowledge-based approach, simulation approach, trade-off method, probability method, analytical method, linear programming, goal programming, dynamic programming, and non-linear programming.

6.2.1. AH method
AH method is the most straightforward method to size PV-battery–diesel hybrid system. This method detailed out in a handbook of PV design practices by Sandia National Laboratory (SANDIA, 1995). 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). The size of diesel generator is selected to cover peak demand. This method does not take into account the relationship between the output of PV, generator sets, and storage capacity. Unless the very accurate data are used to select the value for autonomous days, this can easily lead to the specification of oversized components and suboptimal results. This method is used in Bhuiyan and Ali Asgar (2003), Ming, Buping, and Zhegen (1995), Protogeropulos, Brinkworth, and Marshall (1997) to size the standalone PV systems.

6.2.2. Trade-off method
The trade-off method is introduced by Gavanidou and Bakirtzis (1993) 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 LOL 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.

6.2.3. Probability method using LPSP technique
The concept of LPSP was introduced (Ofry & Braunstein, 1983) to design standalone PV systems. This technique enables the determination of the minimum sizes of the PV system and storage capacity, and yet assures a reliable power supply to load. The reliability of power supply is measured by total number of hours per year for which the consumer’s power demand is greater than PV supply. The study is performed during a period of one year to collect the state of charge (SOC) of battery as function of time. The cumulative distribution function of the battery SOC is derived. The LPSP is then determined by calculating the value [1 − {cumulative proportion of the time where battery SOC is higher than the SOC min.}]. Similar work is done including wind generators in Borowy and Salameh (1996), Ghali, El Aziz, & Syam. (1997) and Ali, Yang, Shen, and Liao (2003), then adopted this concept to find the optimum size of the battery bank storage coupled with a hybrid PV–wind autonomous system. Long-term data of wind speed and insolation recorded for every hour of the day are deduced to produce the probability density function of combined generation. For the load distribution being considered, the probability density function of the storage is obtained. Finally, the battery size is calculated to give the relevant level of the system reliability using the LPSP technique.

6.2.4. Analytical method with LPSP technique
A closed form solution approach to the evaluation of LPSP of standalone PV system with energy storage, as well as standalone wind electric conversion system, is presented in Abouzahr and Ramakumar (1990). Similar to Borowy and Salameh (1996), in this paper also, authors have defined the LPSP as probability of encountering the state of charge (SOC) of battery bank falling below a certain specified minimum value. However, instead of using long-term historical data to determine LPSP, LPSP is determined by integrating the probability density function of power input to the storage. In addition to the above publications, there are several other publications that analyze and estimate reliability of a standalone PV system, using LOL probability (LOLP). These publications include Diaf, Belhamel, Haddadi, and Louche (2008), Diaf, Notton, et al. (2008), Klein and Beckman (1987), Yang, Lu, and Zhou (2007), Diaf, Diaf, Belhamel, and Haddadi (2007).

6.2.5. Knowledge-based approach
A knowledge-based design approach that minimizes the total capital cost at a pre-selected reliability level is introduced in Ramkumar, Abouzahr, and Ashenayi (1992) and Ramkumar, Abouzahr, Krishnan, and Ashenayi (1995). The overall design approach is as follows: first, a year is divided into as many times sections as needed. For each section the rating of energy converter and the sizes of energy storage system that satisfy the energy needs at the desired reliability level at the minimum capital cost are determined. Then, a search algorithm is used to search for feasible configurations. Since the final design is selected based on the seasonal designs, the user must decide whether to select the worst or best case designs or the designs in between.

6.2.6. Simulation approach
In this approach, design of hybrid renewable energy system comprising PV/wind/battery systems is carried out using the same concept as used in HOMER (https://analysis.nrel.gov/homer/includes/downloads/HOMERBrochure_English.pdf). Initially, simulation is performed using a time step of usually one hour (though not necessary) to identify all possible combinations that satisfy the desired level of reliability of user. An optimal combination is then extracted from these combinations on the basis of economic parameters. The reliability level is calculated by total number of load unmet hours divided by the total number of hours in simulation period. The similar approach is used by Ali et al.
(2003), Bernal-Agustín et al. (2006), Celik (2002) to find the optimal configurations. The simulations are done by varying fraction of wind and PV energy from zero to one, at the battery-to-load ratio (the number of days that the battery is able to supply the load while fully charged) of 1.25, 1.5, and 2.0, and various energy-to-load ratios (the ratio of the energy produced by renewable component to energy demand).

