

# Fault Ride-Through Capability of Modular Multilevel Converter Based STATCOM

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**Abstract:** The modular multilevel converter (MMC) has become the competent topology for medium and high power applications. The striking features of MMC are superior harmonic performance, reduced losses, modularity, flexibility in converter design and fault handling capability. This paper proposes a MMC based static synchronous compensator (M-STATCOM) with focus on fault ride through capability. The M-STATCOM system is subjected to symmetrical and asymmetrical ac network faults. The proposed system is capable of reactive power compensation, harmonic cancellation, fault tolerant operation and simultaneous load balancing. Simulations are conducted in MATLAB/Simulink environment to evaluate the M-STATCOM performance.

**Key words:** Fault ride through capability, Flexible ac transmission systems, Modular multilevel converter, Reactive power compensation, STATCOM

## I. INTRODUCTION

The increased development of power electronics technology and focus on renewable energy power generation leads to significant changes in power system operation. The intermittent nature of renewable energy sources may cause frequency and voltage instability increasing power quality problems featured with harmonic distortion, low power factor, and phase imbalances to the utility grids. The compensation of the non linear loads without affecting the normal operation of the power system is of major concern. Flexible AC transmission systems (FACTS) opens up the new opportunities for controlling power and enhancing the usable capacity of present as well as new and upgraded lines. The static synchronous compensator (STATCOM) is one of the crucial FACTS controllers which can provide flexible control to mitigate power system disturbances. Converters presently employed in FACTS controllers are the voltage sourced type, but current sourced type converters may also be used. The major reasons for the preference of the voltage sourced converter are: (1) Current sourced converters require power semi conductor devices with bi directional blocking capability. (2) Practical current source termination of the converter dc terminals is much lossier than voltage source termination. (3) The voltage source termination tends to provide an automatic protection of the power semiconductors against transmission line voltage transients. Current sourced converters may require additional over voltage protection or higher voltage rating for the semiconductors [1, 2].

Voltage sourced converters are broadly classified as: (1) Diode clamped multilevel converter (2) Flying capacitor multilevel converter (3) Cascaded multilevel converter. The diode clamped multilevel converter has some drawbacks such as excessive use of clamping diodes, difficulty in controlling the real power flow and diode reverse recovery of clamping diodes would become a major design challenge in high power applications. The flying capacitor multilevel converter suffers with drawbacks of excessive number of storage capacitors, inverter control can be very complicated and switching losses are high for real power transmission. The cascaded multilevel converters are capable of attaining desired voltage levels with less number of components. The only disadvantage of this topology is the need for separate dc sources thus limiting its applications [3]-[9]. The modular multilevel converters have emerged as next generation converter for high power applications. The striking features of MMC are modular structure, transformerless operation, fault tolerant operation, utilization of standard components and excellent quality of output voltages with low harmonic distortion [10-11]. Hence the industry has chosen MMC to deal with high power applications. They provide a reliable solution to build STATCOM eliminating the use of coupling transformer and enabling the power exchange with the power system. In addition, it can operate under unbalanced conditions such as during symmetrical and unsymmetrical faults thus avoiding the power system collapse [12].

This paper is outlined as follows. Section II deals with basic structure of MMC and its dynamics. The simulation results are discussed in section III. The conclusion is presented in section IV.

## II. MMC DYNAMICS

### A. Basic Structure of MMC

Fig. 1 shows the schematic diagram of three phase MMC. Structurally, a modular multilevel converter is the cascaded connection of number of identical submodules (SMs). A three phase MMC consists of three legs which in turn consists of two arms: upper arm and lower arm. Each arm consists of N number of series connected sub modules and an arm inductance  $L_{arm}$ . The sub modules are the building blocks of MMC. Each sub module consists of a half bridge configuration and a sub module capacitance. The output voltage of the submodule depends on the states of its upper

