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A study on load sensitive power generation in hybrid renewable energy system using evolutionary algorithms based-energy management system control

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Electricity being an inevitable a non-substitutable demand of modern human society has always been an interesting domain to explore about. No doubt, in present day, a sustainable society and prospective human living can't be expected without sufficient electricity. Such significances lead industries to explore various source of energy and thus power system comes into existence to meet quality and reliability of power generation and transmission to the beneficiaries. On the contrary, exponentially rising demand in power requirements have put curves over the head of industries as well as governing agencies to enable optimal power supply for meeting the demands. To achieve this goal achieving novel and robust power generation, storage, transmission and allied control systems are of great significance. Undeniably, the exponential rise in population, industries and allied power demands has alarmed academia-industries to achieve eco-friendly and reliable sources of energy. Amongst major sustainable and eco-friendly energy sources, Renewable Energy Sources (RESs) like Wind-Turbine (WT), Photovoltaic (PV) cells, etc. have emerged as the vital solutions. Realizing cost-efficient and reliable power supply, integration of different RESs have gained immense attention globally, thus giving rise to a new power system concept named Hybrid RES (HRES) system. Amongst major HRES systems, WT-PV combination is the better option. However, non-linear nature of power generation makes overall HRES control intricate that demands robust control strategy by considering both non-linear power generation as well as dynamic load conditions. Load side variation often causes power outage and faults in the grid network. It motivates researchers to develop more efficient and reliable Energy Management System (EMS) to perform load and generation sensitive charging-discharging control for efficient EMS function. In this paper, the proposed PV-WT HRES model encompasses with variable speed controlled PMSG WT generator and EMS control units. For getting novel and robust EMS control function, the proposed model allows an Evolutionary Algorithm (EA) assisted PID controller to optimize PID gain parameters for efficient transient control. In this paper, Flower Pollination Algorithm (FPA) has been developed to be used for online PID tuning. The simulation results reveal that the proposed FPA based PID controller system showing better charging-discharging control even under dynamic load condition.

Keywords: Renewable energy sources, hybrid RES, non-linear load-generation, sensitive EMS control, metaheuristic algorithm, bi-directional converter, Li-ion battery, permanent magnet, synchronous generator, wind-turbine, PID controller.

Introduction

In recent years, the exponentially rise in electricity demand to meet residential, commercial and industrial power requirements have alarmed academia-industries to achieve more efficient source of energy while maintaining environmental sustainability. To fulfill such demands, Renewable Energy Sources (RESs) have emerged as the potential solution. Interestingly, features like eco-friendly, low cost, and sustainability make RESs the vital energy source for future. The future trends and new challenges for 2025 are briefly summarized for wind energy, solar energy, wave energy, fuel cells, and storage with batteries and hydrogen, separately[2]. The concept of Hybrid Renewable Energy Systems (HRES) is essential for today's scenario. Different types of the optimization tools and metaheuristic techniques can be used in renewable energies[7]. According to the BP statistical world review of world energy report-2018, is not satisfied demand as per today's need. It is an alarming condition that the world is on an unsustainable position[31]. The dynamic variation in load side might impose significantly huge change in energy consumption and hence can affect overall EMS. On the other hand, an inferior EMS system might lead sever damage of the infrastructure and may impose load shedding conditions. Under such circumstances developing a load sensitive EMS control model can be vital. Similarly, the non-linearity in power generation in HRES due to dependency on the local environmental conditions can make power transmission vulnerable. Thus, considering real-time dynamism in power generation, transmission and load conditions in the Hybrid-RES system containing PV cells and the Wind Turbine systems developing a highly robust and efficient EMS control system is must.

A power grid with Hybrid-RESs requires battery storage units to store power generated from the individual RESs and make it at the reach of consumers[1,12]. To ensure optimal power distribution and transmission across the grid network, Energy Management System (EMS) and allied Battery Management System (BMS) are must. As stated, to enable quality power and reliable transmission enabling efficient charging and discharging of the battery system (i.e. BMS) can play significant role[16]. Developing a robust EMS and/or BMS solution by considering dynamic generation pattern as well as load variation can be of utmost significance to ensure reliable and safe power transmission for HRES power grid network[27]. To deal with such HRES non-linearity optimizing charging and discharging control in EMS by considering both power generation condition as well as load side variation can be stated as the driving force behind this research. Though, numerous efforts have been made for EMS control in RES systems[26], majority of the existing systems use traditional controllers such as PID controllers, Fuzzy controllers for state of charging and discharging control. Prominently, classical PID controllers use static gain parameters to perform charging-discharging control which may take more time in achieving convergence, especially for transient control. On the other hand, Fuzzy controllers require huge and precise membership functions to perform control that under exceedingly high non-linearity and dynamism seems highly complicate. Heuristic algorithm such as the Genetic Algorithm (GA), Particle Swarm Optimization, Ant Colony Optimization (ACO), etc. have been applied for PID gain parameter estimation to be used in EMS control. Though, this metaheuristic algorithm assisted EMSs have augmented performance; however, the key issues like local minima and convergence makes them questionable to delivery optimal solution. It motivates authors to exploit and develop more efficient algorithms to perform enhanced PID assisted online EMS control in PV-WT based HRES systems. With this motivation, in this research paper, enhanced metaheuristic algorithm like Flower Pollination Algorithm (FPA) has been developed for PID gain parameter tuning that eventually leads more efficient and transient state of charging and discharging control. Unlike classical EMS control systems, proposed models apply ITAE error function as the objective function to perform algorithm (FPA) assisted PID gain parameter estimation that eventually perform generation and load-sensitive battery charging and discharging control. The MATLAB 2015b/SIMULINK based simulation with PV-WT HRES (photovoltaic-wind turbine Hybrid Renewable Energy System) system has revealed that proposed HRES model exhibits more swift charging-discharging control along with efficient WT speed control that as cumulative solution achieves maximum power generation while maintaining optimal power provision to the loads.

