Low-Power Quality Improvement Using PI and PSO Controlled DSTATCOM for Medium Voltage Distribution System

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ABSTRACT

The moment an unbalanced and nonlinear load is coupled to the distribution network, we looked at a few of the power quality challenges that manifest. The reactive power adjustment was also covered in addition to these matters. An application of distribution static compensators (DSTATCOM) is used to address power quality issues. When the proposed SRF control method is used using DSTATCOM, the issues of reactive power and harmonics are mitigated. An optimization approach known as Particle Swarm Optimization (PSO) is used in this study to fine-tune the DC bus voltage. We consider here one application of PSO: tuning of a PI controller. In the nonlinear and unbalanced distribution loads system, the PSO-PI technique is better than the conventional PI controller as regards to effectively correct the reactive and harmonic powers in the system. Compared to the PI and PSO-PI controllers, DSTATCOM also analyzes and contrasts compensating reactive power, regulation of DC voltage, and harmonic distortion elimination.

1. INTRODUCTION

The Majority of industrial and commercial loads need high quality reliable electricity. Thus, the power quality has to be ensured. The increasing usage of power electronics equipment exacerbates any power quality issues in the contemporary electrical power system [1–4]. The reactive power and seconders generated at the ac mains are being supplemented by a wide variety of power conversion devices, power electronic hardware, nonlinear loads, speed drives, domestic appliances, transformer saturation, etc. [4]. Due to poor power quality, several power quality problems have been contributing to harmonic distortion, including motor and transformer overheating, sensitive device failure, and interference with nearby communication cables. An unbalanced voltage load may result in a negative sequence current and a lower-order harmonic element of the power system. [5, 6].

Specifically, DSTATCOM, an inverter-based architecture with four legs, is used. To compensate for the power quality issues outlined above, a synchronous reference frame (SRF) algorithm technique is employed [7–10]. Compensating devices are used for power factor correction, load balancing, and voltage regulation. The traditional PI controller is used to obtain the DC link voltage of the P&I value. The DC link voltage of the distribution system's P&I values can be adjusted with the aid of the particle swarm optimization (PSO) technology [15-20]. Upon experimenting the PSO-PI controller in MATLAB/SIMULINK, the compensation in PSO-PI controller was seen to work better as compared to conventional PI controller.

2. SYSTEM CONFIGURATION

A Three-phase distribution transformers that convert 11kV power into 400V can be used to provide a nonlinear and unbalanced load, as seen in Fig.1. A distribution static compensator (DSTATCOM) connects this load to a four-wire, three-phase distribution system. There are harmonics at the PPC, a nonlinear connection, and an imbalanced (unbalanced) load. The DSTATCOM can decrease harmonics in the current waveform both at the PCC and the source, and it can also decrease features of voltage waveform imbalance. An Lf filter inductance, a C_{dc} power supply, and a capacitor for the dc link comprise the four legs of the four-legged voltage source inverter (VSI) that is the DSTATCOM. V_{dc}, the dc voltage rating of the capacitor, is 1.6 times the maximum dc voltage. The four legs on this VSI are eight IGBT switches. The six IGBT switches can be used to compensate the current harmonics and imbalance whereas the other two switches can be used to compensate neutral

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current and imbalance. A better alternative to the use of split phase capacitors is to utilize the fourth leg to make up the neutral current which looks like a capacitor does. The unbalanced load and the three-phase nonlinear load make up the unbalanced and nonlinear. Cf, or capacitor filtering, is used. The main advantage of this kind is that filters aren't needed.

