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POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEM USING IRPT BASED DSTATCOM

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Abstract - *This paper introduces the Modeled Distribution Static Compensator (DSTATCOM) in the MATLAB SIMULINK Toolkit to reduce power quality problems in distribution systems. DSTATCOM is one of the custom power equipment used in power conditioning distribution system. DSTATCOM was developed to compensate for the reactive power demanded by non-linear and unbalanced loads. The source power factor is also improved and the total harmonic distortion in the source currents is reduced. DSTATCOM can heal brownouts, inflammation and imbalance by injecting reactive current into the system. The instantaneous reactive power principle is used to obtain the reference source current to control the DSTATCOM. Static Distribution Compensator (DSTATCOM) has become a potential option to reduce power quality (PQ) problems in distribution networks with non-linear loads. Basically, DSTATCOM maintains the PCC voltage and inverter intermediate circuit voltage using two PI controllers AC and DC. These gain values are typically calculated by Pi controllers based on a model-based or trial-and-error method. This paper presents a comparative study of an optimization-based approach to obtain kp and ki values of a pi controller.*

***Key Words*: Power quality, Distribution static compensator, PI Controller, Harmonic Distortion, PCC**

1. INTRODUCTION

Today, most loads in industry, home and agriculture are naturally inductive, such as induction motors, ceiling fans, agricultural pumps, etc. In the case of these inductive loads, the currents drawn by the load from the source are collected into voltage. Thus, the reactive power load on the system increases, increasing losses in the distribution system and reducing the ability for active power flow through the distribution system. Due to advances in power electronics technology, systems can have non-linear loads like rectifiers, inverters, uninterruptible power supplies (UPS), computers, etc. [1] are increasing. These non-linear loads can cause the frequency component of currents in the system to become a non-primary frequency component. Thus, due to this harmonic component of the waveform, the quality of the power is affected [2]. In addition, there is an imbalance effect in the operation of transformers and generators. The solution to improving power supply quality is to use custom power supply equipment [3] such as DSTATCOM. The control schemes reported in the literature for DSTATCOM control are a scheme based on synchronous reference frame theory (SRF), current compensation using DC bus regulation, instantaneous reactive power (IRP) theory, neural network techniques [4].

2. SYSTEM CONFIGURATION

A distribution feeder connected to unbalanced and non linear load is shown in the below Fig. 1. Working performance of the DSTATCOM using instantaneous reactive power theory (IRP) is analyzed by the modeling system shown in Fig.1 in MATLAB Simulink tool.

