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**POWER QUALITY ENHANCEMENT USING 7 LEVEL CASCADED H-BRIDGE
INVERTER BASED D-STATCOM WITH PQ THEORY**

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ABSTRACT

This paper presents an investigation of Seven-Level H – bridge Inverter is used in a Distribution Static Compensator (DSTATCOM) in Power System (PS), making use of seven level cascaded inverter benefits of low harmonics distortion, reduced number of switches to achieve the seven- level inverter output over the conventional cascaded seven level inverter and reduced switching losses. In order to improve the power factor, compensate the reactive power and suppress the total harmonics distortion (THD) drawn from a Non-Liner Diode Rectifier Load (NLDRL) of DSTATCOM, we propose a Level Shift Pulse Width Modulation (LSPWM) technique is used as control for the switches of H – bridge Inverter. The PQ theory is used to generate the reference compensating current for DSTATCOM. The proposed system is simulated in the MATLAB environment using simulink and results are discussed

KEYWORDS: DSTATCOM, Cascaded H-Bridge Inverter, Power Quality, PQ Theory, PWM .

INTRODUCTION

In present day's power distribution systems is suffering from severe power quality problems. These power quality problems include high reactive power burden, harmonics, currents, load unbalance, excessive neutral current etc. The measure of power quality depends upon the needs of the equipment that is being supplied. What is good power quality for an electric motor may not be good enough for a personal computer. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. Some remedies to these power quality problems are reported in the literature. A group of controllers together called Custom Power Devices (CPD), which include the DSTATCOM (distribution static compensator), The DSTATCOM, is a shunt-connected device , which takes care of the power quality problems in the currents. The proposed DSTATCOM is modelled and its performance is simulated, harmonic elimination and load balancing with linear loads and non-linear loads. When the STATCOM is applied in distribution system is called Distribution-STATCOM (DSTATCOM) and its configuration is the same, or with small modifications, oriented to a possible future amplification of its possibilities in the distribution network.

The DSTATCOM exhibits high speed control of reactive power to provide voltage stabilization, flicker suppression. It utilizes a design consisting of a GTO or IGBT-based voltage sourced converter connected to the power system via shunt transformer. The DSTATCOM

protects the utility transmission or distribution system from voltage sags and/or flicker caused by rapidly varying reactive current demand. In utility applications, a DSTATCOM provides leading or lagging reactive power to achieve system stability during transient conditions. The DSTATCOM can also be applied to industrial facilities to compensate for voltage sag and flicker caused by non-linear dynamic loads, enabling such problem loads to co-exist on the same feeder as more sensitive loads. The DSTATCOM instantaneously exchanges reactive power with the distribution system without the use of bulky capacitors or reactors. A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer.

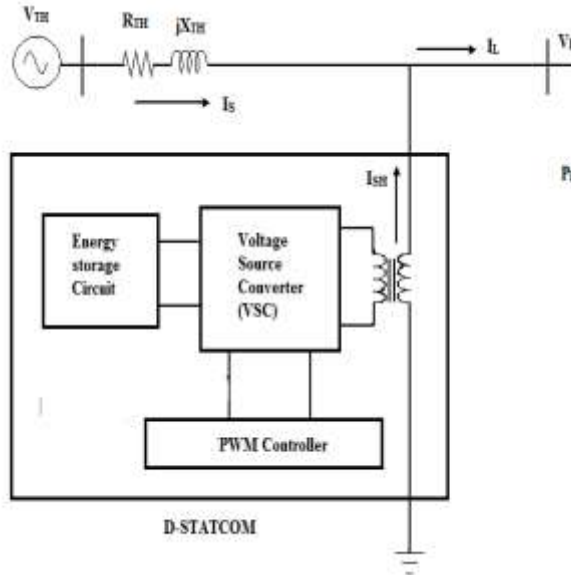


Fig 1 Block diagram of DSTATCOM

The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

Operation of D-STATCOM

D-STATCOM controllers can be constructed based on both VSI topology and Current Source Inverter (CSI) topology . Regardless of topology, a controller is a compound of an array of semiconductor devices with turn off capability (i.e., IGBT, GTO, IGCT etc.) connected to the feeder . The VSI converter is connected to the feeder via reactor and has a voltage source capacitor on the DC side. The CSI converter is connected on the AC side via capacitor and has a current source inductor on the DC side. In practice, CSI topology is not used for DSTATCOM. The reason for this is related to the higher losses on the DC reactor of

