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Optimization of Hybrid Renewable Energy System using BPSO-PID based Load sensitive EMS

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ABSTRACT: This paper represents the optimization of Hybrid Renewable Energy(Wind-Turbine/PV) system using Evolutionary Algorithm like Binary Particle Swarm Optimization(BPSO) based PID .Due to Unreliablity of Renewable Energy sources nowadays Hybrid Renewable Energy system is preferred ,especially wind and PV system is gaining more popularity due to its several advantage like cost, efficiency and reliability. Use of Batteries become manadatory for the supply of Reliable energy system.But the charging and discharging of Batteries based on Load sensitivity or during power outages or poor quality power generation became one of challenging aspect. This paper represents the Control of Batteries through Evolutionary algorithm approach like BPSO(Binary particle swarm optimization) which is used for the tuning of PID parameters, through which charging and discharging of battery is controlled.

KEYWORDS: Hybrid RenewableEnergy System, Energy Management system, Binary Particle Swarm Optimization, PID, Evolutionary Algorithms.

I.INTRODUCTION

To enable potential energy solution, Renewable Energy Sources (RESs) such as Wind-Turbine (WT), Photovoltaic (PV) cells, and hydro-electric power generation have emerged as the potential alternatives. To further exploit the efficacy of these power systems, in last few years hybrid generation systems have been suggested that employs multiple RESs.Though there has been research on prediction and/or working a precise kind of energy storage method or EMS for remote electricity grids [13]–[16], some mechanism consider maximizing the diverse features of numerous kinds of energy storage and the dissimilar accessibilities of numerous kinds of RESs creating a hybrid energy production and storage method. However, mutually planning for energy storage in conjunction with RES generation pattern and load variations affects the cost and efficacy of the power system. With this motivation, in this paper a novel and robust EMS system control is developed by considering both generation non-linearity as well as load variations. The concept that considering load variations for both EMS control and generation side control (for example, Rotor Side Control (RSC) in WT Energy Conversion System (WECS)) can enable reliable power generation and control to meet quality power demands. To control charging and discharging of EMS or battery systems, authors [17] have applied classical Proportional-Integral (PI) or Proportional-Integral-Derivative (PID) controllers. However, in major researches static PID or PI controllers’ gain parameters are used that seems limiting particularly to achieve EMS control under dynamic or non-linear generation and load side variation. On contrary, do deal with dynamic load conditions and non-linear generation conditions, assigning optimal gain parameters to PI/PID controller is must. With this motivation, in this paper a novel and robust EC based PID control has been designed for EMS control. In our research work, predominant EC scheme named BPSO have been applied distinctly to perform PID parameter tuning. Interestingly, our proposed model considers load side variation as well as generation side non-linearity to control EMS. This as cumulative solution enables optimal charging and discharging of the battery system so as to enable continuous and reliable power delivery to the customers. In addition, our proposed model considers load variations too for controlling RSC (such as wind speed control). These all as cumulative solution enable a reliable and efficient EMS system for quality power delivery.

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II. RELATED WORK

This section discusses some of the key literatures pertaining to EMS systems. Undeniably, a number of efforts have been made to develop better EMS control systems; however rising complexity of operating environment often opens up demands for further optimization.

Authors in [18] developed a two-level optimization model for coordinated energy management between distribution systems and clustered WT-PV-battery MGs. In their model, the higher level of the system functions as distribution network, while lower level focused on incorporating synchronized operation of multiple MGs (Micro Grids). To enable coordination of the power swap among multiple MGs and distribution network, authors derived an Interactive Game Matrix (IGM). In [19] an optimization model was developed for energy management in hybrid RES system encompassing RES and diesel generators. To enable efficient EMS, authors focused on charging and discharge control for which they developed Dynamic Programming (DP) algorithm. Similarly, a control technique for hybrid energy system employing RES was proposed in [20], where authors used individual storage designed using Super Capacitor (SC) module. Though their approach could be cost efficient and augmented life time, could not address mitigating fluctuations caused due to generation side non-linearity and load variations. In [21] authors developed EMS control model to be used in hybrid RES system. Additionally, a control model to deal with system nonlinear was developed in [21]. Authors in [22] derived a controller model for energy management of a stand-alone RE hybrid scheme. Their proposed model encompassed five major components, namely, PV arrays, WT, electrolyzer, hydrogen storage tanks, and fuel cell. Authors in [23] developed a DC connected hybrid RES for stand-alone applications where RESs were used as main energy sources and battery units were considered as storage to meet load demand. However, their classical EMS system could not address the non-linearity in load demands that requires efficient EMS provision. Authors [24] developed a DC connected hybrid solar wind energy scheme for stand-alone applications. Authors applied Adaptive Neuro Fuzzy inference scheme (ANFIS) to estimate the panel voltage based on which the highest power could be obtained. A classical EMS model was developed in [25], where authors considered MG parameters to control EMS. One of the key issues in hybrid RES system is its instability under non-linear generation scenario. To assess system stability authors [26] developed control model that considers micro-grid parameters to derive control decision. In [27], authors developed a grid-connected hybrid RES system that comprised WT generation system, PV, Battery Storage System (BSC) and loads. To enable better EMS control authors applied a Programmable Logic Controller (PLC). Utilizing power converters and control algorithms with RES was developed in [28] to enable efficient EMS. A meta-model plan for hybrid RES based power system was developed in [29] where authors applied two types of storage i.e. electric and hydraulic tools. Demand Response (DR) strategy based energy management model was developed in [30]. Their proposed model exploited energy demands from load side and MGs voltage profile to control EMS for enabling secure power delivery.

