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Performance Analysis of MMC Based Static Compensator with Equivalent Model

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Abstract— ***In Continuous development of power electronics converters and hence the control and modeling methods for the converters has been a very active and interesting research topic. Comparing with the traditional two level voltage source converter configurations, the modular multilevel converter is being considered as the preferred VSC technology used in the application of the high power. To reduce the total harmonic distortion, number of modules in modular multilevel converters is increased. Hence, the performance analysis of the modular multilevel converter based system become time consuming on any simulation platform. In this paper the performance analysis of MMC based static compensator with mathematical model and dq-control is presented with reduced simulation time using the simulation on the PSCAD software.***

Keywords—Modular Multilevel Converter, Mathematical Model, DQ Control, Simulation Time.

I. INTRODUCTION

Use of power electronics converters is increasing day by day in power and energy system. From the long time high voltage power transmission system is working on the alternating current system [1], [2]. There are some benefits of the high voltage DC transmission system like; lower transmission loss, the capacity to transfer additional power over the same right of way and the ability to interconnect system that is not synchronized or use of different frequencies [3].

The advantages of the power electronics converter in power transmission system may be cancelled by the cost associated with converters stations as well as the losses created by the switching elements required to invert or the rectify the power at the each end of the DC transmission system [4]. The new configuration of IGBT devices which is based on the voltage source converter (VSC) is modular multilevel converter (MMC) which has been advanced and presents the multiple benefits over the conventional two-level and line commuted power electronics converters [4].

In comparison with traditional converters, there are some benefits of the modular multilevel converters like; higher capacity and flexibility to incorporate multiple units, related to conventional two-level voltage source converters it has lower switching frequency by increasing numbers of modules and hence, the output waveforms have lower harmonic distortion and lower losses of the converter, and improved reliability as the converter can function even when some switches or capacitor in the module experiences a problem [5].

Because of higher number of levels in the output the need for filter banks is reduced and hence space and cost is reduced. No reliance on huge inductances to force current continuity during switching as it is required for the commutation of current source converters. In some cases the requirement for expensive transformer is removed [5].

The advantages of the modular multilevel converter can make a smart option and may help to improve the weaknesses of traditional converters in the modern power transmission system. The dynamic performance especially for the converters which is constructed with a huge number of modules must be studied using simulation before the converter can be fully deployed in a large scale application [4].

Modular multilevel converters used in high power applications have large number of modules. Therefore for doing the analysis of these converters in simulation software will increase the time. Hence to reduce the time of simulation for the MMC with high number of modules, equivalent modules of the converter can be used. Various equivalent models for MMC are used by many researchers to reduce the time of simulation and hence the analysis can simplified. In this paper performance of MMC based static compensator with equivalent model is investigated and the results are compared with actual model.

II. MODULAR MULTILEVEL CONVERTER

The key conception behind the modular multilevel converter is to use the floating capacitors as a base of voltage injections [7]. These floating capacitors are connected or disconnected (coming in or going out) using a switching circuitry to generate the required output voltage level. The module of MMC which is the basic building block of the converter is shown in Figure 1.Depending on the dimension of the converter, each separate module is composed of the similar basic elements: two IGBTs with anti-parallel diode and a capacitor. An antiparallel thyristor is also used to protect the diode switches from the large current experienced during a DC-side fault, until the circuit breaker is opened [8].

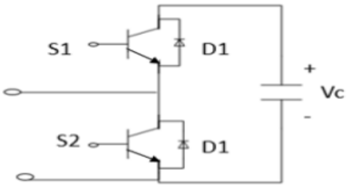

Figure 1: Single module of MMC converter

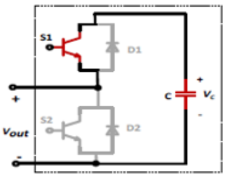

Figure 2(a): MMC Module Mode-1

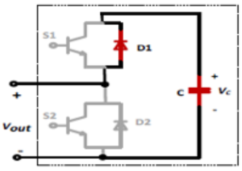

Figure 2(b): MMC Module Mode-2

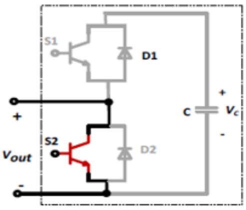

Figure 2(c): MMC Module Mode-3

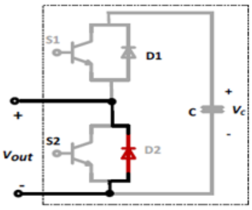

Figure 2(d): MMC Module Mode-4

As shown in the Figure 2 in the each module has four individual states [5]:

1. In the first mode the current is flowing from negative to positive terminal and the submodule capacitor is put in the arm by closing the upper switch.
2. In the second mode the current is flowing from negative to positive terminal and the capacitor is put in the arm by opening the lower switch (the antiparallel diode with upper switch ensures the insertion of capacitor).
3. In the third mode the current is flowing from negative to positive terminal and the capacitor is bypassed by closing the lower switch.
4. In the last mode the current is flowing from positive to negative terminal and the capacitor is bypassed by opening the upper switch (the antiparallel diode with lower switch ensures the bypass of capacitor).

