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A Novel Two Level Inductor Boost Converter for Multilevel Inverter based STATCOM System

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ABSTRACT

STATCOM is one of the shunt type FACTS controllers which can supply reactive power and improve bus voltage. STATCOM, a regulating device used on alternating current transmission networks, 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 two-level inductor boost converter. The output of the two-level inductor boost converter is applied to the multilevel inverter system. The ability of STATCOM to improve the receiving end voltage is analysed using the proposed two-level inductor boost converter. The performances of the two-level inductor boost multi-level STATCOM systems are compared with the single boost converter multi-level STATCOM systems in terms of THD and receiving end voltage. From the results it has been proved that much reduction in THD and improved receiving end voltages have been obtained by using the two-level inductor boost converter based STATCOM system.

Keywords: Flexible Alternating Current Transmission System (FACTS); Static synchronous Compensator (STATCOM); Static VAR Compensator (SVC); Modular Multi-level Converters (MMC); Total Harmonic Distortion (THD); Photovoltaic cell (PV).

INTRODUCTION

FLEXIBLE ac transmission systems (FACTS) are being used extensively in power system to enhance the system utilization, power deportation quantity as well as the power quality of ac system interconnections [1], [2]. As a typical shunt FACTS device, static synchronous compensator (STATCOM) is employed at the point of common connection (PCC) to absorb or inject the appropriate reactive power, through which the voltage quality of PCC is improved [3]. In recent years, many topologies have been enforced to the STATCOM. Amid these various types of topology, H-bridge cascaded STATCOM has been extensively acknowledged in high-power applications for the following abilities: quick response speed, small volume, high efficiency, minimal synergy with the supply grid and its individual phase control ability [4]–[7]. Compared with other types of converter H-bridge cascaded STATCOM can obtain a high number of levels more easily and connected to the grid directly without using the bulky transformer. This empowers us to minimize cost and maximize the use of H-bridge cascaded STATCOM [8].

There are two technological difficulties which are there in H-bridge cascaded STATCOM up to date. First, the curb approach for the current loop is an significant factor influencing the compensation performance. Yet, different non-ideal factors, such as the small bandwidth of the output current loop, the time delay lured by the signal disclosure circuit, and the reference command current generation process, will deteriorate the compensation effect. Second, H-bridge cascaded STATCOM is a perplexing system with many H-bridge cells in each phase, so the voltage imbalance issue caused by different active power losses among the cells,

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various switching patterns for different cells, parameter variations of active and passive components inside cells will influence the reliability of the system and even lead to the breakdown of the system. Hence, lots of researches have focused on seeking the solutions to these problems.

In terms of current loop control, recently used methodology involves linear control method, in which the non-linear equations of the STATCOM model are linearized with a specific equilibrium. The most widely used linear control schemes are PI controllers [9], [10]. In [9], to regulate reactive power, only a simple PI controller is carried out. In [10], through a decoupled lured strategy, the PI controller is employed in a synchronous d–q frame. However, it is hard to find the suitable parameters for designing the PI controller and the performance of the PI controller might degrade with the external disturbance. Thus, a number of intelligent methods have been proposed to modify the PI controller efficiency such as particle swarm optimization [11], neural networks [12], and artificial immunity [13]. In literature [14], [15], adaptive control and linear robust control have been reported for their anti-external disturbance ability. In literature [16], [17], a popular dead-beat current controller is used. This control method has the maximum bandwidth and the speedy current tracking reference. The steady-state performance of H-bridge cascaded STATCOM is improved, but the dynamic performance is not improved. In [18], a dc injection elimination method called IDCF is proposed to build an additional closed loop for the dc component of the output current. It can improve the output current quality of STATCOM. However, the circuit configuration of the cascaded STATCOM is the delta configuration, but not the star configuration. Moreover, an adaptive theory-based improved linear sinusoidal tracer control method is proposed in [19] and a leaky least mean square-based lured methodology is expected in [20]. But these methods are not for STATCOM with the cascaded structure. By using the traditional linear control method, the controller is characterized by its simple control structure and parameter design convenience, but poor dynamic control stability.

Other control approaches apply nonlinear control which directly compensates for the system nonlinearities without requiring a linear approximation. In [21], a transfer function linearization controller is designed. By adding a damping term, the oscillation amplitude of the internal dynamics can be effectively decreased. However, the stability cannot be guaranteed [22]. Then, many new modified damping controllers are designed to enhance the stability and performance of the internal dynamics [23]–[26]. However, the implementation of these controllers is very complex. To enhance robustness and simplify the controller layout, a passivity-based controller (PBC) based on fault dynamics is proposed for STATCOM [27]–[30]. Furthermore, the exponential cohesion of system equilibrium point is guaranteed. Nevertheless, these methods are not designed on the basis of STATCOM with the H-bridge cascaded arrangement and no literature is verified experimentally.