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III. SYSTEM MODELING

Typically, hybrid system is considered to maintain a load power to be lower. In our Hybrid-RES design WECS contains Permanent Magnet Synchronous Generators (PMSG) wind-turbine of 3kW power capacity, while PV module is a single diode design with 1kW power generation capacity. The difference between the power generated by RESs and the power demanded from the load side over a period of time T can be minimized by means of controlling changing-discharging control and by controlling RES in accordance. Hybrid-RES structure applied in this research work operates autonomously and supplies power to the DC bus in series with the RESs. In addition, it can supply power to the batteries, directly [42]. An illustration of hybrid-RES system containing WT-PV sources is given in Fig.1. The considered simple structure, supplies power to the load continuously and facilitates a good charging and discharging control of the battery.

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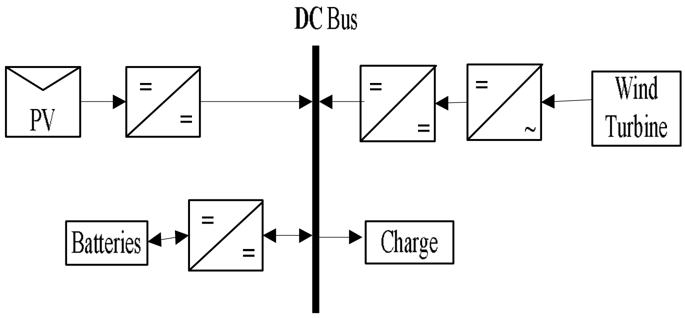

Fig. 1. Schamtic of the Hybrid-RES system

The following sub-sections brief about different components used in our proposed Hybrid RES systems and their functional characteristics.

A.Photovoltaic System

The PV generator converts the solar energy into electrical energy. This is realized through series connection and parallel modules. Literatures [43][44][45] state that the PV cell may also be represented as a current generator whose electrical behavior is similar to a current source shunted by a diode. The simplicity and accuracy make the single diode model as the simplest PV model that comprises five components; a current source, one diode and two resistors including series resistance and shunt resistance. The current I_p generated by PV cell on the basis of the output voltage V_p can be obtained using following equation (1).

$$I_P = I_{SC}\left[1 - C_1\left(e^{\left(\frac{V_P-\Delta V}{C_2 V_{OC}}\right)} - 1\right) + \Delta I\right] \quad (1)$$

where C_1 and C_2 signify the constants. Mathematically, these constants are obtained using (2) and (3).

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

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

Similarly, the other variables ΔI and ΔV are obtained using following equations:

$$\begin{cases} \Delta T = T - T_{ref} \\ \Delta I = \alpha\left(\frac{L}{L_{ref}}\right)\Delta T + \left(\frac{L}{L_{ref}} - 1\right) I_{SC} \\ \Delta V = -\beta\Delta T - R_s \Delta I \end{cases} \quad (4)$$

In above equations, the variables α and β state the temperature coefficients of the current and voltage, respectively. Other variables, L and L_{ref} represent the solar radiation and solar radiation reference (W/m^2), respectively. Similarly, temperature and the reference temperature of the cell (◦C) is presented by T and T_{ref}, correspondingly. I_{SC} and I_{MPP} signify the short-circuit current and the peak current at the Maximum Power Point (MPP). Similarly, V_{oc} and V_{MPP} represent the open-circuit voltage (V) and the voltage at the MPP. R_s signifies the series resistance of the PV system (Ω).

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B. Wind Turbine

In the proposed WECS system, WT with the power generation capacity of 3kW is considered. The overall WECS design encompasses a wind turbine, Permanent Magnet Synchronous Generation (PMSG) unit, an AC/DC converter and a DC/DC (Buck) converter. The structure of this design is on the basis of three-phase Diode Bridge and consists of Buck converter to transform the rectified voltage. The mechanical power generated from the wind is calculated using (7).

$$\lambda = \frac{R\Omega_t}{v} \tag{7}$$

where R states the radius of the wind turbine $[m]$ and Ω_t refers the rotational speed $[rad/s]$.
An schematic of the WECS system is presented in Fig. 3.

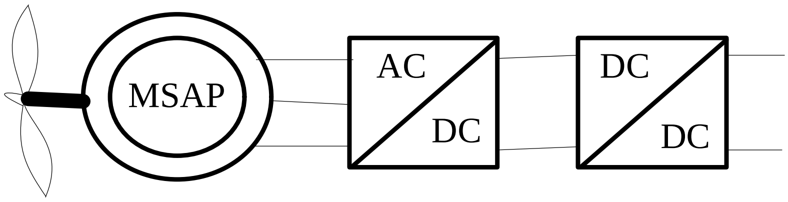

Fig. 2. Wind Turbine Energy Conversion System

The power coefficient Cp characteristic is based on the specific speedλ. To design WECS model a reference work in [46] is considered. Mathematically (9),