The modular multilevel converter is a variety of voltage source converter, therefore the general theory and operation principles of conventional VSCs applies to it. The structure of five level three phase MMC is shown in Figure 3. While, traditional VSCs used in high power applications, the switches are connected in series and must be gated concurrently, the structure of MMC permits series connected module to operate individually. From the dc side, all three phase legs are shown to be a parallel connection of three voltage sources.

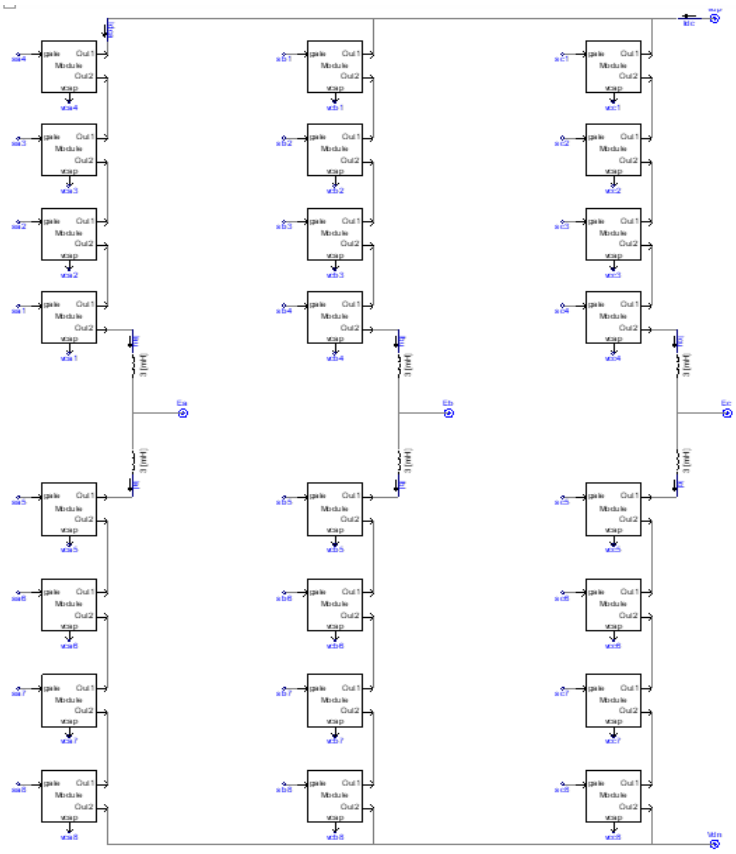

Figure 3: Five level three phase modular multilevel converter

The modules in the arm are connected or bypassed based on the modulation and balancing control method. To ensure balance capacitor voltages and hence the stable operation of converter, energy should be uniformly distributed which can be achieved by capacitor balancing algorithm. The sinusoidal pulse width modulation (SPWM) is one of the popular methods used for the voltage source converters. Basic principle of SPWM is represented in Figure 4. If the triangular signal is smaller than the required signal then the resulting command is zero. If the triangular signal is larger than the required signal then the command high. The resulting signal is a series of the pulses of varying duration as shown in Figure 4.

