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Harmony Search Algorithm Based Control of DFIG Wind Energy System in Multi Machine Power Systems

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***Abstract:** In wind energy conversion system (WECS) Double Fed Induction generator (DFIG) preferred, though it has many advantages when used in wind energy system, but DFIG is very sensitive to the grid disruptions. When an error occurs DFIG is greatly affected in the multi- machine system. The voltage and power gets deviated. The main purpose of this paper is to stabilize the DFIG under fault conditions, but the performance of the DFIG is depends on the PI controller parameters. By using Harmony Search Algorithm (HSA) technique the PI controller parameters are tuned, by this the efficiency of a system can be improved and the voltage and power oscillations can be reduced. The simulation is performed in detailed model of four-machine two-area system. The whole process is done in the MATLAB Simulink software. A comparative study is done between tuning of PI parameter with HSA and actual existing system.*

***Keywords:** Wind energy conversion system (WECS), DFIG, Harmony search algorithm (HSA), Multi-machine system.*

I. INTRODUCTION

Electricity had become an important part in today's environment satisfying the needs of human life. In recent years due to increase in environmental concern the various methods of generation of power are being involved by using renewable energy resources, wind power generation is the most available and exploitable forms of renewable energy. In this various challenges may occur like stability and performance of the system can vary, because of this, the generator choice plays a vital role in WECS. Among all the generators the DFIG is more flexible generator that can deal withthe multivariate existence of the wind, it reduces the stress on the turbine originating from wind gusts and turbulence, and it allows extracting the optimum amount of power from the wind. The stability and transient response of the grid-connected DFIG system is heavily influenced by factors such as power system failures, non-linearity.In AC grid connection the control of active and reactive power with DFIG based wind forms were proposed in ref [1]. In a practical system, a single DFIG cannot be connected to the grid, if the problem persists, when a single machine connected to an infinite bus, there are many solutions are present in the reports [2-4]. Number of DFIG's will be connected to a multi-machine system.In China, a practical multi-machine wind farm is represented in ref [5].

Multi-machine system's main difficulties are post faults and improving stability and to achieve a good transient response. Under the post fault conditions, the efficiency of DFIG system needs to be improved. The performance and stability of DFIG system depends on PI controller parameters. By selecting appropriate parameters values of PI controller, the system's efficiency can be boosted. For selection of the PI controller parametersthere are many methods like Bacteria foraging technique [6], particle swarm optimization (PSO) technique [15] are proposed, with a single generator connected to grid, Composite Differential Evaluation (CoDE) [7] technique is proposed with wind farm connected to a grid.

HSA is in fact analogous to the process of finding the best solutions. The HS technique has been effectively introduced in various engineering design, ecological planning, wind speed prediction, etc. The comparative study is done between the PSO, CoDE and HSA.

II. DFIG MODEL IN WECS

Fig1 shows a wind energy system with DFIG. The wind turbine is coupled by mechanism of gearbox to the generator shaft.The stator of DFIG is directly connected to the grid, but through back-to-back converters the rotor is connected to the grid.The DC link capacitor is placed between the two converters.Both converters are operated by the grid side controller (GSC) and the rotor side controller (RSC). GSC's aim is to maintain the steady voltage of the DC connection. RSC's aim is to improve the active power and voltage [10, 11]. Depending on the wind velocity, there are two operating modes, they are super synchronous generating mode and sub synchronous generating mode.
Depending on the mode of operation, Bi-directional power flow through the rotor circuit.

