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Comparative Study of PQ and DQ Theory for Diode Clamped Multilevel Inverter based D-STATCOM

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***Abstract*—The heavy engineering industries have conventionally opted for higher ranges of distribution voltage to cater the demands of high power load. However, some of the loads are demanding high power ratings at medium voltage levels. The conventional inverters operating in this range are two level inverters. These inverters despite of being economical, requires high DC link voltages and lags behind for the power quality parameters. For high-power, medium-voltage applications, multilevel inverters are deployed in industrial applications. The multilevel inverters are constructed in variety of configurations and levels according to the load requirements. These multilevel inverters are also used in power quality enhancement devices like active filters and STATCOM due to their inherent advantages as reduced harmonics contents, reduced voltage stress on switching devices and minimized losses in the switching. This paper focuses on implementation of D-STATCOM with diode-clamped multilevel inverter (DCMLI). A comparative study of DCMLI based D-STATCOM with synchronous reference frame (SRF often referred as DQ) theory and instantaneous reactive power (IRP often referred as PQ) theory is presented with MATLAB simulations.**

***Index Terms*— Power Quality, STATCOM, Multilevel Inverter STATCOM, diode clamp, harmonics.**

I. INTRODUCTION

In an electrical power system, the unbalance is observed in voltage and frequency if active and reactive power balance between sending end receiving end is disturbed. Most of the loads today are inductive (induction motors) and non-linear type (rectifier) [1, 2]. The earlier type draws a lagging reactive power and the later type introduces harmonics in the system and thereby deteriorating the power quality. The reactive power demand increases the system losses as well as reduces the deliverable active power. A voltage fluctuation in terms of sag and swell is another major power quality problem. It leads to the power fluctuations and tripping of the circuit breakers. The nonlinear loads like arc furnace, welding machine etc. also contributes to the flickering problems [3].

The D-STATCOM has been increasing gaining attention at distribution levels on account of constant and consistent capacitive and inductive reactor power compensation capabilities [4]. It is connected across the system to be compensated. It can regulate the voltage at point of common coupling and provide reactive power

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compensation as well as it can reduce harmonics. A voltage source inverter is the heart of the D-STATCOM which is often driven with pulse width modulation (PWM) and other control techniques. These control techniques all together regulates PCC voltage, compensates reactive power and mitigates harmonics. The control techniques are often developed to address assorted power quality issues [5, 6].
A multilevel inverter is the best topology for managing large power with medium voltage sources. It delivers a smoother voltage waveform, generates high voltages using devices with lower ratings, and decreases the stress on switching components. Thus, compared to conventional inverter topologies, the multilevel inverter delivers superior power quality. Diode Clamped, , Flying-Capacitor, and Cascaded H-bridge inverters are the three basic topologies of multilevel inverters [7]. This paper uses diode clamped multilevel inverter for simulation studies of multilevel D- STATCOM.

