ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system

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ARTICLE INFO

Keywords:
PV system
Wind systems
Modeling
Homer
PSO techniques

ABSTRACT

PV and wind hybrid are found to be the most lucrative solution for the diminishing traditional energy sources. Whereas these alternatives sources of the energy have many remarkable rewards like cost of energy and feasibility etc. The attributes of these sources of being cost effective and stable are possible due to their complementary nature as compared to independent energy systems. Therefore, these systems have admirable capability to meet energy crisis up to some extent. The proposed work gives the idea about various configuration, control strategy, techno-economic analysis and social effect. The findings of comprehensive review will help for further improvements in hybrid system design and control with respect to practical system implementation. This paper also presents a case study of remote area Barwani, India and results are compared using Homer and PSO. The resulting analysis reveals that configurations of hybrid system are the most techno-economical feasible solution concerning COE, renewable fraction, maximum renewable penetration, levelized cost, operating cost, mean electrical efficiency, and emission amongst various hybrid system configurations using PSO as compared to HOMER.

1. Introduction

The worldwide switching towards reliable and feasible hybrid renewable energy system is mainly due to two reasons; the potential techno-economic advantages of hybrid combinations and the rapid depletion of conventional sources of energy. In India, a large portion of remote area, not access electricity. Diesel generators (DG) is used to meet required load demand for that remote areas. Operating cost of DG is high due to fluctuation in fossil fuel cost and maintenance of generator. Therefore alternate source of energy like photovoltaic and wind along with its various hybrid combinations offer suitable options for electricity generation for off-grid area. The PV and wind renewable energy (RE) are found to be the significant nonconventional power generation option in the era of ever-increasing crises of energy with their profitable traits like environment-friendly, bulk availability, location-reliance. It has the advantage to increase the reliability and decrease the cost of the total life cycle. In Economic Times report, India's gross RE potential (up to 2022) is estimated at 175 GW [1]. The range of annual typical for solar insolation and wind speed are 5–10 m/s and 3–6 KWh/m^2 respectively is enhancing by the researchers of various countries to minimize the dependency on conventional sources [2,3].

The design consideration of wind energy based systems using appropriate technology to meet the load demand of different areas with respect to achieving various objectives is investigated. Objectives such as suitable location, assessment of present and future energy requirement, estimation of payback period, evaluation of LPSP, economic along with energy reliability analysis etc are reported [2–4,34]. The design of PV based hybrid systems [28–30,33,35,46] and PV-Wind based hybrid system [5–10,24–26,31,32,36–45,47,48] to assess the practical performance of the system using distinct methodology for a variety of geographical locations to meet the load demand are presented to obtain the widespread goals as follows:

- Optimal sizing/configuration of hybrid system components.
- Reliable operation control of hybrid system.
- Minimize the annual COE
- Minimize LPSP for a given load.
- Satisfy the load demand by effective use of renewable sources.
- Decrease the pollutant emissions.
- Improve battery efficiency.
- Higher conversion efficiency.
- Reasonable price and ease of operation.
- Estimation of the loss-of-load probability (LLP).
- Minimize costs of O & M of the PV sections and the battery.
- Minimize life cycle costs and ensuring reliable system operation by appropriate design and process control of HRES.

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http://dx.doi.org/10.1016/j.rser.2017.06.033
Received 10 March 2016; Received in revised form 31 May 2017; Accepted 9 June 2017
1364-0321/

Nomenclature

DG	Diesel generators
GTREI	Global Trends in Renewable Energy Investments
IEA	International Energy Agency
LLP	loss of load probability
HRES	Hybrid renewable energy systems
$\mathbf{P^T_{WIND,each}}$	**Power by wind turbine**
$\mathbf{v_r}$	**Nominal speed of wind turbine**
V	**Wind speed**
$\mathbf{v_o}$	**Cutout speed**
$\mathbf{v_J}$	**Cut in speed**
$\mathbf{P_{RW}}$	**Wind generator rated power**
τ	The hourly self-discharge rate
LOLR	Loss of load risk
$\mathbf{P^T_l}$	Energy demand of the particular hour
$\eta_{inverter}$	Efficiency of the inverter
IMD	Indian meteorological data
NASA	National Aeronautics and Space Administration
O/M	Operation & maintenance
CO_2	Carbon dioxide
RE	Renewable energy
PV	Photovoltaic
$P_{PV,each}$	Power generated by PV system.
P_{RS}	PV panel rated power.
R	Solar radiation factor.
R_{cr}	Certain radiation
R_{srs}	Standard solar radiation
η_G	DG efficiency
N	No. of swarm
$\mathbf{P^T_{WIND}}$	Power generated by wind turbine.
$\mathbf{P^T_{PV}}$	Power generated by PV panel
$\mathbf{P^T_{BIO}}$	Power generated by Biomass
$\mathbf{P^T_l}$	Energy demand for the particular hour.
η_{bc}	Charge efficiency of the battery bank
LA	Load Autonomy
HLOL	Hour's which loss of load occurs
HTOT	Hour's operation system
LPSP	Loss of Power Supply Probability
LLP	Loss of Load Probability
UL	Unmet Load
TNPC	Total net present cost
NPW	Net present worth
C_{ANN}	Annualized cost,
CRF	Capital recovery factor,
i	Interest rate,
T_{PLT}	Project lifetime
LCC	Life cycle costs
COE	Cost of energy
NOx	Nitrogen oxide
SO2	Sulfur dioxide
$\mathbf{E^T_{battery}}$ and $\mathbf{E^{T-1}_{battery}}$	Charge measure of the battery at time T and T-1
GA	Genetic algorithm
CO	Carbon monoxide
PSO	Particle swarm optimization
$\mathbf{F_{dsl}}$	**Diesel fuel consumption l/h**
P(t)	**DGpower(kW)**
$\mathbf{P_R}$	**Rated power of the DG**
A, B	Are the costand parameters (l/kW), constant value is a round 0. 08145 and 0. 246
$\mathbf{F_{dsl}}$	**Diesel fuel consumption l/h**
P(t)	**DG power (kW)**
η_T	Total efficiency
η_B	Thermal efficiency
k	k^{th} iteration number
w	Inertia weight
r_1 & r_2	Random numbers
c_1 & c_2	Velocity coefficients
DOD	Dept of discharge

- Minimize the total annual cost including initial cost, operation cost and maintenance cost etc.

The various strategies for modeling and control of hybrid system using different methodologies and software such as different dispatch strategies and different design software namely PVSYST, SolSim and Hybrid Designer, HYBRID2, SOME, PHOTO, HOMER, SEU-ARES, ARES, F-Chart Software, RAPSYS and RETScreen etc are developed [11–23,27,49,50]. The PV-wind HRES with battery unit and DG as a support be capable of electrifying the remote area population where it

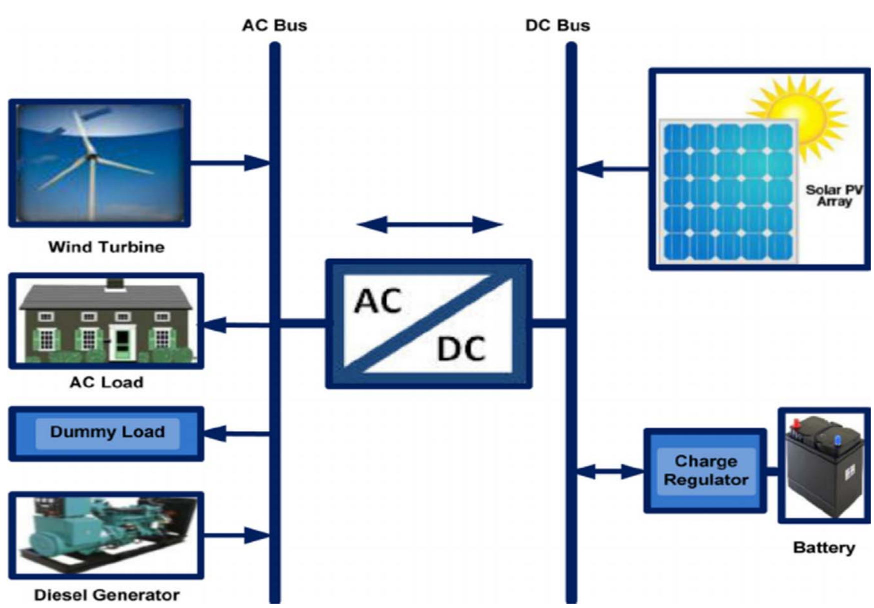

Fig. 1. Block diagram of a typical PV-wind hybrid system.

is uneconomical to extend the conventional utility grid. The merits of HRES can be achieved only when the system is designed and operated appropriately [99]. Boolean model in Geographical information system software is used for identifying the location for best optimal solution of the HRES in Middle-East [122]. The typical model of HRES is in Fig. 1 [93].

The introductory part related to the hybrid system optimal configurations is described in part I. The reviews on a series of combination HRES are presented in part II. The design modeling of HRES elements is described in part III. The various control strategy for HRES are given in Section 4. The software tools for designing hybrid renewable energy system are discussed in part VI. In Section 5 discussed about Optimization Objectives for HRESs which responsible to boot up the performance of system. The case study is reported for design of HRES for remote area by using HOMER and PSO in part VI. The Particle swarm optimization technique is presented in part VII. The comparative results of Homer and PSO are presented in part VIII. Suggestions and future scopes related to the work are reported in part IX. At the end the conclusions are presented in part X.

2. Description of HRES

The HRES comprises of solar PV, wind turbine, inverter, battery and some additional components. This section presents numerous available PV, wind combinations such as PV scheme, wind scheme and PV/wind HRES. If the renewable energy resources (RE) generated power exceeds required load demand, than surplus power is delivered to charge the battery bank unit. Thereafter the battery comes into play when the generation of RE is insufficient to meet the load demand. The PV/wind HRES operation depends on the each component performance. Therefore rectifying each renewable source performance, individual renewable energy source is modelled is discussed in this section

2.1. PV system

The PV energy is abundantly available in the environment and it is free from the pollution. The nature of PV system output power depends on the geographical location. The PV system is a possible RE source, which utilizes to overcome the dependency on fossil fuel [51–56,98]. Fig. 2.1 shows the representation of hybrid PV generation unit consisting of PV generator, DG, inverter and battery system. The different combinations of PV/diesel based hybrid systems through battery bank storage and DG supplementary unit are considered to investigate the potential benefits and effective utilization of PV-diesel systems to fulfill the consumer load demand requirement [57]. The PV-diesel based hybrid systems have complementary characteristics as follows [46,57–59,100,102,108,113,114,126,131,134,135,140]:

- Working cost of PV system is minimum as compared DG
- O & M cost minimum as compared DG diesel
- Reduces battery storage requirement
- Better dependability
- Less emissions
- System autonomy
- Accuracy analysis
- Reduce generation costs and increase the reliability of energy supply
- Maximize the techno-economic benefits
- find out a number of storage days

Investigation of PV system for obtaining the maximum generation, cost economy solution and reliable operation with various objectives are reported using a number of programming languages and software such as C++ and FORTRAN etc [60–64]. Based on the literature, it's analyzed that the optimally designed of PV/DG systems is more techno-economic and feasible as compared to PV without DG systems. The summary of studies based on PV system is presented in Table 1.

2.2. Wind energy system

Wind energy is also freely available in environment, pollution free source of energy. The performance of the output power generation of wind energy system various according to the wind potential of design location. The condition for feasible solution and techno-economic wind energy system is the selection of higher wind energy potential geographical location is necessary [65,66].

The feasible and cost effective model of wind system to compare, performance of different wind machines at various locations are investigated regarding average velocity and the turbine machine characteristics [65]. Furthermore, the various constraints are investigated for wind system at different locations is carried out with following parameters as [66–70,115,123,125,143]:

- Feasibility
- Economic viability
- Optimal system configuration
- Capacity meeting of the load demands
- The benefits and potential of wind power
- Cost of wind energy
- Energy security

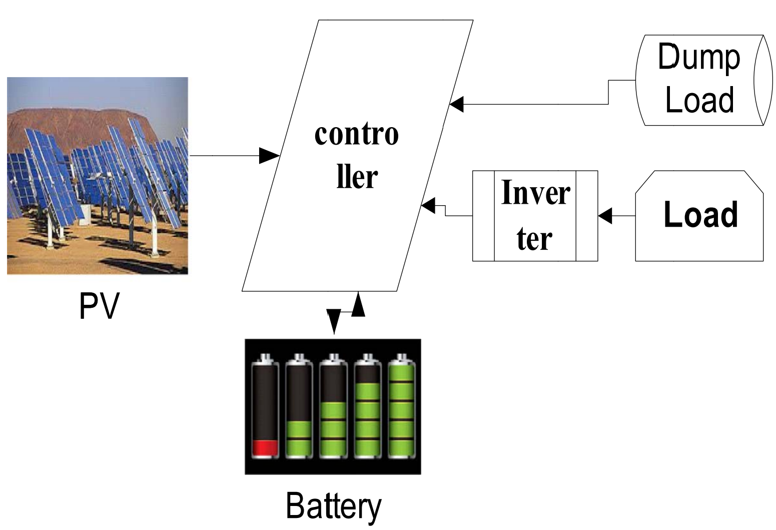

Fig. 2.1. Block diagram of PV system.

Table 1
Outline of PV system, wind system and PV/ wind hybrid system.

