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SPECIAL ISSUE: COMPUTATIONAL INTELLIGENCE AND CAPSULE NETWORKS

A novel power optimized hybrid renewable energy system using neural computing and bee algorithm

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ABSTRACT

With rapid depletion of non-renewable energy resources or the fossil fuels like coal, petroleum etc., there has been a significant shift in innovations towards exploiting and tapping of energy from renewable energy resources like sun, bio gas, wind etc., E Off late, there has been an increased research towards combined or hybrid integrated energy generation systems based on renewable resources like sun-wind, sun-biogas etc., These hybrid systems effectively address the past demerits observed in standalone systems which could provide substantial power only during specific periods and seasons. For example, solar power would be much reduced during the night time. Hence hybrid systems effectively counteract this issue as the lack of stability in one system is well compensated by the other. This research paper proposes an optimized hybrid PV-wind power generation system with optimization towards maximization of power generated from the system with the help of neural architecture and bee colony algorithm. The proposed system has been implemented and tested for a wide range of solar irradiances and wind velocities and maximum and stable power generation has been observed when compared to existing techniques.

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Renewable sources of energy; hybrid systems; optimization algorithms; bee colony algorithm; maximum power point tracking

1. Introduction

Renewable sources of energy have been gaining widespread significance in recent times especially with the increasing global awareness about rapidly depleting non-renewable sources of energy like petroleum-based products, coal, etc. Based on the statistics from the monthly energy review article provided by U.S. Energy information administration as of April 2017, it could be seen that about 37% of energy consumed in the United States is from petroleum, 29% from natural gas and 15% from coal. In countries like India, the scenario deviates with more dependency on petroleum and coal which has resulted in rapid depletion of these fossil fuels. Hence there has been an increased research in techniques and methods to tap energy from renewable sources of energy like solar power, Wind power and Biomass. The amount of power generated from each of the renewable sources of energy is depictd in Figure 1 which is a statistics provided by Eurostat. It could be clearly seen that the amount of power generated from renewable sources of energy has grown in leaps and bounds especially from 2005 and is continuing to grow on an exponential scale till date.

In recent times, more interests have been shown towards developing hybrid energy systems [1,2] which are a combination of two or more number of energy sources. A typical hybrid combination involves solar – wind power generation systems [3] which have been dealt with in this research paper. The motivation behind going for hybrid power energy systems lies in the fact that a single power generation system could not be suitable for all kinds of seasons. For example, in the Indian scenario, the months from March to June are characterized by high solar irradiation patterns at which maximum power generation from solar panels could be extracted. But, the efficiency of these systems drop down when winds bringing seasonal rains characterize the months of August down to October in certain regions of India where power generation drop from solar systems could be compensated to a certain extent by tapping energy from wind turbines. In addition to the above fact, it could be noted that winds in India are not only seasonal but also occur in random patterns whenever air current disturbances occur over the geographical area. On the other hand wind turbines could be utilized to harvest the wind energy which is expected to contribute to nearly 12% of the global power market by 2020. A multi-hybrid system for energy generation could be implemented by integrating more than two number of energy sources like wind, solar, hydro mechanism or generators. An appropriate switching system could switch between the different resources depending on the load and stability requirements of the end application user. A simple scheme of

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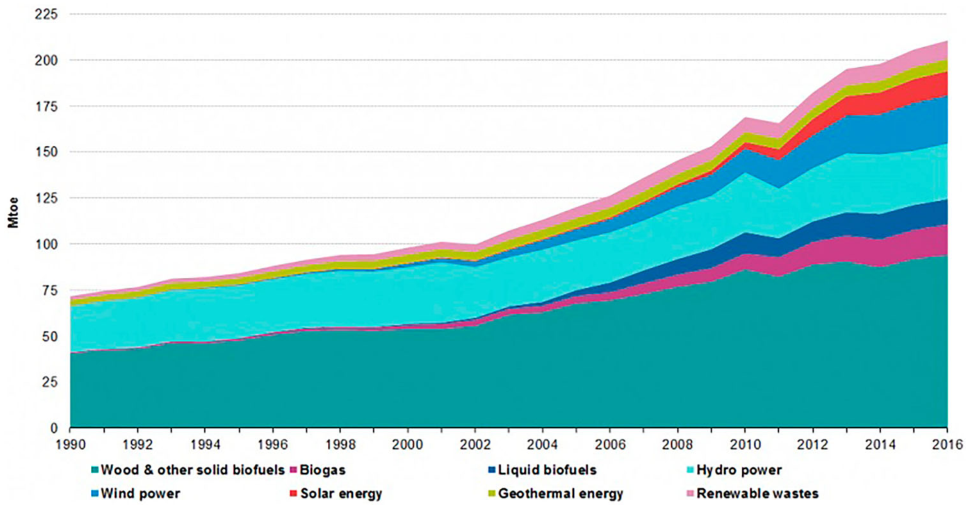

Figure 1. Illustration of share of power generation from renewable sources.

a multi-hybrid renewable energy system is depicted in Figure 2.