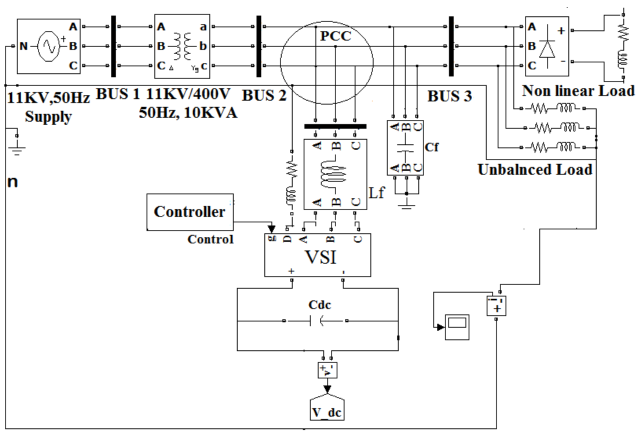


Fig. 1. Suggested setup for the system in the presence of nonlinear and imbalanced loads.

3. CONTROL ALGORITHM

This control algorithm of synchronous reference frame (SRF) is divided into two parts such as

1. Compensation plan for harmonics
2. Compensation for active and reactive currents

The Block diagram of Harmonics current compensation as shown in Fig.2.

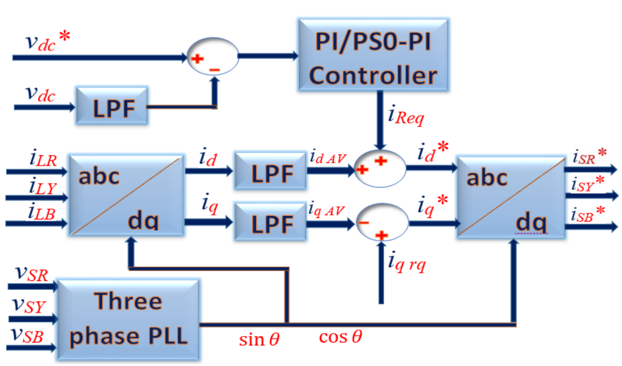


Fig. 2. Block diagram of harmonics current compensation.

The two-phase stationary frame is created from the three-phase load currents of d-q-0 using the equation provided in harmonics current correction Eq. 3.1.

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{LR} \\ i_{LY} \\ i_{LB} \end{bmatrix} \quad (3.1)$$

This is where the load currents of the R, Y, and B, phases are represented by i_{LR}, i_{LY}, and i_{LB}, respectively. i_d is the load current within the direct axis component and iq is quadrature axis component. An angle θ is used to represent the transformation. The voltage sources that provide cosθ and sinθ are a three-phase PLL (phase locked circle) block, which synchronizes the voltage and current. Equations (3.2) and (3.3) demonstrate that the current components id and iq, respectively, possess both an average and a fluctuating value.

$$i_d = i_{d\,av} + i_{d\,oc} \quad (3.2)$$

$$i_q = i_{q\,av} + i_{q\,oc} \quad (3.3)$$

where, id av = average component of current of id and iq, id oc = oscillating component of id and iq. You may think of the oscillating part as waves. The average and reactive sides of the active and reactive current values can be stated respectively as equation (3.4) and equation (3.5) after the oscillatory current component is removed by use of a low pass filter.

$$i_d = i_{d\,av} \quad (3.4)$$

$$i_q = i_{q\,av} \quad (3.5)$$

The final active reference current (id*) is obtained by adding required loss current of ireq. The required current component (ireq.) is getting from the PI or PSO-PI controller's output current. Added value of ireq to id av. The overall active reference current with the equation (3.6). This has been coined the id*.

$$i_d{}^* = i_{d\,av} + i_{req} \quad (3.6)$$

The active reference current is denoted by i_{d*}, and the component of required current is i_{req}. The i_{req} helps keep the DC link voltage constant and also provides DSTATCOM with its required losses. As far as active and reactive current compensation goes.

