Design and Simulation of Direct Power Control Based DSTATCOM

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Abstract: A DSTATCOM (DSTATCOM) is a custom power device [current controlled Voltage Source Converter (VSC)] when connected to the power system used for reactive power compensation. The DSTATCOM with PI controlled Space Vector Pulse Width Modulation (SVPWM) technique has maximum peak overshoot and big settling time. For Park's transformation and for control, SVPWM technique requires Phase Locked Loop (PLL) for measurement of changeable frequency. This paper explains a DSTATCOM using space vector based Hysteresis Current Controller (HCC) for reactive power compensation and its performance compares with that of the PI controlled SVPWM method. Compared to SVPWM control technique, the HCC technique is strong and has quicker transient performance. In addition, this technique doesn't require PLL for measurement of frequency. It has reduced switching losses and is simple to implement. The performance of DSTATCOM with HCC is considered in MATLAB/SIMULINK environment.

Keywords: DSTATCOM, Voltage Source Controller, SVPWM, PLL and Hysteresis Current Controller.

I. INTRODUCTION

Power quality maintenance in a power system is very important in today's circumstances because of the increase in wide variety of loads that contaminate the power system. For magnetization, inductive loads like arc furnaces, induction motors, induction generators and power transformers, require reactive power and if the reactive power is consumed from the grid, a voltage dip occurs. This voltage dip affects supplementary sensitive loads that are connected to the grid. Hence, it is essential for inductive load users to compensate for the required reactive power. If the reactive power supplied by the compensator is more than the requirement of the grid, voltage swell occurs, which again affects sensitive loads. Different types of compensation schemes such as series compensation and shunt compensation have been proposed in the literature (Figure 1). Fixed capacitor can supply a fixed amount of reactive power, but fails for dynamic loads. Static VAR compensator can generate/absorb the required reactive power by connecting and disconnecting reactor banks and capacitor banks to the network by proper switching action, but has less transient response and less dynamic performance [5]. The aim of the paper is to design the efficient control strategy for DSTATCOM. Nowadays domestic reference documents about the control are the studies of the nonlinear control which needs difficult theory, fuzzy computation process. But the approach in document using PI controller is not easy to set parameters and do not ideal immunity. In this paper based on double switching tables, the direct power control is employed [1]. From the angle of power, the method adopts voltage outer loop and power inter-loop control structure, the detection value of power is viewed as reference value owing to the instantaneous power theory, then the switch regulations which are influenced by the ac voltage and instantaneous value of power to control the converter to export the reactive power, which could adjust the reactive current of transmission line indirectly, The paper builds the simulation model, the results of it show the high effectiveness of this DSTATCOM control strategy.

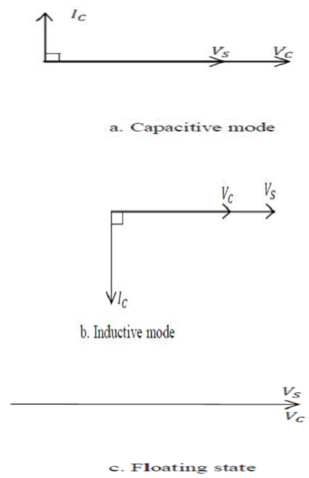

Figure 1: DSTATCOM operating modes.

II. CONTROL STRATEGY FOR DYNAMIC LOADS

The single line diagram of a grid coupled DSTATCOM at the Point of Common Coupling (PCC) all the way through the coupling inductor/filter is shown in figure-2. It consists of a 2 level VSC, DC capacitor and a control circuit. Loads connected to the grid can vary dynamically also shown in the figure. The reactive power required by the load is supplied by DSTATCOM by suitable control action.