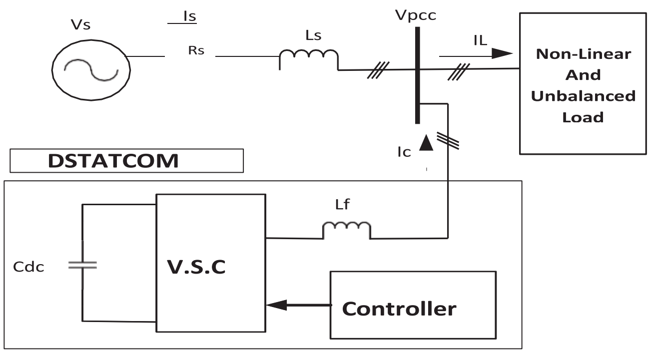


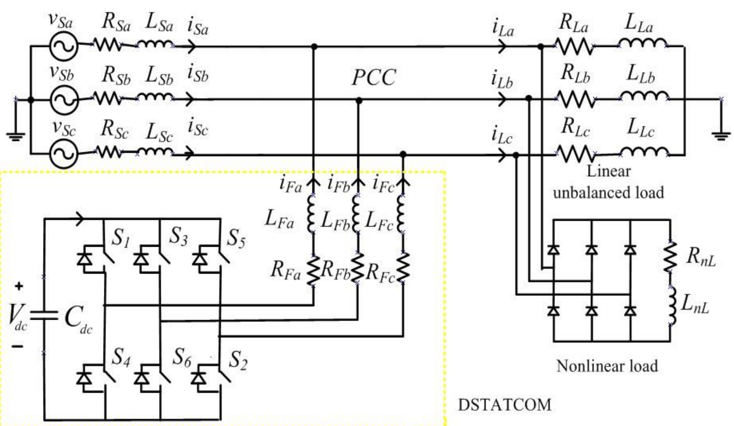
Fig.1.Configuration of DSTATCOM

In the system diagram of Fig. 1, Rs and Ls represent the source resistance and source inductance. Non-linear loading is achieved by connecting a three-phase diode rectifier to a resistive-inductive (R-L) load. Unbalanced loading is achieved by adding different impedance values to the three phases. The three-phase voltage source converter (VSC) acts as a DSTATCOM, composed of six bipolar insulated gate transistors (IGBTs) and antiparallel diodes connected to each IGBT [5]. The DC side of the voltage source converter (VSC) contains a capacitor which is used to maintain a constant voltage for the switching operation of the IGBT switch. The DC capacitor is not used for any reactive power compensation. The interface inductor, Lf, is connected to the AC side of the voltage source converter to compensate for the high-frequency components of the offset current [6]. The Cdc storage capacitor does not exchange active power between the DSTATCOM and the load. The circuit breaker is used to observe the performance of the DSTATCOM before and after compensation (that is, for connecting and removing the DSTATCOM to the system).

3. Design and Control Algorithm

DSTATCOM is a custom power device, which is connected in parallel to the system to reduce any pq-related performance issues. In general, it is a solid state power converter capable of producing or extracting independently controlled reactive and real power at its terminals when connected to a power source or device. The three-phase three-wire system connected to the DSATATCOM is shown in Figure 1. This includes balanced three-phase sources connected to unbalanced loads and non-linear loads, where VSA, VSB and VSC are the source voltages of the phases a , b and c respectively [7]. DSTATCOM consists of a VSI, which is connected to the PCC via interface inductors.

The non-linear load is the uncontrolled ac to dc converter with the RL load R_{nL} and L_{nL}. The source side currents are represented as i_{Sa}, i_{Sb} and i_{Sc} and the load currents as i_{La}, i_{Lb} and i_{Lc}. The compensator currents are symbolized as $i_{F\,a}$, $i_{F\,b}$ and $i_{F\,c}$. The feeder inductances and resistances of distributed three phases is denoted as $L_{S,abc}$ and $R_{S,abc}$ respectively, also filter inductances and resistances are represented by $L_{F,abc}$ and $R_{F,abc}$ respectively for three phases. The dc- link capacitor of VSI and voltage are given by C_{dc} and v_{dc}, respectively. synchronous reference frame based technique is used for reference currents generation and these are then compared with the actual currents and the error is given to HBCC. The generated gate signals are provided to the inverter.



is the angle of transformation, then transformation of currents are done by using Park's transformation. iLd and iLq both contains dc and ac components due to the harmonics present in the system and dc component components are removed using the either high pass filter or the mean block [8],[9].

For generation of reference source currents components, SRF theory is used. It is on the basis of transformation of three From these dq axis components which is again transferred into abc frame by using inverse Park's transformation. From

