Performance Analysis of DSTATCOM based Wind Energy System by using Harmony Search Algorithm

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ABSTRACT- When wind control is integrated into the lattice structure, it impacts both the network and the entire system. The functionality of the supply systems is mainly limited to the connection between the transmission and generation systems on one side and a direct load on the other. Typically, the most common fault is a line-to-ground fault, which can be observed when it occurs in the system. To enhance power quality by maintaining the power factor, minimizing transients in wind energy generation systems, and improving the performance of the grid connected to wind energy conversion systems, DSTATCOM is employed to provide a rapid response to various power quality issues, such as voltage stabilization and reactive power compensation. The suggested optimization method, in conjunction with the existing optimization strategy, is used to adjust the PI controller for the D-STATCOM at the common coupling point within the grid-connected wind energy conversion system. The performance is simulated using MATLAB/Simulink.

Keywords - PI (Proportional and Integral) Controller, D-STATCOM, Harmony Search Algorithm, Wind Generator, Permanent magnet synchronous Generator.

1. INTRODUCTION-

A power system network aims to deliver continuous electrical energy to end-users safely. The safe and steady action of the power network assures the reduction in socio-economic costs, since the power system's unsteadiness may even lead to an expensive blackout [3]. The structure and the main components in wind turbines working in a limited variable-speed area are parallel to fixed speed wind mill [5] and the wind generator works in a limited speed area which has usually a permanent magnet synchronous generator (PMSG) with a converter linked to the circuit of rotor. And, the generator's rotating speed fluctuates around 1000 rpm or 1500rpm, hence a gearbox is essential. Since the supply system has a finite, rather than an infinite, currents outside the direct control of the utility can adversely affect power quality [5][6]. That is why it's quite important to have power quality protection at the incoming utility meter and each piece of sensitive electronic equipment throughout your facility [4]. The various causes for power quality disturbances are Power electronic devices, IT and office equipment, Arcing devices, Load switching, and large motor starting current [9]. It has overcome the synchronous condenser because of its lower investment cost, better dynamics, no inertia, and lower operating and maintenance costs. A power VSC based on high-power electronic technologies is the heart of D-STATCOM [3] [10]. It provides reactive power compensation in AC networks. DSTATCOM is a static device that needs to be controlled by a PI (Proportional and Integral) controller. The main functions of control block is used for fault detection, drop in voltage and rise in voltage in the system, voltage computation, trigger pulse generation to the sinusoidal PWM based inverter and ending the trigger pulses when the event has progressed. External devices such as mechanically switched capacitor banks are also controlled by the control blocks. These control blocks are designed on the basis of various control theories and algorithms like instantaneous Synchronous Reference Frame (SRF) theory etc. There is three types of optimization method is used to control D-STATCOM for better performance [10]. Different fault conditions like Line to ground, Line to Line, LLL, and double line to ground fault occur in the system. Performance is going to analyzed in most common fault condition which is line to ground fault, Fault analysis is done based on, Terminal voltage, Rotor speed deviation, Mechanical torque deviation, Electrical torque deviation, and Power deviation [4] [12]. The conventional controller is a feedback controller. It estimates an error value as the distinction between the value of measured process and the preferred set point value and then drives the controlled plant to keep the steady state error equal to zero. But the optimized PI controller doesn't need any mathematical equation and definite objective function it is coding based method which is performed in simulation. The main contributions of this research are outlined as the efficiency of the grid-connected wind energy conversion system and offer quick relief from a variety of power quality issues such voltage stabilization, reactive power compensation and good dynamic response.

2. PROPOSED METHODOLOGY-

The D-STATCOM is the flow of electron control VSI. It injects current into the power network to maintain the phase angle of the source voltage in the preferred value and also to maintain the source current free from harmonics. An injection of the current from the compensator negates the harmonics in the load, reactive part, and also the current in the double-fed induction generator; as a result, it enhances the power factor as well as the power quality. The proposed control block consists of the generator, non-linear load, and D-STATCOM along with an optimized PI controller connected at the common coupling point. Without power electronic device the generator parameters can be observed in the source side and is rectified with the help of optimization technique by tuning the values of the PI controller and STATCOM. PI (Proportional and Integral) controller and STATCOM are very effective in achieving stability Control algorithm is a simple control algorithm foe active compensating devices such as DSTATCOMs for AC voltage regulation at load terminals (at PCC) and load balancing of unbalanced loads.

