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FPA Based Power Quality Improvement for Hybrid Renewable Energy systems

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ABSTRACT:- This Paper represents the need of Hybrid Energy system and the usage of Evolutionary algorithm for Hybrid Renewable Energy system.Nowadays Hybrid Power system like Wind-Turbine/PV is preferred because of reliability and cost effectiveness.But in order to maintain the Reliability, Renewable energy sources requires energy storage devices like Batteries .During the faults or load variation or poor quality power generation energy storage devices plays an crucial role,by discharging the suitable amount of power in order to balance the generation and load.In these paper we are controlling both generation side as well as load side through EMS. Unlike traditional control measure, our proposed system uses enhanced evolutionary computing algorithm such as Flower Pollination Algorithm (FPA) to enable optimal PID tunning so as to enable dynamic charging and discharging control of the EMS in proposed Hybrid-RES system. Overall simulation results signify that the proposed FPA-PID based control model enables efficient generator side control and load sensitive EMS control to enable reliable power delivery.

Keywords:- Flower Pollination Algorithm,Hybrid Renewable Energy System,Energy Management System,PID Controller,Wind Turbine,PV Module.

I. INTRODUCTION

The socio-economic growth in India as well as global social-horizon has led the exceedingly rising demand for power sources to meet residential, commercial and industrial requirements. Today's augmenting power demand; power crises because of conservative sources and impact of conservative source on atmosphere are a few of the causes for giving extra concentration towards Renewable Energy Sources (RESs). RESs such as wind and solar proffers another source of energy that are in universal pollution free, technically effectual, and atmospherically maintainable and supplies electricity without providing rise to carbon dioxide emissions [1]. The estimated future shortage in fossil fuels, ecological concerns, and proceeds in smart grid [2] techniques arouse the increasing diffusion of RE. Reflecting through some statistics, researches depicts that facilitating entire energy requirements of the US can be availed through RE [3]. Additionally, a recent survey by National Renewable Energy Laboratory (NREL), revealed that almost 80% of the entire electricity need of countries like U.S. can be availed through RESs till 2050 [4]. The high diffusion of RE is particularly familiar in remote grids, or Micro-Grids (MG) with tiny carbon footprints [5]. Mainly RESs are highly sporadic in nature. In different geographical places, the accessibility of such energy sources differs significantly in dissimilar environmental places. In the similar place, the quantity of production also oscillates dependent on the time of day, season, and climate situations. A grid with elevated RE diffusion requires to construct enough energy storage, to make sure an continuous supply to end consumers and create the finest employ of produced energy [6][7]. The different categories of energy storages are namely, super- capacitors, flywheels, chemical batteries, pumped hydro, hydrogen, and compressed air [8-13]. And all categories have different features, e.g., round-trip energy efficiency, highest capacity/power rating, energy loss over time, and investment/operational costs. Though there has been research on prediction and/or working a precise kind of energy storage method for remote electricity grids [14]–[17], 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.

Additionally, in recent years RES has gained immense attention across industries to meet environmental friend energy provision. Though, facilitating cost efficient and reliable power transmission has always been an open research area for academia-industries. In major research efforts either single RES type energy source is taken into consideration or merely traditional control strategies are applied for EMS purposes. Considering a cost effective solution integrating different RES systems can be of paramount significance. Meanwhile, enriching the integrated or hybrid RES system can be significant for a cost efficient power supply. A robust and efficient EMS system in conjunction with hybrid RES system can play a vital role to provide cost effective and reliable power transmission.Evolutionary algorithm like Flower Pollination is used for tuning the PID Parameters ,through which charging and discharging of Batteries are controlled, thereby providing the required power during outages .

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 [23] 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. To enable coordination of the power swap among multiple MGs and distribution network, authors derived an Interactive Game Matrix (IGM). In [24] 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 [25], 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 [26] authors developed EMS control model to be used in hybrid RES system. Additionally, a control model to deal with system nonlinear was developed in [26]. Authors in [27] 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 [28] 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 [29] 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 [30], 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 [31] developed control model that considers micro-grid parameters to derive control decision. In [32], 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 [33] to enable efficient EMS. A meta-model plan for hybrid RES based power system was developed in [34] where authors applied two types of storage i.e. electric and hydraulic tools. Demand Response (DR) strategy based energy management model was developed in [35]. Their proposed model exploited energy demands from load side and MGs voltage profile to control EMS for enabling secure power delivery.