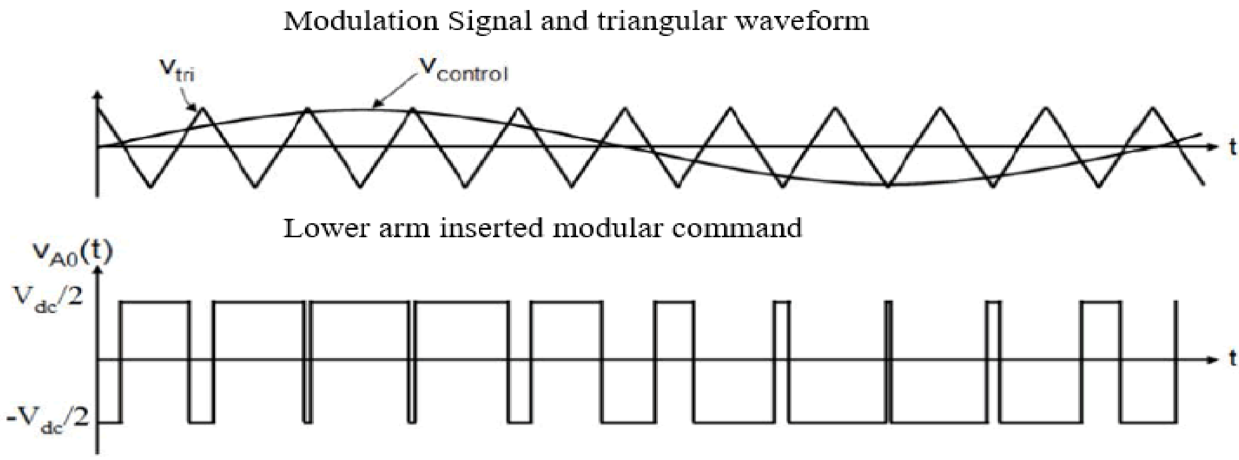

Figure 4: Representation of SPWM method

III. MMC EQUIVALENT MODEL

The MMC is a preferred voltage source configuration for HVDC transmission system. Due to higher voltage levels in HVDC system the number of modules used will be very high and hence large number of semiconductor switches and capacitors are used in the converter. The large number of devices make the analysis of the MMC based system very complex in simulation software. Hence, equivalent models of converters are preferred for the simulation to reduce the time. [10]-[13]. In this work, the analysis of MMC based static compensator is done using detailed equivalent models proposed in [10]. In this approach, the semiconductor switches are treated as two-state resistance and the capacitor is modeled as a voltage source in series with a resistance using trapezoidal integration. Using this concept the FORTRAN script is written in PSCAD software for all modules of each arm.

IV. PSCAD SIMULATION

The simulation of the standalone MMC and MMC based static compensator are carried out in PSCAD/EMTDC using actual model and the equivalent model to compare the performance of both the models. The simulation parameters of the MMC are shown in Table 1. The PSCAD simulation model of standalone MMC is shown in Figure 5 and configuration of module is shown in Figure 6. The equivalent model of MMC is shown in Figure 7. This model is implemented by writing FORTRAN script for each arm. The output generated by script is given to the controlled voltage of the arm. The number of output voltage level of the converter will be N+1 where the N is a number module in the arm. The simulated model of the MMC incorporates the SPWM technique and bubble sort algorithm for the switching and voltage balancing purpose respectively. The capacitor voltage balancing block is shown in Figure 8. The balancing of the capacitor voltage is achieved by connecting or bypassing appropriate module based on current through an arm. It can be either positive (charging the capacitors) or negative (discharging the capacitors). This creates 4 possible operation cases.

1. The current in the arm is positive and a module is to be bypassed. In this case, the module with the highest voltage level should be bypassed.
2. The current in the arm is positive and a module is to be injected. In this case, the module with the lowest voltage level should be injected.
3. The current in the arm is negative and a module is to be bypassed. In this case, the module with the lowest voltage level should be bypassed.
4. The current in the arm is negative and a module is to be injected. In this case, the module with the highest voltage level should be injected.

Table 1: MMC Parameters

DC Side Voltage	9 Kv
Converter Parameters	No of Modules in a phase = 8
	Capacitance of module = 1900 μF
	Arm Inductance = 3 mH
	Switching Frequency = 1 kHz
Load	Resistance = 15 Ω
	Inductance = 83 mH