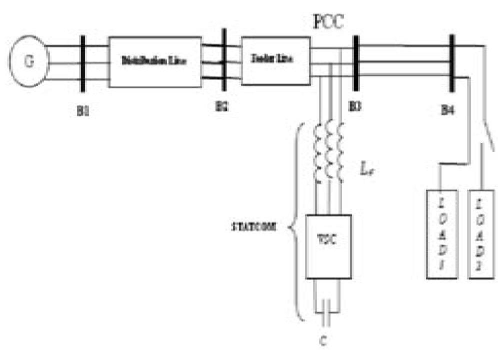

Figure 2: Single line diagram of a DSTATCOM with dynamic loads.

The objective of the planned SVM-HCC based DSTATCOM is to supply the essential reactive power to the load resulting in improvement of power factor. SVM-HCC is a current control method that requires a reference for its control. From the instantaneous active power (p) and instantaneous reactive power (q) equations of the load in α-β frame, as given by Equation (1), the reference current is computed [3].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (1)$$

Where, V_α, V_β, $i_{\alpha,}$ and i_β are stationary α-β frame representation of b-phase voltages and currents. From the instantaneous values of active power (p*) and reactive power (q*) to be supplied by the DSTATCOM using expressions given in Equations (2) and (3), the reference current required for the HCC can be evaluated.

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \quad (3)$$

The instantaneous active power (p*) that is to be supplied by the DSTATCOM can be evaluated from the energy stored in the DC capacitor and is given by:

$$p^* = -\frac{dE}{dt} = \frac{1}{2} C \frac{d(V_{DC}^2)}{dt} \quad (4)$$

Where, V_{dc} is the capacitor voltage. To improve the power factor, only reactive power is to be compensated and the steady state value of p* should be zero, which is ensured by maintaining a constant capacitor voltage. The instantaneous reactive power to be compensated (q*) must be equal and opposite to that of the instantaneous load reactive power requirement ($-q_L$). Hence, Equation (3) is modified and it gives Equation (5).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ -q_L \end{bmatrix} \quad (5)$$

Equation (5) gives the reference current in α-β frame, which is to be compared with the actual current of the DSTATCOM in the same frame of reference, and fed to the HCC as shown in Figure-3.

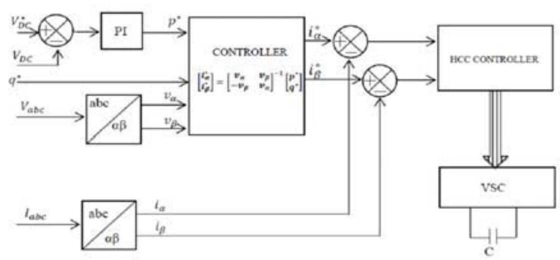

Figure 3: Block diagram of SVM based HCC.

III. SPACE VECTOR BASED HYSTERESIS CURRENT CONTROL METHOD

In this paper, for controlling output current of the DSTATCOM, SVM based HCC is implemented with multilevel hysteresis comparators. The error in current is represented in stationary (α-β) frame and the error in current vector is controlled to lie within the tolerance region. The VSC output voltage space vectors in α-β plane shown in figure-4. The possible switching states and corresponding normalized α-β values of vectors shown in table-1. It can be observed that there are three discrete levels along β axis and four discrete levels along α axis. Hence a four-level hysteresis comparator on α axis and a three-level hysteresis comparator on β axis are used, to identify the region of the error in the current vector. When the DSTATCOM output current exceeds the tolerance region on one particular axis a new voltage vector with the opposite value of α (or β) component is applied. Suppose the DSTATCOM output current is in sector I, and the tolerance region from the bottom (or top) side if error exceeds, to bring the error in the current vector within the tolerance region, the next voltage vector with larger (or smaller) value of β component is applied. Similarly, the tolerance region from the left (or right) side if the output current exceeds, to bring the error in current vector inside the tolerance region, the next voltage vector with larger value (or smaller) of α component is applied. For all other cases, the current controller must select zero voltage vectors to achieve minimum switching losses [2].