CSI compared to the DC capacitor of VSI. Moreover, a CSI converter requires reverse blocking semiconductor switches, which have higher losses than reverse conducting switches of VSI. And, finally, the VSI-based topology has the advantage because an inductance of a coupling transformer can constitute, partially or completely, the inductance of an AC filter. The VSI converters for D-STATCOM are constructed based on multi-level topologies , with or without use of a transformer. These solutions provide support for operation with a high level of terminal voltage. Additionally, DSTATCOM controllers can be a compound of several converters configured to various topologies, to achieve higher rated power or lower PWM-related current ripples. In this solution it is necessary to provide inter converter communication at the control level to distribute information about set controller power or currents. The cascade multi converter topology is similar to the parallel configuration, but in this case the constituent converters do not share power equally, but successively, depending on the requirement. In this case, no communication between constituent converters is required, but on the other hand it is also not possible to use common PWM strategy.

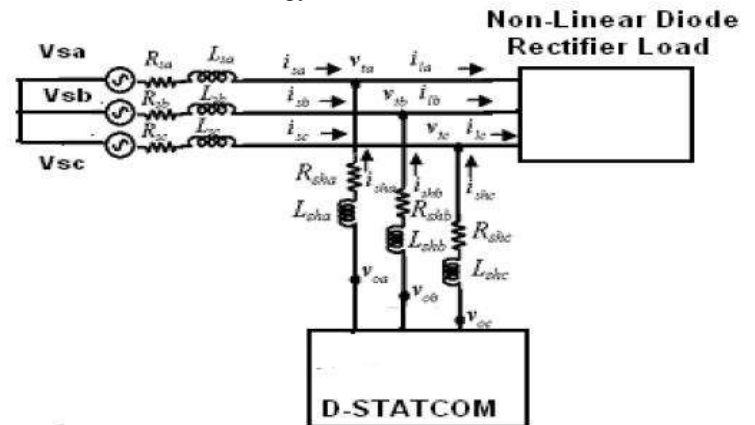


Fig 2 operation principle of DSTATCOM

PQ Theory (control for harmonics compensation)

The instantaneous power theory or p-q theory was introduced by Akagi in 1983. This method uses algebra transformation also known as Clarke transform for three phase voltage and current. The three phase voltage and current are converted into α - β using eq. (4) and eq. (5), where i_{abc} are three phase line current and v_{abc} are three phase line voltage. This proposed theory derives from the conventional p-q theory or instantaneous power theory concept and uses simple algebraic calculations . It operates in steady-state or transient as well as for generic voltage and current power systems

that allowing to control the active power filters in real-time. The active filter should supply the oscillating portion of the instantaneous active current of the load and hence makes source current sinusoidal.

The p-q theory performs a Clarke transformation of a stationary system of coordinates abc to an orthogonal reference system of coordinates α, β . In abc coordinates axes are fixed on the same plane, apart from each other by 120 deg as shown in Fig 6. The instantaneous space vectors voltage and current V_a, i_a are set on the a-axis, V_b, i_b are on the b axis, and V_c, i_c are on the c axis. These space vectors are easily transformed into α, β coordinates. The instantaneous source voltages V_{sa}, V_{sb}, V_{sc} are transformed into the α, β coordinate's voltage by Clarke transformation as follows:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

where, α and β axes are the orthogonal coordinates. The instantaneous power p for the three phase circuit can be defined as

$$p = v_\alpha i_\alpha + v_\beta i_\beta$$

Similarly, the instantaneous reactive power q is defined as below.

$$q = -v_\beta i_\alpha + v_\alpha i_\beta$$

Therefore in the matrix form the instantaneous real and reactive power are given as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

The α - β currents can be obtained as

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

Where, $\Delta = v_\alpha^2 + v_\beta^2$

The instantaneous active and reactive power p and q can be decomposed into the average and an oscillatory component.

$$p = \bar{p} + \tilde{p} \quad \& \quad q = \bar{q} + \tilde{q}$$

where, \bar{p} and \bar{q} are the average parts and \tilde{p} and \tilde{q} are the oscillatory parts of the real and reactive instantaneous powers, respectively. The compensating currents can now be calculated to compensate the instantaneous reactive power and the oscillatory component of the instantaneous active power. In this case the source transmits only the non-oscillating component of active power. Therefore the reference source $i_{s\alpha}^*$ and $i_{s\beta}^*$ in α - β co ordinate are expressed as

$$p = v_\alpha i_\alpha + v_\beta i_\beta$$

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$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix}$$

These currents can be transformed in abc quantities to find the reference current in a-b-c coordinate

