

ROLE of DC-MLI based D-STATCOM in Distribution Network with FOC Induction Motor Drive

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ABSTRACT: Rated voltage and rated frequency supply should be supplied to the consumer end. With the introduction of many non-linear loads at the consumer end, Power Quality problem is a serious threat to the Power System. The potency of D-STATCOM using SRF control theory in a Distribution Network with Field Oriented Control (FOC) Induction Motor drive as non-linear load with Diode-Clamped Multilevel inverter is examined. D-STATCOM is a shunt linked device used for the reactive power compensation, for harmonic elimination and load balancing. For high-power and medium-power applications, Multilevel inverters are used as they can extract input current and produce output voltage with very low distortion. Simulation of D-STATCOM using SRF control theory with 7 level Diode-Clamped Multilevel Inverter has been performed in MATLAB/SIMULINK.

KEYWORDS: DC-MLI, FACTS, Field Oriented Control (FOC), STATCOM, SRF, THD, VSI.

I. INTRODUCTION

Power System is a subsystem of Electrical Engineering which composes of the generating, transmitting and distributing sections of the electric power. It is the chief duty of Power System engineers is to meet the consumers electric power demand. With the introduction of many non-linear loads at the consumer end, Power Quality problem is a serious threat to the Power System. As per IEEE, "Power Quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment". Common Power Quality problems that can be observed in daily life are Voltage Sag, Voltage Swell, Voltage Flickering, Over-Voltage and Under-Voltage. Impulsive transients, Oscillatory transients and Harmonics are also Power Quality problems. At the distribution side, Custom Power devices are used which mainly include Unified Power Quality Conditioner (UPQC), Distribution Static Compensators (D-STATCOM) and Dynamic Voltage Restorer (DVR).

D-STATCOM, a shunt linked Custom Power device employed for the reactive power compensation at the distribution side. It is also used for elimination of harmonic level and balancing of the loads at the distribution end. Various control algorithms for extracting the reference source current components are defined in the literature to analyze the performance of D-STATCOM such as Instantaneous Reactive Power (IRP) theory, Adaline Based Control Algorithm, Load balancing, Synchronous Reference Frame (SRF) theory, Symmetrical Component Theory and many others. Among from all, IRP and SRF control algorithms are usually used.

Multilevel inverter finds usage in many industrial high power applications. Multilevel inverters produce output with more number of voltage levels, producing a more sinusoidal voltage waveform and however reducing the harmonic distortion in the system. Multilevel inverters are superior to conventional VSIs and CSIs due to their low distortion in the output voltage waveform and reducing the dv/dt stress on the switches.

The work in this paper is based on the role of Diode Clamped Multilevel Inverter based DSTATCOM in Distribution Network with Field Oriented Control Induction Motor drive. SRF control theory based DSTATCOM is implemented with a 7-level DC-MLI to compensate for the non-linearity caused due to FOC- Induction Motor drive.

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II. CUSTOM POWER DEVICES

The notion of Custom Power devices was made known by N. G. Hingorani in the Power System. At the distribution end, Custom Power devices are used whereas FACTS device are used at the transmission end. For improving the system reliability and power transfer quality at the transmission end, FACTS devices are used whereas the Custom Power devices are employed for Power Quality improvement that is transmitted to the end user.

Custom Power Park is defined as the consolidation of different CP devices in a particular area to improve both the current quality and voltage quality for both linear and non-linear loads. To achieve high Power Quality, DVR, Static Transfer Switches, Active Power Filters (APF) and backup generator are used. Customer Power Park serve the consumers who are in a request of high grade of power and are eager to pay an extra charge sum for the services provided to them.

Custom Power devices are classified into current breaking devices and compensating power devices. SSB, SSCL and SSTs are some of the current breaking or solid state devices. Compensating devices are either used to compensate the load power factor, unbalance load, etc. or to enhance supplied voltage. D-STATCOM, DVR and UPQC are the Compensating devices.

III. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

Nowadays, many utilities and industries face the voltage sag problem which is one of the most common Power Quality issues caused due to the use of non-linear loads like motors, pumps, fans etc. at the distribution end. These loads draw excessively lagging power factor currents which reduce the flow of active power through the network and increase the losses on the system.

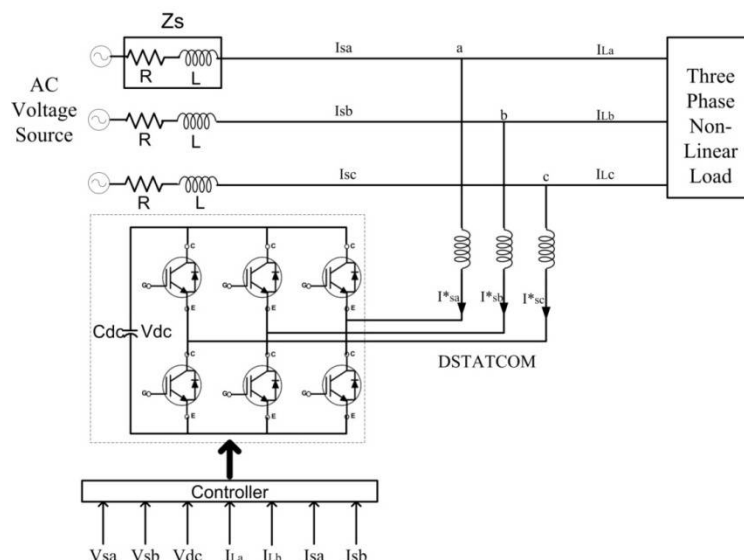


Fig. 1 Basic structure of D-STATCOM

D-STATCOM, a Custom Power device on the whole is a Voltage Source Converter (VSC) linked in shunt at PCC at the distribution end of the Power System network. Custom Power device used for load current harmonics compensation and to control unity power factor load. To maintain the isolation between the D-STATCOM system and the distribution end of the network system, a coupling transformer is used linking the two. D-STATCOM provides fast and continuous inductive reactive power compensation and capacitive reactive power compensation.

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Configuration of D-STATCOM

D-STATCOM mainly constitute of:

1. Voltage Source Converter
2. Coupling Transformer
3. DC Capacitor Voltage
4. LC Passive Filter

Control Strategy for D-STATCOM- SRF Theory

D-STATCOM is employed for harmonic easing; reactive power compensation or load balancing at the distribution end of the network. Different control theories or algorithms are used for extracting reference source currents. Some of the strategies SRF theory, IPR theory, Adaline Based algorithm, DC bus regulation for current compensation and some schemes based on artificial intelligence. Amongst from these schemes, SRF based theory is used to study the performance of the DSATCOM with Field Oriented Control (FOC) induction motor drive as a non-linear load is examined.

Synchronous Reference Frame (SRF) Theory

SRF theory, a $d-q$ control theory is based on the conversion of 3 phase current frame $a-b-c$ to synchronously rotating $d-q$ frame. Schematic plan of SRF theory is explained in Figure 3. To the Phase Locked Loop (PLL) block, voltage signals V_a , V_b and V_c are applied to obtain sine and cosine signals.

Load current signals I_{La} , I_{Lb} and I_{Lc} are converted from 3 phase quantities to 2 phase quantities i.e I_α and I_β with the help of **Clark's transformation** following the equations:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad (2)$$

Park's transformation is used for converting balanced two-phase stationary quantities to 2-phase rotating reference frame.