In terms of dc voltage balancing control in capacitor, there are three major issues: overall voltage stabilization clustered stabilizing control, and specific balancing control. In literature [31], under the assumption of all dc capacitors being equally charged and balanced, they can only eliminate the imbalances caused by the inconsistent drive pulses without detecting all dc capacitor voltages. In [32]–[34], additional hardware circuits are required in the methods based on AC bus energy exchange and dc bus energy exchange, which will maximize the cost and the complexity of the system. In [35], a method based on zero-sequence volt-age interjection is enhanced and it will increase the dc capacitor voltage endurance capacity. On the confliction, the methodology using negative-sequence current in [36] do not require the maximum mar-gin of dc capacitor voltage, but the action of STATCOM is minimized. In [8], the individual phase with active power cluster is lured independently. In [37] and [38], it is super imposing the cosine component of the system voltage with clustered output voltage, but it can be easily affected by an inaccurate phase-locked loop (PLL). In [39], the active voltage vector superposition method is enhanced. The selective harmonic elimination modulation method is used in [40] and [41], in which dc voltage balancing control and low-frequency modulation are achieved. Compared with the method in [40] and [41], a methodology shifting phase angle for dc voltage stabilization control is proposed in [42] and [43], through which the desirable effect can be easily achieved, whereas it is limited by the capacity of STATCOM. In [44], the dc voltage and reactive power are lured. yet, it cannot be extensively used due to fact that many non-ideal factors are neglected. In [45] and [46], the proposed method assumes that all cells are distributed with equal reactive power and it uses the cosine value of the current phase angle. It could lead to system instability, when using the zero-crossing point of the cosine value. In [47] and [48], the results of experiments are obtained in the downscaled laboratory system. Thus, they are not very persuasive in this condition.

In this paper, a new control method based on PBC theory with Lyapunov function dynamic stability is expected to control the current loop. Active disturbances rejection controller (ADRC) is first pro-posed by Han in his proposed work [49], and extensively used [50]–[53]; furthermore, it finds its new application in H-bridge cascaded STATCOM for clustered balancing control. It realizes the best dynamic compensation for the external disturbance. By moving the modulating wave vertically for self stabilizing control, it is much accessible to be accomplished in field-programmable gate array (FPGA) correlated with existing methods. H-bridge cascaded STAT-COMs rated at 10 kV and 2 MVA are constructed and a series of verification tests are executed. The experimental results have verified the viability and effectiveness of the proposed control methods.

II. CONFIGURATION OF THE STATCOM SYSTEM

Fig. 1 shows the circuit configuration of the STATCOM. By controlling the current of STATCOM directly, it can absorb or provide the required reactive current to achieve the purpose of dynamic re-active current compensation. Finally, the power quality of the grid is improved and the grid offers the active current only. The block diagram of proposed system is shown in Fig. 2.

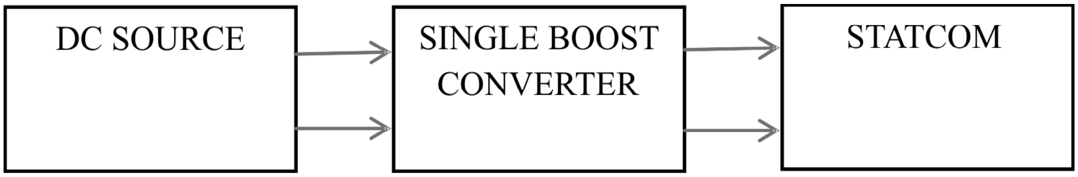


Figure 1: Existing system

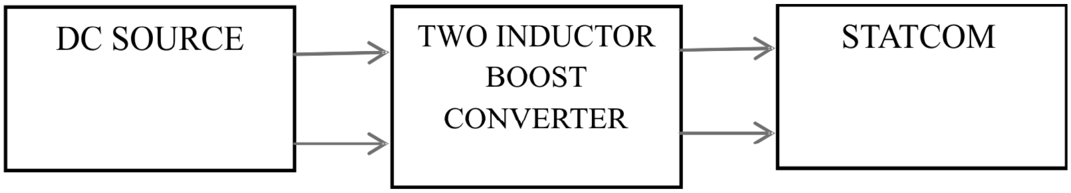


Figure 2: Block diagram of proposed system

III. SIMULATION RESULTS

The comparisonof fivelevel and seven level based STATCOM systems is done using MATLAB and the result are presented here. The five level based STATCOM is shown in Fig.3.1 DC is boosted using single boost converter and it is applied to the five level inverter. The output voltage of five level inverter is shown in Fig.3.2.The frequency spectrum for the output is shown in Fig.3.3 and the THD is 16.7%.