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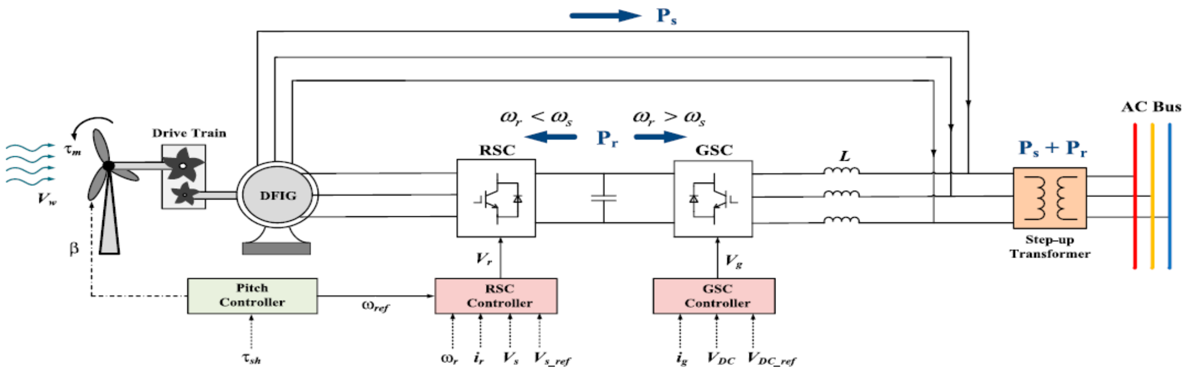

Fig 1: Schematic diagram ofDFIG grid-connected WECS

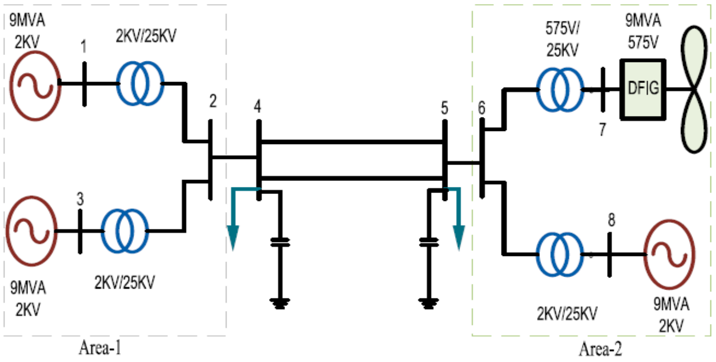

Fig 2: Multi-machine two area power system

III. PARTICLE SWARM OPTIMIZATION (PSO)

PSO is metaheuristic algorithm that means it makes some assumptions to find an optimal solutions, it can search the solutions in very large search space and gives best. PSO algorithm maintains multiple potential solutions at one time. The algorithm of PSO can be described in the 3 steps.

1. Evaluate fitness of each particle.
2. Update individual and global best.
3. Update velocity and position of each particle.

This process will repeat until the stopping condition is met. Flow chart was shown in fig 3.

But the process is time consuming, settling time, peak overshoot are more at post faults.

IV.COMPOSITE DIFFERENTIAL EVOLUATION (CODE)

Composite differential evaluation is population based stochastic technique, here the process for selection of PI controller parameters is random selection of control parameter settings to generate three trail vectors, among them best is selected. The process is done as the following algorithm.

1. Evaluate fitness.
2. Generation of the trail vector.
3. Selection of best trail vector individual.

The termination will do when the number of generation is greater than the maximum generation.

The flow chart is shown in fig 4.

