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Modeling and Individual Voltage balancing Control of Modular Multilevel Cascade Converter

(MMCC-SDBC) -Based STATCOM

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Abstract: *This paper develops a new control method for Modular Multilevel cascade converter-based STATCOM. The MMCC-SDBC is characterized by cascade connection of multiple single phase H-bridge (or full bridge) converter cells per leg, thus facilitating flexible circuit design, low-voltage steps, and low electromagnetic-interference emissions. These Converters have classically been commutated at fundamental line frequencies, but the evolution of power semiconductors has allowed the increase of switching frequencies and power ratings of these devices, permitting the use of pulse width modulation techniques. This paper introduces a new control technique individual voltage balancing strategy, which solves dc bus voltage balancing problems, maintaining the delivered reactive power equally distributed among all the H-bridges of the converter. The proposed model is developed and analyzed using MATLAB/Simulink Software and the simulation results obtained justify the accuracy of proposed control technique.*

Keywords: *Cascaded H-bride, Individual balancing control, Multilevel converter, Static compensator (STATCOM).*

1. INTRODUCTION

A Static compensator (STATCOM) is basically one of the shunt-type FACTS controllers, and DSTATCOMs are the distribution network STATCOMs. There are some variations of the STATCOM, but their composition is basically the same. One STATCOM is composed of one inverter with energy storing capacitors on its dc side, inductances and a coupling transformer on its ac side, and a control system, and it is connected in parallel with the power grid, as shown in Fig. 1.

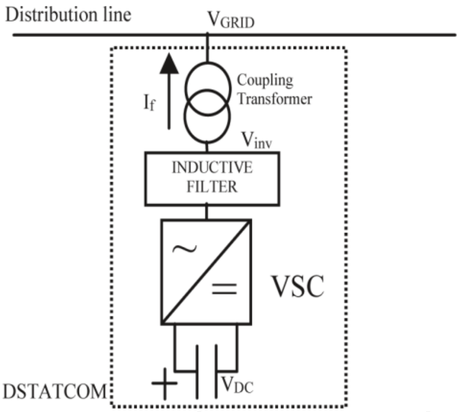

Fig.1. *STATCOM basic structure and vectorial diagram*

The STATCOM controls the reactive-power flow in the electric line, injecting or absorbing it. This reactive-power output of the converter is controlled by varying the amplitude of the output voltage [2].

The evolution of existing power semiconductor switches (GTO, IGBT) and the appearance of new ones (IGCT, IEGT, etc.), combined with the utilization of new inverter topologies, have allowed the increase of power and voltage ratings of electronic converters. This means that, in some cases, even the coupling transformer is not necessary, and the inverter could directly be connected to medium voltage levels [3]. Therefore, in this kind of application, the cascaded H-bridge multilevel topology presents several advantages compared to other multilevel topologies [4]–[6]. Fig. 2 shows one phase of the cascaded H-bridge multilevel converter with N H-bridges that are connected in series. The output phase voltage of $2N + 1$ level could be obtained from this converter. STATCOMs based on the SDBC are paid more attention.