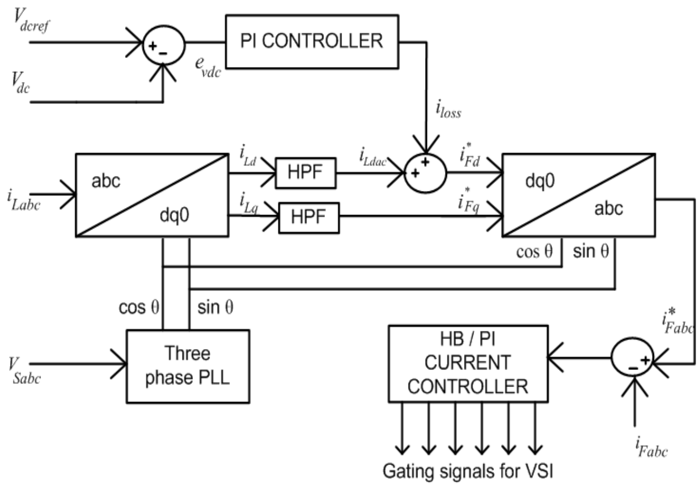


fig 3 : Control technique block diagram

these reference filter or compensating current are compared with actual filter currents. Then the error current is given to hysteresis based controller and switching signal for VSI is generated. The design of the DSTATCOM is done as in the [10].

CONTROL ALGORITHM

The general control block diagram of DSTATCOM is shown in Figure 2. The DSTATCOM control function is to keep the source currents balanced, sinusoidal and at the required angle with the corresponding terminal voltage. To achieve the ambition of DSTATCOM, instantaneous isometric component theory (ISCT) is used to generate the VSI reference current. The ISCT also has the ability to control the power factor of the current source. Since a non-rigid voltage source is considered in this article, direct use of terminal voltages to calculate filter reference currents will not provide satisfactory compensation [11]. Therefore, the positive sequence principal component of the voltage is obtained generate reference filter currents as described in sub-section B [12]. According to this theory when a

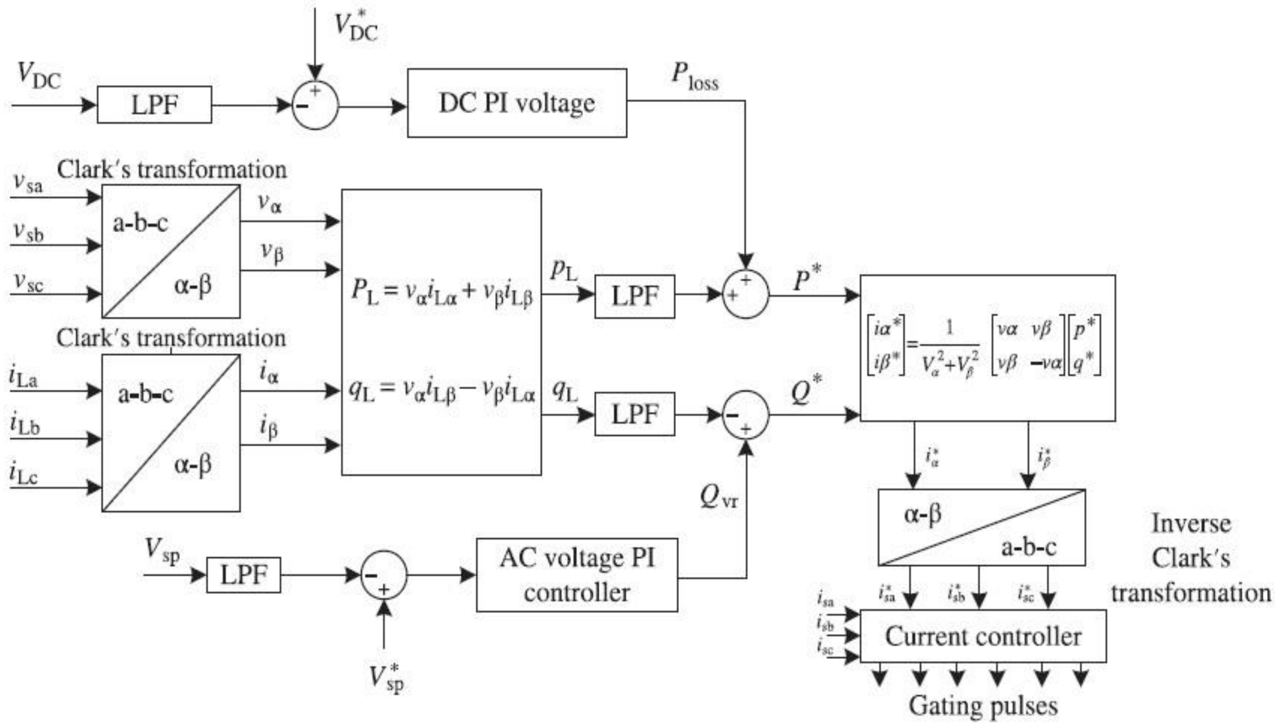


Figure 4.Instantaneous reactive power theory-based control algorithm of DSTATCOM

$$\begin{bmatrix} V s\alpha \\ V s\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} \quad [3.1]$$

