Enhancement of Power Quality in Wind Power Distribution System by Using Hybrid PSO-Firefly based DSTATCOM

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Abstract - Electricity generation, electric power transmission and final distribution to an electricity meter are some of the processes performed in the industry of electric power. Power quality is an important factor to show the wellness of electric power. Due to the changing behavior of power generation in wind systems, more power quality issues may occur. This paper presents the simulation and analysis of Distribution Static Synchronous Compensator for voltage sag mitigation, harmonic distortion and power factor improvement using the control strategy named hybrid PSO-Firefly algorithm. The hybrid control strategy effectively enhances the performances of Distribution Static Synchronous Compensator in order to provide the faster and dynamic response. By utilizing the novel control strategy the compensation in the proposed work was completely admirable when compared with the existing techniques like proportional integral and derivative controller and proportional integral and derivative-particle swarm optimization control. The reduction of harmonics achieved to a lower percentage as 1.216 in the proposed work. The operation of simulated control method for Distribution Static Synchronous Compensator is performed in MATLAB SIMULINK.

Keywords: Distribution Static Compensator (DSTATCOM), Firefly, Particle Swarm Optimization (PSO), PID Controller, Wind distribution system.

1. Introduction

One of the basic needs of every country is electricity which is a prime sector in countries. The electric power expected by the client is inheritable through transmission units and provided to the individual clients. It is necessary to satisfy this need with high level of power quality [1]. The power quality is the term coincident with stable supply of power. For the continuity of electric power supply number of techniques are utilized in the power distribution system [2]. One of the solutions for the continuous power supply is the incorporation of renewable energy resources to the power system [3].

Among the different kinds of sources the wind and solar are the most desired sources of energy. The issue related with power quality is either linked up with components of the system or the consumers of the distribution system [4-6]. To secure a harmony amongst free market activity in the power distribution system the wind turbines need to work together with whatever is left of the creation units in the system so as to make it feasible for the distribution system [7-8]. The nature of supply joining with the wind power systems is still a swaying issue [9-10]. The power quality issues in a distribution system are considered in three levels such as generation, transmission and distribution [11].

With the increasing penetration of renewable energy sources, particularly wind energy, as well as the growing percentage of power electronics-based devices and plants in the electrical supply grid, power quality issues ranging from voltage sags/swells, harmonics and unbalances to short-duration interruptions do pose a great challenge to the supply reliability [12]. Integration of large amount of wind energy in an interconnected power system creates concerns about secure, reliable and economical operation of the entire power system [13]. The problems arise in the wind based system starts from wind generator. The power quality shortcomings are generally voltage variations and stability. These issues are overcome with the aid of compensators [14-17]. An effective nonlinear Takagi-Sugeno(T-S) fuzzy model controller using local linear dynamic state space models can be used to capture the maximum power from variable speed wind turbine [18]. When the wind generators go off the grid, a reduction in power generation will be experienced [19]. The power quality concerns are solved by compensators like STATCOM [20], static VAR compensator (SVC) and the recently used one is DSTATCOM [21]. The compensation devices needs controllers for its working it may a device or some intelligent techniques like artificial neural network, fuzzy control [22-23]. Sliding mode power controller (SMPC) for voltage source converter (VSC) applied to wind energy systems aims at regulating the DC-link voltage of the converter and precisely tracking arbitrary power references, in order to easily control the system's power factor [24].

Custom Power Device is a powerful device in light of semiconductor switches idea to secure delicate loads if there is an unsettling influence from power line. The DSTATCOM with two control modes operation is discussed in to enhance power quality [25- 26]. In most researches the design of DSTATCOM is accumulated with parallel filter capacitor. The reactive power compensation, power factor correction, demolishing of harmonics for the effective enhancement in power quality is provided by the compensators. The unified power quality controllers provides faster response and they are based on switching converter technology while the DSTATCOM devices are capable of real and reactive power absorption or injection for the betterment of power quality with harmonics elimination. [27-28].

In the proposed work the power quality problems in wind based distribution system are mitigated with the help of DSTATCOM. The controlling of compensator is given through the hybridized PSO-Firefly optimization algorithm. The optimization work used to select the proper gain parameters of proportional integral derivative controller. The tuned PID with proper gain values provides control signal to DSTATCOM. The power quality problems are eliminated by the selected compensator with proper control signal.

The control strategy utilizing the artificial intelligence (AI) based controller is much interesting and robust technique than the existing controlling methodologies. In the existing methodologies the PID controller tuned itself for obtaining the proper gain values. The process of self-tuning might increase the operational time. But the AI controllers take over the process of tuning the gains of PID controller so that it automatically generated the control signal in an accurate and faster manner. The error minimization also a robust operation by the optimization algorithm through the number of iterative functions. Thus in order to get the faster and vigorous control signal, the proposed methodology utilizes the optimization based controller technique. The particle swarm optimization algorithm is combined with firefly algorithm in the proposed method. The hybridization takes place to eliminate the slower convergence of the particle swarm optimization. Updating the positions of particles in PSO reduce the convergence ability of the algorithm so by utilizing the firefly algorithm the faster position movement is evaluated. Thus the overall proposed work is well suitable to reduce the power quality issues in the wind power distribution system.

2. Related Works

The renewable energy resources had developed its presence in power distribution system for enhancing the interruption in power supply. ArashAsrari*et al.* [29] had developed Pareto-based metaheuristic optimization in order to reduce the voltage related power quality issues in distribution system. The multi-objective constraint based proposed methodology was tested on the 69 bus distribution system. The considerable improvement was studied in the resultant part for the sag and drop mitigation of the considered system.

Chandan Kumar *et al.* [30] had discussed the constraints in the implementation of current control and voltage control modes of the distribution static compensator. The current control mode was tested and identified as not suitable for the enhancement of load voltage. Instead of that the voltage control mode was adopted as the controlling mechanism of DSTATCOM and the operation was verified. The results obtained from the simulation indicate the interruptions in the power feeder and power supply channel were diminished by distribution static compensator.

Sabha Raj Arya et al [31] had addressed a novel control methodology for the synchronous reluctance generator with a prime mover biogas/biomass diesel motor. The neural network controlled distributed static compensator was utilized for the load sensitivity reduction and voltage management in the synchronous reluctance generator. The distracted currents measured by the proposed method were considered for the generation of reference currents. The simulation results had shown the better enhancement in the overall outcome.

The solid state devices and equipment were the cause of the power quality issues in the power system and it was analysed bySrinivas et al. [32]. The distribution static compensator was taken as the compensating device with the control algorithm combined least mean square-least mean fourth. The Matlab based Sim Power System toolbox was utilized to generate the reference currents with active and reactive power. The proposed algorithm controlled the compensation device by minimizing the error signal. The output of the system was found satisfactory with reduced harmonics in the supply currents. The distribution static compensator with battery energy storage had utilized to enhance the power quality in wind integrated power system [33]. The load uncertainties sag and swell had studied and rectified by DSTATCOM.