As depicted in the above figure, it could be seen that multiple resources have been utilized for tapping of renewable energy and appropriate switching mechanisms employed as per the load and voltage requirements. A large volume or array of storage mechanisms are required to store the harvested energy from different sources. The proposed work takes into account a double energy source mechanism namely solar panels and wind turbines and the combined experimental model have been tested and various performance metrics recorded.

2. Related work

Hybrid renewable energy systems (HRES) are the recent trends in development and implementation of techniques for tapping renewable energy resources as the limitations on one mechanism is compensated by the other mechanism. A few recent research papers regarding various issues in implementation of HRES have been reviewed and presented in this section. It could be observed from studies in the literature [4] that implementation of HRES is attributed to several factors like analysis of power reliability from the integrated system or hybrid systems and the cost of installation and maintenance of the entire system. Power reliability analysis [5] could be analysed by means of various computed parameters like loss of load hours and probability and system performance level. System performance level is a critical design parameter as it describes that degree to which the desired load cannot be met with the designed system. Other optimization parameters include sizing of the system [6–10] which bears a direct consequence on the system cost. Before actual implementation, the optimization with respect to sizing could be done with the help of tools [11] like HOMER, HYBRID2, etc. After the design, the optimization could be done with the help of algorithms based on artificial intelligence, graph cut techniques, iteration and probabilistic-based methods. Storage is yet another criterion which is quite necessary to be optimal considering the quantity of storage versus the system cost [12,13]. Literature indicates different storage mechanisms involving super capacitors [21], flywheels, hydrogen cells [14], and super conducting magnetic energy storage [15]. Comparative studies of efficiencies of different storage mechanisms found from the literature have been presented in a tabulated manner in Table 1.

Table 1. Comparative study of different storage mechanisms.

Storage type	Cost	Energy density	Efficiency
Hydrogen fuel cells	High	Variable and dependent	50%
Flywheel	Low	Low	90%
Super capacitors	High	Low	95%
SMES	High	Low	90%
Battery	Low	High	80%

It could be seen from the above comparative analysis that energy and cost have a direct trade off between them and a correct balance is essential depending on the application to which it is being put use to. In addition to design and load considerations and constraints, literature also indicates optimization techniques being employed to improve the quality of power generated from the hybrid system. A popular technique employed includes the particle swarm optimization (PSO) which is essentially a statistical search algorithm and employed to determine the amount of power that can be generated from the system under study to meet the required load demand. Another application of PSO could be found in the works of the same author [16] implemented with the objective function of minimization of cost function thus making the problem a multi-objective optimization. Other optimization algorithms found in the literature include the genetic algorithm based optimal power generation which has a multi-objective optimization problem formulation with

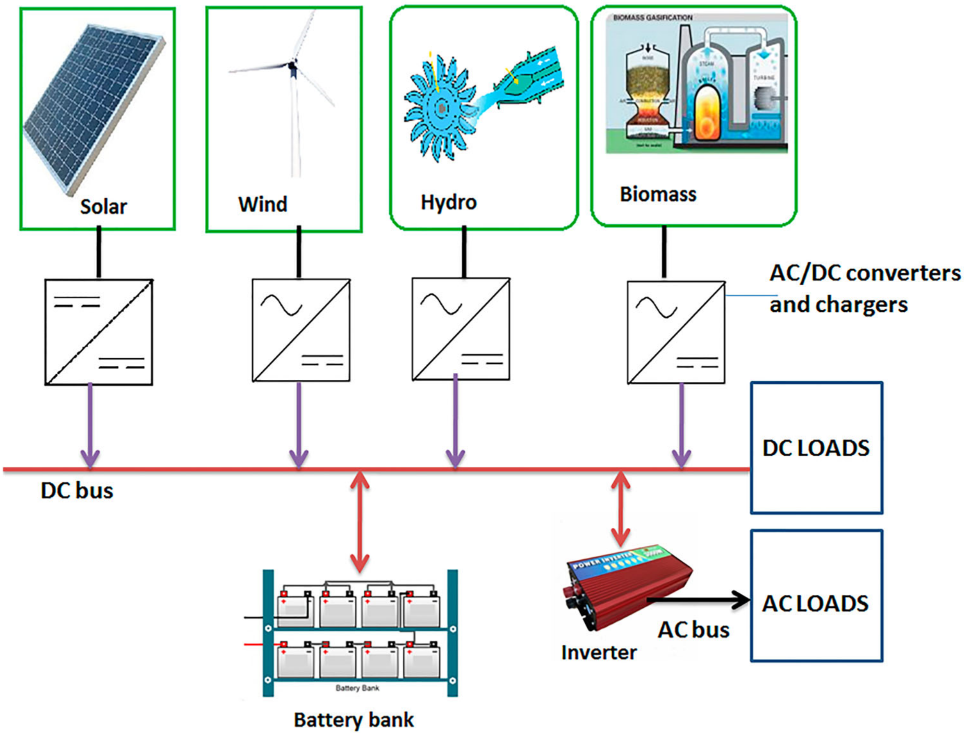

Figure 2. Illustration of a multi hybrid system for renewable energy generation.