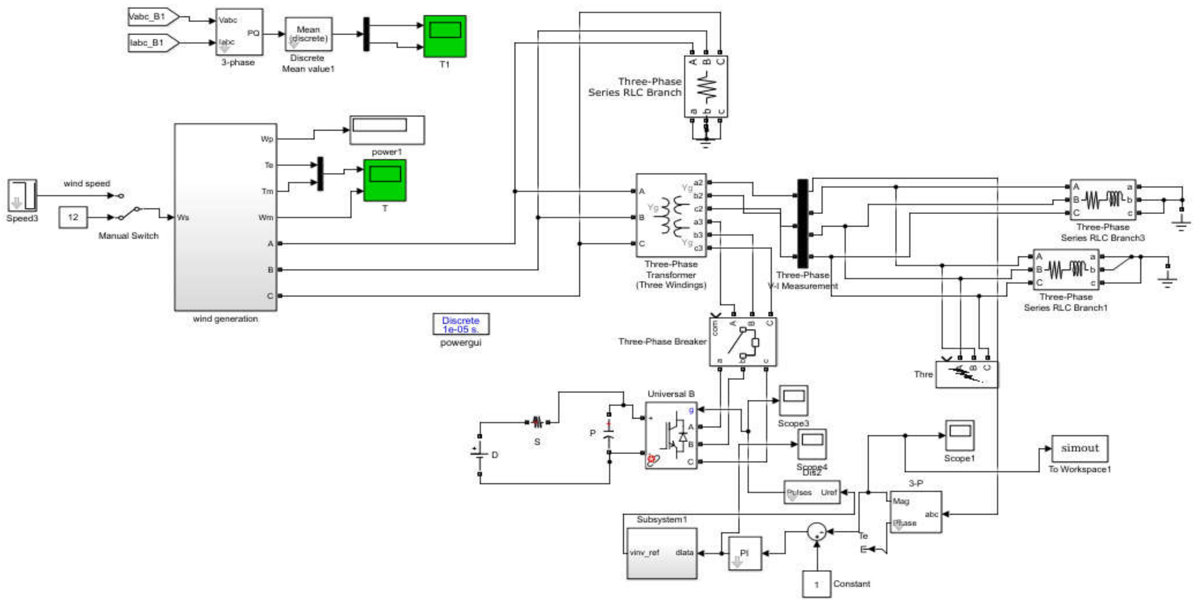

Fig. 2.1- Wind power generation system with DSTATCOM and PI controller

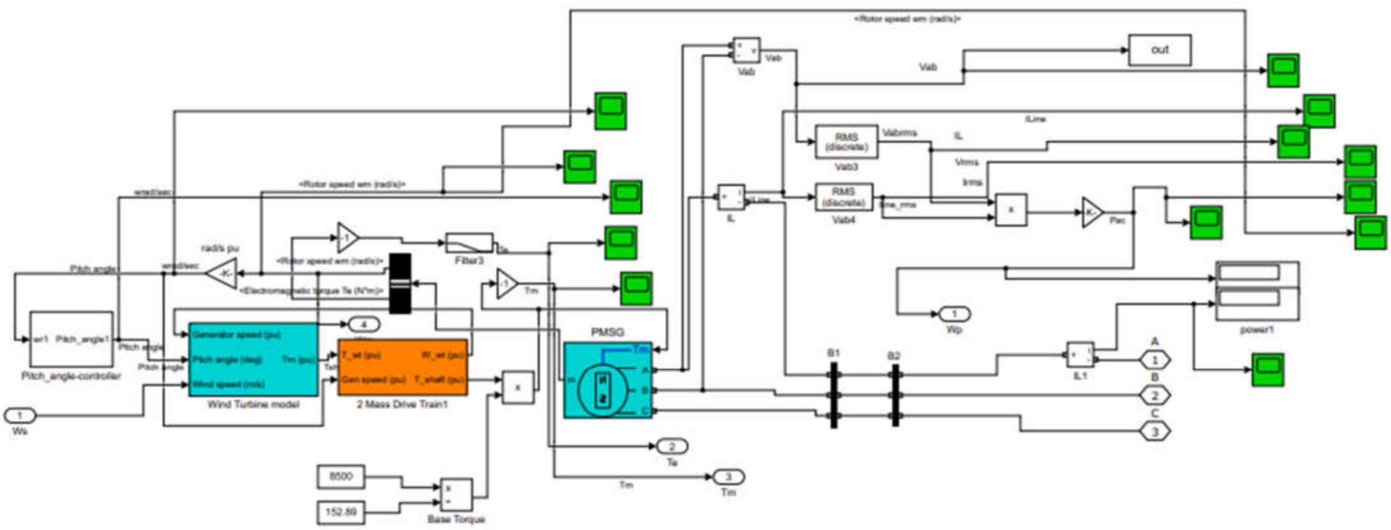

Fig-2.2- Simulation model of Wind turbine and power Generation system

The control algorithm inherently provides a self-supporting DC bus of VSC used as a DSTATCOM. It can be used for the direct current control of the VSC currents of the DSTATCOM. There are three algorithms that are performed as conventional values and Harmonic search algorithm.