Off GD/ GD conn.	Design Place	Demand category	Technique	Objective Function	Findings	References
photovoltaic system						
Off GD/ GD conn.		–	–	Cost	Current and future opportunities of photovoltaic scheme.	Post et al. [51]
Off GD	Jordan	water pumping motor	Matlab	Reliability and Economic feasibility study	Design an optimal PV system for irrigation applications	Mahmoud [52]
GD connected	Portu-gal	Grid connected	Monte Carlo simulation	Reliability	Evaluated an techno-economic solution which is more dependability system.	Traca et al. [55]
Off GD	Dhahran ,Saudi Arabia	Residential buildings	Matlab	Potential of utilizing hybrid system	Develop photovoltaic scheme to meet required consumer demand.	Shaahid et al. [57]
Off GD	Saudi Arabia	Commercial	Matlab	Feasibility of hybrid system	Developed an optimal system with DG application and also reduce the emission effect.	Shaahid et al. [58]
GD connected	–	Utility Systems	probabilistic approach	Production cost.	Optimize an grid connected PV system in addition of battery back unit on the bases of excepted energy not supply.	Marwali et al. [64]
Wind system						
Off GD	Kerala, India	Water pumping	Matlab	Distribution of wind velocity	Design an technique for evaluation the performance of wind prospective.	Mathew et al. [65]
Off GD	Morocco	Residential	–	Cost of electricity generated and fuel saving	Determine the feasible solution for lowest per unit cost of electricity.	Nfaoui et al. [68]
GD connected	–	commercial	fuzzy logy	To generate fuzzy membership functions and control rules for the controller.	Design a technique for identify the slow performance of wind turbine with DG system	Chedid et al. [76]
Off GD	dhahran	industrial	Matlab	Identified the viability of hybrid system in dhahran	Parametric study of wind generating systems	Elhadidy et al. [79]
SA	Irbid -Jordan	–	–	Finding the capacity factors (CF)	Study on the wind turbine constrains.	Salameh et al. [75]
PV/Wind hybrid system						
Off GD	Hong Kong	Telecommunication	Matlab	Reliability, and probability of power supply	Study on weather data and probability analysis of hybrid power generation systems.	Yang et al. [144]
Off GD	Crete, Greece	Residential	Genetic Algorithm	COE and GHG release	A novel methodology for minimization of carbon emission and also COE.	Katsigiannis et al. [95]
GD connected	Spain	Utility system	GRHYSO	TNPC	Develop HRES with utility supply for obtaining lower cost of energy.	Dufo-Lo´ pez et al. [92]
Off GD	Egypt	Agricultural load	HOMER	Economic	Design a optimal and cost effective and pollution free HRES without using DG.	Kamel et al. [91]
Off GD	south of Tunisia	Residential	iterative technique	Economic	Feasible HRES for purification of water.	Mariem et al. [83]
GD connected	Saudi Arabia	commercial	Matlab	Load distribution and power generation	Design HRES by using available renewable resources to fulfill the consumer electricity requirements.	Elhadidy et al. [82]

- Assessment of wind power availability
- Atmospheric degradation

The optimal sizing methodology of wind system by means of collective ant colony optimization and artificial bee colony is presented [71]. The optimal configuration of wind system is analysis through the genetic algorithm technique [75]. By taking the various constraints of wind system components feasible sizing is evaluated by using Monte-Carlo simulation technique [74]. The techno-economic and reliability also investigated by neural network technique, regression analysis technique [72,73]. The different methods to train the wind data are used for improving the rated wind turbine power output on yearly basis [75,78]. The optimal configuration planning and control for wind energy system are described to increase the system performances with respect to reduce cost of energy and enhance reliability by utilizing a battery backup effectively [76–79]. The block diagram of wind system is in Fig. 2.2. The outline of studies based on wind system is presented in Table 1.

2.3. PV/wind energy system

The renewable PV and wind resources are reciprocal to each other with respect to weather conditions. Therefore, the combined use of PV and wind hybrid system is more effective with regard to energy production throughout the year as compared to individual source. The single source system like PV energy system or wind energy system requires battery backup and DG unit in standalone system to achieve better performances, which affects hybrid system cost, reliability, cost of energy and environmental emission [80–82]. The optimal design of PV-Wind based hybrid systems by considering a variety of system performance parameters such as total annual cost, loss of power supply probability, sensitivity analysis, demand side management, reduction of losses, and pollutant emissions are developed using different software tools, techniques and methodologies as follows:

- HOMER [20,85,88,91,93,97,98]
- Tabu search (TS) [86]
- HYBRID2 [11,12,80]
- SOMES [19,80]
- Harmony search (HS) [86]
- MATLAB software tool [81,83–85,92,99,103,120]
- Genetic Algorithm (GA) [90,95,96]
- Particle swarm optimization (PSO) [86,87,89,122,130,149,150]
- Simulated annealing (SA) [86]
- ARENA 12.0 [94]
- Sliding Mode control [129]
- Probabilistic method [133,144,145]
- Auxiliary method [136]
- Analytical method [138–140,146]
- Monte carlo simulation [146]

The reviews on the existing status of sizing with working of PV-based energy systems are discussed [131,132], Wind-based hybrid energy systems [127,128] and PV-Wind based hybrid energy systems [117,119–122,127,132,137–139,141,147,148] are reported using several methodologies to obtain different objectives. The representation of PV/wind hybrid energy system is in Fig. 2.3 and the review of PV/Wind hybrid system is shown in Table 1. Based on the comprehensive literature reviews in the field of different combination of HRES using several techniques following wide findings can be given as:

- The HRES found to be a superior alternative with the aim of incorporate substitute for electricity production.
- More or less the entire reviewed systems comprise with generation system which has more than one source, has high reliability and more feasible system as compare to the single source renewable energy system
- In a recent trend, the multi-objective sizing methodologies and hybrid optimization methods are developing to facilitate the reliable, environmentally friendly and feasible design of HRES.
- PV/Wind HRES with backup energy unit such as battery banks, DG and fuel cells can help decrease the energy costs, emissions and improve reliability of the system.

3. Modeling of HRES elements

The optimal sizing of the PV/wind HRES is depended on various modeling parameters. Numerous modeling parameters are discussed in literature, amongst all thus modeling parameters the best optimal modeling of HRES is specified below (Fig. 3).

3.1. Modeling of PV system

A number of technique/methods are discussed in literature for

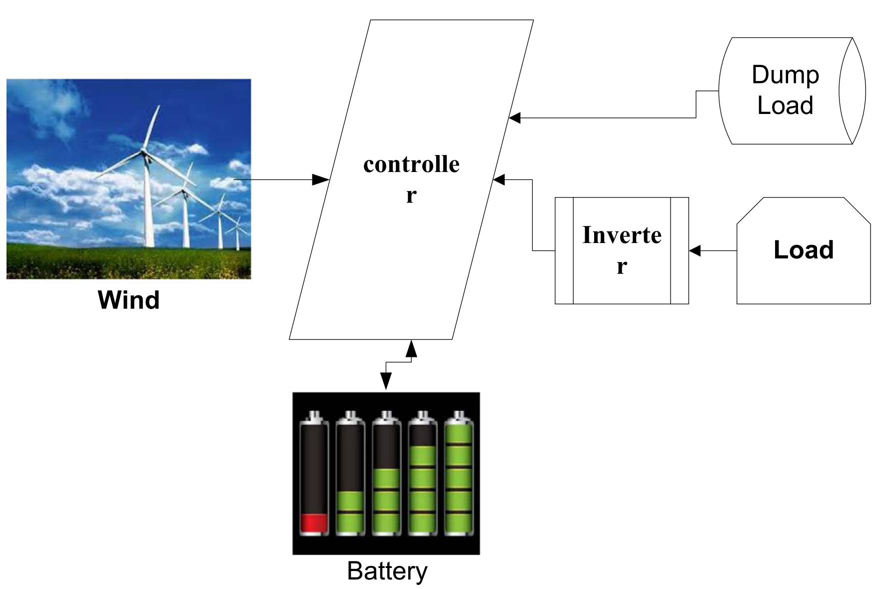

Fig. 2.2. Block diagram of wind system.

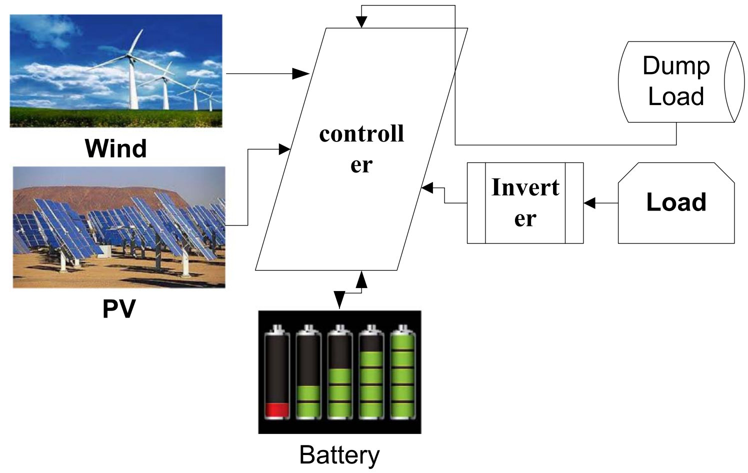

Fig. 2.3. Block diagram of PV-wind hybrid system.

modeling of PV system by considering distingue criteria as [24,86,89,99,102,122,149]:

- Maximum power point tracker (MPPT) system
- PV area based system
- Considering the order of solar insolation based system
  a. First order equation
  b. Second order equation
- Equivalent circuit based on

a. Single diode configuration
b. Double diode configuration

- PV module output equation based system
  a. With temperature effect
  b. With-out temperature effect

The above-described PV models can be used to model the system with second-order effects of solar radiation in output power. The output of PV depends on radiation. On basis of hourly radiation data, output power of the PV system for fixed surface can be evaluated as [122]:

$$\mathbf{P}_{\mathbf{PV,each}} = \begin{cases} \mathbf{P}_{\mathbf{RS}}\left(\frac{\mathbf{R}^2}{\mathbf{R}_{\mathbf{srs}}\mathbf{R}_{\mathbf{cr}}}\right) & \mathbf{0} \le \mathbf{R} < \mathbf{R}_{\mathbf{CR}} \\ \mathbf{P}_{\mathbf{RS}}\left(\frac{\mathbf{R}}{\mathbf{R}_{\mathbf{srs}}}\right) & \mathbf{R}_{\mathbf{CR} \le \mathbf{R}} < \mathbf{R}_{\mathbf{srs}} \\ \mathbf{P}_{\mathbf{RS}} & \mathbf{R}_{\mathbf{srs}} \le \mathbf{R} \end{cases} \quad (1)$$

Where

$P_{PV,each}$= Power generated by PV system.
P_{RS}= PV panel rated power.
R= Solar radiation factor.
R_{cr}= certain radiation at 150 W/m^2
R_{srs}= Standard solar radiation at 1000 W/m^2

3.2. Modeling of wind system

The wind energy conversion modeling process includes the modeling of wind turbine dynamics as well as generator. Based on the available wind speed range, a wind turbine is selected and the power law is utilized for consideration of preferred hub height of the wind turbine through vertical profile of the wind speed [10,24]. The out Power of wind energy system by taking various parameters is evaluated with given equation [86,89,102,115,122,124,149]:

- Swept area
- Considering the order of wind speed based system

a. First order equation
b. Second order equation
c. Third order equation

A Number of wind system models can be used for modeling of the system, however, this work presented with first order effects of wind speed in output power. The output power and torque of the wind turbine can be given as follow [86,122].

$$\mathbf{P}^{\mathrm{T}}_{\mathrm{WIND,each}} = \begin{cases} 0 & V \le v_J \text{ or } V \ge v_o \\ P_{Rw}\left(\frac{V - v_J}{v_R - v_J}\right) & v_J < V < v \\ P_{Rw} & v_r \le V < v_o \end{cases} \quad (2)$$

Where,

$P^{T}_{WIND,each}$ = power generated by wind turbine
v_r = Nominal speed of the wind turbine
V = Wind speed
v_o = Cut out speed
v_J = Cut in speed
P_{RW} = Wind generator rated power

3.3. Modeling of DG

HRES performance and output power are relying on upon climate conditions. PV, Wind hybrid system output power and battery back-up are produced insufficient power to meet required load demand because of lower response of PV and wind resource input data. Therefore DG unit is used to meet this additional load demand which increases the HRES reliability. In HRES, DG unit application depends on type of the load demand. DG unit followed by two different strategies such as load following and cycle charging. The application of DG strategy depends on requirement of the HRES [126]. In load following strategy, DG unit supplies the power only to meet the required load demand and lower priority objectives like charging of battery, electrolyzer and deferrable load are left to renewable power source. In case of cycle charging strategy, DG unit run at full output power, it supplies power to the meet load demand and excessive power is used to charge the lower priority objective. The cycle charging method is more effective and increases the reliability of HRES as compare to the load following strategy [127,128]. DG work as backup power supply for hybrid system generated power not fulfill as per load requirement. The DG increases the system reliability and makes the system more cost effective. DG hourly fuel consumption and efficiency analysis according to given formula [149]:

$$F_{dsl}(t) = A.\ P_R + B.\ P(t) \tag{3}$$

Where,

$F_{dsl}(t)$ = Diesel fuel consumption l/h
$P(t)$ = DG power (kW)
P_R = Rated power of the DG
A, B = Are the costand parameters (l/kW), constant value is around 0. 08145 and 0. 246

$$\eta_T = \eta_B \times \eta_G \tag{4}$$

Where,

η_T = Total efficiency
η_B = Thermal efficiency
η_G = DG efficiency

In optimal sizing of any HRES for lowest cost, DG must be run on 70–90% of total load [129,130].