The novel control design for unified power quality conditioner with multi converters for mitigating the power quality issues in three phase four wire distribution systems with two feeders had proposed in [34]. The control strategy for the design was the modified synchronous reference frame theory. The three voltage source converter connected with the distribution system were utilized to solve the voltage sag and harmonics issues while linear and nonlinear loading. The fuzzy logic controller was the technique for improving the DC link capacitor's dynamic response. From the result analysis the efficiency of the proposed technique was proved. F.H. Zadeh and M.R. Naseh*et al.* [35] had developed certain harmonic reduction factor for three wire systems. Due to the presence of non-linear loads, the consumer sector of the power supplies gets affected. Distribution and induction generator modeling in wind turbine systems is responsible for the production of harmonics. And hence the usage of UPQC improves the performance of harmonic reduction.

Sensitivity and power quality improvement via the development of power system analysis has been proposed in R.A.J.Amalorpavaraj *et al.* [36]. The inadequate disconnection of wind turbines leads to voltage swag & swell due to the rms voltage variation. Dynamic voltage restorer regulates the terminal voltage of the wind forms. Here, the compensation of injected voltage is achieved via the development of PWM based firing signals.

3. Proposed Methodology

The maintenance of generating power and the fulfillment of customer needs are the main objectives of power system operation. In some of the unpredictable situations the compensation is provided by additional devices such as distribution generations integrated into the power system. In recent years the inexhaustible energy sources such as wind, solar energy systems are integrated into the power system. Among those resources the wind energy system has the increasing demand in today's environment. The reason for increasing willingness is the gratification of renewable energy systems are reduced usage of fossil fuels, reduced cost and reduction of greenhouse gases [37].

The wind energy systems are integrated into the distribution power systems for the continuation of power supply. Likewise one of the promising distribution systems is the wind power distribution system. While the integration of wind systems provides betterment in supplying system power supply at the same time it generates a new problem that is power quality reduction. In the same way the generation of wind energy is oscillating one because of the wind blows.

In the power transmission or distribution system the reduction of voltage variations can be done through a fast reactive power compensator named DSTATCOM (Distribution Static Compensator). The commonly known voltage variations are sags and swells. Due to the rapidly varying reactive power demand these voltage variations cause power quality reduction or instability. The three phase power measured at load and the error value is identified by comparing the measured value with the reference value, which is given as the input to Hybrid PSO-firefly algorithm. The objective of this hybrid algorithm is to make the mean square error value as minimum as possible. The hybrid algorithm output is used for tuning the parameters of PID controller. The output of the PID controller is given into the PWM controller, which generates the control signal for DSTATCOM.

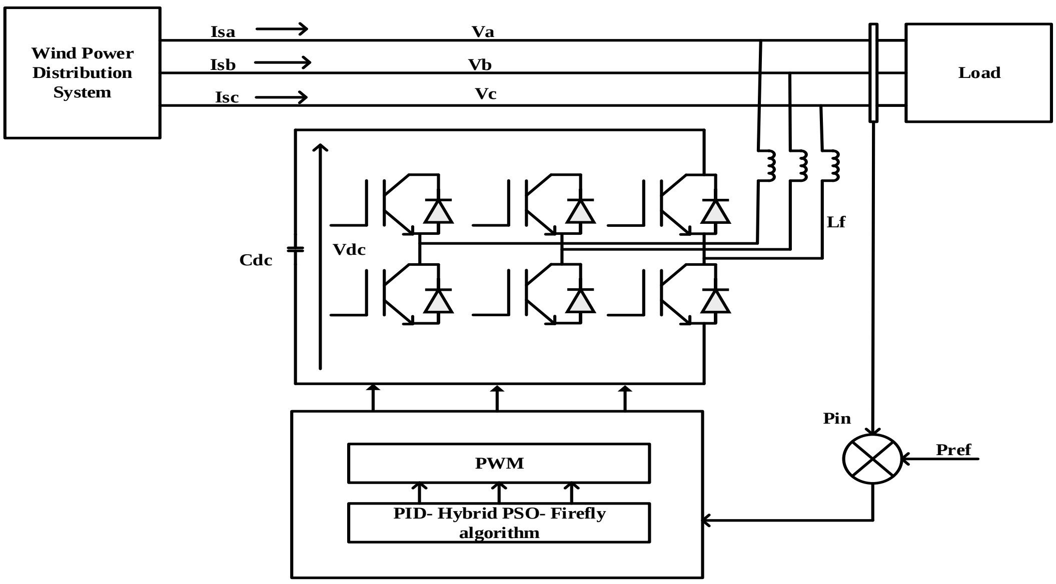

Fig. 1. Block diagram of the proposed system

Figure 1 represents the block diagram of the proposed methodology. The wind power distribution system is considered for the power quality enhancement. The load is connected to the distribution system in between that the power is measured to for generating the control signal. The DSTATCOM obtained control signal from the PID-Hybrid PSO-Firefly algorithm as an error minimized signal. The injection from the compensating device improves the power quality by mitigating the issues.

3.1. Estimation of DSTATCOM parameters

DSTATCOM is one of the custom power devices used for the enhancement of power quality in distribution system. It injects reactive currents into the distribution system, which cancels the reactive components of load currents thus making source currents harmonic free [38].

3.1.1. Voltage of DC bus:

The DC bus voltage for a three phase VSC is defined as,

$$V_{dc1} = 2\sqrt{2}\,\frac{V_{ll}}{\sqrt{3}s} \tag{1}$$

Where, V_{ll} = AC line to line output voltage of DSTATCOM = 415 V for a 250 KVAr DSTATCOM

'*s*' is denoted as the modulation index which is generally considered as 1. The value of V_{dc1} for the proposed DSTATCOM = 677.69 V

3.1.2. DC bus capacitance:

The parameter C_{dc} can be estimated using the values of nominal value of DC voltage and the estimated DC bus voltage. The DC bus capacitance can be defined as,

$$C_{dc} = K\,\frac{2\{V_{ph}(c.I)t\}}{\{(V_{dc})^2 - (V_{dc1})^2\}} \tag{2}$$

In the above equation V_{dc1} is the minimum level of DC bus voltage (677.69 V);

V_{dc} is the nominal value of DC voltage (700 V)
Overloading factor denoted here is c (1.2)
V_{ph} is the phase voltage (240 V)
'I' is the phase current (38.95 A)
'*t*' is the recovering time of DC bus voltage (t = 0.04s)
K varies from 0.05 to 0.15

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Based on these values, C_{dc} = 8822.39 μF

3.1.3. AC Inductor:

The AC inductance for DSTATCOM is defined below,

$$L_f = \frac{\sqrt{3}sV_{dc}}{12cf_{sw}i_{rc}} \tag{3}$$

In Eq. (3) the value of switching frequency (f_{sw}) is taken as 10 KHz; and i_{rc} is the ripple current, given by

$$i_{rc} = 0.83I_{rms} \tag{4}$$

I_{rms} is the rated current rms value.

$$I_{rms} = \frac{250\times10^3}{\sqrt{3}\times415} = 347A \tag{5}$$

By using I_{rms} value, irc = 288.01A. Therefore the value of inductance is 10^{-4} H.