2.1 Harmony Search based PI Controller for D-STATCOM- The HSA depends mainly on the musical process of searching for a pleasing harmony. The musicians are the decision variables of the function to be optimized. The notes of the musicians represent the decision variable values. The harmony is considered the optimal solution vector. Unlike the gradient optimization techniques, the HSA is a stochastic search and a free derivative algorithm. Furthermore, it has a simple mathematical model and is easier to implement in engineering problems.

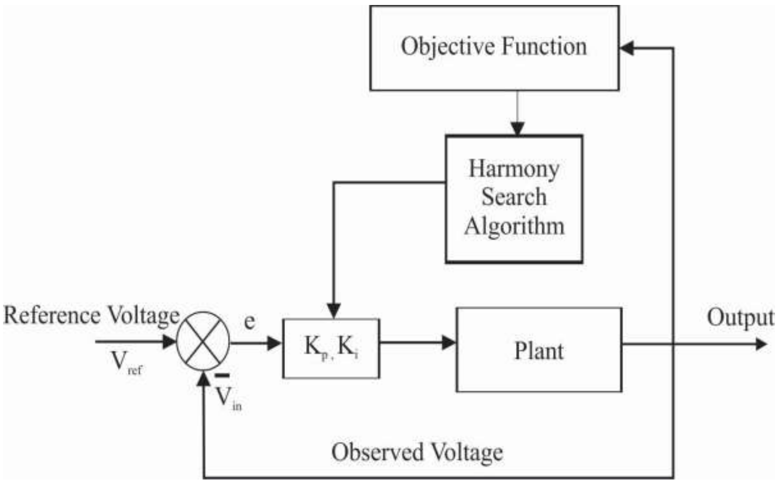

Fig. 2.1- HSA based PI Controller

3. MATHEMATICAL MODELLING AND CONTROL ALGORITHM

3.1 STATCOM CONTROL ALGORITHMS

3.1.1 Frequency Domain: *d-q* Control Algorithm for Unbalanced Conditions

A control method is built based on the mathematical model for unbalanced circumstances that is presented. The control algorithm's goal is to provide decoupled control of the current components in the d and q axes as well as separate control of positive and negative sequence currents.

Firstly, five new variables are introduced $\left(w'_{pd\_p}, w'_{pd\_q}, w'_{dc}, w'_{pd\_n}, w'_{pq\_n}\right)$

$$\begin{bmatrix} w'_{pd\_p} \\ w'_{pq\_p} \\ w'_{pd\_n} \\ w'_{pq\_n} \\ w'_{dc} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & \frac{-k_p\omega_B}{L'_p}S_{d\_p} \\ 0 & 0 & 0 & 0 & \frac{-k_p\omega_B}{L'_p}S_{q\_p} \\ 0 & 0 & 0 & 0 & \frac{-k_p\omega_B}{L'_p}S_{d\_n} \\ 0 & 0 & 0 & 0 & \frac{-k_p\omega_B}{L'_p}S_{q\_n} \\ \frac{3k_p\omega_B C'}{2}S_{d\_p} & \frac{3k_p\omega_B C'}{2}S_{q\_p} & \frac{3k_p\omega_B C'}{2}S_{d\_n} & \frac{3k_p\omega_B C'}{2}S_{q\_n} & \frac{-\omega_B C'}{R'_c} \end{bmatrix} \begin{bmatrix} i'_{pd\_p} \\ i'_{pq\_p} \\ i'_{pd\_n} \\ i'_{pq\_n} \\ v'_{dc} \end{bmatrix} + \begin{bmatrix} \frac{\omega_B}{L'_p}v'_{id\_p} \\ \frac{\omega_B}{L'_p}v'_{iq\_p} \\ \frac{\omega_B}{L'_p}v'_{id\_n} \\ \frac{\omega_B}{L'_p}v'_{iq\_n} \\ 0 \end{bmatrix} \quad (3.1)$$