3.4. Modeling of battery system

Generally two type of modeling are used for battery system modeling first is SOC based equation and second is an EMF based equation for charging and discharging [24,86,89,99,102,122,149]. In a situation when HRES generate excessive power and after fulfilling the load requirement excess power is remaining. This excess power is used to charge the battery bank unit. This backup power of the battery bank is utilized when load demand is not meet through the HRES. So that the battery bank increase the efficiency when sufficient power generation is not available from HRES [132]. The battery size varies on the upper limit of DOD, heat and lifespan. In HRES, battery is used for the purpose of storage, battery balance the power between supply and load demand. The input power of the battery can be negative or positive due to charging and discharging process. Evaluation, state of charge with respective productivity and time consumption as [122]:

(i) $P_{PV}^T + P_{WIND}^T + P_{BIO}^T = P_{DEMAND}^T$
In this situation of the battery, capacity of battery, stable and not change.

(ii) $P_{PV}^T + P_{WIND}^T + P_{BIO}^T > P_{DEMAND}^T$
In this situation, Total hybrid (PV + Wind + Bio) power of the system is more than to load demand. At this condition battery is in charging position and charged quantity of the battery at time (t) is given as;

$$E_{battery}^T = E_{battery}^{T-1}.\ (1-\tau) + \left[(P_{PV}^T + P_{WIND}^T + P_{BIO}^T) - \frac{P_l^T}{\eta_{inverter}}\right]\eta_{bc} \tag{5}$$

Where,

$\mathbf{E_{battery}^T}$ and $\mathbf{E_{battery}^{T-1}}$ = Charge quantities of the battery
T − 1 and **T**= Battery bank charge times.
$\mathbf{P_l^T}$ = Energy demand of the particular hour
$\mathbf{P_{WIND}^T}$ = Power generated by wind turbine.
$\mathbf{P_{PV}^T}$ = power generated by PV panel
$\mathbf{P_{BIO}^T}$ = power generated by Biomass
$\mathbf{P_l^T}$ = Energy demand for the particular hour.
$\boldsymbol{\eta_{bc}}$ = Charge efficiency of the battery bank
$\boldsymbol{\eta_{inverter}}$ = Efficiency of the inverter
$\boldsymbol{\tau}$ = The hourly self-discharge rate

(i) $P_{PV}^T + P_{WIND}^T + P_{BIO}^T < P_{demand}^T$

In this situation, the total power generated by hybrid (PV + Wind + Bio) system is less than to load demand. At this time battery bank is in discharge position and the charge amount of the battery bank is given in equation. The storage battery bank set at a nominal capacity and it only allows discharge at that limit.

$$E_{battery}^T = E_{battery}^{T-1}.\ (1-\tau) + \left[\frac{P_l^T}{\eta_{inverter}} - (P_{PV}^T + P_{WIND}^T + P_{BIO}^T)\right]\eta_{bf} \tag{6}$$

Where, η_{bf} = Discharging efficiency of battery bank

3.5. Converter/Inverter

The electronic converter is needed to balance energy flow amongst the AC and DC elements. The converters/inverter converts the electrical energy from one form into another (Converter AC to DC, and inverter DC to AC) with the desired frequency of the load. The efficiency of the inverter can be given as [149]:

$$\eta_{imv} = \frac{\mathbf{P}}{\mathbf{P + P_0 + kP^2}} \tag{7}$$

Where, P, P_0 and k are determined by using following equations as:

$$\boldsymbol{P_0} = 1 - 99\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right)^2; \boldsymbol{k} = \frac{1}{\eta_{100}} - \boldsymbol{P_0} - 1, \text{And} \boldsymbol{P} = \boldsymbol{P_{out}}/\boldsymbol{P_n} \tag{8}$$

Where, $\boldsymbol{\eta_{10}}$ and $\boldsymbol{\eta_{100}}$ are the efficiency of the converter on ten percent and hundred percent, which is specified via assemblers.

4. Control strategies

The HRES configuration has various components and many components are variable nature such conventional sources, renewable source, DG and bake up unit [101–06]. So that it is essential to control the variable nature of the each system component. By applying a proper control strategy, it can be possible to obtain an optimal solution at higher reliability and lower cost of the HRES. 'The power supply and records communication information (Fig. 3).

In HRES the controller is essential for monitoring and controlling of different variables according to load requirement and also controls the output voltage, frequency, active power from dissimilar power elements. Generally four categories of controllers used to control the operation of HRES which can be given as follows [102–107]:

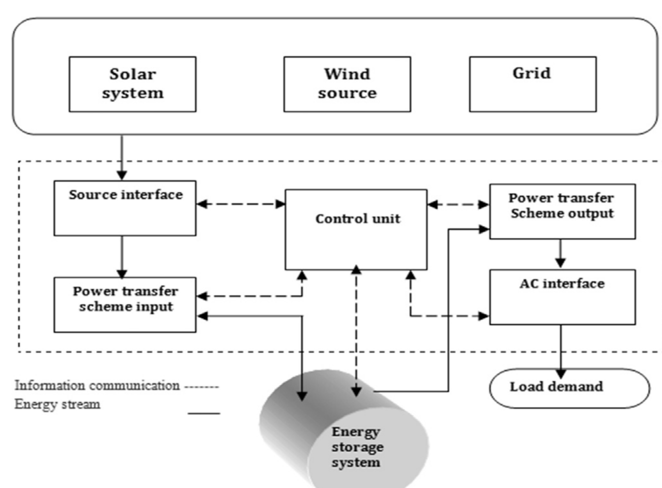

Fig. 3. The power supply and records communication information.

Table 2
The detail description of the technical & economic objective Table 2.

Authors	Renewable source	Off GD/ GD connected	Load type	Objective constrains	Optimization technique	Highlights
Yang et al. [36]	PV, wind	Off GD	telecommunication	LPSP: power of the system	GA	Consider five decision variable of pv, wind and evaluated optimal hybrid system at minimum annual cost
M.K. Deshmukh et al. [131]	PV, wind	Off GD/ GD connected	–	LOLP: current required/supply of the system		Analysis for feasibility and technical competitiveness and LOLP concept.
S. Iniyan et al. [61]	PV, wind, bio-energy	Off GD	Domestic and commercial	Unit cost and efficiency	MOP	minimizes the cost/efficiency ratio and optimum allocation of different RES for various end-uses
Daming Xu et al. [38]	PV, wind	Off GD	–	LPSP: total capital cost	GA	Evaluated optimal configuration with total capital cost
Daniel et al. [89]	PV, wind	Off GD	commercial	penalty for carbon emissions, economic cost of carbon, element power consumption	PSO	System is developed to meet load demand though PSO and homer software
Mohammad et al. [119]	PV, wind	GD connected	Domestic	Index of availability; battery bank, power purchased from grid, PV wind power	MOGA	Design a multi-objective system to meet the load demand.
levelized cost of energy LCE						
Motaz Amer et al. [86]	PV, wind	Off GD	house	Net capacity factor, annualized costs, interest rate, O & M cost, installed capital cost	PSO	Lowest Cost of energy is evaluated by considered various cost parameter.
Hongxing Yang et al. [48]	PV, wind	Off GD/ GD connected	Dynamic load model	LPSP: Capital cost battery wind PV. Lifetime year of PV. battery wind. annual energy supplied	–	Investigation of HRES model for sizing capacity of PV, wind and battery.
Javier Carroquino et al. [83]	PV	Off GD	Agriculture load	Annual Energy Annual discount rate Total net present cost	GA	Developed economic PV diesel hybrid system for agriculture load
Diaf et al. [33]	PV, wind	Off GD		LPSP: Annual Energy Annual discount rate Total net present cost Useful lifetime	–	Find the optimal configuration amongst the system components to meet system reliability at lowest cost of energy
Matteo Ranaboldo et al. [10]	PV, wind	Off GD		solar resource; tracking factor; annual degradation rate; performance factor; O & M cost cost of the system; cost of the required land; discount rate	–	Considered various components constrains and evaluated levelized cost of energy for small community load
Ramakumar et al. [114]	PV, wind Biomass, tidal, Hydro....	Off GD/ GD connected	Various Load Demand	cost of energy annual capacity factor in per-unit; amortization period, years; O & M installed (capital) cost fixed annual interest rate in per-unit	–	Present the idea about economic sizing of hybrid system and design optimal hybrid system.
B. Ould. et al. [96]	PV, wind	Off GD	Commercial and Domestic	The annual consumed energy levelized replacement cost of energy; levelized capital cost of energy; levelized O & M cost of energy.	–	Evaluated techno-economic sizing of hybrid system w.r.t levelized cost of energy and carbon dioxide.
Total Net present cost TNPC						
Yildiz Kalinci et al. [59]	PV, wind	Off GD	Residence	the project life time the nominal capital, the replacement, the O & M cost and the salvage costs.	Homer	Homer tool is used for two different hybrid system model and PV wind system is more optimal as compare to wind only system
Subho Upadhyay et al. [84]	PV, hydro, biomass and biogas energy	Off GD	Residence	cost of energy (%); total net present cost;	PSO and Homer	Optimal Hybrid system is design for various load demands of rural places by using PSO and Homer.

(continued on next page)

Table 2 *(continued)*

Authors	Renewable source	Off GD/ GD connected	Load type	Objective constrains	Optimization technique	Highlights
				capital recovery factor; total generated electricity over a period; discount rate (%); day of the year (d); life of the plant (year).		
Juan et al. [80]	PV, wind, gasoline generator	Off GD	household appliances	the annualized capital cost; the annualized replacement cost; the annualized maintenance cost; the project lifetime; the annual real interest rate.		Design techno-economic hybrid system
Lanre Olatomiwa et al. [81]	PV, wind	Off GD	Load profile of the community	The Total Annualized Cost ($/Year); The Capital Recovery Factor; Annual Real Interest Rate; The Project Lifetime In Years.	–	Developed optimal PV system configuration amongst six different locations
Kanase et al. [138]	Micro-hydro power, biomass, PV and wind	GD connected	Residence	the average production cost; the summation index to take account of all apparatus; the load factor for apparatus; the O & M charge rate in per unit; the paying back period in years; the capital cost for the *i*th device; the rating in kW of the *i*th device.	–	Developed a grid connected hybrid system for rural load profile determine the reliability.

- Centralized control
- Distributed control
- Combined/Hybrid control (combined with distributed and centralized)
- Multiple control

In each and every case the source has its own controller, which center of attention on Supreme process of the related element with existing information. Signals of energy sources along with backup unit of the HRES are managed through the centralized or main controller planning in the centralized control arrangement. Various constraint of power elements arrangement is may be controlled by global optimization with respect to the entire available information [104–108]. The centralized unit has disadvantage as it takes more computation time, because it is related to particular end letdown. Next technique is distributed control; in this strategy has only one power source which is connected by the mean of separated local unit for that region every element are connected with together for communication of measurement information. It also helps to evaluation of global optimization. This type of control unit is more advantageous as a minimum computational load without any failure, but it has disadvantage of multiple communications [108,109,117]. The problems of distributed control unit can be overcome by use of numerous available artificial intelligence techniques. The multi-agent system based methodologies are best suited it.

The next control technique is hybrid control method, which is the combination of distributed and centralized control units [110,119,120]. The hybrid control unit uses the local and global optimizations which can be achieved by above two control technique discussed. This control technique has less failure issue. The demerit of this method is high intricacy for information conversion system. The last technique is multilevel method; working principle is same as hybrid control technique with the exception of better control on the system in addition working on basis of current information [120,121].

The main features of using an effective control strategy for HRES are as follows [46,77,100–125,138]:

- To maximize the utilization of RE sources
- To fully optimize the energy management system
- To maximize efficiency of the system
- To minimize the fuel consumption of engine driven generator
- To maximize the system components service life
- To maintain reliable system operation
- To improve the stability of operation
- To manage the operating constraints for example restricted night-hours of diesel generator, load priorities, and minimum battery SOC.
- To control the energy dispatch strategies and the direction of power flow in the system with respect to timescale
- To improve the power quality of operation
- To provide the synchronization mechanisms and reconnection function during progression

5. Optimization objectives for HRES

Hybrid renewable energy system, optimal design depends on numerous parameters such as technical parameters and economic parameters. The technical parameters criteria as system efficiency, environmental Objectives (relating to the natural world and the impact of human activity on its condition) and reliability to fulfill the load demand at minimum emission and higher efficiency. Hybrid renewable energy system cost minimizes through the economic criteria such as minimization of per unit cost of energy (levelized cost of energy), total net present cost (TNPC) and various cost related optimization.