attributes constituted by optimal selection of configurations for PV panels, power reliability, load balancing, minimization of emission and maximization of renewability. Ant colony optimization [17] algorithms have also been effectively used for optimal sizing of the given HRES system based on input parameters such as wind speed, annual load requirement, solar radiation and temperature. Experimental results by the authors confirm the superior performance of the proposed ACO by minimizing the overall cost of the HRES system. Simulated annealing [18] techniques have been investigated and applied to HRES systems for optimization in system sizing with the objective function of minimizing the system cost. A simulation model has been first designed using ARENA12 and experimented in the country of Turkey with solar irradiation and wind speed measured between two consecutive years from 2011. Experimental analysis indicates a 10% improvement in the objective function.

Literature also indicates hybrid algorithms in the form of Tabu – simulated annealing [19] algorithms for optimal sizing of standalone photovoltaic systems. Both the algorithms are meta-heuristic in nature and their application yields a short computation time for convergence. Evolutionary algorithm [20] have not only been found to be applied on design constraints like sizing, power quality but also on efficient switching techniques and tuning of PI controllers used in the maximum power point tracking systems [15]. Literature also classifies the implementations into offline system and on grid HRES systems [21]. Based on the above findings from the literature, it could be seen that an efficient HRES system relies on an efficient optimization technique which could be multi-objective based with several attributes providing multiple objective parameters at the output. The proposed research work incorporates an artificial bee colony and neural network hybrid algorithm which is found to show superior performances when implemented in standalone system. The proposed method with the hybrid algorithm is elaborated in the next section followed by the experimental results and discussion.

3. Proposed work

A simple illustration of the proposed hybrid scheme is shown in Figure 3 depicting dual input energy systems composed of wind and solar panels.

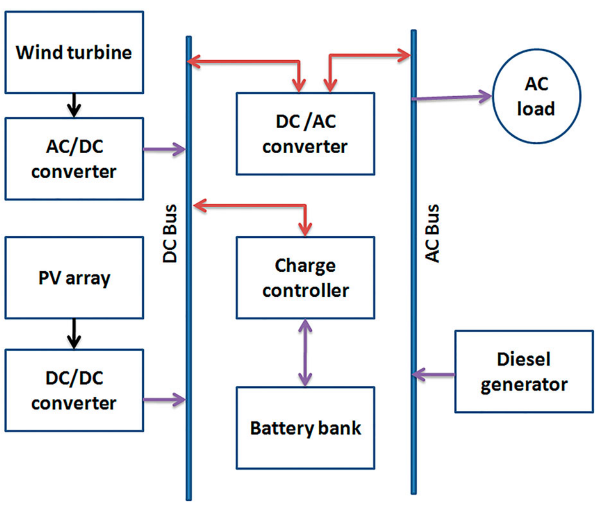

Figure 3. Illustration of proposed hybrid model.

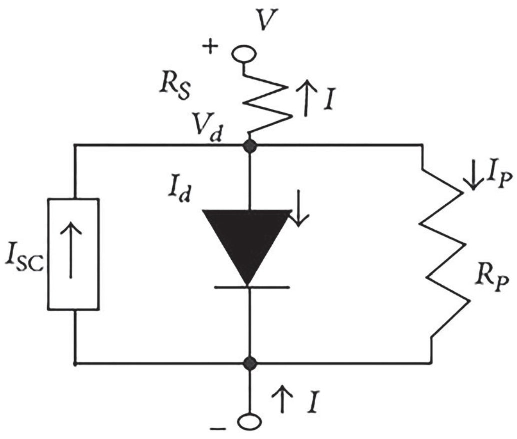

Figure 4. Equivalent circuit of single PV cell.

The proposed model utilizes a battery bank for energy storage. Before formulating the hybrid algorithm, it is essential to frame the voltage and current equations from PV models and Wind turbines.

3.1. Mathematical model of PV panel

Considering a clear and sunny day, the total solar irradiation striking the panel could be written as

$$\mathrm{IRD} = D_N e^{-km}[[cos\beta\cos(\varphi_s - \varphi_c)]sin\theta - sin\beta cos\theta + S_{DF}\left(\frac{1+cos\theta}{1}\right) + r\left(sin\beta + S_{DF}\left(\frac{1-cos\theta}{2}\right)\right)] \quad (1)$$

where IRD is the total irradiation striking the panel, D_N is the day number, φ_s is the azimuth angle of solar incidence, φ_c denotes the PV panel azimuth angle, r is the reflection factor, θ indicating the PV panel tilt angle, β denoting the altitude angle and S_{DF} indicating the sky diffusion factor. A single PV cell could be modelled as shown in Figure 4 from which the voltage and current equations could be formulated.