So, that the STATCOM mathematical model equation is transformed to

$$\frac{d}{dt}\begin{bmatrix} i'_{pd\_p} \\ i'_{pq\_p} \\ i'_{pd\_n} \\ i'_{pq\_n} \\ v'_{dc} \end{bmatrix} = \begin{bmatrix} \frac{-R'_p\omega_B}{L'_p} & \omega & 0 & 0 & 0 \\ -\omega & \frac{-R'_p\omega_B}{L'_p} & 0 & 0 & 0 \\ 0 & 0 & \frac{-R'_p\omega_B}{L'_p} & \omega & 0 \\ 0 & 0 & -\omega & \frac{-R'_p\omega_B}{L'_p} & 0 \\ 0 & 0 & 0 & 0 & \frac{-\omega_B C'}{R'_c} \end{bmatrix} \begin{bmatrix} i'_{pd\_p} \\ i'_{pq\_p} \\ i'_{pd\_n} \\ i'_{pq\_n} \\ v'_{dc} \end{bmatrix} + \begin{bmatrix} w'_{pd\_p} \\ w'_{pq\_p} \\ w'_{pd\_n} \\ w'_{pq\_n} \\ w'_{dc} \end{bmatrix} \quad (3.2)$$

Newly introduced variables represent the outputs of PI controllers. With the known values of $w'_{pd\_p}, w'_{pd\_q}, w'_{dc}, w'_{pd\_n}$ and w'_{pq_n} all four adjustable parameters $\left(S_{d\_p}, S_{q\_p}, S_{d\_n} \text{ and } S_{q\_n}\right)$ can be computed. The STATCOM mathematical model is reduced to five first-order functions, improving the converter performance. The developed control scheme is shown in Fig. 4.1 showing a general current control loop and the DC-voltage control loop.

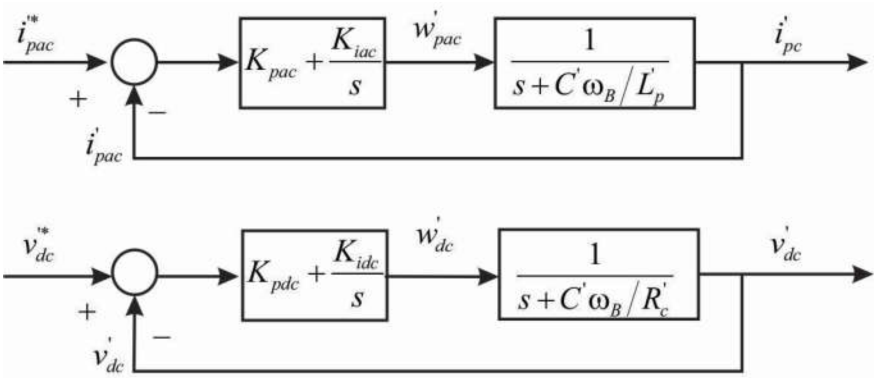

Fig. 3.1 Current control loop and DC-voltage control loop

The controlled signals (positive and negative-sequence currents, DC voltage) are first compared to the reference ones (marked with an asterisk). The difference is then applied to a PI controller. The output of each controller is a corresponding variable w'_{pac}. With the solution of the values of adjustable parameters $\left(S_{d\_p}, S_{q\_p}, S_{d\_n} \text{ and } S_{q\_n}\right)$ can be calculated. The two adjustable parameters for the positive sequence $\left(S_{d\_p}, S_{q\_p}\right)$ are calculated with the known values of w'_{pd_p}, w'_{pd_q}. The first parameter is used to control positive-sequence active current $\left(i'_{pd\_p}\right)$ and the second one is used to control the positive-sequence reactive current $\left(i'_{pq\_p}\right)$. Furthermore, with the known values of w'_{pd_n} and w'_{pq_n}, the adjustable parameters for the negative sequence $\left(S_{d\_n}, S_{q\_n}\right)$ can be calculated. One is used for negative sequence active current $\left(i'_{pd\_n}\right)$ control and the other is used for negative-sequence reactive current $\left(i'_{pq\_n}\right)$ control. From the output of the DC-voltage controller w'_{dc} the reference positive-sequence active current $\left(i'_{pd\_p}\right)^*$ is calculated so that the DC component of the capacitor voltage is maintained at constant value.

To sum up, with four adjustable parameters all four currents can be controlled. With the DC control loop variable $w_{dc}^{'}$ the reference value of the positive-sequence active current is calculated. With the described control algorithm all four currents (*d* and *q*-axes currents of the positive and negative sequence) are decoupled. However, as all the currents share a common DC bus, a change in the DC component of the DC-side voltage affects all the currents. Therefore, the positive-sequence active current control loop has to be fast enough to keep the DC voltage at a constant level.