Proposed method

This section primarily discusses about the functional components of the proposed PV-WT HRES system.

Power grid design:

Considering flexibility of the implementation and abundance in nature, our proposed HRES model encompasses PV-WT HRES system where WT power generator is selected for a power generation capacity of 3 kW, while PV model with single diode design possesses power generation capacity of 1 kW. Here, we hypothesize that the difference in between the power generated by PV-WT HRES and the power demanded from load side over certain time period can be reduced by means of sizing. With this intend our proposed HRES power grid network embodies a stand-alone network with multi RESs. Here, the RESs considered functions independently and supplies power to the DC bus connected in series with PV-WT RESs. Furthermore, it can supply power to the Li-Ion batteries, as depicted in Fig. 1. As depicted in Fig. 1, considered PV-WT HRES design supplies power to the load continuously and facilitates load and generation non-linearity sensitive battery charging and discharging control.

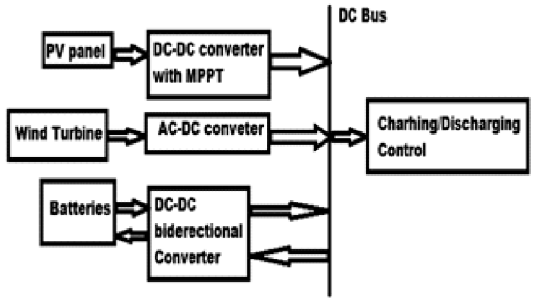

Fig. 1. PV-WT HRES power grid design.

The detailed discussion of the above stated PV-WT design model is given as follows:

(*1) Mathematical modelling of single-diode photovoltaic (PV) cell based RES system:*

Single-diode PV model contains a current source, one diode and two resistors, series and shunt resistor. Here, the photo generated current (I_p) primarily replies on the output voltage (V_p), which is mathematically derived as (1).

$$I_p = I_{sc}[1 - C_1(e^{\frac{v_p - \Delta v}{c_2 v_{oc}}} - 1) + \Delta I] \quad (1)$$

In eq. (1), the constant parameters and state the constants, which can be obtained using eqs. (2) and (3), respectively

$$C_1 = \left(1 - \frac{I_{MPP}}{I_{SC}}\right) e^{\left(\frac{-V_{MPP}}{C_2 V_{oc}}\right)} \quad (2)$$

$$C_2 = \frac{\left(\frac{V_{MPP}}{V_{oc}} - 1\right)}{\ln\left(1 - \frac{I_{MPP}}{I_{SC}}\right)} \quad (3)$$

The current and voltage gradient parameters ΔI and ΔV can be estimated using eq. (4).

$$\Delta T = T - T_{ref} \quad (4)$$

$$\Delta I = \alpha\left(\frac{L}{L_{ref}}\right)\Delta T + \left(\frac{L}{L_{ref}} - 1\right) I_{SC} \quad (5)$$

$$\Delta V = -\beta\Delta T - R_s\Delta I \quad (6)$$

As above equations, the parameters α (5) and β (6) signify the temperature coefficients of the current and voltage, respectively. The other parameters and state the current solar radiation and solar radiation reference, respectively. These radiation parameters are measured in the unit of W/m^2. In eq. (4), the temperature (T) and the reference (cell) temperature (T_{ref}) are measured in °C units. In eq. (5), the current components I_{SC} and I_{MPP} state the short-circuit current and the peak current at the Maximum Power Point (MPP) tracking condition. Meanwhile, voltage components and state the open-circuit voltage (V) and the voltage at the MPP. The other parameter in eq. (6) states the series resistance of the PV system (Ω).

(2) Wind turbine RES generator:

The mechanical output power of the wind turbine is represented by the cube law eq. (27)

$$P_{wind} = \frac{1}{2} KC_p \rho A v^3 \quad (7)$$

where ρ is air density (kg m^{-3}), C_p is the power coefficient which is a function of tip speed ratio and blade angle. This relationship is basically provided by the turbine manufacturer. A is the wind turbine rotor swept area, v is the wind speed (m/s). The tip speed ratio is given by

$$\lambda = \frac{rw_t}{v} \quad (8)$$

In (8), the variable r refers the radius of the rotor (m), while the angular speed of the generator is denoted by w_t (rad/sec). Thus, the above stated WT design, the applied WT system can be symbolically presented as Fig. 2. Here applied WT model is designed based on the three-phase Diode Bridge armored with Buck converter that effectively transforms the rectified voltage.

