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Sensitivity Analysis of Load Frequency Control Problem considering impact of Wind Penetration using improved Harris Hawks Optimizer

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***Abstract:** This paper suggest a new technique known as Harris's Hawk Optimizer which is used to solve multi objective constraints. This optimizer is predicated on gray wolf multi objective optimisation approach and intended by symbiotic trapping behavior of Harris's Hawk. These hawks are called as wolf bundle of azure. Here in this paper the sensitivity analysis to judge robustness with Harris hawk optimization technique for load frequency control is effectually and consistently presented. The result indicates unimodel and multimodel for various benchmarking functions examining sensitivity analysis and the valve point loading effect. The concluding results gained using improved HHO are compared with other algorithms and found to be encouraging.*

***Keywords:** Benchmark test functions, Multidisciplinary Engineering Design Optimization, Harris Hawks Optimization, sensitivity analysis.*

I. INTRODUCTION

The main problem in Load Frequency Control (LFC) is that they are interconnected power system and its operation. The power demands are increasing day by day due to their huge size, modification in arrangement, renewable energy sources and upcoming uncertanities[1]. Analysis of Automatic Generation Control, a large interconnection between the various areas plays an important role in power system. Scientists have invented many number of controlling plans to maintain the load frequency to get better outcomes[2].

As per above discussion, few key points of the present work:

1. To get constant power in the system
2. There should not be exceeding of the generators limit and Tie-lines limit.
3. There must be constant frequency all the time, frequency should not change by the load.[2]

The valuable research contributions proposed lots of Automatic Generation Control (AGC) problems as well as solutions, like AGC controller, special qualities, excitation and AC/DC links in parallel transmission.

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The recent approach in AGC has been proposed in support with Genetic Algorithm, Fuzzy logic, etc[3].

The foremost part is the frequency control in automatic generation control which can be maintained through governor but it also needs to be managed with tethered signals directly proportional to the frequency[3]. Automatic generation control is eminent and crucial for transmission, distribution and generation of the electrical supply that is maintained with power quality under the tolerable range[4].

1.1 Architecture of Power System Control

The transmission, distribution and generation are the main aspects in the field of electrical power. Power system needs to be first configured and designed, remote control units and data acquisition system for accurate and reliable operation and control of electrical power usage[5]. A well-equipped information technology and the services to control the centers. There are lots of instability problems occur day by day like rotor angle, voltage and frequency that can totally damage the whole system if not managed properly after the power system being addressed to a disturbance.

1.2 Load Frequency Control (LFC) problem in Power System

The generation and the distribution problems arise due to instability and performance. The huge deviation in the frequency can damage the whole system and produce malfunction. The purpose of automatic generation control keeps the frequency in a controlled range so that the system runs smoothly without any disturbance. The thermal power plants can be controlled with heat balance data. When the boiler produces enough heat to transfer it to the next level it pressurized the condensed air and then it transfers to the high pressure valve and low pressure valve to get the required pressure at the output side[6].

This below schematic diagram shows the full operation of load frequency control and automatic generation controller. Steam can be used to run the turbo generator with converting the low pressure into high pressure. Now the high pressure runs the generator and the generator provides the required output, which require for transmission and distribution by keeping the frequency constant using the frequency sensor.

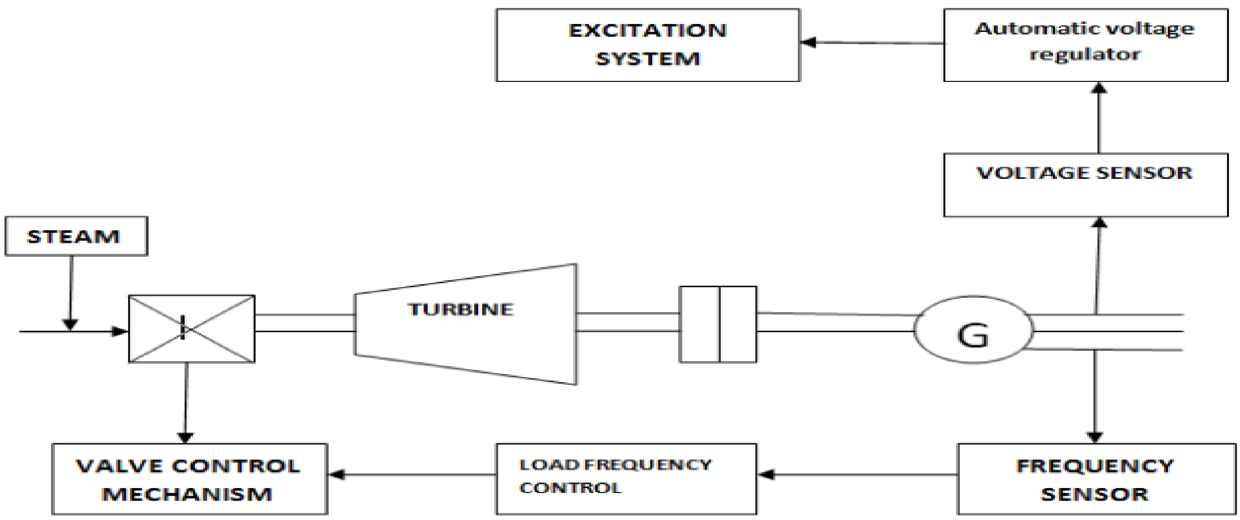


Fig-1 LFC and AVR representation of synchronous generator.