The Simulink diagram of two bus system with seven level inverter is shown in Fig. 4.1.The five level inverter is now replaced by seven level inverter. The output voltage of solar system is shown in Fig. 4.2and its value is 50 volts. The boost converter and switching pulses are shown in Fig. 4.3 and 4.4 respectively.The output voltage of boost converter is shown in Fig. 4.5 and its value is 23 volts. The ripple in output voltage is shown in Fig. 4.6 and the ripple voltage is 0.95 volts.The circuit of multi-level inverter is shown in Fig.

4.7.The switching pulse for multilevel inverter and output voltage of multilevel inverter is shown in Fig. 4.8 and 4.9 respectively. The voltage across load 1, load 2 and STATCOM are shown in Fig. 4.10.

The real and reactive powers are shown in Fig.4.11.The frequency spectrum for the output of MLI is shown in Fig. 4.12 and the THD is 7.7%

The boost converter is replaced with two inductor boost converter. The circuit of TIBC based seven level inverter system is shown in Fig.5.1.The output voltage ofsolar system is shown in Fig.5.2.The TIBC and its pulses are shown in fig 5.3 and 5.4 respectively .The output voltage of two inductor boost converter is shown in Fig.5.5.Zoomed view of output voltage is shown in Fig.5.6.and the ripple voltage is 0.5 volts. The frequency spectrum is shown in Fig.5.7 and the THD is 6%.The summary of ripple voltage and THD is given in Table 1.

Table 1
Comparison of Multilevel inverter

Multilevel inverter	*Vin*	*Vo*	*Ripple voltage*	*THD*
Five level	48v	200v	-	16.76%
Seven level Single boost converter	48v	240v	0.95	7.78%
Seven level TIBC converter	48v	263v	0.53	6.00%

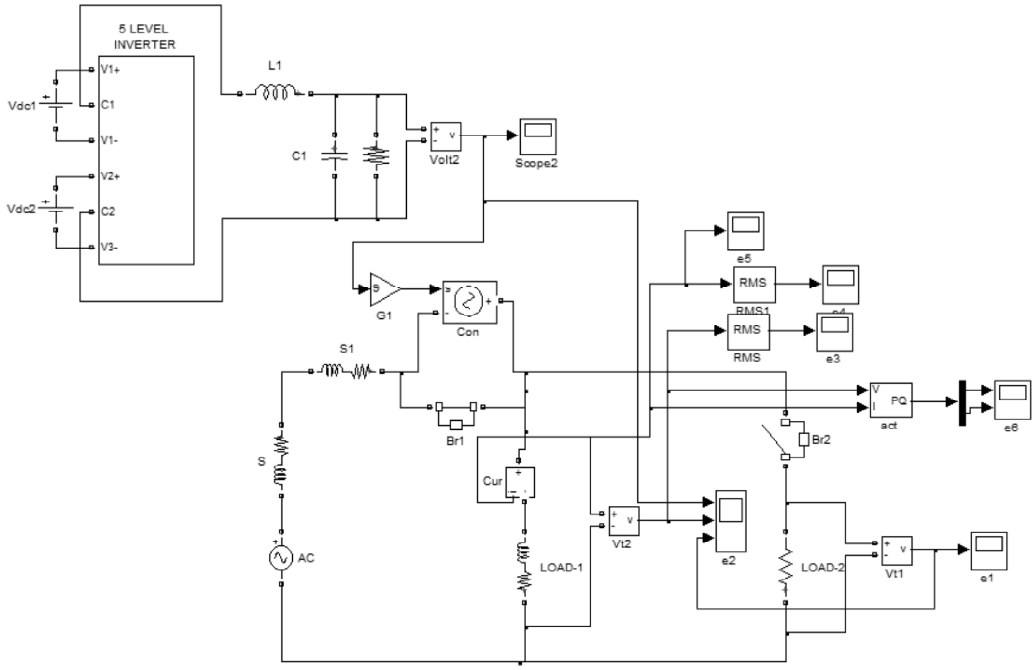
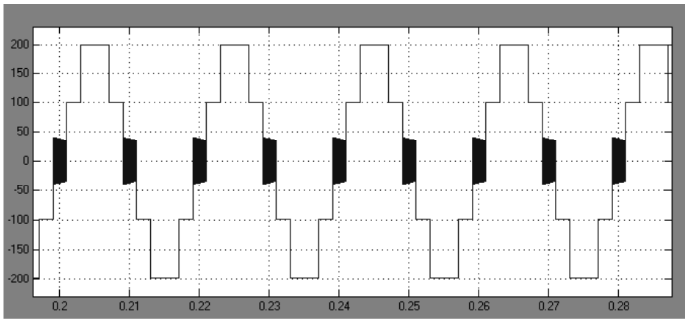