After **Clark's Transformation**, **Park's Transformation** is done by using the following equation:

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (3)$$

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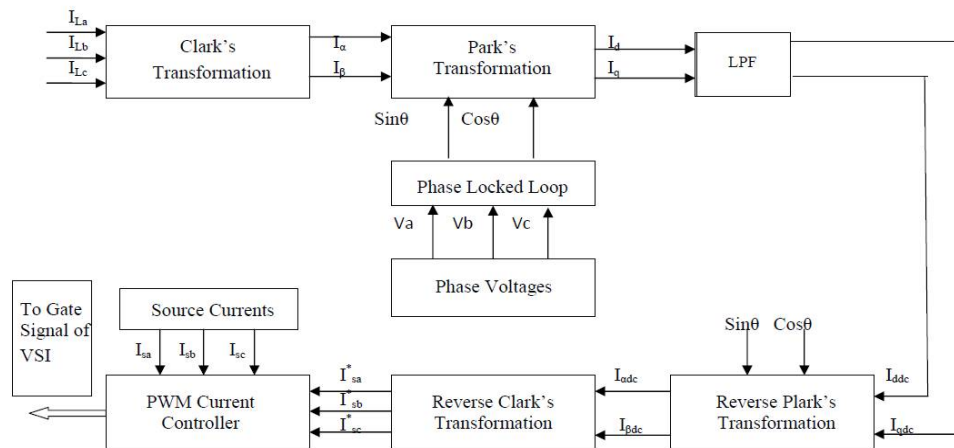


Fig. 2 Schematic plan of SRF based theory

Basic schematic plan of SRF based theory is shown in figure 2 describing all the steps involved in the SRF based theory. The sequence of all transformations is shown in figure.

For extraction the DC component from the synchronously rotated currents, Low pass filter is used. These extracted DC currents are altered back into $I_{\alpha DC}$ and $I_{\beta DC}$ using **Reverse Park's Transformation** equation:

$$\begin{bmatrix} I_{\alpha dc} \\ I_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I_{d dc} \\ I_{q dc} \end{bmatrix} \quad (4)$$

Reverse Clark's Transformation is applied to obtain 3-phase Reference Source Currents I_{sa}^* , I_{sb}^* and I_{sc}^* from the derived DC currents using the equation:

$$\begin{bmatrix} I_{sa}^* \\ I_{sb}^* \\ I_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_0^* \\ I_{\alpha dc}^* \\ I_{\beta dc}^* \end{bmatrix} \quad (5)$$

IV. MULTILEVEL CONVERTERS

Converter is a conversion device used to alter the nature of electric supply i.e. from DC to AC and vice-versa, DC to DC as well as AC to AC. Voltage source inverters (VSI) are basically two-level inverters. Basically, Multilevel inverter began with 3 level inverter. Multilevel inverters are fundamentally used to obtain sinusoidal voltage from several levels of voltage extracting input current with very low distortion operating at lower switching frequency; generate smaller torque ripples in the motor. These can generate output voltages with mature medium-power semi conductor technology with lower distortion. The output waveforms access a more sinusoidal wave with a reduced harmonic distortion when numbers of level are increased.

Multilevel inverters have replaced the conventional VSIs because it is difficult to use conventional VSIs in high voltage appliances due to their high device rating constraints and increased switching losses. Basically Multilevel Inverters are used for Static VAR compensators, for Adjustable Speed Drives (ASD), back to back high voltages inter tie and many more. Basic standard Multilevel Inverters are DC-MLI, FC-MLI and Cascaded H-Bridge MLI.

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DC-MLI: Diode-Clamped Multilevel Inverter

Nabae, Takahashi and Akagi put forward the first 3 level DC-MLI in year 1981. The DC-MLI is also acknowledged as Neutral Point Clamped (NPC) Multilevel Inverter. Without requiring exact voltage match condition, it doubles the device voltage level. DC-MLI is basically used for Static VAR compensation, for inter-connection of high-voltage systems, Variable speed motor drives, mills, conveyors and so on.

For p -level inverter, at the DC bus $(p-1)$ capacitors are required producing p level of phase voltage with $(2p-1)$ levels of output line voltage. Blocking diodes of high voltage rating are required for DCMLI with $(p-1)*(p-2)$ number of clamping diodes required in each phase. Available commercial ratings of DCMLI are 2.2 to 6.6 kV, 3.7 to 44MVA. For our work, Simulation of 7-level DC-MLI is implemented on MATLAB/Simulink R2015b. Simulation of 7-level DC-MLI is shown in Figure 3.