From Figure 4 the short circuit current

$$I_{SC} = I + I_d + I_p \quad (2)$$

Therefore,

$$I = I_{SC} - I_0\left\{\exp\left[\frac{q(V+\mathrm{IR})}{nk_bT_c}\right] - 1\right\} - \left(\frac{V+\mathrm{IR}}{R_p}\right) \quad (3)$$

The dependence of short circuit current on solar irradiation and temperature could be modelled as

$$I_{SC} = I_{SC-c} + K(T_{cell} - T_{ref}) * \mathrm{IRD} \quad (4)$$

Photocurrent equation of PV module in terms of irradiance and temperature is given by

$$I_{ph} = I_{sc} + K_i(T - T_{ref})\beta/1000 \quad (5)$$

and the reverse saturation current is given as

$$I_{RS} = \frac{I_{SC}}{\exp\left[\frac{qV}{N_s kAT}\right] - 1} \quad (6)$$

3.2. Mathematical model of wind turbine

If A is the surface area of the turbine under consideration, v the wind velocity, ρ the air density and C_p the power coefficient, the available power is computed as

$$P = \frac{1}{2}\rho C_p A v^3 \quad (7)$$

The double-fed induction generator is governed by the following model equations:

$$\begin{aligned}
V_{ds} &= R_s I_{ds} + \frac{d}{dt}\varphi_{ds} - \theta_s\varphi_{qs}; \quad \varphi_{ds} = L_s I_{ds} + MI_{dr}\\
V_{qs} &= R_s I_{qs} + \frac{d}{dt}\varphi_{qs} + \theta_s\varphi_{ds}; \quad \varphi_{qs} = L_s I_{qs} + MI_{qr}\\
V_{dr} &= R_s I_{dr} + \frac{d}{dt}\varphi_{dr} - \theta_r\varphi_{qr}; \quad \varphi_{dr} = L_r I_{dr} + MI_{ds}\\
V_{qr} &= R_s I_{qr} + \frac{d}{dt}\varphi_{qr} + \theta_r\varphi_{dr}; \quad \varphi_{qr} = L_r I_{qr} + MI_{qs}
\end{aligned} \quad (8)$$

where r/s indicate rotor/stator, V/I their respective voltages and currents, L, M are the mutual inductances, θ is the electrical speed and φ is the flux. The DFIG is connected to a energy storage super capacitor which is a series RLC circuit, and is frequency, temperature, and voltage dependent in ideal cases.

3.3. Problem formulation

The proposed hybrid optimization model is formulated as

$$\min f(Z, O) \quad (9)$$

defined as the objective function subjected to the following constraints defined as

$$e_k(Z, O) = 0; \quad k - 0, 1, 2 \ldots .n \quad (10)$$

$$Z_{min} \le Z \le Z_{max} \quad (11)$$

$$O_{min} \le O \le O_{max} \quad (12)$$

3.4. Algorithm

A comprehensive flow of the working of HRES system is depicted in Figure 5 which takes into account inputs like hourly irradiation values, wind speed, temperature and generates appropriate switching control signals to charge up a battery system which is taken as the storage element in the proposed work.

Optimization in the flow process is achieved by the use of artificial bee algorithm which is a well-known statistical tool used for searching of best solution among

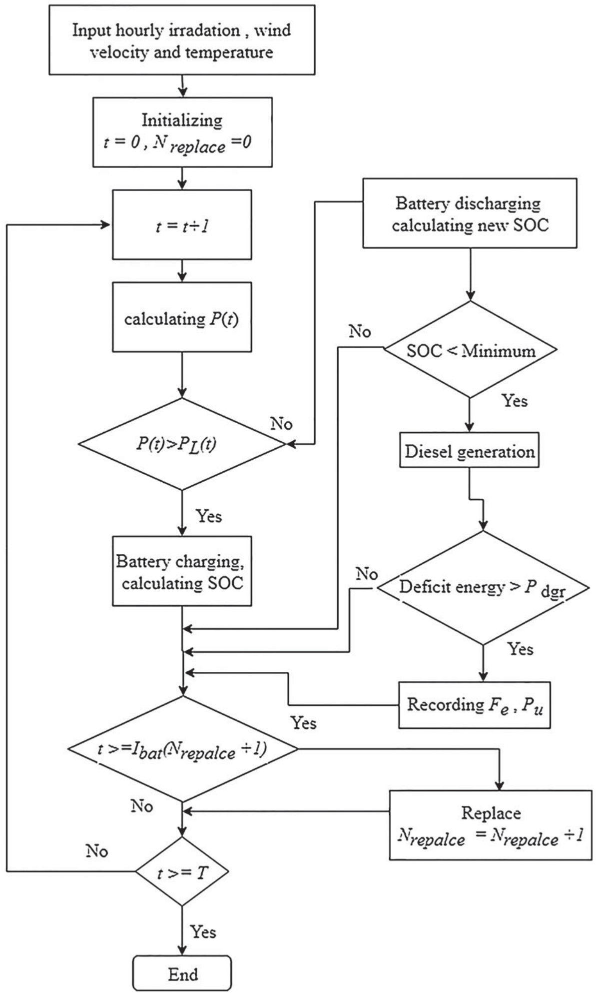

Figure 5. Flow process of proposed HRES.

a pool of available solutions. It is based on the nature inspiring phenomena of food collection by bees where the food positions are continuously updated by the bees. The primary objective of the bees is to search and find the best location of food with high quantity of nectar. Based on the above evolutionary behaviour, the search process for best attributes in the HRES system is computed through the pseudo given below.