III. SYSTEM MODELING

Hybrid Systems-A Combination of Wind,Solar,Convertor,Battery Bank with Load provides much efficiency compared to other system.In order to Maintain the Realibity they are provided with Batteries which acts during outages or load variations or gaults. The main design lies here is the consideration of charging and Discharging of battery through Evolutionary algorithm approach, which is explained in detail in the following sections.

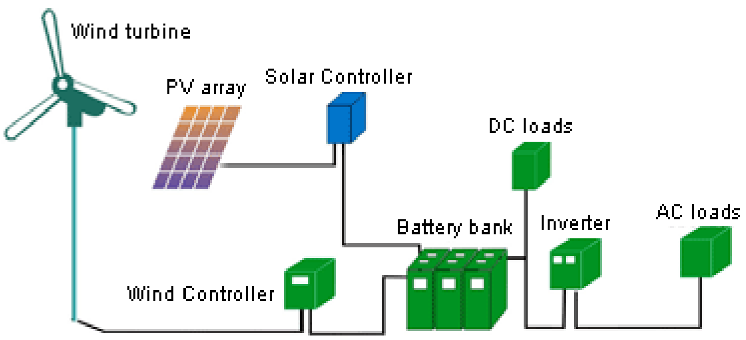

Fig. 1. System Modeling of Hybrid RES

IV. ENERGY MANAGEMENT IN HYBRID-RES POWER SYSTEMS

A.EMS Control systems

Undeniably, controlling EMS charging and discharging is a highly intricate but inevitable task. Here, these functions operate on the basis of certain conditions and system states such as generation patterns and the load side demands. To perform it, certain rules are required to be incorporated based on which the instant system state can be obtained and accordingly charging-discharging control could be performed. For illustration, in WECS a functional speed control unit employs the data of the knowledge about the speed of the motor shaft and compares it with the reference data based on which it executes rules to increase or decrease the power of the motor. Similarly, in charging-discharging control of the EMS system exploring load information plays decisive role. Unlike traditional approaches where merely the load variation is taken as input to decide charging-discharging control, in our model both power generation pattern as well as load dynamics are taken as input to perform scheduling of the charging and discharging. To achieve it, we have applied PID controller due to its ability to perform swift control decision in real-time environment.

B. 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 [54]. In our proposed EMS control model PI controller with EC based parameter tuning is applied.

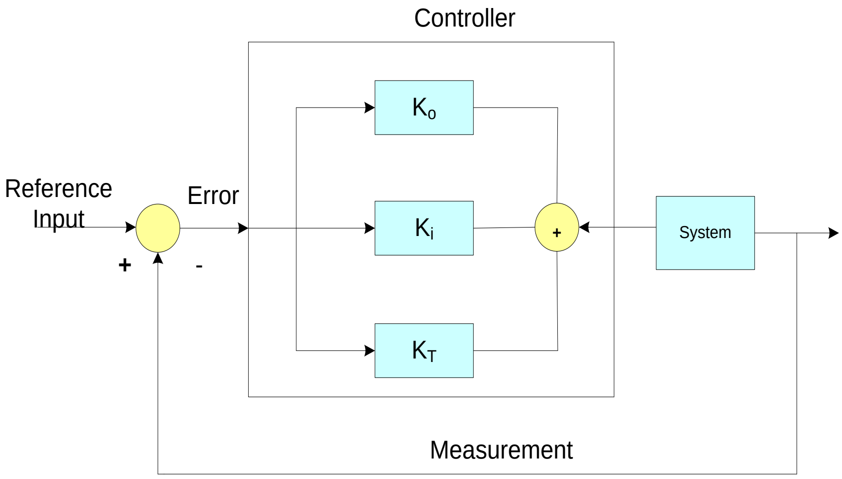

Fig. 2 Schematic of PID controller

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

$$G_{Controller} = K_D + K_T s + \frac{K_i}{s} \quad (2)$$

p(1)=1
(3)

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 different enhanced EC algorithms such as FPA and HSS to perform PID parameter running in real-time environment. A symbolic function of EC based PID tuning is illustrated in Fig. 8.