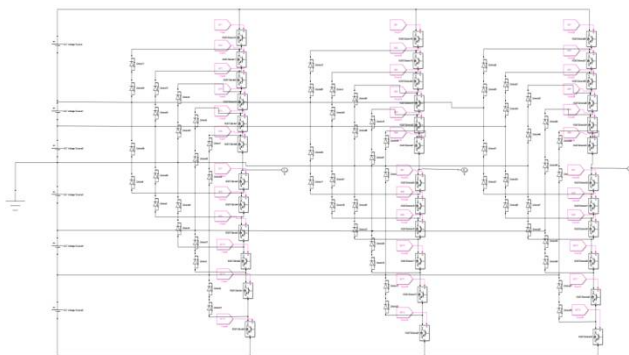


Fig. 3 Simulation of 7-level Diode-Clamped MLI

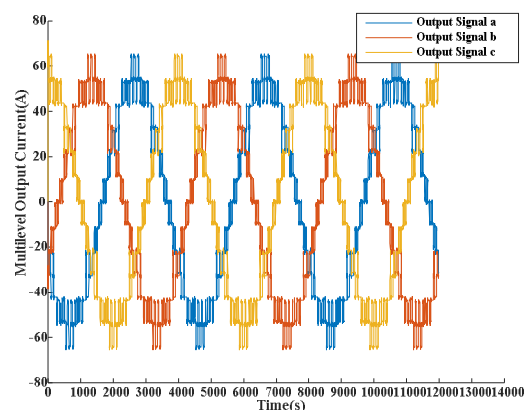


Fig. 4 Output Waveform of 7-level DC-MLI

MATLAB/SIMULATION of 7-level Diode-Clamped Multilevel inverter with its corresponding output waveform are shown in figure 3 and figure 4. A common DC bus is used for all 3 legs of the inverter and $(V_{DC}/6)$ is the voltage across each capacitor. Each leg of inverter consists of six complimentary switch pairs such that only one switch is operated during the operation.

V. SYSTEM TEST AND RESULTS

In this paper, MATLAB/SIMULINK R2015b software has been used to design the D-STATCOM model based upon $dq0$ transformation and a 7 level DC-MLI. This system is analysed for an Induction Furnace Drive non-linear load under working conditions. The SRF control technique is employed for D-STATCOM which observes the difference between the load current and reference current. Consequently, the gating signals for Multilevel inverter are produced. The output waveforms for source phase voltage, source current, load current and compensating current with their FFT Analysis are shown below.

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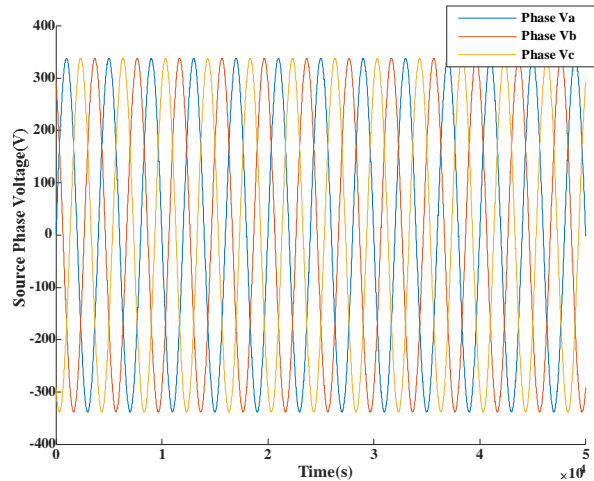