3.2. Mathematical Modeling of DSTATCOM

DSTATCOM controller is not only used for solving voltage related problems like system voltage regulation, voltage profile improvement, voltage harmonics reduction but also to solve current related issues. There are two methods relies with the designing of DSTATCOM device, voltage source inverter and current source inverter methods. In the proposed approach, VSI based system is used.

The configuration of the DSTATCOM is shown in Figure 2. The configuration consists of inverter or voltage source converter, DC link capacitor and a coupling inductor. In the appropriate designing of DSTATCOM some of the things taken into consideration are,

1) Selection of power rating of switches
2) Choke value determination
3) Capacitor value identification

The insulated gate bipolar junction transistors were utilized as switches in the medium voltage applications.

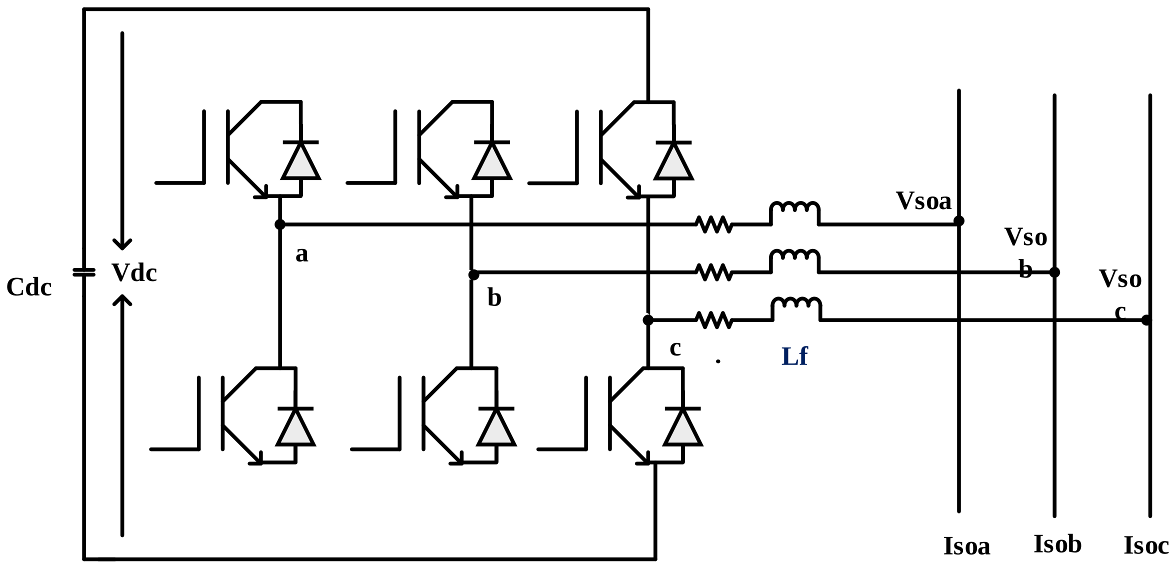

Fig. 2. Configuration of DSTATCOM

Initially the mathematical modeling is started with the measurement of three phase source voltage and source current [39]. They are defined below,

$$V_{soa} = V_m \sin \omega T \quad (6)$$

$$V_{sob} = V_m \sin\left(\omega T - 120^0\right) \quad (7)$$

$$V_{soc} = V_m \sin\left(\omega T + 120^0\right) \quad (8)$$

Where V_m = Maximum voltage value, ω is the angular velocity and T is the time duration.

From the three phase measurement the voltage value for PCC is derived as,

$$V_{pcct} = \sqrt{\frac{2}{3}\left(V_{soa}{}^2 + V_{sob}{}^2 + V_{soc}{}^2\right)} \quad (9)$$

The in-phase and quadrature phase unit prototype of PCC (Point of Common Coupling) is expanded from the three phase voltages and PCC voltage. The in-phase unit prototypes are,

$$u_{ai} = \frac{V_a}{V_{pcct}}; \quad u_{bi} = \frac{V_b}{V_{pcct}}; \quad u_{ci} = \frac{V_c}{V_{pcct}}$$

The quadrature phase unit templates are defined below,

$$u_{aq} = \frac{(-u_{bi} + u_{ci})}{\sqrt{3}} \quad u_{bq} = \frac{\sqrt{3}u_{ai} + u_{bi} - u_{ci}}{\sqrt{2}\sqrt{3}}$$

$$u_{cq} = \frac{-\sqrt{3}u_{ai} + u_{bi} - u_{ci}}{\sqrt{2}\sqrt{3}}$$

The load currents for each phase are estimated by using the following relationship,

$$I_{la} = I_{lb} \sin(wT - \phi) \quad (10)$$

$$I_{lb} = I_{lb} \sin\left(wT - \phi - \frac{2\pi}{3}\right) \quad (11)$$

$$I_{lc} = I_{lc} \sin\left(wT - \phi + \frac{2\pi}{3}\right) \quad (12)$$

The DC component of real and reactive power can be expressed as the function of active and reactive load power and oscillating components of real and reactive power are expressed as below,

$$P_{DC} = P_{Load} - P_o \quad (13)$$

$$Q_{DC} = Q_{Load} - Q_o \quad (14)$$

Where P_{DC} is the DC component of real power; Q_{DC} is the DC component of reactive power; P_{Load} is the instantaneous active load power; Q_{Load} is the instantaneous reactive load power; P_o is the oscillating component of real power; Q_o is the oscillating component of reactive power.

The instantaneous load real and reactive power can be derived as,

$$P_{Load} = V_{pcct}\left(I_{la}u_{ai} + I_{lb}u_{bi} + I_{lc}u_{ci}\right) \quad 15)$$

$$Q_{Load} = V_{pcct}\left(I_{la}u_{aq} + I_{lb}u_{bq} + I_{lc}u_{cq}\right) \quad (16)$$

The real and reactive power can be separated into two components. These two components are known as DC component and oscillating component. Generally the oscillating components of real and reactive power produces a zero mean value. The theory of instantaneous real and reactive power eliminates the values of oscillating components for current compensation. The DSTATCOM devices are generally injects currents to eliminate the harmonic components of currents.

In the source current the active power component has two divisions or parts. Likewise the reactive power component in the source current has two parts.