$$\dot{x} = \begin{bmatrix} i_q \\ i_d \\ \dot{\omega}_e \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ g_3 \end{bmatrix} u_w = \begin{bmatrix} -\frac{r_s}{L} i_q - \omega_e i_d + \frac{\omega_e \emptyset_{sr}}{L} \\ -\frac{r_s}{L} i_d + \omega_e i_q \\ \frac{P}{2J}\left(T_m - \frac{3}{2}\frac{P}{2}\emptyset_{sr} i_q\right) \end{bmatrix} + \begin{bmatrix} -\frac{\pi v_{DC} i_q}{3\sqrt{3}L\sqrt{i_q^2 + i_d^2}} \\ -\frac{\pi v_{DC} i_d}{3\sqrt{3}L\sqrt{i_q^2 + i_d^2}} \\ 0 \end{bmatrix} u_w \tag{8}$$

$$i_w = \frac{\pi}{2\sqrt{3}} \sqrt{i_q^2 + i_d^2 u_w} \tag{9}$$

i_d and i_q represent the components homopolar, which is the direct and the quadrature three-phase currents from the Park transformation.ω_e is the electric angular velocity, r_s and L signify the resistance and inductance of winding per phase the stator, respectively. The other variable P refers the numbers of poles of the PMSG, while J signifies the moment of inertia of the rotor. In addition, the other variable $\emptyset_{sr}$ represents the flux generated because of the stator currents, v_{DC} is the DC bus voltage, u_w is a simple function of the duty cycle of the converter used (for this configuration: $u_w = 1/\delta$), i_w is the current from the turbine and injected into the DC bus and T_m is the mechanical torque produced by the turbine. Mathematically,

$$T_m = \frac{P_m}{\omega_e} \tag{10}$$

C. Electrical Storage System

In our proposed Hybrid-RES power system, Nickel-Cadmium batteries are used as electrical storage system. Undeniably, a number of battery systems such as Lithium-Ion, Lead-Acid, Nickel-Cadmium are used as energy storage system; however excessive dynamism in power generation and load fluctuation demand more robust and stable battery system. Considering charging-discharging characteristics of the battery system in Hybrid-RES power system, we have applied Nickel-Cadmium batteries as energy storage system. A simple illustration of the battery system design is

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presented in Fig 4. Here, the source voltage is considered as the battery that varies with their state of charge. Noticeably, the state variation takes place as per the battery current. The state will be decreases when it is positive (battery discharge) and discharges. The charge will be increases when it is negative (battery charging) [47] [48].

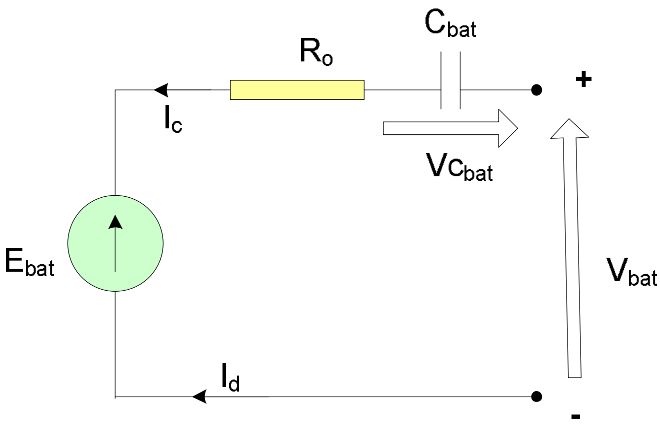

Fig. 3. Equivalent circuit diagram of a cell of the Nickel-Cadmium Battery

D. Proportional-integral-derivative (PID) controller

In present day industrial applications, PID controllers are the most commonly applied controllers, particularly for electrical or electronic system control. A simple schematic of the PID controller is given in Fig. 4. PID controller employs the continuous time and the transfer function to perform control functions [49]. In our proposed EMS control model PI controller with EC based parameter tuning is applied.

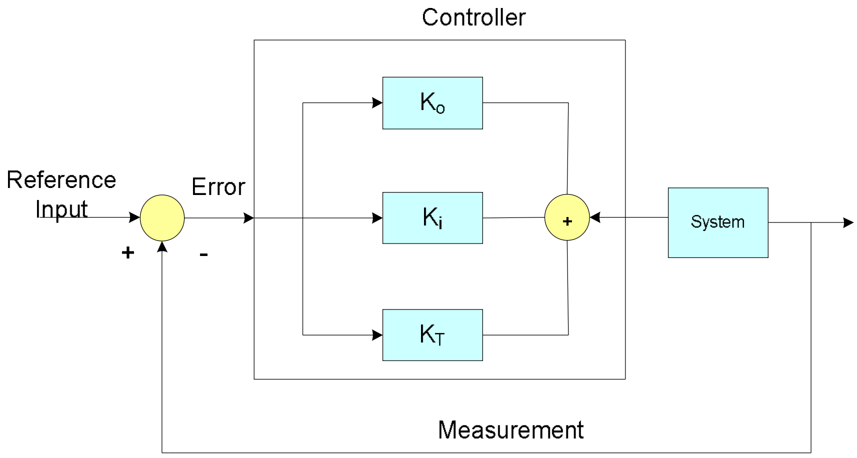

Fig. 4. Schematic of PID controller

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{e(t)}{dt}\right] \quad (13)$$

$$G_{Controller} = K_D + K_T s + \frac{K_i}{s} \quad (14)$$

This is the matter of fact that the robustness of PID controller enables it to be one of the prominent alternatives for EMS control; however the static or fixed gain parameter of the classical PID confines its suitability, particularly under those conditions like exceedingly dynamic non-linear generation and load variation. To deal with these limitations, optimal PID parameter selection and tuning can be of paramount significance. With this motivation, in this research work we have applied t enhanced EC algorithms BPSO to perform PID parameter running in real-time environment. A symbolic function of EC based PID tuning is illustrated in Fig. 7.