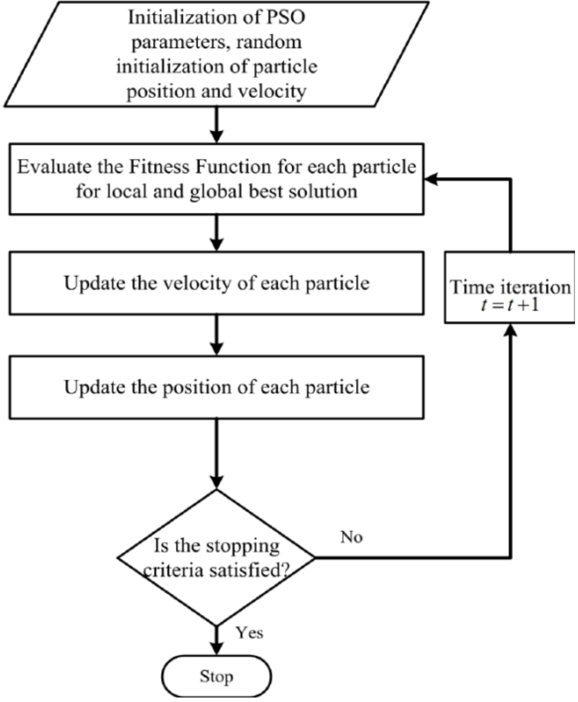

Fig 3: Flow chart of PSO

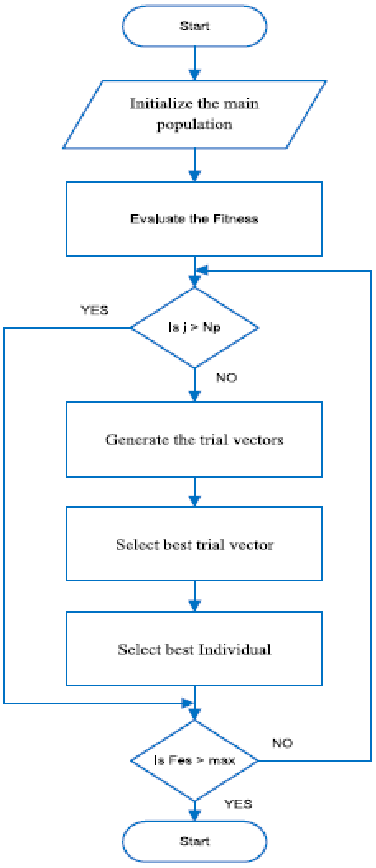

Fig 4: Flow chart of CoDE

V. SYSTEM CONFIGURATION UNDER STUDY

Fig 2 shows DFIG in multi-machine system. It is based on the Kundur's model of modified two area system. It consists of two areas, two generators are installed in each area. Both generators in area 1 are synchronous generators. In area 2, one generator is synchronous and other wind farm is DFIG. There are six wind turbines in the wind farm each rated 1.5MW. Other generatorratings, transformers, transmission line parameters and load values are specified in Ref [13].

The load flow solutions are given below

P_{G1} = 4.587 MW P_{G2} = 8.554 MW
P_{G4} = 7.163 MW P_{G3} = 3.965 MW

P_{12} = 1.365 MW is the tie- line power flow. If the transmission line fault occursthe original PI parameterswill oscillates, the active power supplied to the DFIG in fig 5. Also the DFIG system's voltage profile oscillates in fig 6. This is drastically affectssystem stability and the system's transient response after the fault.

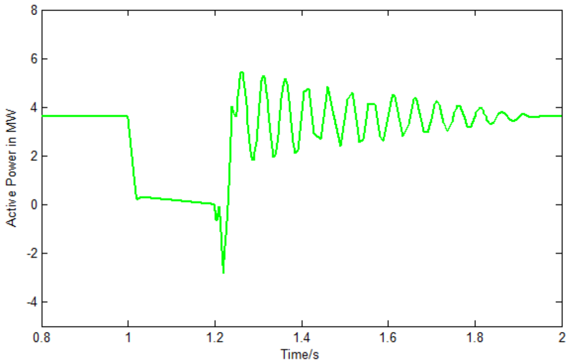

Fig 5: DFIG's active power at fault

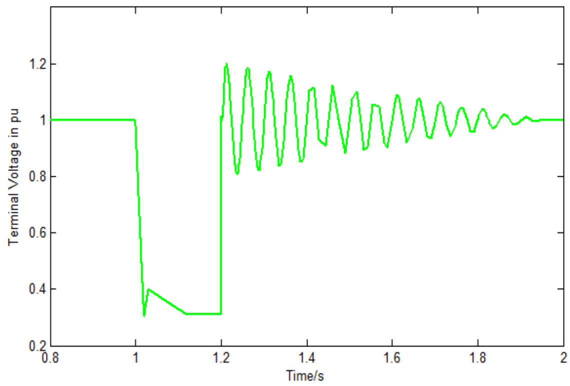

Fig 6: DFIG's Terminal voltage at fault

VI. HARMONIC SEARCH ALGORITHM (HSA)

The HSA method was first suggested by Z.W. Geem et al. in 2001 [8], this is influenced by the fundamental values of musician improvisation of harmony.HS is oriented by the musical quest for perfect harmony.Every instrument's pitch dictates the creative quality, like the fitness function values, the accuracy of the decision variables is calculated.In the optimization, the original solution is randomly generated within a specific range of decision variables.If these decision variables have an objective function value, a promising solution can be found,and then next time,Opportunity for the best solution will be found. The flow chart of the HS is given in fig 7.