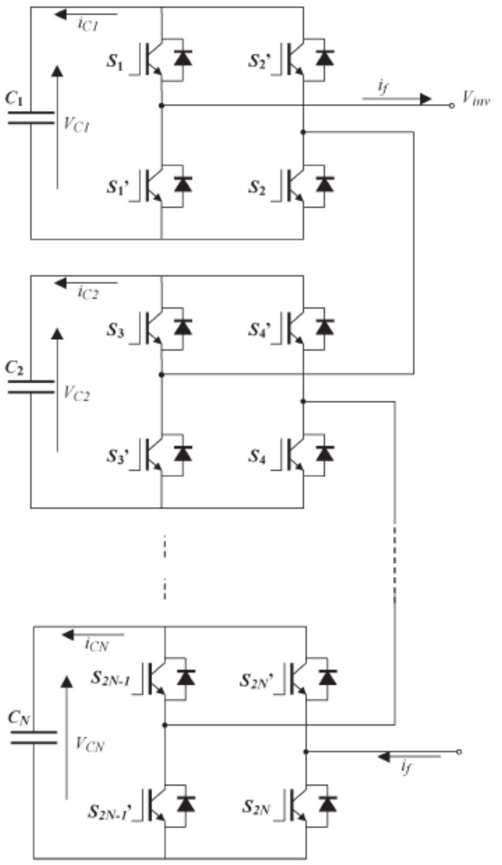

Fig.2. *Single-phase cascaded H-bridge multilevel converter.*

The SDBC seems to be a better choice than the DSCC from a practical point of view because the converter-cell count required for the SDBC is only 1.7 (= √ 3) times of that for the SSBC [1]. Peng and Wang presented a control method of an SDBC-based STATCOM with stair-case modulation, in which the amplitude of each cluster current is determined by offline calculation based on phasor diagrams [7]. This paper develops a MATLAB/Simulink model of an SDBC-based pulse width-modulated (PWM) STATCOM for negative-sequence reactive-power control.

This paper proposes a control method called individual voltage balancing technique that is characterized by forming a feedback loop of the circulating current among the delta-connected clusters, leading to stable dc-mean voltage control of all the dc capacitors. In this paper theoretical equations are derived which are related to ac-voltage fluctuations of each dc capacitor.

2. SDBC-BASED STATCOM

The two kinds of flicker compensators with an SDBC-based STATCOM are shown in Fig 3. The SDBC is characterized by easily increasing the voltage and current ratings without using line frequency converter transformers. Fig. 3(a) shows a 22-kV/33-kV system with a grid transformer. Each cluster of the SDBC is connected in delta configuration via a single coupled inductor. The leakage inductance of the transformer works as ac-link inductors between the grid and the SDBC. Fig. 3(b) shows a 6.6-kV system with no grid transformer. Each cluster of the SDBC is connected via three non coupled inductors. The SDBC can be connected directly to the 6.6-kV grid because the non coupled inductors work as ac-link inductors.

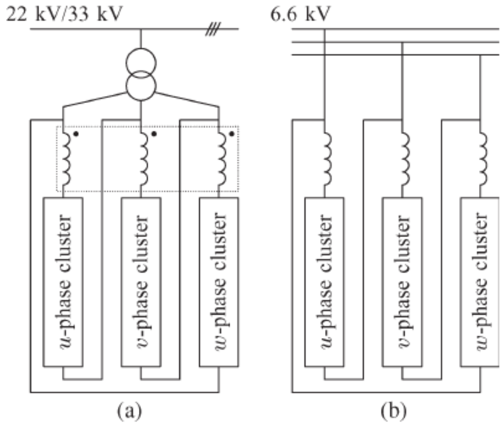

Fig.3. *Flicker compensators with the SDBC-based STATCOM. (a) 22-kV/33-kV system with a grid transformer. (b) 6.6-kV system with no grid transformer.*

The detailed circuit configuration of the 100-V 5-kVA STATCOM is shown in Fig 4. Each cluster of the SDBC consists of cascade connection of three bridge cells (i.e., single-phase full-bridge PWM converters), and the three clusters are connected in delta configuration via a single coupled inductor *L*. The SDBC is connected to a three-phase ac mains of 100 V (line to line in rms) via a three-phase ac-link inductor *LS* that corresponds to the leakage inductance of the grid transformer in Fig. 3(a). Here, *vuv*, *vvw*, and *vwu* are the cluster voltages, *iuv*, *ivw*, and *iwu* are the cluster currents, and *p* and *q* are the instantaneous active and reactive powers at the PCC. The following relations exist between the compensating currents and the cluster currents:

$$iu = iuv - iwu \quad iv = ivw - iuv \quad iw = iwu - ivw. \qquad (1)$$

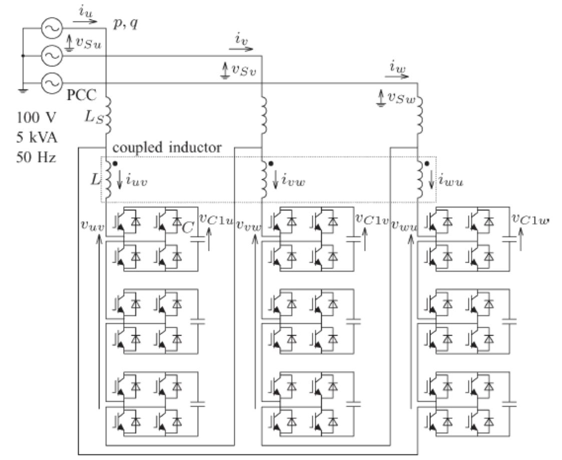

Fig.4. *The Circuit configuration of 100-V 5-kVA PWM STATCOM.*

3. CONTROL TECHNIQUE OF THE MMCC-SDBC

Voltage control of the nine floating dc capacitors in Fig. 4 can be divided into the following:

1) cluster-balancing control;

2) circulating-current control;

3) individual-balancing control.

Individual-Balancing Control

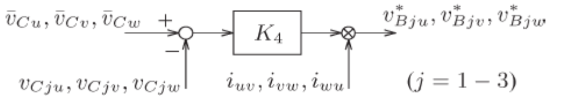

Fig.5. *Block diagram of Individual-balancing control.*

The Fig. 5 shows the block diagram of the individual balancing dc-capacitor voltage control. It forms an active power between the ac voltage of each bridge cell and the corresponding cluster current [21]. The voltage commands are given by the following expressions.

$$\begin{aligned} v^*_{Bju} &= K_4(\bar{v}_{Cu} - v_{Cju})i_{uv} \\ v^*_{Bjv} &= K_4(\bar{v}_{Cv} - v_{Cjv})i_{vw} \\ v^*_{Bjw} &= K_4(\bar{v}_{Cw} - v_{Cjw})i_{wu}. \end{aligned} \tag{2}$$

The Fig. 6 shows the block diagram of the implementation of this active-power distribution control strategy for dc-bus voltage balancing. It has to be remarked that the balancing strategy could ideally work with any modulation strategy, regardless of the switching frequency.

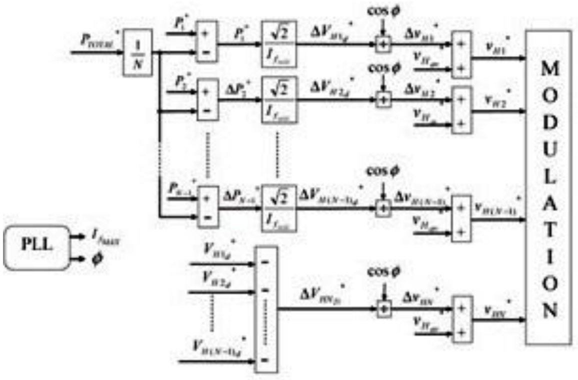

Fig. 6. *Voltage balancing strategy block diagram.*

If the STATCOM output voltage is equally divided among all the H-bridges, the active power that is delivered by each H-bridge would be the same and equal to the average output power P_{HAV} , where

$$P_{\mathrm{H_{AV}}} = \frac{1}{N} \cdot P_{\mathrm{TOTAL}}. \tag{3}$$

The reason for this identical active-power distribution is that the output-voltage vectors of the series-connected H-bridges are identical; therefore, the *d*-axis projection of these vectors would also be identical and equal to the average value

$$V_{\mathrm{Hd_{AV}}} = \frac{1}{N} \cdot V_{\mathrm{Hd}}. \tag{4}$$

If the particular active-power reference of each H-bridge is different from the average active power that is calculated in (3), the *d*-axis component of the H-bridge output voltage should also be different from the average voltage that is calculated in (4). The active power that is delivered by each H-bridge is equal to

$$P_i = V_{\mathrm{H}_i d} \cdot I_f = (V_{\mathrm{Hd_{AV}}} + \Delta V_{\mathrm{H}_i d}) \cdot I_f = P_{\mathrm{H_{AV}}} + \Delta P_i. \tag{5}$$

Therefore, the output voltage reference of this particular H-bridge should be modified to achieve the required active power. This modification has to be done by modifying only the *d*-axis component of the output voltage so that only the active power that is delivered by the H-bridge, and not the reactive power, is modified

$$\Delta V^*_{\mathrm{H}_i d} = \frac{P^*_i - P^*_{\mathrm{H_{AV}}}}{I_f} \tag{6}$$

for $i = 1, 2 \ldots (N - 1)$.

