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Enhancement of Energy Management System of Hybrid Renewable System by HSS

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Abstract: The cost of a renewable energy (RE) is higher than a conventional fuel-driven engine, but has less or negligible operating cost. Due to the above advantage of RE on the reliability and cost effectiveness, system designers are looking for ways to combine known as hybrid power system. Therefore, hybrid power system is used to reduce the dependency either on conventional energy. In these Paper we are combining Wind Turbine and PV System, through which EMS is controlled. But considering the Reliability and quality, charging and Discharging of battery remains an prime importance especially during the Power outages or Load variations. Unlike conventional approaches, Evolutionary algorithm like Hyper-Spherical Search (HSS) are used for tuning the PID Parameters through which charging and Discharging of Batteries are controlled. Usage of Evolutionary algorithm not only improves the power quality but also maintance balance between generation and load.

Keywords: Hybrid Renewable Energy System, PID Controller, Hyper-Spherical Search, Wind-Turbine, PV.

I. INTRODUCTION

Exploring in depth it has been found that majority of evolutionary computing algorithms have been applied only for cost optimization of the RES system or design optimization; however load sensitive EMS has not been addressed significantly. In addition, only generic Evolutionary approaches such as Flower Pollination Optimization (FPO) and Hyper Spherical Search (HSS) optimization algorithm are used only for either cost optimization or speed control (for wind-turbine or MPPT control in PV RES). Unfortunately, not much effort is made to enhance EMS controllability under dynamic load conditions. In some of the literatures the generic PID controllers are used to perform EMS; however the limitation of the PID controller (i.e., tuning parameter estimation) has not been addressed so far. With this motivation, in this research effort a highly robust and efficient Evolutionary Computing Based Load-Sensitive Energy Management System has been developed. The proposed research effort encompasses different evolutionary computing algorithms to strengthen controllability of the EMS system (i.e., battery management system) connected with Hybrid-RES (i.e., Photovoltaic and Wind-Turbine). Realizing the aforementioned limitations and future scopes (for optimization), in this research different Evolutionary Computing algorithms including FPO and HSS optimization algorithm have been applied to enhance PID based control model for efficient EMS and load sensitive controllability. Over the last decade the energy management issue has become the vital issue. The main reason for the enhancing significance is the quick extend of the employ of tools sensitive to power system interruptions and the extensive employ of non-linearly behaving power electronic converters. The calculation of WTs is able to have a major consequence and enlarges the difficulty of this issue. Conditional on the grid configuration and the category of WT employed dissimilar power quality issues may occur. The arbitrary character of wind resources, the wind farm produces vacillating electric power [18]. These vacillations have a negative impact on immovability and power quality in electric power methods. Large scale incorporation of Distribution Grid (DG) units in the sharing grid not only influences the grid planning although as well has an impact on the action of the DG. Through the link of DG units, some features are influenced that are 1) power quality 2) voltage control 3) grid losses 4) fault level 5) protection method. The augment in numeral of received induction producers to the grid, causes the power quality issues primarily in present Harmonics, reactive power and power factor. These issues will be extra demanding in weak grids [19-22]. The concurrent changing process of RESs produced outcomes into extreme inrush of reactive power from grid, which is unwelcome.

II. RELATED WORK

Authors have made effort not only to enhance control solutions, but also on enabling more efficient battery system. Authors [36] designed a large-scale lithium-ion battery energy storage station (BESS) and found it better alternative for Hybrid-RES system containing wind/PV combinations. In [37] authors developed a control strategy to alleviate power fluctuations conditions by employing hybrid storage energy system (HESS) made of super conducting storage and

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battery systems. They applied low-pass filters to reduce power fluctuations in RES systems. In [38] authors developed an intelligent model for power management of the Res systems comprising WT, PV, battery storage and diesel engine (DE). Authors focused on regulating power flow between energy sources and the battery storage to enable stable power supply to the load side. However, they could not address load variance to enable EMS controllability. In such cases a signal processing based approach was developed in [39] where authors focussed on EMS control of non-RES and RES based for power grid network. To improve charging and discharging of the battery and ultra-capacitor, the mixtures of hybrid energy and storage devices were considered in [39]. A better control measure was suggested in [40] where authors developed a multi-objective combinatorial technique to enhance hybrid RES design for stable power supply. A load sensitive power management model was developed in [41], where authors amalgamated WT and PV in a best proportion for which a Battery Energy Storage System (BESS) was applied to balance the power demand and generation. Their proposed method intends to match the required power by controlling BESS and hybrid RES functions. A similar effort was made in [42]. In [43] authors derived a scheduling model for energy distribution by driving twofold objectives. At first, the model was invented to guarantee social welfare-optimal allotment of the energy generated from the divided RE producer. Later, the model goals at cost-optimal strategy of consumers' controllable appliances considering a practical time-varying quadratic pricing of the energy bought from the sharing network. The solution approach relies on a dispersed optimization algorithm that was created through two-level iterative process joining Gauss-Seidel decomposition with competitive game formulation. However, authors could not address the load sensitive EMS management and other grid parameter control to enable reliable power delivery. In [44], a multi-objective energy management model was proposed for grid-connected hybrid energy system. Authors derived a Time-of-use Demand Side Management program to enable EMS while considering industrial load side demands. A Decision Support System (DSS) was developed in [45] to enable hourly energy management of a mix of RES. However, authors could not address the dynamic variation in load. Authors in [46] focused on energy maintainability of hybrid Renewable/Alternative Energy (RE/AE) power production scheme. They addressed the system configurations, production unit sizing, storage requirements, and energy management and control.