6.2.7. Linear programming method
This is a well-known popular method used by number of researchers to find the optimum size of renewable energy systems. A very good explanation and insights into how linear programming (LP) method can be applied to find the size of wind turbine and PV system in a PV–wind hybrid energy system is detailed out in Markvast (1997). The method employs a simple graphical construction to determine the optimum configuration of the two renewable energy generators that satisfies the energy demand of the user throughout the year. It is essential to note that method does not include battery bank storage and diesel generator. LP method was used in Swift and Holder (1988) to size PV–wind system, considering reliability of power supply system. The reliability index used is defined as the ratio of total energy deficit to total energy load. Other applications of this method are available in Chedid and Rahman (1997) and Ramakumar, Shetty, and Ashenayi (1986).

6.2.8. Non-linear programming method
The basic approach used in this method aims to take the interdependency between sizing and system operation strategy into account. Thus, it can simultaneously determine the optimal sizing and operation control for renewable hybrid energy system. This method has been used in Seeling-Hochmuth (1997) to determine the optimum size of hybrid system configuration.

6.2.9. Genetic algorithm method
Genetic algorithms are an adequate search technique for solving complex problems when other techniques are not able to obtain an acceptable solution. This method has been applied in Tomonobu, Hayashi, and Urasaki (2006), Dufo-Lopez and Bernal-Augustin (2005), and Shadmand and Balog (2014). The works reported in these papers use the hourly average metrological and load data over a few years for simulation. In reality, the weather conditions are not the same every day and in every hours of the day. Therefore, under varying every hour and every day weather conditions, the optimum number of facilities to use the hourly average data may not be able to be supplied without outages over a year. In such situations, the use of genetic algorithm method has been found most suitable.

6.2.10. Particle swarm optimization
The particle swarm algorithm was first presented by Kennedy and Eberhart (1995) as an optimization method to solve non-linear optimization problems. This procedure is inspired by certain social behavior. For a brief introduction to this method, consider a swarm of p particles, where each particle's position represents a possible solution point in the design problem space D. Every single particle is denoted by its position and speed; in an iterative process, each particle continuously records the best solution thus far during its flight. As an example of optimal sizing of hybrid energy systems by means of PSO, refers to Hakimi and Moghadas-Tafreshi (2009) and Haghi, Hakimi, and Tafreshi (2010).

6.3. Outcomes
Above literature review leads to following conclusion:

(1) There are different software packages existing with varying degree in user friendliness, validation of simulation models, accuracy of system models, and possible configuration to simulate.

(2) Most of these software tools simulate a given and predefined hybrid system based on a mathematical description of component characteristic operation and system energy flow. But, the
Table 4. Software based on optimization of hybrid system