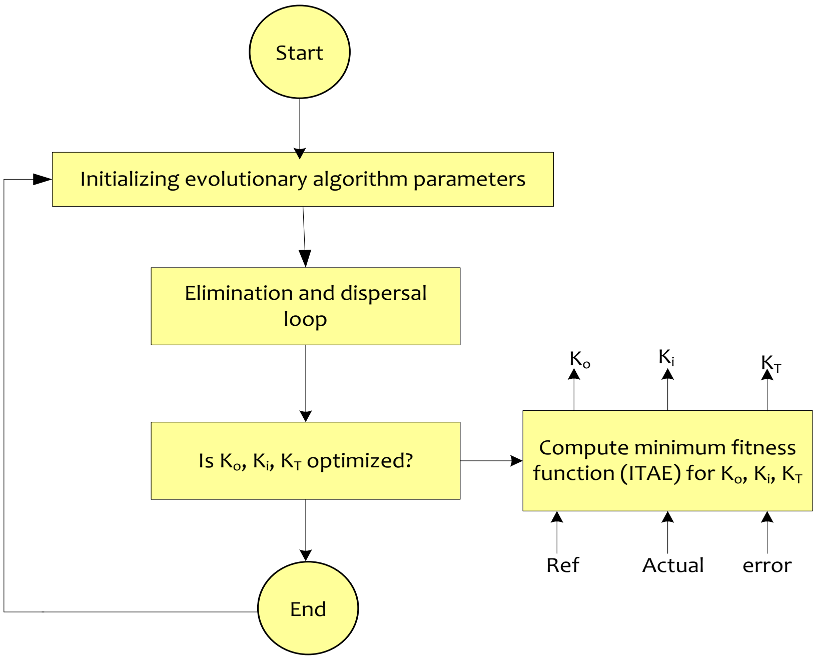

Fig. 3 Evolutionary Computing based PID parameter tunning for load sensitive EMS control

Being evolutionary computing algorithm, FPA requires an objective function to perform PID parameter tunning. 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 tunning parameters. A brief of the ITAE objective function is given as follows:

C. 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 (4), which is obtained as the difference between the load power and the generated power.

$$\mathrm{ITAE} = \int_0^{\infty} t|e(t)|\,.\,dt \qquad (4)$$

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 (4) 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 FPA and HSS 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.

D. Evolutionary Computing Algorithms

Generally, Evolutionary Computing (EC) algorithms are derived from the natural phenomenon such as FPA is based on flower pollination; HSS is based on spherical search. Similarly, other EC algorithms such as Ant Colony Optimization (ACO), Bee Foraging Optimization (BFO), Genetic Algorithm (GA) too employs respective natural behaviour to obtain certain optimal or sub-optimal solution. Especially, these algorithms become inevitable in case of NP-Hard problems. Considering present study, where emphasis is made on obtaining the best PID tuning parameters to perform charging and discharging control of the EMS system so as to enable dynamic or load sensitive controllability. Amongst major solutions available (say, random PID parameters as population), EC algorithms can help in retrieving the best solution to achieve efficient and swift control of charging and discharging of the battery systems. A brief of the EC algorithms; FPA and HSS is given as follows:

E. Flower Pollination Algorithm (FPA)

In the year 2012, yang was found FPA, enthused through the flow pollination procedure of flowering plantations. The rules of FPA are given as follows.

- ✓ Rule1: Biotic and cross-pollination is able to be measured as a procedure of global pollination method, and pollen-carrying pollinators go in a manner that obeys Le'vy flights.
- ✓ Rule 2: A biotic and self-pollination are employed for local pollination.
- ✓ Rule 3: Pollinators for example insects is able to develop flower dependability that is equal to a reproduction probability, which is proportional to the comparison of two flowers engrossed.
- ✓ Rule 4: The communication or changing of local pollination and global pollination is able to be managed through a switch probability$p \in [0,1]$, by exploiting a slight bias toward local pollination.

These rules are converted into the updating equations so as to formulate updating formulas. For instance, in the pollination step, flower pollen gametes are took through pollinators for example insects, and pollen is able to go above a long distance since insects is capable of fly and go in a extra longer range [55]. Thus, rule 1 and flower dependability is able to be signified mathematically as:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - \mathcal{B}) \quad (5)$$

where x_i^t signified as the pollen i or solution vector x_i at iteration t, and B signifies the present finest solution establish amongst every solutions at the present iteration. The scaling factor is γ to manage the step size. Additionally, $L(\lambda)$ is the parameter that matches to the potency of the pollination, which is fundamentally as well the step size. Because insects might go above a long space with a variety of distance steps, to reproduce this feature professionally, we can employ a Le'vy flight. i.e, from a Levy sharing, we draw L>0:

$$L \sim \frac{\lambda \Gamma(\lambda) \sin(\pi\lambda/2)}{\pi} \frac{1}{S^{1+\lambda}}, (S \gg S_0 > 0) \quad (6)$$

where Γ (λ) stands for the standard gamma function and this sharing is applicable for big steps s > 0.
After that, to form the local pollination, both Rule 2 and Rule 3 are able to signify as:

$$x_i^{t+1} = x_i^t + U\left(x_j^t - x_k^t\right) \quad (7)$$

where x_j^t and x_k^t are pollen from dissimilar flowers of the similar plant species and it is fundamentally reproduces the flower dependability in a restricted area. Scientifically, if x_j^t and x_k^t are from the similar species or chosen from the similar population, this equally becomes a local arbitrary walk if we draw U as of a standardized sharing in [0, 1]. However the flower pollination behavior is able to happen at every scale, both local and global, adjacent flower patches or flowers in the not-so-far-away area are extra possible to be pollinated through local flower pollen than those distant. So as to reproduce this, we are able to fruitfully employ the switch probability like in Rule 4 or the propinquity probability p to change between usual global pollination to intensive local pollination. In the beginning, we can utilize a naïve value of $p = 0.5$ as at first value. A beginning parametric illustrated that $p = 0.8$ may work superior for most functions [55].

In figure 4. Demonstrates the pseudo-code of fundamental levels of FPA.

Flower Pollination Algorithm [55]
Define objective function $f(x), x = (x_1, x_2, \ldots\ldots, x_d)$
Initialize a population of n flowers/pollen gametes with random solutions
Find the best solution Bin the initial population
Define a switch probability $p[0, 1]$
While $(t < MaxGeneration)$
For $i = 1{:}\,n$ (all n flowers in the population)
if $rand < p$,

Draw a (d-dimensional) step vector L which obeys a Lévydistribution Global pollination via $x_i^{t+1} = x_i^t + L(B - x_i^t)$
else
DrawUform a uniform distribution in [0,1]
Do local pollination via $x_i^{t+1} = x_i^t + U(x_j^t - x_k^t)$
end if
Evaluate new solutions
If new solutions are better, update them in the population
end for
Find the current best solution B
end while
Output the best solution found

Fig. 4. Algorithm for FPA

F. HES and optimization model

As demonstrated in fig. 10, 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.

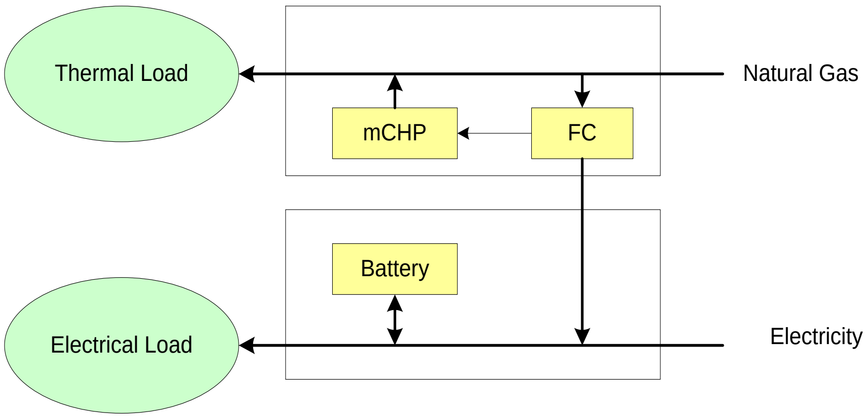

Fig. 5. Integrated HES.

G. Objective function (OF)

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

$$OF = \min\left(\sum C_{FC,i} + \sum C_{gas,i} + \sum C_{U,i} + \sum C_{B,i}\right) \tag{8}$$

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

$$C_{U,i} = T \times MU_i \times C_{U_b} \times P_{U,i} \tag{9}$$

$$\mathrm{C_{FC,i}} = \mathrm{T} \times \mathrm{C_{gas_b}} \times \mathrm{P_{eFC,i/\eta FC,i}} \tag{10}$$

$$\mathrm{C_{gas,i}} = \mathrm{T} \times \mathrm{C_{gas_b}} \times \mathrm{P_{gas,i}} \tag{11}$$

$$\mathrm{C_{B,i}} = \mathrm{T} \times \mathrm{C_{B_b}} \times |\mathrm{P_{B,i}}| \tag{12}$$

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, $\mathrm{C_{B,i}}$ is estimated in relation to (11). Furthermore, if the FC starts up (shuts down) in a time break, the FC start up cost (shut down cost) is appended to (9).