5.1. Technical criteria

The design of optimal of hybrid renewable energy which has higher reliability and less emission, appropriate consideration of technical objectives is a must. Various technical objectives are discussed in the literature such as maximizing the availability of power, LPSP, LOL, minimization of emission, minimization cost and minimization efficiency proportion. The optimal sizing of hybrid system is evaluated at minimum annually cost by considering the various decision variable of the PV and wind source in optimization process [36]. The author describes the hybrid renewable energy system design, methodology and evaluation technique [131]. Optimal hybrid system model is developed to minimize the cost/ efficiency ratio and analysis was done to find out the reliability factor of solar PV power plant and wind turbine generator [61]. The brief outline of is given in Table 2. The optimal configuration is obtained by considering objective as minimization of total net present cost by using genetic algorithm optimization technique [38]. A standalone hybrid system is developed to meet the load and water desalination demand by using PSO and also result are compared with the homer software. The developed program considered with various constraints like gravimetric penalty cost for carbon emission, element cost of carbon dioxide, and annual system component power consumption to obtain the optimal configuration of the hybrid system [89]. A muti-objective genetic algorithm technique is developed for grid connected hybrid system is design to meet a load of a small community at a lower cost [119].

5.2. Economic optimization

Another constraint for optimal sizing of hybrid renewable energy system is economic optimization. An Economic optimization which includes minimization levelized cost of energy, minimization total net present cost and other cost-linked optimization. By minimizing all this constraints of the economic optimization a cost effective solution of the hybrid system can be obtained. HRES is designed by considering losses of load demand and production regions using PSO and evaluated lower cost of the energy [86]. Hybrid PV-Wind model is developed to optimize the capital size of the hybrid system with battery bank [48]. Agriculture load demands such as drip irrigation and water pumping can also be satisfied by PV-diesel hybrid system at economical cost [83]. Various studies are reported in literature for optimal sizing of hybrid PV wind system to meet system reliability at lowest levelized cost of the energy [10,33,54,85,96,114].

Taking objective as minimization of total net present cost also helpful to obtained optimal solution of hybrid system. Total net present cost is summation of the initial cost, operating and maintenance cost and replacement cost of the component used in hybrid system. Homer software is used to design a hybrid system by considering two different model such as wind system and another is PV-wind hybrid system and found that PV-wind hybrid system provides lowest total net present cost of the system [59]. Comparative solutions are evaluated for lowest total net present cost of the solar-hydro-biomass-biogas hybrid system at various load profile of the rural area using PSO and Homer [84]. The techno-economic optimal hybrid system is evaluated by considering the effect of uncertainty nature of renewable energy sources (PV, wind) [80]. The hybrid system feasibility performance varies with change in the design location. PV-diesel-battery system is found optimal configuration amongst six different locations [81]. The brief outline of is given in Table 2

6. Case study

This case study is giving an idea for modeling of a hybrid system to electrify the rural areas by using locally available renewable energy resources. The optimal sizing is done through the PV, wind and biomass which are available at design location of barwani, MP, India.

The comparative result analysis is present for HRES through the Homer and particle swarm optimization technique.

6.1. Recent scenario of renewable energy

Global trends in renewable energy investments (GTREI) 2016 highlight the growing significance of RE in tackling climate change and the wider sustainable expansion program. Rising renewable energy use, for the first time in 40 years, global carbon emissions related with energy consumption is constant in year 2016 while the global financial system grew. Although previous emissions reductions were connected with downturns in the worldwide economy, the carbon stabilization in 2016 has been associated with extended penetration of RE and increases in energy performance [53]. Wind power annual market forecast by region and solar installation capacity by region are shown in Figs. 4 and 5 [56]. In India entirety power generation capability is of 263.66 Gigawatts and RE capability of 34.35 Gigawatts as on March 2015. The worldwide installed capacity of RE is 630 Gigawatt (370 Gigawatts wind and 177 Gigawatts solar) in which India has 22.6 Gigawatts wind, and 3.3 Gigawatt solar which is shown in Table 3.

In India the growth/access of renewable energy power generation is rapidly increased in recent year. In year 2000, half of the population of Indian not access electricity and the cost of energy is very high in urban/rural areas. The report of International energy agency, twenty percent of population of the India without access to electricity, information is given in Table 4. The populaces not having electricity is engaged in a similarly minor number of states: for all intents and purposes 66% are in two thickly settled northern and north-eastern states, UP and Bihar.

In massive swathes of the Republic of India, together with the bulk of southern states, electrification rates are already well higher than of ninetieth. Of the overall without access, the massive majority – some 220 million people – live in rural areas wherever extending access may be a bigger technical and financial challenge. In urban regions, electrification rates are abundant higher, however, the standard of service remains terribly uneven, particularly in India's massive sub-urban slum areas that are home to around 8.8 million households [66].

6.2. Renewable energy resources

The case study is presented for remote area of barwani MP, India at dimension of 22.71 north's along with 75.85 easts. On basis of Indian meteorological data report huge availability of renewable energy resource in the country [110]. These energy sources are naturally obtainable and discontinuous; due to these issues our primary preference to supply the power as village base power station is RE sources such as solar and wind. The input data of renewable energy sources for design location is obtained from NASA [111]. All HRES combination under study is shown in Fig. 6.

6.3. PV resource

The design location has great potential of solar radiation. The PV resource at design location is 5.531 kWh/m^2/d averages annually. The clearance index in addition insolation data of solar resource in Fig. 7.

6.4. Wind resource

The wind speed data of the design location annually is 4.5 m/s. According to Fig. 7 wind is not same for each month of the year. The value of wind is higher in December and minimum value in the June months which is shown in figure [111].

6.5. Biomass

Rice mill located in the village of Barwani, which produce per day rice paddy is around 460 kg. It is expected in the study that rice husk production is 25% of the paddy and immature paddy production is 3% of the paddy. So, that a total biomass production of the rice mill is 115 kg/d [112].

6.6. load demand

The proposed design location has household daily load demand is 110.6 kWh/d. The average and peak load demand are 4.61 kW and 13.23 kW respectively. Hourly load data consumption of the village is given in Fig. 8.

6.7. Cost of hybrid system element's

HOMER design hybrid system according to the detail of cost parameters used in the system such as principal cost, substitute cost, operation & maintenance (O & M) cost. The cost of input parameters like wind turbine, solar PV cell, DG set, battery, converter and biomass gasifier unit are in the given in Table 5.

7. Result and discussion for homer

The optimal sizing is done through the homer software. This software takes input data on hourly basis of each component used for sizing purpose like cost parameter, energy resource data, constraints, system control data etc. It presents result on basis of lowest cost of HRES. The results of various configuration of the hybrid system are presented in Table 6.

7.1. Emission

The emissions factor is computed separately for each pollutant of the power system before simulation. The yearly emission of pollutant is calculated through multiplying the emissions factor with full yearly diesel fuel utilization for the period of simulation. When calculating different O & M cost than production of pollutants such as CO_2, CO, NO_2, SO_2, particulate matter, unburned hydrocarbon are used. The hybrid combination of DG, P/Batt./DG, W/Batt./DG, P/W/DG as shown in Table 6 produces harmful gases. The PV/Wind/Battery hybrid combination does not produce any harmful gas emission but this hybrid system is not more optimal with respective to higher cost and reliability issue. P/W/Batt./DG, P/W/Bio/DG/Batt system has less emission as compared to other combination. By using P/W/Batt/DG, P/W/Bio/DG/Batt system emission is reduced.

7.2. Production

The power generation for the various HRES is relying on the different combinations of hybrid system. Design tool calculates the power generation,

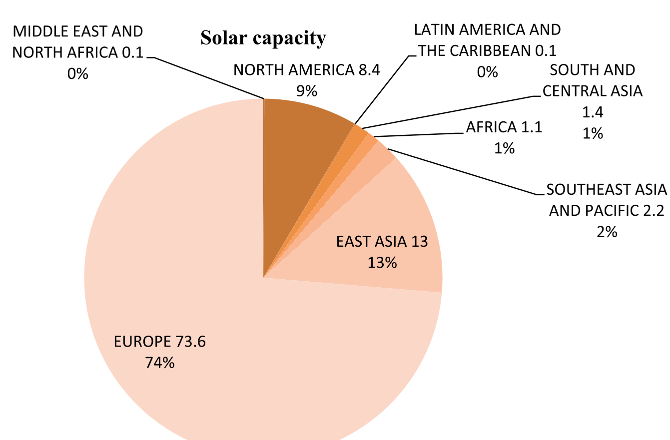

Fig. 4. Solar installation capacity by region.

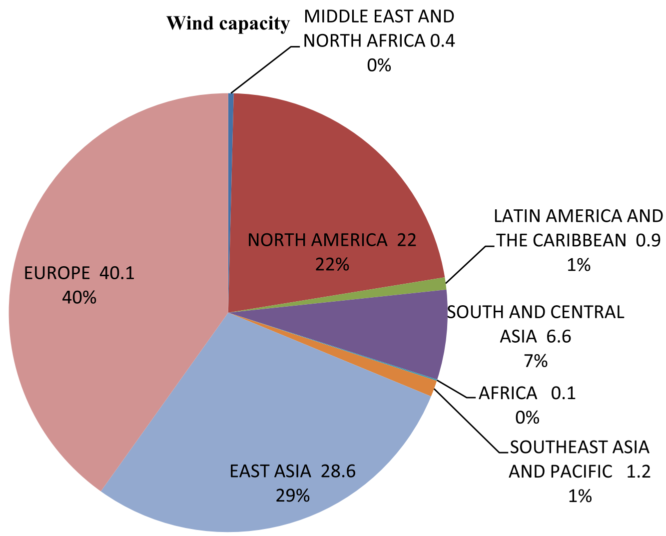

Fig. 5. Wind installation capacity by region.

Table 3
Renewable energy scenario in India.

Source	Installed capacity at 03/ 2012	power generation capability 03/ 2015	Target as per 12th plan 03/ 2017	modified target still 2022
PV power	941	3383	10,941	100000
Wind	17,352	22,645	32,352	60,000
Biomass	3225	4183	6125	10,000
Small hydro	3395	4025	5495	5000
Total	24,914	34,351	5495	175000

Table 4
States in India without electricity access, 2013 [66].

State	Population While Not Access Electricity (Million)			Percentage of Population While Not Access Electricity		
	Rural	Urban	Total	Rural (%)	Urban (%)	Total (%)
Uttar Pradesh (UP)	80	5	85	54	10	44
Bihar	62	2	64	69	19	64
West Bengal	17	2	19	30	7	22
Assam	11	0	12	45	9	40
Rajasthan	10	0	11	22	2	17
Odisha	10	0	11	32	4	27
Jharkhand	8	0	9	35	4	27
Madhya Pradesh	7	1	8	16	3	12
Maharashtra	6	1	6	11	2	7
Gujarat	2	2	3	7	6	6
Chattisgarh	2	0	3	14	6	12
Karnataka	1	0	1	5	1	3
Other states	3	2	6	2	2	2
Total	219	15	238	26	4	19

release by the each source which is connected to the hybrid system to meet load demand and supply energy. Through result analysis, it's noticed that the shortage capability is zero in DG and P/W/DG system, therefore hybrid configuration makes adaptive towards satisfying hundred percent of the electrical demand from the stand-alone hybrid system and the desired in operation reserve. This is often a high-quality demand for the standalone hybrid system where several unmet load state or electricity deficiency for annually is not acceptable. Excessive power generation through P/W/Batt HRES 73,627 kWh/yr is used to charge the battery bank unit. With respective power generation P/W/Batt system is more optimal solution.

7.3. Cost ($)

The HOMER software gives the output result on base of the TNPC of hybrid optimization model and HOMER arrange the output result in order to lower to higher TNPC. TNPC of the hybrid system is defined as the current value of the all component cost used to design system minus current value earn by that component over a whole period of operation. TNPC is indicating addition of capital cost components plus O & M cost plus replacement costs, fuel cost plus penalties of the emission plus electricity through the grid connection. From the simulation results of the case study design hybrid system it is analyzed that the system connected to P/W/Bio/DG/Batt system has lowest total net present cost $179326.20, levelized cost $ 0.3237 and the operating cost $5871.13.00 amongst all hybrid system. The TNPC and operating cost is approximately same to P/W/DG/Batt hybrid combinations. So that on the basis of cost function P/W/Bio/DG/Batt hybrid combinations is a more suitable option.

7.4. Fuel

The proposed hybrid system design has included a generator and the generator operates on diesel fuel oil. The diesel fuel price taken is $0.8/Litter. Design software gives the result based on diesel fuel oil per Kg consumed. The HRES only with DG needs diesel fuel which increases the cost of system. Amongst various configurations only P/W/Batt not consumes diesel fuel so that this hybrid system is more optimal solution.

7.5. Sensitivity analysis

Sensitivity analysis is defined for those parameters which are not constant, their value depends on other condition like climate change which affects wind speed and solar radiation, fuel price and market price fluctuation which affect component cost. HOMER software evaluates the output result by sensitivity analysis. Sensitivity analysis discards the impractical arrangements and arranges the feasible configuration list in order from higher to lower optimal solutions. In this case study the various sensitive variables is taken as weather condition and diesel price and cost of component used in hybrid system design.

7.6. Optimization results

Design hybrid system homer tool, optimize and simulate for each configuration and arrange the list of optimal hybrid combination with respective lowest TNPC. In the case study load demand is 110.6kWh/d. The obtained results through the software are to fulfill the required load demand at minimum cost of energy. Optimization results show that the most cost-effective solution is P/W/Bio/Batt/DG. The relative analysis of optimal configurations' presented in Table 6.