3.2.1. Estimation of active power components of source currents:

The two parts of active power component of source current are $I_{sp}\, and\, I_{sq}$. These two components are estimated as,

$$I_{sp} = \frac{2P_{DC}}{3V_{pcct}} \quad (17)$$

$$I_{sq} = \begin{bmatrix} K_p V_{error} + K_i \int V_{error} dt \\ + K_d \frac{d}{dt}(V_{error}) \end{bmatrix} \quad (18)$$

In the above equation, $V_{error} = V_{dc}^{*} - V_{dc}$

Where V_{dc}^{*} = Reference voltage of DC bus;

V_{dc} = Sensed DC bus voltage of DSTATCOM

The amplitude of the active component of the reference source current is given by,

$$I_{samplitude} = \begin{bmatrix} amplitude\ of\ (I_{sp}) \\ + amplitude\ of\ (I_{sq}) \end{bmatrix} \quad (19)$$

The active power component of reference source current is estimated as,

$$\left.\begin{aligned} I_{sai}^{*} &= I_{samplitude} * u_{ai} \\ I_{sbi}^{*} &= I_{samplitude} * u_{bi} \\ I_{sci}^{*} &= I_{samplitude} * u_{ci} \end{aligned}\right\} \quad (20)$$

3.2.2. Estimation of reactive power components of source currents:

Similarly for the calculation of active power components of source currents the reactive power components are estimated. The reactive power component of reference source current is given below,

$$\left.\begin{aligned} I_{saq}^{*} &= I_{s1amplitude} * u_{aq} \\ I_{sbq}^{*} &= I_{s1amplitude} * u_{bq} \\ I_{scq}^{*} &= I_{s1amplitude} * u_{cq} \end{aligned}\right\} \quad (21)$$

The value of reference source current is evaluated from the real or active and reactive power components. The evaluated values of reference source currents are,

$$\left.\begin{aligned} I_{soa}^{*} &= I_{sai} + I_{saq} \\ I_{sob}^{*} &= I_{sbi} + I_{sbq} \\ I_{soc}^{*} &= I_{sci} + I_{scq} \end{aligned}\right\} \quad (22)$$

The above reference source currents (extracted) are compared with source currents. The error difference in the mentioned comparison is amplified. The amplified value is given to the PWM device for generating the switching signals for DSTATCOM.

3.3. Modeling of Proposed Controller

The reference value for the controller of DSTATCOM is computed from the voltages ($V_{soa}, V_{sob}, V_{soc}$) and currents ($I_{soa}, I_{sob}, I_{soc}$). The control signal for DSTATCOM is given by PID- Hybrid PSO Firefly controller. The error value find out by these two inputs are given as the input of the Hybrid PSO-Firefly. The output of the hybrid technique is given as the input of the PID controller.

The mean square error is defined as,

$$Mean\ Square\ Error(MSE) = \frac{1}{N}\left[P_{reference} - P_{in}\right]^2 \quad (23)$$

The proposed work relies with the hybrid combination of Particle Swarm Optimization - Firefly algorithm. The concept of the PSO algorithm is evolved with food source detection. Consider that group of birds (particle) are searching for food. Each particle in that group has its own position and velocity but these parameters are continuously changing one. If any of the bird finds the food source it will make very high sound. Then the other birds are moving towards that bird.

Therefore the position of each bird or particle is keep updated up to the identification of food source. The updating of position of each particle is defined by movement of fireflies [40]. Figure 3 denotes the flow chart for the proposed hybrid algorithm.

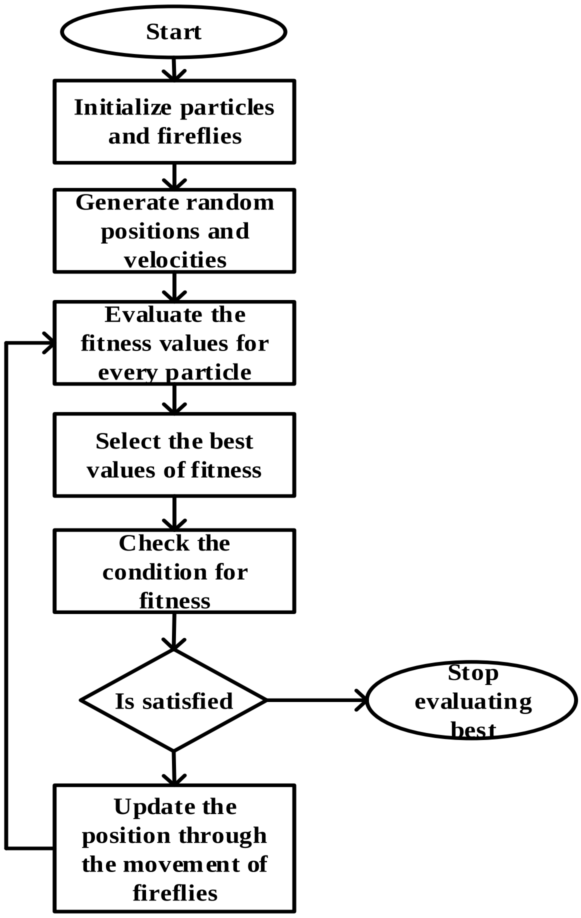

Figure 3. Flowchart for the proposed control method

Initially all values are initialized that is number of particles and number of fireflies. The velocities and positions are randomly generated for each particle. The fitness of each particle is evaluated, from which the best particle found out. After that the condition for fitness is checked if it is satisfied stop the evaluation of best values. If the condition is not satisfied the position and the velocity of the particle is updated to find the new fitness value.

The velocity of the particle is defined as,

$$V_{new} = \begin{bmatrix} V_{old} + c_1 * random\,1 * p_{best}.p_{ii} \\ + c_2 * random\,2 * g_{best}.p_{ii} \end{bmatrix} \quad (24)$$

In Eq. (24) c_1 and c_2 are the positive constants which holds the value of 0.7 ($c_{1=}$ c_2) for the proposed method; the mentioned parameters random1 and random2 are the random variables in the range [0, 1].

The objective function for the proposed algorithm is,

$$Objective\ \ function = \min(MSE) \quad (25)$$

The movements of fireflies denote the position up gradation of the particles. The movement of firefly is changed with the changing brightness.

The movement of firefly is defined as,

$$P_{ii} = P_{ii-1} + V_{new} e^{-\gamma r^2} + \alpha\varepsilon \quad (26)$$

In Eq. (26), r is the distance between the two fireflies; γ is the light absorption coefficient which usually lies between [0.1, 10]; α is the randomization parameter and ε is the random number both are having the value in the range between [0,1]. The distance between two fireflies is estimated using the below equation,

$$r = r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (27)$$

4. Results and Discussion

The proposed Power Quality Enrichment in Distribution System using the PID-Hybrid PSO Firefly based DSTATCOM is implemented in the working platform of Matlab / Simulink.

In today's electricity industry one of the notified concerns is power quality. While the introduction of advanced and complicated devices power quality becomes especially important, because the performance of these devices is very sensitive to the quality of power supply. The electronic devices are become less tolerant to power quality problems and very sensitive to disturbances such as voltage sags, voltage swells, voltage flickers, harmonics and load unbalance etc. In the proposed work the system is discussed with three power quality mitigating parameters known as voltage sag, voltage swell, and harmonic distortion.

In Table 1 the parameter setting of the proposed method is given. The grid voltage is initiated as 380 KV with 50 Hz and it is a three phase grid. The parameter ranges of induction motor generator, line series inductance, inverter, IGBT switches and load are tabulated below. The nonlinear load is selected with a rating of 25 kW. Table 2 represents the algorithmic parameters of particle swarm optimization, firefly and hybrid algorithm.