H. 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:

$$P_{eFC,i} + P_{B,i} + P_{U,i} - P_{eL,i} = 0 \quad (13)$$

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:

$$P_{gas,i} + P_{hFC,i} - P_{hL,i} = 0 \quad (14)$$

I. 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.

J. Battery operation constraints

Idyllically, if a battery is discharged/charged through $P_{B,i}$ in a time break, its energy is decreased/increased via $P_{B,i}\times T$, 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:

$$w_i = w_{i-1} - \frac{P_{B,i}}{\eta_{dch}} \quad (15)$$

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

$$W_i = W_{i-1} + P_{B,i} \times \eta_{ch} \quad (16)$$

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:

$$W_{min} < W_i < W_{max} \quad (17)$$

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 $P_{B,i}\times T$ that is restricted to its highest value in the discharge manner. The subsequent disparity stated the drawbacks of the discharging rate for the battery:

$$\frac{W_i - W_{i-1}}{T} \le P_{Bdch\ max} \quad (18)$$

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

$$\frac{W_i - W_{i-1}}{T} \ge P_{Bch\ max} \quad (19)$$

IV. 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 FPA 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 FPA 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 FPA based EMS control

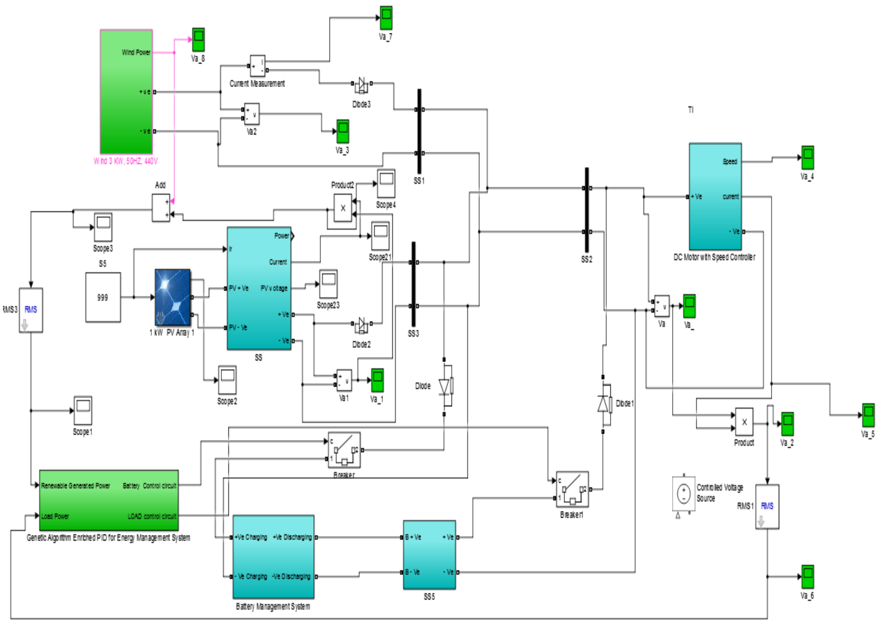

Fig. 6. Developed Hybrid-RES system comprising Wind-Turbine and Photovoltaic Cells

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.