II. Diode Clamped Multilevel Inverter

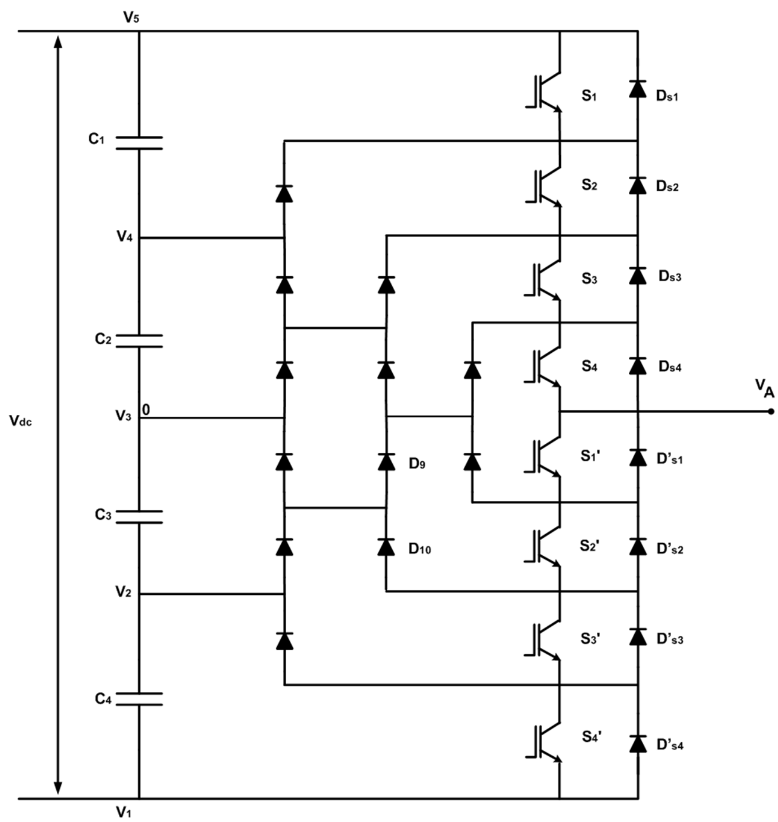

Figure 1: Inverter Leg configuration of five levels DCMLI

Figure 1 shows a typical configuration of five levels DCMLI inverter leg. In this configuration, the arrangement of diodes is made in such a way that it supplies multiple voltages in various stages to the capacitor banks that are connected in series. A diode relieves the stress on other electrical components by transmitting a little amount of electricity. In case of DCMLI, the maximum value of the output voltage never exceeds the one half value of the input DC voltage. This can be thought of as a major limitation of DCMLI but it is often managed by deploying additional number of diodes, capacitors and switches. Due to the basic frequency that is utilized by all switching devices and the straightforward back-to-back power transfer scheme, this type of inverter offers high efficiency [8].

III. Control Theories and MATLAB Simulations

A MATLAB model of diode clamped multilevel D-STATCOM is build as shown in figure 2. The system specifications are indicated in table 1. Five level diode clamped multilevel inverter based D-STATCOM [9] is constructed for the overall system implementation. The THD analysis of the system is done in three stages. At first, the THD is measured for the loading conditions as specified in table 2 for uncompensated system. Secondly the IRP theory based controller for D-STATCOM is used for compensation and THD is measured. And at last the SRF theory based controller for D-STATCOM is used for compensation and THD analysis is done. The THD level for both control schemes is done.

TABLE I. SPECIFICATIONS OF DEVELOPED MATLAB SIMULINK MODEL

Source Parameters	Vrms (Ph-Ph) = 11 kV Frequency = 50 Hz
Transformer Parameters	Δ - Y grounded Nominal Power = 20kVA Frequency = 50 Hz V1 = 11 kV V2 = 400 V
Line & Load Parameters	RL Branch: Resistance R = 0.4 Ω, Inductance L = 3.55mH Non Linear Load: Resistance R = 15Ω, Inductance L = 60mH
STATCOM Parameters	DC Link Voltage = 600 V, Capacitance C_1=C_2=C_3=C_4= 250 µF Switching Frequency = 5 kHz, LC Filter: Inductance L = 50 mH, Capacitance, C = 2000 µF
Three Phase Circuit Breaker	Initial status: Open Switching times= 0.5s Breaker resistance Ron= 0.001Ω

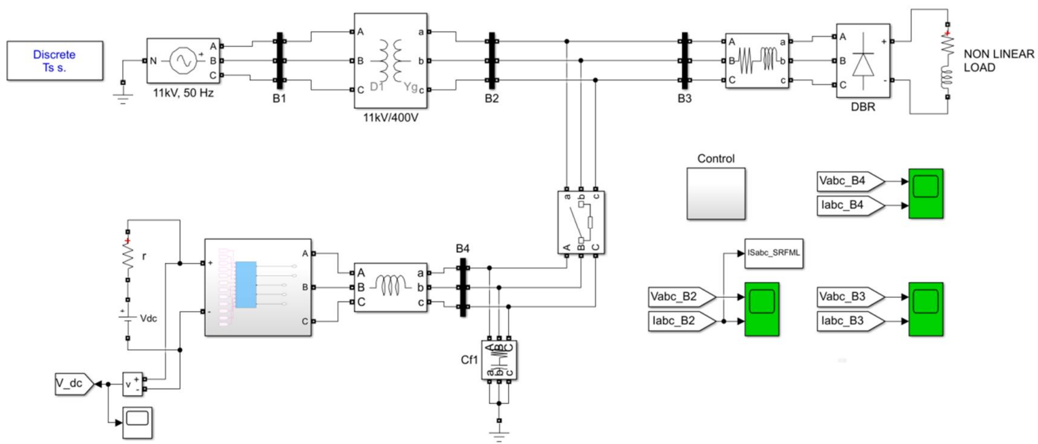

Figure 2: MATLAB Model of D-STATCOM

A. SRF Theory (d-q Theory)

The d-q theory is based on time domain reference signal eradication technique [11 - 12]. It performs the operation for voltage and current waveforms in steady state or transient states. The three phase AC voltage or current is converted by the synchronous reference frame theory into a synchronously rotating two axis d-q reference frame using Park's transform.