The total output voltage of the STATCOM device must remain the same to maintain the total active and reactive powers that are supplied to the grid. Therefore, the total variation of the voltage reference must be zero

$$\sum_{i=1}^{N} \Delta V_{H_i d} = 0. \tag{7}$$

Therefore, for the Nth H-bridge

$$\Delta V_{H_N d} = -\sum_{i=1}^{N-1} \Delta V_{H_i d}. \tag{8}$$

4. MATLAB MODELING OF MMCC-SDBC

The Simulink model of Single H-bridge converter using MATLAB SimPowerSystems tool is shown is shown in Fig. 7.

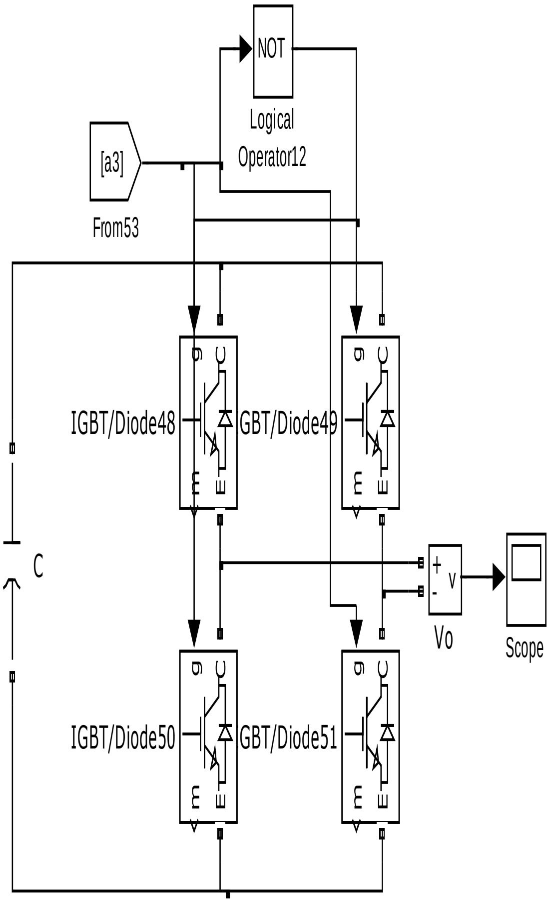

Fig.7. *Simulink block diagram of H-bridge Converter*

And also the Simulink model for generation of pulses for one H-bridge is shown in Fig.8.

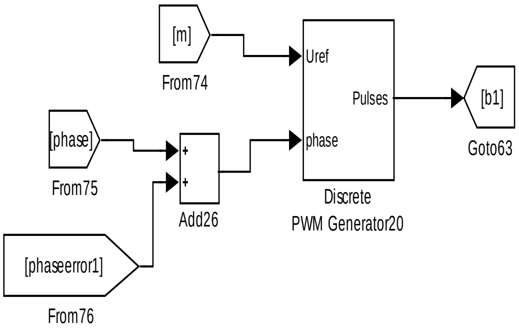

Fig.8. *Simulink block diagram of pulse generator*

The Simulink model of proposed Modular Multilevel cascaded converter for one phase is shown in Fig. 9.