III. MAIN OBJECTIVE

Taking into consideration of the inevitable need of a robust load sensitive EMS control model for Hybrid-RES systems, in this research paper emphasis is made on enabling swift and efficient control decision by considering both non-linear power generation pattern as well as load side variations. Our proposed model, as Hybrid-RES encompasses Wind-Turbine Energy Conversion System (WECS) and PV cells as power generators, while Nickel-Cadmium batteries are considered as power storage device. Considering control mechanism to assist reliable power generation and transmission (say, delivery) to the customers, we emphasize on enabling efficient charging and discharging control of the EMS system where realizing power-system dynamics both the generation pattern as well as load side variations are taken into consideration. Unlike major existing approaches where either PI or PID controllers are used to control generator side parameters such as WT speed control or pitch angle control, or even EMS charging-discharging control, we have enhanced PID parameters using EC approaches. Non-deniably, the classical approaches with static PID parameters (i.e., gain parameters) can't be optimal for control functions, particularly under dynamic load or generation conditions. Realizing such limitations of the existing approaches and taking it as motivation, in our research enhanced EC schemes such as FPO and HSS optimization algorithm are applied to perform on-line PID parameter tunning to assist swift EMS control and stabilization. Some of the key contributions of this research paper are:

1. Hybrid-RES based Power system
2. Consideration of both the non-linear power generation patterns as well as dynamic load variations to control EMS functions
3. Enhanced EC algorithms (HSS) based PID parameter tuning to assist online EMS control.

The detailed discussion of our proposed research work and implementation is given in sub-sequent sections.

IV. SYSTEM MODEL

This section primarily discusses the key components of the proposed Hybrid-RES systems and algorithmic optimization to achieve optimal non-linear generation and load sensitive EMS control.

A. System Modeling

Typically, the hybrid system is considered to maintain a load power to be lower. In our proposed design WECS contains WT of 3kW power capacity. Similarly, the considered PV module is a single diode design having power generation capacity of 1kW. The difference between the power generated by RESs and the power required by the load over a period of time T can be minimized by means of sizing. In our hybrid-RES design a stand alone or public network connected with multi RESs are considered. 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 [47]. An illustration of hybrid-RES system containing WECS and PV modules is given in Fig.1. The considered simple structure, supplies power to the load continuously and facilitates a good charging and discharging control cycles of the battery.

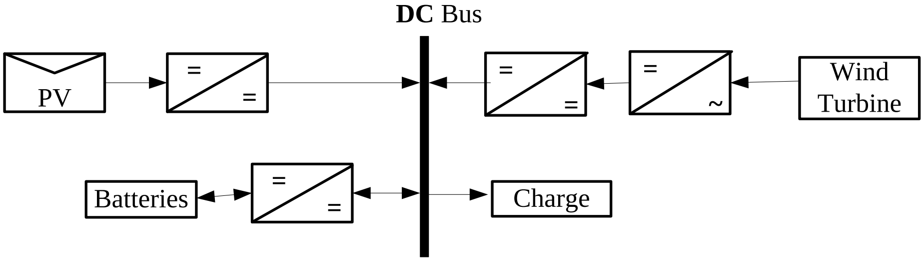

Fig. 1 Hybrid-RES system architecture

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

B.The DC bus

The coupling of the two RESs, PV and WT and additional components (say, supplementary sources) such as ESS or batteries is enabled through a DC bus, is illustrated in Fig. 2. The mathematical expression for the state model is given in equation (1).

$$\frac{dV_{DC}}{dt} = \frac{I_{pv} + I_{w} + I_{bat} - I_{ch}}{C_{DC}} \quad (1)$$

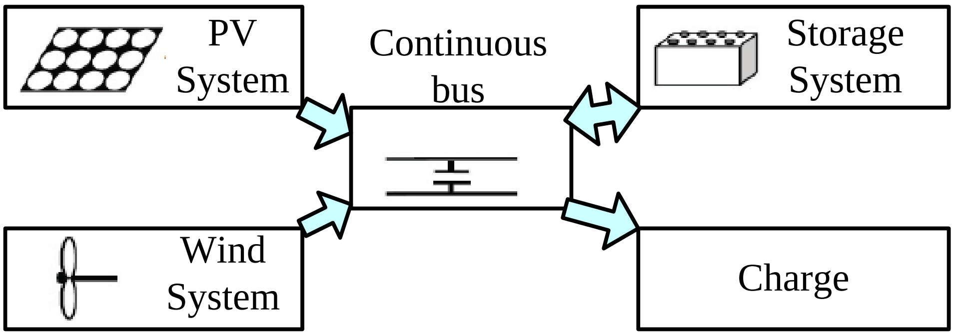

Fig. 2 Coupling of the different components, PV, WECS and Battery units using DC bus

V. ENERGY MANAGEMENT IN HYBRID-RES POWER SYSTEMS

In practice, the energy management of the different sources is one of the most intricate tasks in Hybrid-RES system. This is because of the non-linear generation pattern, voltage degradation in grid network and dynamic load variation. The overall proposed EMS system intends to optimize or augment the usage of the energy generated through the different RESs.

Some of the key objectives are given as follows:
- To fulfill dynamic energy demands from load side;
- To perform load sensitive adaptive charging-discharging control;
- To minimize charging and discharging cycles of the battery;
- To limit the excessive charging and discharging of the battery;
- To limit the discharging or loading of the battery above its maximum charge or discharge.