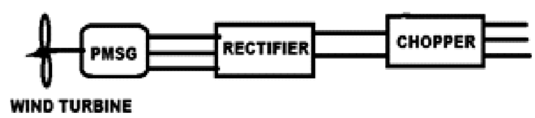

Fig. 2. Rectifier and Chopper assisted WT RES system.

In this research we have considered the work to design WT RES model. Mathematically it is estimated as (9),

$$\dot{x} = \begin{bmatrix} i_q \\ i_d \\ \dot{\omega}_e \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ g_3 \end{bmatrix} u_w$$

$$= \begin{bmatrix} -\frac{r_s}{L} i_q - \omega_e i_d + \frac{\omega_e \phi_{sr}}{L} \\ -\frac{r_s}{L} i_d - \omega_e i_q \\ \frac{P}{2J}\left(T_m - \frac{3}{2}\frac{P}{2}\phi_{sr} i_q\right) \end{bmatrix} + \begin{bmatrix} -\frac{\pi \nu_{DC} i_q}{3\sqrt{3}L\sqrt{i_q^2 + i_d^2}} \\ -\frac{\pi \nu_{DC} i_d}{3\sqrt{3}L\sqrt{i_q^2 + i_d^2}} \\ 0 \end{bmatrix} u_w \quad (9)$$

$$i_w = \frac{\pi}{2\sqrt{3}} \sqrt{i_q^2 + i_d^2 u_w} \quad (10)$$

As stated in above eq. (10), the current components i_d and i_q signify the components homopolar which is nothing else but the direct and the quadrature three-phase currents, derived from the Park transformation. In eq. (9), ω_e states the electric angular velocity while r_s and L state the resistance and inductance parameters of the winding per phase the stator, correspondingly. Similarly, P states the total numbers of poles in the PMSG generator, while J states the inertia of the rotor component. Additionally, Φ_{sr} signifies the flux generated due to the stator currents. The voltage component v_{DC} states the DC bus voltage while u_w signifies a duty cycle function (for the used converter). Mathematically it is estimated as $u_w = 1/\delta$. The current component i_w states the current generated from the turbine followed by injection to the DC bus as depicted in Fig. 1. The mechanical torque generated by the turbine is presented by the term T_m. Mathematically, torque generated can be defined as (11).

$$T_m = \frac{P_m}{\omega_e} \quad (11)$$

Energy management in HRES power systems

Considering non-linearity in PVWT HRES system, assuring optimal EMS control is highly intricate task. It becomes more mammoth in case of exceedingly non-linearity in power generation, voltage depletion and drop across network, and varying load conditions. Considering it as motivation, in this research a robust EMS control model is developed that considers both the dynamic load variation as well as generation pattern to perform charging-discharging control.

(1) EA Assisted PID controller for generation and load sensitive EMS control:

In fact, to exhibit optimal perform EMS control enabling optimal charging-discharging control is must; however, it turns out to be too complicate during exceedingly high non-linearity in load and generation. Typically, charging-discharging control functions based on system states like power generation patterns and the load variation. To achieve it, rules are applied on the basis of the instant system state requirements and thus the charging-discharging control is achieved. For example, in WT RES speed control unit applies the knowledge about motor speed and compares with the reference data which helps in executing rules for increasing or decreasing the motor power. Meanwhile, in charging-discharging control the load information can help in regulating charging discharging states and duration also called State of Charge (SOC) control. This research work applies both generation side non-linearity as well as load variation to perform charging-discharging control. We have applied PID based controller which has been further augmented with FPA assisted charging-discharging control. Primarily, here main focus on exhibiting PID gain parameter tuning to achieve better function.

Before discussing the proposed metaheuristics algorithms for PID control function, a snippet of PID controller is given as follows:

(2) Proportional-Integral-Derivative (PID) controller:

The function of a PID controller can be understood by eq. (12). In EMS control function, the following condition or gain parameter definition is applied in (13).

$$u(t) = K_p \left[e(t) + \frac{1}{T_i}\int_o^t e(t)dt + T_d \frac{e(t)}{dt} \right] \quad (12)$$

$$G_{Controller} = K_p + K_d s + \frac{K_i}{s} \quad (13)$$

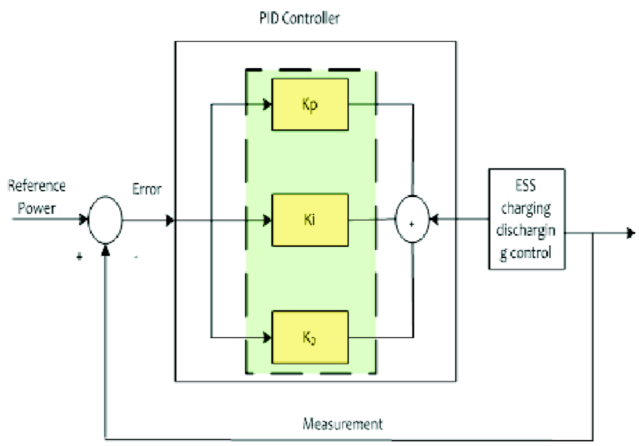

Fig. 3. PID Controller for EMS control.