4. RESULT ANALYSIS-

PERFORMANCE PARAMETERS OF PI CONTROLLER AND STATCOM OBTAINED BY CONVENTIONAL VALUES AND HARMONY SEARCH ALGORITHM WITHOUT POWER ELECTRONICS LOAD

This section describes the analysis of different intelligent control method applied for parameter estimation of PI controller and STATCOM. Without electronics load generator parameters are taken into account like Voltage, current and power. At the other hand electromagnetic torque, Mechanical torque and Rotor speed deviation here with the help of optimization technique. System is designed for the most common fault that is line to ground fault. At this faulty condition system is performed with conventional value and with harmony search algorithm.

By tuning the parameters of PI and STATCOM, Firstly analysis is done with manual setting of value of kp and ki for PI controller STATCOM. After that STATCOM and PI controller is tuned based on optimization technique which is named as Harmony Search (HS) algorithm. From the above-mentioned method best result is obtained in the HS algorithm as it converges fast as compared to conventional PI controller.

Table 4.1- Performance parameters of PI controller and STATCOM

PARAMETERS → / TUNING METHODS ↓	P	I	Vdc
With conventional values	10.762	9.345	10
Harmony Search Algorithm	6.2945	8.1158	7.46

4.1 Simulation results for wind generator parameters with conventional value-

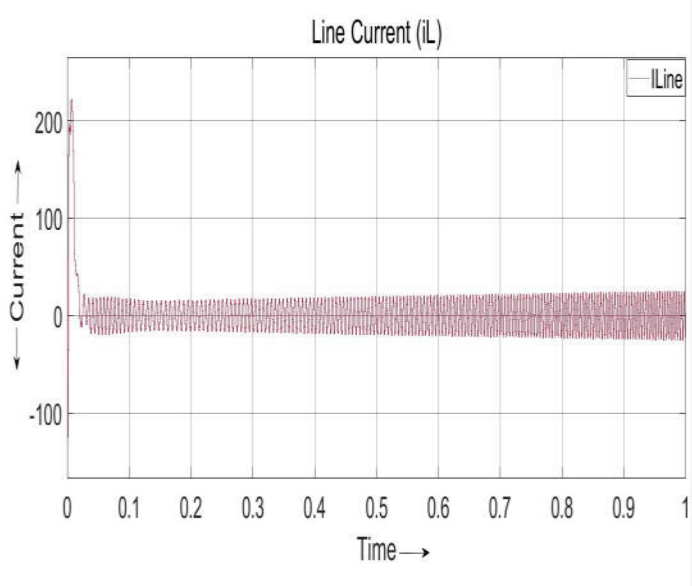

Fig 4.1.1- Current waveform with conventional value

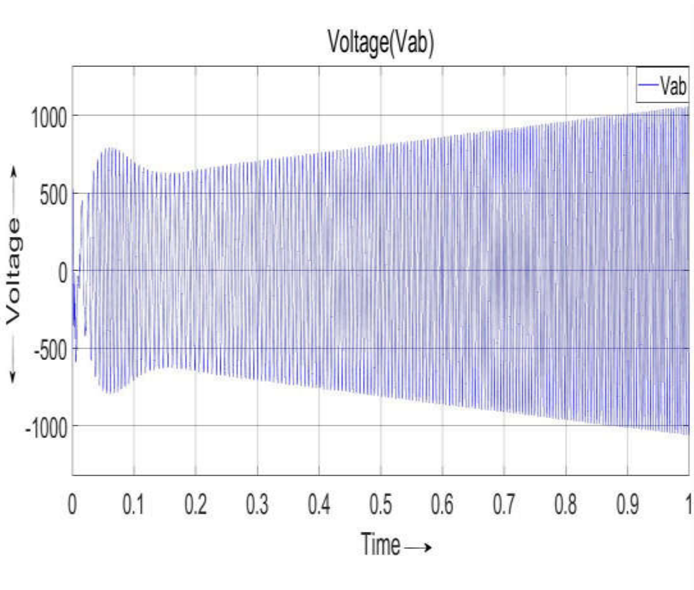

Fig 4.1.2- Terminal Voltage with conventional value

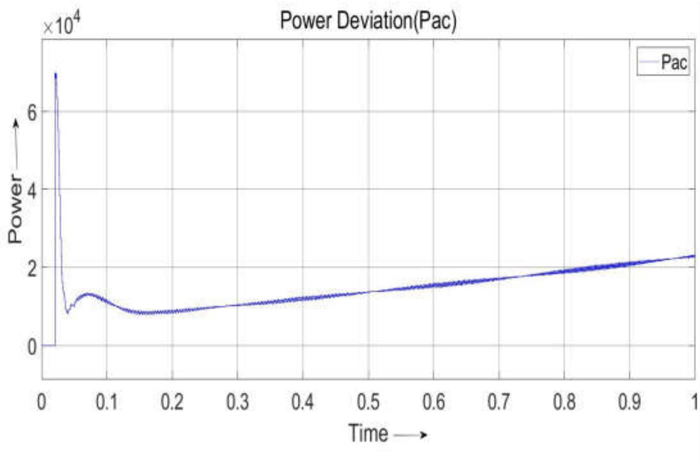

Fig 4.1.3- Power with conventional value

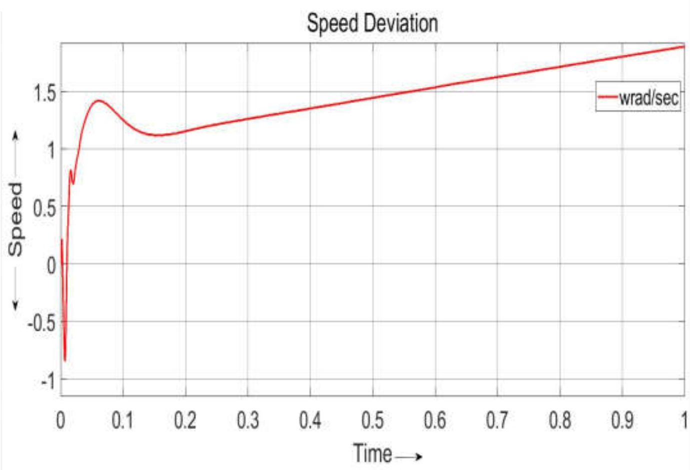

Fig 4.1.4- Rotor speed with conventional value

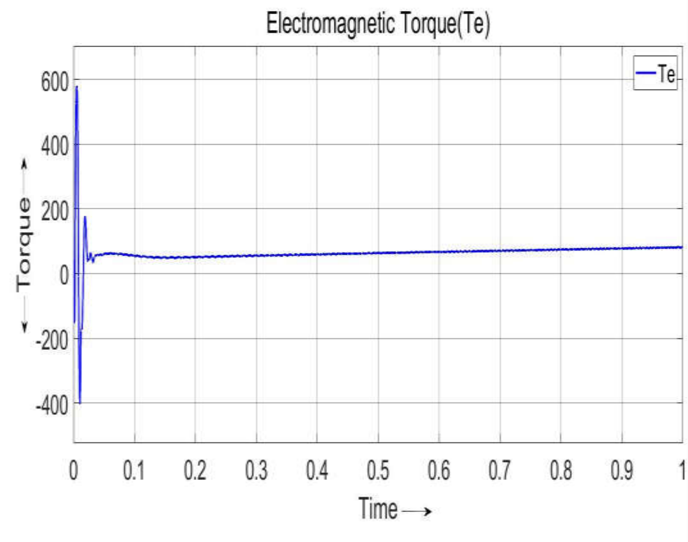

Fig 4.1.5- Electromagnetic Torque with conventional value

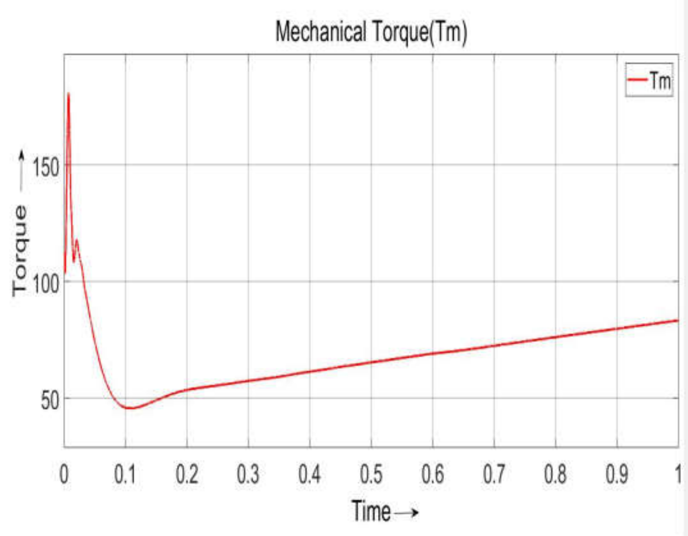

Fig 4.1.6- Mechanical Torque with conventional value

4.2- Simulation results of wind generator parameters for Harmony search algorithm

