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Comparison of Five Level and Seven Level Inverter Based Static Compensator System

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Abstract

The STATCOM is one of the shunt type FACTS controllers which can supply reactive power and improve bus voltage. STATCOM has advantages like transient free switching and smooth variation of reactive power. This paper deals with the comparison of five level and seven level based STATCOM systems. Usually DC output from the PV source is amplified using a single boost converter. The output of the boost converter is applied to the multilevel inverter system. The ability of STATCOM to improve the receiving end voltage is analyzed using the proposed boost converter. The performance of five level and seven level STATCOM systems are compared in terms of THD and receiving end voltage

Keywords: *static synchronous compensator, static VAR compensator, modular multi-level converters, optimal power flow*

1. Introduction

Like the static VAR compensator (SVC), the basic function of the STATCOM is to provide flexible reactive power with enhanced performance and faster speed of response at important points of the transmission system [2]. STATCOM made up of completely controllable power electronic valves by Pulse Width Modulation control [3]. The most prominent converter topologies providing voltage support in faster rate are two-level and three-level, along with modular multilevel Voltage Source Converter. They are normally linked to a power grid using a power grid point with tap-changing facilities [4-7]. The functional behavior of the Voltage Source Converter from AC side resembles voltage source in controllable form. Such a characteristic has been exploited in power system studies to represent the STATCOM as a controllable voltage source behind coupling impedance [8, 9]. This is not dissimilar in which synchronous compensator represented in studies of power flow. Such a simple concept portrays the reality that at the fundamental frequency, output of the STATCOM converter's voltage may be adjusted against the AC system's voltage in the converter to accomplish very tight control targets, a capability afforded by the switched-mode converter technology [1-9]. However, all its fascination this theory fails to describe the operation of the STATCOM from its DC side. Some obvious disadvantages of the STATCOM model based on the equivalent voltage source concept are: 1) no easy way to determine whether voltage source converter's operation is linear or not [10]; 2) switching losses tend to be neglected and 3) the ohmic losses of the converter internally along with the converter's magnetic are lumped together with those of the interfacing transformer, more often is a tap changer. This endowed to develop realistic STATCOM model for fundamental operation in frequency domain [1]; one which overcomes the disadvantages of the equivalent voltage source and suitable for gauging both conventional multi-level and modular multi-level converters (MMC) [11, 12], on large power networks and in an optimal manner. The proposed scheme now may be considered as a companion paper of [1] where the conventional power flow solution of the STATCOM model has been put forward. In the OPF problem, optimum operating point subject to system's realistic operating finite regions.

In the optimal power flow (OPF) formulation presented in the paper, the system aim is chosen to be the cost of generators' active power dispatch [13].The results obtained from an OPF solution may not necessarily agree with those obtained from a conventional power flow may not obey with results obtained from OPF solution. The solution space is structured by set

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the boundaries on control state variables and functions (i.e., nodal active and reactive power flows) [2]. Adhering to the necessary optimality criteria will eventually result in convergence towards a different operating point (optimum) than the one obtained by the conventional power flow calculation. The OPF formulation requires creating a Lagrangian function with appropriate penalty functions to keep the system operating conditions within their acceptable boundaries whilst adhering to the necessary optimality criteria. The reason is that the key part of the optimality criteria found in OPF formulations is not incorporated in the conventional power flow formulation. For instance, and as exemplified by the OPF simulations presented in the paper, the converter's internal switching losses are reduced when compared to those obtained with a conventional STATCOM power flow algorithm. Optimal solutions of the new STATCOM model yield considerable reductions in power system losses and in the converter's internal power losses, when compared to the solutions furnished by the STATCOM model solved using conventional power flows [1]. Furthermore, optimal solutions with the new STATCOM model will also yield improved solutions compared to the optimal solutions provided by the voltage source representation of the STATCOM and with less computational complexity. The above literature does not deal with comparison of five level and seven level based STATCOM systems for power quality improvement. The present work proposes seven level based STATCOM for voltage quality improvement.

2. STATCOM

The equivalent electric circuit for the STATCOM model is shown in Figure 1.