To accomplish above mentioned objective in this research work enhanced EC algorithms such as HSS is developed which assists PID controller’s parameter tuning that eventually lead optimal and swift control of the battery charging and discharging. Our proposed algorithm generates the degree of involvement of the distinct RESs to meet the demands from load side in terms of power. Retrieving dynamic knowledge about the required bus voltage, it becomes easy to achieve the current references for controlling individual RES. Further, the DC/DC converters assure the control of the currents of different RESs to the reference currents by maintaining the DC bus voltage fixed.

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A. 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), Integral Time absolute Error (ITAE), and Mean square Error (MSE). In this paper, we have applied ITAE reduction as the objective function to perform PID parameter tuning, where FAP and/or HSS 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 (2), which is obtained as the difference between the load power and the generated power.

$$ITAE = \int_0^\infty t|e(t)|\,.dt \qquad (2)$$

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 (2) characterizes the 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 HSS algorithm. 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.

B.HES and optimization model

As demonstrated in fig. 3, the proposed HES comprise a battery, an FC, and thermal and electrical loads. The thermal load is able to be provided via either a natural gas supply or the improved heat from the FC. The electrical load is able to be given through the main grid, FC, or the battery.

Reducing the working cost of providing stipulate for an single house is the major function of the energy management system (EMS). Operation scheduling is executed for single day or more before to efficiently employ accessible energy resources. The aim of this paper is to reduce single day-ahead working costs. It is unspoken that the HES elements have been already installed therefore installation costs are not measured.

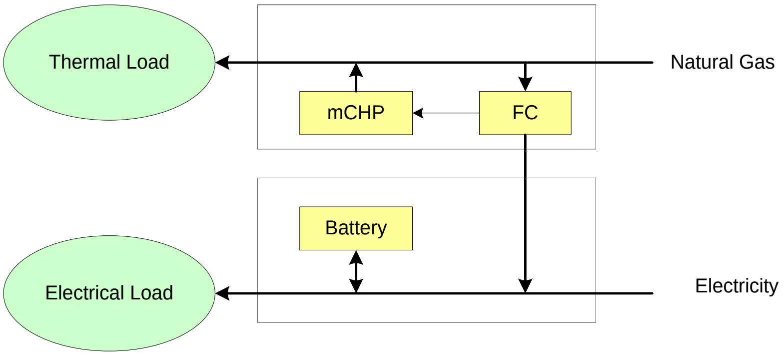

Fig. 3. Integrated HES

C. Objective function (OF)

The OF must be reduced so as to optimize the scheme:

$$OF = min\left(\sum C_{FC,i} + \sum C_{gas,i} + \sum C_{U,i} + \sum C_{B,i}\right) \qquad (3)$$

where every condition of this OF is given as follows [56,57]:

$$C_{U,i} = T \times MU_i \times C_{U_b} \times P_{U,i} \qquad (4)$$

$$C_{FC,i} = T \times C_{gas_b} \times P_{eFC,i/\eta FC,i} \qquad (5)$$

$$C_{gas,i} = T \times C_{gas_b} \times P_{gas,i} \qquad (6)$$

$$C_{B,i} = T \times C_{B_b} \times |P_{B,i}| \qquad (7)$$

The $P_{B,i}$ is negative in charging manner and positive in discharging manner. So as to have a positive battery working cost in its dissimilar operation methods, $C_{B,i}$ is estimated in relation to (7). Furthermore, if the FC starts up (shuts down) in a time break, the FC start up cost (shut down cost) is appended to (5).

D. Constraints of power balance

If no electrical load is permitted to be truncated, electrical and heat exacts must be fully fulfilled. Hence, the electrical power balance is able to be stated as:

$$P_{eFC,i} + P_{B,i} + P_{U,i} - P_{eL,i} = 0 \tag{8}$$

where $P_{B,i}$ stands for the electrical power of the battery that is able to be negative or positive in charging or discharging action methods, respectively. Like the electrical power balance, in case of no thermal storage device installation, the subsequent equation states the thermal power balance:

$$P_{gas,i} + P_{hFC,i} - P_{hL,i} = 0 \tag{9}$$

E. Constraints of devices

Every device has operation constrictions that must be met via the cost reduction process. The constrictions of FC and the battery are described in the following two subsections.

F. Battery operation constraints

Idyllically, if a battery is discharged/charged through $P_{B,i}$ in a time break, its energy is decreased/increased via $P_{B,i}$×T, as in practice, the energy minimization of discharging battery at the rate of $P_{B,i}$ is equivalent to $P_{B,i} \times T)/\eta_{dch}$ that is able to be simplified through assuming a time period of T = 1 h as follows:

$$w_i = w_{i-1} - \frac{P_{B,i}}{\eta_{dch}} \tag{10}$$

Likewise, if the battery soaks up $P_{B,i}$ in single time period, its charge level is raised through $P_{B,i}$×T×η_{ch} that is able to be stated as follows and assume that T=1h.

$$W_i = W_{i-1} + P_{B,i} \times \eta_{ch} \tag{11}$$

Obtainable energy in a battery is restricted through its capability in order that the condition of the battery charge cannot infringe the detailed margins, as stated through the subsequent disparity:

$$W_{min} < W_i < W_{max} \tag{12}$$

By means of drawbacks, the rates of battery charging and discharging are faced. The obtainable energy in the battery is reduced in a time period through $P_{B,i}$×T that is restricted to its highest value in the discharge manner. The subsequent disparity stated the drawbacks of the discharging rate for the battery:

$$\frac{W_i - W_{i-1}}{T} \leq P_{Bdch\ max} \tag{13}$$

In the same way, the subsequent disparity states the drawback of the charging method of the battery:

$$\frac{W_i - W_{i-1}}{T} \geq P_{Bch\ max} \tag{14}$$

VI. HSS ALGORITHM

Generally, optimization is a method of creating somewhat superior and is formed as follows:

$$min\{f(x)|x \in X\} \tag{15}$$

$$subject\ to : g(x) \geq 0;\ \ h(x) = 0$$

The least value of the OF, f(x), is establish via the optimization process exposed to a few constrictions that are classified as parity and disparity constrictions, h(x) and g (x), respectively. The value of the OF depends on the set of verdict parameters, x, maneuvering in the feasible range of values $X_{i,min} \leq x_i \leq X_{i,max}$. The HSS algorithm is a metaheuristic approach employed in non-linear optimization issues. The usefulness of this algorithm above the customary optimization techniques was illustrated The purpose of this technique to reduce the working cost of the energy scheme is explained in the next four stages:

A. Parameter initialization

This stage has a few factors that must be allocated through the consumer. These factors are N_{pop} (size of initial population), N_{SC} (numeral of hyper-sphere centers), and r^1_{min} , r^1_{max} , Pr^1_{angle} , r^2min, r^2max and Pr^2_{angle} which are explained in the next sections.

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B. Generation of initial population

Similar to other evolutionary algorithms, this algorithm, initiates by means of a first set of N_{pop} solutions that area arbitrarily produced. Every verdict factorx_i, is arbitrarily chosen as of $[X_{i,min}, X_{i,max}]$ by a uniform possibility. Every solution is known as a ‘‘particle” which is recognized through a vector by means of the dimension of N, $[p_1, p_2, \dots, p_N]$, and every one is a verdict variable. The OF value of a particle is decided through calculating the OF f at a particle, that is, $f\,(p_1, p_2, \dots, p_N)$. The battery power and the electrical power of the FC are free variables in every time period in order that, every power in each sections of the incorporated energy scheme is decided via knowing these two variables Hence, the working cost of the energy scheme is the function of these two free parameters in all time period. Taking into consideration two free parameters in all time period, the issue dimension is $N = 48$ through which the daily scheme operation cost is able to be estimated

C. Hyper-sphere center nomination

The particles are arranged on the basis of their OF values in rising order and the finest N_{SC} particles are chosen to be the hyper-sphere centers (SCs).

D. Particle distribution among hyper-spheres

N_{pop} particles are produced and their NSC is chosen as the SCs. The residual particles are shared amongst the SCs taking into account the SC dominance that is inversely relative to the OF value. The objective function difference (OFD) for every SC is explained as the dissimilarity between the OF value of that SC and the highest OF value of the SCs to separate the particles proportionally. i.e., also expressed as$OFD_{SC} = f_{sc} - max\{f(X)|X\ is\ an\ SC\}$. As a result, the normalized dominance of every SC is described through the next equation:

$$D_{sc} = |ODF_{sc}|/\left|\sum OFD_i\right| \qquad (16)$$

After that, the first numeral of particles which belong to an SC will be equivalent to round$\{D_{SC} \times (N_{pop} - N_{SC})\}$, selected randomly through every SC from the residual particles.

E. Searching

In this stage, a particle looks for a superior solution through searching the space restricted via a sphere. Sc is the center and r is the radius of this sphere i.e., the distance between the particle and the equivalent SC. Through altering the parameters of the particle in the spherical coordinates (namely $r\ and\ \theta$), the searching process is carried out. It must be noticed that in N-dimensional space, there should be $N - 1$ angles (θs) in spherical coordination that symbolizes a point. In the search method, every angle of a particle is altered via radians with the likelihood of Pr^1_{angle} . The variable α is arbitrarily chosen in all iteration among $(0, 2\pi)$ by means of a uniform sharing. The angle(s) of a particle is changed before the distance between the particle and the center is arbitrarily chosen between $[r^1_{min}, r^1_{max}]$ which is decided as the percentage of the r and it can be computed in an N-dimensional hyper-sphere is as follows:

$$r^2 = \sum_{i=1}^{N} \left(P_{i,\ center} - P_{i,\ particle}\right)^2 \qquad (17)$$

The search method of a particle in its search space is done once altering hs and r and estimating the OF. In the method of searching in its sphere, a particle might attain a place with a lesser OF value than its equivalent SC. In this condition, the SC labels and this particle are swapped. This state must be verified after the search process. Once searching the entire particles in their equivalent hyper-spheres, the SCs search in a same method in the sphere by employing the center of the SC. This search alteration is signified through $[r^2 min, r^2 max]$ as the drawbacks of the search radius, and Pr^2_{angle} as the likelihood of altering the SC angle. It must be noticed that r^2_{min} , r^2_{max} are decided as the percentage of r . In the space search, the values of the free parameters are altered. In every time period, the scheme constrictions must not be infringe their suitable range. The parameter must be customized in the condition where any constriction breaches the suitable range. The method of parameter customizations to reach entire scheme constrictions was described in [57].

F. Dummy particle recovery

A set of particles created through the every SC and its equivalent particles. Amongst entire particles, quite a few have biggest value of the OF and it is not predictable that they will attain the global lowest value of the OF. These types of particles are called dummy particles and are allocated to other SCs in this stage. Initially, the particle sets must be arranged in relation to their SOF (Set Objective Function) value to get the worst set through the dummy particles. The SOF value of a set is affected through the OF value of the SC and the particles as given as follows:

$$\mathrm{SOF} = \mathrm{f_{sc}} + \gamma\ \mathrm{mean}\{\mathrm{f_{particles\ \ of\ SC}}\} \qquad (18)$$