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ 0 \end{bmatrix}$$

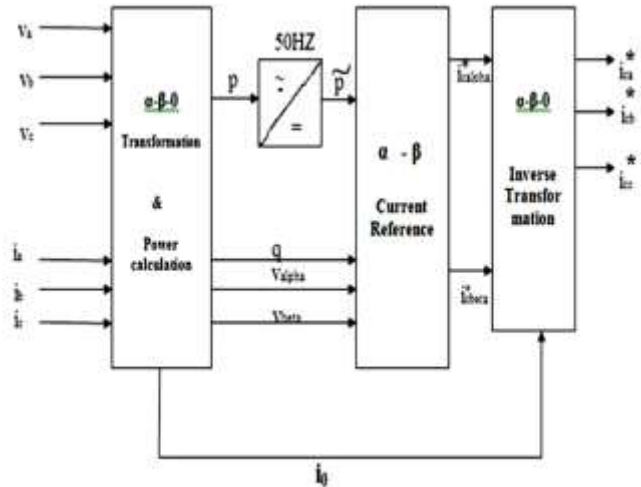


Fig 3 showing Block diagram of P-Q Theory

Cascaded H-Bridge Multilevel Inverter

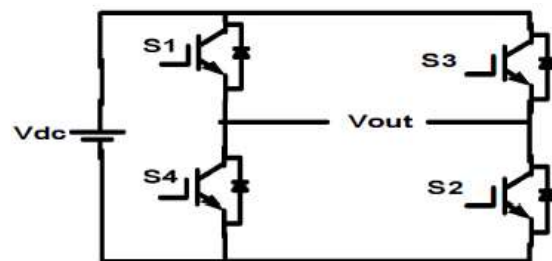


Fig 4 Single cell of CHB inverter

Fig 4 shows the circuit model of a single CHB inverter Configuration. By using single H-Bridge we can get 3 voltage levels. The number of output voltage levels of CHB is given by $2n+1$ and voltage step of each level is given by $V_{dc}/2n$, where n is number of H-bridges connected in cascaded.

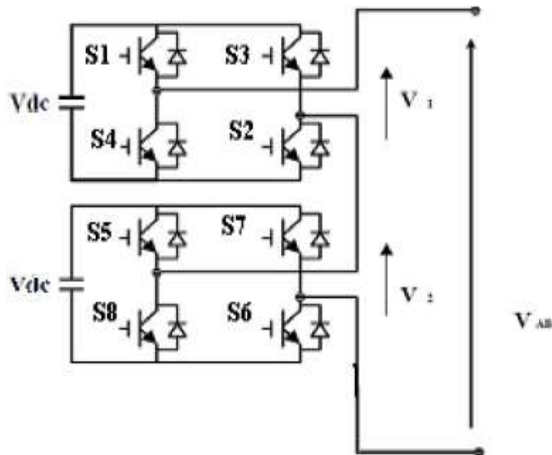


Fig 5 Block diagram of 5-level CHB inverter mode

PWM Techniques for CHB Inverter

Phase Shifted Carrier PWM (PSCPWM)

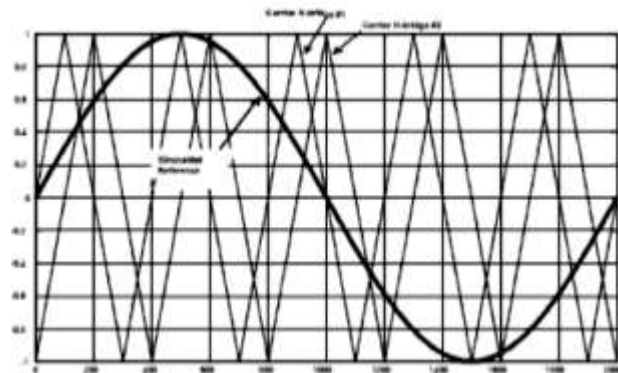


Fig 6 shows phase shift carrier PWM

The number of triangular carriers required for a m-level inverter is given by m-1 and the Carrier phase shift = $180/s$, where s is the no. of H-bridges for phase. From the reference currents, the actual source currents are compared and by using PWM technique the switching signals for voltage source inverter are generated. After getting switching signals from the triangular-sampling current modulator, the DSTATCOM operates in any one of the mode by controlling the firing angles of the switches by using controller which is connected to the converter thereby maintaining system voltage balanced.