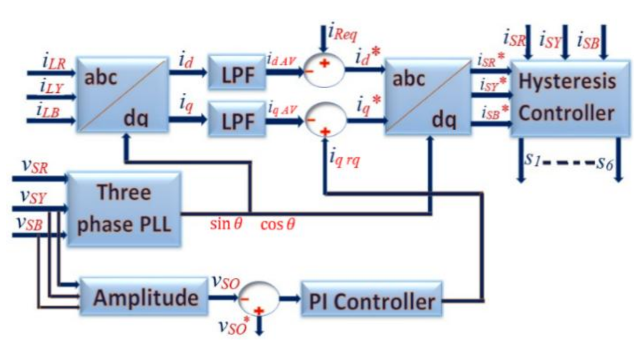


Fig. 3. Displays the active and reactive current compensation block diagram.

Fig. 3 depicts the active and reactive current compensation block diagram 3.

A formula for Vso, the source voltage's amplitude, may be found in equation (3.7).

$$\text{Vso} = \sqrt{2/3\,(V_{SR}^2 + V_{SY}^2 + V_{SB}^2)} \quad (3.7)$$

When Vso = volts amplitude of Source, Vso* = Reference source volts, V_{SR} = phase-R source volts, V_{SY} = phase-Y source volts, V_{SB} = phase-B source volts.

The difference between V_{SO}* and V_{SO} abundance of source the PI controller receives the voltage. Reaching the PI controller will be the second phase.

According to the equation, the reactive current (iqrq) is the PI controller's output. (3.8).

$$i_{qrq}(n) = i_{qrq}(n\text{-}1) + K_{pq}(V_{te}(n) - V_{te}(n\text{-}1)) + K_{iq}V_{te}(n) \quad (3.8)$$

The integral gain (K_{iq}) and proportional gain (K_{pq}) of the PI controller, respectively. To maintain a steady voltage, the i_q av is added to the i_q, r_q at the PCC. The reactive reference current's i_q* component is then derived using eq. (3.9).

$$i_q{}^* = i_{qav} + i_{qrq} \quad (3.9)$$

where, i_q* = Reactive reference current component, iq rq = Reactive current. To obtain the three-phase load current (i_{SR}*, i_{SY}*, and i_{SB}*) transforms using equation. (3.10) from the components of the active and reactive reference current (id*, iq*).

$$\begin{bmatrix} i_{SR}{}^* \\ i_{SY}{}^* \\ i_{SB}{}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_0{}^* \\ i_d{}^* \\ i_q{}^* \end{bmatrix} \quad (3.10)$$

With better VSI switching of IGBTs using hysteresis band controller currents. A comparison is done between the collected three phase currents (i_{SR}, i_{SY} and i_{SB}) and the three phase reference currents (i_{SR}*, i_{SB}* and i_{SY}*) that is measured. Hysteresis band controllers also offer the following advantages particularly: Effortless implementation, Unmatched Stability Faster reaction time compared to other regulators (e.g., Linker based, miscreant, feed forward, etc.). With better VSI switching of IGBTs using hysteresis band controller currents. A comparison is done between the collected three phase currents (i_{SR}, i_{SY} and i_{SB}) and the three phase reference currents (i_{SR}*, i_{SB}* and i_{SY}*) that is measured.

4. RESULTS AND DISCUSSION

The proposed model of DSTATCOM of active and reactive current-compensation control methods with PI and PSO-PI controllers, as well as the adjustment of harmonic currents in a voltage source inverter, have been tested into the MATLAB/SIMULINK environment under unbalanced and nonlinear loads test the model. Harmonics, imbalances, reactive power, and power factor may all be fixed by connecting the proposed model at the power conversion converter (PCC). We ran the simulation for 0.2–0.3 seconds. To evaluate DSTATCOM's feasibility, the following instances are used:

- Without DSTATCOM, it is nonlinear and imbalanced.
- PI Controlled DSTATCOM is nonlinear and imbalanced.
- The PSO-PI controlled DSTATCOM is nonlinear and imbalanced.