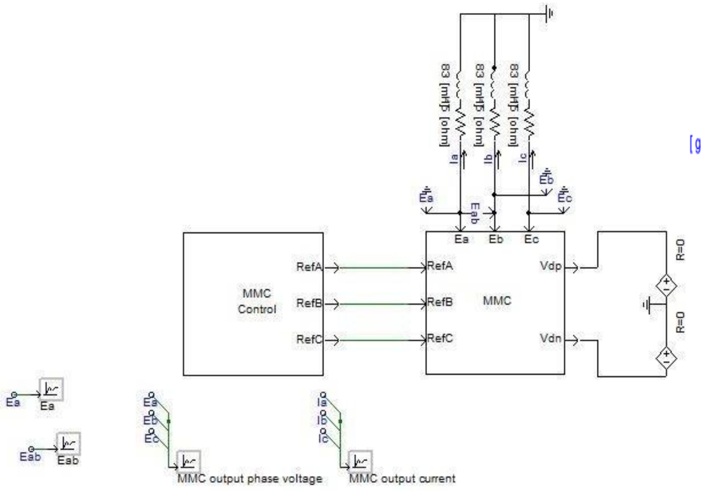

Figure 5: PSCAD simulation model of standalone MMC

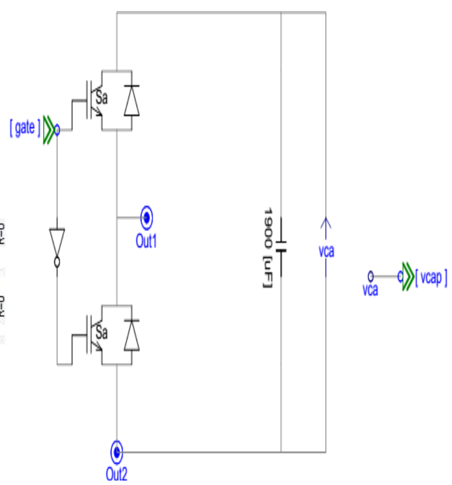

Figure 6: Module of MMC

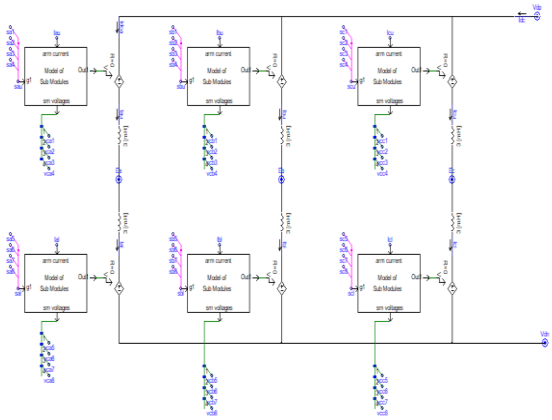

Figure 7: Equivalent model of MMC.

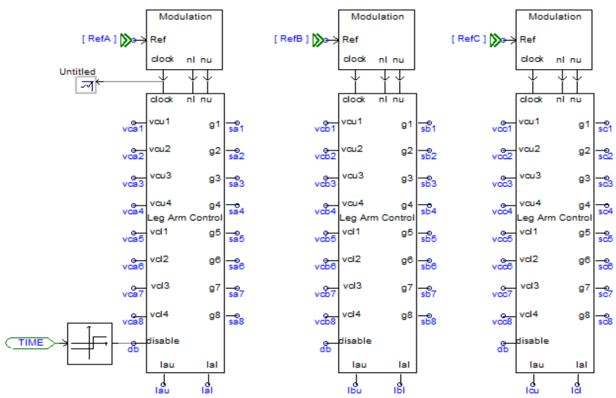

Figure 8: MMC capacitor voltage balancing block

The simulated result of the 5-level MMC using actual model and equivalent model are shown in Figure 9 and Figure 10 respectively. These Figures shows Ea, the output voltage of the phase, Eab, the output line to line voltage, three phase output phase voltage and current. The comparison of these result shows that the equivalent model gives the same results as of the actual model of the MMC.

To compare the time of simulation of actual model and equivalent model, the system was simulated for 5 second duration with 50 μs simulation time-step. For 8 modules per phase in MMC (24 in total), the actual simulation takes approximately 52 seconds whereas the equivalent model takes 11 seconds. Hence, the equivalent model is 4.72 times faster than the actual model. This effect on simulation time will be significantly high with increase in number of modules in MMC.