8. Particle Swarm Optimization technique (PSO)

The Particle Swarm Optimization (PSO) is a famous algorithm based on population of swarms, which is primarily initiated by Kennedy & Eberhart in 1995 [142]. Throughout the PSO, the particle has learning to wing closed to a promising region in the search space. PSO method initializes the casual location of particles and updates their particles location based on the personal and neighbor's best experience [77]. The updated value of location depends on the updated values of the velocity in each generation (or iteration). The particles location in the next iteration updates by summation of previous iteration location and the current iteration velocity. Let us assume total M location of N swarm respective velocities. Consider v_k and x_k are the velocity and population location respectively for k^{th} iteration and also v_{k-1} and x_{k-1} velocity and location respectively for previous

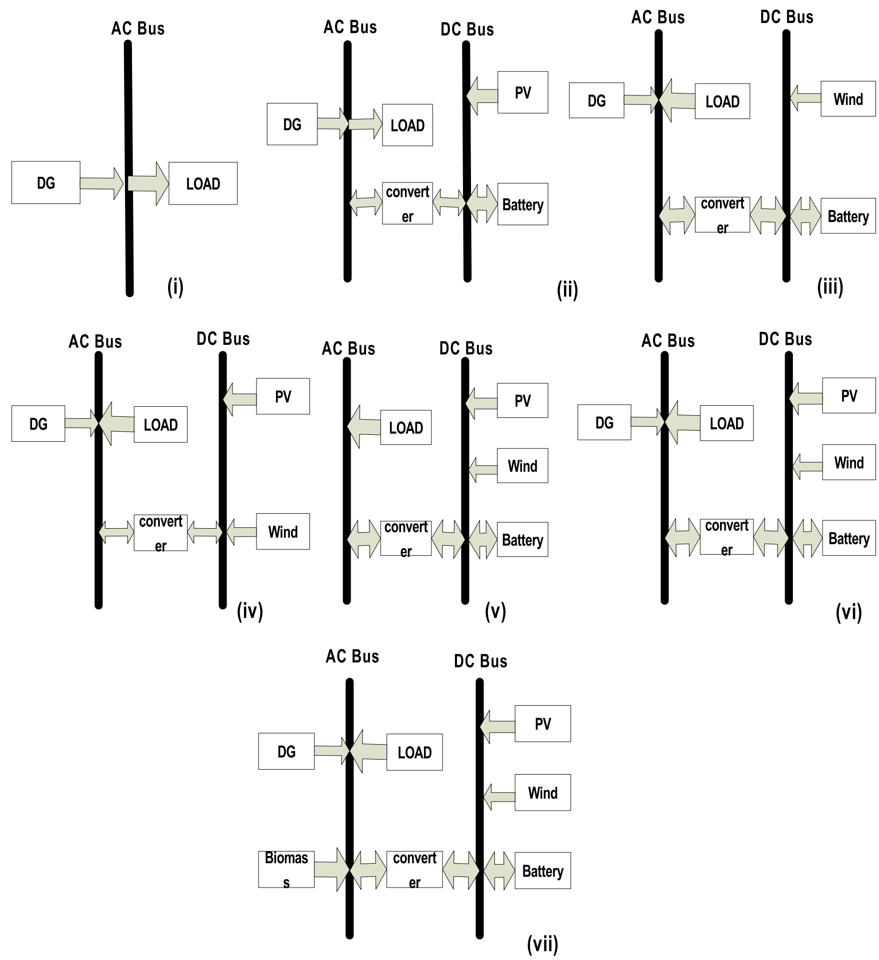

Fig. 6. Model of various combination of the HRES (i) DG (ii) PV-Battery-DG (iii) Wind-Battery-DG, (iv) PV-Wind-DG, (v) PV-Wind-Battery, (vi) PV-Wind-Battery-DG, (vii) PV-Wind-Biomass-Battery-DG.

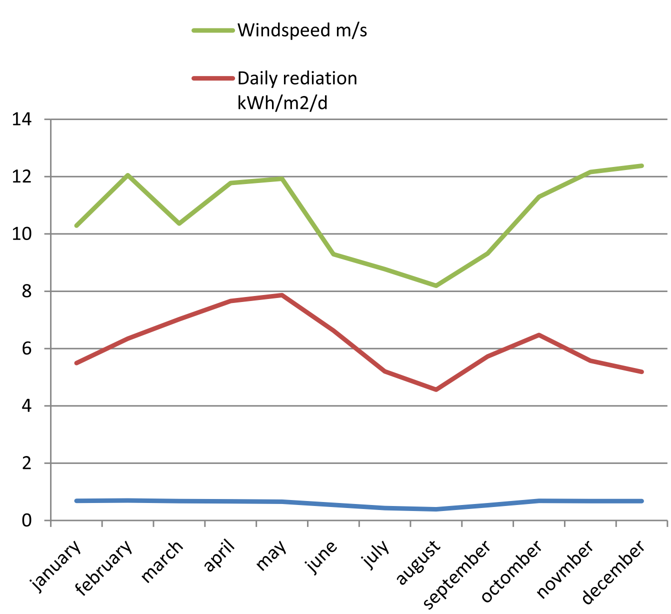

Fig. 7. Renewable energy resource data of PV-Wind.

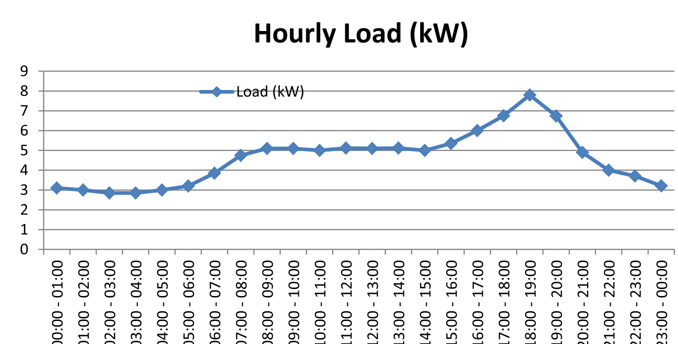

Fig. 8. Daily load demand data.

iteration. The equation for updated values of velocity and location for k^{th} iteration are given as [77]:

$$v_k = w_k * v_{k-1} + c_1 r_1 (x_{pbest,k-1} - x_{k-1}) + c_2 r_2 (x_{gbest,k-1} - x_{k-1}) \tag{9}$$

$$x_k = x_{k-1} + v_k \tag{10}$$

Where N, k, w, r_1 and r_2 and c_1 and c_2 are the no. of swarm, k^{th} iteration number, inertia weight, random numbers (between 0 and 1) and velocity coefficients respectively. The flow chart for optimal sizing of hybrid system using PSO is given in Fig. 9.

9. Comparative results of homer and PSO

The comparative results analysis of PV-wind-battery-DG-biomass hybrid system by using HOMER and PSO is shown in Table 6. The total emissions of the hybrid system including with PV-wind-battery-DG-biomass is 13489.22 kg/yr using HOMER and using PSO is 12436.68 kg/yr, which shows PSO gives 1052.54 kg/yr lesser emissions than HOMER. The renewable fraction of the hybrid system including with PV-wind-battery-DG-biomass is 73.2 using HOMER,

Table 5
Input parameters used hybrid system.

S.N	Items Cost ($)			Other parameters	Life span
1	Wind turbine(1 kW)			Hub height: 30 m Rotor diameter 1.75 m	20 year
	Initial:3200	Replacement: 3000	O & M :80		
2	PV(120W)			Derating factor:80%	20 year
	Initial:550	Replacement:550	O & M :02	Ground reflectance:20%	
3	Inverter(10 kW)			Efficiency: 90%	15year
	Initial:6666	Replacement:6666	O & M :00		
4	Battery(3kWh)			capacity:240 Ah	3550 h
	Initial:250	Replacement:250	O & M :10	voltage:12V	
5	Diesel Generator(10 kW)			Minimum load ratio: 30	15,000 h
	Initial:5500	Replacement:5500	O & M :0.2		
6	Biomass (Gasifier-Engine-Generator Unit 10kw)				
	Initial:5000	Replacement:4500	O & M: 0.03	Lower Heating value:5.5	15,000 h

while using PSO is 78.30 respectively, which indicates that the PSO gives a higher renewable fraction. The maximum renewable penetration of the hybrid system including with PV-wind-battery-DG-biomass is 965.5 using HOMER and using PSO is 926.33 respectively, which demonstrates that PSO gives superior results as evaluate to HOMER.

TNPC of PV-wind-battery-DG-biomass HRES is 179,326.20 $ using

Table 6
Relative analysis of the different design of HRES.

	Homer Results								PSO Results	
S.n	Description	DG	P/Batt/ DG	W/Batt/DG	P/W/DG	P/W/Batt	P/W/Batt/DG	P/W/Boi/DG/ Batt	P/W/Batt/DG	P/W/Boi/DG/ Batt
	Optimal Confriguration	DG	20PV +40Battery	15WT +30Battery	10PV+20WT	40PV+20WT +80Battery	10PV+8WT +10Battery	10PV+6WT +3Bio. +10Battery	10PV+7WT +10Battery	11PV+5WT +2Bio. +10Battery
1	Emission Kg/yr (CO+CO_2+NO_2+SO_2+ Unburned Hydrocarbons + Particulate Matter)									
	Total emission	63881.15	20416.76	26968.1	30159.80	–	15712.31	13489.22	15167.34	12436.68
2	Electricity generation									
	surplus power Kwh/y	5471.00	1471.9	6635.00	40,631.0	73,627.0	7051.10	4833.1	–	–
	Unmet Electric Load Kwh/y	–	9.3	00.00	7.2	16.1	8.5	10.4	–	–
	Capacity Shortage Kwh/y	–	27.4	00.00	40.3	24.4	37.6	39.1	–	–
	Renewable Fraction	–	58.4	54.	46.8	100	65.20	73.2	66.02	78.30
	Max. Renew. Penetration	–	1139.4	1785.90	2381.2	3529.2	1132.00	965.5	1098.00	926.33
3	Cost									
	Total net peresent cost $	284,505.80	189,839.4	215,419.2	286,885.2	344,664.1	182,318.1	179,326.20	179876.64	170,657.59
	Levelized cost $	0.5452	0.4094	0.4128	0.5498	0.6607	0.3638	0.3237	0.3278	0.2899
	Operating cost $	21,369.59	9340.20	11,216.63	12,806.21	5208.41	7118.86	5871.13	67,74.25	4566.38
4	Fule									
	Overall diesel consumed L	23,622.00	3933.00	9972.00	11,152	–	7180.00	5016	–	–
	diesel per L/d	64.73	10.8	27.53	30.6	–	19.7	13.7	–	–
	Avg diesel L/hour	2.7	0.449	1.14	1.27	–	0.820	0.573	–	–
5	Battry									
	Energy Input Kwh/ yr	–	18,530.00	8548.90	–	12,954.00	6302.20	5705.20	–	–
	Energy Out Kwh/yr	–	15,838.00	7267.50	–	11,011.00	5366.10	4861.30	–	–
	Storage Depletion Kwh/yr	–	94.07	1.02	–	0.01	10	12.87	–	–
	Losses Kwh/yr	–	2598.70	1280.40	–	1943.10	926.13	831.05	–	–
	Annual Throughput Kwh/ yr	–	17,178.00	7882.70	–	11,943.00	5820.30	5272.80	–	–
	estimated Life yr	–	8.27	13.51	–	18	14.96	18	–	–
6	Efficiency									
	signify electrical η %	19.72	20.43	18.93	19.58	–	19.87	21.88	21.09	22.97
7	Componants									
	PV	n	y	n	y	y	y	y	y	y
	Wind turbine	n	n	y	y	y	y	y	y	y
	DG	y	y	y	y	n	y	y	y	y
	Battery	n	y	y	n	y	y	y	y	y
	inverter	n	y	y	y	y	y	y	y	y
	Biomass	n	n	n	n	n	n	y	y	y