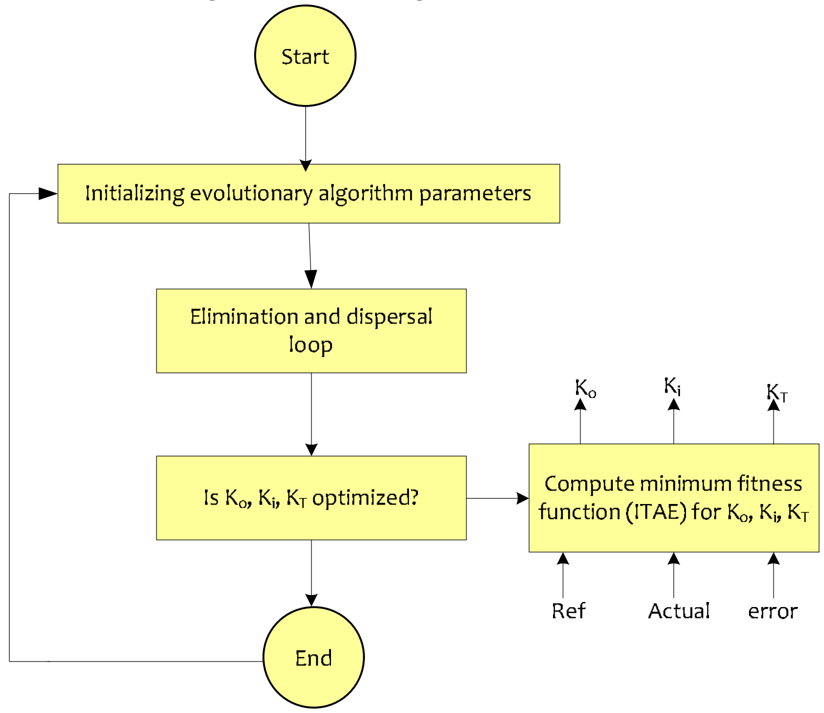

Fig. 5. Evolutionary Computing based PID parameter tunning for load sensitive EMS control

Being evolutionary computing algorithm, BPSO requires an objective function to perform PID parameter tuning. Evolutionary algorithms intend to maximize objective function iteratively to achieve optimal or near-optimal solution. In our proposed model, Integral Time Absolute Error (ITAE) is applied as objective function to optimize the PID tuning parameters. A brief of the ITAE objective function is given as follows:

IV. **Objective function (OF)**

Generally, there are numerous indices applied to assess PID controller performance. Some of these indices are; Integral Square Error (ISE), Integral Absolute Error (IAE), ITAE, and Mean Square Error (MSE). In this paper, we have applied ITAE reduction as the objective function to perform PID parameter tuning, where BPSO tries to reduce ITAE iteratively to achieve optimal PID parameters so as to enable swift and efficient EMS control. The efficiency or capability of ITAE to avoid long duration transient makes ITAE suitable for our study. Mathematically, ITAE is given in equation (15), which is obtained as the difference between the load power and the generated power.

$$\mathrm{ITAE} = \int_0^{\infty} t|e(t)|\,.\,dt \quad (15)$$

Noticeably, once achieving the minimum objective function $e(t)$, the respective PID parameters are selected and based on which the charging and discharging control is performed using PID controller. In addition to the above mentioned, ITAE based PID parameter tuning, in our model as supplementary enhancement, we have applied EC-PID scheme (i.e., enhanced EC based PID controller) for Wind-Turbine speed control. In this case equation (15) characterizes the

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objective function e(t) as the error between the reference speed and the actual speed of the PMSG WECS. Now, applying above mentioned objective functions, we have performed PID (tuning) parameter optimization using BPSO algorithms. A brief of the EC schemes applied in this research work is given in the following sub-sections. In this paper, the emphasis is made on applying EC schemes mainly for EMS control optimization to avoid any outage probability and to facilitate quality power to the customers.

V. BPSO (BINARY PARTICLE SWARM OPTIMIZATION)

Typically, BPSO algorithm represents a type of stochastic heuristic optimization approach that performs removal of the features from the correlation investigation. It applies swarm intelligence technique to identify optimum PID tuning parameter or gain parameters by means of obtaining global minima. In this algorithm, the particles inform the inner velocity in PSO and dissimilar to the classical GA, BPSO avoid iterative crossover and mutation process that significantly reduces computational overheads and time. In addition, through GA chromosome distributes key information to one another, which is usually avoided in BPSO which executes information swap via finest area. Classical EC algorithms functions in the continuous domain but BPSO can be adapted into the discrete domain too.