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ila \\ Ilb \\ Ilc \end{bmatrix} \quad [3.2]$$

These two expressions calculate the instantaneous active power P_L and the instantaneous reactive power QL which flow into the load side

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} Vs\alpha & Vs\beta \\ Vs\beta & -Vs\alpha \end{bmatrix} \begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} \quad [3.3]$$

Let $\widetilde{P_L}$ and $\overline{P_L}$ be the DC component and the P_L AC element, and let $\widetilde{Q_L}$and $\overline{Q_L}$be the DC component and the Q_L AC element, alternately.

$$P_L = \widetilde{P_L} + \overline{P_L} \quad [3.4]$$

$$Q_L = \widetilde{Q_L} + \overline{Q_L} \quad [3.5]$$

In these terms, the basic load power is transformed into P_L and Q_L DC components and the distortion or negative

sequence is transformed into $\widetilde{P_L}$and $\widetilde{Q_L}$AC components. The effective and passive power parts of DC are obtained using two LPFs

The reference current in two phase system is

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \frac{1}{Vs\alpha^2 + Vs\beta^2} \begin{bmatrix} Vs\alpha & Vs\beta \\ Vs\beta & -Vs\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad [3.6]$$

Isa* Isb* Isc* are the reference three-phase storage signals

$$\begin{bmatrix} Isa^* \\ Isb^* \\ Isc^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vs\alpha & Vs\beta \\ -Vs\beta & Vs\alpha \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \quad [3.7]$$

To regulate demand cycles for implicit present command, this IRPT-based power algorithm can be readily altered. In this case, for the DSTATCOM power factor correction mode, p*, P_L, P_{LOSS} and Q*, Q_L, P_{VP} in equation 3.4,3.5 and after the transformation from the α−β frame to the abc frame, three-phase transformed currents are reference supply currents and must be compared with sensed supply currents in the PWM current controllers as shown in Figure 4.2. The term P_{LOSS} is an instant active power needed to adjust to its reference value the voltage of the VSC's DC capacitor used as a DSTATCOM. In addition, qvr is Instantaneous reactive power theory-based control algorithm of DSTATCOMs Power Quality Problems and Mitigation Techniques instantaneous reactive power necessary to adjust the PCC voltage to its reference value (these are achieved using a PI controller similarly to the above algorithms as shown in Figure), and P_L and Q_L are the extracted load fundamental active and reactive power components, respectively. In the case of ZVR at PCC (voltage regulation mode of operation of the DSTATCOM), a PI voltage controller over the PCC voltage is used similarly to the above algorithms and its output is used to estimate p* and q* as

$$P^* = P_L + P_{loss} \quad [3.8]$$

$$Q^* = Q_{vp} - Q_L \quad [3.9]$$

After the transformation, three-phase transformed currents are reference supply currents and these are compared with sensed supply currents.

4. PI CONTROLLER TUNING FOR DSTATCOM

Conventional PI tuning

There are several methods for tuning the PI controllers, most of them are model based approaches. For a complicated nonlinear plant like DSTATCOM, model based approaches are complex and time consuming. So that simple trial and error based approach is used as conventional method of PI tuning such as in [13]

5. SIMULATION AND RESULTS

The performance of the DSTATCOM using IRP theory for power quality improvement in the distribution system is studied by observing waveforms of the different parameters of the system before compensation and after compensation.

5.1 Results Before Compensation

Fig. 5 shows the results of simulation without connecting the DSTATCOM to the Point of Common Coupling (PCC).