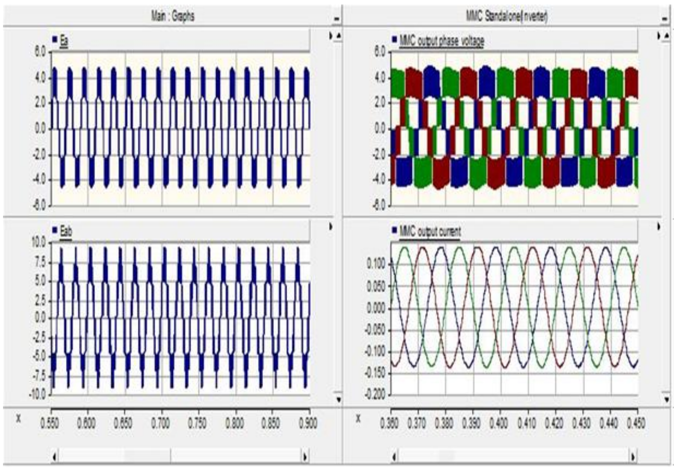

Figure 9: Output waveforms of MMC using actual model

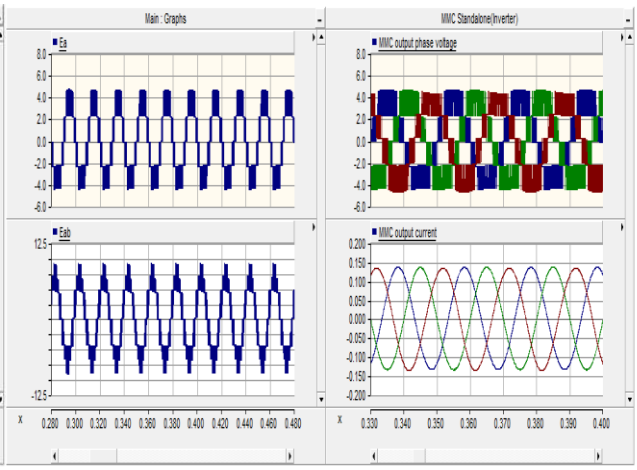

Figure 10: Output waveforms of MMC using equivalent model

To verify the dynamic performance of the model, 55MVA MMC based static compensator is implemented in PSCAD as shown in Figure 11. The output of the converter is controlled using dq-control method as shown in Figure 12. In this control method dc-link voltage and reactive power are maintained at set value. The reactive power reference is initially set at -0.8 pu and it is changed to 0.8 pu at 1s. The simulation result of this system is shown in Figure 13 and Figure 14. Figure 13 shows the waveform of the DC link voltage and the DC link Current. Figure 14 shows the measurement of the P(Active Power) and the Q (Reactive Power). Since the MMC is used as static compensator, the active power transfer is approximately zero as can be seen from the results. The reactive power is negative before 1s and positive after 1s as per the set value. Hence, the performance of the system is satisfactory.