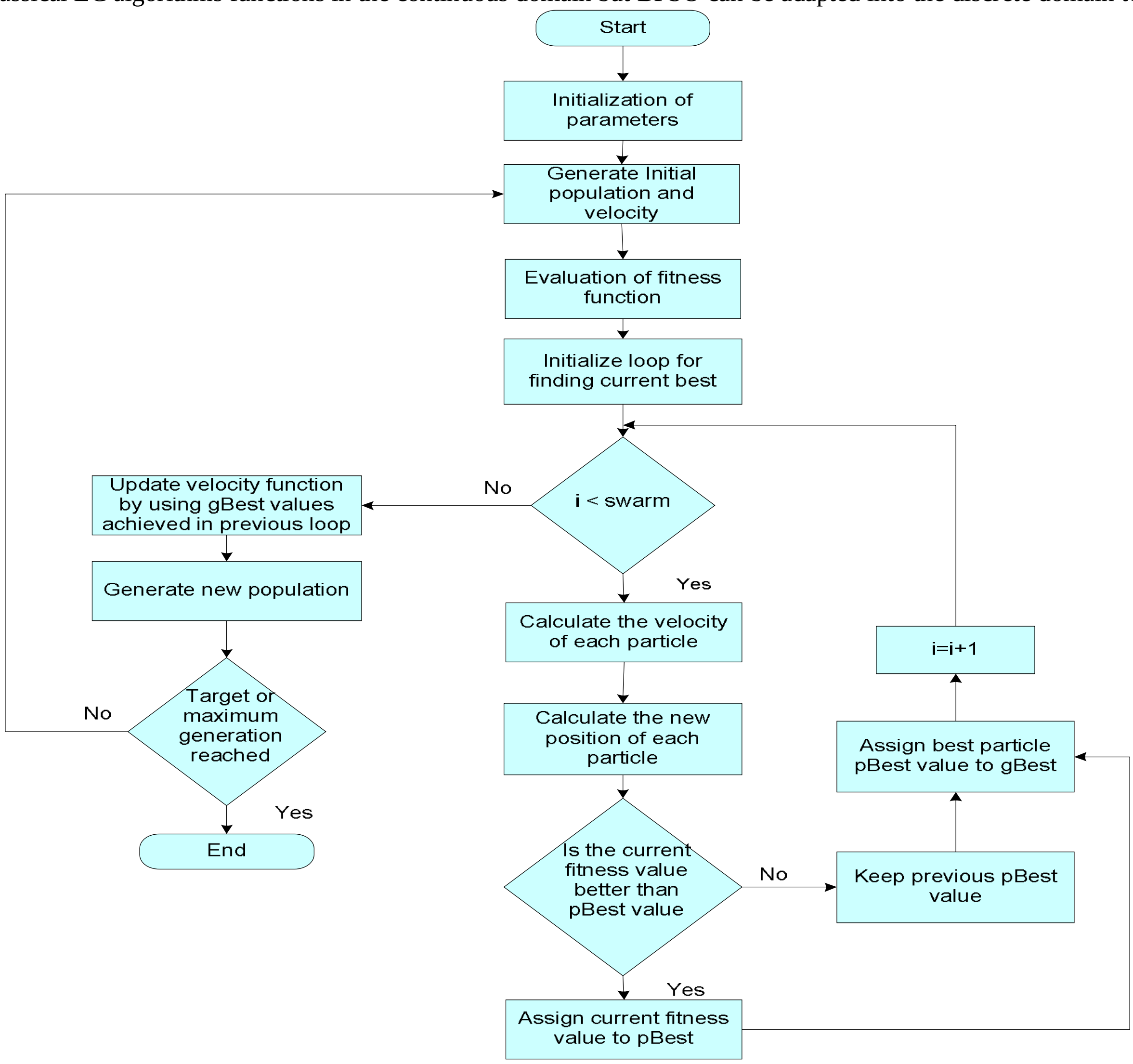

Fig. 6. Steps involved in BPSO algorithm.

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As depicted in Fig. 8, BPSO primarily contains four parameters; initialization, generate initial population and velocity, particle own finest position and global finest position amongst every particles.

In BPSO based PID parameter tuning, a population containing chromosomes of PID gain parameters is initialized randomly and sprinkled in the search space. The parameter $x_i = x_1 + x_2 + , \dots , + x_I$ and $V_i = V_1 + V_2 + , \dots , + V_I$ are signified as initial positions and velocities of the particles, respectively. the particles inform their velocities in all iteration [50]. Mathematically,

$$\sum_{t=1}^{24}\sum_{i=1}^{I} V_i^{t+1} = \sum_{t=1}^{24}\sum_{i=1}^{I}\left(\omega V_j^t(j) + c_1 r_1\left(X_{lbest,i}(j)\right) - x_i^t(j)\right) + c_2 r_2\left(X_{gbest,i}(j) - x_i^t(j)\right) \quad (16)$$

where V_i^{t+1} refers the velocity of particle in impending time slot, w states the inertia factor, V_j^t presents the current velocity, r_1 and r_2 are arbitrary numerals, c_1 and c_2 are local and global pulls respectively, x_i^t signifies the particles present place, X_{lbest} represents local finest place and X_{gbest} stand for global finest place. Here, the particle's velocity is mapped in between 0 and 1 by using sigmoid function (16),

$$sig(V_i^{t+1}(j)) = \frac{1}{1 + exp(-V_i^{t+1}(j))} \quad (17)$$

The random values given to each particle (signifying PID gain parameters) in the population are contrasted by exploiting the sigmoid function to produce a binary coded population.