4.1. Nonlinear & imbalanced without DSTATCOM

Figure 4.1 illustrates how the harmonic current and unbalance in the source current (BUS-1) and PCC (BUS-2) waveforms are introduced by the nonlinear and unbalanced loads being interfaced to the suggested distribution system. Refer to Fig. (a). the source voltage waveform with an unbalanced and nonlinear load. Fig. (b) Should make it clear the nonlinear and imbalanced load causes harmonic distortion and an imbalanced source current waveform (bus 1). It is evident from the Fig. (c). the PCC current waveform (bus-2) is not balanced and creates harmonics, besides giving source current harmonics, in the nonlinear and unbalanced load. The Fig. (d) Illustrates nonlinear, imbalanced load current waveform when there is no DSTATCOM. The Fig. (e). Shows the current waveform of phase-R in the per-phase at PCC.

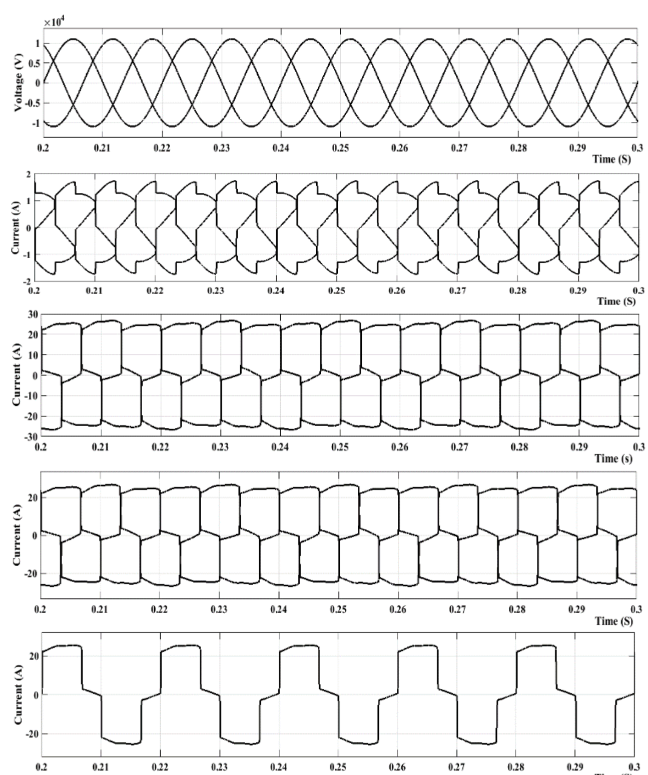


Fig.4.1. a). Supply waveform voltage, b). Supply waveform of current, c). The PCC waveform current, d). Load current, (e). The per-phase current waveform of PCC condition, without DSTATCOM, under onlinear and imbalanced load.