Input: Initial Population $S \leftarrow \{x_1, x_2, x_3, x_4, \ldots..x_n\}$, *N*$_{size}$, *penalty value* δ
Output: S_Optimum
Initialize
//Initialize the food sources and compute nectar mount
It = 0;
Do while
For each employed bee
Find the food source in the neighbourhood and evaluate the fitness of new food source
Select the bee with the best fitness
Assign remaining bees to look for new food source
Evaluate fitness of bees
Update optimum ()

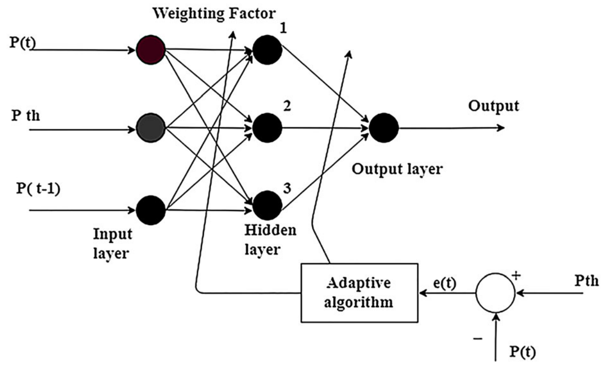

Figure 6. ANN architecture for wind turbine.

End while
Return best solution
end

Based on the above pseudo code, the proposed algorithm has been implemented on the HRES system and an extensive analysis and observations have been done with respect to voltage and current and optimized values of power generation found when compared to existing techniques like GA based.

4. Results and discussion

A three-layer feed forward network has been used in the proposed work with the output of each neuron given by

$$O_n = \varphi \sum_{j=1}^{n} U_{ij}x + B \tag{13}$$

where φ is the activation function, W is the weight, x and B are the input and bias respectively (Figure 6).

In the above architecture, the feedback path contains the adaptation algorithm where the previous state output and threshold are compared to compute the error $e(t)$. The difference is fed back into the network to update the weight factors to minimize the error. The error in the case of study arises due to variations in the wind speed which influences the voltage regulation factor. A significant error signal is generated when the voltage level drops below the steady-state level. The learning process or weight update is governed by the following equation:

$$U(t+1) = U(t) + \alpha \frac{e_p(t)x(t)}{|x(t)|^2} \tag{14}$$

The proposed HRES model has been implemented in MATLAB Simulink environment with the following specification. The specifications are divided into three categories. The specifications with respect to PV standalone system, specifications with respect to Wind turbine standalone system and the battery specifications have been tabulated as shown below (Table 2).

Table 2. Specifications of components used in the proposed HRES.

PV Panel		Wind turbine		Battery	
Power	200 W	Power	35 KW	Capacity	600 Ah
O/c voltage	30 V	Cut in speed	3 m/s	Voltage	2 V
S/c current	8.5 A	Cut out speed	25 m/s	Efficiency	80%
Vopt	24 V	Wind speed	11 m/s	Discharge rate	1%
Iopt	8 A	Rotor radius	9 m	Discharge current	75 A
PV efficiency	13.5%	Max wind speed	52 m/s		

Using the specifications in SIMULINK, the HRES system has been developed in MATLAB as shown in Figure 7.

Prior to testing, the rate of dependence of solar irradiation and temperature for a given day has been measure hour wise and plotted as shown in Figure 8.

It could be clearly seen from the above figure that the solar irradiation reaches a peak at noon consecutively causing gradual increase in temperature with maximum of up to 31.8°C with maximum solar irradiation observed to be at 915 W/m^2. The input solar irradiation and temperature followed by wind speed observed on a windy day is depicted in Figure 9. The input solar irradiation and wind speed as inputs to the HRES provide an output voltage and current a plot of which is depicted in Figure 10 for a observed solar irradiation of 900 W/m^2 and wind speed of 8.5 m/s.

A detailed analysis of how far the evolutionary algorithm powered MPPT follows the solar pattern is depicted in Figure 11.

The difference between the conventional MPPT algorithm without optimization and with optimization is clearly depicted in Figure 12.