II. TYPES OF CONTROL APPROACHES

There are two types of control system.
(i) Load Frequency regulator/control
(ii) Automatic Generation regulator/control

2.1 Load Frequency Control

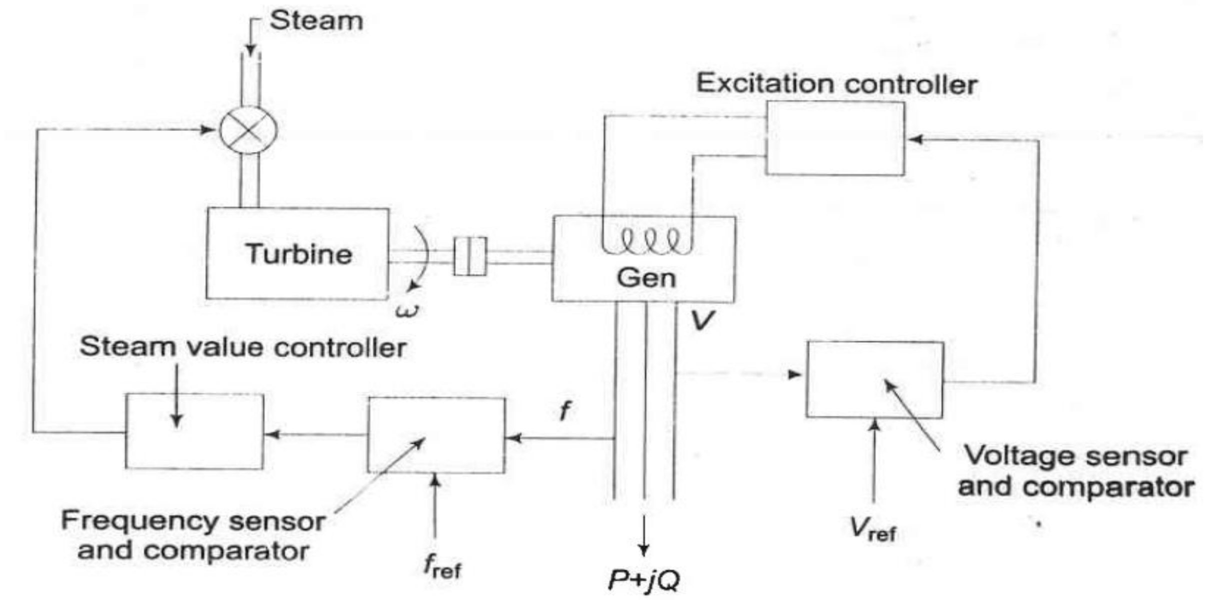


Fig-2 Excitation voltage and load frequency of turbo-generator.

Power system operations vary all the time, they are not steady in nature. Real and imaginary power always change because of the imbalance in transmission power due to increasing and decreasing fashion in power or it can be expressed as fluctuations in the power supply. Load demand alteration can be point out: (i) slow variations in average demand, and (ii) fast random variation around the average[7]. To get the idea of Load frequency control let's look upon a case of controlling output power of the generator of a closely knit electric area so that a constant frequency can be maintained. All generators are connected together with each other to get the required output to keep the power angles at a specific range. This portion is called control area. Termination of control management area generally coincides with an individual electricity board company[7]

To grasp the meaning of load frequency control, let's take a case with separate load is supplied to a single turbo-generator.

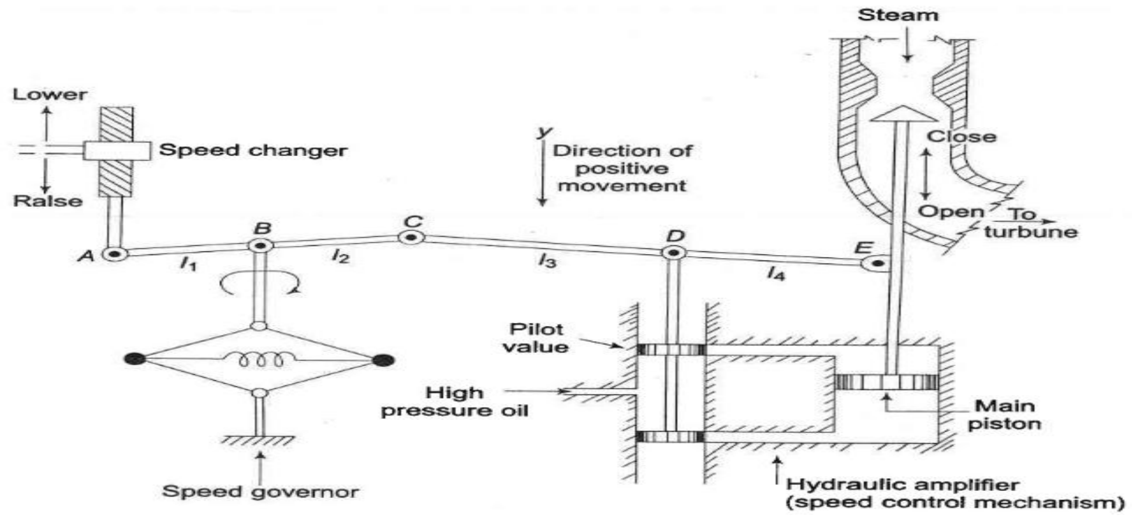


Fig-3 Turbine speed governor system

(i) *Fly-ball speed governor*: Governor is main body of this system that detects variations in frequency or speed. When speed goes up the fly ball shifts outward and point *B* goes downward. When speed declines the fly ball moves inward and point *B* comes in contact and starts with linkage mechanism upwards[7].

(ii) *Hydraulic amplifier*: It has pilot faucet and a piston as the main part of the system. In this amplifier, low power is converted into high power to get the high pressurized steam. This helps to open and close the steam faucet to get the pressurized steam[7].

(iii) *Linkage mechanism*: ABC joints are connected at B and CDE at the other link pointed at D. The link management gives the full control over the valve so that the speed can be changed accordingly. It gives feedback from steam valve shifting(link4)[7].

(iv) *Speed changer*: With the adjustment in turbine it gives constant output power at the end. When it declines, it open up the upper side pilot faucet to get huge amount of steam is transferred to the turbine in steady state (hence more power output will be there). The opposite happens when it is used in upward movement of speed changer[7].