Figure 3.1: Circuit diagram of five level inverter



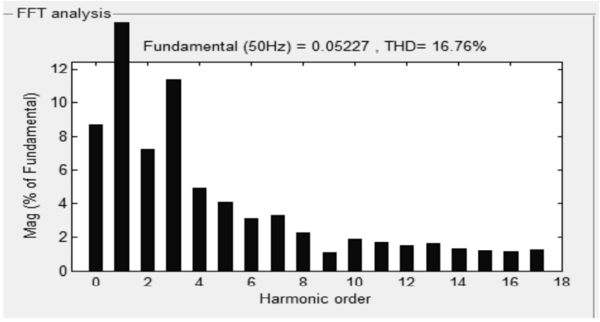


Figure 3.2: Five level inverter output voltage

Figure 3.3: Total Harmonic Distortion

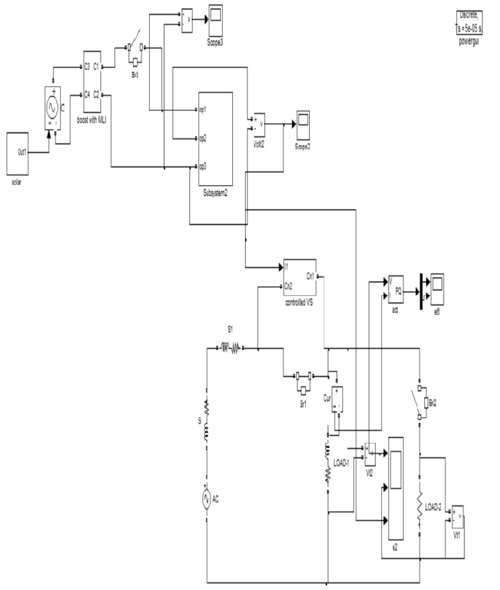


Figure 4.1: Circuit diagram of single boost converter with seven level inverter

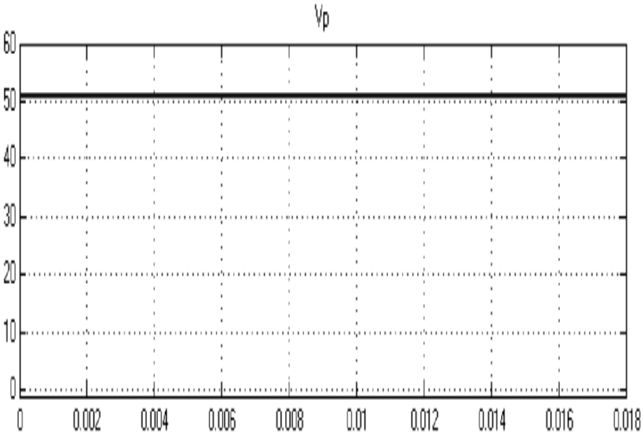


Figure 4.2: Solar output voltage