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta - 120) & \cos(\theta + 120) \\ \sin\theta & \sin(\theta - 120) & \sin(\theta + 120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{... (1)}$$

This transformation is required because the fundamental component is converted into a constant that can be low pass filtered in a synchronous reference frame, leaving behind the high frequency components that are easily isolated. A low pass filter also avoids phase problems in the signal, which may arise if a high pass filter was used to filter a DC component. In order to use this theory, the load current is converter from a three-phase frame to a d-q reference frame. The resulting direct component (d) and quadrate component (q) contain both AC as well as DC components. The fundamental component is given by the DC part, whereas the harmonic component is represented by the AC portion. Fundamental components are shown in the d component, whereas harmonic contents are shown in the q component. The relevant pulses for the inverter are obtained using the transformation of the inverse park.

$$\begin{bmatrix} i_a{}^* \\ i_b{}^* \\ i_c{}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin(\theta) & 1 \\ \cos(\theta-120) & \sin(\theta-120) & 1 \\ \cos(\theta+120) & \sin(\theta+120) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \qquad ...(2)$$

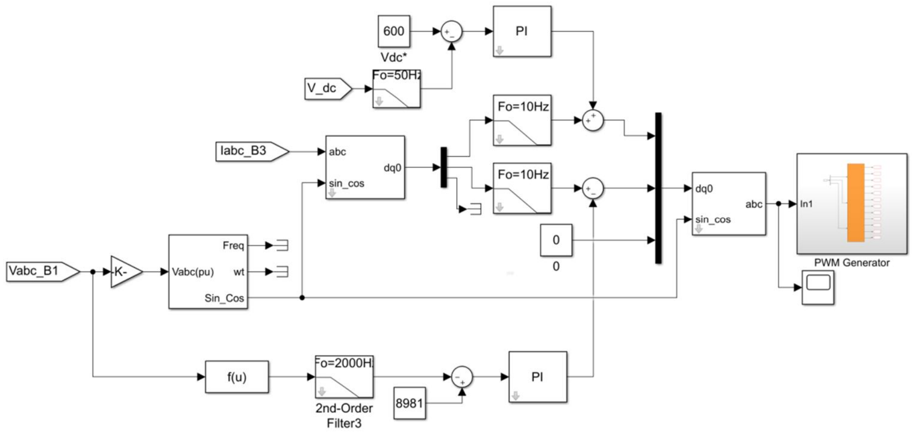

Figure 3: D-STATCOM Control using DQ theory

B. IRP Theory (p-q theory)

Akagi et al. proposed a unique theory in 1983 called "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits" [13]. The time-domain-based p-q theory is applicable for both steady-state and transient operation with voltage and current waveforms. This theory can be further extended for controlling the active filters. The p-q theory uses Clarke's Transformation for converting the stationary reference a-b-c coordinates to α-β-0. While the coordinate 0 is associated with the zero sequence component, the components α and β are orthogonal.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = T.\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{or} \quad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = T.\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad ...(3)$$

$$\text{Here, } T = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \qquad ...(4)$$

The p-q theory power components are then calculated from voltages and currents in the α-β-0 coordinates. The control scheme of D-STATCOM with p-q theory is shown in figure 4