Control area concept

So far we've got thought of the simplified case of a single turbo-generator supplying a separated load. With considering a viable system a number of generating station and loads. The extended power system can be segregate into subareas i.e. State Electricity Board in which generators are imperviously coupled to create a consistent group, all the generators work as an unison when there is an alteration in speed and load. This purports that controlling strategies can be converted into single speed governor, load system and turbo generator. The above control strategies help to get full control over generator independently. so far, therefore, applicable to self-governing control area[7].

2.2 Automatic Generation Control

Figure 4 gives the graphical representation of an automatic voltage regulator. It contains main exciter which starts to excite the alternator field to get the full control on the output voltage. The error e = $V_{ref} - V_T$ controls the exciter field, which is suitably amplified with the help of various amplifiers[7].

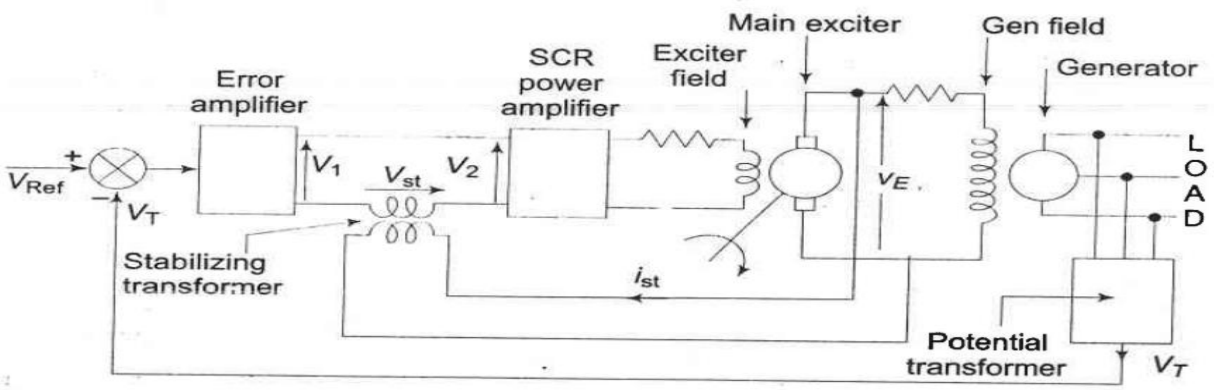


Fig-4 Schematic diagram of alternator voltage regulator scheme

III. SPEED GOVERNOR DEAD-BAND SYSTEM ON LFC

Result of speed governor dead-band takes full control over speed of governor, there must be variation in the speed with the variation in valve's position which changes the overall output. Automatic generation control, the dead-band result indeed is very important as very lesser signal can be used for consideration. With the increment in input signal, speed of the governor is set to a particular value, it will react when it reaches to a specific point. When there is an input signal decrement, such alike action comes into play. The block diagram of speed governing system is shown in Figure 5.

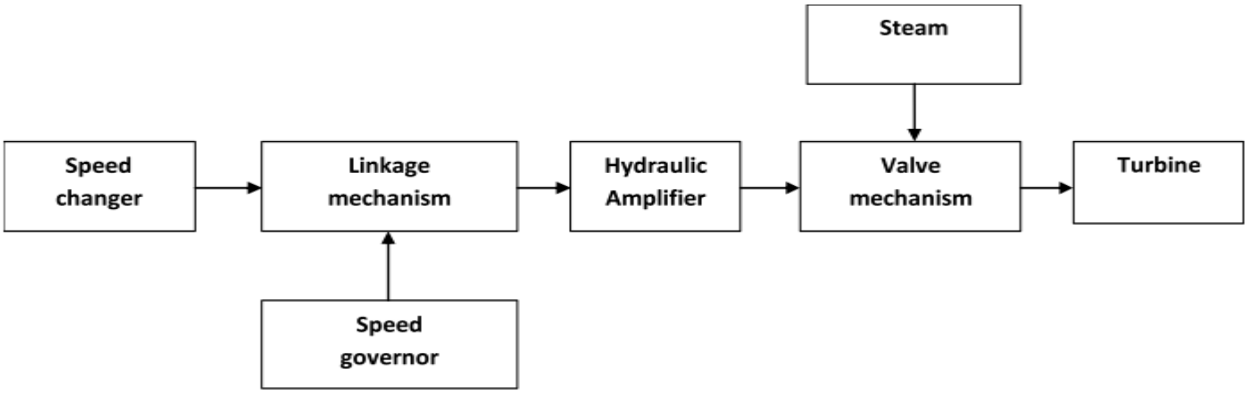


Fig-5 Block diagram of speed governing system.

Load frequency control has speed which is the heart of automatic generation control. By the help of speed governing system, speed of the turbine can be controlled as per the requirement. If load increases due to any reason at the load side then speed of the turbine will reduce, to keep the turbine speed constant, speed changer can be used to make the operation in an equilibrium position. Speed governor is connected with a linkage mechanism, through which speed governor can be operated. To operate valve mechanism, hydraulic amplifiers are used to get the proper control over the valve. Servomotor is inserted in between the governor and the valve to get the full control. It has pilot valve and main piston. With this management, by converting the low power valve to high power piston a hydraulic amplification can be obtained[8].

IV. MATHEMATICAL STRATEGY OF HYBRID HARRIS HAWKS OPTIMIZER

In this paper HHO algorithm includes exploitative and exploratory phases which is inspired by surprise pounce,the nature of exploration of a prey and different strategies based on attacking phenomenon of Harris hawks.This is one of the gradient-free and inhabitants based algorithms for optimization technique which can useful to formulate on any types of optimization problem. HHO have some major phases, such as, phase of exploration, conversion from exploration to exploitation and phase of exploitation.