| Software          | Developed by | Advantages                                                                 | Disadvantages                                                                 | Ref.                                      | Year | Availability             |
|-------------------|--------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------|------|--------------------------|
| HYBRID 2          | NREL; Canada  | Technical accuracy of the model is very high                               | Model is incapable to optimize the energy system                             | HYBRID 2 ([http://www.ceere.org/rerl/projects/software/hybrid2/index](http://www.ceere.org/rerl/projects/software/hybrid2/index)), Barley (1995) | 1993 | [http://www.ceere.org/rerl/rerl_hybrid-power.html](http://www.ceere.org/rerl/rerl_hybrid-power.html) |
| PV SYS            | Geneva University in Switzerland | It allows determination of PV size and battery capacity                  | Limitation for renewable energy sources                                       | PVSYST 4.35 ([2009](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1992 | Not free www.pvsyst.com  |
| INSEL            | University of Oldenburg, Germany | Flexibility in creating system model and configuration                    | Does not perform system optimization                                         | Planning and installing PV system ([2003](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1996 | Not free www.insel.eu    |
| SOLSIM           | Fachhochschule Konstanz, Germany | The unit to calculate life cycle cost                                      | In capable to find the optimal size of hybrid system                         | Schaffrin ([1998](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1987 | NOT Free                 |
| WATSUN-PV        | University of Waterloo, Canada | The model used for DC motors is a simple relationship between the voltage and current supplied by the array and the torque and angular speed of the motor | The database does not include information of motors or pumps                  | Tiba and Barbosa ([2002](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | –    | NOT FREE                 |
| PV-DESIGN PRO    | –             | Database already includes most information needed for PV system design    | The module and climate database are very comprehensive                       | Planning and installing PV system ([2005](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | –    | –                        |
| RAPSIM           | Murdoch University Energy Research Institute, Australia | The control variables that determine on-off cycles of the diesel generator | Battery aging effect is not considered in this model                         | Pryor et al. ([1999](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1997 | Unknown, after 1997 any change are not accounted |
| RETScreen        | Government of Canada through Natural Resources Canada’s Commet ENERGY research centre | This software is to minimized the green house gas emission, life cycle cost, energy generation | 1. Does not support calculation of more advanced statistics/analysis          | RETScreen ([2009](http://www.ceere.org/rerl/rerl_hybrid-power.html)), Sinha and Chandel ([2014](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1996 | Free [http://www.retscreen.net/](http://www.retscreen.net/) |
| PHOTO            | The Helsinki University | Various control strategies can also be considered                          | High computational time                                                       | Manninen et al. ([1990](http://www.ceere.org/rerl/rerl_hybrid-power.html)) | 1990 | Unknown                  |
| SOMES            | University of Utrecht Netherlands | The model contains an optimization routine to search for the system with lowest electricity cost | SOMES does not give optimal operating strategy                               | SOME ([http://www.web.co.bw/sib/somes_3_2_description.pdf](http://www.web.co.bw/sib/somes_3_2_description.pdf)) | 1987 | Not free [http://www.usu.nl/EN/Pages/default.aspx](http://www.usu.nl/EN/Pages/default.aspx) |
| HOMER            | National Renewable Energy Laboratory (NREL, USA), | This tool offers a powerful user interface and accurate sizing with detail analysis of the system | Technical accuracy of HOMER is low because its components mathematical models are linear and do not include many correction factors | HOMER ([http://analysis.nrel.gov/homer/includes/downloads/HOMER-Brochure_English.pdf](http://analysis.nrel.gov/homer/includes/downloads/HOMER-Brochure_English.pdf)) | 1993 | Not Free [www.homerenergy.com](http://www.homerenergy.com) |
| RAPSYS           | University of New South Wales, Australia | This software can simulate a wide range of renewable system components that may be included in a hybrid system configuration | It does not optimize the size of components                                   | RAPSYS (www.upress.uni-kassel.de/online/frei/978-3-933146-19-9) | 1987 | [www.upress.uni-kassel.de/online/frei/978-3-933146-19-9](http://www.upress.uni-kassel.de/online/frei/978-3-933146-19-9) |

(Continued)
mathematical models used for characterizing system components are unknown due to commercial reasons.

(3) Some of these software tools (such as HYBRID 2, RAPSIM), though incorporate financial costing but incapable of determining optimal hybrid system configuration.

(4) For the optimal hybrid system design problem so far only two software tools (HOMER and SOMES) exist, using simplified linear system components mathematical models but varying the design randomly within a chosen range of component sizes.

(5) Technical accuracy of HOMER is low because its components mathematical models are linear and do not include many correction factors. SOMES does not give optimal operating strategy and not freely available to the designer/users.

(6) Majority of the software packages require the user to come up with a pre-design system. Therefore, a better system performance with lower cost could be achieved in many of these designs only if the system configuration could be optimized.

(7) With reference to search methodology-based optimization of hybrid systems, several previous works have certain limitations: some gives oversized components; some leave many design configurations for user to select; some do not consider the important parameters/correction factors in the design; and some are very lengthy and time consuming.

(8) Many papers are available for sizing by using artificial intelligent techniques, such as GA and PSO, etc. these new artificial intelligent techniques which can also be considered while sizing of hybrid renewable energy system. These artificial intelligent techniques provide best possible solution as compared to other software tools, but they face a crisis in the form of poor performance when a number of hybrid system components are increased such as PV, wind, generator, batteries, etc.

7. Case studies

A routine of software tools are used to design hybrid system which are discussed in Section 6. Among all these software GA, PSO, and HOMER found to be more suitable for evaluating optimal sizing of hybrid renewable solution. In this case study design of optimal sizing of different combinations of PV/wind hybrid energy-based power system for rural electrification in the key area by using HOMER software tool is presented.