Basically, the HS optimization method comprises of the following steps:

A. *Initialize the problem:*

Optimization Issue can be described as

$Min. f(x_1, x_2, \dots, x_d)$
(1)

Where f is fitness function, $x_i(\ i = 1,2, \dots .. d)$ is decision variable i and d. HSAincludes a harmonymemory (HM), which shows the registered harmony memory considering rate (HMCR), and pitch adjusting rate (PAR).

B. *Initialization of HM:*

N numbers of harmonies are produced in the search space and stored in HM. For initialization of HM eq (2) can be used. The initial HM includes a number of random alternatives when considering optimization problems.

$$x_{i,j} = l_j + \text{rand} * (u_i - l_j)$$
(2)
$$i = 1,2, \dots\dots N;\ j = 1,2, \dots\dots d$$

Where l_j and u_j are upper and lower bounds of j, rand is random number in the range of 0 and 1.

$$HM=\begin{bmatrix} x_{1,1} & x_{1,2} & \dots x_{1,d} & f_1 \\ x_{2,1} & x_{2,2} & \dots x_{2,d} & f_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_{N,1} & x_{N,2} & \dots x_{N,d} & f_N \end{bmatrix}$$
(3)

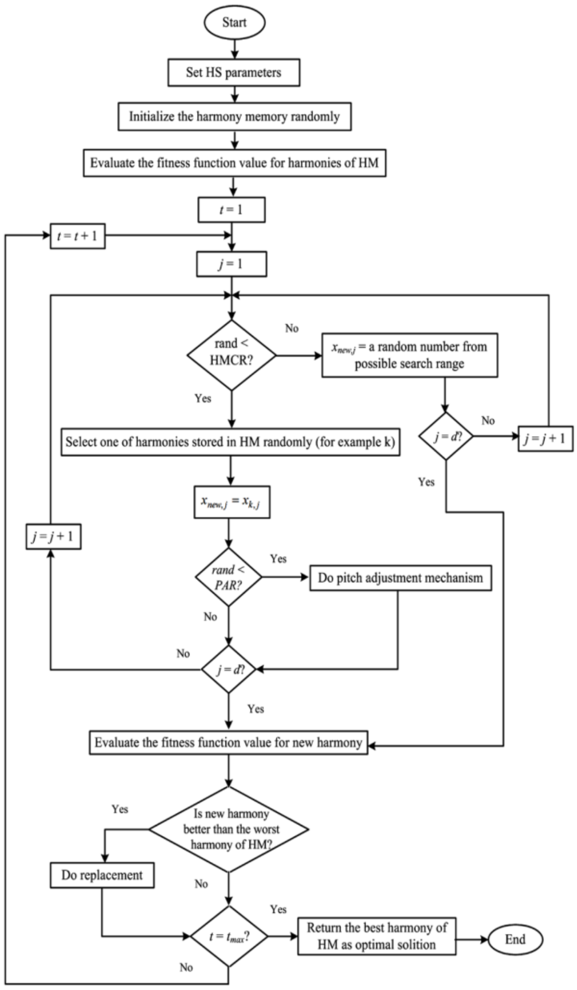

Fig 7: HS algorithm flow chart

C. *Improving a new HM:*

A new vector of harmony, $x_{new} = (x_{new,1}, x_{new,2}, \dots, x_{new,d})$ is obtained by using existing harmony. For decision variable j, the following process is done. This process has to be done until a new harmony is generated.

Stage-1:

rand is generated in the range of [0 1]. If rand $> HMCR$ randomly a $x_{new,j}$(new harmony) is generated by eq (4). HMCR is in the range of 0 and 1.

$$x_{new,j} = l_j + \text{rand} * (u_i - l_j)$$
(4)

If rand $\leq$ HMCR, that harmony will be stored in the HM randomly. The value of HMCR is small (probability of 1-HMCR). For example,HMCR of 0.9 implies that the tone will be a HM sounding with a chance of 0.9, will besound spontaneously with a probability of 0.1 from a potential range.