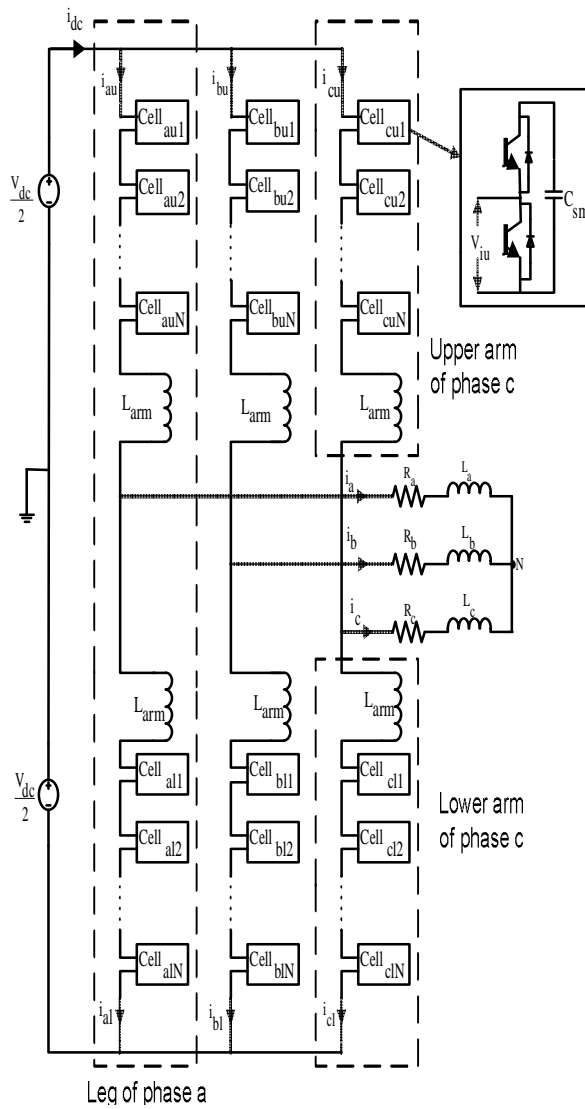


Fig.1: Schematic of three phase MMC

power switch and lower power switch. When the upper switch is turned ON, the lower switch is turned OFF, the capacitor is inserted into the arm and the output voltage of the submodule is the capacitor voltage; when the lower switch is turned ON, the upper switch is turned OFF, then the capacitor is bypassed and the output voltage becomes zero. Based on this equivalence, the output voltage of the whole arm is the sum of the output voltages of the  $N$  submodules within the arm [13-14].

**B. M-STATCOM Configuration**

Fig. 2 represents the MMC-STATCOM configuration which provides power system stability under contingency conditions. Fig. 3 represents the equivalent model of MMC for a single phase (say 'a'). The SMs in each arm can be regarded as controlled voltage sources, and they are connected in series to form a controlled voltage source with upper and lower arm voltages as  $V_{au}$  and  $V_{al}$  respectively.  $V_{dc}$

and  $I_{dc}$  are dc-link voltage and current.  $i_{au}$  and  $i_{al}$  are upper and lower arm currents.  $V_a$  is the ac output voltage of phase a [15]-[19].