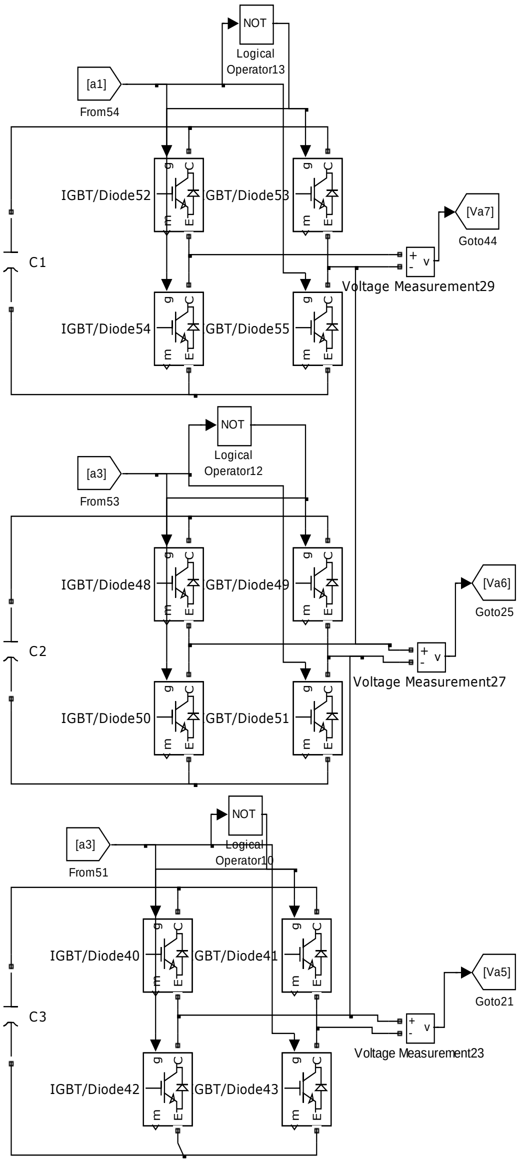

Fig. 9. *Simulink block diagram of MMCC for One phase.*

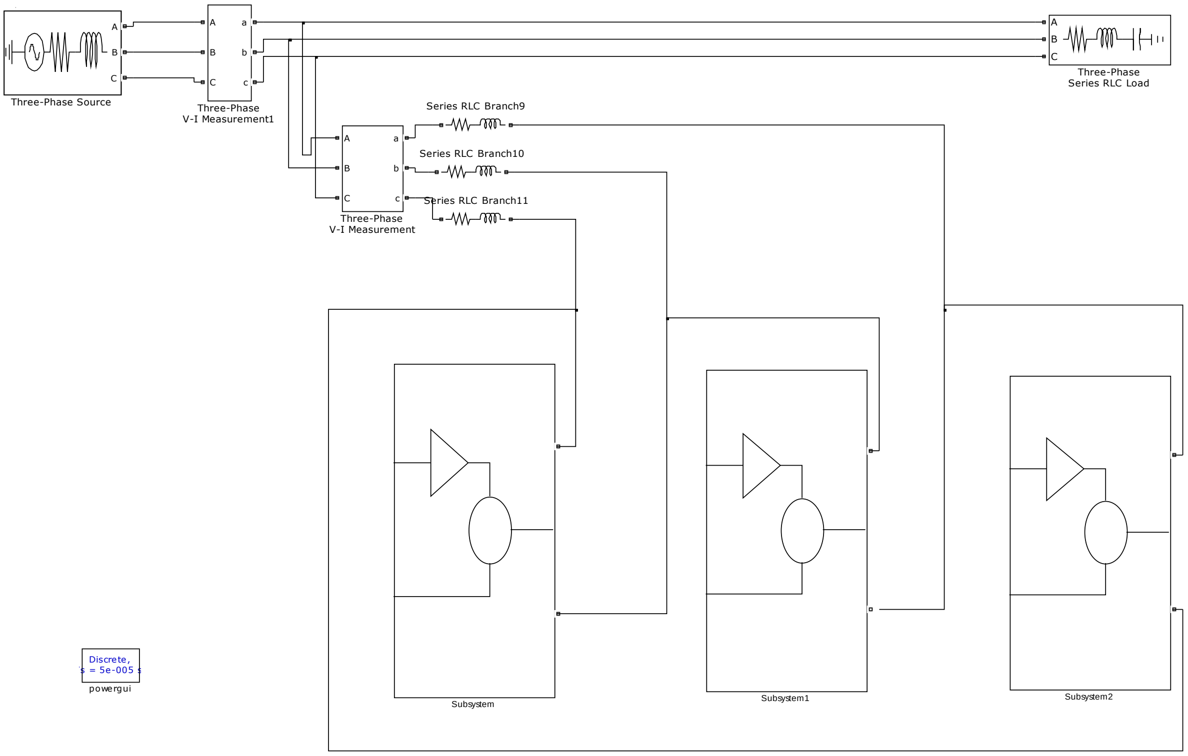

Fig.10. *Simulink block diagram of Modular Multilevel Cascaded Converter in Single delta bridge configuration (MMCC-SDBC) as STATCOM.*