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A minute value for γ reasons the SOF value of a set to be decoded through the SC OF value, and rising γ will raise the function of the particles in deciding the SOF. In this research paper, γ is employed as the value 0.1. The process of dummy particle revival is formed through selecting a few of the dummy particles as of the hyper-spheres by means of the biggest SOF and allocating it to the additional SCs. For this reason, the diverse of SOF (DSOF) for every set is employed that is simply decided via the given equation:

$$\mathrm{DSOF} = \mathrm{SOF} - \max_{\mathrm{groups}}\{\mathrm{SOF\ of\ groups}\} \qquad (19)$$

By exploiting the computed DSOF, the particle is allocated to one of the SCs taking into consideration the assigning probability (AP) estimated for every SC, as given as follows:

$$\mathrm{AP} = |\mathrm{NTOF}| / \left|\sum \mathrm{NTOF}_i\right| \qquad (20)$$

The dummy particle is allocated to the i-th SC by means of the likelihood of AP_i. In brief the worst set which contains the highest SOF will misplace its dummy particle(s). This particle seeks the original SC amongst the entire SCs on the basis of their APs. It must be noticed that if an SC has no particles, it will be altered to a particle and an original SC will be establish by employing this process.

G. Determining new SCs and particles

At the final stage of all iteration, the entire particles and SCs are arranged in relation to their OF values and the finest ones are chosen as the original SCs for the other iteration and the residual particles are separated between these original SCs.

H. Convergence testing

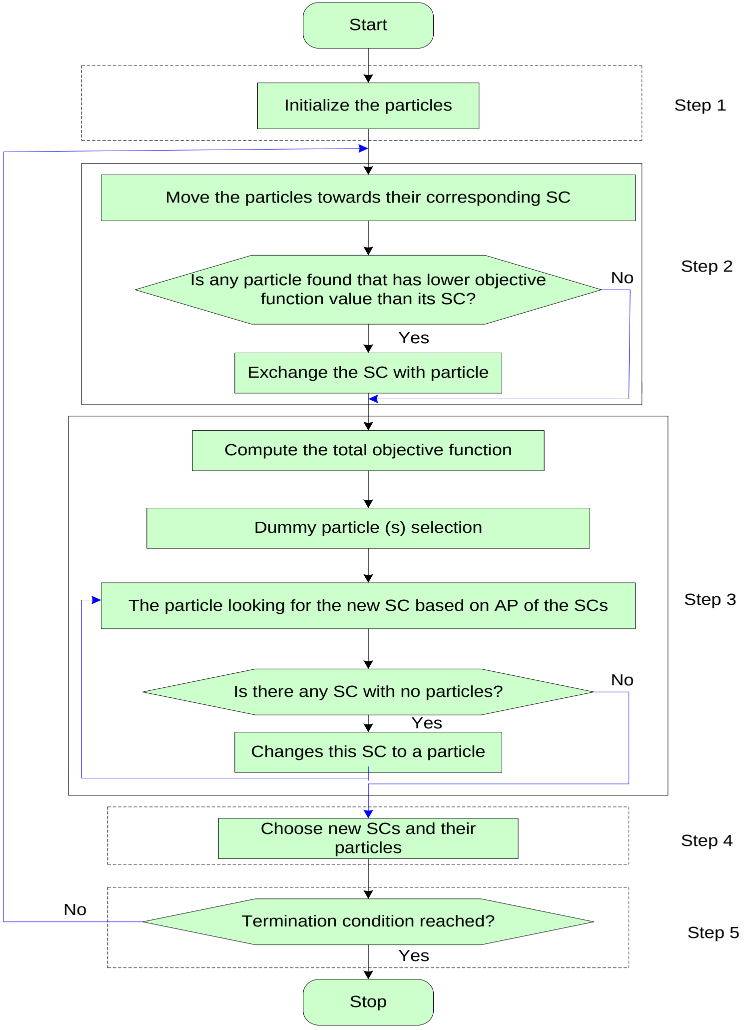

Fig. 4. Flowchart of HSS algorithm [58]

At last, the entire SCs excluding the finest one will be removed and the entire particles will be allocated to the finest SC. In this situation, there is roughly no dissimilarity between this SC and the particles. The algorithm is ended if the highest numeral of iterations is attained or the proportion of dissimilarity between the finest SCs in two resulting iterations becomes lesser than a fixed threshold. The flowchart of the proposed algorithm on the basis of five stages described above is illustrated in fig 11.

VII. CONTROL OF POWER CONVERTERS

A.Control of the PV string

The control of the PV string is created to control the output current i_l of the Buck converter linked to the PV source to a reference current $I_{l\ ref}$ is computed via the algorithm of management. Therefore, we employed a sliding mode control, where the sliding surface was selected in order to in balance:

$$I_l \rightsquigarrow I_{lref} \tag{21}$$

The sliding surface measured is given as follows:

$$S = I_l - I_{l\_ref} \tag{22}$$

Controlling the Buck converter have to guarantee the upholding and the attractiveness and to the sliding surface. This is attained through having at any time:

$$S\dot{S} < 0 \tag{23}$$

The combination of the equation (22) and (23) is given as follows:

$$\dot{S} = \frac{U * V_{pv} - V_{DC}}{L} \tag{24}$$

To guarantee the situation provided through (40), we select the control U in order to have:

$$\dot{S} = -K\mathrm{sign}(S) \tag{25}$$

with:

$$K > 0$$

$$\mathrm{sign}(s) = \begin{cases} 1 \text{ si } S \geq 0 \\ -1 \text{ si } S < 0 \end{cases}$$

Via joining

$$U = \frac{L}{V_{pv}}\left[\frac{V_{DC}}{L} - K\ \mathrm{sign}(S)\right] \tag{26}$$

In order to manage the duty cycle of the converter linked to the PV source, this control is applied.