In this research work emphasis is made on achieving optimal PID parameter tuning using metaheuristics algorithms. Here, flower pollination algorithm is used. The implementation strategy for the proposed algorithm assisted PID tuning is given in Fig. 4. Noticeably, for any heuristic based parameter optimization metaheuristics algorithms require achieving certain defined objective function for which error reduction (i.e. the difference between current value and the expected value) is the dominating measure. With this motivation, in this paper we have applied Integral Time Absolute Error (ITAE) function as the objective function to achieve optimal PID gain parameters.

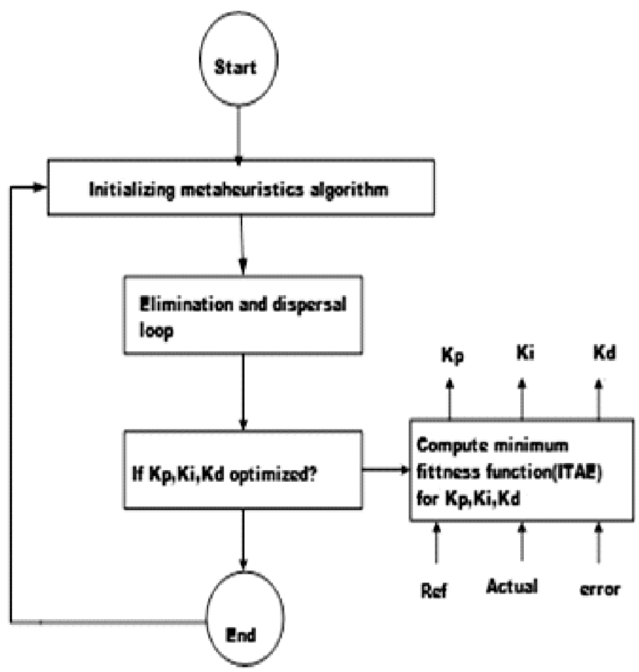

Fig. 4. Metaheuristics algorithm assisted PID parameter tunning for generation and load sensitive EMS control.

A snippet of the defined objective function is presented as follows:

(3) Integral time absolute error (ITAE):

In this proposed metaheuristic based PID tuning model, the considered optimization algorithms intend to reduce ITAE iteratively so as to achieve optimal load and generation sensitive charging and discharging function. The robustness of ITAE in avoiding long duration transient and convergence makes our proposed ITAE-PID control function more efficient to assist real-time or online EMS control. Noticeably, in this proposed EMS model the difference between the load power and the generated power is considered to estimate error.

$$\mathrm{ITAE} = \int_0^{\infty} t\,|e(t)|\,.\,dt \tag{14}$$

Once retrieving the minimum objective function, as stated in eq. (14) the gain parameters at that iteration is assigned to the PID controller to exhibit charging-discharging control.

(4) Flower Pollination Algorithm (FPA) based load and generation sensitive EMS control:

In this paper, the aforesaid rules have been incorporated to perform update of the equations to be used for optimal solution. For illustration, in pollination phase gametes of the flower pollen are selected or taken by pollinators and thus the pollen can be capable of moving over a long distance. In this manner, as stated above the rule 1 of the FPA and flower dependability can be defined through (15).

$$x_j^{t+1} = x_j^t + \gamma L(\lambda)(x_j^t - \beta) \tag{15}$$

In above mentioned eq. (15), x_j^t states the pollen j with the solution vector x_j at the step t. The other variable β signifies the current fittest solution amongst all feasible solution sets at the step or generation. Here, the variable γ controls the step size to perform best solution retrieval or movement towards the best solution. $L(\lambda)$ refers the factor matching the pollination's potency and the step size. Since, insect can move and/or travel over a long distance or search space with different distance steps this feature has been incorporated through Levy's flight pattern (16).

$$L \approx \frac{\pi\tau(\lambda)\sin(\pi\lambda/2)}{\pi} \cdot \frac{1}{s^{1+\lambda}}, (s \rangle\rangle s_0 \rangle 0) \quad (16)$$

where $\tau(\lambda)$ signifies the gamma function to be applied for big steps $s > 0$.

On the other hand, to perform local pollination by

$$x_j^{t+1} = x_j^t + u(x_m^t - x_q^t) \quad (17)$$

In (17), the variable x_m^t and x_q^t signifies pollen belonging to the different flowers of the same plant (species). Noticeably, in case pollens, x_m^t and x_q^t belong to the same species or are taken from the same population, it turns out to be a local random walk if we draw u as of a standardized sharing in [0, 1].