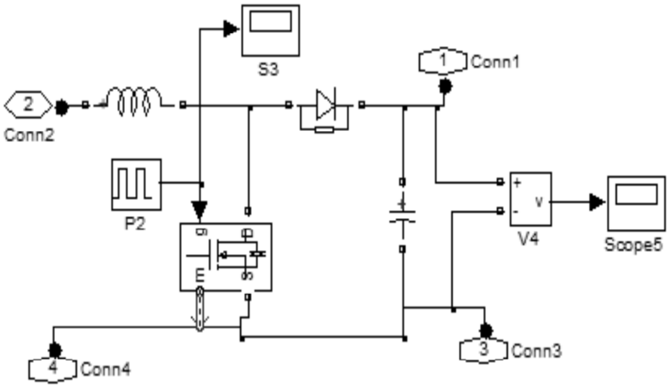


Figure 4.3: Single boost converter

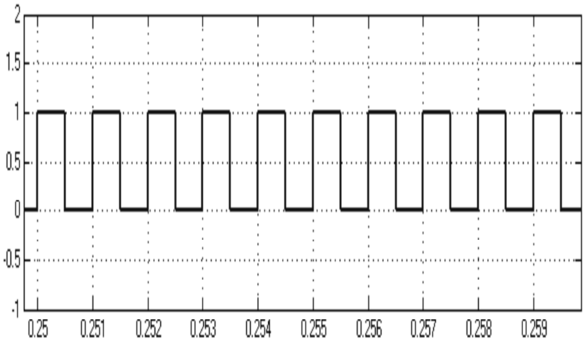


Figure4.4: Switching pulse for boost converter

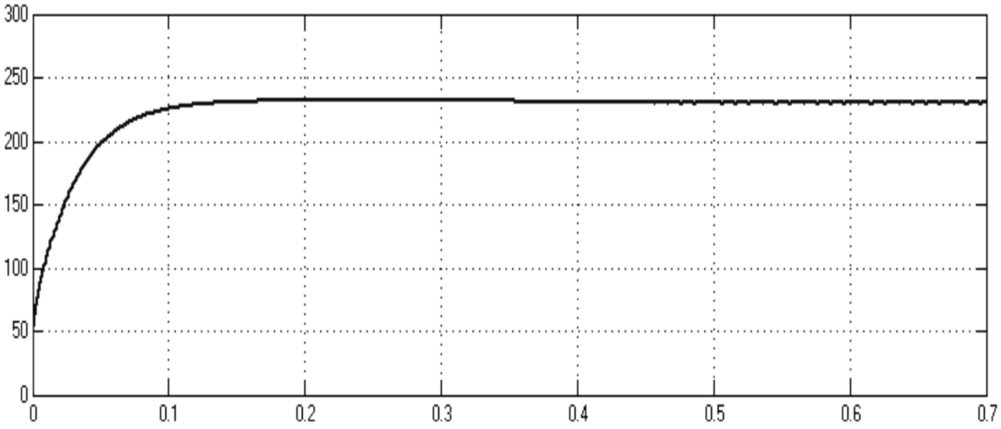


Figure 4.5: Boost converter output voltage

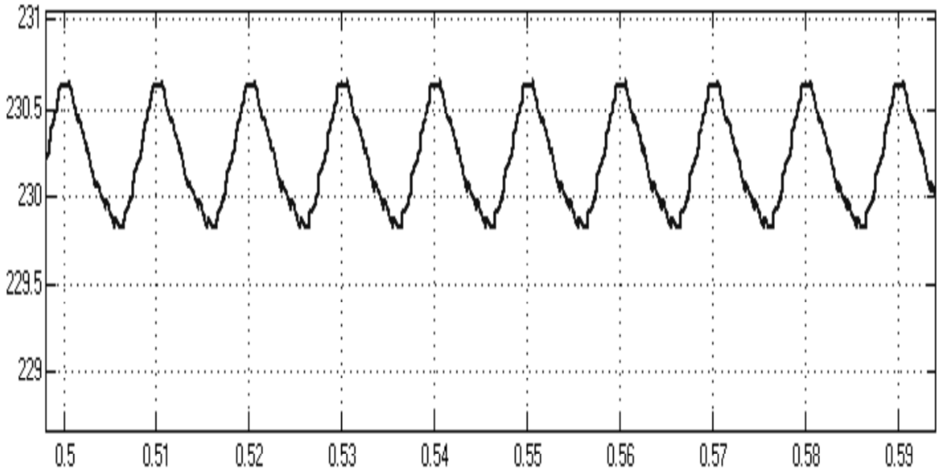


Figure 4.6: Ripple output voltage

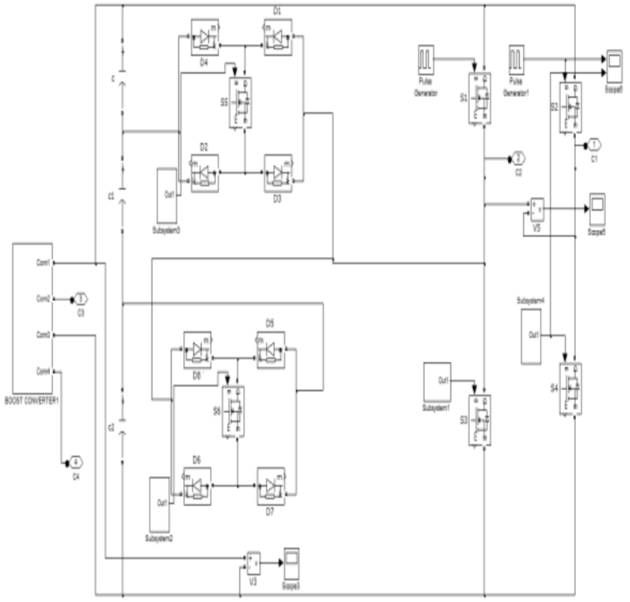