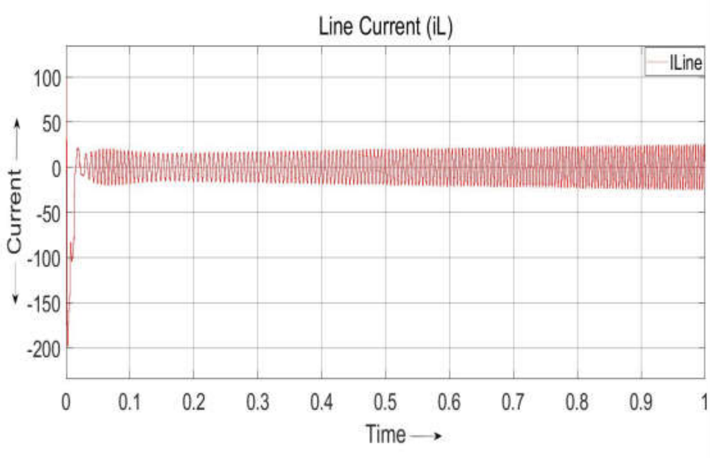

Fig 4.2.1- Line Current with HS algorithm

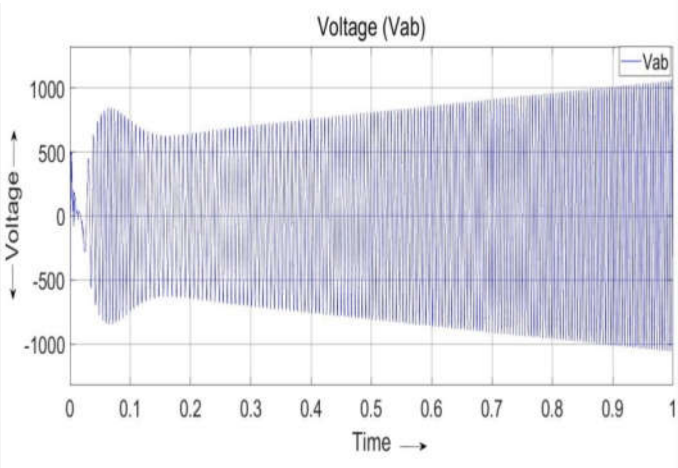

Fig 4.2.2- Terminal voltage with HS Algorithm

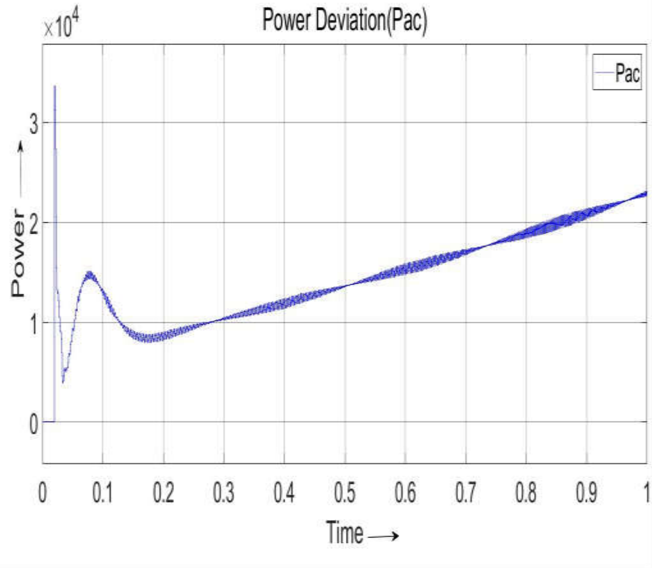

Fig 4.2.3- Power with HS Algorithm

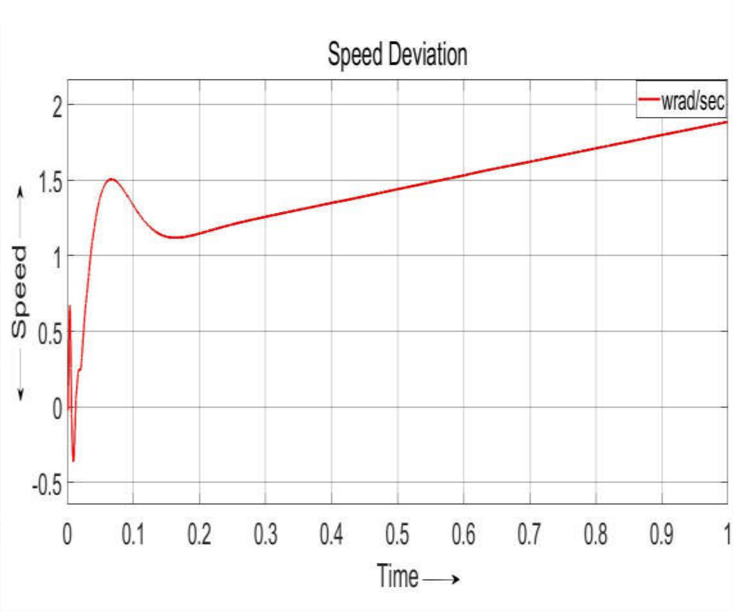

Fig 4.2.4- Rotor Speed HS Algorithm

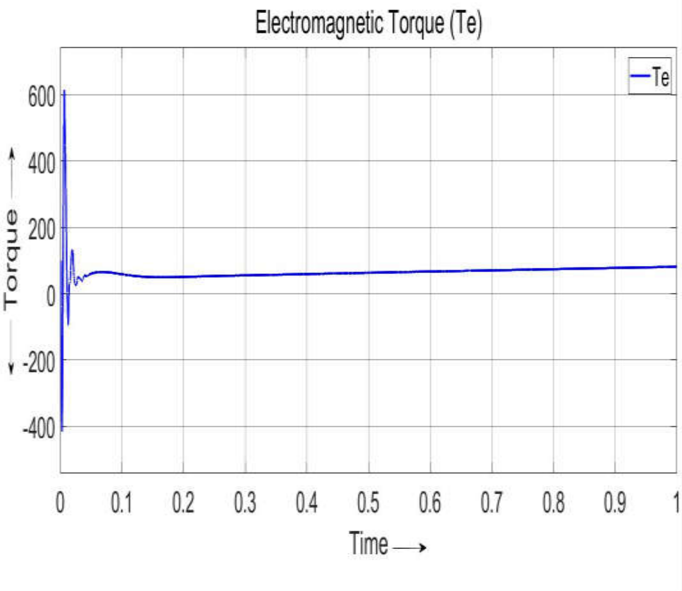

Fig 4.2.5- Electromagnetic Torque with HS Algorithm

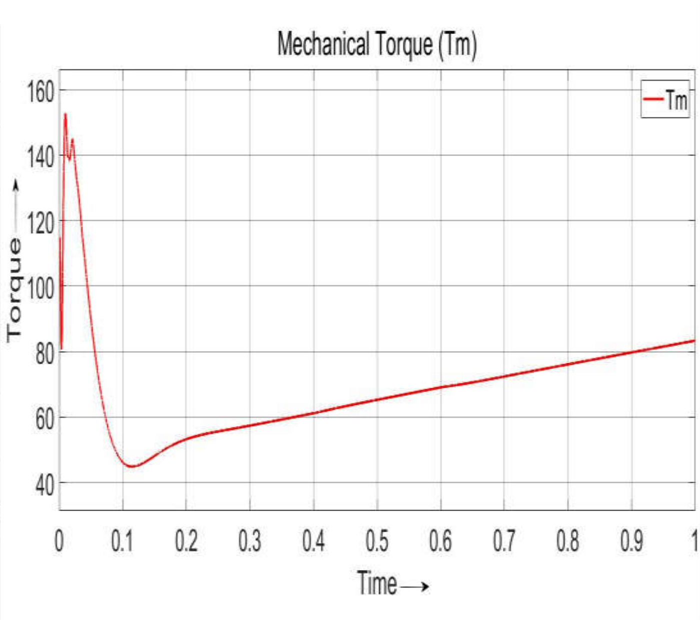

Fig 4.2.6- Mechanical Torque with HS Algorithm

The convergence rate of the harmony search algorithm is much faster as compared to ant colony optimization and genetic algorithm. Thus it can be concluded that the harmony search algorithm is best as compared to manual method.

5. CONCLUSION- The coordinated wind energy period and the optimized PI-D-STATCOM system with battery capacity have demonstrated impressive performance. D-STATCOM as a power electronic designed to manage potential risks. To evaluate the D-STATCOM's function for integrating wind energy into the electrical system, fault analysis was conducted without sacrificing its effectiveness. Electrical failures near generator stations pose serious threats to the stability of the. Therefore, the system's performance was assessed by incorporating a D-STATCOM to maintain voltage levels near normal after simulating a line-to-ground fault at a bus-bar close to the wind energy period. By integrating optimized controller parameters, variations in terminal voltage, rotor speed, mechanical torque, electromagnetic torque, power, and line current were measured under various operating conditions. The results showed a reduction in deviations, indicating that the system exhibits a good dynamic response when disturbed. Additionally, other deficiencies within the analysed system were noted. This underscores the system's strong reactive performance in the event of disturbances. The perfect adjustment of the PI controller parameters in D-STATCOM for a linear load was achieved using experimental methods and Harmony Search Algorithm (HSA). It was determined that HSA was the most suitable approach for addressing the challenges identified in MATLAB.

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