The complete Simulink model for proposed Modular Multilevel Cascaded Converter with Single delta bridge configuration is shown in Fig 10. And the developed Individual voltage balancing technique is modeled using MATLAB as shown in Fig 11.

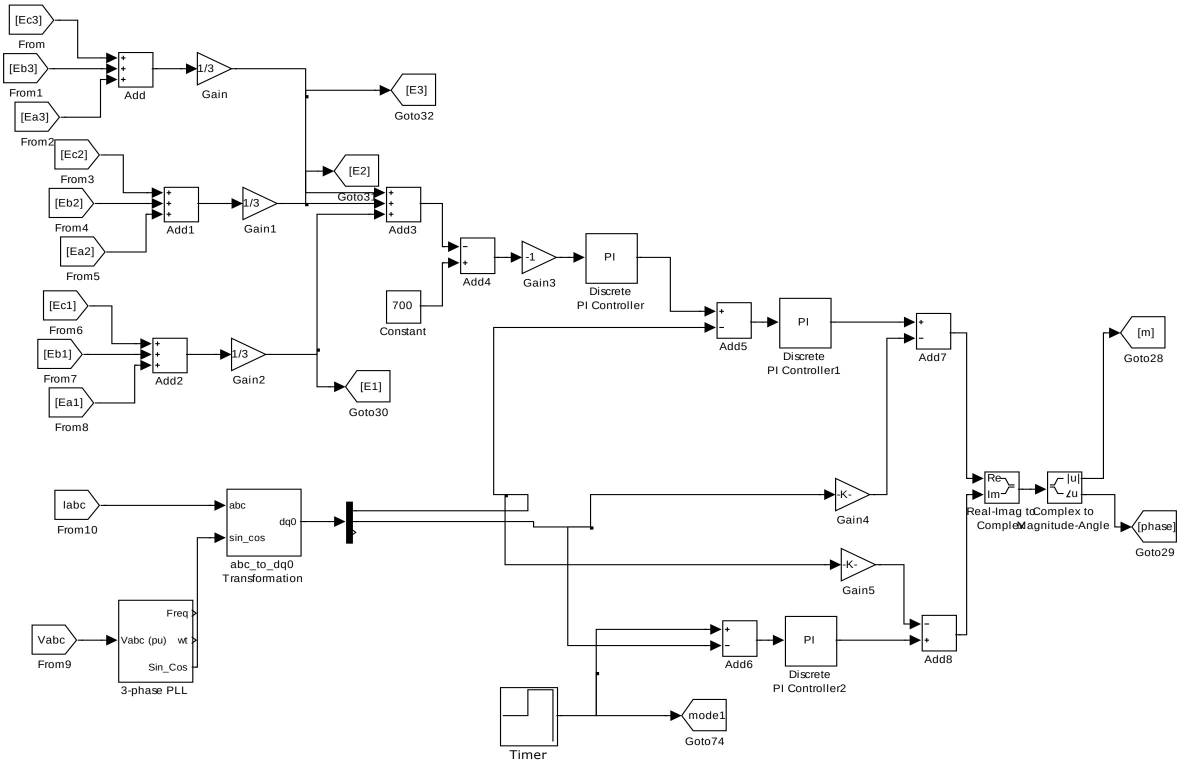

Fig. 11. *Simulink block diagram of proposed Individual voltage balancing technique.*

5. SIMULATION RESULTS

The three phase output voltage waveform of Modular Multilevel cascaded converter as a STATCOM is shown in Fig 12.