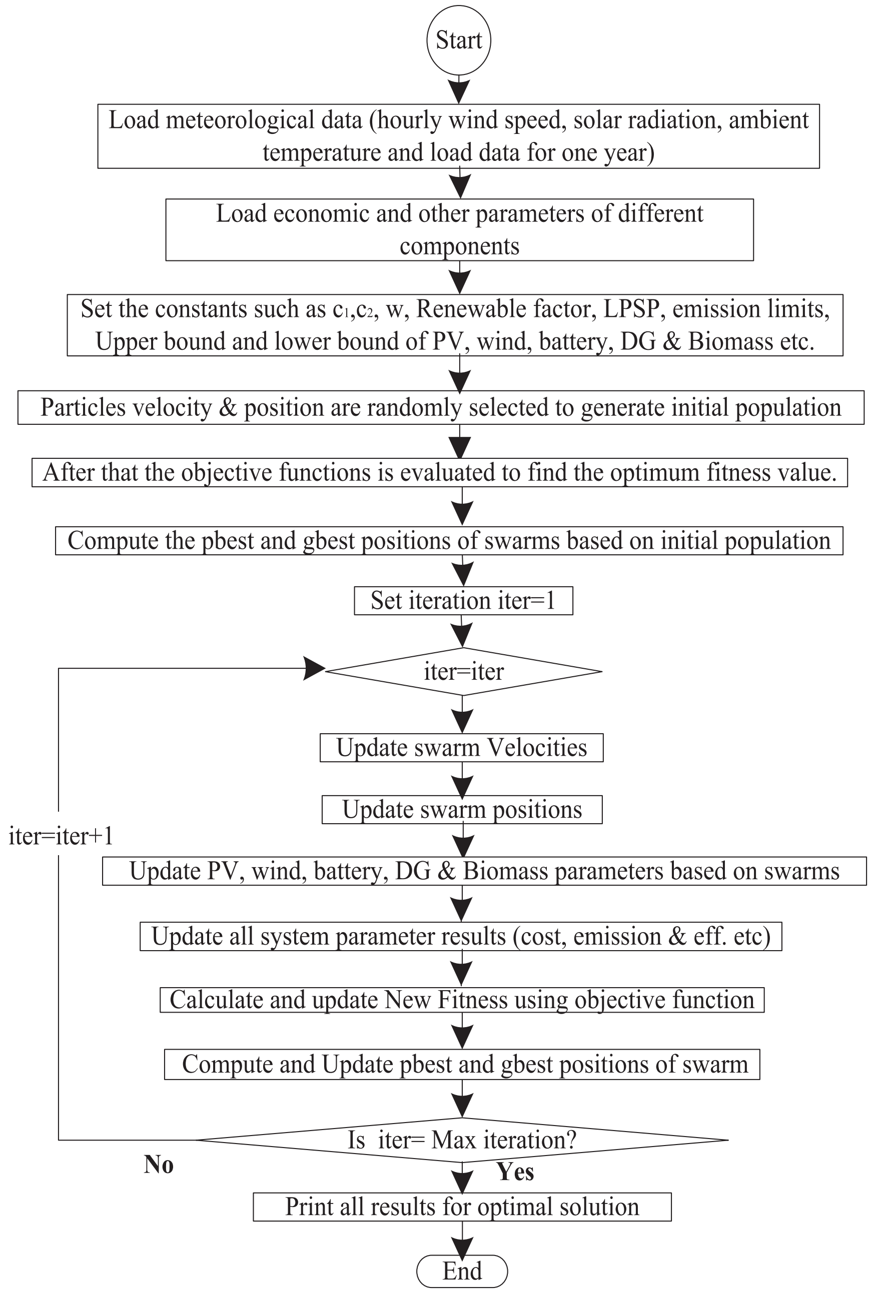

Fig. 9. Flow chart for optimal sizing of hybrid system using PSO.

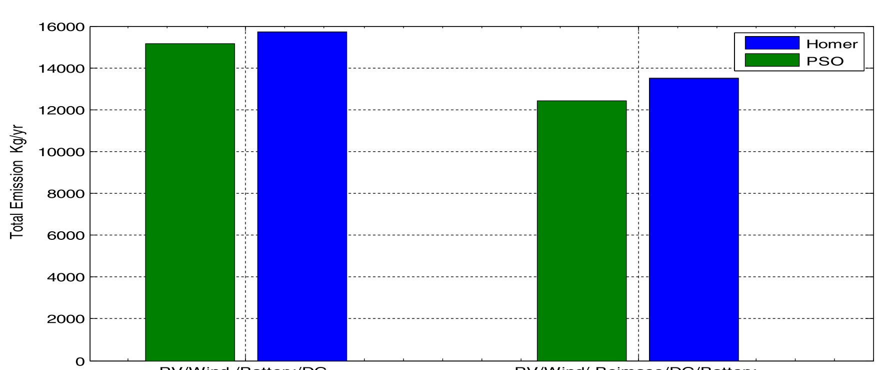

Fig. 10. Comparative emission results of hybrid system.

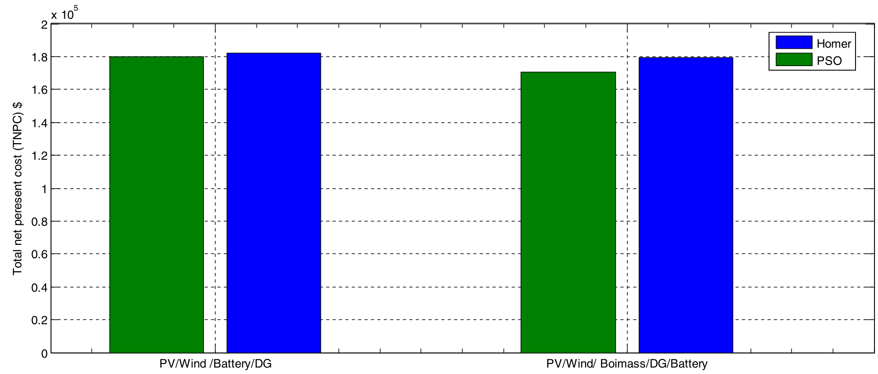

Fig. 11. Comparison for total net present cost of hybrid system.

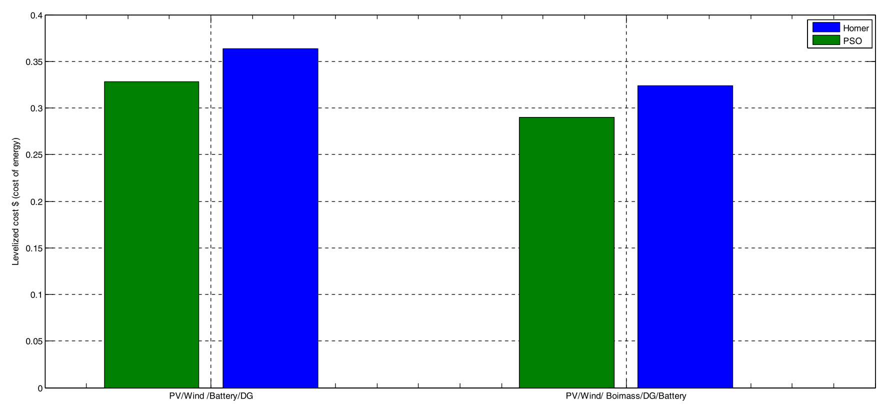

Fig. 12. Comparison Levelized cost (cost of energy) of energy of hybrid system.

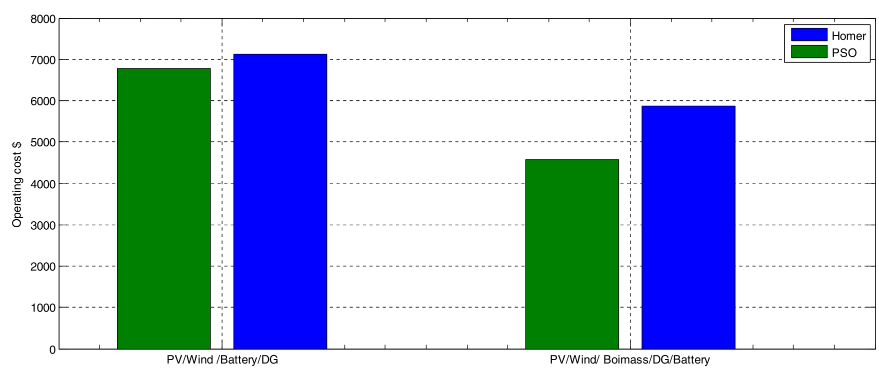

Fig. 13. Comparison operating cost of energy of hybrid system.

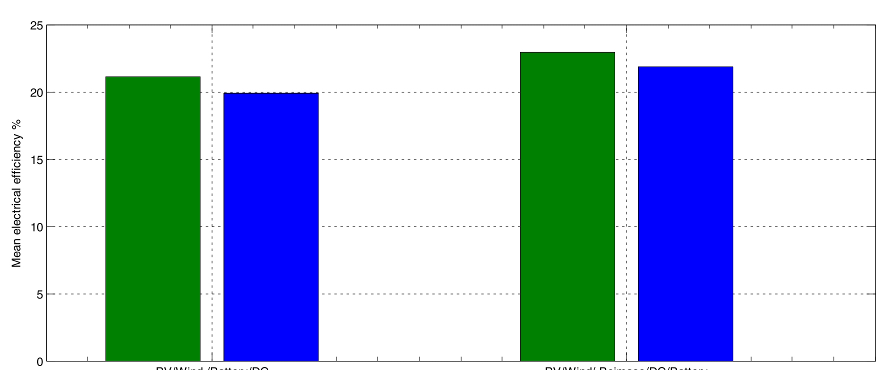

Fig. 14. Comparison mean electrical efficiency of hybrid system.

HOMER and using PSO is 170,657.59 $, which shows that TNPC is less in case of PSO. The levelized cost (COE) of the hybrid system including with PV-wind-battery-DG & biomass is 0.3237 $ with HOMER and with PSO is 0.2899 $, which reveals that levelized cost is less using PSO. The operating cost of the hybrid system including with PV-wind-battery-DG & biomass is 5871.13 $ using HOMER, while using PSO

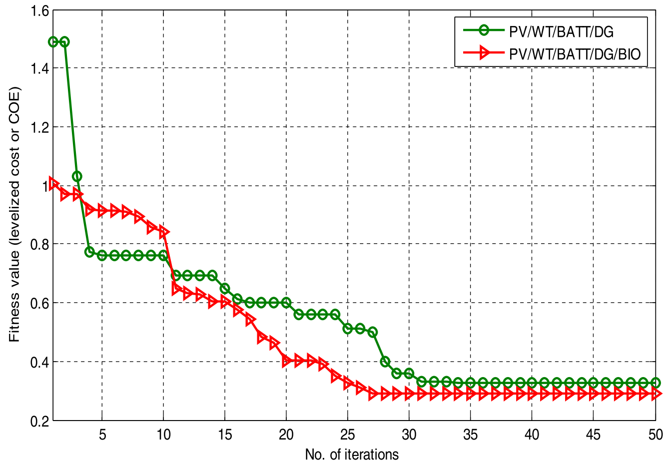

Fig. 15. Fitness convergence using PSO for different hybrid systems.

Table 7
Comparison of existing and proposed methodology for HES.

Parameters	Existing methodology (Ref. [149])	Proposed Methodology
Levelized cost $ (COE)	0.32 0.35 1.87	0.2899

are 4566.38 $, which shows that operating cost by PSO is smaller than HOMER. The mean electrical efficiency of the hybrid system including with PV-wind-battery-DG & biomass is 21.88% using HOMER, while using PSO is 22.97%, which indicates that electrical efficiency is higher with PSO. The above comparative analysis reveals that the PSO give better results than HOMER with respect to all presented parameters, which is shown in Figs. 10–14. The Fig. 15 demonstrates the convergence of objective fitness function with respect to iterations. Similarly, the comparative analysis of another case like PV-wind-battery-DG is presented by considering various parameters.

10. Implication and opportunity

In above all sections discussion about various techniques, sizing options and modeling technique controlling strategies. On the basis of literature work it is observed that some modification and future implementations are needed in field of HRES. Such as in the hybrid system the work of the converter is to convert the power from ac to dc or dc to ac but in this process few of power losses accurse. So the efficient operation of HRES it is necessary to eliminate the losses trough the converter. Battery operation also affected due to random charge and discharge process due to this the maintenance cost of the battery is increased and also the life of the battery also reduce which directly enhance the capital cost of the hybrid system. An effective control strategy is needed to proper transformation of essential information which maintained the system performance of the hybrid system. Another action is grid support system, it is essential for hybrid system optimal operation to connect grid because hybrid system is dependent on weather conditions which is badly affect system reliability and insufficient power generation to fulfill the required load demand. The component cost of renewable system is very high due to these reasons cost of energy is increased so that there is need to reduce the manufacturing cost of the components. Government support is needed for increasing the utilization of HRES, it is essential to give subsidy on renewable energy goods from central and the state government. Load demand also affects the HRES performance because if the load and supply deviation is increased, the whole HRES is falling down. The stability of HRES is depending on the Clement condition so it is necessary to transient analysis of the renewable energy sources.

11. Conclusion

The analysis of numerous hybrid systems design using different technology indicates that the hybrid renewable energy sources have enough capability to improve the system performances such as cost of energy, reliability and to overcome the problem of LPSP, pollutant emissions, mismatch of demand and LLP etc. In review paper also discussed various configurations of PV, wind sources and technical, economic parameters effect on hybrid system performance. The system controllers are providing the monitoring of hybrid system and continue the necessity of demand even as observance of HRES output voltage as well as frequency. The optimal HRES has following merits such as less emission, environment-friendly, meet to load demand, improvement in public health, provide employment, stable in addition to reduced COE, dependable and flexible hybrid combination etc.

A case study of various stand-alone HRES arrangement for isolated areas in India by using HOMER software tool and the comparative analysis of existing and proposed methodology is also presented which shows the superiority of proposed methodology using PSO as given in Table 7. The proposed methodology estimates best feasible HRES configuration is P/W/Bio/Batt/DG regarding the TNPC, emission along with COE. The comparative result analysis of case study using HOMER and PSO are presented for two best combinations of hybrid combination presented in Table 6. Comparative analysis obtained P/W/Bio/Batt/DG HRES is feasible combination concerning COE is 0.2899$ and emission is 12,436 kg/year amongst various hybrid system configurations using PSO.