In stationary reference frame, the DSTATCOM output voltage have four values of non-zero voltage vectors in α axis and three values of non-zero voltage vectors in β axis as shown in figure-4. Therefore, a current controller of four level comparators in α axis and three-level comparators in β axes is used in this method. The outputs of hysteresis comparators Dα (in α axis) and Dβ (in β axis) determine the output voltage vector of the DSTATCOM, as shown in Figure-4 and tabulated in Table-2. These vectors are stationary reference frame selected in such a way that the slope of the error in current vector and error is within the square tolerance area. The sector information of reference voltage vector Vn* is obtained for each 60°, the comparator outputs, Dα and Dβ, remain constant. Hence, the controller should select two non-zero voltage vectors adjacent to the reference voltage vector Vn* and a zero voltage vector. Once the value of Dα or Dβ changes, the reference voltage vector Vn* moves to the next sector. In each sector, the controller selects two nonzero voltage vectors and a zero vector, as done in the previous sector. Thus, by this method, the switching frequency of the inverter is significantly reduced.

Table 1: Three-phase switching states, respective voltage space vectors and their β values

S_a^*	S_b^*	S_c^*	V_n	$\frac{V_\alpha}{V_{dc}}$	$\frac{V_\beta}{V_{dc}}$
0	0	0	V_0^0	0	0
1	0	0	V_1	2/3	0
1	1	0	V_2	1/3	$1/\sqrt{3}$
0	1	0	V_3	-1/3	$1/\sqrt{3}$
0	1	1	V_4	-2/3	0
0	0	1	V_5	-1/3	$-1/\sqrt{3}$
1	0	1	V_6	1/3	$-1/\sqrt{3}$
1	1	1	V_0^1	0	0

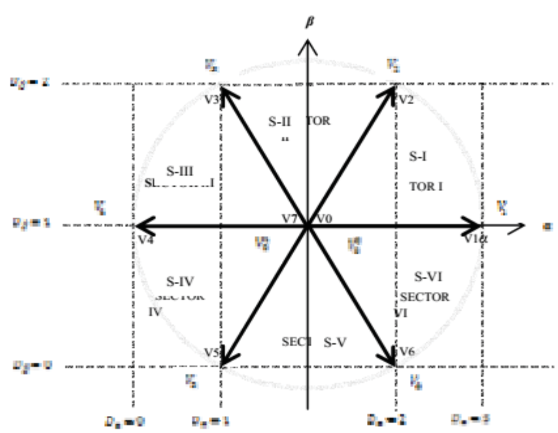

Figure-4.Determining sector information from Hysteresis Comparator outputs

Table 2: Switching table of the proposed vector-based HCC method

$D\alpha$ \ $D\beta$	0	1	2
0	V_5	V_4	V_3
1	V_5	V_0	V_3
2	V_6	V_0	V_2
3	V_6	V_1	V_2

IV. MATHEMATICAL MODELING

The structure diagram of DSTATCOM is shown in Figure 5. L is the filter inductor, R is the equivalent resistance, C_{dc} is the energy storage capacitor, U_{sa}, U_{sb}, and U_{sc} are the three phase voltages of grid, U_a, U_b, U_c and i_{La}, i_{Lb}, i_{Lc} are DSTATCOM three phase output voltages and currents. In Figure 5, there are six IGBTs.