Level Shifted Carrier PWM (LSCPWM)

Pulse width modulation. Each cell is modulated independently using sinusoidal unipolar width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier Level shift by $1/m$ (No. of levels) for cascaded inverter 1S introduced across the

cells to generate the stepped multilevel output waveform with lower distortion

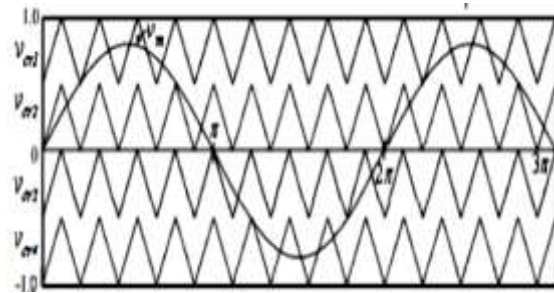


Fig 7 shows level shift PWM

Matlab/Simulink modeling and simulation results

Figure- 8 shows the Matab/Simulink power circuit model of DSTATCOM. It consists of five blocks named as source block, nonlinear load block, control block, APF block and measurements block. The system parameters for simulation study are source voltage of 11kv, 50 hz AC supply, DC bus capacitance 1550e-6, Inverter series inductance 10 mH, Source resistance of 0.1 ohm and inductance of 0.9 mH Load resistance and inductance are chosen as 30mH and 60 ohms respectively.