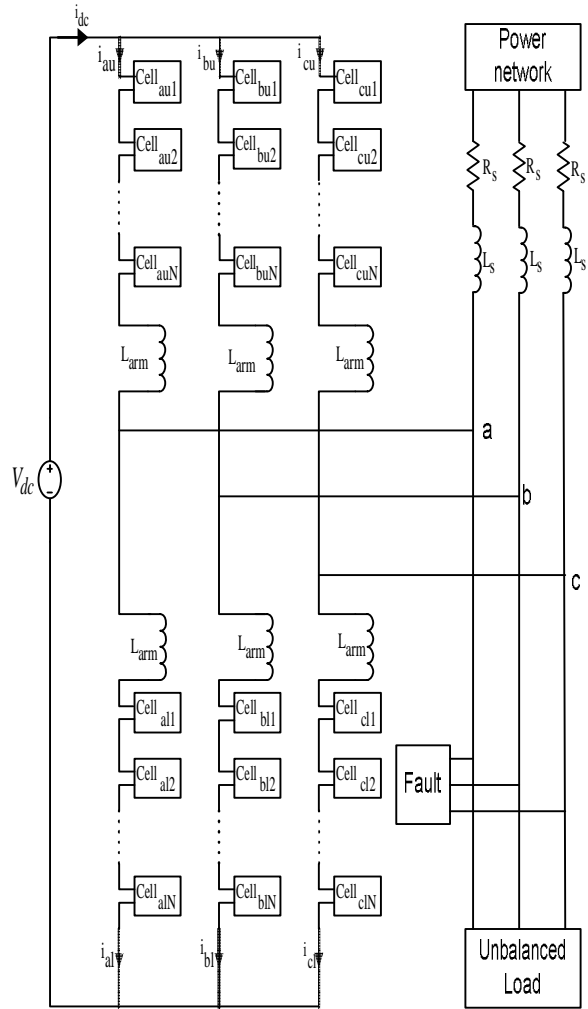


Fig.2: MMC-STATCOM configuration

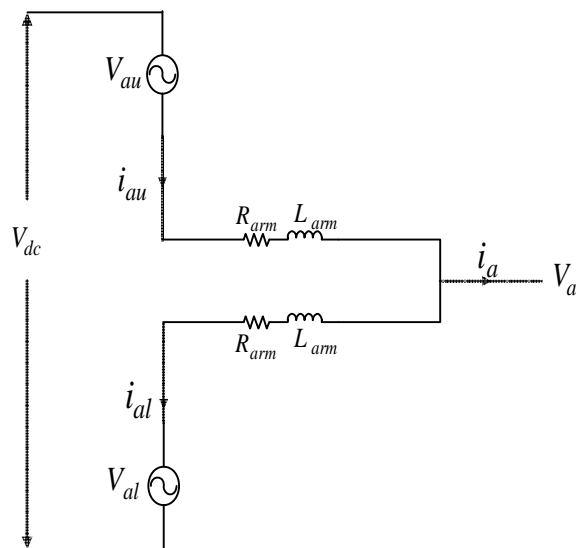


Fig. 3: Equivalent model of MMC for phase a

1) Voltage/Current control at AC side

Applying the kirchoff's voltage law (KVL) to the converter arms of phase a in Fig. 3 yields:

$$\left. \begin{aligned} \frac{V_{dc}}{2} &= V_{au} + L_{arm} \frac{di_{au}}{dt} + R_{arm} i_{au} + V_a \\ \frac{V_{dc}}{2} &= V_{al} + L_{arm} \frac{di_{al}}{dt} + R_{arm} i_{al} - V_a \end{aligned} \right\} (1)$$

According to kirchoff's current law, the phase current is given by:

$$i_a = i_{au} - i_{al} \quad (2)$$

Defining a control variable as:

$$V_{a1} = \frac{1}{2}(V_{au} - V_{al}) \quad (3)$$

On solving (1), (2) and (3) the system eq. on AC side can be obtained as:

$$\frac{1}{2}(L_{arm} \frac{di_a}{dt} + R_{arm} i_a) = -V_a - V_{a1} \quad (4)$$

From (4), it can be concluded that the ac side voltage and current can be controlled by controlling the arm voltages.

2) Voltage/Current control at DC side

The circulating current flowing in the upper arm and lower arm is given by:

$$i_{cir} = \frac{i_{au} + i_{al}}{2} \quad (5)$$

Defining a control variable as

$$V_{a2} = \frac{1}{2}(V_{au} + V_{al}) \quad (6)$$

On solving (1), (5) and (6) the system eq. on DC side can be obtained as:

$$L_{arm} \frac{di_{cir}}{dt} + R_{arm} i_{cir} = \frac{1}{2} V_{dc} - V_{a2} \quad (7)$$

From (7), it can be concluded that average power at dc side is controlled by controlling the circulating current and the arm voltages. The circulating current relates to the power loss and must be properly controlled.

C. Control strategy of M-STATCOM

Fig. 4 represents the control strategy of the proposed M-STATCOM configuration. The voltage command  $v_r^*$  is the system load voltage under healthy conditions. It is compared with the load voltage  $V_r$  under fault conditions and the error is processed through a PI controller. The output of the PI regulator is denoted as  $V_{ref}$  which acts as the reference signal for pulse generation. In order to generate the pulse pattern for M-STATCOM, phase disposition pulse

width modulation (PDPWM) is employed. This technique is simplest of all the PWM techniques and it provides load voltage and current with lower harmonic distortion.