Stage-2:

In a possible range, by using the pitch adjusting mechanism (PAM) the improved note will shift to next value. The range of PAR is [0 1], if PAR value is small, results in poor PAM, if PAR value is large, results in rich PAM. Instead of that, if rand $\leq$ PAR improved note will shift to next value by eq (5)

$$x_{new,j} = l_j + \text{bw} * (\text{rand} - 0.5) * \left| u_i - l_j \right| \quad (5)$$

If rand $> PAR$ improved note does not exist.

In eq (6) where bw is bandwidthand $rand$is a random number that varies between 0 and 1, term $(\text{rand} - 0.5)$used to select decision variable randomly, term $\left| u_i - l_j \right|$used to control the range of decision variable.

D. *Updating the Harmonic Memory:*

The HM is replaced in this phase depending on the significance of fitness function. If new Harmony vector $f_{new}$is better than the previous worst harmony in HM, f_{new} will replace it in the HM.

E. *Check termination criteria*:

The termination criterion is done when the number of iterations will reach, otherwise the three and four steps are repeated until termination criterion is fulfilled [14].

VII. SIMULATION RESULTS

The results are analyzed for certain operating conditions. All simulations are carried out in the R2011a version of SIMULINK Matlab on 2 area 4 machine system. Area 1 to Area 2 tie-line power is 1.365MW without any system fault.

A. *Case 1: Fault at Bus 4, 3-Phase to Ground Fault:*

At time 1s on a 3-phase transmission line, fault resistance is 0.001 Ω.

The active power response is shown in the fig 8. With actual parameters [12], the system's transient response is poor, by using HSA the power oscillations are drastically decreased with optimized PI controller parameters and setting time is below 0.25s.With less settling time, the machine reaction is very fast.

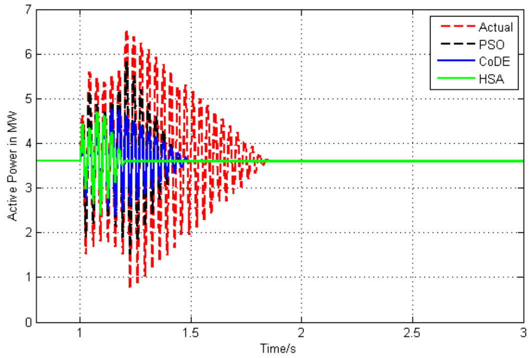

Fig 8: Active power

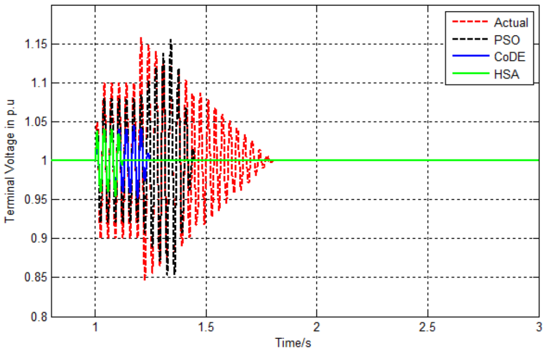

Fig 9: Terminal voltage

The terminal voltage was enhanced with the less peak overshoot and there are very few oscillations in voltage. The settling time is less than 0.2s, this can be seen in fig 9.

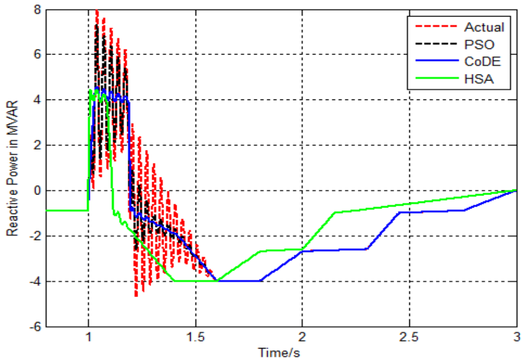

Fig 10: Reactive power

The control of reactive power was done in fig 10.