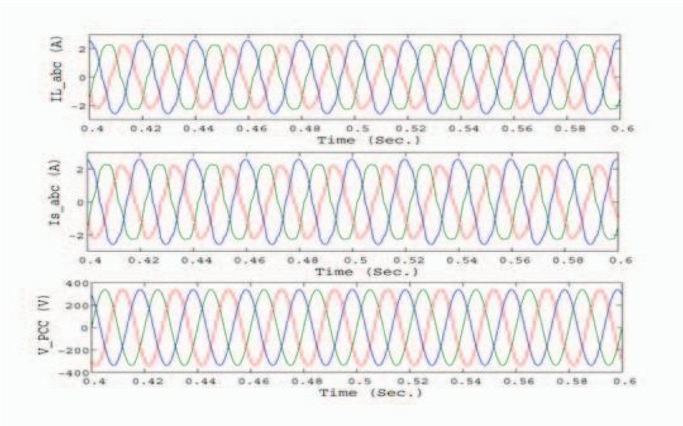


Fig. 5. Simulation Results without DSTATCOM

From Fig. 5 it is observed that due to unbalanced and non linear load, source currents and load currents get unbalanced and some distortion is present in their waveform. Also power factor of the source is not unity, as voltage at PCC and source currents are not in Phase with each other. Total Harmonic Distortion for the source current is 13.55%

5.2 Results After Compensation

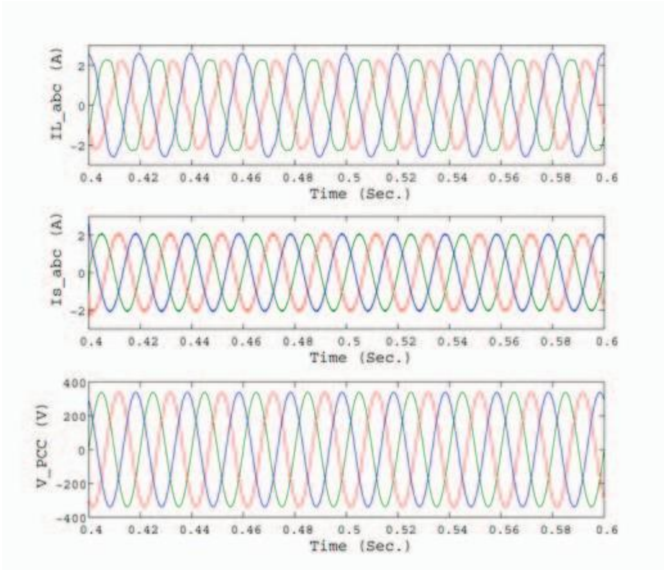


Fig. 6. Simulation Results with DSTATCOM

After connecting DSTATCOM to the system it is observed from Fig.6 that load current is same which is drawn by load but source current is approximately sine wave, also source current and voltage at PCC are in phase with each other. So, power factor is maintained equal to unity. Total Harmonic Distortion (T.H.D) in the source current is found to be 4.77% which is less as compare to T.H.D before compensation.

5.3 Compensator Current

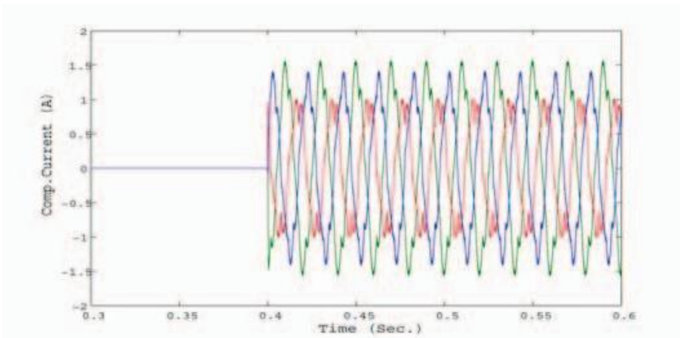


Fig. 7. Compensator Current

From Fig. 7 it is clear that DSTATCOM is connected to the system at 0.4 second, so before connecting the DSTATCOM to system the current injected by DSTATCOM into system is zero but after connecting DSTATCOM it will inject reactive current into system to maintain the unity power factor and also to improve power quality of the system.