4.1 Phase of exploration

In this section the mechanism of HHO is discussed. Considering the natural hunting strategy of Harris hawks, they detect the prey and track it by using their dominant eyes but the victim cannot be realize it easily. Thus, after several hoursthe Harris hawks delay some time by observing and monitoring the site to detect the prey. Now for HHO, the Harris hawks are taken as best solution in each step which is taken as the projected prey and which is also in nearly optimum region. In this optimization technique Harris hawks settle randomly on some positions and wait to detect and locate the prey based on two types of strategies. Now considering the equal chance w for each balancing strategy which is based on the locations of the another members of the family to near enough to them when attacking and the rabbit as a prey, shown in equation (1) for such condition where $w\langle 0.5$ or balance on random positions which is shown in equation (2) where $w \ge 0.5$ and equation (3) is determine the average location of Harris hawks.

$$H(iter+1) = \{H_{rand}(iter)|H_{rand}(iter) - 2e_{s2}H(iter)|, w \ge 0.5$$

(1)

$$H(iter+1) = \{(H_{rabbit}(iter) - H_m(iter)) - e_{s3}(L_{Bound} + e_{s4}(U_{Bound} - L_{Bound})), w\langle 0.5$$

(2)

$$H_m(iter) = \frac{1}{N}\sum_{i=1}^{N} H_i(iter)$$

(3)

Where, $e_{s1,}e_{s2,}e_{s3,}e_{s4}$ and w are arbitrary numbers in between (0, 1) and these are improved in each iteration,

$H_{rabbit}(iter)$ = Rabbit's position,

$H_{rand}(iter)$ = Number of Harris hawks are selected from recent population

N = Total number of Harris hawks

This model is basically used to generate location randomly in between the range of upper and lower boundary. This optimization technique consist of some rules, firstly, the solution which is generated basically based on other hawks including its random location, secondly form equation (1) and (2) usually to find out the best value of different location and the component of random scale which is based on range of upper and lower bound of variables where e_{s3} is represented as coefficient scale which used to advance increase the rule of nature randomly, while the value of e_{s4} is mostly near about 1 and this pattern is distributed in similar manner including average position. According to this rule, algorithm of HHO add the movement of scale length up to lower bound L_{Bound} .After that to provide more exploration in different section of space of feature which is considered as randomization of coefficient of scaling.

There is also possible to create different types of updated rules, but here we developed simple rule which has the capability to copycat the nature of the hawks. The ordinary location of the Harris Hawks is achieved by using the equation (3).

4.2 Conversion from the phase of exploration to the phase of exploitation

In this algorithm, based on HHO optimization technique can transference from exploration condition to exploitation condition and after that alteration between various types of nature base on exploitative behavior which is based on the avoidance energy of the prey. Due to this avoidance behavior, it decreases the energy of the prey. The equation based on the behavior of the energy of the prey is given bellow:

$$EG = 2EG_0\left(1 - \frac{iter}{iter_{\max}}\right) \quad (4)$$

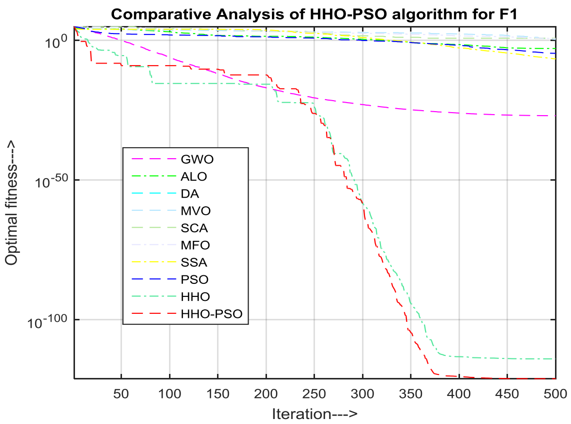
Where, EG= Avoidance energy of the prey, EG_0= Initial condition of the energy, $iter_{max}$ = Maximum iteration

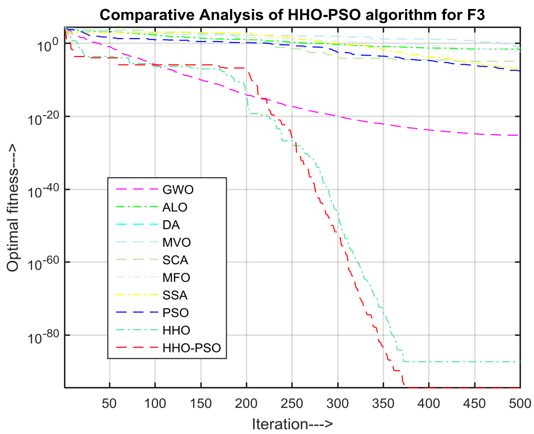
V. RESULTS AND DISCUSSION

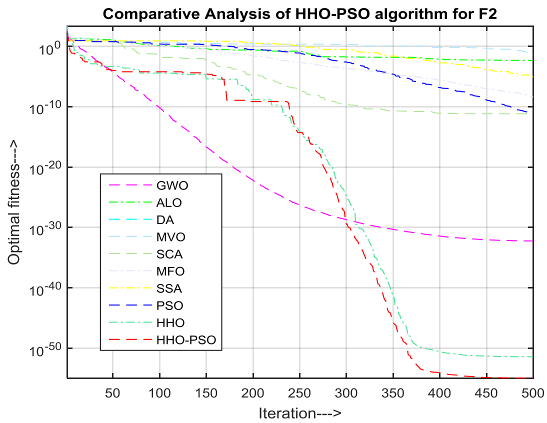
For verification of outcomes, thirty trials are observed to overcome the stochastic nature of projected iHHO-PSO algorithm with each are estimated for mean, best values, worst value and standard deviation. For the approval of phase of exploitation recommended approach, unimodal benchmark functions F1, F2, F3, F4, F5, F6 and F7 are to be considered as in Table-1. The estimate outcomes for unimodal benchmark functions has been shown in Fig. 6 in comparison with other latest established algorithms GWO [36], GSA [38], FEP [42], ALO [12], SMS [43][44], BA [14], FPA [34], CS [45][32], FA [46], GA [46], GOA [35], MFO [50], BA [39], SMS [40], MVO [51], DA [26], BDA [26], BPSO [41], BGSA [18], SCA [56], BA [14], FPA [26], SSA [23], FEP [17], and WOA [19] with respect to SD and mean values.