B. The Control of the process of storage

The major function of the bidirectional converter is to control the charging or discharging of the battery (figure (5)) to either soak up the excess power provided through renewable sources or future necessities of the load if the power is insufficient. This quantities to sustain a voltage equal to the bus voltage reference V_{DC_ref}. After that we express the balance regime in:

$$I_l \rightsquigarrow -I_0 \tag{27}$$

$$V_{DC} \rightsquigarrow V_{DC\_ref}$$

Therefore, we select the sliding surface as given as follows:

$$S = k_1(I_l + I_0) + k_2(V_{DC} - V_{DC\_ref}) \tag{28}$$

By exploiting the sliding surface, we obtain superior control of the bus voltage and we ensure a superior management of the power transferred to the load.

Through obtaining the expression (28) and replacement via

$$\dot{S} = k_1\left(\frac{U * V_{bat} - V_{DC}}{L}\right) + k_2\left(\frac{I_l + I_0}{C_{DC}}\right) \tag{29}$$

$$U = \frac{L}{k_1 * V_{bat}}\left[\frac{k_1 * V_{DC}}{L} - k_2\left(\frac{I_l + I_0}{C_{DC}}\right)\right] - K.\mathrm{sign}(S) \tag{30}$$

VIII. RESULTS AND ANALYSIS

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 HSS is 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 HSS 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 HSS Algorithm.

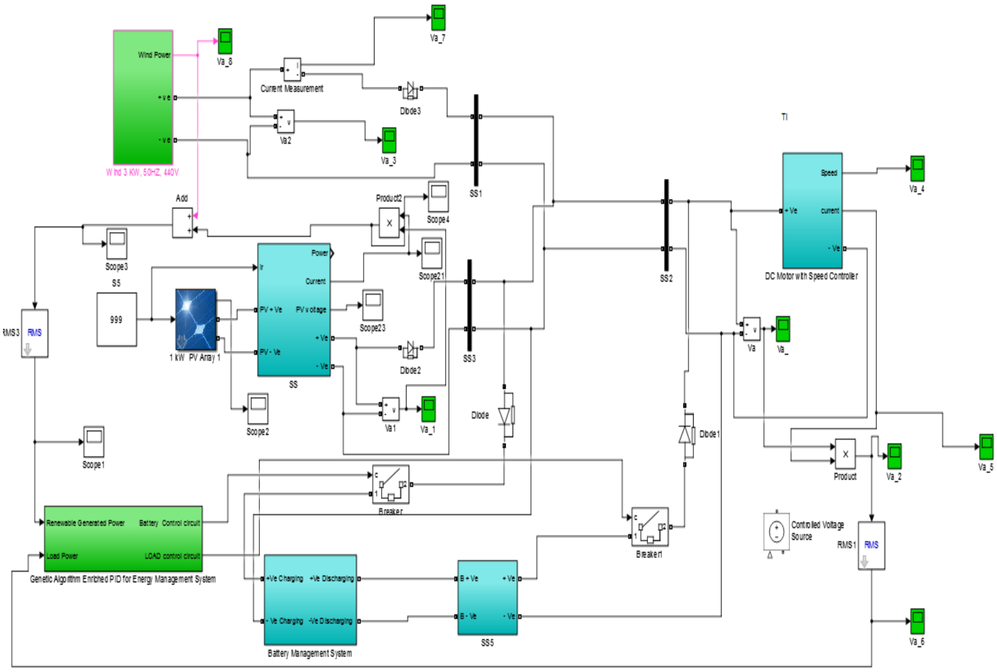

Fig. 5. Developed Hybrid-RES system comprising Wind-Turbine and Photovoltaic Cells

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. 15 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 Watts. The current generated from WECS is shown in Fig. 14. Here, the continuous 440 Volt power is generated (Fig. 15). 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. The comparison of the generated current and voltage can be found in Fig. 18.

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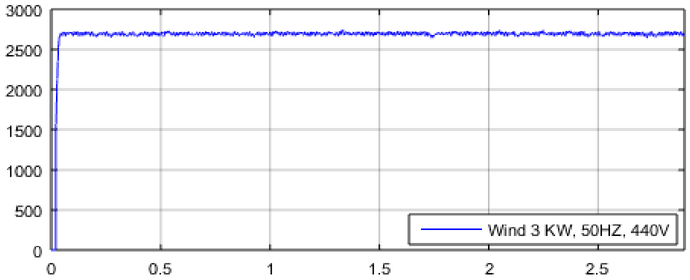