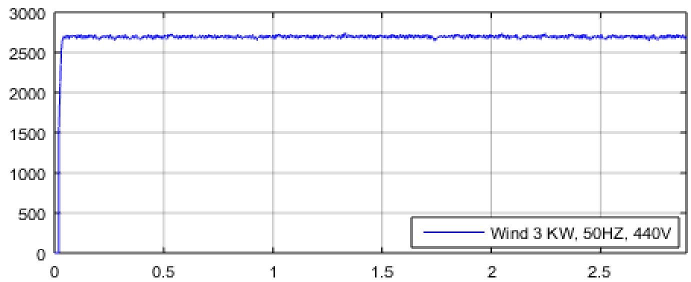

Fig. 7. WECS generated power (W) with classical PID control

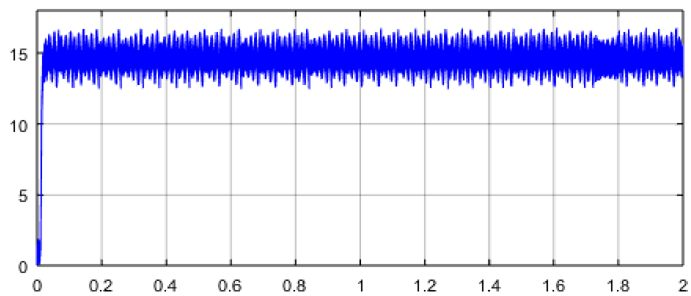

Fig. 8. WECS current output (A) with classical PID control

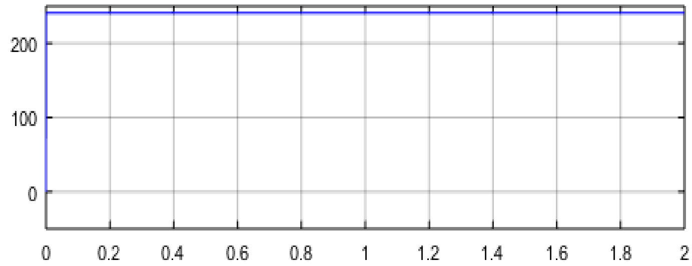

Fig. 9. WECS voltage output (V) with classical PID control

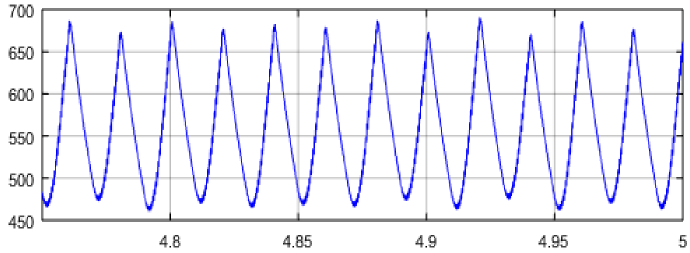

Fig. 10. PV cell generated power (W) with classical PID control

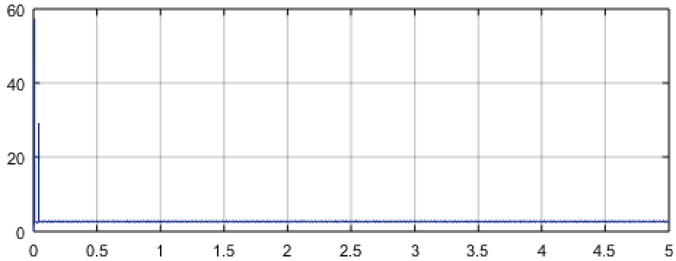

Fig. 11. PV cell generated current (A) with classical PID control

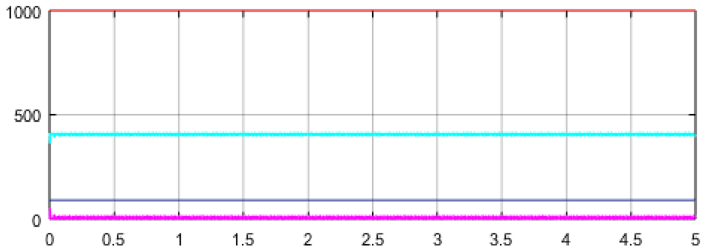

Fig. 12. PV cell generated (above) and current (below) (W) with PID

The overall generated power under varying or dynamic load condition (Fig. 20) is given in Fig. 19. The overall load sensitive power generation by Hybrid PV/WT RES system could be visualized in Fig. 19. Here, it can be found that as combined RES solution, it generates approximate 3.6kW of power at almost stable generation rate. The robustness of the proposed model could be visualized through the generation control under varying load (Fig. 20). Here, it can be easily visualized that the proposed EMS control model assures efficient power generation by controlling speed or WECS system by considering load side variations. 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. 21.