Table 4. (Continued)

| Software | Developed by | Advantages | Disadvantages | Ref. | Year | Availability |
|----------|--------------|------------|---------------|------|------|--------------|
| ARES     | University of Cardiff, UK | ARES is able to predict the occurrence of loss of load thus giving a direct measure of the system autonomy | The battery aging and its effects on system performance has not been addressed as part of this program. | Morgan et al. (1995, 1997) | – | Not found |
| PV F-chart | F-chart software | It suitable for prediction of long-term average performance. Extremely fast execution | Tracking options fixed | Planning and installing PV system (2005), Klein and Beckman (1993) | 1993 | Not free www.fchart.com |
7.1. Renewable energy resources

A Jamny Ven village Barwani (latitude 22.71 and longitude 75.85) Madhya Pradesh, India site renewable energy resource is an important factor for developing hybrid systems. According to IMD wind and solar energy are available in many parts of India in large quantities (http://homepage.mac.com/unarte/solar_radiation.html). These energy sources are discontinuous and naturally obtainable; because of these issues our primary preference to power the village base power station is renewable energy sources like wind and solar. Climate data for particular site renewable hybrid energy systems are important factors to study the possibility of the former the confidential information, wind and solar energy resources data for the village are taken from NASA (Lilienthal & Flowers, 1995).

### Table 5. Summary of search methodology for design hybrid system

| Ref. | Software | SA/GC | Parameters optimized | Load type | Highlights |
|------|----------|-------|----------------------|-----------|------------|
| Ghali et al. (1997), Bhuiyan and Ali Asgar (2003), Ming et al. (1995), Porto-geropoulos et al. (1997) | AH method | SA | PV, battery | Residential | To operate the estimated load reliably in the month of minimum insolation taking into account different types of power losses |
| Gavanidou and Bakirtzis (1993) | Trade-off method | SA | PV, wind battery | Residential | Design that is a reasonable compromise between the conflicting design objectives under most foreseeable conditions |
| Ghali et al. (1997), Borowy and Salameh (1996), Ali et al. (2003), Ofry and Braunstein (1983) | Probability method using LPSP technique | SA | PV, battery | Residential | Determine the minimum (and thus the economical) sizes of the solar cell array and storage system capacity |
| Abouzahr and Ramakumar (1990), Klein and Beckman (1987), Yang et al. (2007), Diao et al. (2007), Diao, Notton, et al. (2008), Diao, Belhamel, et al., 2008; Borowy and Salameh (1996) | Analytical method with LPSP technique | SA | Wind battery | Industrial | To evaluate the relationship between the amount of energy storage and the loss of power supply probability under various operating conditions |
| Ramkumar et al. (1992, 1995) | Knowledge-based approach | SA | PV, wind biogas, battery | Residential | A knowledge-based design approach that minimizes the total capital cost at a pre-selected reliability level |
| Ali et al. (2003), Bernal-Agustín et al. (2006), Celik (2002) | Simulation approach | SA | PV, Wind Battery | Residential | An optimum combination of the hybrid PV–wind energy system provides higher system performance than either of the single systems for the same system cost for every battery storage capacity |
| Chedid and Rahman (1997), Markvast (1997), Ramakumar et al. (1986), Swift and Holder (1988) | Linear programming (LP) method | GA | PV, wind battery | Residential | 1. Linear programming techniques to minimize the average production cost of electricity while meeting the load requirement in a reliable manner  
2. A controller that monitors the operation of the autonomous grid-linked system is designed |
| 8 | Non-linear programming method | SA | PV, wind battery | Residential | A general method has been developed to jointly determine the sizing and operation control of hybrid-PV systems |
| Dufo-Lopez and Bernal-Augustin (2005), Shadmand and Balog 2014), Tomonobu et al. (2006) | Genetic algorithm method | GA | PV, wind battery | Residential | The proposed methodology employs a techno-economic approach to determine the system design optimized by considering multiple criteria including size, cost, and availability |
| Haghii et al. (2010), Hakimi and Maghaddas-Tafreshi (2009), Kennedy and Eberhart (1995) | Particle swarm optimization | SA | Wind fuel cells, hydrogen tanks | – | Minimize the total costs of the system in view of wind power uncertainty to secure the demand |
7.2. Solar energy resource

Hourly solar emission information was collected from the environment Barwani Jamny village. Long-term average annual resource scaling (5.531). Solar power is higher in summer season when compared to the winter season. Here solar insolation and clearance index data are shown in Table 4.