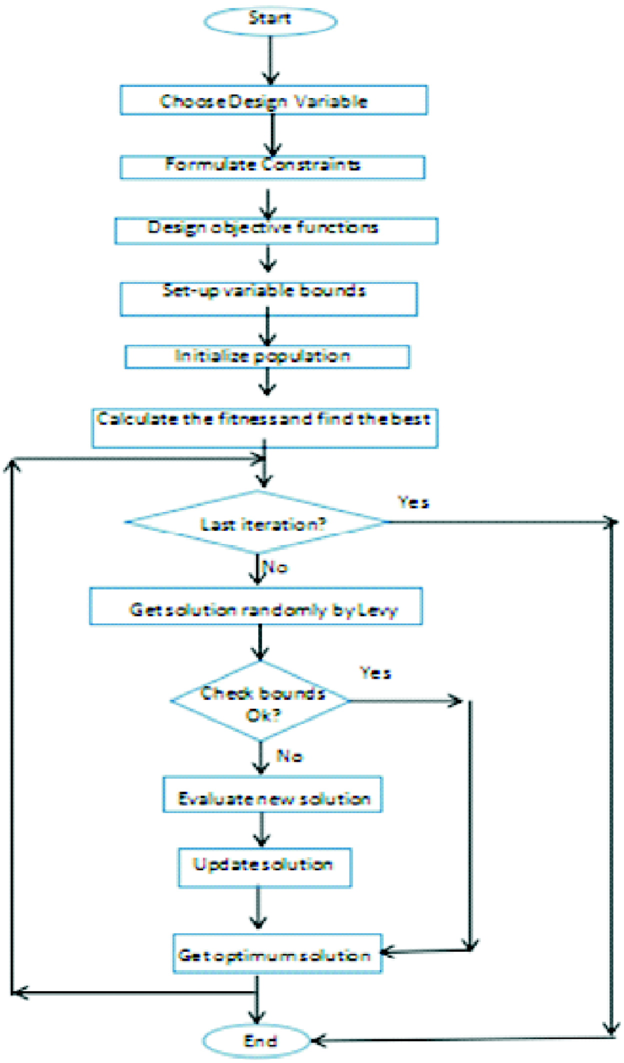

Fig. 5. Workflow of FPA algorithm.

This paper is assessed efficacy of the flower pollination algorithm for HRES design parameter estimation.

Proposed model

This research paper proposed a robust EMS control function for PV-WT HRES system where the emphasis was made on achieving load and generation sensitive EMS control under non-linear or dynamic conditions. Here, WT model with PMSG generator having maximum capacity of 3 kW, while PV system was considered for single diode design with 1kW power capacity. A snippet of the developed HRES-EMS model is given in Fig. 6.

Results and discussion

In Fig. 7, the highest power generated was observed to be 2900 Watts by WT system, whose maximum capacity is 3000 W. Fig. 8 and Fig, 9 exhibit the current and voltage generated by WT, respectively.

Fig. 10 exhibits PV-RES generated power. Fig. 11 shows non linear load side demand variations. Fig. 12 shows speed control variation during dynamic load conditions. Fig. 13 shows switching control. Fig. 14 exhibits the overall power generated by proposed PV-WT HRES system. The maximum power generated with FPA-PID based (load sensitive) EMS control was found to be 3840 Watts. In this paper hybrid generated power in Fig. 15 also shows a better result compared to[20]. The maximum value reaches at the point (x = 0.1) from 3240 Watt[20] to 3260 W. It can be observed that algorithm in paper[20] and FPA algorithm both near-similar performance however FPA gives slightly more output power under load and generation sensitive charging and discharging control. FPA-PID which emphasizes on retrieving optimal solution by exploiting search space, has depicted better and stable performance. However, superiority of these heuristics approaches for PID tuning in EMS control can't be ignored. As contribution, this research paper recognizes FPA based PID controller for EMS control in HRES system to ensure reliable and quality power delivery to the customers.