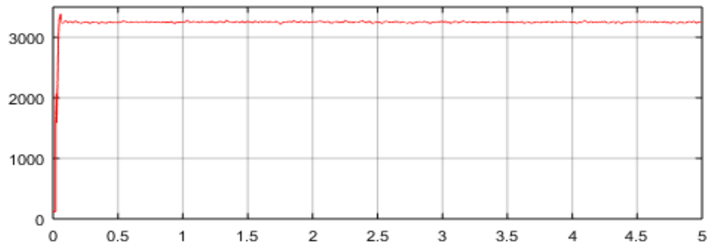

Fig. 13. Hybrid-RES generated power (W) with classical PID control

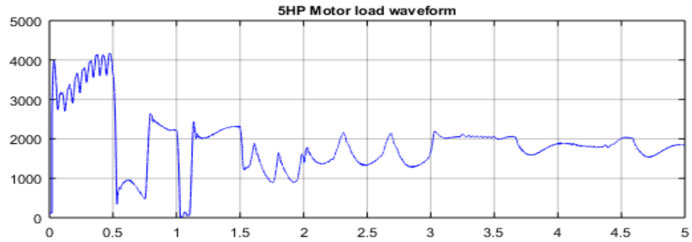

Fig. 14. Load side power (W) demand variation

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. 23.

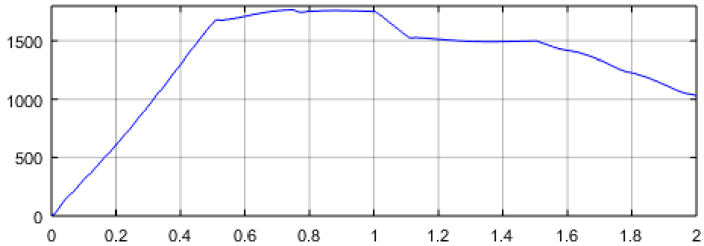

Fig. 15. Speed control (r/s) with reference to PID

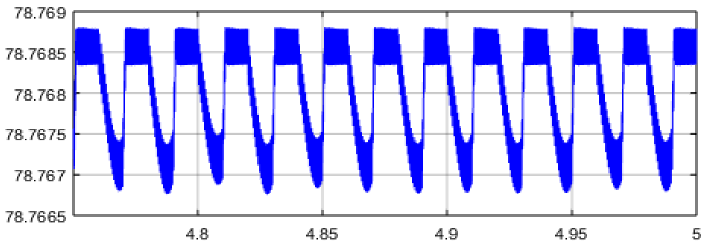

Fig. 16. Charging and Discharging control with reference to PID based EMS control