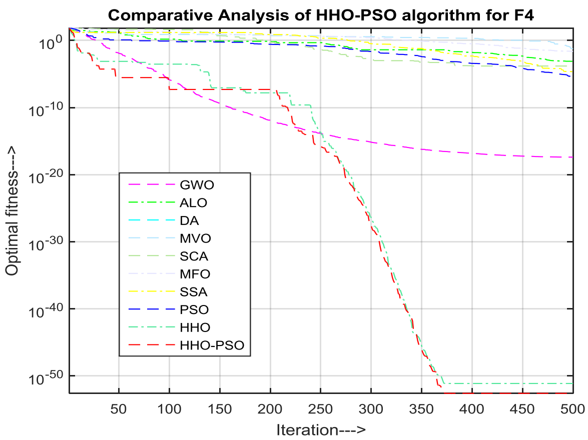
Table-1: Test results for Unimodal Benchmark functions using iHHO-PSO algorithm

Functions	Mean	SD	Best	Worst	Median	p-Value
F1	7.62395E-98	3.11E-97	9.4E-118	1.67E-96	2.3E-103	1.73E-06
F2	2.49263E-51	1.2E-50	9E-58	6.56E-50	9.05E-55	1.73E-06
F3	7.3765E-75	4.02E-74	3.39E-98	2.2E-73	8.85E-88	1.73E-06
F4	1.23147E-47	6.73E-47	4.52E-57	3.69E-46	2.82E-53	1.73E-06
F5	0.007324027	0.008526	0.000442	0.035424	0.003318	1.73E-06
F6	0.000143993	0.00025	5.53E-07	0.001333	6.96E-05	1.73E-06
F7	0.000177047	0.000174	1.02E-05	0.00077	0.000127	1.73E-06









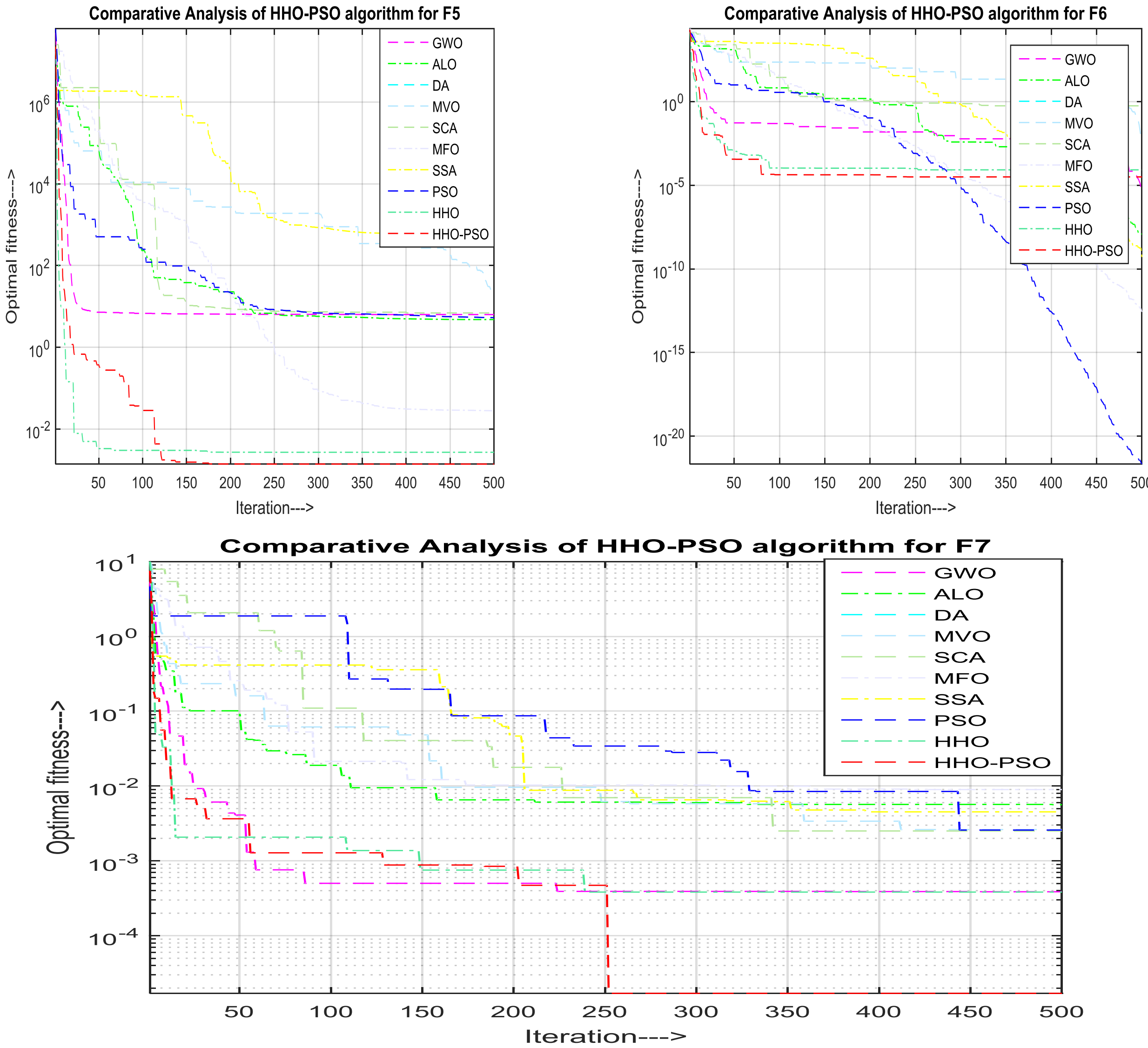
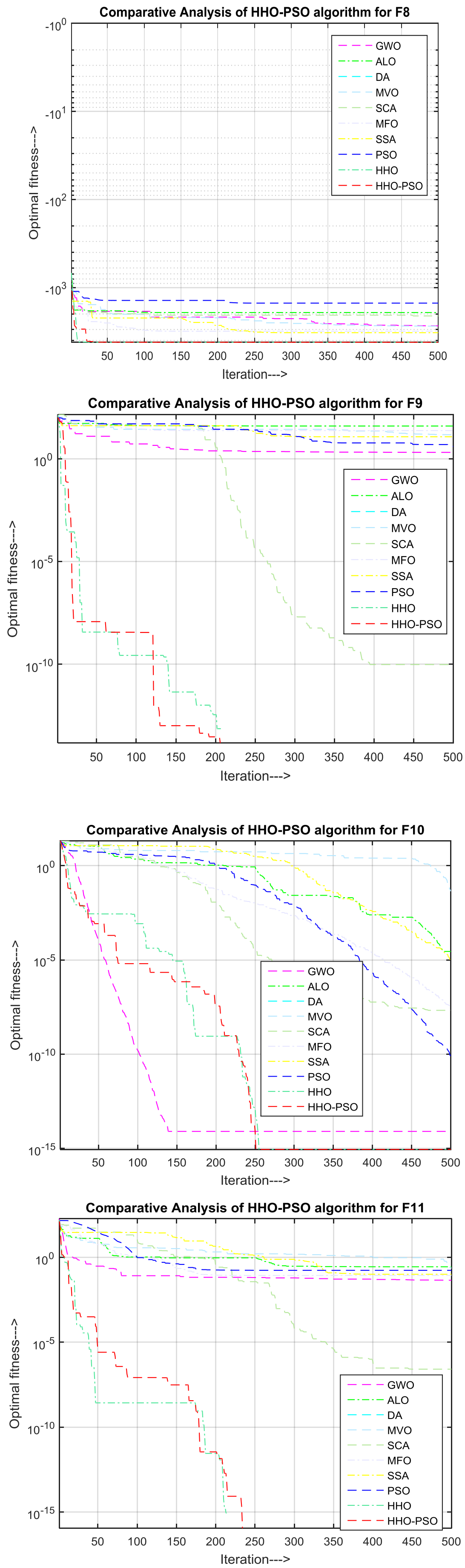