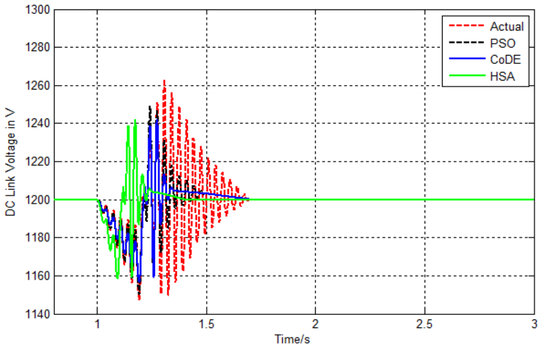

Fig 11: DC link voltage

With less peak overshoot, the oscillations in DC link voltage are minimized with less settling time, in fig 11.

As compared to the other optimization techniques the system response is fast during the post faults.

B. Case-2: A mid-point fault on three phase line in one of the tie-line in between the 2 areas:

A fault at the mid-point on the three phase transmission line at time t=1s, power and voltages are get oscillates. With the actual PI parameter values active power deviates more seen in fig 12.

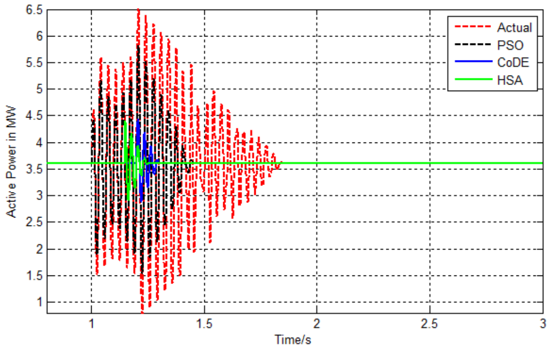

Fig 12: Active power

The deviations in the terminal voltage are minimized as compared with the actual values in fig 13.

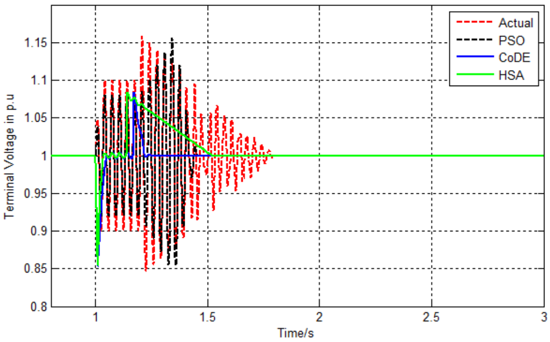

Fig 13: Terminal voltage

The reactive power flow is improved with the new PI parameter values using HSA in fig 14.

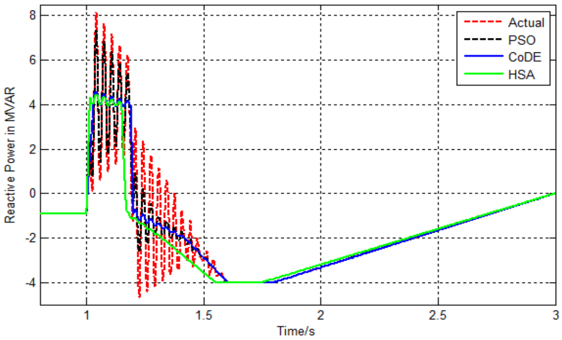

Fig 14: Reactive power

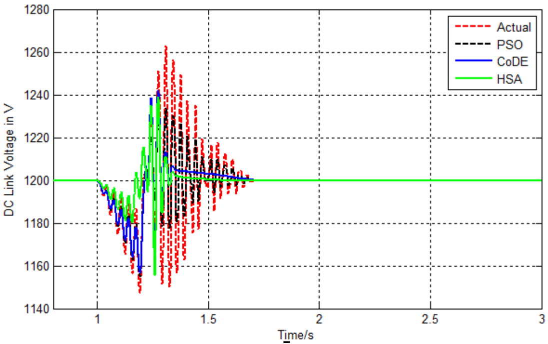

Fig 15: DC link voltage

DC link voltage is enhanced with the tuned system, shown in fig 15.
Similarly the active power and the terminal voltages are also enhanced, when the fault occurred at the bus-5 by using HSA, can be seen in fig 16 and fig 17.