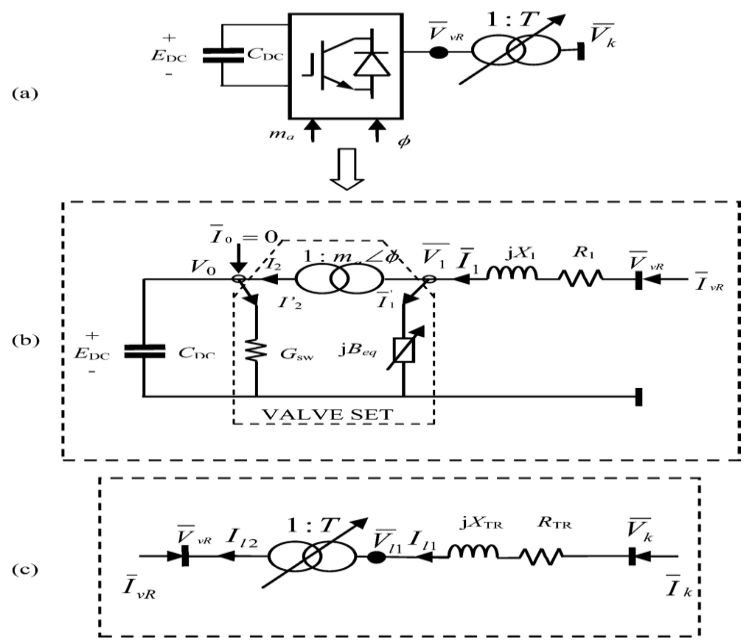

Figure 1. (a) STATCOM schematic representation; (b) Voltage source converter equivalent circuit; (c) On-load tap-changing transformer equivalent circuit

The STATCOM consists of two main components—a voltage source converter (VSC) and a tap-changing coupling transformer (LTC), as illustrated in Figure 1(a). The VSC is modeled as an ideal complex tap-changing transformer, shown in Figure 1(b). The reason for using a complex tap changer to model the VSC operation stems from the following fundamental relationship applicable to the PWM controlled operation of the VSC:

$$V_1 = m'a\, e^{j\phi} E_{DC} \quad (1)$$

Where tap magnitude m'a of the ideal complex tap-changing transformer corresponds to the amplitude modulation coefficient of an actual two-level, three-phase VSC, defined as *m'a* =(√3/2)*ma* ,in which the PWM-controlled VSC operates in the linear range with 0 <ma < 1[5]. The phase angle ϕ is the phase angle of the complex voltage V1 relative to the system phase reference. It should be noted that such aggregated relationships are also applicable to represent the fundamental frequency operation of three-level, three-phase VSCs driven by PWM control since in this application the interest is in the relationship between E_{DC} and V_1 through ma and ϕ This would be regardless of the number of switches and converter levels.

On the other hand, modular multilevel converters (MMC) have a different construction design and operating principles than PWM-driven converters. They comprise several small DC choppers with bi-directional switches, making up sub-modules of each leg of the three-phase converter. Assuming that the output DC voltage of each sub-module is controlled to maintain an average value of E_{dc}, then the constant input DC voltage in each leg of a three-phase MMC-VSC with N sub-modules would be E_{DC} = N x E_{dc} [11, 12]. It follows that the number of active sub-modules in the multi-level converter dictates the value of the voltage magnitude on the AC side of the converter. It turns out that (1) also represents very well the aggregated effects of this operation if one thinks of ma as a discrete tap as opposed to the continuous tap associated with the PWM-driven VSC converters. For numerical efficiency within the power flow or the OPF solution, a continuous tap is assumed and at the end of the convergent solution, the nearest physical tap is selected and one further iteration is carried out to fine tune the overall power flow solution. This would not be different to schemes adopted elsewhere for the tap selection of LTC transformers where discrete taps are considered as opposed to continuous ones [14]. As shown in Figure 1(b), the complex tap-changing transformer represents the internal operation of the converter under PWM control. The converter's input DC voltage, E_{DC} is provided by the capacitor bank C_{DC}, which is connected in parallel with a resistor (conductance) of value Gsw representing the converter's internal switching losses at a constant DC input voltage. The reactive power control feature of the VSC is, on the other hand, represented in the valve set modeled by a notional variable shunt susceptance in the AC side of the ideal, complex, tap changing transformer. The VSC model is completed by adding series impedance to the AC side of the complex-tap transformer in which the series resistor R1 is associated with the ohmic losses which are commensurate to the AC terminal current squared. The series inductance represents the converter's interface magnetics.