Fig.6: Convergence curve of HHO-PSO with GWO, ALO, DA, MVO, SCA, MFO, SSA, PSO and HHO for Unimodal Benchmark functions

Table-2 depicts the solution of multi-modal benchmark function using hHHO-PSO algorithm whose convergence curve outcomes shown in fig. 8 when compared with other latest algorithms GWO [36], GSA [38], FEP [97], ALO [12], SMS [98], BA [14], FPA [34], CS [100], FA [101], GA [102], GOA [35], MFO [50], BA [103], SMS [104], MVO [51], DA [26], BDA [26], BPSO [105], BGSA [18], SCA [56], BA [14], FPA [106], SSA [63], FEP [97] and WOA [69] with respect to SD and mean values.

Table-2: Test results for Multi-modal Benchmark functions using **HHO-PSO** algorithm

Functions	Mean	SD	Best	Worst	Median	p-Value
F8	-12568.8	0.946745	-12569.5	-12565.1	-12569.1	1.734E-06
F9	0	0	0	0	0	1
F10	8.88E-16	0	8.88E-16	8.88E-16	8.88E-16	4.32E-08
F11	0	0	0	0	0	1
F12	1.13E-05	1.5E-05	9.73E-10	6.46E-05	4.86E-06	1.734E-06
F13	0.000113	0.000166	1.49E-06	0.000674	5.53E-05	1.734E-06



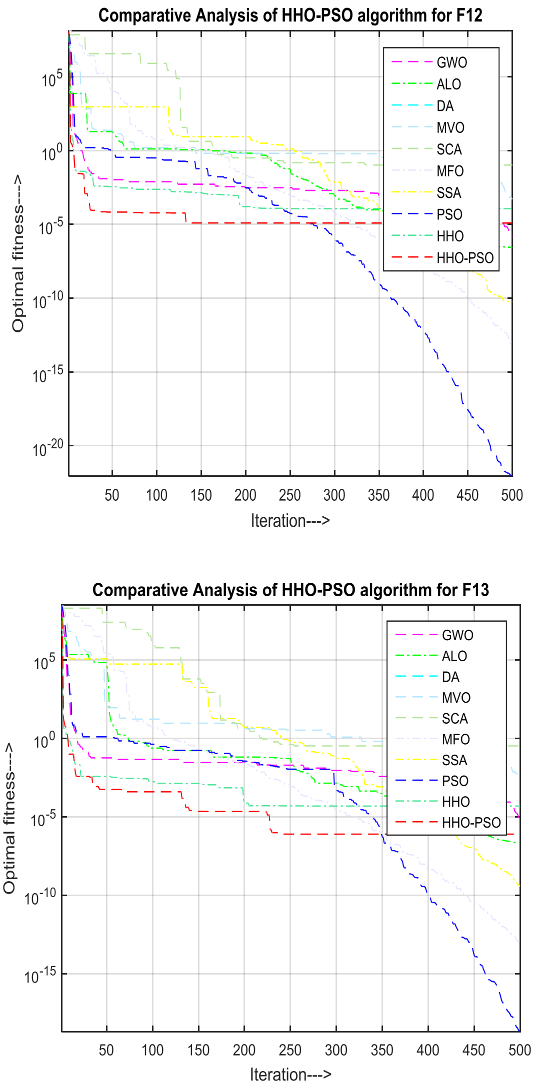
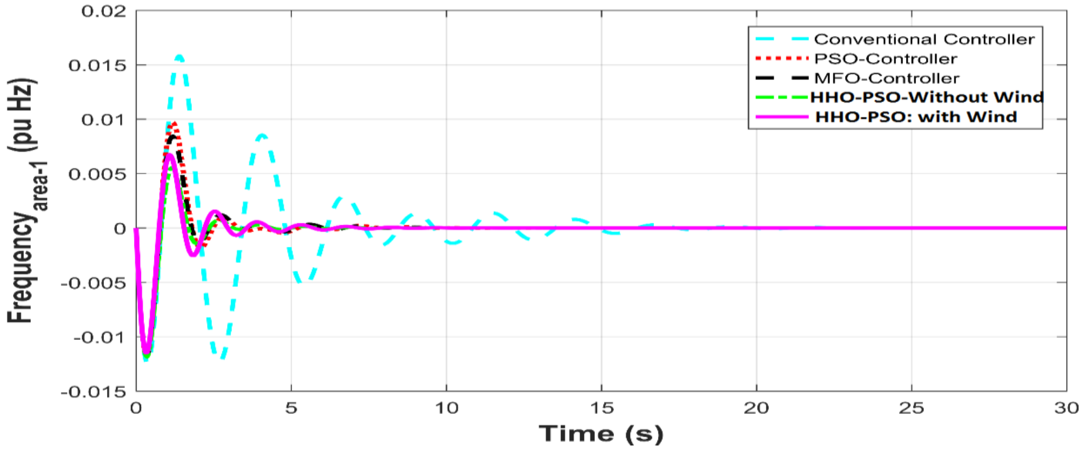