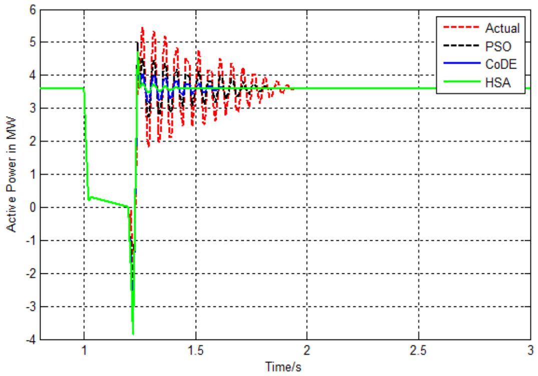

Fig 16: Active power

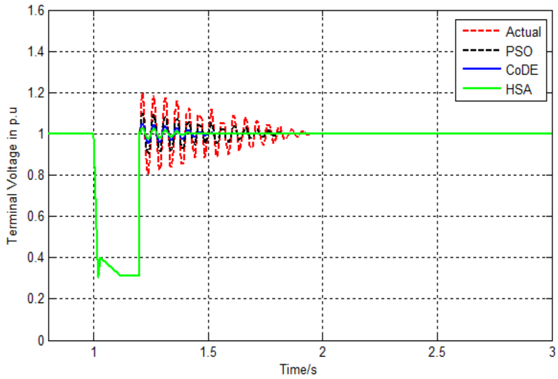

Fig 17: Terminal voltage

C. *Case-3: When one of the tie-line gets disconnected*:

The tie-line is disconnected by opening the circuit breaker at time t=1+6/60s. The effect of the system is less but the active and reactive powers get slightly affected, but that can also be improved by using tuned parameters of HS algorithm are shown in fig 18 and 19.

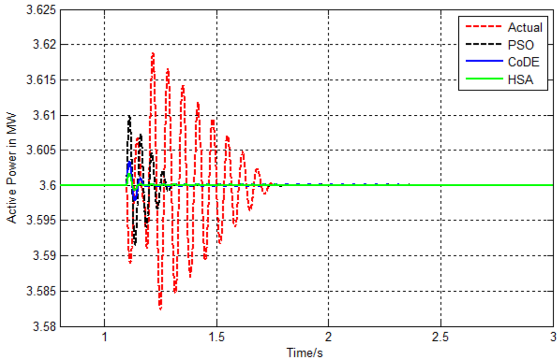

Fig 18: Active power

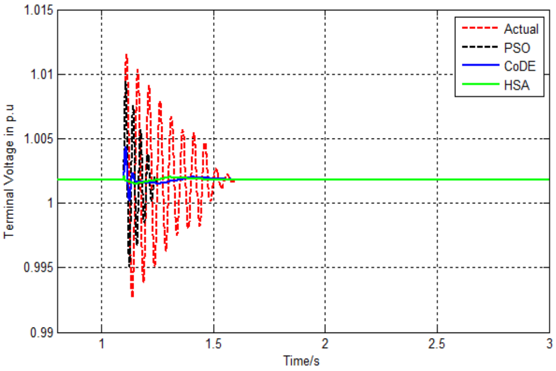

Fig 19: Reactive power

By observing the above figures it is clear that the oscillations are almost zero in both active and reactive power.

D. *Case 4: Sudden load increase of 20%*:

The load in bus 5 is instantly increases by 20% at t = 5s to determine the reliability of the HS tuned system.The active power in the initial system oscillates widely. By using HAS,the efficiency of the system gets improved in fig 20.