Fig. 6. WECS generated power (W) with classical PID control

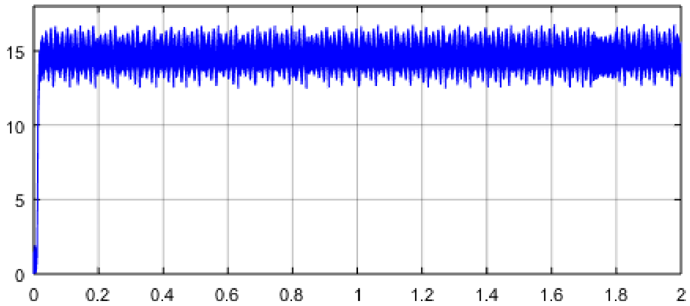

Fig. 7. WECS current output (A) with classical PID control

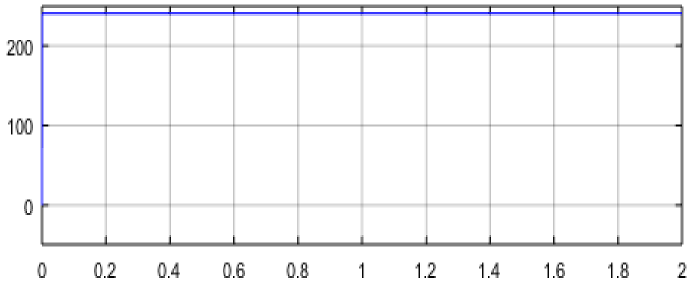

Fig. 8. WECS voltage output (V) with classical PID control

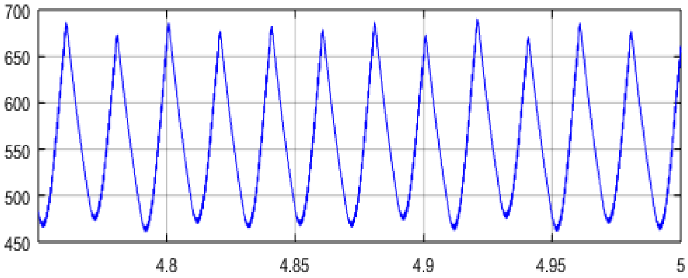

Fig. 9. PV cell generated power (W) with classical PID control

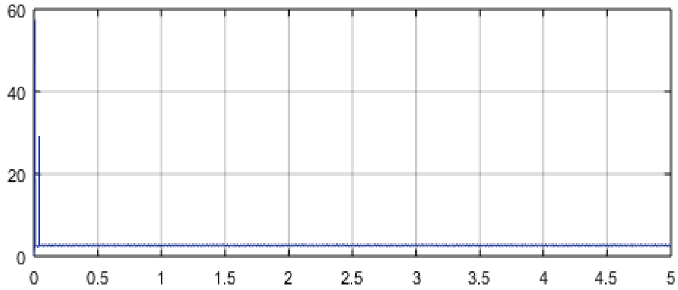

Fig. 10. PV cell generated current (A) with classical PID control

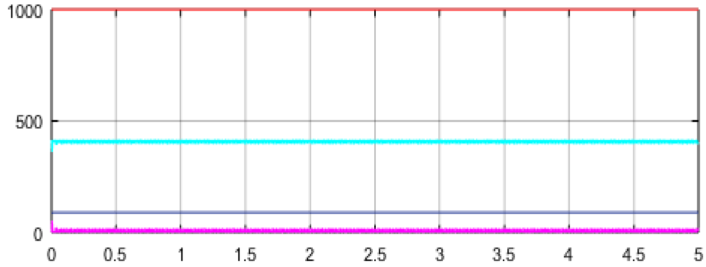

Fig. 11. PV cell generated (above) and current (below) (W) with PID

The overall generated power under varying or dynamic load condition is given in Fig. 12. The overall load sensitive power generation by Hybrid PV/WT RES system could be visualized in Fig. 13. Here, it can be found that as combined RES solution, it generates approximate 3.6kW of power at almost stable generation rate.

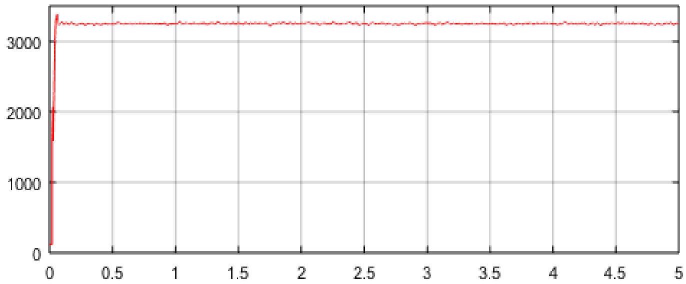

Fig. 12. Hybrid-RES generated power (W) with classical PID control

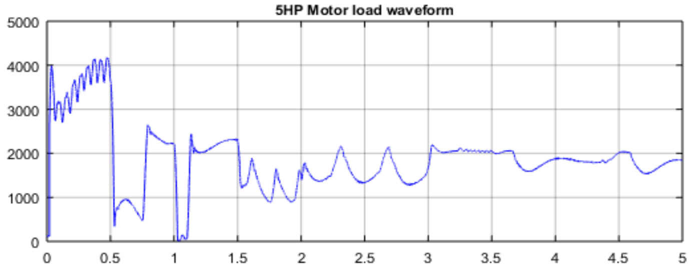

Fig. 13. Load side power (W) demand variation

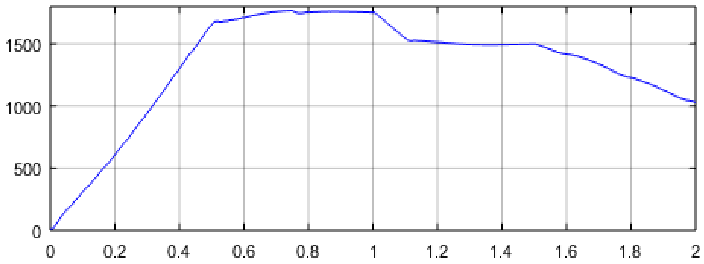

Fig. 14. Speed control (r/s) with reference to PID

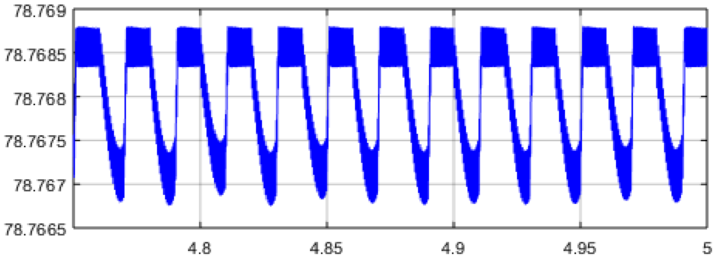

Fig. 15. Charging and Discharging control with reference to PID based EMS control