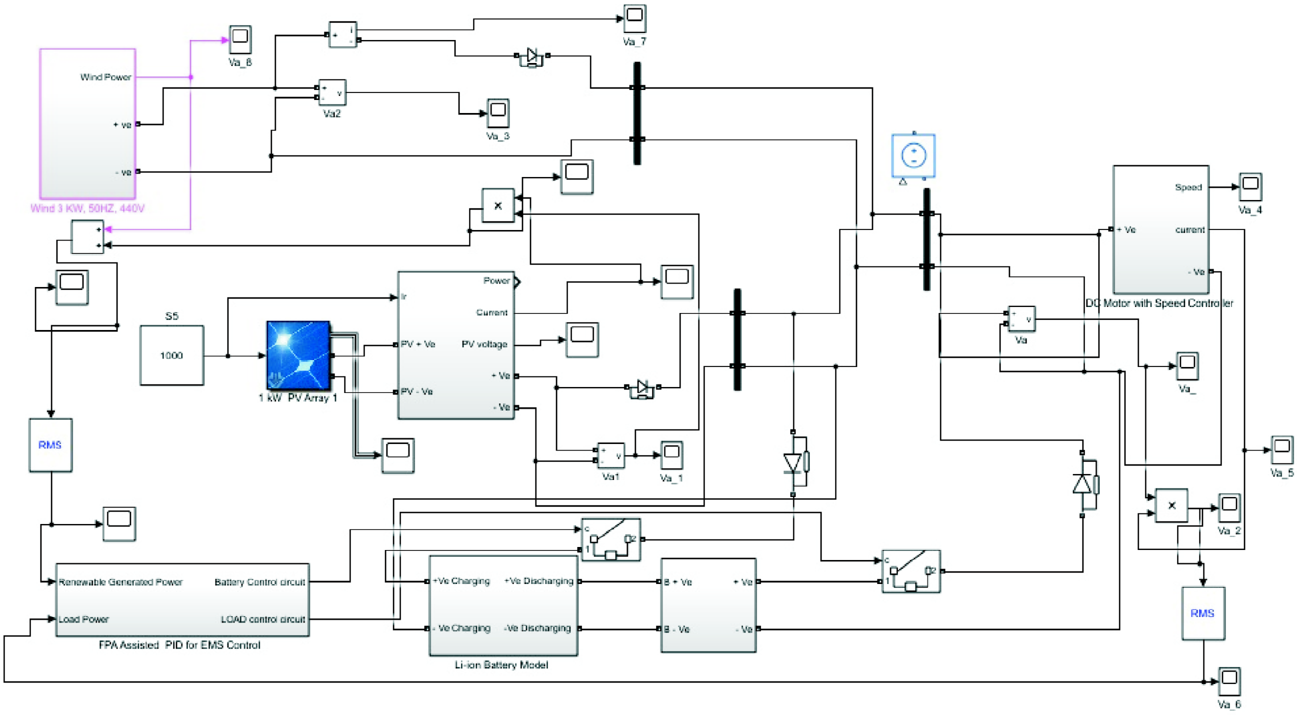

Fig. 6. Proposed PV-WT HRES EMS control model.

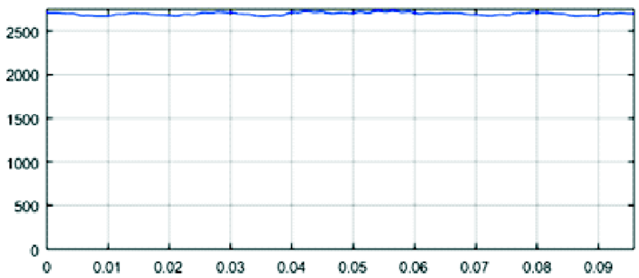

Fig. 7. WT-RES Power generated with FPA-EMS control.

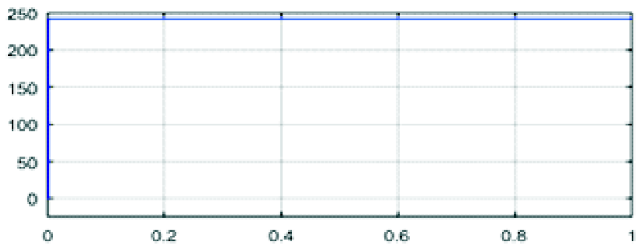

Fig. 9. WT-RES voltage (V) generated with FPA-EMS control.

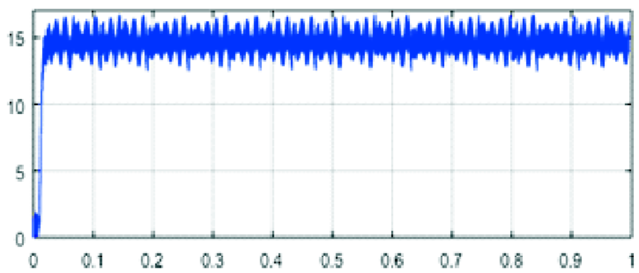

Fig. 8. WT-RES current (A) generated with FPA-EMS control.

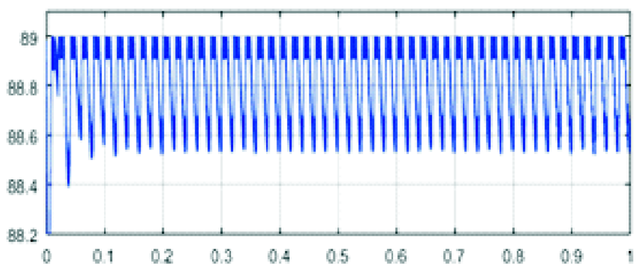

Fig. 10. PV-RES generated power (W) with FPA-EMS control.

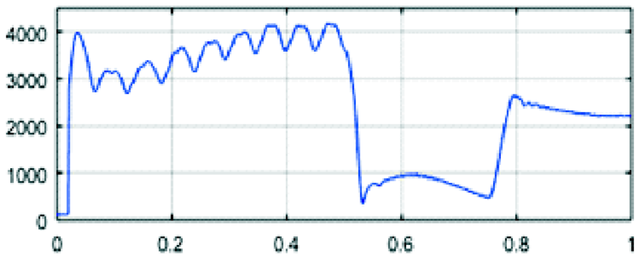

Fig. 11. Load side demand variations with FPA-EMS.

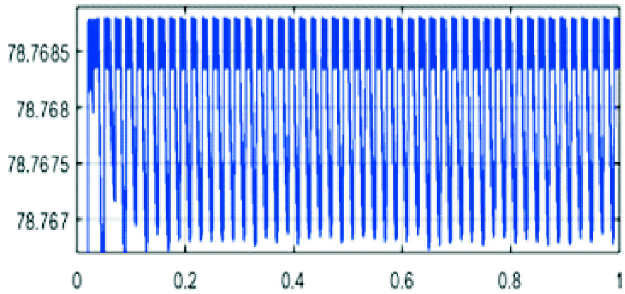

Fig. 13. Switching control with FPA-EMS model.