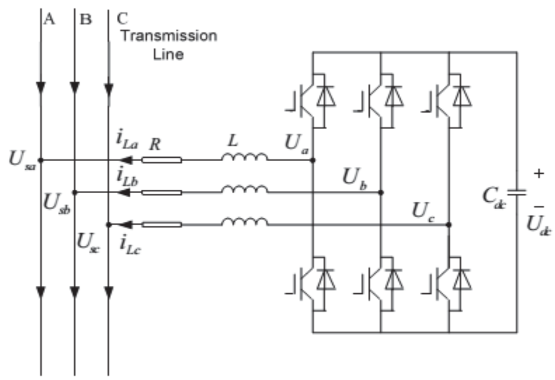

Figure 5: The structure diagram of DSTATCOM

According to Kirchhoff's Law, the result can be calculated as:

$$\begin{cases} i_{La} = \dfrac{1}{L}(U_{sa} - U_a - Ri_{La}) \\ i_{Lb} = \dfrac{1}{L}(U_{sb} - U_b - Ri_{Lb}) \\ i_{Lc} = \dfrac{1}{L}(U_{sc} - U_c - Ri_{Lc}) \\ U_{dc} = \dfrac{1}{C_{dc}}(s_a i_{La} + s_b i_{Lb} + s_c i_{Lc}) \end{cases}$$

S= [S_a, S_b, S_c] is the switching function of IGBTs. and when the initial phase angle has the same value with the voltage phase of the injection point, the output active and reactive expression of DSTATCOM as following basing on the theory of instantaneous power detection can be showed, which is in the d-q axis:

$$\begin{cases} P = \dfrac{2}{3} U_{sd} i_{Ld} \\ Q = -\dfrac{2}{3} U_{sd} i_{Lq} \end{cases}$$

The control aims of DSTATCOM are P→P* and Q→Q*, which mean the output active and reactive of DSTATCOM P and Q should trace their reference value P* and Q* [4], in order to control the output current phase, the follow method is used, from which the grid voltage phase θ can be got, the simulation structure diagram shown as:

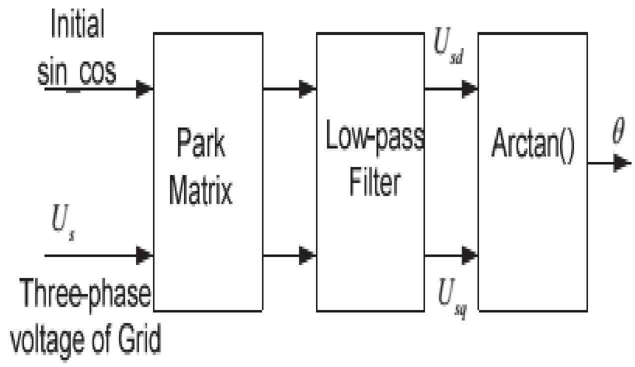

Figure 6: Diagram of Phase- Locked Loop

V. MATLAB/SIMULINK RESULTS

The figure 7 shows the MATLAB/SIMULINK circuit of the DPC based DSTATCOM using SVPWM

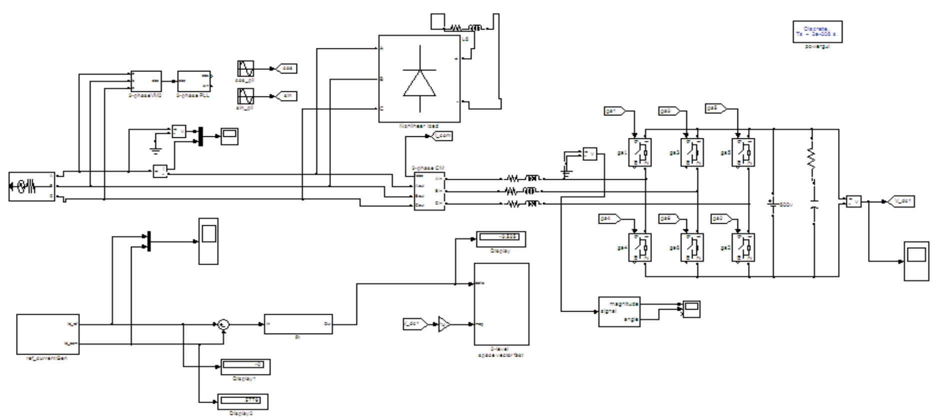

Figure 7: MATLAB/SIMULINK circuit of proposed DSTATCOM

The figure 8 shows the implementation of SVPWM in MATLAB/SIMULINK.