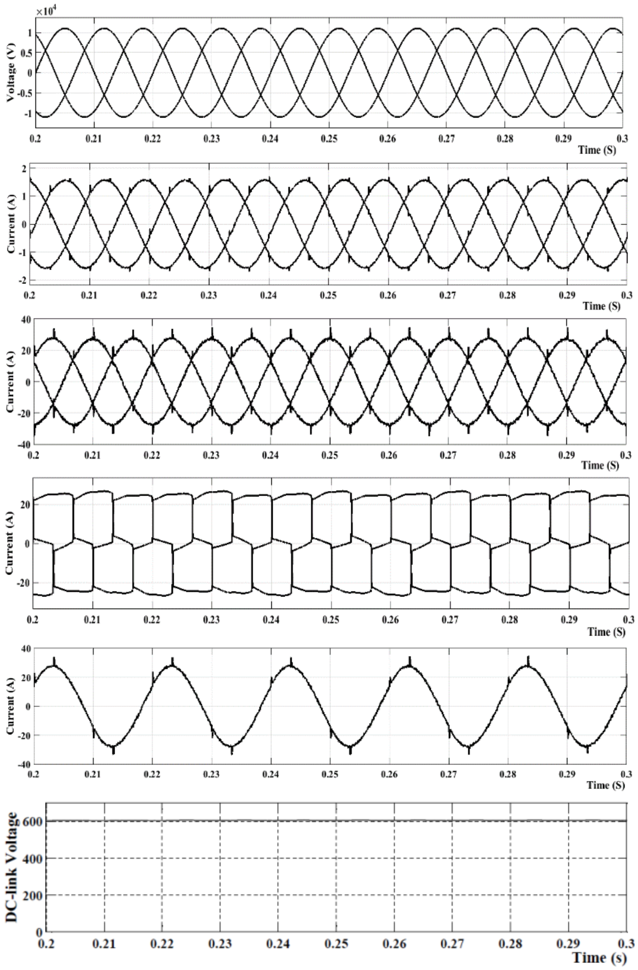


Fig.4.2 – a). Source voltage waveform, Fig. (b). the source current waveform, Fig. (c). Present waveform on PCC (Bus-2). Fig. (d) Shows the waveform of the load current. Current waveform of phase-A in fig. (e). At the PCC. Fig. (f) Vdc bus voltage, with DSTATCOM controlled by PI controller.

4.2. Nonlinear and imbalanced with PI controlled DSTATCOM

The PI-controlled DSTATCOM is linked to the PCC. The analogous diagram to balance source and PCC current harmonics and waveform imbalance is shown in Fig. 4.2. Reactive power is being injected into the system via the DSTATCOM. To maintain a steady DC-link voltage, it makes use of a relative basic (PI) regulator. The source voltage has changed after the PI-controlled DSTATCOM has been connected, as seen in Figure 4.2(a) of the figure. DSTATCOM corrects the source current waveform. Figure (b) shows the corrected source current (BUS-1) waveform using SRF-PI controlled DSTATCOM. The impact of the SRF-PI driven DSTATCOM on bus 2's (the PCC) current waveform is seen in figure (c). The Figure (d), the load current is seen after connecting the PI controlled DSTATCOM. The R-Phase current that is depicted in figure (e) indicates the adjustment at PCC. The figure (f) presents the value shows the DC bus voltage while the 600V DC source inverter is being corrected, and the voltage value was kept constant.

4.3. Nonlinear and imbalanced with PSO-PI controlled DSTATCOM

The PSO-PI controlled DSTATCOM is linked to the PCC. The DSTATCOM also reduces supply current harmonics by injection of the reactive power necessitated to counteract current harmonics at the PCC. To regulate the voltage at the DC interface, a PSO-PI regulator is used. In fig. 4.3, you can see the associated diagrams.

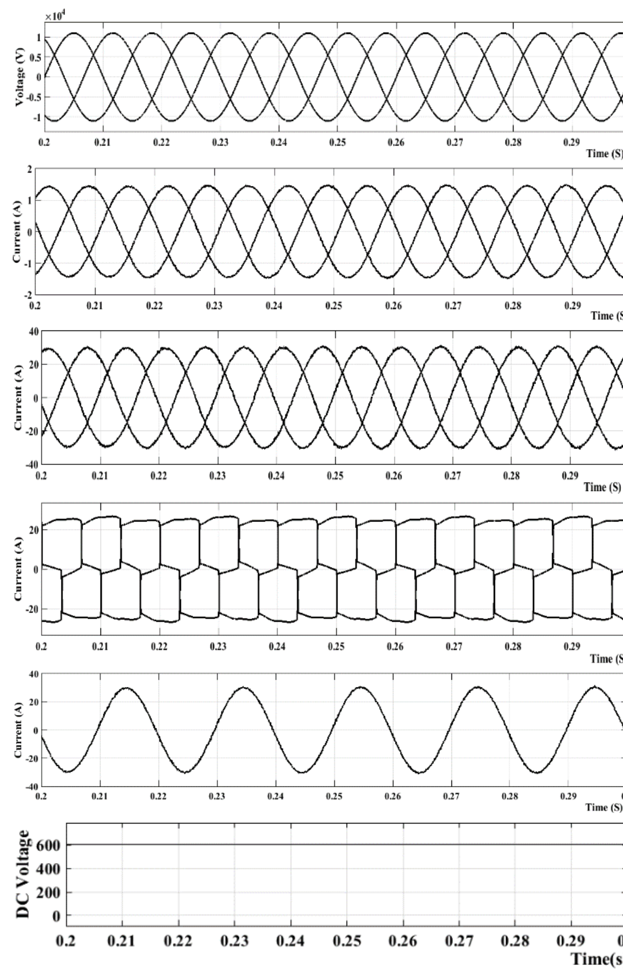
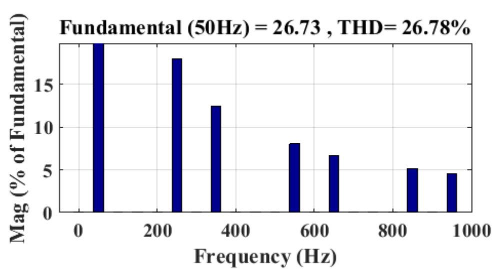