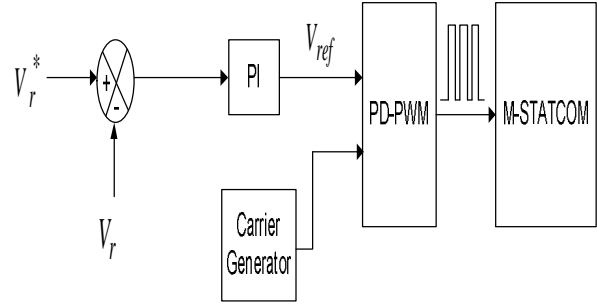


Fig. 4: Control strategy of M-STATCOM

In this method all the carriers above and below the zero reference line are in same phase. The carriers are generated accordingly by using carrier generator. The reference signal is positioned at the centre of the carrier set and continuously compared with the carriers. At every instant, whenever the magnitude of reference wave is greater than a carrier wave the output goes to 1 and a positive ongoing pulse is generated. As the reference falls below each carrier the output goes to 0 and a negative ongoing pulse is generated. These pulses act as the gating signals of switches in MMC [20].

III. SIMULATION STUDY

The proposed M-STATCOM is simulated in MATLAB/Simulink. Fault ride-through capability can be defined as the ability of the converter to withstand different types of faults. The system is tested for symmetrical fault, unsymmetrical fault and with combination of linear and non linear loads to prove the fault ride-through capability of the converter. The parameters of the test system are presented in table I.

Table I. Specifications of proposed system

|                               |        |
|-------------------------------|--------|
| Power capacity                | 5MVA   |
| Line to Line RMS voltage      | 25KV   |
| Source inductance             | 200μH  |
| Source resistance             | 25mΩ   |
| Number of sub modules per arm | 2      |
| Arm inductance                | 2.5mH  |
| Sub module capacitance        | 3.6mF  |
| Fundamental frequency         | 50Hz   |
| Carrier Frequency             | 1050Hz |

Case I: Symmetrical fault

In this case, the proposed M-STATCOM system is subjected to three phase symmetrical fault. The fault is applied between the interval of 0.1s-0.2s. Fig. 5 represents the load voltage and load current without any compensation. It can be observed during the fault condition the voltage and current dropped to very low value. Fig. 6 represents the simulated waveform of active and reactive power. During the fault, the active power and reactive power are suddenly declined resulting in power system collapse.

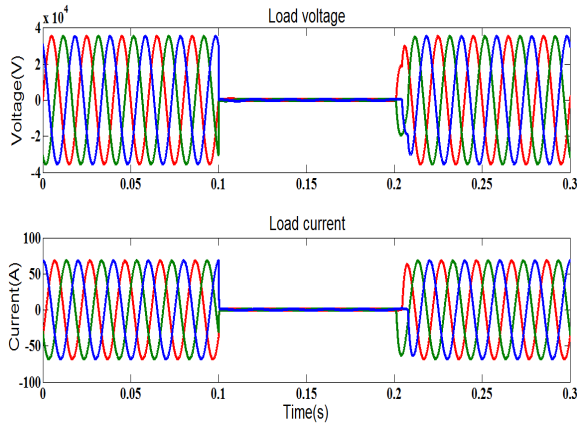


Fig. 5: Simulated waveforms of load voltage and load current without compensation

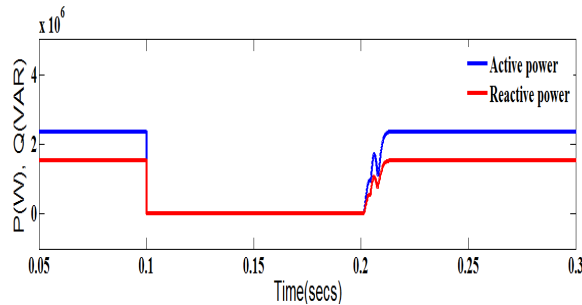


Fig. 6: Simulated waveforms of active power and reactive power without compensation