Fig. 8 shows that, DC link voltage of the DSTATCOM is maintained at constant level of 700V DC with the help of PI controller for the proper switching operation of the IGBT device of voltage source converter.

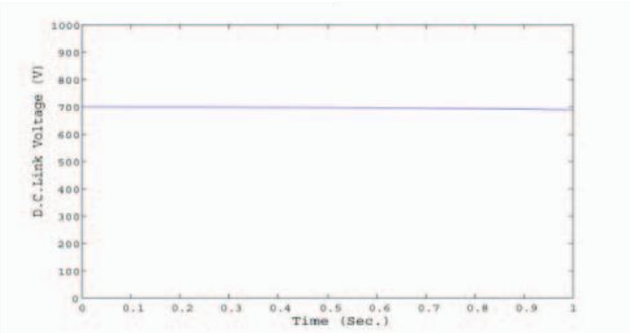


Fig. 8. DC Link Voltage

bove simulation result shown in figure is waveform of source current without compensation & with compensation. After 0.1 second when the STATCOM starts operating it injects reactive power to compensate harmonics with increased current. The THD graph before compensation and after compensation is shown below

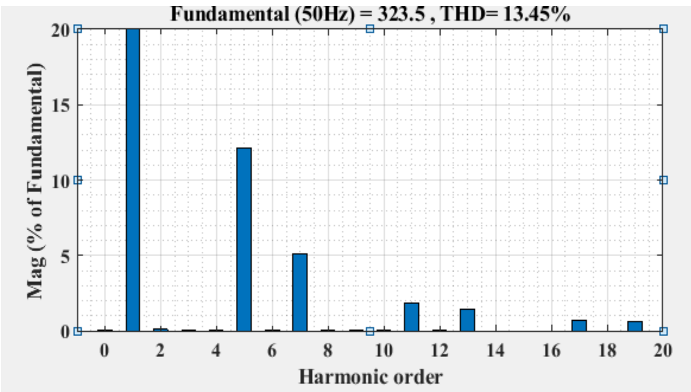


Figure 9 Total harmonics distortion before compensation

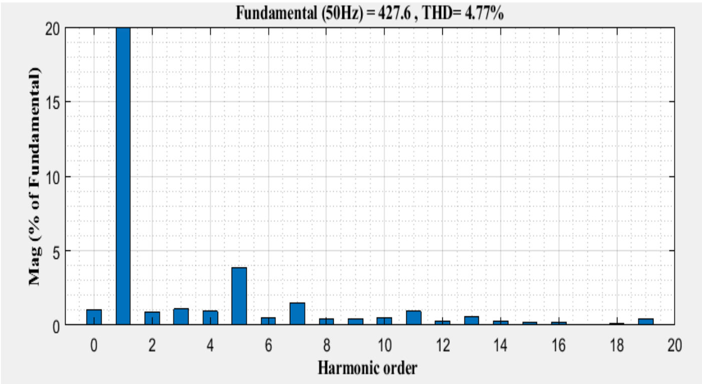


Figure 10 Total harmonics distortion after compensation

The graph shown above is THD before & after compensation. The harmonics was found to be 13.45% before compensation in which 5th& 7th harmonics are prominent. After t = 0.1sec when compensation is applied the harmonics is reduced to 4.77% which decrement of 5th & 7th harmonics.

CONCLUSION

Custom power devices can be used for power quality improvement in the distribution system.IRP theory for controlling the DSTATCOM reduce the unbalance in the system, harmonic components are also reduced. Power factor of the system is improved and maintained equal to unity. The response of the DSTATCOM is fast for compensation of the reactive power as compared to conventional reactive power control devices.

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