Fig. 6 Output Waveform of Source Phase Voltage

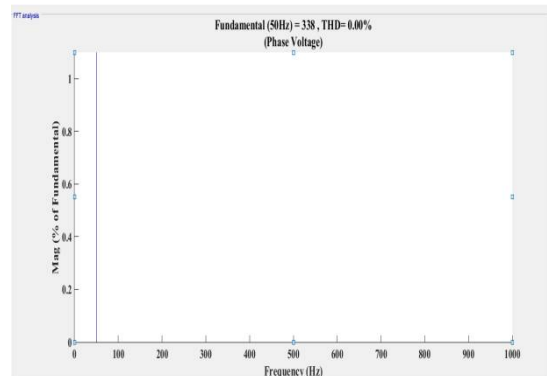


Fig. 7 Frequency Spectrum of Source Phase Voltage

Figure 6 shows the output waveform of Source Phase Voltage with the corresponding Frequency Spectrum in Figure 7. The Total Harmonic Distortion (THD) level in the Source Phase Voltage is 0.0%.

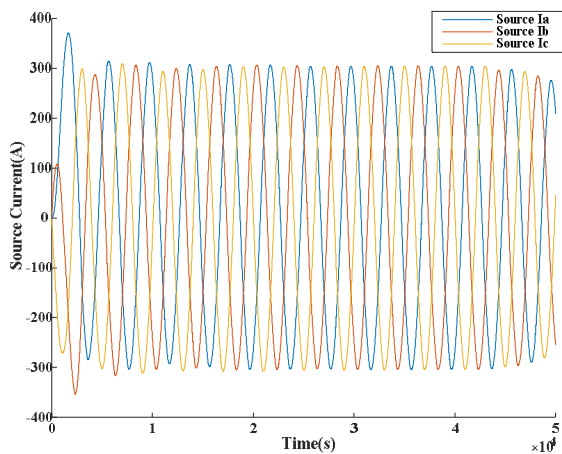


Fig. 8 Output waveform of Source Current

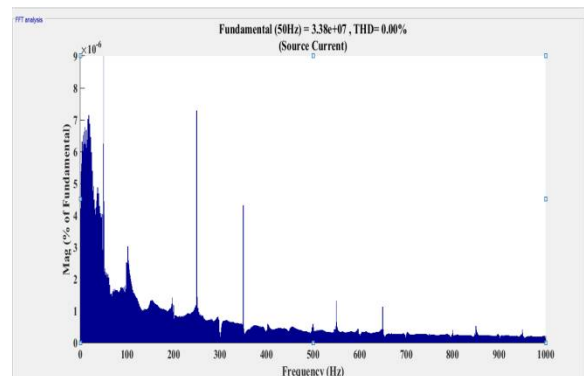


Fig. 9 Frequency Spectrum of Source Current

Figure 8 shows the output waveform of Source Current with the corresponding Frequency Spectrum in Figure 9. The Total Harmonic Distortion (THD) level in the Source Current is 0.0%.

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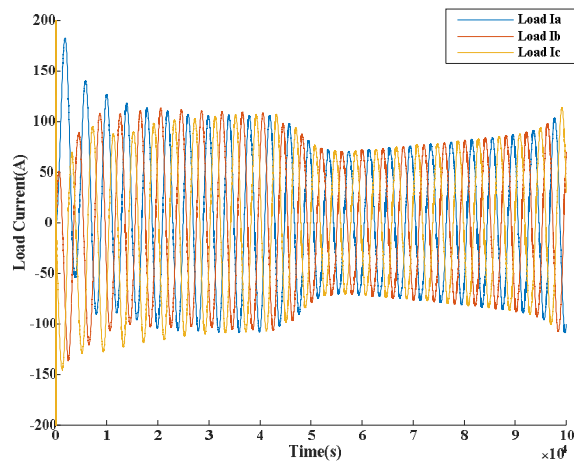