Table 1: Parameter Description

Parameter	Range
Grid Voltage	3-Phase, 380 KV, 50 Hz
Induction Motor / Generator	3.35kVA, 300V, 50 Hz, P = 4,Speed = 1440 rpm, Rs = 0.01 Ω, Rr = 0.015Ω, Ls = 0.06 H, Lr = 0.06 H
Line Series Inductance	0.05 mH
Inverter Parameters	DC Link Voltage = 700 V DC link Capacitor =10000 µF Switching frequency = 10 kHz
IGBT Rating	Collector Voltage = 1200 V Forward Current = 50 A Gate voltage = 20 V Power dissipation=310 W
Load parameter	Non-linear Load 25 kW

Table 2: Parameter Description of algorithms

PSO		Firefly		PSO-Firefly	
No. of iterations	500	No. of iterations	250	No. of iterations	100
No. of populations	10	No. of populations	15	No. of populations	10
Inertia weight	0.5	Light absorption coefficient	1	Light absorption coefficient	1
-	-	Attraction coefficient	2	Attraction coefficient	2
-	-	-	-	Inertia weight	0.9

4.1. DSTATCOM with PID Controller

The gain values with this control technique is given as K_p= 0.5, K_i = 0 and K_d= 0.5. The output of this PID controller is given to the PWM block, where the pulses will be generated and given to DSTATCOM. The power quality issues such as voltage swell, voltage sag and harmonic distortion is considered for analysis.

Figure 4 shows the simulation model of DSTATCOM with PID controller. By tuning the gains of PID controller the control signal is obtained for the compensation unit. The nonlinear and load is connected with the wind power distribution system and in the point of common coupling the DSTATCOM is connected.

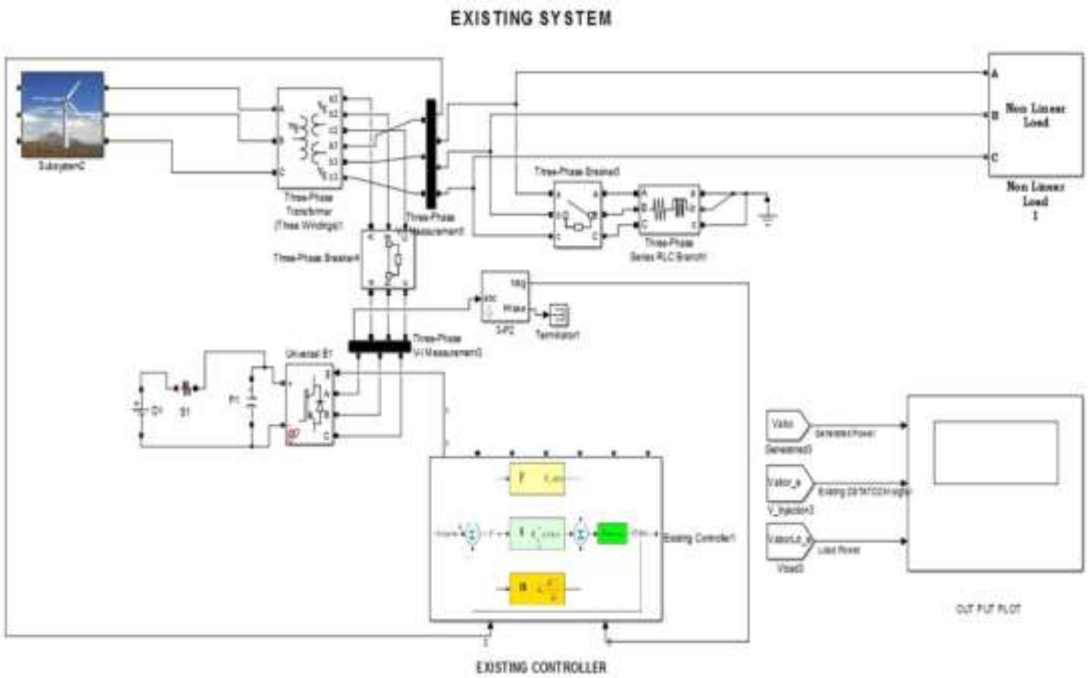

Fig. 4. Simulation model of DSTATCOM with PID controller

Figure 5 shows the simulation results consisting of the generated signal, DSTATCOM signal and the load signal. In the generated signal, voltage swell is occurred during 0.2 to 0.4 sec. for duration of 0.2 sec. and the voltage sag occurred during 0.5 to 0.7 sec. for duration of 0.3 sec. During voltage swell, the voltage is increased to 400 kV and during sag it is decreased to 190 kV. The load signal compensated by the DSTATCOM clearly shows that there is no much variation in the voltage during swell but during sag the voltage is improved to almost 290 kV and the average load voltage is around 350 kV. The total harmonic distortion (THD) after compensation by DSTATCOM is 2.493%. The compensation provided by this technique is not enough to fulfill the required load demand.

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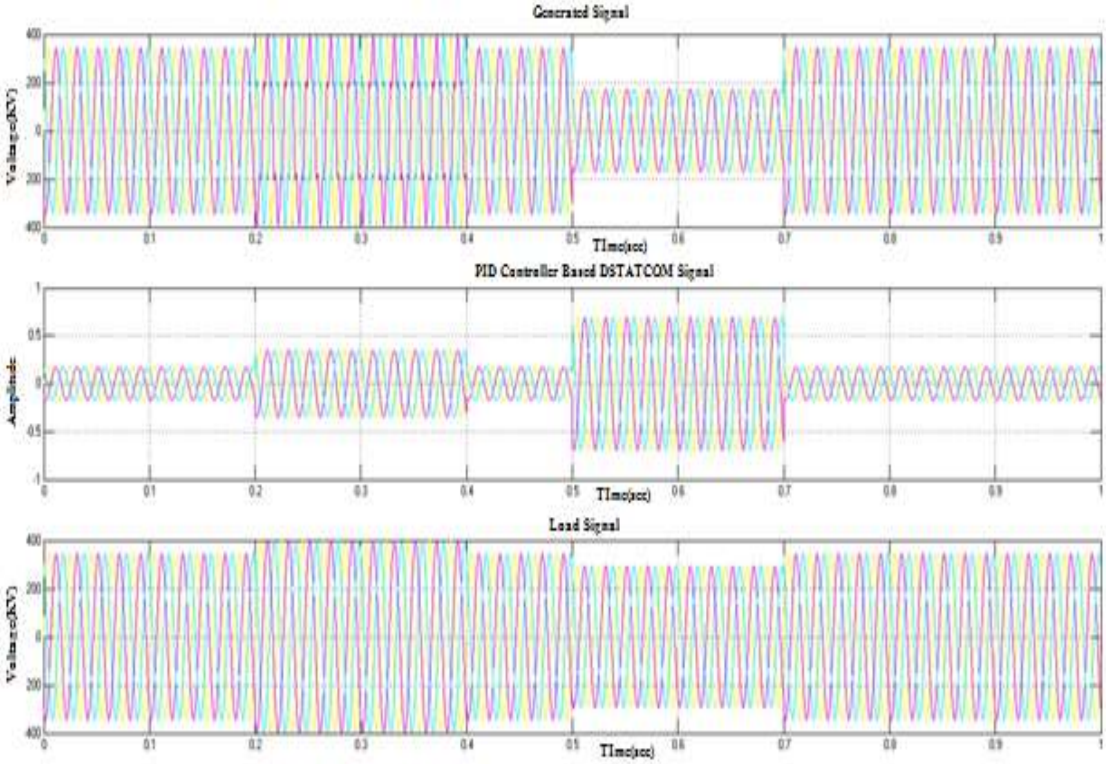

Fig. 5. Simulation results with PID control based DSTATCOM

4.2. DSTATCOM with PID-PSO Controller

The Simulink model for existing PID-PID based compensation is represented in the successive figure. In this technique, the existing PID control is combined with particle swam optimization (PSO) method to obtain the optimized gain values. Hence it forms a PID-PSO control technique to provide the required compensation needed to improve the power quality in the system.