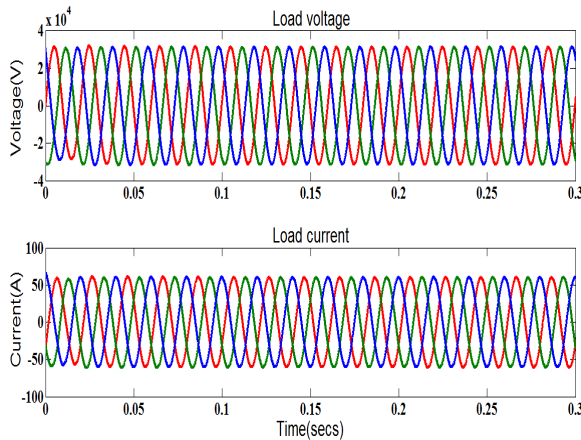
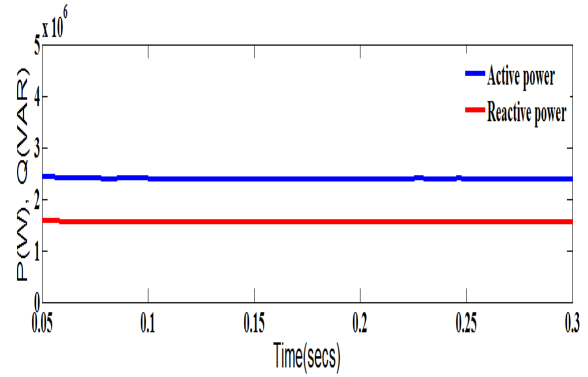


Fig. 7: Simulated waveforms of load voltage and current with compensation



Case II: Unsymmetrical fault

In this case, the proposed M-STATCOM is subjected to unsymmetrical fault (L-G fault). Fig. 9 represents the simulated waveforms of voltage and current without compensation. Since it is an L-G fault, the voltage collapse can be observed in one phase only (phase a). The load currents are of unequal magnitude during the fault. Fig. 10 shows the simulated waveforms of active power and reactive power. During the fault, the power oscillations are predominant in the system which is of power quality concern. In order to compensate the voltage collapse, the STATCOM suitably injects the reactive current. Fig. 11 demonstrates the load voltage and current with compensation and it can be observed that the load voltages and currents are well balanced even in the event of fault. Fig. 12 represents the active and reactive power exchanges with the ac network.

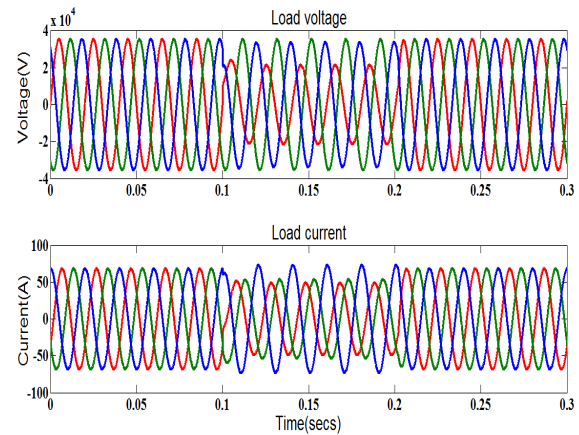


Fig. 9: Simulated waveforms of load voltage and load current without compensation

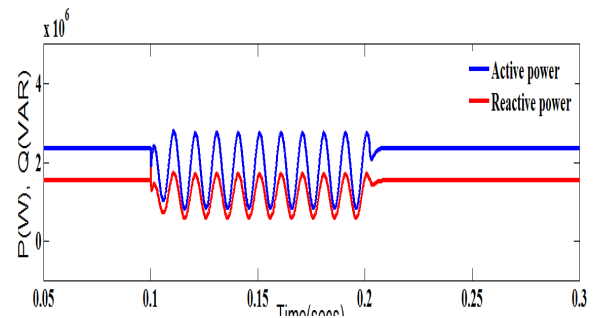


Fig. 10: Simulated waveforms of active power and reactive power without compensation