Fig.4.3 (a) shows the supply voltage waveform. Fig. (b) Waveform of the supply current source, Fig. (c). Present waveform of PCC (bus 2) as in Fig. (d). Fig. (e) Shows load current wave of the system. The existing waveform at the PCC in phase, as seen in Figure (f). The DC-link type is its voltage, which is managed by a DSTATCOM and a PSO-PI controller.

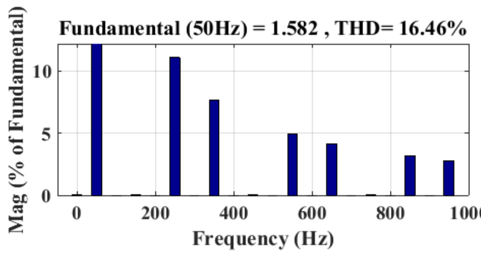
The source voltage waveform is shown in fig. 4.3 (a), and the PSO-PI algorithm is used to control DSTATCOM. As illustrated in fig. (b), the corrected source current (BUS-1) waveform is shown using a DSTATCOM controlled by PSO-PI. In order to view the corrected current waveform at the PCC (BUS-2) with the assistance of PSO-PI controlled DSTATCOM, one can refer to fig. (c). When DSTATCOM is controlled with PSO-PI the current load waveform appears in fig. (d). the present waveform at the PCC when PSO-PI controls the phase-R can be viewed in Fig. (e). the dc bus keeps the voltage source inverter at 600V. DC bus voltages that the PSO-PI based DSTATCOM controls see in fig. (f).

4.4. Total Harmonic Distortion Analysis (THD)

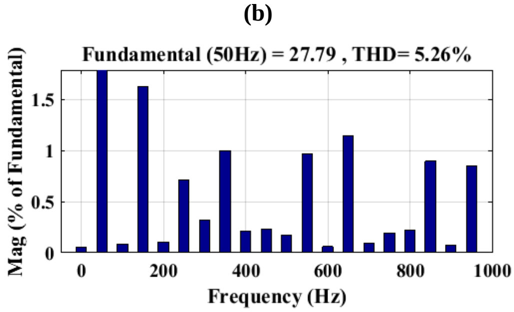
The overall harmonic distortion issues in the suggested distribution system are seen in fig. 4.4. These issues are caused by a nonlinear and unbalanced load running without the DSTATCOM, with the DSTATCOM, with a PI Controller, and with Controlled DSTATCOM with PSO-PI. Illustrations 4.4(a) and (b). Displays that, in the absence of DSTATCOM, PCC is measured at 26.78% and source current harmonic distortion at 16.46%. Diagrams 4.4(c) and (d). The results demonstrate that the PCC is 5.26% and the source current harmonic distortion is 3.43% when using the PI controlled DSTATCOM. Diagrams 4.4(e) and (f). Using a PSO-PI driven DSTATCOM, the results reveal a PCC of 2.29% and a source current harmonic distortion of 1.79%.