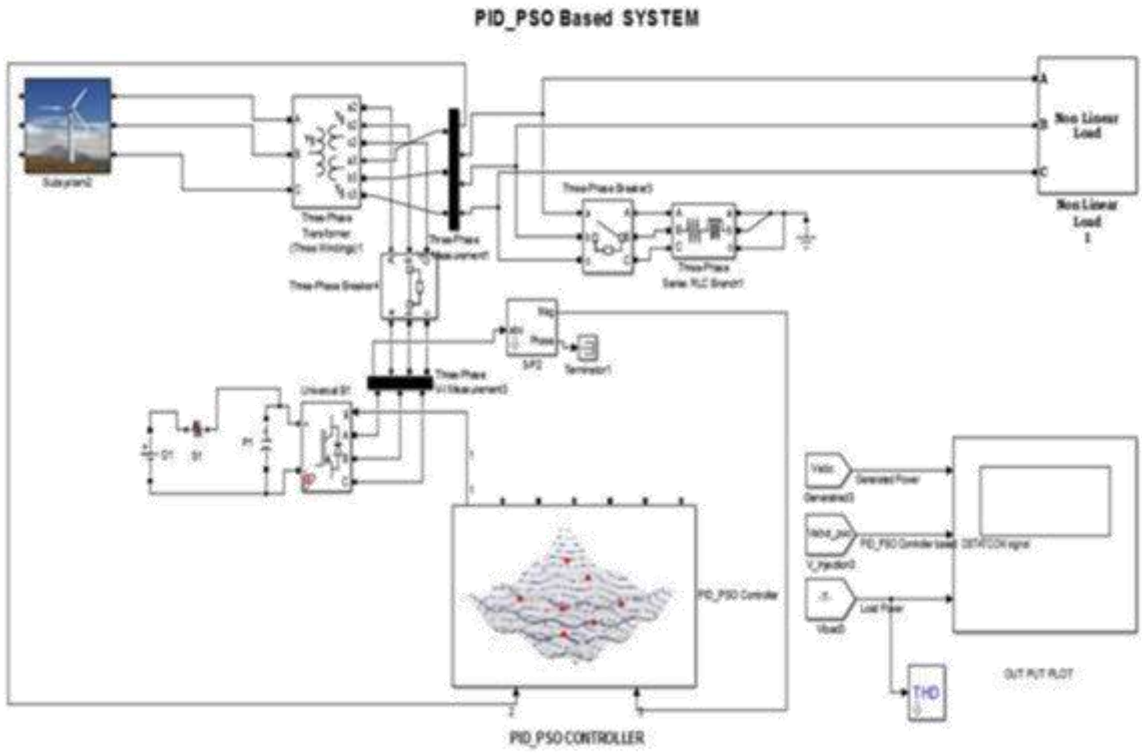

Fig. 6. Simulink model of existing PID-PSO controller system

The gain values with PID-PSO control technique are given as K_p= 0.8225, K_i = 0.05 and K_d= 0.8910. Figure 6 depicts the control block diagram of PID-PSO controller based DSTSTCOM and figure 7 shows the simulation results with PID-PSO controlled DSTATCOM. The compensated load signal shows that the swell is decreased to around 390 kV and during sag the voltage is improved to 360 kV and the average load voltage is 375 kV. The total harmonic distortion (THD) after compensation by DSTATCOM is 1.851%. With PID-PSO controller based DSTATCOM, the average load voltage is improved and THD value is reduced further indicating the betterment of the PID-PSO control system.