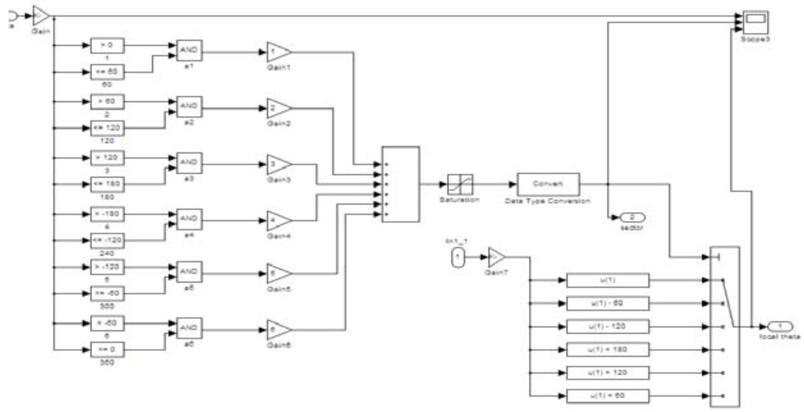

Figure 8: MATLAB/SIMULINK circuit of SVPWM

The figure 9 shows the Active and Reactive power waveforms of the source. It is clear from the waveforms that the reactive power drawn from the source is almost zero because DSTATCOM is supplying the needed reactive power to the load.

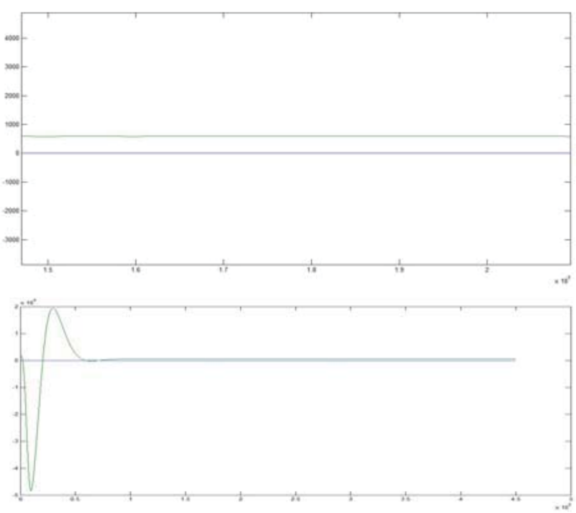

Figure 9: Output waveforms of Active and Reactive Powers

The figure 10 shows the waveforms of source voltage and source current which are sinusoidal because of DSTATCOM.

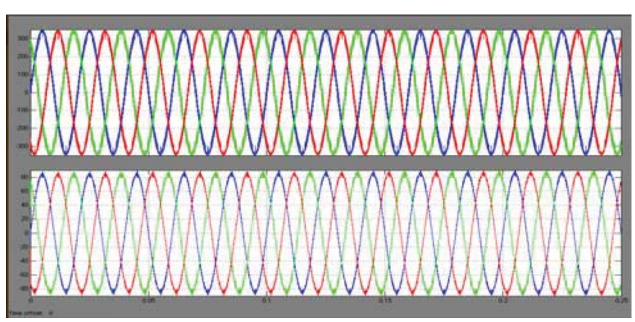

Figure 10: Source current and Source voltage waveforms

VI. CONCLUSION

This paper presents a DSTATCOM based on Direct Power Control for reactive power compensation using space vector based Hysteresis Current Controller (HCC) and compares its performance with that of the PI controlled SVPWM method. The HCC technique is strong and has quicker transient performance compared to SVPWM control method. In addition, this technique does not require PLL for measurement of frequency, has reduced switching losses, and is easy to implement. The performance of DSTATCOM with HCC is studied in MATLAB/SIMULINK environment.

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