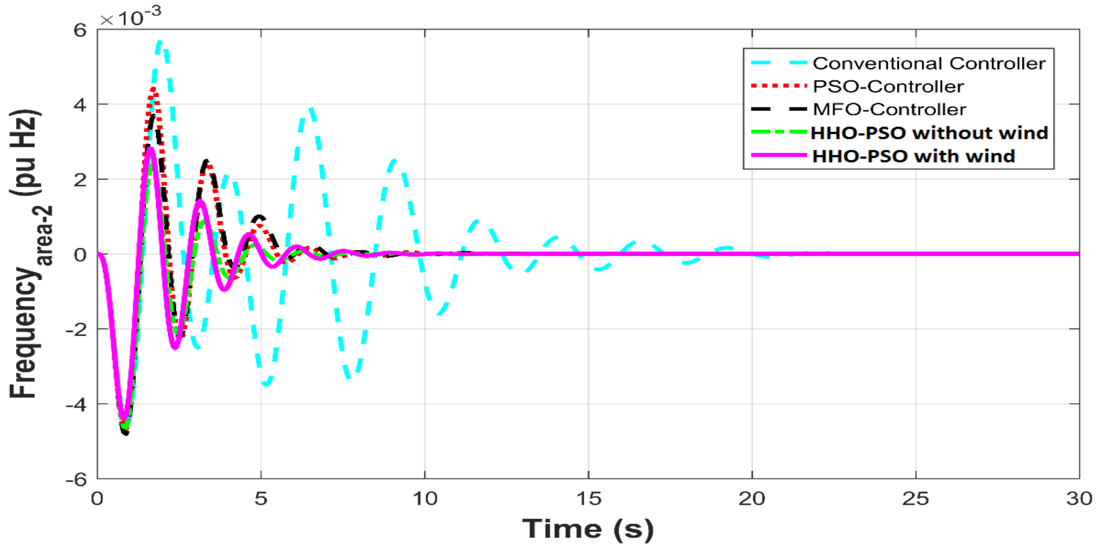
Fig.7: Convergence curve of iHHO-PSO with GWO, ALO, DA, MVO, SCA, MFO, SSA, PSO and HHO for Multi modal Benchmark functions

VI. SENSITIVITY ANALYSIS OF TEST SYSTEMS

Sensitivity analysis in terms of frequency deviations, actual power flow and error in tie-line, and output response of different generators after immediate load variation in suggested system w.r.t. penetration of wind and without wind has been shown in Figs.8-10.

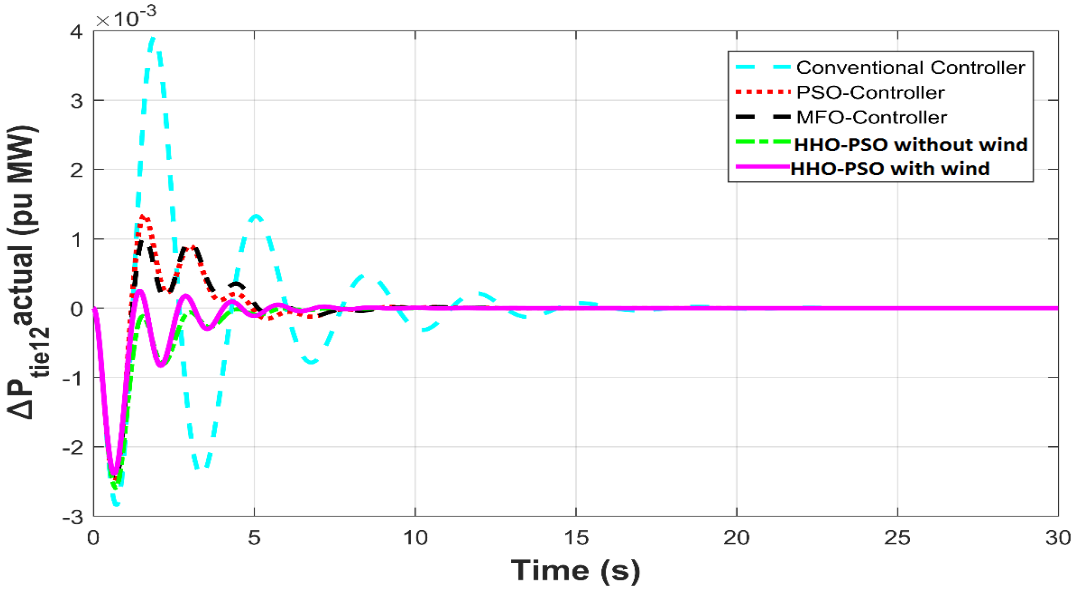


(a)