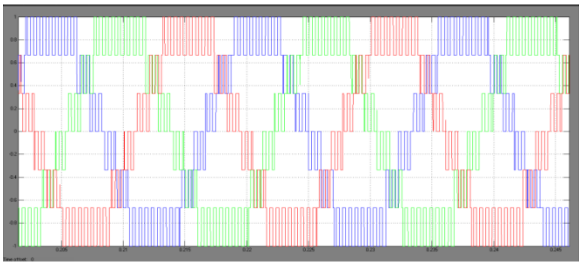

Fig.12. *Simulation output three phase voltage Vabc of STATCOM*

The RMS voltage output voltage waveform of a SATCOM is shown in Fig 13.

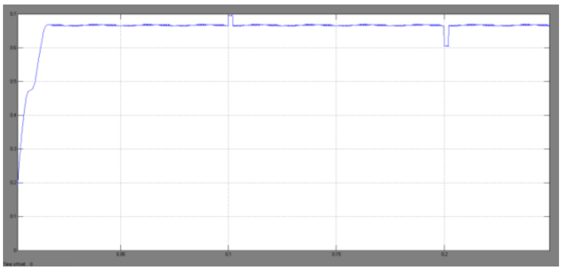

Fig.13. *Simulation RMS output voltage waveform Vrms of SATCOM*

The seven level output line voltage waveform of a STATCOM and output line current of STATCOM for phase A is shown in Fig 14.

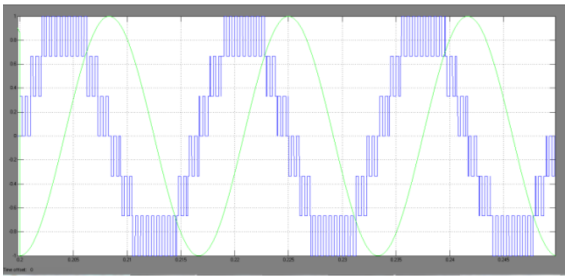

Fig.14. *Simulation output voltage waveform of Va And Ia*

The active power output waveform of MMCC-SDBC based STATCOM connected to the supply system is shown in Fig 15.

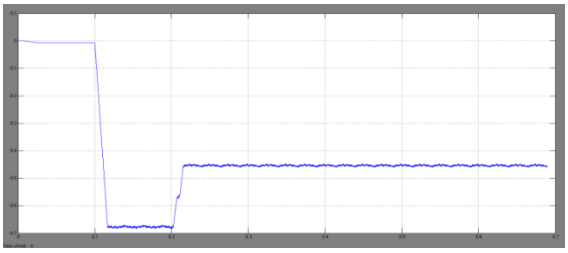

Fig. 15. *Simulation waveform of Active output power of STATCOM*

The output direct axis current waveform of STATCOM is shown in Fig 16.

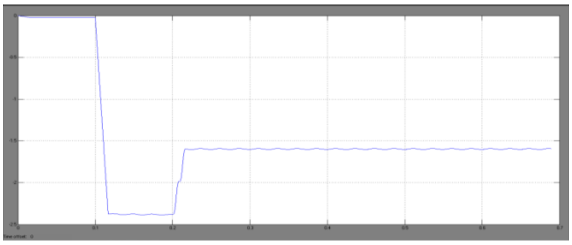

Fig.16. *Simulation waveform of direct axis current of STATCOM*

6. CONCLUSION

In this paper a MATLAB/Simulink model for Modular Multilevel Cascaded Converter with Single delta configuration (MMCC-SDBC) based SATCOM using SimPowerSystems tool is developed. The proposed Individual Voltage Balancing control strategy, which is adequate for PWM techniques and by this control strategy, the reactive power that is supplied by the STATCOM to the grid is regulated, and the reactive power that is supplied by each one of the series-connected H-bridges is maintained identical. And the proposed control strategy has been simulated and observed the obtained simulation results in all cases. The dc-bus voltages are kept balanced in all the circumstances, and the reactive power that is delivered by the STATCOM is equally distributed among all the H-bridges. Hence the cascaded H-bridge multilevel topology is shown as one of the more suitable topologies for the reactive-power compensation applications.

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