Figure 4.7: Multilevel inverter circuit diagram

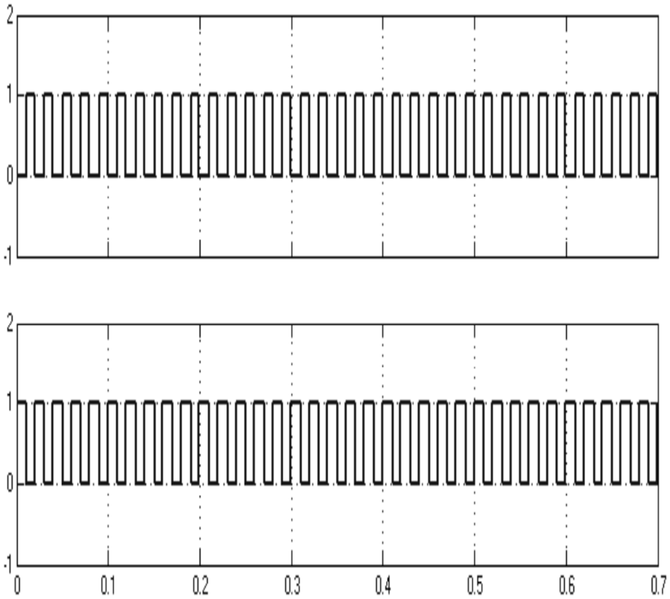


Figure 4.8: Switching pulse for inverter switch M1,M3

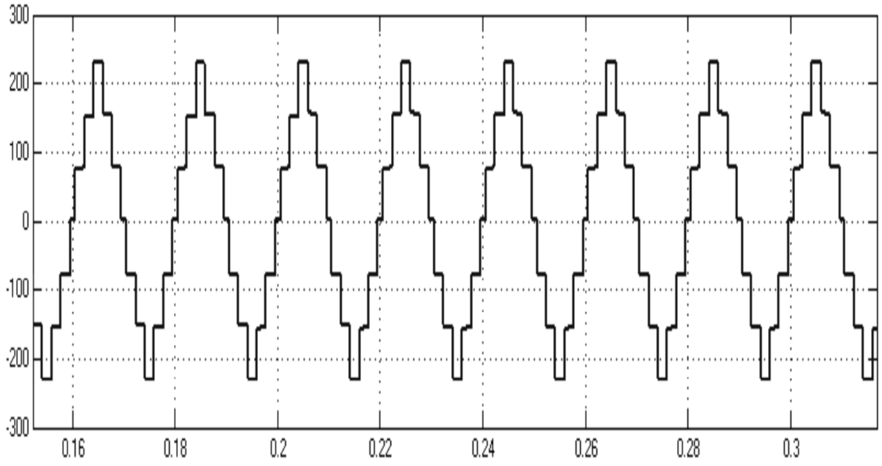
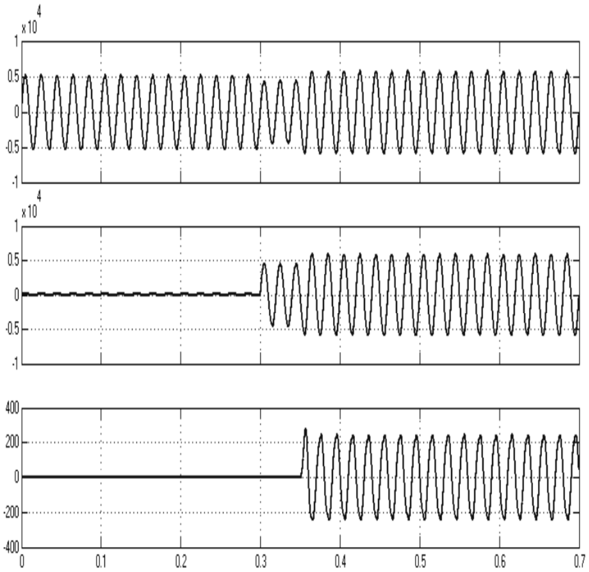


Figure 4.9.Multilevel inverter output voltage



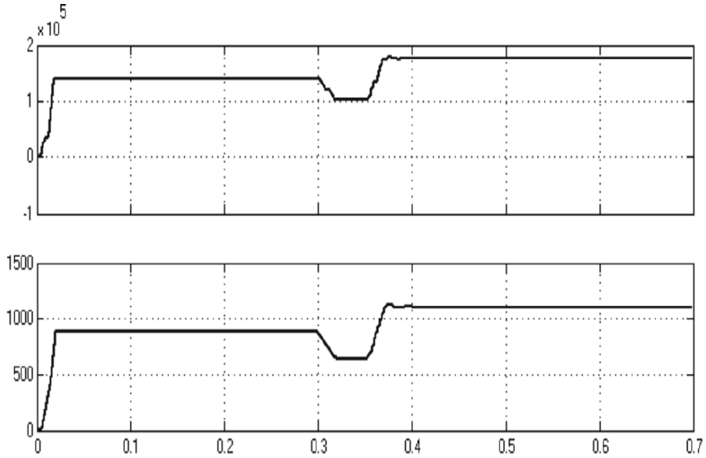
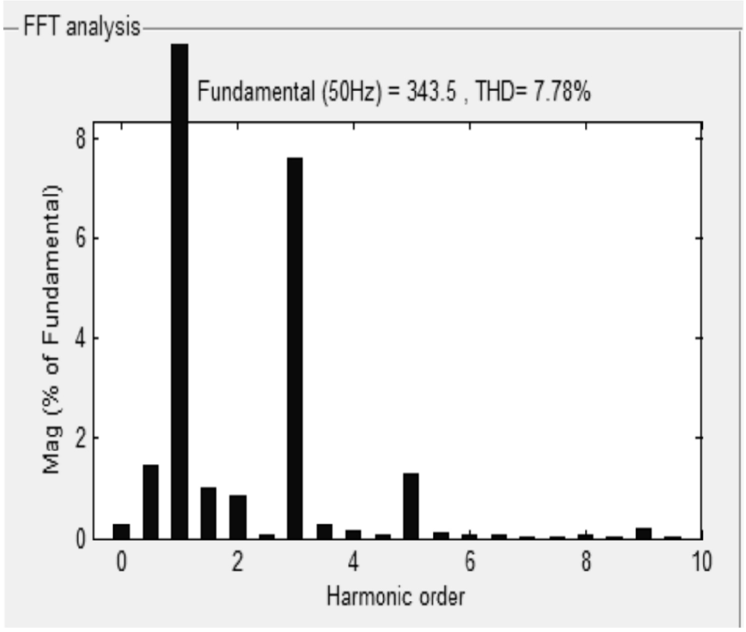