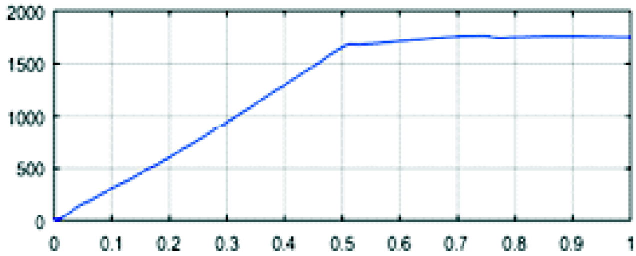

Fig. 12. Speed control variation with FPA-EMS.

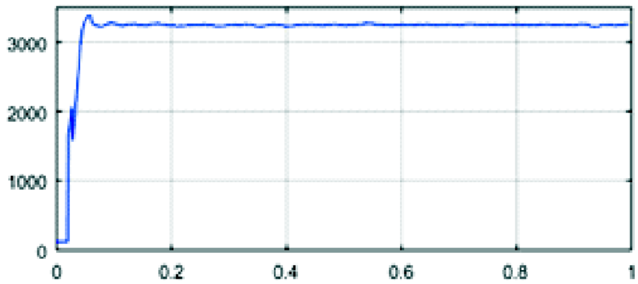

Fig. 14. Proposed PV-WT HRES based overall power (W) generation with FPA-EMS control.

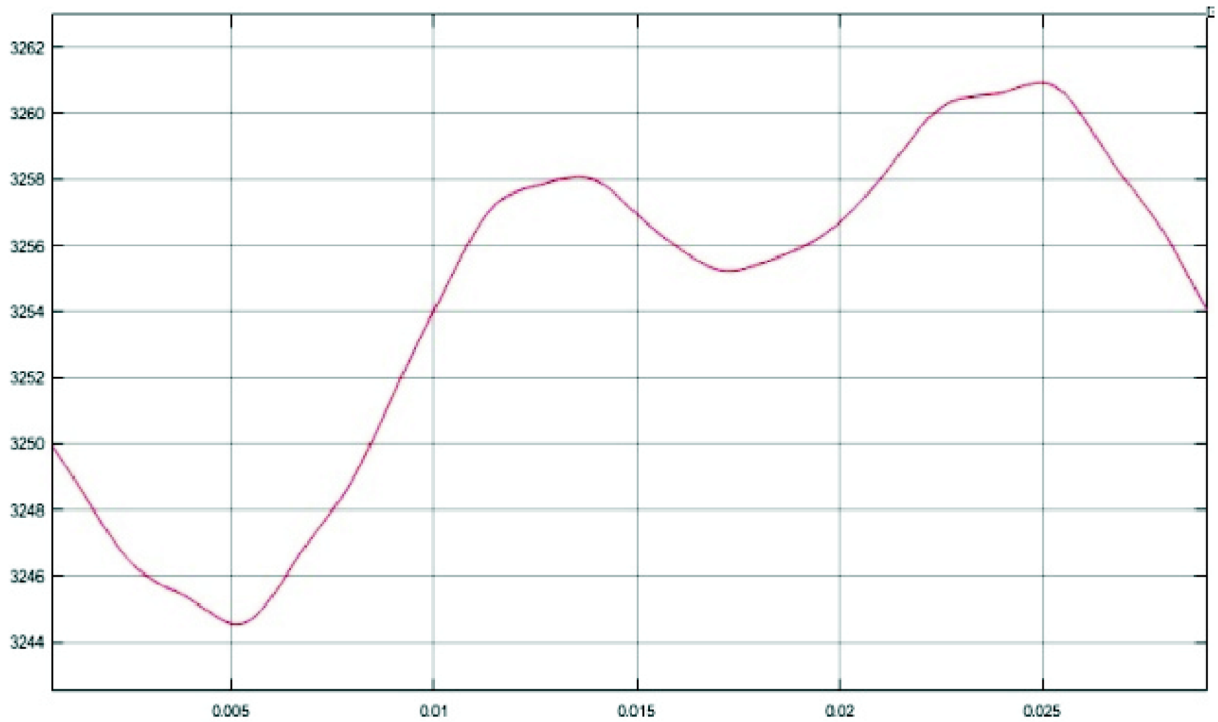

Fig. 15. Hybrid generated power FPA-EMS control.

Conclusion

In this research work proposed metaheuristic algorithm based PID systems like flower pollination based PID tuning to perform swift and transient charging-discharging control for PV-WT HRES power system. One noticeable contribution is the inclusion of load and generation sensitive EMS followed by condition-awareness based WT speed control that helps in overall performance augmentation. Simulation results reveal that the proposed FPA based PID for EMS control can achieve more efficient performance and hence can be applied for real-time power grid management for reliable quality power supply.