Finally, the characteristic feature of bee algorithm which is the convergence speed is clearly depicted in Figure 13 in which it is evident that it clearly

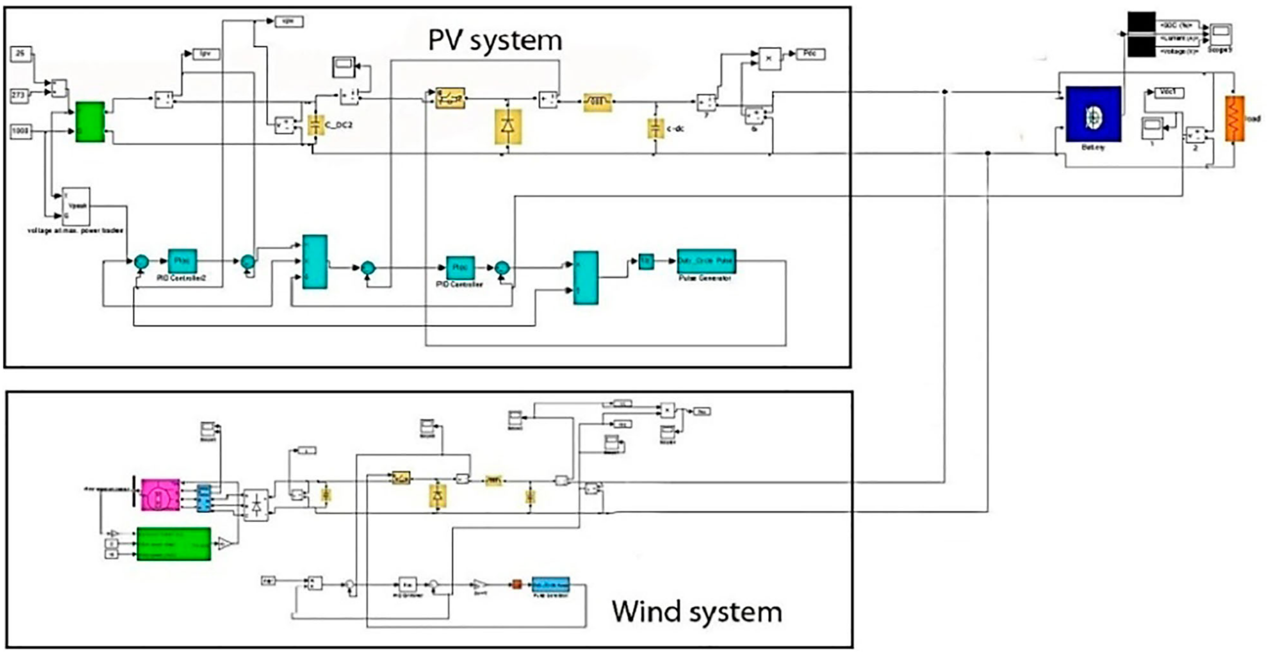

Figure 7. Proposed HRES system implemented in SIMULINK.

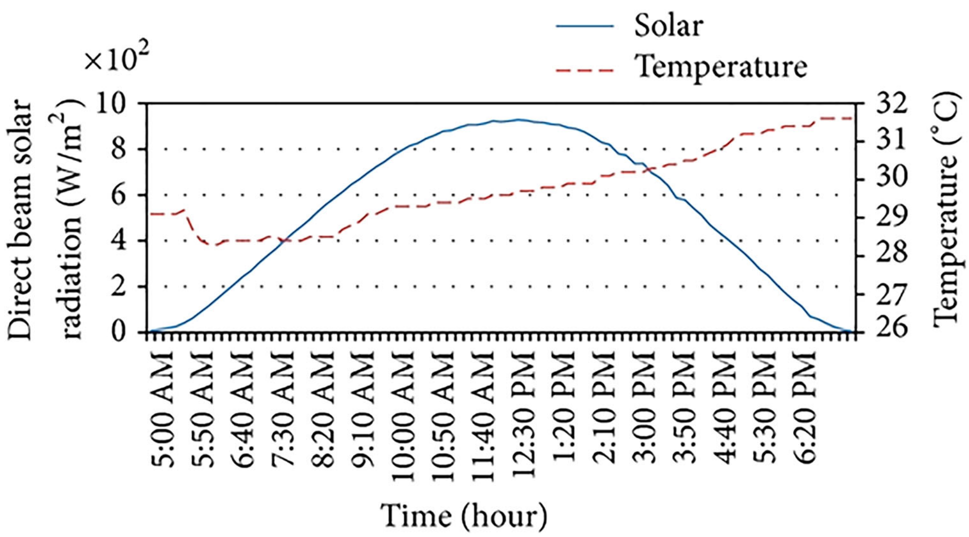

Figure 8. Solar irradiation.