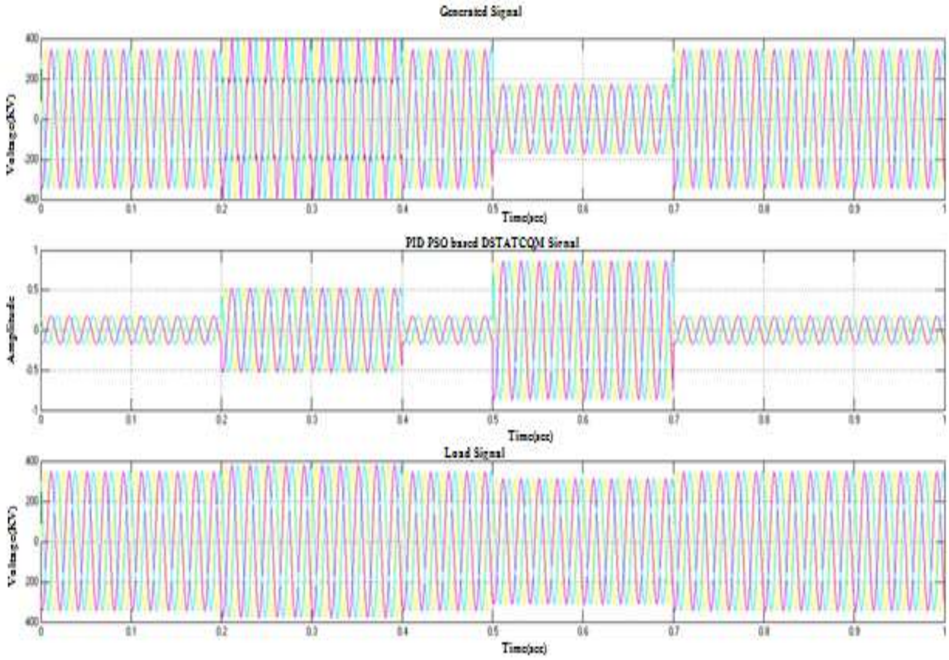

Fig. 7. Simulation results with PID-PSO control based DSTATCOM

4.3. DSTATCOM with Proposed PID-Firefly Controller

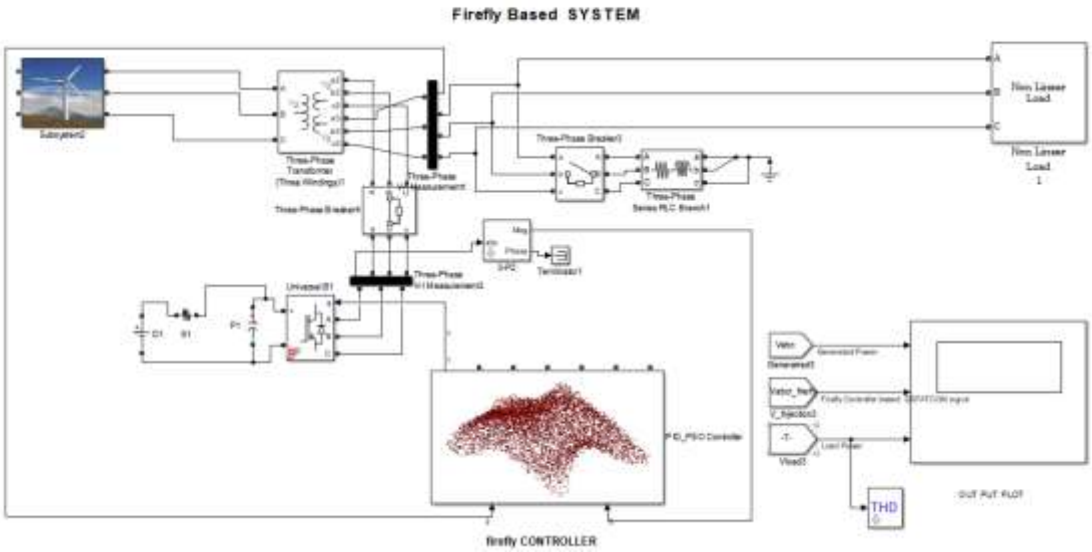

Fig. 8. Simulink model of existing Firefly controller system

Figure 8 represents the Simulink block for DSTATCOM using Firefly Controller. The compensation is generated fromthe combined PID- firefly technique. The gain values are optimized and utilized for the generation of control signal.

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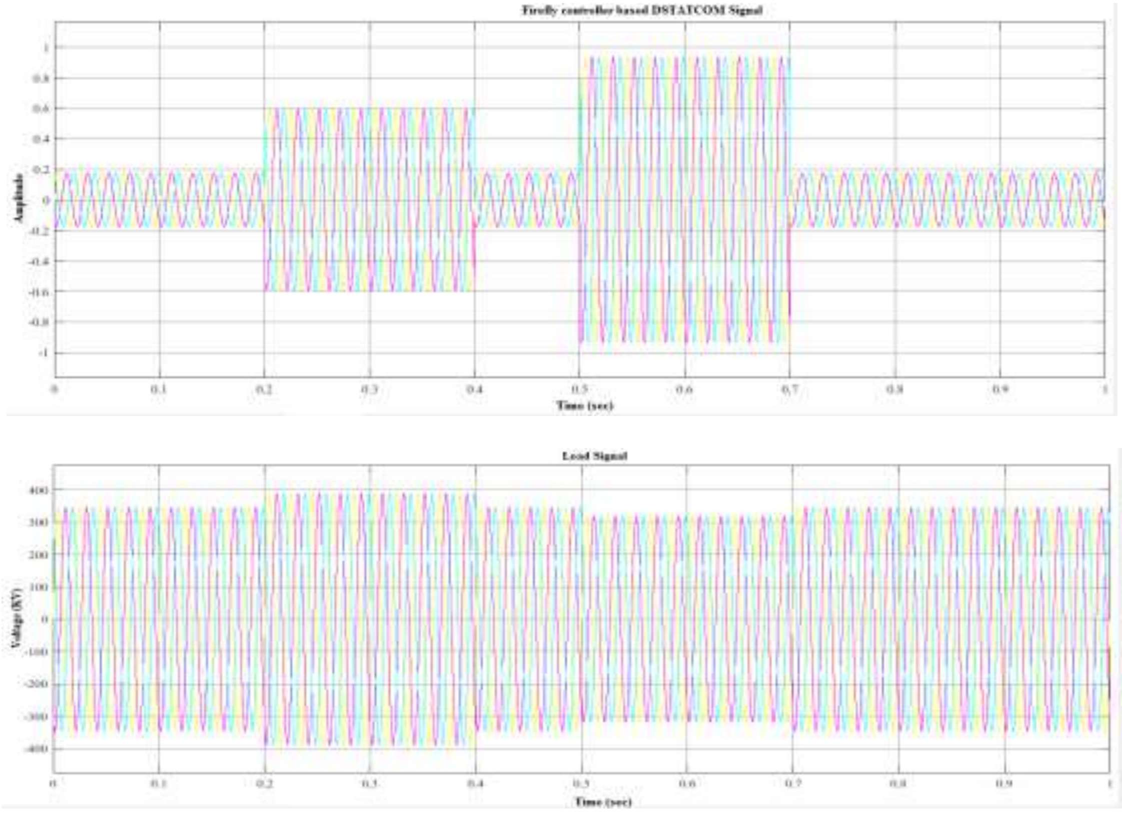

Fig. 9. Simulation results with PID-Firefly based DSTATCOM

Figure 9 depicts the simulation results for the existing firefly based control technique for DSTATCOM. The control signal is utilized for mitigating the sag, swell and harmonics. The issues cleared load signal shows that the swell is decreased to around 388 kV and during sag the voltage is improved to 365 kV and the average load voltage is 376 kV. The total harmonic distortion (THD) after compensation by firefly controlled DSTATCOM is 1.735%.

4.4. DSTATCOM with Proposed Hybrid PSO-Firefly Controller

Figure10 represents the Simulink block for DSTATCOM using Hybrid PSO-Firefly Controller.The gain values with this control technique is given as K_p= 0.63, K_i = 00504 and K_d= 1.9688. The output of this PID controller is given to the PWM block, where the pulses will be generated and given to DSTATCOM.