3. Simulation Result

Five level and seven level based STATCOM systems are modeled and simulated using MATLAB Simulink and the results are presented. The Simulink diagram of five level STATCOM is shown in Figure 2. The output of the STATCOM is shown in Figure 3. The FFT analysis is done and the spectrum is shown in Figure 4. The THD works out to 16.7%.

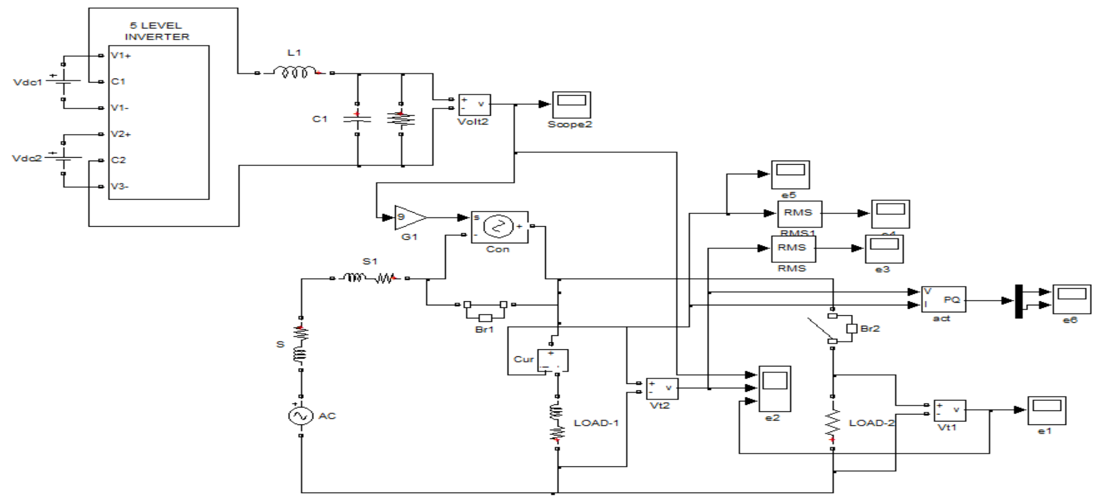

Figure 2. Circuit Diagram with Five Level Inverter based STATCOM

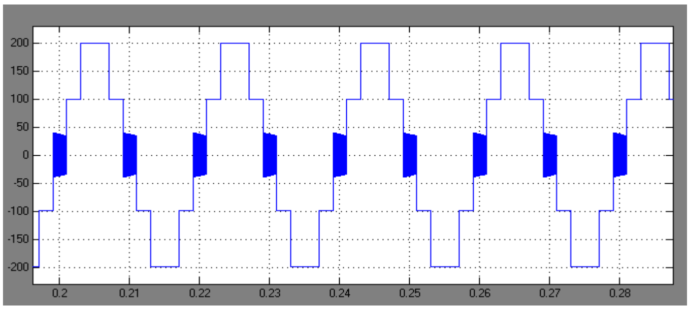

Figure 2. Fivel Level Output Voltage of STATCOM

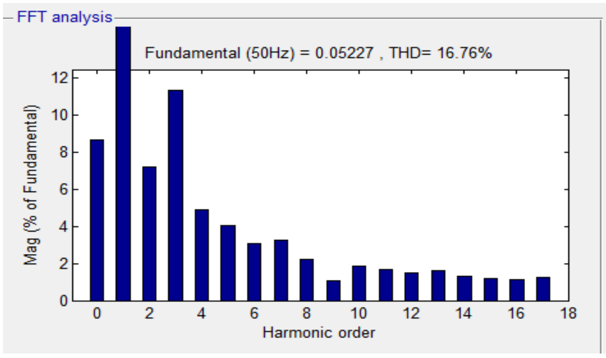

Figure 3. Frequency Spectrum

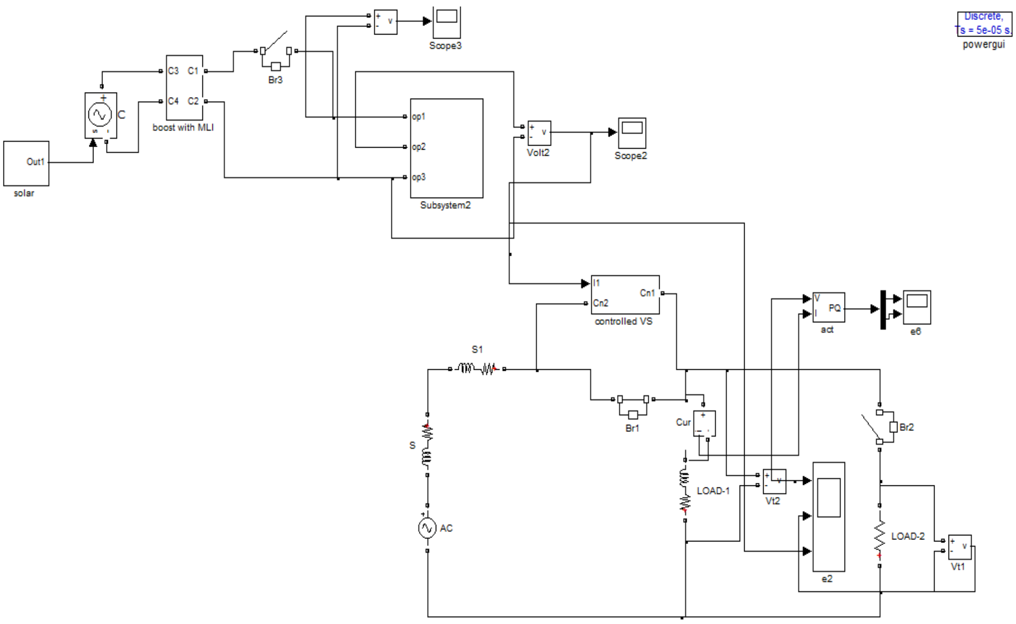

Figure 4. Circuit Diagram with Seven Level Inverter based STATCOM

The Simulink model of seven level MLI based system is shown in Figure 5. The five level inverter is replaced by a seven level inverter. The output of the PVcell is shown in Figure 6. The boost converter circuit and its switching pulses are shown in Figure 7 and 8 respectively. Figure 9 shows the output of the boost converter and its value is 240V. The Circuit of the seven level inverter is given in Figure 10. The pulse for M1 and M3 are depicted in Figure 11. The output of the seven level inverter is shown in Figure 12 and Voltage across load 1, load 2 and output of STATCOM are given in Figure 13. It can be seen that the drop in voltage is nullified by using STATCOM. The real and reactive powers are shown in Figure 14 and the FFT analysis is done and the spectrum is shown in Figure 15.