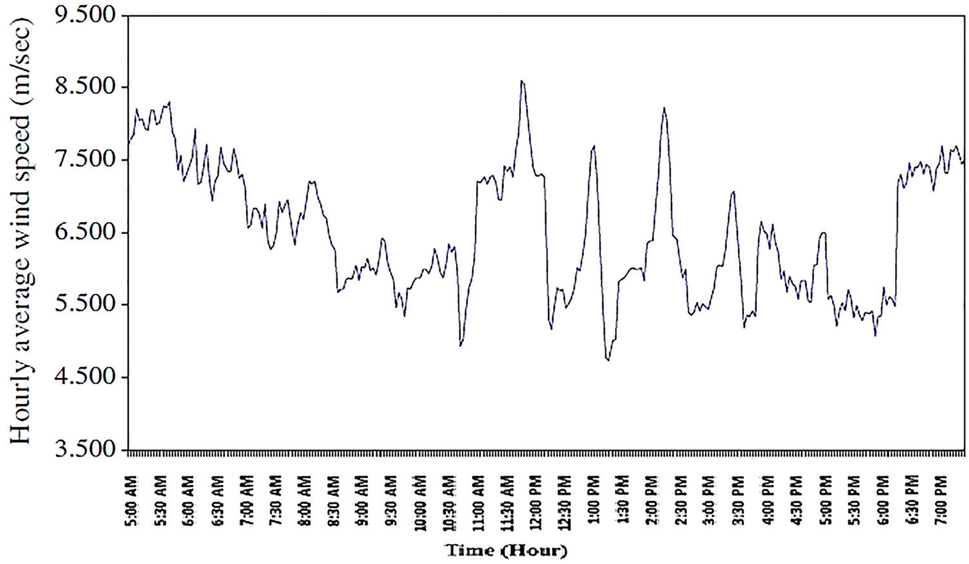

Figure 9. Wind speed measurement.

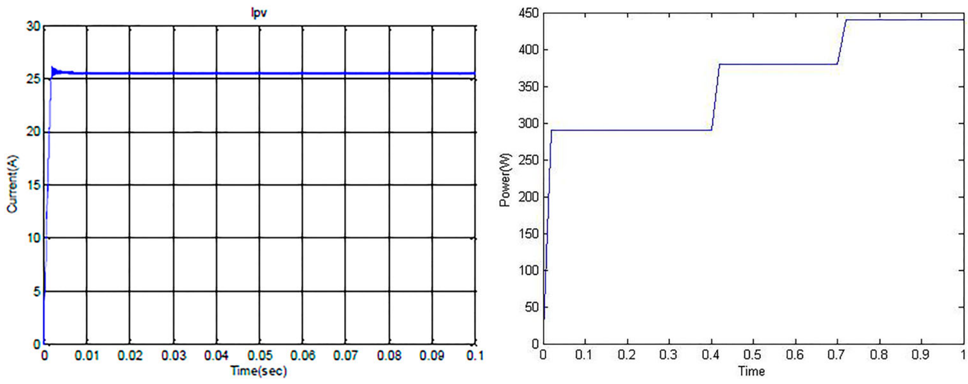

Figure 10. PV panel output current and power (900 W/m^2/25°C, 8.5 m/s).

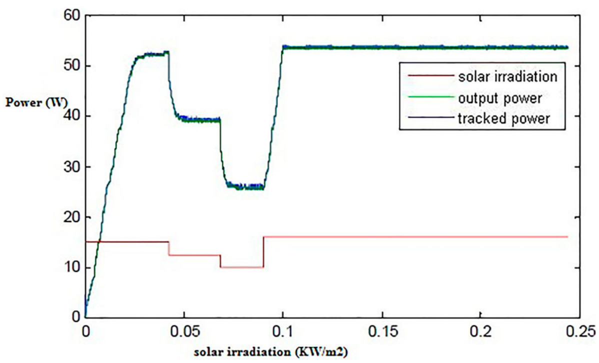

Figure 11. Performance of MPPT tracking with BEE algorithm.

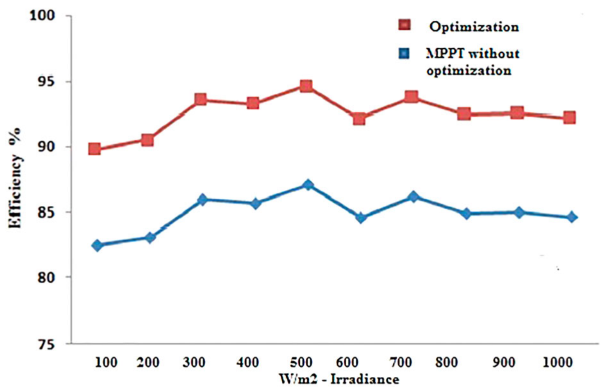

Figure 12. Comparative analyses with and without optimization.

outperforms PSO and Genetic algorithms achieving a fast convergence speed thus reaching stability.