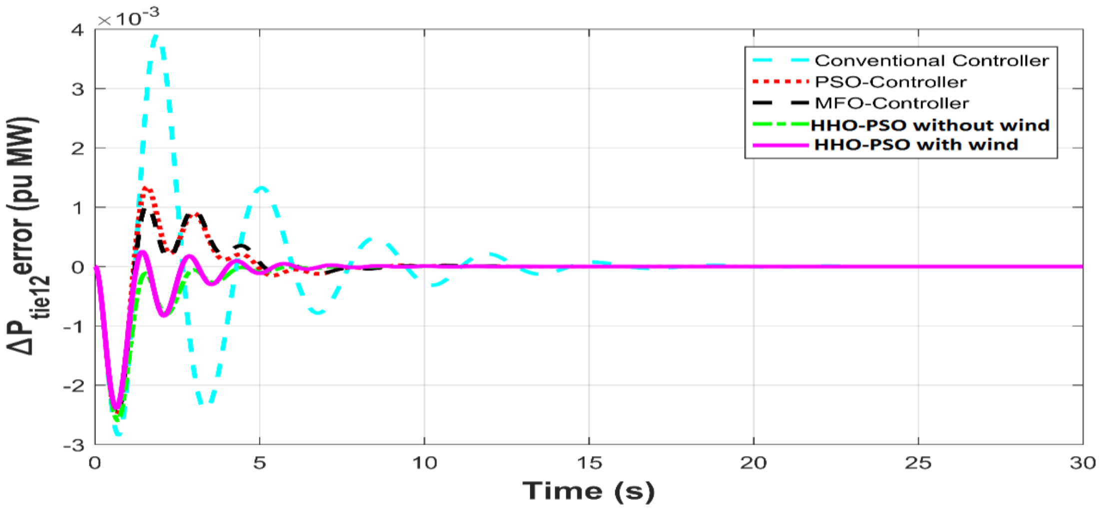


(b)

Fig. 8 (a)-(b): Dynamics response of different areas frequencies with various controllers (with and without wind power)

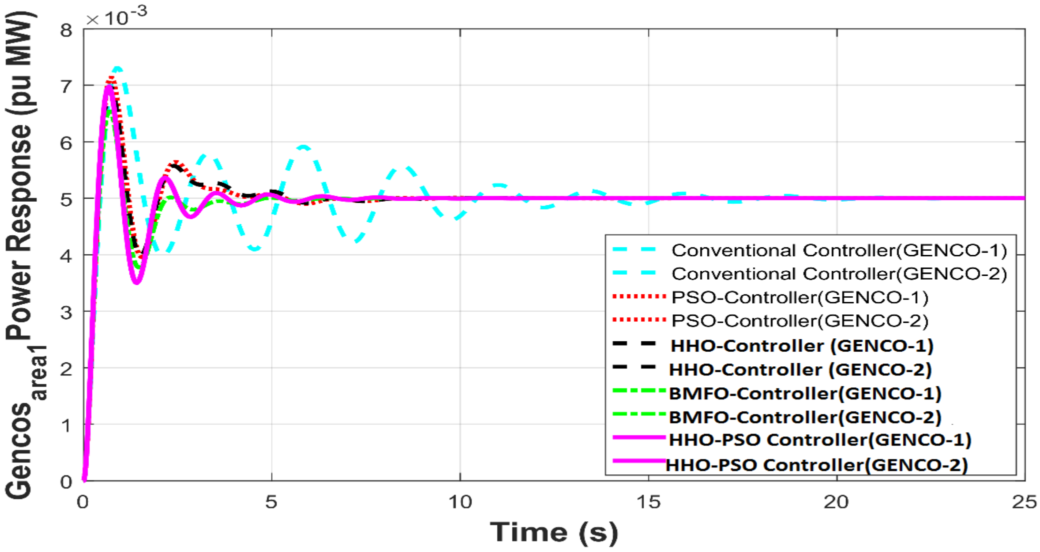


(a)

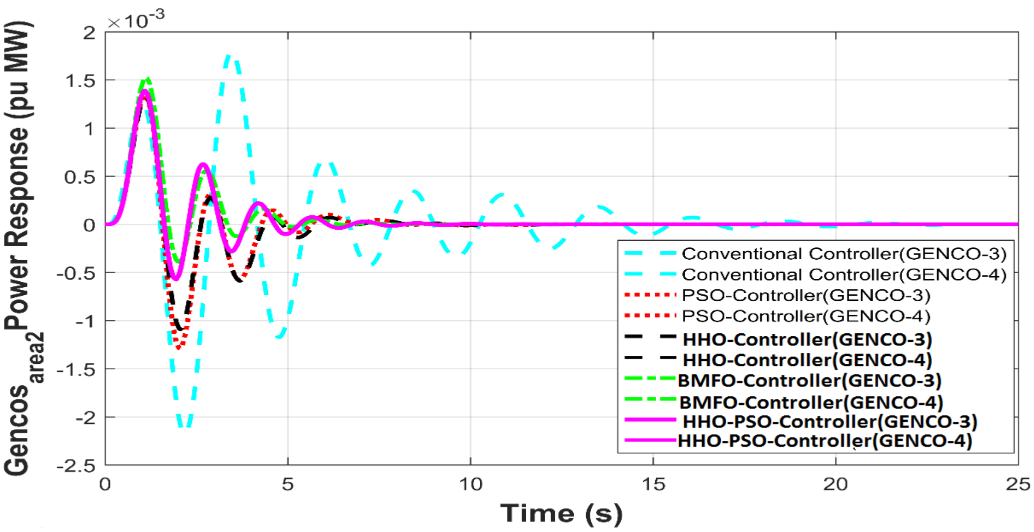


(b)

Fig. 9 (a)-(b): Variation in actual tie-line power flow with various controllers (with and without wind power)



(a)



(b)

Fig.10(a)-(b): Multi-Area generation response with various controllers and its sensitivity analysis

VII. CONCLUSION

In this research paper, hybrid model of LFC involving thermal, hydro and wind generations are presented in which PID controllers are applied to govern power generation from standard as well as wind energy sources in addition to soak up surplus generation from RESs. Improved HHO is tested to seek out best results of gains of PID controllers whose result shows that these controllers are capable to conserve the frequency support of system underneath the fluctuation of load and sustainable power generations.

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