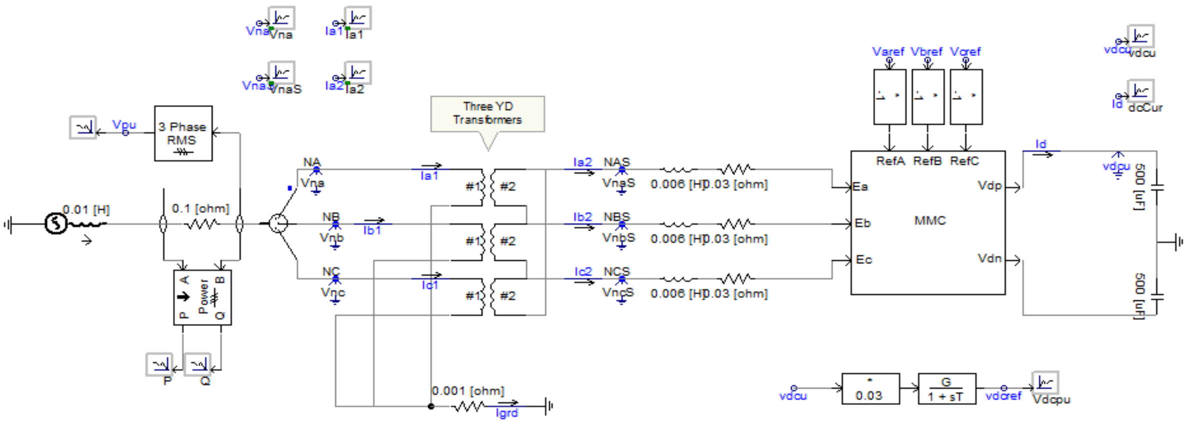

Figure 11: MMC based static compensator

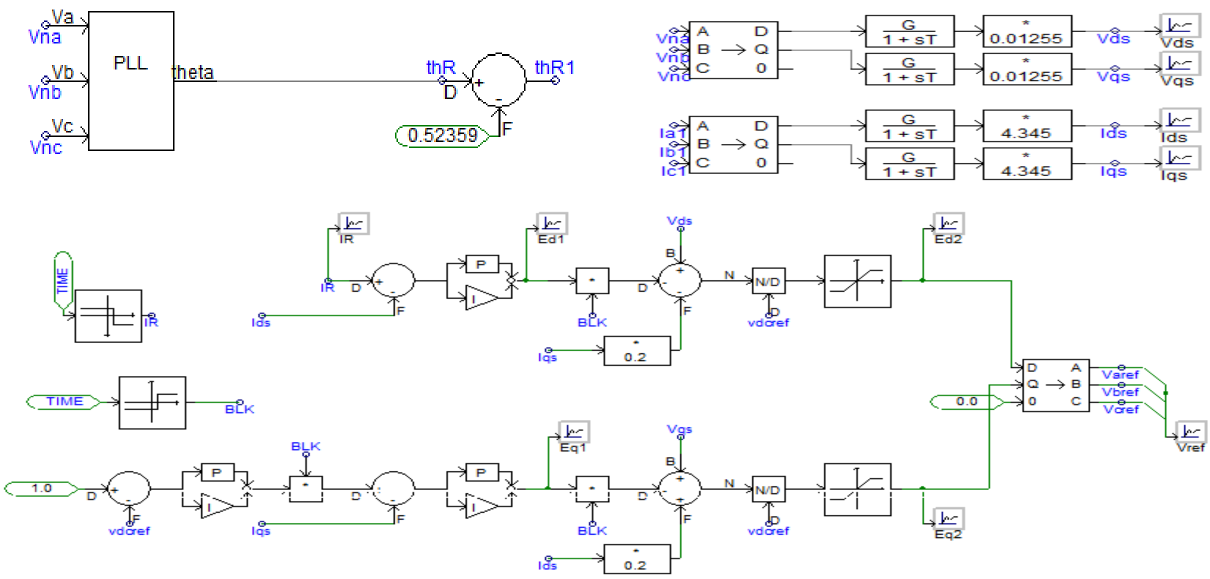

Figure 12: dq-control method for MMC based static compensator

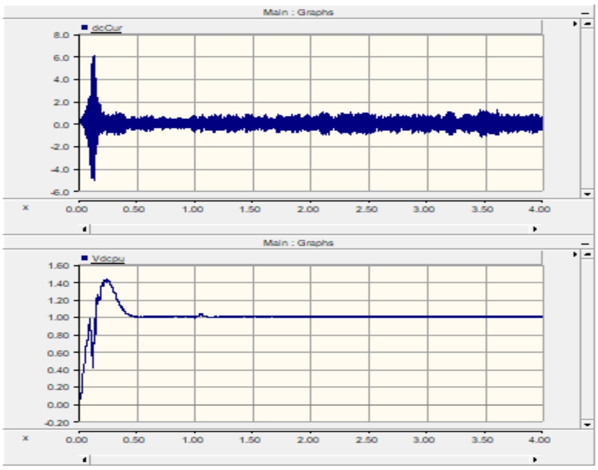

Figure 13: Output Waveform of DC Current and DC Voltage

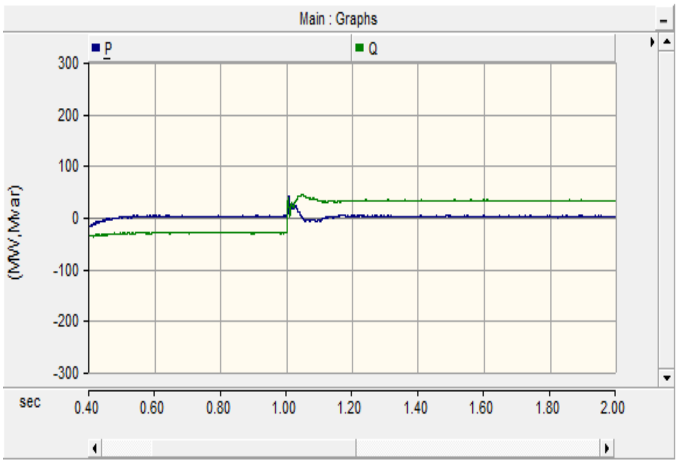

Figure 14: Output Waveform of Active Power (P) and Reactive Power (Q)

V. CONCLUSION

The simulation of the standalone modular multilevel converter and modular multilevel converter based static compensator are performed in PSCAD/EMTDC software using actual model and the equivalent model to compare the performance of both the models. The comparison of the results using both models shows that the equivalent model gives the same results as of the actual model of modular multilevel converter. The comparison of simulation time of actual model and equivalent model shows that the simulation speed is increased using equivalent model. The dynamic performance of the modular multilevel converter based static compensator is also satisfactory. Hence, the equivalent model of the converter is very useful particularly for the MMC with large number of modules.

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