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B.HSS-PID TUNED HYBRID RES

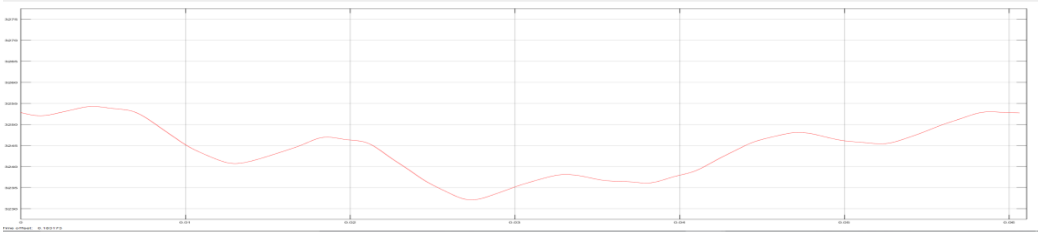

Fig. 16. Hybrid Generated Power of HSS-PID

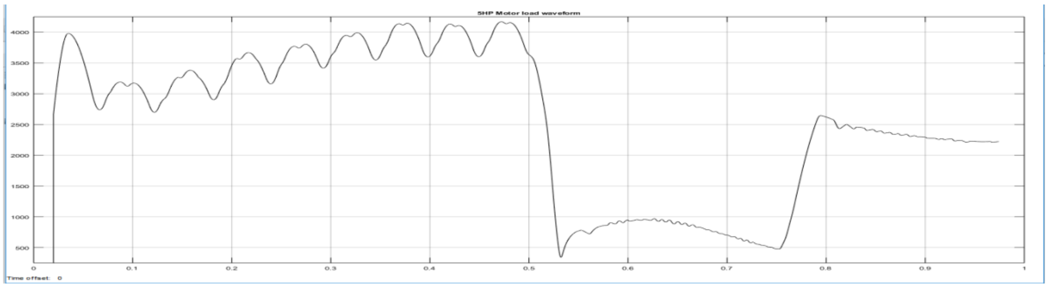

Fig. 17. Load Power of HSS-PID.

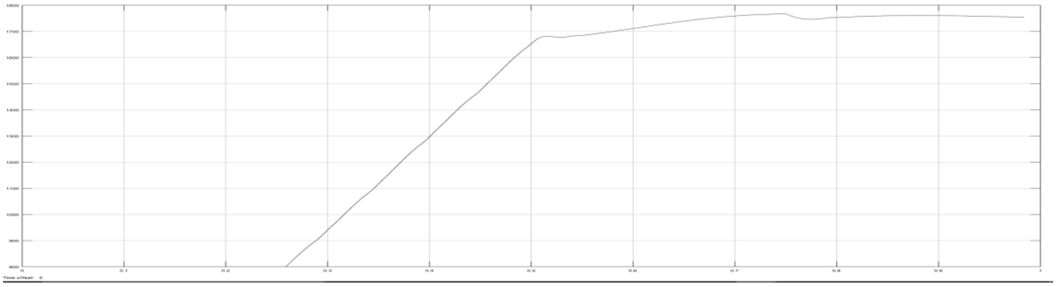

Fig. 18. Speed Control of Hybrid-RES with HSS-PID

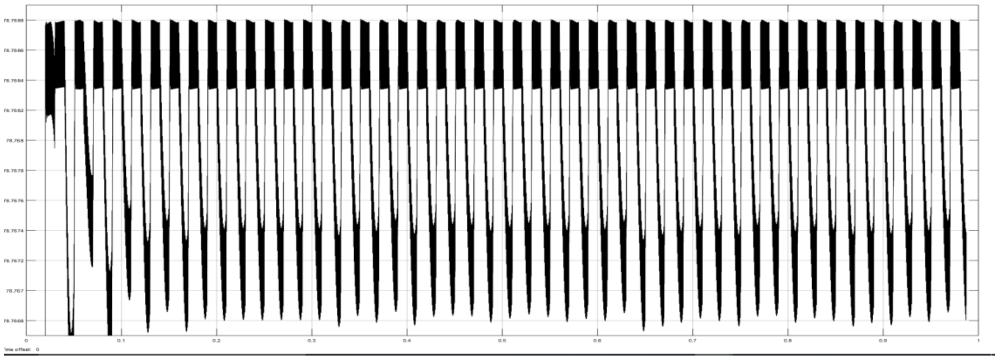

Fig. 19. Charging and Discharging of Hybrid-RES with HSS.

IX. CONCLUSION

Considering the of energy management system (EMS) in Hybrid-Renewable Energy Sources (RES), in this research work a robust load-sensitive EMS control model was developed for PV-Wind Turbine RES system. Unlike traditional approaches, in this work both non-linear generation and dynamic load variations were taken into consideration to perform charging and discharging control of the Nickel-Cadmium battery based EMS, called BEMS. It has enabled proposed system to schedule or execute control functions as per load demands that ultimately enables generator side control such as wind-turbine control to achieve maximum power point to meet dynamic load demands., However, to alleviate the issue of online PID parameter tuning for efficient charging and discharging control of the EMS, evolutionary computing algorithm named HSS (Hyper Sperical Algorithm) have been applied. The PID parameter

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tuning (or optimization) makes overall control decision swift and efficient that eventually alleviates the probability of the power outage and faults. Simulation results affirm that the proposed HSS based PID controller provides more stable and efficient (quality) power delivery irrespective of generator side fluctuation and dynamic load demands. 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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