References

1. C. Abbey and G. Joos, *IEEE Trans. Ind. Appl.*, 2007, **43(3)**, 769.
2. Blaabjerg, Frede and M. Ionel Dan, *Electric Power Components and Systems*, 2015, **43(12)**, 1319.
3. A. Bellini, S. Bifaretti, V. Iacovone and Cornaro, *Applied Electronics*, 2009.
4. J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galvan, R. Guisado, M. Prats, J. Leon and N. Moreno-Alfonso, *IEEE Trans. Ind. Electron.*, 2006, **53(4)**, 1002.
5. M. K. Deshmukh and S. S. Deshmukh, *Renewable and Sustainable Energy Reviews*, 2008, **12**, 235.
6. Ellabban Omar, Frede Blaabjerg and Haitham Abu-Rub, *Renewable and Sustainable Energy Reviews*, 2014, **39**, 48.
7. Fathima A. Hina and K. Palanisamy, *Renewable and Sustainable Energy Reviews*, 2015, **45**, 431.
8. Garcia Pablo, P. Torreglosa Juan, M. Fernandez Luis and Francisco Jurado, *International Journal of Hydrogen Energy,* 2013, **38**, 14146.
9. Guangqian Du, Bekhrad Kaveh, Azarikhah Pouria and Maleki Akbar, *Renewable Energy,* 2018, **122**, 551.
10. Anil Gupta and Arun Shandilya, *International Journal of Emerging Technology and Advanced Engineering,* 2014, **4(4)**, April .
11. J. Garcia-Gonzalez, R. de la Muela, L. Santos and A. Gonzalez, *IEEE Trans. Power Sys.*, 2008, **23**, 460.
12. H. Ibrahim, A. Ilinca and J. Perron, *Renewable Sustainable Energy Rev.*, 2008, **12(5)**, 1221.
13. T. Lu, Z. Wang, Q. Ai and W. J. Lee, *IEEE Transactions on Industry Applications*, 2017, **53(3)**, 1739.
14. Deepyaman Maiti, Ayan Acharya, Mithun Chakraborty and Amit Konar, "Tuning PID and $PI^{\lambda}D^{\delta}$ Controllers using the Integral Time Absolute Error Criterion", IEEE, 978-1-4244-2900-4/08/$25.00@2008.
15. G. Martins Fernando, *Int. J. Engng Ed.*, 2005, **21(5)**, 867.
16. Marko Stefan and Darul'a Ivan, *Journal of Electrical Engg.*, 2007, **58(1)**, 58.
17. Oriti Giovanna, Anglani Norma and Julian Alexander L, "Hybrid Energy Storage Control in a Remote Military Microgrid with Improved Supercapacitor Utilization and Sensitivity Analysis", 2018 IEEE.
18. Olatomiwa Lanre, Mekhilef Saad, M. S. Ismail and M. Moghavvemi, *Renewable and Sustainable Energy Reviews,* 2016, **62**, 821.
19. Sikder Partha Sarothi and Pal Nitai, *Journal of King Saud University-Engineering-Sciences*. https://doi.org/10.1016/j.jksues.2019.02.002.
20. S. B. Shivakumar, Sampatha Kumar and V. Patil, *IJIREEICE*, 2017, **5(9)**.
21. Tahani Mojtaba, Babayan Narek and Pouyaei Arman, *Energy Conversion and Management,* 2015, **106**, 644.
22. M. S. Taha, H. H. Abdeltawab and Y. A. R. I. Mohamed, *IEEE Journal of Emerging and Selected Topics in Power Electronics*.
23. H. Zhou, T. Bhattacharya, D. Tran, T. Siew and A. Khambadkone, *IEEE Trans. Power Electron.*, 2011, **26(3)**, 923.
24. E. M. Bouharchouche, Berkouk and T. Ghennam, "Control and energy management of a grid connected hybrid energy system PV-wind with battery energy storage for residential applications", Eighth International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, 2013, pp. 1-11.
25. S. K. Khadem, Basu and M. F. Conlon, "Power Quality In Grid Connected Renewable Energy Systems: Role Of Custom Power Devices", International Conference On Renewable Energies and Power Quality, Spain, 2010, **III**, pp.23-25 March .
26. M. Khalid, A. V. Savkin and V. G. Agelidis, "Optimization of a power system consisting of wind and solar power plants and battery energy storage for optimal matching of supply and demand", IEEE Conference on Control Applications, Sydney, NSW, 2015, pp. 739-743.
27. X. Li, D. Hui, M. Xu, L. Wang, G. Guo and L. Zhang, "Integration and energy management of large-scale lithium-ion battery energy storage station", 15th International Conference on Electrical Machines and Systems (ICEMS), Sapporo, 2012, pp. 1-6.
28. M. Trifkovic, M. Sheikhzadeh, K. Nigim and P. Daoutidis, "Hierarchical control of a renewable hybrid energy system", IEEE 51st IEEE Conference on Decision and Control, Maui, HI, 2012, pp. 6376-6381.
29. BP Statistical Review of World Energy, 2019, 68th Edition.
30. K. Ogata, "Modern Control Engg.", 4th ed., Prentice Hall, New Jersey, 2001.