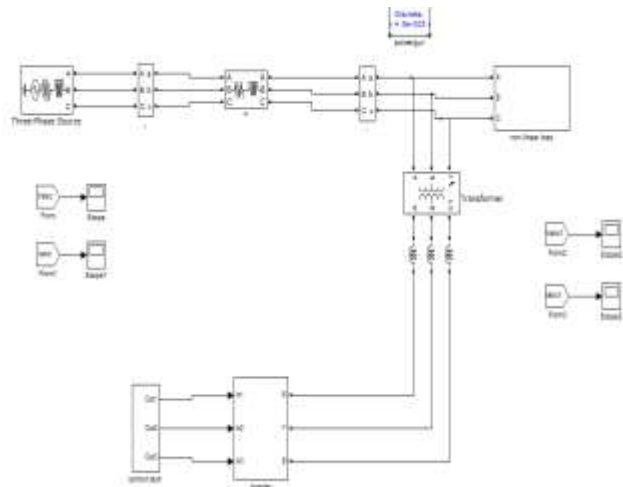


Fig 8 shows the matlab model of DSTATCOM

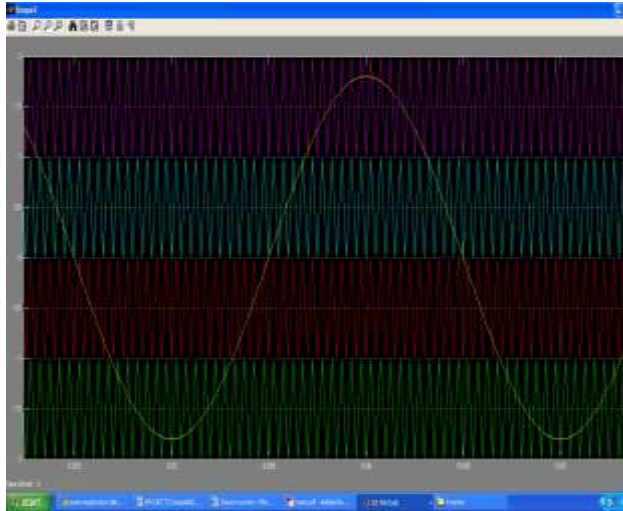


Fig 9 shows the o/p of LSCPWM

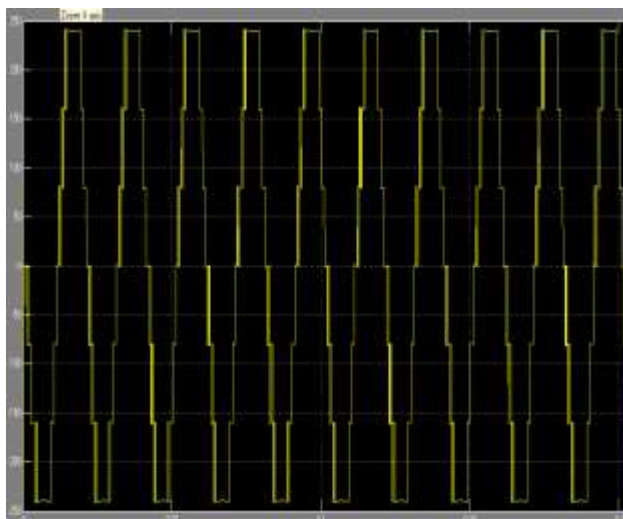


Fig 10 shows the 7 level output of inverter

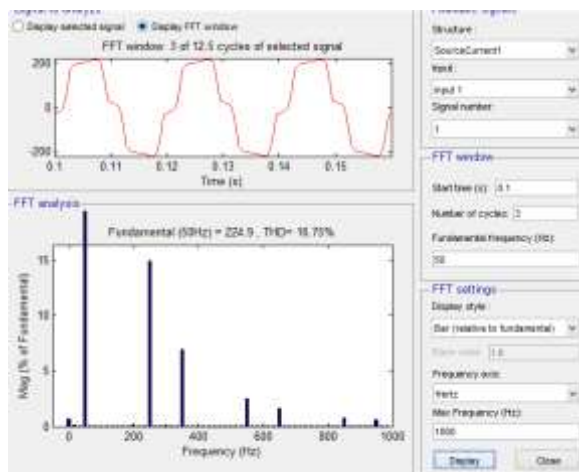


Fig 11 shows the 16.75% THD without connecting DSTATCOM

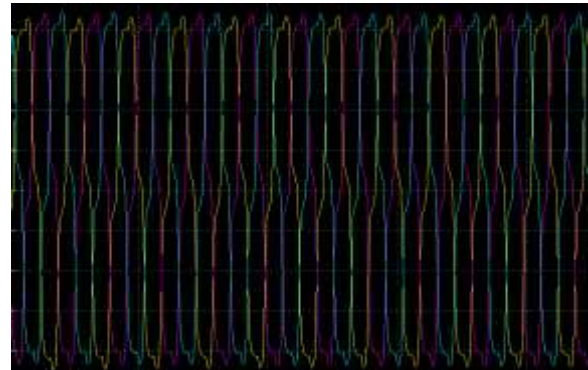


Fig 12 shows the load current waveform without connecting DSTATCOM

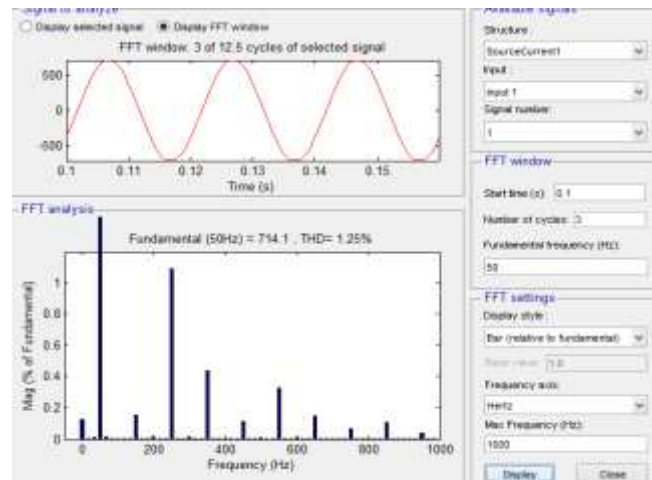


Fig 13 shows the 1.25% THD after connecting DSTATCOM

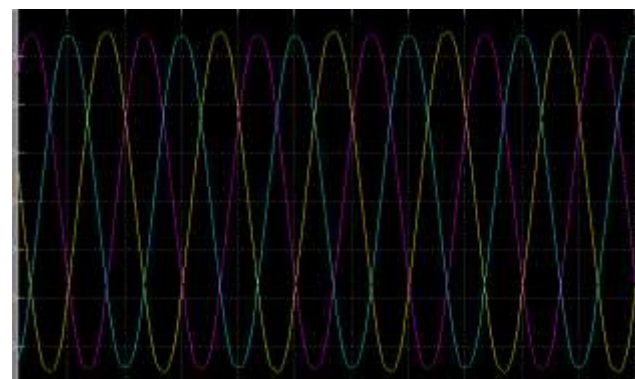


Fig 14 shows the load current waveform after connecting DSTATCOM

CONCLUSION

The cascaded inverter switching signals are generated using triangular-sampling current controller; it provides a dynamic performance under transient and steady state conditions, THD analysis also within the IEEE standards. Instantaneous real-power theory based

cascaded multilevel inverter based DSTATCOM is connected in the distribution network at the PCC through filter inductances and operates in a closed loop. A five level & seven as well as nine level cascaded multilevel voltage source inverter based DSTATCOM using instantaneous realpower controller is found to be an effective solution for power line conditioning to compensate harmonics, reactive power and power factor with the IRP controller reduces harmonics and provides reactive power compensation due to non-linear load currents; as a result source current(s) become sinusoidal and unity power factor is also achieved under both transient and steady state conditions. THD analysis also within the IEEE standards. This proposed model is implemented using Matlab/Simulink software and the obtained results.

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