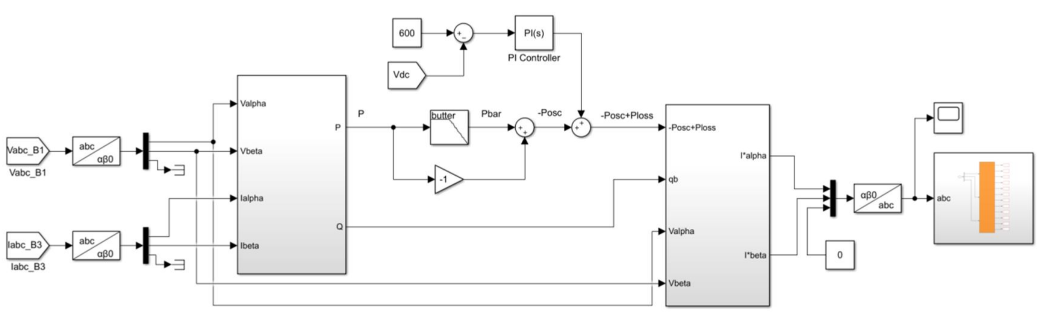

Figure 4: D-STATCOM control with PQ theory

IV. SIMULATION RESULTS

The simulation results are shown for performance analysis of diode clamped multilevel inverter based STATCOM with SRF theory and IRP theory fig. 5 shows the harmonic contents of uncompensated system. The THD of uncompensated system is seen to be 15.13%.

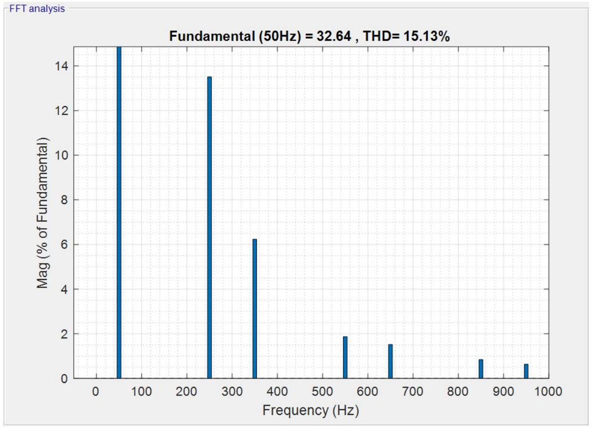

Figure 5: Total Harmonic Distortion without STATCOM

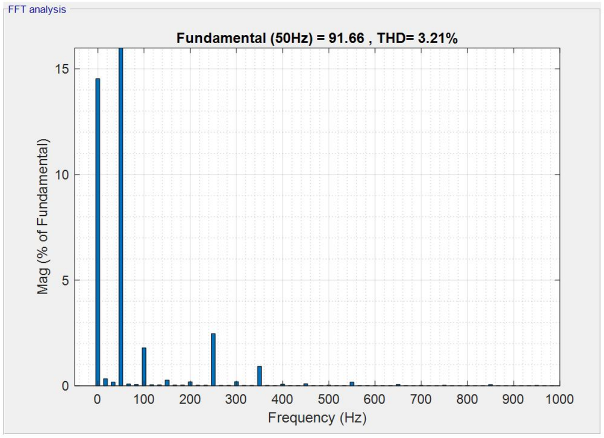

Figure 6: Total Harmonic Distortion STATCOM controlled by IRP (p-q) theory

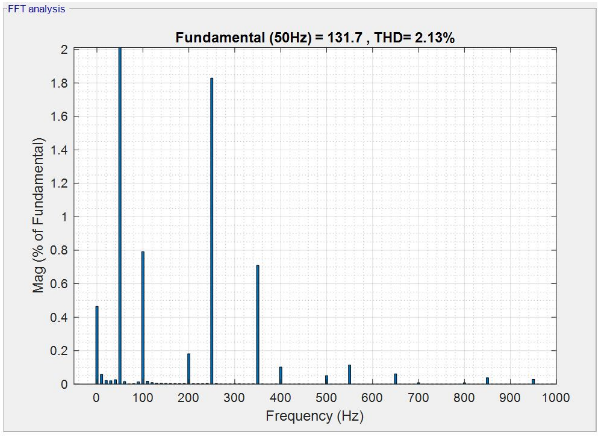

Figure 7: Total Harmonic Distortion STATCOM controlled by SRF (d-q) theory

The figure 6 shows the harmonics contents of compensated system with diode clamped multilevel inverter based STATCOM with IRP theory. Here, the THD is found to be reduced to 3.21%. When the system is compensated with diode clamped multilevel inverter based STATCOM with SRF theory the THD contents are reduced to 2.13% as seen in figure 7.

V. CONCLUSION

The application of diode clamped multilevel inverter configuration for STATCOM is demonstrated through MATLAB Simulink based simulations. The synchronous reference frame theory based control proves to be inch better than the instantaneous reactive power theory. The THD reduction up to 2.13% is achievable through SRF theory as compared to the 3.21% THD of the IRP theory.

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