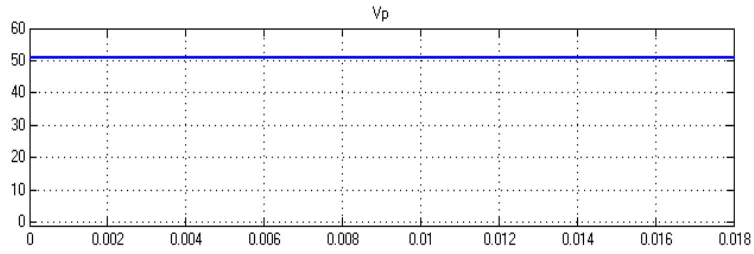

Figure 5. Output voltage of Solar system

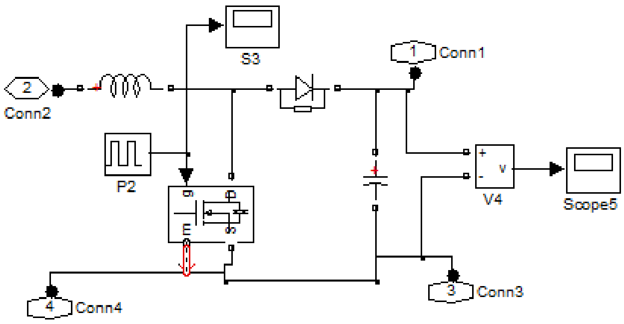

Figure 6. Single boost converter

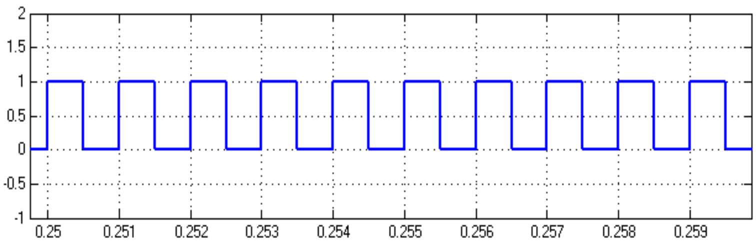

Figure 7. Switching pulse for boost converter

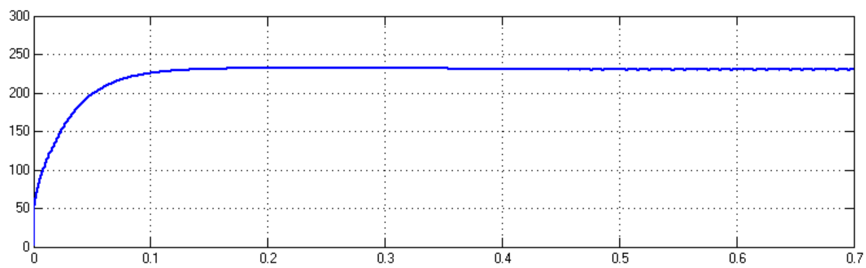

Figure 8. Output voltage of Boost converter

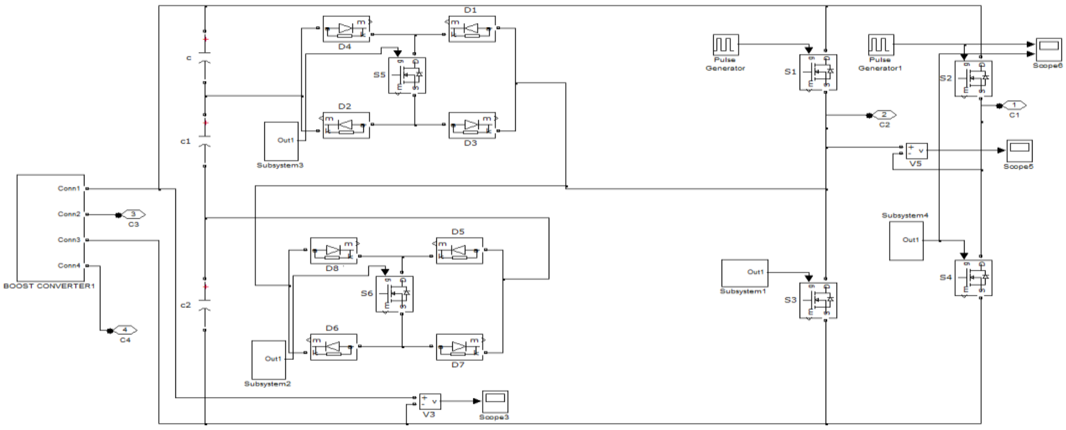

Figure 9. Circuit of Multilevel Inverter

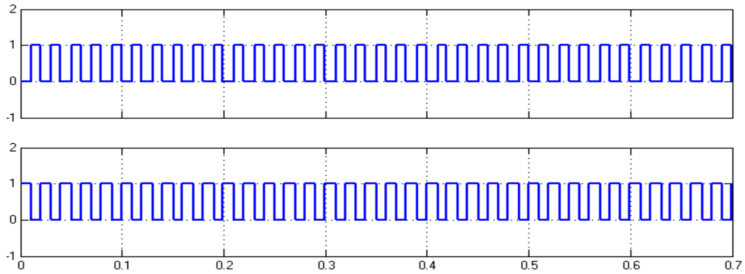

Figure 10. Switching pulse for multilevel inverter switches M1, M3

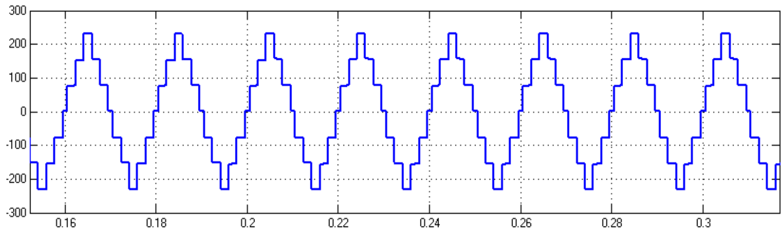

Figure 11. Output voltage of 7 level Inverter.