$$x_i^{t+1} = \begin{cases} 1 & sig(V_i^{t+1}(j)) < r_{ij,} \\ 0 & otherwise \end{cases} \quad (18)$$

Particles record their places relation to neighbors in all iteration. The local best places are formed through the particles are signified as $X_{lbest} = X_{lbest1} + X_{lbest2} + \_\_\_ + X_{lbestN}$. The local best values are obtained which is then followed by the retrieval of the other global best location. The g^{th} particle among the particles is said to be the global best place if it gratify the objective function, along with the global finest places are signified as $X_{gbest} = X_{gbest1} + X_{gbest2} + \_\_\_ + X_{gbestN}$. The swift convergence to achieve optimum solution is the predominant cause behind the use of global best value other than local best value. The global best value is signified as the optimum ON/OFF condition of the application and it is a binary coded string. By exploiting the matching cost of global finest value, the fitness function of every particle is estimated. The simulation environment of BPSO implementation for PID parameter optimization is presented in Table 2.

Table 2 BPSO Parameters and its values

Parameters	Values
Number of iterations	300
Swarm size	200
v_{max}	4
v_{min}	-4
w_i	2
w_f	0.4
c_1	2
c_2	2
n	11

Thus, applying above discussed algorithms PID parameters are tuned and are further applied to perform charging and discharging control of the EMS system. The results obtained are discussed in the next section.

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VI. RESULTS AND DISCUSSION

Considering the significance of a robust EMS control model for Hybrid-RES system, in this work the emphasis was made on exploiting both load variations and non-uniform generation pattern to perform optimal charging and discharging control. Here, unlike traditional PID based control, EC based PID control was developed, where EC algorithm such as BPSO were applied to enhance PID gain parameters so as to perform swift or transient decision for EMS control. At first, to derive a Hybrid-RES power system, we modeled Wind-Turbine Energy Conversion system (WECS) and Photovoltaic (PV) cells, where WECS was developed for the specification of 3kW generation power, 50 Hz frequency and 440 V supply. Noticeably, here we used PMSG wind turbine of 3kW power. Similarly, PV cell of 1 kV was used to derive PV power system, with traditional Perturb and Observe (PO) Maximum Power Point Tracking (MPPT) facility. In addition to the power generation units other key components, such as DC/DC Buck converter, DC-DC Bidirectional converter, and Nickel-Cadmium Battery Storage System (BSS), two circuit breakers (for charging and discharging control), PID controller (for EMS control as well as speed control of WECS), and BPSO algorithm. The overall models were developed using MATLAB 2015a/SIMULINK tool. As depicted we used DC/DC converter to connect PV cells with DC bus, while bidirectional converters were used in wind-turbine interface to the DC bus. To examine the efficacy of the proposed EC based EMS control, we simulated proposed Hybrid-RES system in three distinct simulation cases; first EMS control using classical PID control with predefined gains (P=1, I=1), second, using BPSO tuned PID control for EMS control under dynamic load and generation patterns.

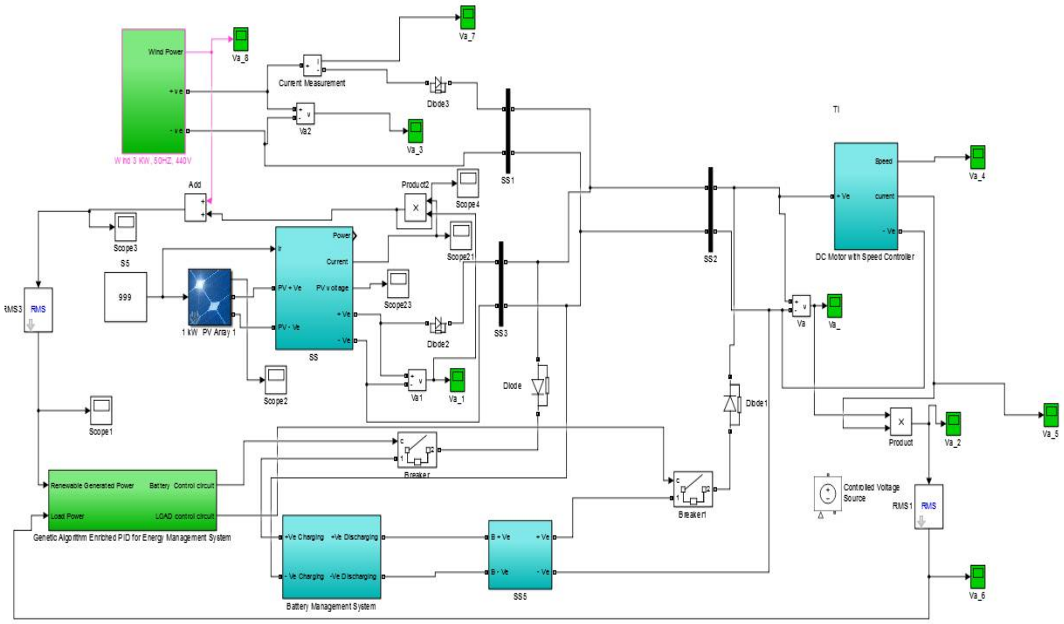

Fig. 7. Developed Hybrid-RES system comprising Wind-Turbine and Photovoltaic Cells

Considering rotor side controllability to assist reliable power generation, initially PID was used. The simulation with different control mechanisms and respective outcomes are discussed as follows:

A. Classical PID Based EMS Control

Since, our proposed EMS control model considers load side dynamism as well as non-linear generation pattern and therefore, we have examined power generation profile and control functions at the load side as well as generators. In addition, realizing the fact that WECS control, particularly wind speed control may play vital role in controlling generator power to meet dynamic power demands, we have assessed PID controller's efficacy towards speed control over simulation period. Fig. 8 presents the WECS generated power during simulation. As stated the WECS under consideration has the maximum generation power of 3kW, initial power generation is found to be approximate 2700

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Watts.. Here, the continuous 440 Volt power is generated Similarly, the generation pattern of the PV cells also depicts power generation in the range of 460 Watts to 680 Watts, while the maximum generation capacity is 1kW.