7.3. Wind energy resource

Confidential information may be an occurrence that is associated with the connection of air, plenty caused mainly by the degree of difference star heating of the Earth’s surface. Seasonal and position variations within the energy arriving from the Sun have an effect on the strength and manner of the wind. Power from the wind depends upon the swept space of the rotary engine blades and, therefore,
the cube of the wind speed, wind energy has been considered as potential toward meeting the continually increasing demand for energy. The wind sources of energy the alteration processes are pollution-free, and it is freely available. Periodical regular wind information for Jamny Ven village was together beginning environmental of Barwani climate. The scaled annual average wind speed is 4.5 the highest value of monthly average wind speed is observed during the month of December with a maximum of 7.195 m/s and the lowest value is observed during June with 2.664 m/s monthly average wind speed. Resource data are shown in Table 4 (Lilienthal & Flowers, 1995).

7.4. Electrical load data
The average estimation of daily energy consumption is 110.6 (kWh/day), peak load is found to be 13.23 KW, and average is 4.61 KW. The information was computed for the entire hour basis daily electrical load condition of a demand for a village of Barwani district. The daily load profile with respective 24 h of day is shown in Figure 6.

7.5. Cost of hybrid system components
The cost of input components which are used to design optimal combination solution is given in Table 5.

7.6. Result and discussion
The study is to design of optimal sizing of different combinations of PV/wind hybrid energy-based power system for rural electrification in the key area (Jamny Ven Barwani) Madhya Pradesh, India where utility supply cost is really high due to limited consumer higher transmission and higher transportation cost. The chosen case study presents a power demand 110.6 kWh/d. The system is designed and optimized as hybrid energy base power system in parliamentary procedure to meet the existing user’s power require at a minimum price of energy. The simulation-based optimization generates the best-optimized sizing of different combinations of wind and PV array with diesel generators for a rural hybrid base power system. Optimal sizing of various combinations such as DG (diesel generator), PV–Battery–DG, Wind–Battery–DG and PV–Wind–DG, PV–Wind–Battery and PV–Wind–Battery–DG are shown in Figure 7. Simulation and optimization result calculated by using HOMER software and analysis on the base of sensitive parameters of PV, wind resources data, and variation in diesel price. Among all six hybrid combinations only two hybrid system Wind-DG and PV–Wind–Battery–DG are more cost-effective, reliable and environmentally friendly solution. Emission and leveling COE of the both hybrid systems are nearly equal, but the total NPC and operating cost of the PV–Wind–Battery–DG is less as compared to Wind-DG hybrid system. As the penetration of solar, wind system will increase; the surplus energy is multiplied. It can be saved and used by foreseeable

| Table 7. Input parameters used hybrid system |
|---|---|---|
| S. No | Items cost($) | Other parameters | Life span |
| 1 | Wind turbine | Hub height: 30 m Rotor diameter 1.75 m | 20 year |
| 2 | PV | Derating factor: 80% Ground reflectance: 20% | 20 year |
| 3 | Inverter | Efficiency: 90% | 15 year |
| 4 | Battery | Capacity: 240 Ahvoltage: 12 V | 3550 h |
| 5 | Generator | Minimum load ratio: 30 | 15000 h |
| 6 | Generator | Minimum load ratio: 30 | 15000 h |
future objective by making use of battery bank. The comparative analysis of all optimal combination is shown in Table 6.

8. Conclusion
For hybrid renewable energy system design number of new technologies are discussed in the literature, but due to some new problems like parameters of renewable source material and design, constraints of load, generator, battery, converter, and cost function, the system performance has