Fig. 10 Output Waveform of Load Current

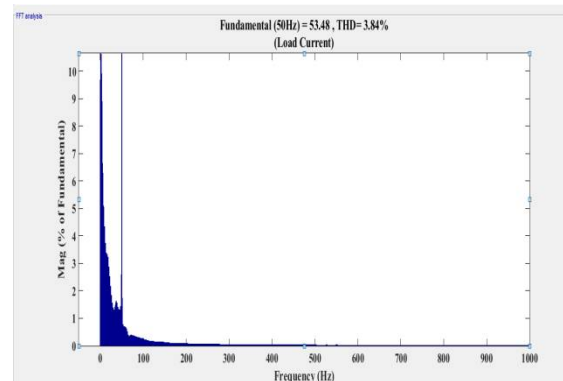


Fig. 11 Frequency Spectrum of Load Current

Figure 10 shows the output waveform of Load Current with the corresponding Frequency Spectrum in Figure 11. The Total Harmonic Distortion (THD) level in the Source Current is 3.84%.

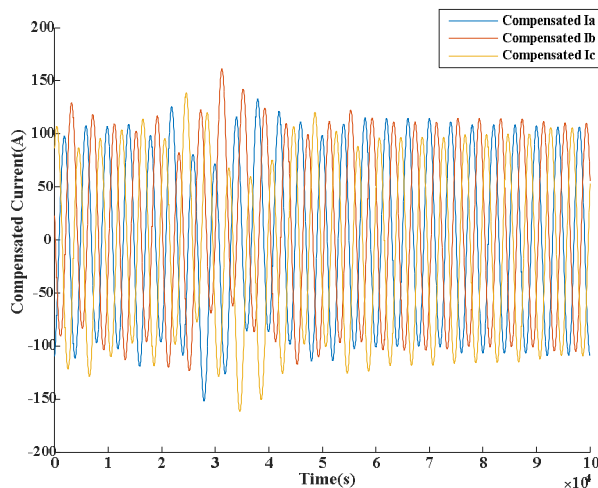


Fig. 12 Output Waveform of Compensated Current

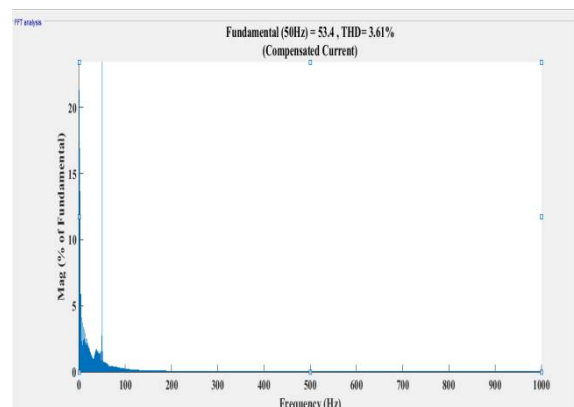


Fig. 13 Frequency Spectrum of Compensated Current

Figure 12 shows the output waveform of Compensated Current with the corresponding Frequency Spectrum in Figure 13. The Total Harmonic Distortion (THD) level in the Compensated Current is 3.61%.

In the test system, it is observed that due to the usage of FOC Induction Motor Drive, the THD level of 3.84% is observed in the load current whereas for the Compensating Current provided by the D-STATCOM is 3.61%. The THD level for supply current is 0% due to the coupling of D-STATCOM in the network. The presence of 0% THD level in source current shows that the designed D-STATCOM efficiently compensates for the load current harmonics.

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VI. CONCLUSION

In the present work, Power Quality and its problems has been discussed with their mitigation techniques. Different types of Custom Power devices are discussed in which particularly MATLAB/SIMULINK model of D-STATCOM has been modelled and simulated for Field Oriented Control (FOC) Induction Motor drive using the Synchronous Reference Frame (SRF) control theory. MATLAB/SIMULINK model of 7 level DC-MLI has also been developed. It is clearly observed from the test results that D-STATCOM efficiently eliminates the harmonics from load current making the 0% THD level for source current. With the use of Multilevel inverter, the output waveform is more sinusoidal with reduced harmonic distortion. From the present work, it can be concluded that D-STATCOM finds applications in effectively enhancing the Power Quality level at distribution side of the Power System.

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