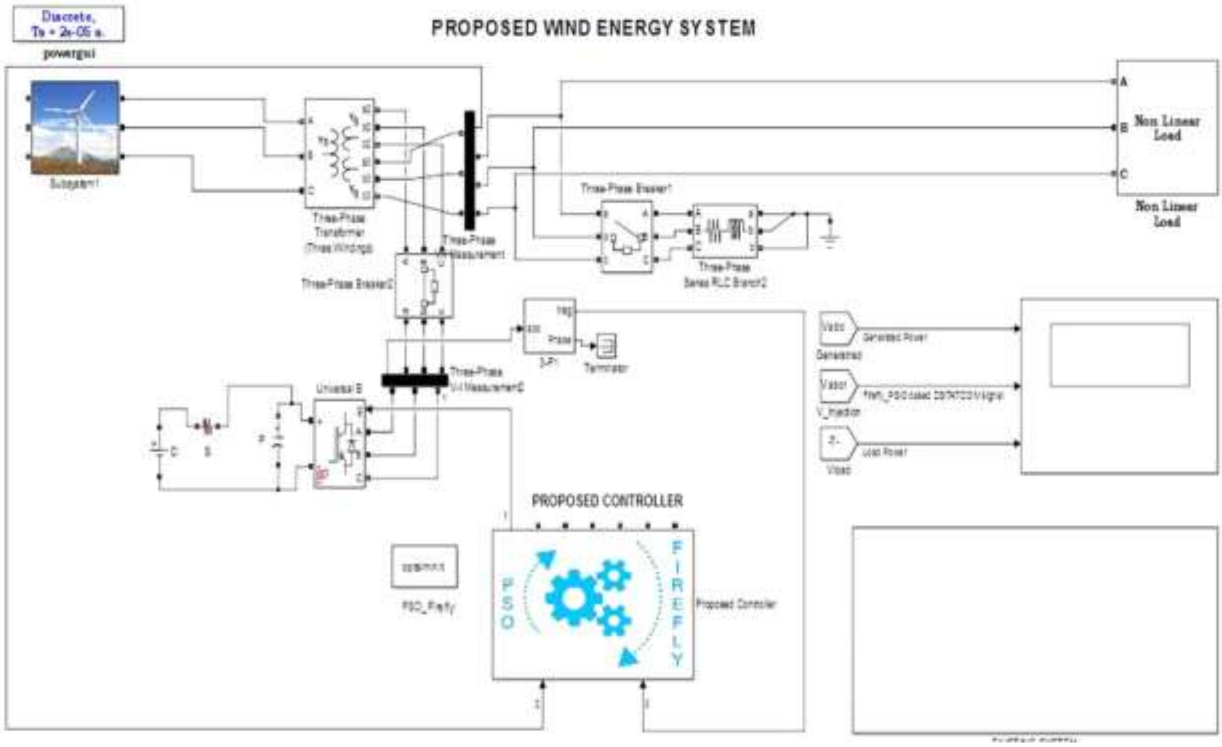

Fig. 10. Simulink model of the proposed system

Figure11 shows the simulation results for the proposed system, providing clear compensation at voltage swell and sag conditions and hence the load signal is a smooth waveform. The compensated load signal shows that the swell is decreased to around 385 kV and during sag the voltage is improved to 375 kV and the average load voltage is 380 kV. The total harmonic distortion (THD) after compensation by DSTATCOM is 1.216%. Therefore, the proposed Hybrid PSO-Firefly controller technique provides much better compensation at both sag and swell conditions than the existing controller techniques. Hence the load requirement is fulfilled and the power quality of the system is improved.

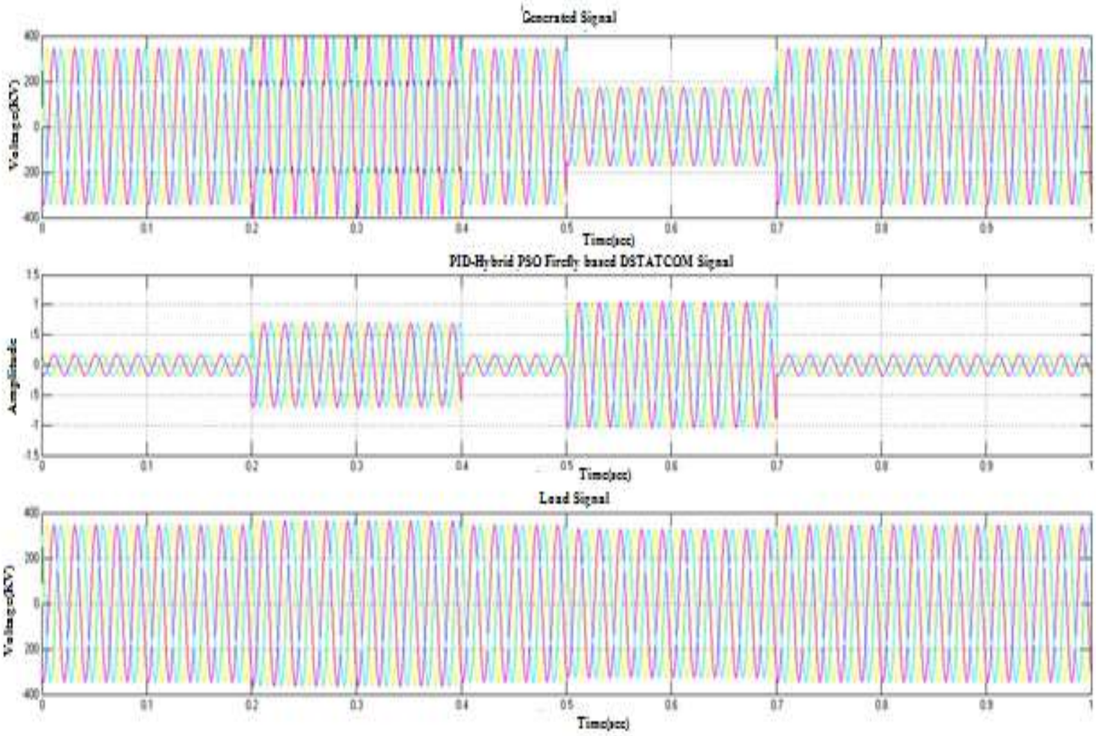

Fig.11. Simulation results with Hybrid PSO-Fireflybased DSTATCOM

Table 3 provides the performance comparison of the proposed method with existing controller techniques. From the table it is proved that the proposed method provides better compensation of voltage sag and swells. Also the harmonics with the proposed method is very much reduced comparing with the existing techniques. The harmonics reduction in terms of percentage is given in the table. The table values provide the better compensation of proposed method. The targeted value of harmonic reduction is achieved by the proposed method. The target value of harmonics is 1.00%. It is greatly achieved through the proposed methodology.

Table 3 Comparison of the proposed method with existing methods

Control Method	Voltage Swell		Voltage Sag		Avg. Load Voltage	THD (%)	
	Before Compensation	After Compensation	Before Compensation	After Compensation		Before Compensation	After Compensation
PID	400 kV	395 kV	190 kV	290 kV	350 kV	3.00	2.493
PSO	400 kV	390 kV	190 kV	360 kV	375 kV	3.00	1.851
Firefly	400 kV	388 kV	190 kV	365 kV	376 kV	3.00	1.735
PSO-Firefly	400 kV	385 kV	190 kV	375 kV	380 kV	3.00	1.216

The comparative analysis of the proposed work was performed with existing control techniques such as PID, PSO and firefly algorithms. The voltage swell from a value of 400 kV to 385 kV is obtained in the proposed control algorithm based compensation. The sag mitigation is also extremely higher when compared with the existing algorithms. The results from PSO and firefly as the separate control algorithms had shown the proposed hybridization makes the compensation better as much as possible.

5. Conclusions

This paper presents an improved method of optimization for DSTATCOM in wind power distribution system by using Hybrid PSO-Firefly control technique. The proposed methodology is executed in the Matlab/ Simulink platform.The power quality issues considered are: voltage swell, voltage sag and harmonic distortion. The proposed PID-PSO-Firefly based DSTATCOM eliminates these problems significantly when compared with the conventional methods.

Because of the hybrid PSO-Firefly algorithm, the proposed control technique is more convergence and robustness comparing with other techniques. The performance of the proposed method is compared with the other methods in terms of sag, swell and harmonics reduction and the effectiveness of this method was proved and clearly shown in the simulation results, where the compensation of voltage swell and sag is done and also the harmonic distortion is reduced very much compared with the existing controller technique.

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