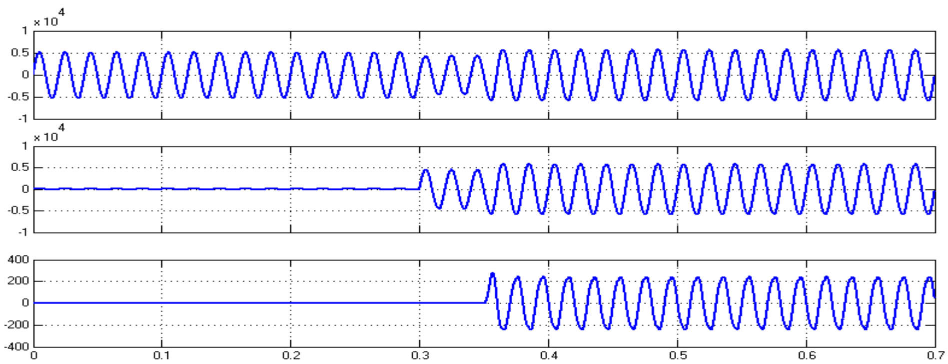

Figure 12. Voltage acrosss Load 1,Load 2 & STATCOM

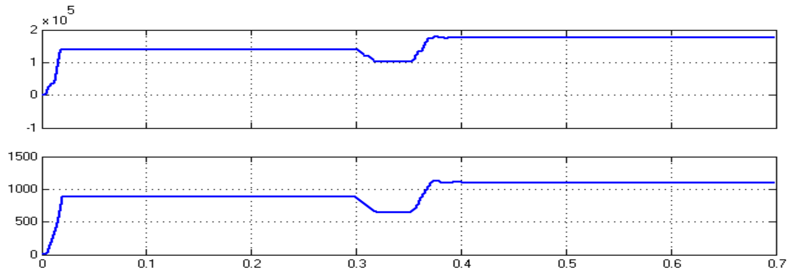

Figure 13. Real & reactive power

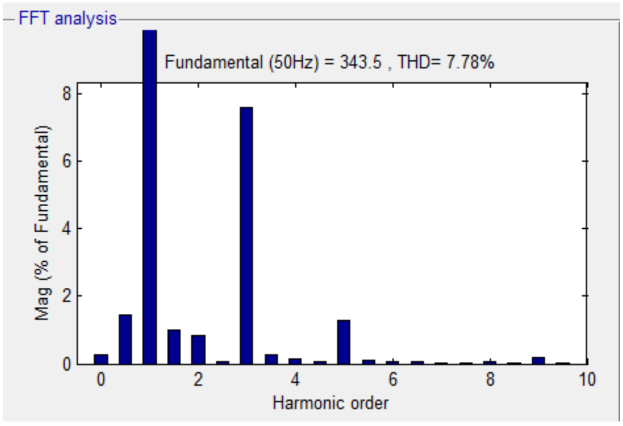

Figure 14. Frequency Spectrum

The FFT analysis is done to evaluate the THD of seven level systems and it is found to be 7.7%.

Table 1. Comparison of Five Level and Seven Level inverter

Multilevel Inverter	Vin	Vo	THD (%)
Five level	48v	200	16.76
Seven level	48v	240	7.78

4. Conclusion

Five level and seven level based STATCOM inverters are designed, modeled and successfully simulated using MATLAB. The results of the systems are compared. The results indicate that seven level based systems produces 20% higher output voltage with reduced THD. The advantages of MLI based STATCOM are reduced harmonics and reduced heating. The disadvantage of MLI based STATCOM is that it requires more number of switches and capacitors in cascaded type and flying capacitor type. The present work deals with two bus systems for five level and seven level STATCOM with reduced number of switches and hence which improves the efficiency of the system. The application of multilevel STATCOM with interleaved boost converter and two inductor boost converter will be investigated in future.

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