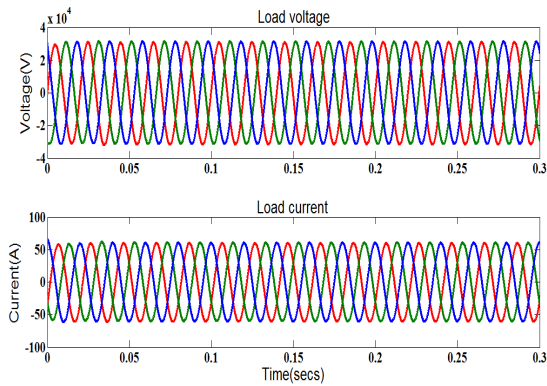


Fig. 11: Simulated waveforms of load voltage and current with compensation

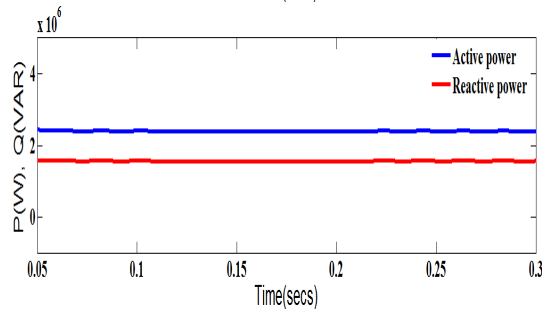


Fig. 12: Simulated waveforms of active power and reactive power with compensation

Case III: Simultaneous load balancing

In this case, the proposed M-STATCOM is operated under varied load conditions. With rapid development and progress of power electronics technology, some of the industrial loads such as AC traction systems, electric arc furnaces, three phase rectifiers etc. cause power quality problems such as phase imbalances, harmonics, low power factor. All these detrimental effects challenge the stability and reliability of power system network. A compensating device should be capable of controlling the power system parameters even in such contingency conditions. To examine the transient performance of M-STATCOM a combination of linear and non linear loads are connected at the load terminals and the system is subjected to three phase fault.

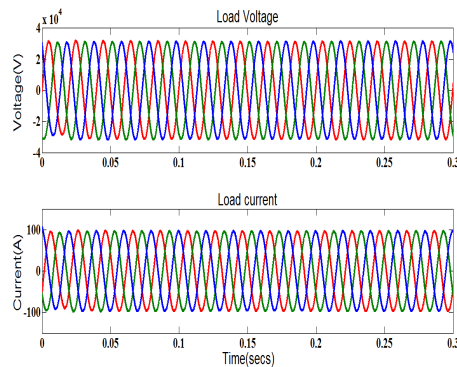


Fig. 13: Simulated waveforms of voltage and current under varied load conditions

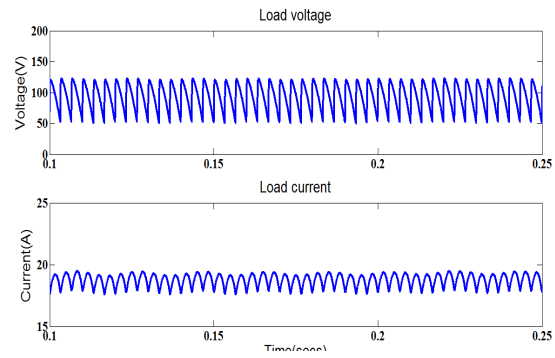


Fig. 14: Simulated waveforms of load voltage and load current of three phase rectifier for  $\alpha=30^\circ$

The connected load is composed of an RL load with  $R=300\Omega$  and  $L=50mH$ , an RC load with  $R=500\Omega$  and  $C=50\mu F$  and a rectifier load with  $V_{RMS}$  as 200V. Fig. 13 represents the simulated waveforms of voltage and current under varied load conditions when the system is subjected to three phase fault. In order to confirm the viability of the M-STATCOM, the simulated waveforms of load voltage and current of three phase rectifier for firing angle of  $30^\circ$  has been presented in Fig. 14. The results reveal that the M-STATCOM can achieve simultaneous load balancing.

IV. CONCLUSION

In this paper, a modular multilevel converter based STATCOM has been presented. Due to its notable features, MMC has already made its way in medium/high voltage power systems and industrial applications such as HVDC and FACTS. A brief description of basic structure of MMC, M-STATCOM configuration and its control strategy has been presented. The M-STATCOM system is subjected to symmetrical and unsymmetrical ac network faults and the results demonstrate that the proposed system has fault ride-through capability. Furthermore, the M-STATCOM is tested under varied load conditions and the results convey that it can achieve simultaneous load balancing.

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