Figure 4.10: Load1,Load2 & STATCOM output voltage

Figure 4.11: Real & Reactive power



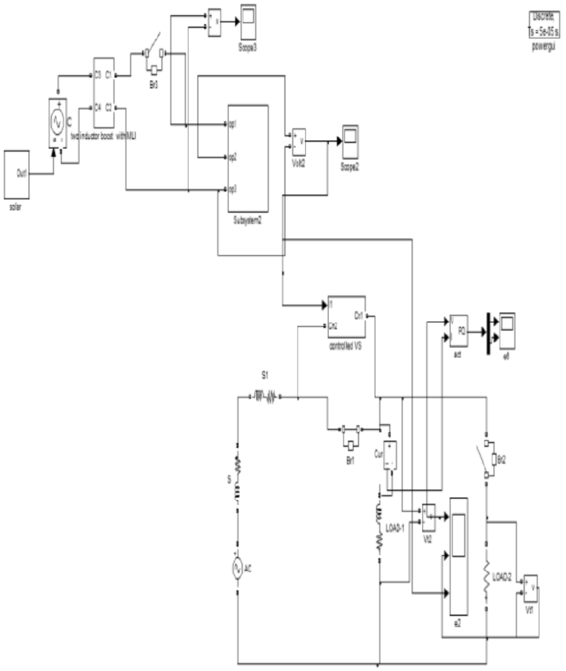


Figure 4.12: Total Harmonic Distortion

Figure 5.1: Circuit diagram of two inductor boost converter with seven level inverter