B.Classical FPA Based PID Controller

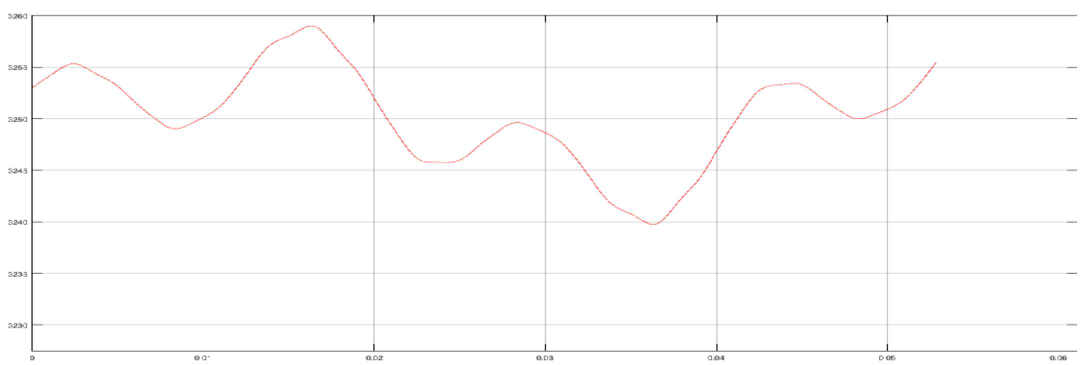

Fig. 17. Hybrid RES generated Power with FPA Based Algorithm

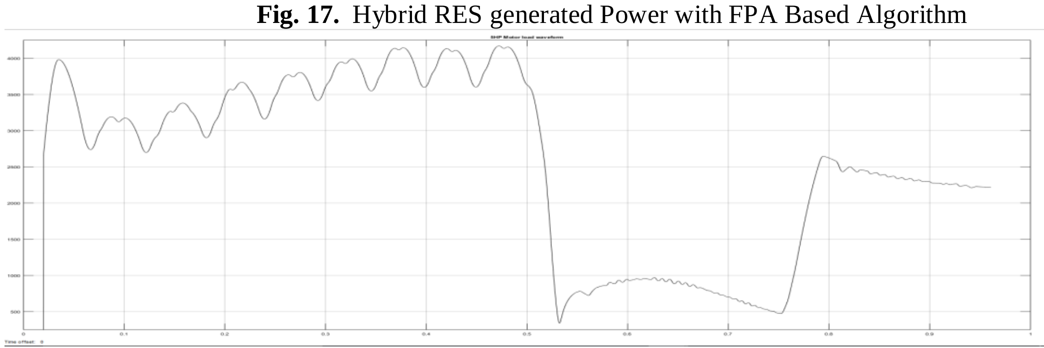

Fig. 18. Load Power with FPA Based Algorithm

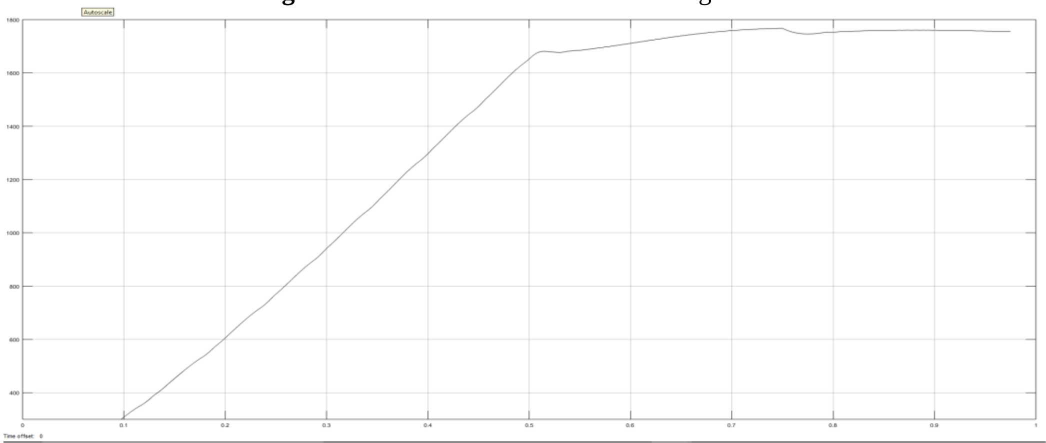

Fig. 19. Speed Controller with FPA based Algorithm

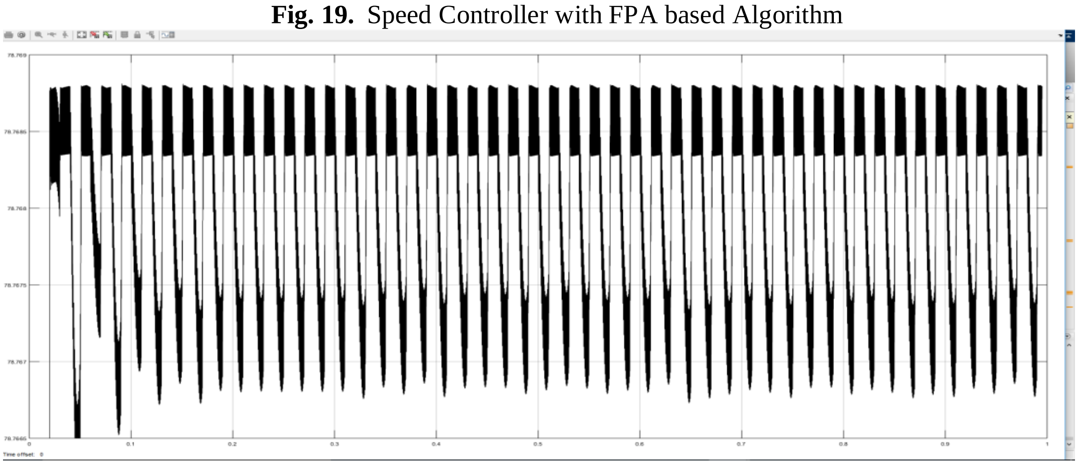

Fig. 20. Charging and Discharging Control with FPA Based Algorithm

V. CONCLUSION

Considering the Importance of Energy Management system in Hyrbid Renewable Sources,the efficient Hybrid Power system is developed.Here the control of charging and Discharging of Batteries is done through the tuning of PID Parameters ,in which the FPA Algorithm is used for tuning the PID Parameters as explained.Results revealed that the Quality of Power generation is increased through FPA Algorithm Compared to an PID Controller.In the future More efficient algorithm would be revealed thereby increasing the Power quality.

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