References

[1] The Economic Times, 26 Oct; 2009.
[2] Nayar CV, Thomas FP, Phillips SJ, James WL. Design consideration for appropriate wind energy system in developing countries. Renew Energy 1991;1(5):713–22.
[3] Bellarmine TG, Joe U. Wind energy for 1990s and beyond. Energy Convers Manag 1996;37(12):1741–52.
[4] Nayar CV, Phillips SJ, James WL, Pryor TL, Remmer D. Novel wind/diesel/battery hybrid energy system. Sol Energy 1993;51(1):65–78.
[5] Bogdan S, Borowy , Salameh Ziyad M. Methodology for optimally sizing the combination of battery Bank and PV array in a wind/PV hybrid system. IEEE Trans Energy Convers 1996;11(2):367–75.
[6] Bagul AD, Salameh Ziyad M. Sizing of stand alone hybrid wind- PV system using three events probability density approximation. Sol Energy 1996;56(4):323–35.
[7] Beyer Hans Georg, Langer Christian. A method for identification of configurations of PV/wind hybrid systems for the reliable supply of small loads. Sol Energy 1996;57(5):381–91.
[8] Seeling-Hochmuth GC. A combined optimization concept for the design and operation strategy of hybrid-PV energy systems. Sol Energy 1997;61(2):77–87.
[9] Erhard K, Dieter M. Sewage plant powered by combination of photovoltaic, wind and bio-gas on the island of Fehmarl, Germany. Renew Energy 1991;1(5/6):745–8.
[10] Diaf S, Notton G, Belhamel M, Haddadi M, Louche A. Design and techno-economical optimization for hybrid PV/wind system under various meteorological conditions. Appl Energy 2008;85:968–87.
[11] Hybrid2: available online at ⟨http://www.ceere.org/rerl/projects/software/hybrid2/index⟩.
[12] Barley CD. Optimal Control of Remote Hybrid Power System, Part I: Simplified Model, in the Proceedings of Wind Power 95,Wasington DC; 1995.
[13] PVSYST 4.35 is available online a; 2008. ⟨www.pvsyst.com⟩ for further information. viewed as of.
[14] Planning and installing PV system: A guide for installers, Architects and Engineers, Published by James & James Ltd, USA in, ISBN: 2005: 1-84407-131-6, 2005, pp. 18–24.
[15] Schaffrin C. SolSim and Hybrid Designer: Self Optimizing Software Tool for Simulation of Solar Hybrid Applications, in Proceedings of EuroSun'98, Portooz; September 1998.
[16] Tiba C, de EM, Barbosa S. Software's for designating, simulating or providing diagnosis of photovoltaic water-pumping systems. Renew Energy 2002;25(1):101–13.
[17] Pryor T, Gray E, Cheok K. How good are RAPS Simulation Program?-A comparison of RAPSIM & HYBRID2, World Renewable Energy Congress, Feb; 1999.
[18] Manninen M, Lund PD, Vikkula A, PHOTO- A Computer Simulation Program for Photovoltaic and Hybrid Energy Systems, Document and users guide, Helsinki University of Technology, Report TKK-F-A-670, ISBN 951 22 04657.
[19] SOME: is available online at ⟨http://www.web.co.bw/sib/somes_3_2_description.pdf⟩.
[20] HOMER:⟨https://analysis.nrel.gov/homer/includes/downloads/HOMERBrochure_English.pdf⟩.

[21] RAPSYS: is available on line ⟨www.upress.uni-kassel.de/online/frei/978-3-933146-19-9⟩.
[22] Morgan TR, Marshall RH, Brink BJ. worth, SEU-ARES- A Refined Simulation Program for Sizing and Optimization of Autonomous Hybrid Energy System, Proceedings of the annual meeting of the International Solar Energy Society, Harare; 1995.
[23] Morgan TR, Marshall RH, Brinkworth BJ. ARES'–A refined simulation program for the sizing and optimization of autonomous hybrid energy systems. Sol Energy 1997;59(4–6):205–15.
[24] Ghali FadiaMA, Abd.El Aziz MM, Syam FathyA. Simulation and Analysis of Hybrid Systems Using Probabilistic Techniques, in proceedings of the Power Conversion Conference, Vol. 2, 3–6 August, Nagaoka, 1997, pp. 831 – 835.
[25] Bogdan S, Borowy , Salameh Ziyad M. Methodology for optimally sizing the combination of battery Bank and PV array in a wind/PV hybrid system. IEEE Trans Energy Convers 1996;11(2):367–75.
[26] Ali B, Yang H, Shen H, Liao X. Computer aided design of PV/wind hybrid system. Renew Energy 2003;28:1491–512.
[27] Klein SA, Beckman WA. USA, PVF-Chart User's Manual Window Version, F- Chart Software, 4406 Fox Bluff Road, Middleton, Wisc. 53562, detail information about F-Chart is available onlin; 1993. ⟨www.fchart.com⟩.
[28] SANDIA. Stand-alone photovoltaic systems: a handbook of recommended design practice'SAND87-7023, printed; 1995.
[29] Bhuiyan MMH, Asgar M Ali. Sizing and stand-alone photovoltaic power system at Dhaka. Renew Energy 2003;28:929–38.
[30] Ming J, Buping L, Zhegen C. Small scale solar PV generating system-the household electricity supply used in remote area. Renew Energy 1995;6:501–5.
[31] Protogeropulos C, Brinkworth BJ, Marshall RH. Sizing and techno-economical optimization for hybrid solar PV wind power systems with battery storage. Int J Energy Res 1997;21(6):465–79.
[32] Gavanidou ES, Bakirtzis AG. Design of a standalone system with renewable energy sources using trade-off methods. IEEE Tran Energy Convers 1993;7(1):42–8.
[33] Ofry E, Braunstein A. The loss of power supply probability as a technique for designing stand-alone solar electric photovoltaic system. IEEE Trans Power Appar Syst 1983;Vol. PAS-102(5).
[34] Abouzahr I, Ramkumar R. Loss of power supply probability of stand- alone electric conversion system: a closed form solution approach. IEEE Trans Energy Convers 1990;5(3):445–52.
[35] Klein SA, Beckman WA. Loss-of-load probability for stand-alone photovoltaic systems. Sol Energy 1987;39(6):449–512.
[36] Yang Hongxing, Wei Zhou, Chengzhi Lou. Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. Appl Energy 2009;86.2:163–9.
[37] Diaf S, Belhamel M, Haddadi M, Louche A. Technical and economical assessment of hybrid photovoltaic/wind system with battery storage in Corsica Island. Energy Policy 2008;36:743–54.
[38] Xu Daming. et al. "*Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms." Electrical and Computer Engineering, 2005. Canadian Conference on*. IEEE; 2005.
[39] Ramkumar R, Abouzahr I, Ashenayi K. A knowledge –based approach to the design of integrated renewable energy systems. IEEE Trans Energy Convers 1992;7(4).
[40] Ramkumar R, Abouzahr I, Krishnan K, Ashenayi K. Design scenarios for integrated renewable energy system. IEEE Trans Energy Convers 1995;10(4).
[41] Celik AN. Optimization and techno-economic analysis of autonomous photovoltaic-wind hybrid energy systems in comparison to single photovoltaic and wind system. Energy Convers Manag 2002.
[42] Bernal Augustin Jose L, Dufo-Lopez R, Rivas David M. Design of isolated hybrid system minimizing cost and pollution emissions. Renew Energy 2006;31:2227–44.
[43] Chedid Riad, Rahman Saifur. Unit sizing and control of hybrid wind-solar power systems. IEEE Trans Energy Convers 1997;12(1):79–85.
[44] Swift AHP, Holder MR. Design of hybrid energy systems. Proc Seven- ASME Wind Energy Symp 1988:175–81.
[45] Tomonobu Senjyu, Hayashi D, Urasaki N. Optimum configuration for renewable generating system in residence using genetic algorithm. IEEE Trans Energy Convers 2006;21(2):459–66.
[46] Rodolfo Dufo-Lopez, Bernal-Augustin Jose L. Design and control strategies of PV-diesel using genetic algorithm. Sol Energy 2005;79:33–46.
[47] Tomas Markvast. Sizing of hybrid photovoltaic-wind energy systems. Sol Energy 1997;57(4):277–81.
[48] Ramkumar R, Sudhakara Shetty P, Shenayi K. A linear programming approach to the design of integrated renewable energy system for developing countries. IEEE Trans Energy Convers 1986;1:18–24.
[49] RETScreen International, National Resources Canada, 26th April; 2009. ⟨http://www.retscreen.net/⟩.
[50] Sinha S, Chandel SS. Review of software tools for hybrid renewable energy systems. Renew Sustain Energy Rev 2014;32:192–205.
[51] Post HN, Thomas MG. Photovoltaic systems for current and future applications. Sol Energy 1988;41(5):465–73.
[52] Mahmoud M. Experience results and techno-economic feasibility of using photovoltaic generators instead of diesel motors for water pumping from rural desert wells in Jordan. IEEE Proc 1990;37(Part C, 6):391–4.
[53] Global Trends in Renewable Energy Investment; 2016. ⟨http://www.fs-unep-centre.org⟩ (Frankfurt am Main), Frankfurt School of Finance & Management gGmbH 2016.
[54] Richard NC. Development of sizing nomograms for stand-alone photovoltaic/storage systems. Sol Energy 1989;43(2):71–6.
[55] Traca A, et al. Source reliability in a combined wind–solar–hydro system. IEEE Trans Power Appar Syst 1983;102(6):1515–20.
[56] Solar - World Energy Council, ⟨https://www.worldenergy.org⟩.
[57] Shaahid SM, Elhadidy MA. Opportunities for utilization of stand-alone hybrid (photovoltaic+diesel+battery) power systems in hot climates. Renew Energy 2003;28(11):1741–53.
[58] Shaahid SM, Elhadidy MA. Prospects of autonomous/stand-alone hybrid (photovoltaic+diesel+battery) power systems in commercial applications in hot regions. Renew Energy 2004;29(2):165–77.
[59] Kalinci Yildiz, Hepbasli Arif, Dincer Ibrahim, Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options international journal of hydrogen energy, 40; 2015, 7652e 7664.
[60] Muselli M, Notton G, Poggi P, Louche A. PV–hybridpower systems sizing incorporating battery storage: an analysis via simulation calculations. Renew Energy 2000;20(1):1–7.
[61] Iniyan S, Sumathy K. An optimal renewable energy model for various end-uses. Energy 2000;25.6:563–75.
[62] Ekren Orhan, Banu Y Ekren. Size optimization of a PV/wind hybrid energy conversion system with battery storage using simulated annealing. Appl Energy 2010;87(2):592–8.
[63] Egido M, Lorenzo E. The sizing of standalone PV-systems: a review and a proposed new method. Sol Energy Mater Sol Cells 1992;26:51–69.
[64] Marwali MKC, Shahidehpour SM, Daneshdoost M. Probabilistic production costing for photovoltaic-utility systems with battery storage. IEEE Trans Energy Convers 1997;12(2):175–80.
[65] Mathew S, Pandey KP, Anil Kumar V. Analysis of wind regimes for energy estimation. Renew Energy 2002;25(3):381–99.
[66] Market Forecasts | GWEC, ⟨www.gwec.net⟩.
[67] Rehman S, Halawani TO, Mohandes M. Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia. Renew Energy 2003;28(4):573–83.
[68] Nfaoui H, Buret J, Sayigh AAM. Cost of electricity generated and fuel saving of an optimized wind-diesel electricity supply for village in Tangier-area Morocco. Renewable Energy: World Renewable Energy Congress, June 1996 at Colorado USA, 1996, p. 831–835.
[69] Elhadidy MA, Shaahid SM. Role of hybrid (wind+diesel) power systems in meeting commercial loads. Renew Energy 2004;29(1):109–18.
[70] Papadopoulos DP, Dermentzoglou JC. Economic viability analysis of planned WEC system installations for electrical power production. Renew Energy 2002;25(2):199–217.
[71] Kefayat M, Lashkar Ara A, Nabavi Niaki SA. A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources. Energy Convers Manag 2015;92:149–61.
[72] Papaefthymiou Stefanos V, Stavros A. Papathanassiou, Optimum sizing of wind-pumped-storage hybrid power stations in island systems. Renew Energy 2014;64:187–96.
[73] Li S, Wunsch DC, O'Hair E, Giesselmann MG. Comparative analysis of regression and artificial neural network models for wind turbine power curve estimation. J Sol Energy Eng 2001;123:327–32.
[74] Feijoo AE, Cidras J, Dornelas JLG. Wind speed simulation in wind farms for steady-state security assessment of electrical power systems. IEEE Trans Energy Convers 1999;14(4):1582–8.
[75] Salameh ZM, Safari I. The effect of the windmill's parameters on the capacity factor. IEEE Trans Energy Convers 1995;10(4):747–51.
[76] Chedid RB, Karaki SH, El-Chamali C. Adaptive fuzzy control for wind–diesel weak power system. IEEE Trans Energy Convers 2000;15(1):71–8.
[77] Bohre Aashish Kumar, Agnihotri Ganga, Dubey Manisha. Optimal sizing and sitting of DG with load models using soft computing techniques in practical distribution system. IET Gener Trans Distrib 2016;10(11):2606–21.
[78] Celik AN. A simplified model for estimating the monthly performance of autonomous wind energy systems with battery storage. Renew Energy 2003;28(4):561–72.
[79] Elhadidy MA, Shaahid SM. Parametric study of hybrid (wind+solar+diesel) power generating systems. Renew Energy 2000;21(2):129–39.
[80] Lujano-Rojas Juan M, Dufo-López Rodolfo, José , Bernal-Agustín L. Technical and economic effects of charge controller operation and coulombic efficiency on stand-alone hybrid power systems. Energy Convers Manag 2014;86:709–16.
[81] Olatomiwa Lanre, Mekhilef Saad, Huda a ASN, Ohunakin Olayinka S. Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. Renew Energy 2015;83:435–46.
[82] Giraud F, Salameh ZM. Steady-state performance of a grid-connected rooftop hybrid wind–photovoltaic power system with battery storage. IEEE Trans Energy Convers 2001;16(1):1–7.
[83] Carroquino a Javier, Dufo-L_opez b Rodolfo, Bernal-Agustín Jos_e L. Sizing of off-grid renewable energy systems for drip irrigation in Mediterranean crops. Renew Energy 2015;76:566e574.
[84] Upadhyay* Subho, Sharma MP. Development of hybrid energy system with cycle charging strategy using particle swarm optimization for a remote area in India. Renew Energy 2015;77:586–98.
[85] Ranaboldo Matteo, Domenech Bruno, Reyes Gustavo Alberto. Off-grid community electrification projects based on wind and solar energies: a case study in Nicaragua. Sol Energy 2015;117:268–81.
[86] Amer Motaz, Namaane A, M'Sirdi NK. Optimization of hybrid renewable energy systems (HRES) using PSO for cost reduction. Energy Procedia 2013;42:318–27.
[87] Maleki Akbar, Askarzadeh Alireza. Comparative study of artificial intelligence techniques for sizing of a hydrogen-based stand-alone photovoltaic/wind hybrid system. Int J Hydrog Energy 24 2014;39(19):9973–84.
[88] Shang Ce, Srinivasan Dipti, Reindl Thomas. An improved particle swarm optimisation algorithm applied to battery sizing for stand-alone hybrid power systems. Int J Electr Power Energy Syst 2016;74:104–17.
[89] Clarke Daniel P, Yasir M Al-Abdeli, Kothapalli Ganesh. Multi-objective optimisation of renewable hybrid energy systems with desalination. Energy 2015;88:457–68.
[90] Wang Lingfeng, Singh Chanan. Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm. IEEE Trans Energy Convers 2009;24(1):163–72.