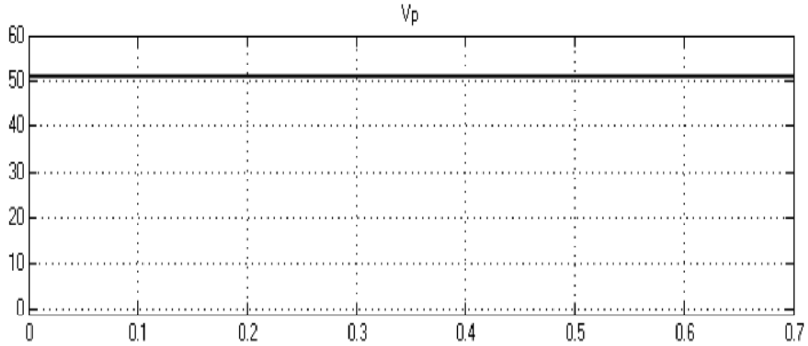


Figure 5.2: Solar output voltage

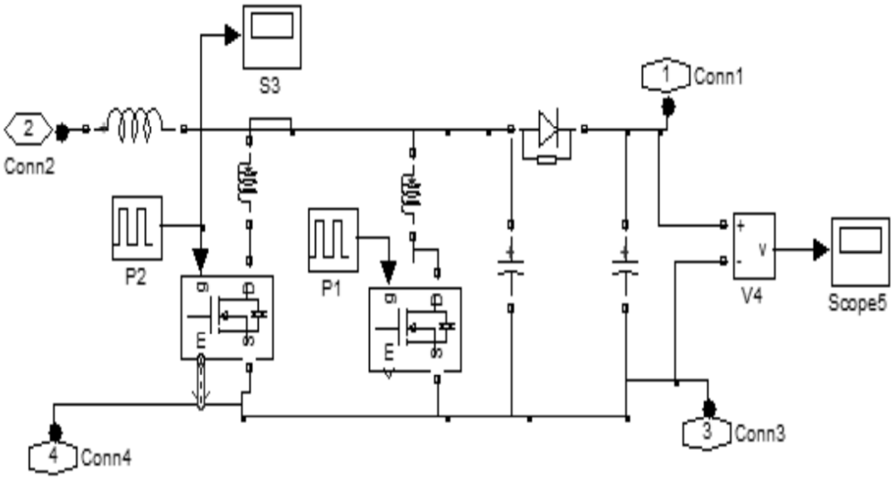


Figure 5.3: Two inductor boost converter

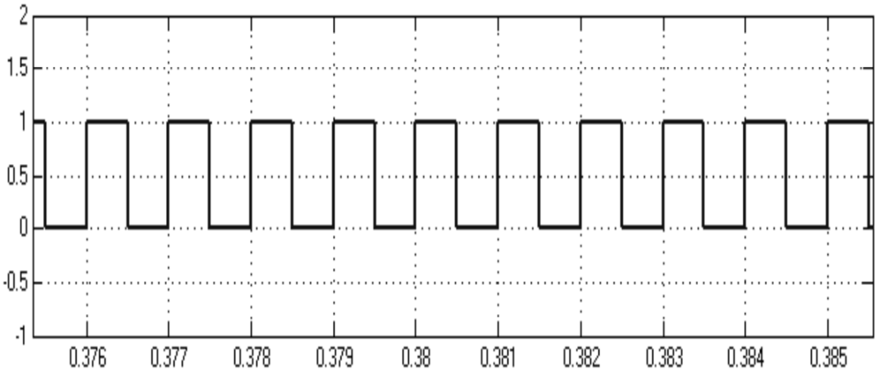


Figure 5.4: Switching pulse for two inductor boost converter

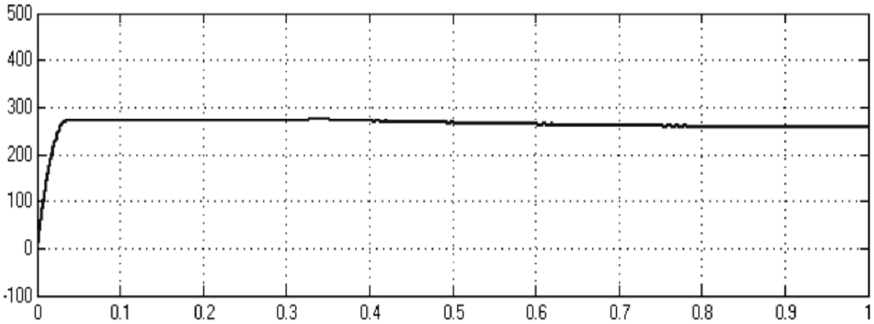


Figure 5.5: Two inductor boost converter

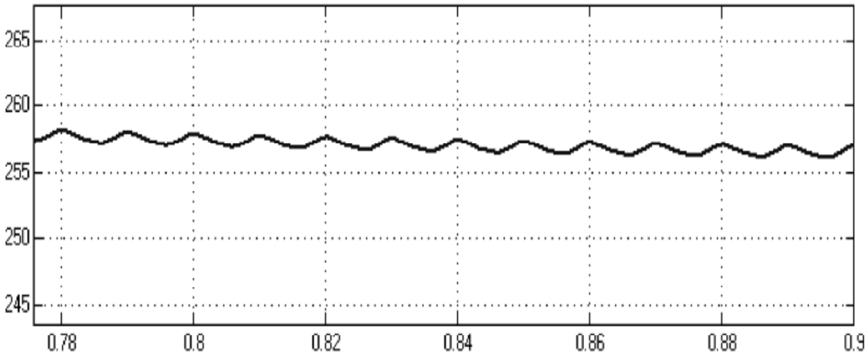


Figure 5.6: Output ripple voltage

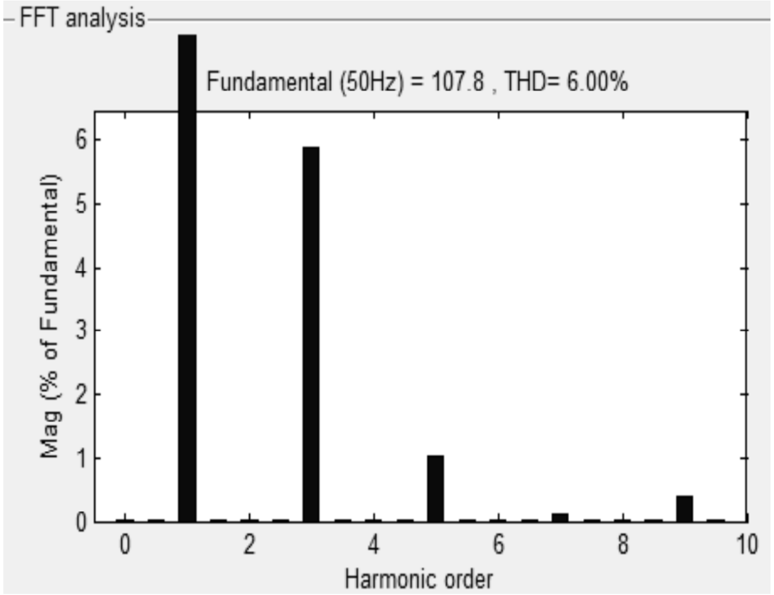


Figure 5.7: Total Harmonic Distortion

CONCLUSION

Single boost and two inductor boost converter based seven level STATCOM system are successfully designed, modelled and simulated using MATLAB and the corresponding resultsare presented. The result identified that ripple voltage and THD are minimum in the case of seven level TIBC based STATCOM system. Thereforethis system is a viable alternative to the existing STATCOM system

The present work deals with open loop controlled SBC and TIBC based STACOM systems. The investigation on closed loop system will be done in future

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