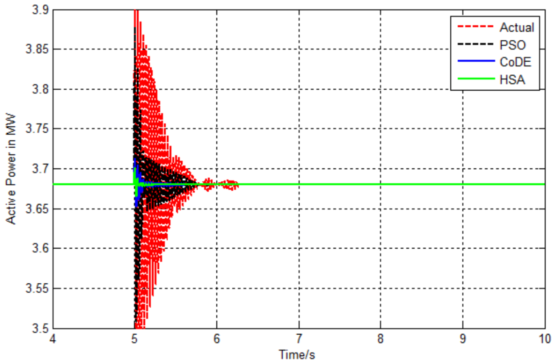

Fig 20: Active power

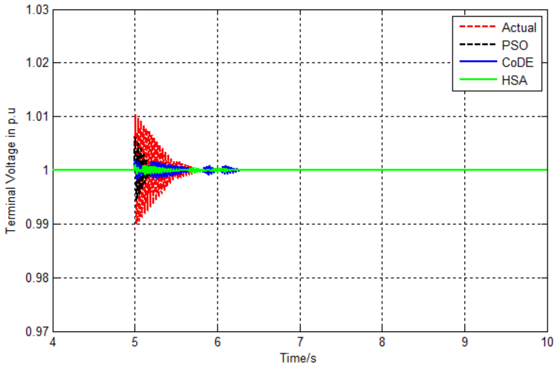

Fig 21: Terminal voltage

In fig 21, terminal voltage is also reduced.The simulation findings indicate that the output of the HS tuned system is superior to the CoDE and PSO tuned system.
At the steady state condition the active power of DFIG in fig 22 and the terminal voltage of DFIG in fig 23 are shown with the same PI controller.

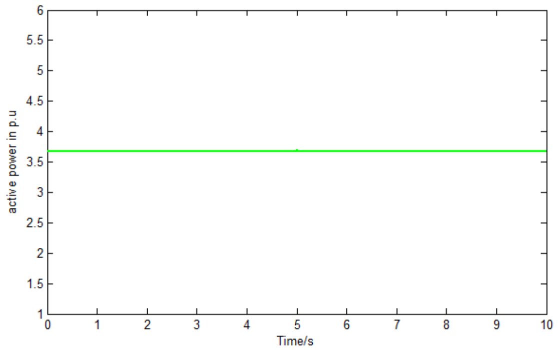

Fig 22: In a steady state, active power

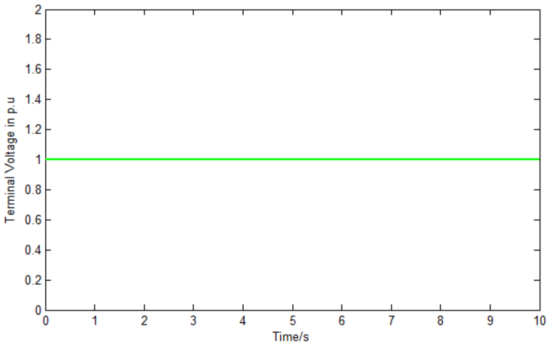

Fig 23: In a steady state, terminal voltage

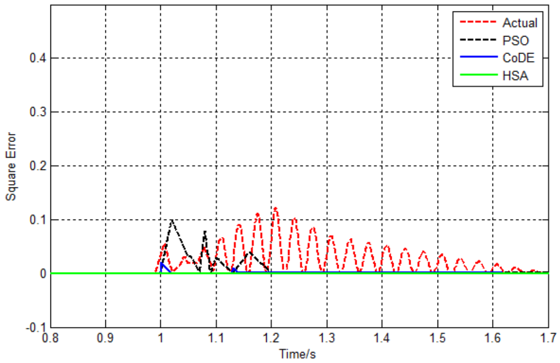

Fig 24: $|\Delta P^2+\Delta V^2|$ for a three-phase fault

In specific, absolute values are taken into account for the sum of power and voltage errors in the square $|\Delta P^2+\Delta V^2|$.Fig 24 shows the better results of the HSA over the initial, PSO and CoDE.

HSA performance is compared to the initial system, tuned PSO system and CoDE [7].

VIII. CONCLUSION

In this paper, DFIG tuning was proposed in multi-machine systems using the HSA.The system of DFIG is configured by changing the PI controller parameters. The efficiency of the DFIG system is enhanced in all cases. The reduced voltage oscillations are improved, power oscillations are drastically reduced in all the four cases. The system's response under fault conditions is very quick. Thus the stability and the transient response were improved.

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