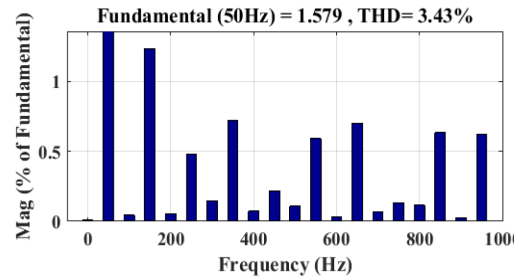
(a)



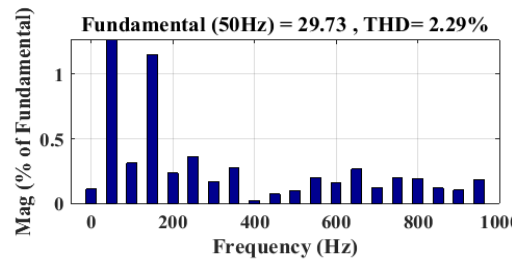
(b)



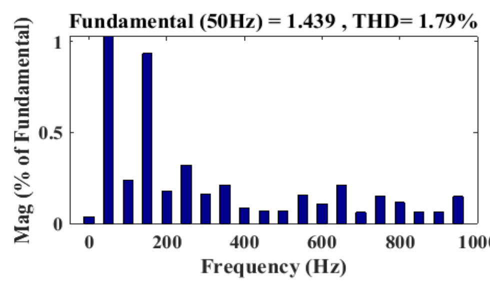
(c)



(d)



(e)



(f)

Fig. 4.4- Indicates the distortion in PCC current and supply current (BUS-1) shown in fig (a) & (b). Without DSTATCOM, the overall distortion in PCC current, denoted as fig. (c) And current distortion of the supply current (BUS-1) as fig. (d) With PI controlled DSTATCOM, The overall distortion in PCC current, current distortion of the supply current (BUS-1) in fig. (e) and (f). With PSO-PI controlled DSTATCOM,

As we have seen in the above study of the total harmonic distortion, the PSO-PI controlled DSTATCOM offers minimal levels of harmonics distortion as opposed to the controlled DSTATCOM controlled by PI.
controller.

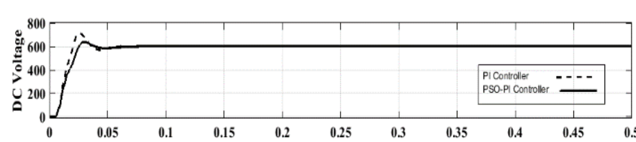


Fig. 4.5- demonstrates the output of the comparison between the changes of the DC-link voltages, examined by PI and PSO-PI controllers.

4.5. Comparison of DC-link voltages

The Fig. 4.5. Show the analysis of the DC-link voltage in PI and PSO-PI controlled DSTATCOM. Evidence may be seen in Figure 4.6. Compared to PI-based DSTATCOM, PSO-PI

DSTATCOM has lower rising and peak-over-shot times and it has lesser settling times.

5. CONCLUSIONS

By employing the Harmonics current compensation and active and reactive current compensation approach, we study nonlinear and unbalanced load conditions in connecting the DSTATCOM at the PCC. Our goals are to minimize reactive power need, mitigate harmonics, and increase power factor. We evaluated the suggested system's performance with the use of PI and PSO-PI controllers. The dc link voltage is robust against environmental disturbances thanks to the two controllers. In nonlinear and unbalanced loading conditions, PSO-PI controller clearly out compares with PI controller in the compensation. The PI values obtained using PSO computing provide superior compensation when contrasted with traditional PI-controlled DSTATCOM. By applying the MATLAB/SIMULINK program, the output results that were produced are validated.

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