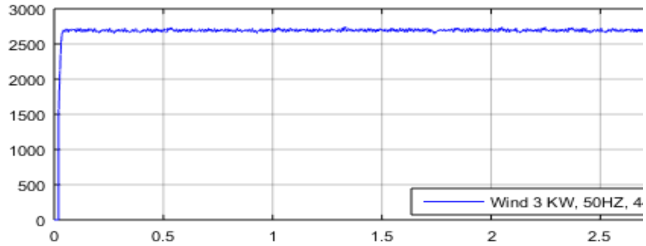

Fig. 8. WECS generated power (W) with classical PID control

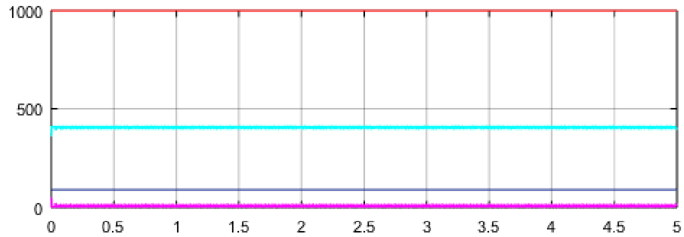

Fig. 9. PV cell generated (above) and current (below) (W) with PID

The overall generated power under varying or dynamic load condition is given in Fig. 10. The overall load sensitive power generation by Hybrid PV/WT RES system could be visualized in Fig. 11. Here, it can be found that as combined RES solution, it generates approximate 3.6kW of power at almost stable generation rate The efficiency of charging and discharging could be easily visualized through these results. The speed control performance by PID controller can be observed in Fig. 12.

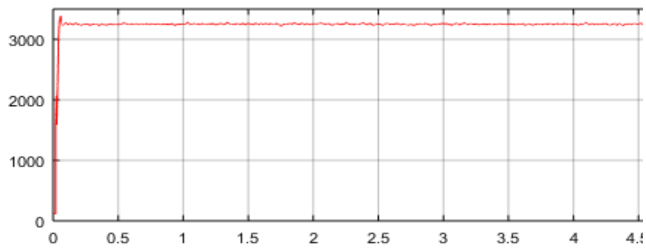

Fig. 10. Hybrid-RES generated power (W) with classical PID control

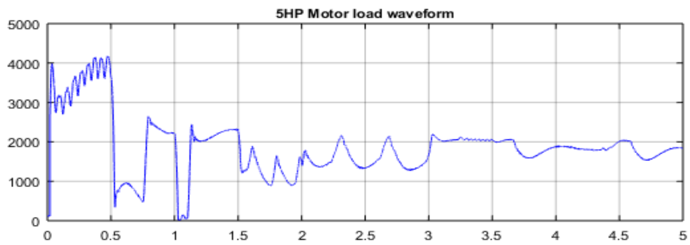

Fig. 11. Load side power (W) demand variation

To achieve stable power generation while fulfilling load demands, controlling wind turbine speed is vital and hence we applied PID controller to control WT speed while considering load demands. Here, PID controller controls WT speed by considering reference speed (1750 r/s) and the actual speed. The speed control output using classical PID is given in Fig. 12.

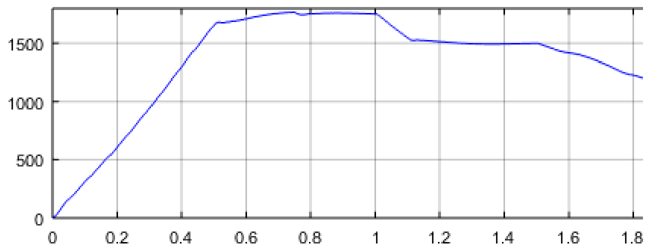

Fig. 12. Speed control (r/s) with reference to PID

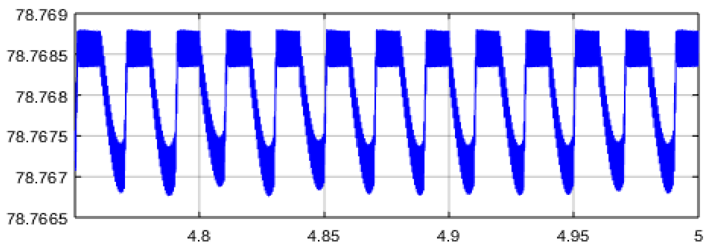

Fig. 13. Chargind and discharging control with reference to PID based EMS control

B. BPSO-PID based EMS Control

Similar to the classical PID controller ,we have applied BPSO algorithm for PID gain parameter optimization to perform load sensitive charging and discharging control. In our simulation, the total number of generations applied was fixed for 100, while lower and upper bound for optimization was fixed at 200. Here, BPSO was used to optimize or obtain the optimal/sub-optimal value for the P and I gain parameters of the PID controller. Fig. 14 presented the WT generated power, which is nearing 2700 Watts.