5. Conclusion and future scope

A hybrid renewable energy system optimized with respect to power generated from two sources namely solar and wind turbine has been implemented in SIMULINK with different solar irradiation and wind velocity patterns. A neural model for training the wind turbine pattern along with a bee optimized MPPT algorithm for the solar panel provided a combined power stored in battery system. The system could be incorporated at medium cost with an average maintenance cost and results indicate a close tracking of the output power with respect to varying solar irradiation values. The system is incorporated with switching mechanism for alternating between the two sources

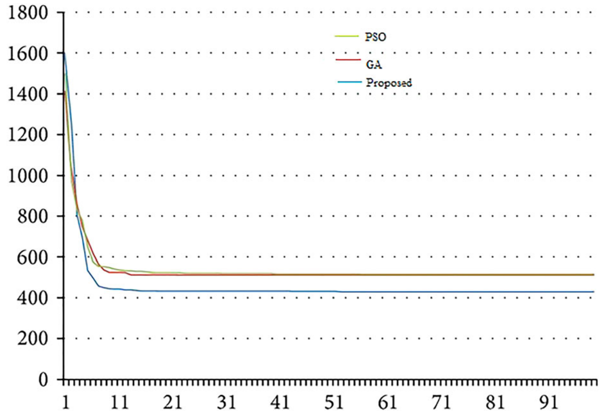

Figure 13. Convergence plot of proposed algorithm for HRES.

of power and output of boost converter is tuned to generate peak power with the help of neural model thus ensuring stability. Stability of power is ensured by the turbine system while peak power with optimum average power is ensured by the PV panel. The entire hybrid system could be expanded by including more number of energy resources which are primarily renewable in nature. Bee algorithm quickly converges ensuring fast stability. However, the system expansion could be limited by cost versus performance trade-off constraints.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Gajbhiye VK, Kanaskar AA, Jawre SS. Solar wind hybrid system – a review. Int J Res Advent Technol. 2017;5(5):112–116.

[2] Yang W, Aydin O. Wind energy – hydrogen storage hybrid power generation. Int J Energy Res. 2001;25:449–463.

[3] Mitra A, Chatterjee D. A sensitivity based approach to assess the impacts of integration of variable speed wind farms on the transient stability of power systems. Renewable Energy. 2013;60:662–671.

[4] Negi S, Mathew L. Hybrid renewable energy system: a review. Int J Electron Electr Eng. 2014;7(5):535–542.

[5] Banos R, Agugliaro M, Montoya G, et al. Optimization methods applied to renewable and sustainable energy: a review. Renewable Sustainable Energy Rev. 2011;15(4):1753–1766.

[6] Li CH, Zhu XJ, Cao GY, et al. Dynamic modelling and sizing optimization of standalone photovoltaic power systems using hybrid energy storage technology. Renewable Energy. 2009;32(3):815–826.

[7] Okinda VO, Odero NA. A review of techniques in optimal sizing of hybrid renewable energy systems. Int J Res Eng Technol. 2015;4(11):153–163.

[8] Dial S, Dial D, Belhamel M, et al. A methodology for optimal sizing of autonomous hybrid PV/wind system. Energy Policy. 2007;35(11):5708–5718.

[9] Ekren O, Ekren BY, Baris O. Break even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage – a case study. J Appl Energy. 2009;86(7):1043–1054.

[10] Arabali A, Ghofrani M, Amoli ME, et al. Stochastic performance assessment and sizing for a hybrid power system of solar/wind/energy storage. IEEE Trans Sustain Energy. 2014;5(2):363–371.

[11] Sinha S, Chandel SS. Review of software tool for hybrid renewable energy. Renewable Sustainable Energy Rev. 2014;32:192–205.

[12] Diaf S, Notton G, Belhamel M, et al. Design and technoeconomical optimization for hybrid PV/wind system under variousmeteorological conditions. Appl Energy. 2008;85(10):968–987.

[13] Bilal BO, Sambou V, Ndiaye A, et al. Optimal design of a hybrid solar wind battery system using the minimization of the annualized cost system and the minimization of loss of power supply probability. J Renewable Energy. 2010;35:2388–2390.

[14] Jain S, Agarwal V. Comparison of the performance of maximum power point tracking schemes applied to single stage grid connected photovoltaic systems. Electric Power Appl. 2007;1(5):753–762.

[15] Ebrahim MA, El Metwally KA, Bendary FM, et al. Transient stability enhancement of a wind energy distributed generation system by using fuzzy logic stabilizers. Wind Eng. 2012;36(6):687–700.

[16] Kang BK, Kim ST, Sung BC, et al. A study on optimal sizing of superconducting magnetic energy storage in distribution power system. IEEE Trans Appl Supercond. 2011;22(3):5701004–5701004.

[17] Amer M, Namaane A, M'sirdi NK. Optimization of hybrid renewable energy systems (HRES) using PSO for cost reduction. Energy Procedia. 2013;42:318–327.

[18] Suhane P, Rangnekar S, Mittal A. Optimal sizing of hybrid energy system using ant colony optimization. Int J Renewable Energy Res. 2014;4(3):683–688.

[19] Lu S, Wang L, Ke S, et al. Evaluation of measured power quality results of a wind farm connected to Taiwan power system. IEEE Trans Ind Appl. 2016;1:42–49.

[20] Yang HX, Burnett J, Lu L. Weather data and probability analysis of hybridphotovoltaic–wind power generation systems in Hong Kong. Renewable Energy. 2003;28(11):1813–1824.

[21] Liu CH, Hsu YY. Design of a self-tuning PI controller for a STATCOM using particle swarm optimization. IEEE Trans Ind Electron. 2010;57:702–715.