[91] Bilal BO, Sambou V, Ndiaye PA, Kébé CMF, Ndongo . Study of the Influence of load profile variation on the Optimal sizing of a standalone hybrid PV/wind/battery/diesel system. Energy Procedia 2013;36:1265–75.
[92] Kamel Sami, Dahl Carol. The economics of hybrid power systems for sustainable desert agriculture in Egypt. Energy 2005;30(8):1271–81.
[93] Dufo-López Rodolfo, José L Bernal-Agustín, Mendoza Franklin. Mendoza design and economical analysis of hybrid PV–wind systems connected to the grid for the intermittent production of hydrogen. Energy Policy 2009;37(8):3082–95.
[94] Mohamed Mohamed A, Ali M Eltamaly, Abdulrahman I Alolah. Sizing and techno-economic analysis of stand-alone hybrid photovoltaic/wind/diesel/battery power generation systems. J Renew Sustain Energy 2015;7.6:063128.
[95] Ekren BY, Ekren O. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. Appl Energy 2009;86(9):1387–94.
[96] Hongxing, Bilala, b* BOuld, Samboua V, Kébéa CMF, Ndiayea PA, Ndongob M Methodology to Size an Optimal Stand-Alone PV/wind/diesel/battery System Minimizing the Levelized cost of Energy and the CO2 Emissions 163–169.
[97] Katsigiannis YA, Georgilakis PS, Karapidakis ES. Multiobjective genetic algorithm solution to the optimum economic and environmental performance problem of small autonomous hybrid power system with renewable. IET Renew Power Gener 2010;4(5):404–19.
[98] Sawle Y, Gupta SC. A novel system optimization of a grid independent hybrid renewable energy system for telecom base station. Int J Soft Comput, Math Control 2015;4(2):49–57.
[99] Sawle Y, Gupta SC. "Optimal sizing of photo voltaic/wind hybrid energy system for rural electrification," in Power India International Conference (PIICON), 2014 6th IEEE, pp. 1–4; 2014.
[100] Gupta1 SC, Kumar DrY, Agnihotri Dr Gayatri. Reast: renewable energy analysis and sizing tool. J Electr Syst 2011;7–2:206–24.
[101] Karakoulidis K, Mavridis K, Bandekas DV, Adoniadis P, Potolias C, Vordos N. Techno-economic analysis of a stand-alone hybrid photovoltaic-diesel–battery-fuel cell power system. Renew Energy 2011;36.8:2238–44.
[102] Dimeas AL, Hatziargyriou ND. Operation of a multiagent system for microgrid control. IEEE Trans Power Syst 2005;20(3):1447–55.
[103] Valenciaga F, Puleston PF. Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy. IEEE Trans Energy Convers 2005;20(2):398–405.
[104] Wang C, Nehrir MH. Power management of a stand-alone wind/photovoltaic/fuel–cell energy system. IEEE Trans Energy Convers 2008;23(3):957–67.
[105] Azmy AM, Erlich I. Online optimal management of PEM fuel cells using neural networks. IEEE Trans Power Deliv 2005;29:1051–8.
[106] Miettinen K. Nonlinear multiobjective optimization. Boston: Kluwer; 1998.
[107] Abido MA. Environmental/economic power dispatch using multiobjective evolutionary algorithms. IEEE Trans Power Syst 2003;18(4):1529–37.
[108] Dufo-Lopez Rodolfo, Bernal-Agustín José L. Multi-objective design of PV–wind–diesel–hydrogen–battery systems. Renew Energy 2008;33(12):2559–72.
[109] Lagorse J, Simoes M, Miraoui G, Abdellatif . A multiagent fuzzy-logic-based energy management of hybrid systems. IEEE Trans Ind Appl 2009;45(6):2123–9.
[110] Sawle Yashwant, Gupta SC, Bohre Aashish Kumar. PV-wind hybrid system: a review with case study. Cogent Eng 2016;3.1:1189305.
[111] http:/homepage.mac.com/unarte/solar_radiation.html.
[112] Zaheeruddin , Manas Munish. Analysis of design of technologies. Tariff Struct, Regul Policies Sustain Growth Smart Grid Energy Technol Policy 2015;2(Iss. 1).
[113] Ghosh B. towards modernized bio-energy – a first hand book for the stakeholders, School of Energy Studies, Jadavpur University, Kolkata, India, Technical Backup Unit on Biomass Gasifier Promotion (A Unit of Ministry of Non-Conventional Energy Sources, Govt. of India); 2004.
[114] Ramakumar R. Economic aspects of advanced energy technologies proceedings of the ieee. vol. 81. no. 3; 1993.
[115] Khalilpour , Rajab Kaveh, Vassallo Anthony. Technoeconomic parametric analysis of PV-battery systems. Renew Energy 2016;97:757–68.
[116] Borowy BS, Salameh ZM. "Dynamic response of a stand-alone wind energy conversion system with battery energy storage to a wind gust," in energy conversion. IEEE Trans on 1997;12(1):73–8.
[117] Nagata T, Sasaki H. A multi-agent approach to power system restoration. IEEE Trans Power Syst 2002;17(2):457–62.
[118] Nehrir MH, Wang C, Strunz K, Aki H, Ramakumar R, Bing J, Salameh Z. A review of hybrid renewable/alternative energy systems for electric power generation: configurations, control, and applications. IEEE Trans Sustain Energy 2011;2(4):392–403.
[119] Shadmand Mohammad B, Balog Robert S. Multi-objective optimization and design of photovoltaic-wind hybrid system for community smart DC microgrid. IEEE Trans Smart Grid 2014;5.5:2635–43.
[120] Torres-Hernandez ME. Hierarchical control of hybrid power systems Torres-Hernandez ME. Hierarchical control of hybrid power systems Ph.D. Dissertation. Mayaguez: University of Puerto Rico; 2007. Mayaguez: University of Puerto Rico; 2007.
[121] Torreglosa JP, García P, Fernández LM, Jurado F. Hierarchical energy management system for stand-alone hybrid system based on generation costs and cascade control. Energy Convers Manag 2014;77(1):514–26.
[122] Upadhyay Subho, Sharma MP. A review on configurations, control and sizing methodologies of hybrid energy systems. Renew Sustain Energy Rev 2014;38:47–63.
[123] Akbar Maleki, Mehran Ameri, Farshid Keynia. Scrutiny of multifarious particle swarm optimization for finding the optimal size of a PV/wind/battery hybrid system. Renew Energy 2015;80:552–63.
[124] Onar OC, Uzunoglu M, Alam MS. Dynamic modeling, design and simulation of a wind/fuel cell/ultra-capacitor-based hybrid power generation system. J Power Sources 2006;161:707–22.
[125] Bhave AG. Hybrid solar–wind domestic power generating system—case study Renew. Energy 1999;17(3):355–8.
[126] Arifujjaman Md, Tariq M, Iqbal E, John M, Quaicoe, Khan. Jahangir Modeling and control of a small wind turbine IEEE transaction; 2005, pp. 778–781.
[127] Notton G, Muselli M, Louche A. Autonomous hybrid photovoltaic power plant using a back-up generator: a case study in a Mediterranean island. Renew Energy 1996;7:371–91.
[128] Nag PK. Power plant engineering, 2nd ed. New Delhi: Tata McGraw-Hill Publishers Co. Ltd.; 2001.
[129] Kaldellis JK, Th G. Vlachos, Optimum sizing of an autonomous wind–diesel hybrid system for various representative wind-potential cases. Appl Energy 2005;83:113–32.
[130] Nema Pragya, Nema RK, Rangnekar Saroj. A current and future state of art development of hybrid energy system using wind and PV-solar: a review. Renew Sustain Energy Rev 2009;13(8):2096–103.
[131] Deshmukh MK, Deshmukh SS. Modeling of hybrid renewable energy systems. Renew Sustain Energy Rev 2008;12.1:235–49.
[132] Wichert B. PV-diesel hybrid energy systems for remote area power generation—a review of current practices and future developments. Sustain Renew Energy Rev 1997;1(3):209–28.
[133] Sinha Sunanda, Chandel SS. Review of recent trends in optimization techniques for solar photovoltaic–wind based hybrid energy systems. Renew Sustain Energy Rev 2015;50:755–69, [ISSN 1364-0321].
[134] Al-Ashwal AM, Moghram IS. Proportion assessment of combined PV–wind generating systems. Renew Energy 1997;10(1):43–51.
[135] Maghraby HAM, Shwehdi MH, Al-Bassam GK. Probabilistic assessment of photovoltaic (PV) generation systems. IEEE Trans Power Syst 2002;17(1):205–8.
[136] Shrestha GB, Goel L. A study on optimal sizing of stand-alone photovoltaic stations. IEEE Trans Energy Convers 1998;13(4):373–8.
[137] Celik AN. Techno-economic analysis of autonomous PV–wind hybrid systems using different sizing methods. Energy Convers Manag 2003;44(12):1951–68.
[138] Kanase-Patil AB, Saini RP, Sharma MP. Development of IREOM model based on seasonally varying load profile for hilly remote areas of Uttarakhand state in India. Energy 2011;36(9):5690–702.
[139] Dufo-Lo´pez R, Bernal-Agustin JL, Mendoza F. Design and economical analysis of hybrid PV–wind systems connected to the grid for the intermittent production of hydrogen. Energy Policy 2009;37(8):3082–95.
[140] Luna-Rubio R, Trejo-Perea M, Vargas-V_azquez D, Ríos-Moreno GJ. Optimal sizing of renewable hybrids energy systems: a review of methodologies. Sol Energy 2012;86(4):107788.
[141] Bhuiyan MMh, Ali Asgar M, Mazumder Rk, Hussain M. Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh. Renew Energy 2000;21(3):403–10.
[142] Zhou W, Lou C, Li Z, Lu L, Yang H. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. Appl Energy 2010;87:380–9.
[143] Kennedy J, Eberhart RC. Particle Swarm Optimization, Proceedings IEEE Conference Neural Networks IV. Piscataway. NJ; 1995.
[144] Hakimi SM, Moghaddas-Tafreshi SM. Optimal sizing of a stand-alone hybrid power system via particle swarm optimization for Kahnouj area in south-east of Iran. Renew Energy 2009;34(7):1855–62.
[145] Yang HX, Lu L, Burnett J. Weather data and probability analysis of hybrid photovoltaic-wind power generation systems in Hong Kong. Renew Energy 2003;28(11):1813–24.
[146] Tina G, Gagliano S. Probabilistic analysis of weather data for a hybrid solar/wind energy system. Int J Energy Res 2010;35(3):221–32.
[147] Khatod , Kumar Dheeraj, Pant Vinay, Sharma Jaydev. Analytical approach for well-being assessment of small autonomous power system with solar and wind energy sources. IEEE Trans Energy Convers 2010;25(2):535–45.
[148] Shivarama Krishna, K, Kumar K Sathish. A review on hybrid renewable energy systems. Renew Sustain Energy Rev 2015;52:907–16. http://dx.doi.org/10.1016/j.rser.2015.07.187.
[149] Mahesh Aeidapu, Sandhu Kanwarjit Singh. Hybrid wind/photovoltaic energy system developments: critical review and findings. Renew Sustain Energy Rev 2015;52:1135–47.
[150] Borhanazad Hanieh, Mekhilef Saad, Ganapathy Velappa Gounder, Modiri-Delshad Mostafa, Mirtaheri Ali. Optimization of micro-grid system using MOPSO. Renew Energy 2014;71:295–306.