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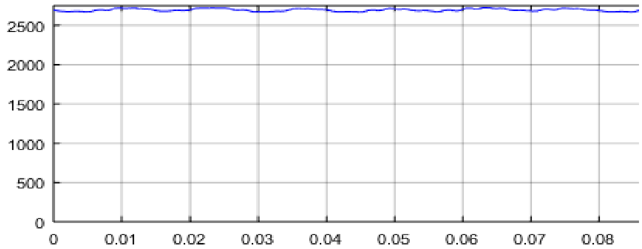

Fig. 14. WECS generated power (W) with BPSO-PID controller

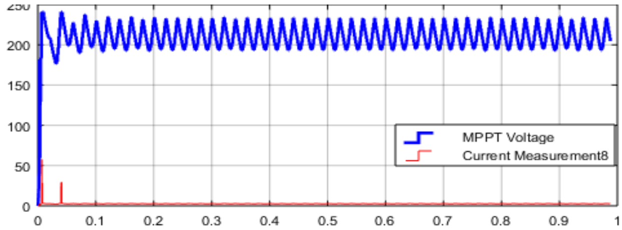

Fig. 15. Voltage (V) and Current (A) generated from PV cell using BPSO-PID assisted RES system

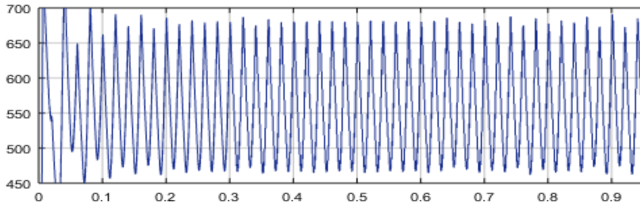

Fig. 16. PV cell generated power (W) with BPSO-PID

The results obtained for HRES power generation (Fig.17), Respective load variations (Fig. 18), and load sensitive WT speed control (Fig. 19), and battery charging and discharging control (Fig. 20) are presented as follows:

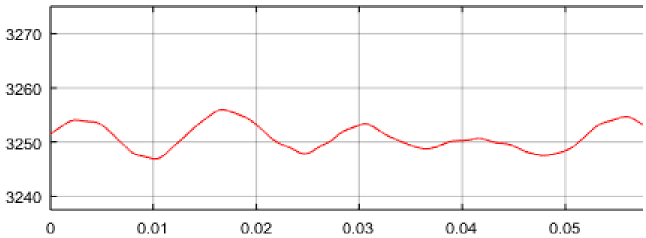

Fig. 17. Total power generated from the HRES system

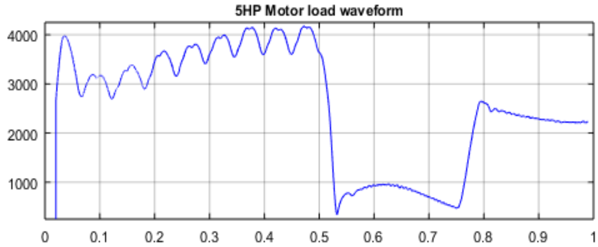

Fig. 18. Dynamic load variation in HRES system

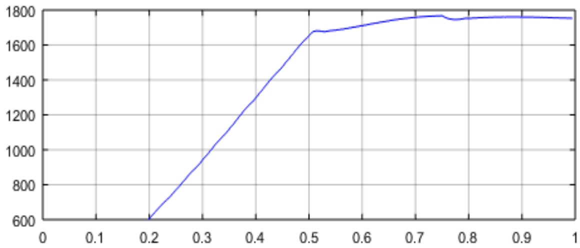

Fig. 19. Speed Conrol with BPSO-PID

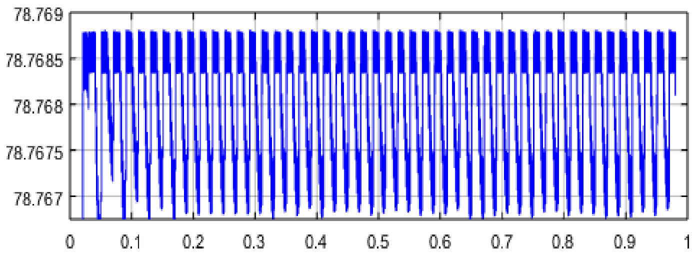

Fig.20.Charging and Discharging control with BPSO-PID

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VI. CONCLUSION

In this research work a robust load-sensitive EMS control model was developed for PV-Wind Turbine RES system. Here both generation side and Load side has been controlled through charging and Discharging of EMS,which in turn is controlled by Evolutionary algorithm based PID.However, to alleviate the issue of online PID parameter tuning for efficient charging and discharging control of the EMS, evolutionary computing algorithms named Binary Particle Swarm Optimization (BPSO) have been applied. The PID parameter tuning (or optimization) makes overall control decision swift and efficient that eventually alleviates the probability of the power outage and faults.. In future, more efficient evolutionary computing approaches could be explored for their efficacy to perform EMS control along with generator side control to assist reliable and quality power supply.

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