| S.No | Description | DG | PV/Battery/DG | Wind/Battery/DG | PV/Wind/DG | PV/Wind/Battery/DG |
|------|-------------|----|---------------|----------------|------------|------------------|
| 1    | Emission    | 62,204.00 | 36,334.00 | 28,394.00 | 61,517.00 | 0 | 29,201.00 |
|      | Carbon dioxide (kg/yr) | 153.54 | 89.69 | 70.09 | 151.85 | 0 | 72.08 |
|      | Carbon monoxide (kg/yr) | 17.01 | 9.93 | 7.76 | 16.82 | 0 | 7.98 |
|      | Unburned hydrocarbons (kg/yr) | 11.58 | 6.76 | 5.28 | 11.45 | 0 | 5.43 |
|      | Particulate matter (kg/yr) | 124.92 | 72.97 | 57.02 | 123.54 | 0 | 58.64 |
|      | Sulfur dioxide (kg/yr) | 1,137.10 | 800.27 | 625.39 | 1,354.90 | 0 | 643.17 |
| 2    | Production  | 5,471.00 | 0 | 14,785.00 | 6,087.40 | 63,747.00 | 7,701.90 |
|      | Excess electricity (KWh/yr) | 0 | 11.6 | 10 | 0 | 22.3 | 9.2 |
|      | Unmet electric load (KWh/yr) | 0 | 40.2 | 38 | 0 | 35 | 37.3 |
|      | Capacity shortage (KWh/yr) | 0 | 33.8 | 47.2 | 0 | 100 | 46.5 |
|      | Renewable fraction | 0 | 496.8 | 2,180.70 | 49.7 | 3,634.60 | 1,453.80 |
| 3    | Cost        | 3,20,873 | 3,44,576 | 3,30,844 | 4,08,347 | 6,27,750 | 3,24,178 |
|      | Total net present cost ($) | 0.6149 | 0.6605 | 0.6341 | 0.7825 | 1.2 | 0.6213 |
|      | Levelized cost ($) | 24,465.94 | 21,355 | 19,297 | 30,607.03 | 23,909 | 19,261 |
| 4    | Fuel        | 23,622.00 | 13,798.00 | 10,783.00 | 23,361.00 | 11,089.00 |
|      | Total fuel consumed (L) | 64.73 | 37.81 | 29.55 | 64.01 | 30.38 |
|      | Avg fuel per day (L/day) | 1.58 | 1.23 | 2.67 | 1.27 |
| 5    | Battery     | 6,953.90 | 6,897.10 | 6,897.10 | 6,897.10 | 6,897.10 | 6,897.10 |
|      | Energy input (KWh/yr) | 5,965.00 | 5,862.60 | 5,862.60 | 5,862.60 | 5,862.60 | 5,862.60 |
|      | Energy out (KWh/yr) | 49.8 | −8.9 | −8.9 | −35.96 | −8.7 |
|      | Storage depletion (KWh/yr) | 939.05 | 1,043.40 | 1,043.40 | 2,048.20 | 973.47 |
|      | Losses (KWh/yr) | 6,470.00 | 6,358.90 | 6,358.90 | 12,368.00 | 5,931.70 |
|      | Annual throughput (KWh/yr) | 13.72 | 13.96 | 13.96 | 18 | 14.96 |
| 6    | Efficiency  | 19.72 | 19.69 | 20.10 | 19.55 | 19.81 |
| 7    | Components  | ✓ | ✓ | x | ✓ | ✓ | ✓ |
|      | Generic flat plate PV | ✓ | ✓ | x | ✓ | ✓ | ✓ |
|      | BWC Excel-R | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
|      | 10 kW genset | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
|      | Discover 12VRE-3000TF-L | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
|      | Converter | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
These kinds of issues have to be attended properly, to resolve these shorted out. Table 7 presents some important suggestion and also scope with regard to potential research. This paper explains several hybrid system combinations for PV and wind turbine, modeling parameters of hybrid system component, software tools for sizing, criteria for PV–wind hybrid system optimization, and control schemes for energy flow management. In this paper for the sizing purpose of the hybrid system, 25 different types of computational software tools are discussed. Among all these software tools, HOMER and GA, PSO gives more feasible result for hybrid system design. Another technique for sizing of hybrid scheme which presents more promising result, such as genetic algorithm and PSO. At least to obtain the operational efficiency, highest system reliability and proper energy flow management, control strategies are suggested in this paper. Controller work as monitoring whole hybrid system and maintain the requirement of load demand while keeping system frequency and output voltage. Additionally, it is been located in which wide range of research work in the community associated with hybrid renewable energy system has been completed. A case study of various standalone hybrid system combinations for a remote location in India by using HOMER and evaluate best optimal hybrid system configuration such as PV–Wind–Battery–DG with respective total NPC, operating cost, COE, and also emission. The optimal hybrid system has following advantages (Table s 8 and 9).
This non-conventional power PV–Wind–Battery–DG hybrid energy method is available to be technically achievable, emission much less along with less expensive with years to come.

Its environment-friendly dynamics helps it be a nice-looking substitute for complementing the energy present inside countryside regions.

Load demand is fulfilled in an optimal way.

On the other hand much more research along with the work usually is needed to increase battery’s strength along with effectiveness with giving attention to decreasing the cost. Hybrid system performance depends on weather condition so as to minimize the issue related to the system reliability and operation there is a need to carry out transient analysis of the system for varying constraint like solar radiation, wind velocity, load demand. The COE sources used in hybrid system are very high so that there is needed to provide subsidy from central and state government to minimize initial cost of the system and also reduced the COE.

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