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PERFORMANCE ANALYSIS OF CASCADE MULTILEVEL INVERTER USING STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

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Abstract: This Dissertation is dedicated to Performance analysis of cascade multilevel inverters using static synchronous compensator (STATCOM). In Flexible AC Transmission systems (FACTS) Controller, the STATCOM have shown easiest in terms of cost effectiveness in a wide range of problem solving abilities from transmission to distribution levels. A cascade multilevel inverter is power electronics devices which convert DC voltage into desired AC voltage. A method is shown that cascade multilevel inverter can be implemented using only a single DC power source and capacitors. To operate a cascade multilevel using a single DC source, it is proposed to use capacitors as the DC sources for all of except the main source. A standard cascade multilevel inverter requires "n" DC source for 2n+1 level. To operate a high voltage application a large number of DC capacitors are utilized in a cascade multilevel inverter using STATCOM. To obtain a low distortion output voltage or a nearly sinusoidal output waveform, a triggering signal should be generated to control the switching frequency of each power semiconductor switch. The STATCOM system is modeled using the ABC transform which calculates the instantaneous reactive power. This model is used to calculate the instantaneous reactive power and design a control scheme. The Simulation results of MATLAB/SIMULINK model indicate the performance of the proposed control system as well as the precision of the proposed model.
Key Words: Cascade Multilevel inverter, STATCOM

I. INTRODUCTION

Nowadays, Transformation has been introduced into the structure of electrical power utilities to improve efficiency of the power system networks by deregulating the industries and opening it to their competitors. This global trend and similar structural change has occurred elsewhere in other industries. The effect of such adjustments will mean that the generation, transmission and distribution systems must now built the new set of rules by open markets. Particular for this transmission sector of power utilities, this adaption may require the construction or modification of inter-connection between regions and countries. In more adaption the new generation patterns will necessitate changes and will require increased flexibility and availability of the transmission system. For these problems are the growing environmental concern and the constraints upon the rights-of way for new installations and facilities. Yet some more demands are continually being made upon utilities to supply increased loads to improve reliability and deliver energy at the lowest possible cost and with improved power quality. The power industry has responded to these challenges with the power electronics based technology of flexible AC transmission systems (FACTS). This term covers a whole family of power electronics controller, some of which may have achieved maturity within the industry, while some others are in the design stage [18]. Medium voltage motor drives and utility application require medium voltage and megawatt power level. For a medium voltage grid some problems occurred to connect only one power semiconductor switch directly. A result of multilevel power inverter structure has been introduced as an alternative in high power and medium voltage application. Multilevel inverters not only achieve high power ratings but also for the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind and fuel cells can be easily provide to a multilevel converter system for a high power application. The concept of multilevel inverter has been introduced since 1975. The term multilevel begun with the three level inverters [1]. Furthermore several multilevel inverter topologies have been developed. The basic concept of a multilevel inverter to achieve higher power is to use a series of power semiconductor switches with lower voltages dc sources to perform the power conversion by converting a staircase voltage waveform. Capacitors, batteries and renewable energy voltage sources can be used as the multiple dc sources in order to achieve high voltage at the output; however the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected. Inverter convert DC power into AC power through waves called either sine wave or modified sine wave. Sine wave is typically found in power from a power plant. Modified sine waves are made to simulate sine waves. Inverter with modified sine waves works well for backup power in houses and are much less expensive. Although there are several types of inverters, all standard inverter use only one switch, or in other words one power circuit.

A. Multilevel Inverter

The converters have to be designed to obtain a quality output voltage or a current waveform with a minimum amount of ripple content. In high voltage and high power applications the conventional two level inverters have some limitations in operating at high frequency mainly due to switching losses and constraints of the power device ratings. Series and parallel combination of power switches in order to achieve the power handling voltages and currents. The conventional two level inverters produce THD levels around sixty percent even under normal operating conditions which are undesirable and cause more losses and other power quality problems too on the AC drives and utilities. For high voltage applications, two or more power switches can be connected in series in order to provide the desired voltage rating. However, the characteristics of devices of the same type are not identical. For the same OFF state current, their OFF state voltages differ. Even during the turn OFF of the switches the variations in stored charges cause difference in the reverse voltage sharing. The switch with the least recovered charge faces the highest transient voltage. For higher current application, the switches are connected in parallel, however because of uneven switch characteristics the load current is not shared equally. If a power switch carries more current than that of the others, then the power dissipation in it increases, thereby increasing the junction temperature and decreasing the internal resistance. This in turn increases its current sharing and may damage the devices permanently which is undesirable for critical applications. The multilevel inverters perform power conversion in multilevel voltage steps to obtain improved power quality, lower switching losses, better electromagnetic compatibility and higher voltage capability. Considering these advantages, multilevel inverters have been gaining considerable popularity in recent years [14].

B. Cascade Multilevel Inverter

A cascaded multilevel inverter consists of a series of Hbridge (single-phase full-bridge) inverter units. The general function of this multilevel inverter is to synthesize a desired voltage from several separate dc sources (SDCS's), which may be obtained from batteries, fuel cells, or solar cells.

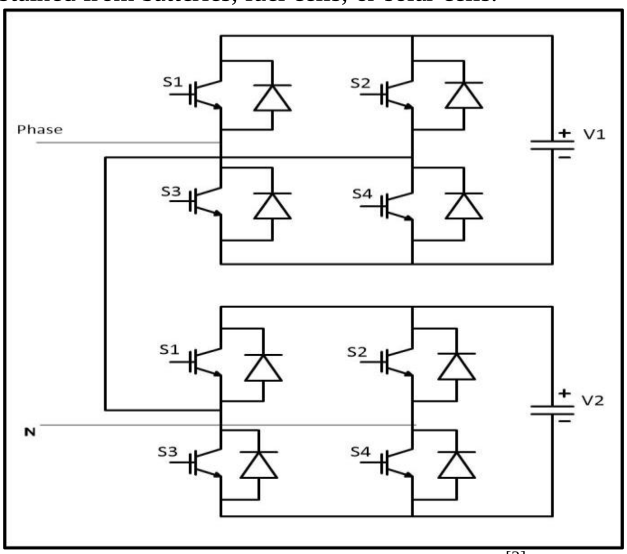


Figure 1. Cascade multilevel inverter [3]

Figure 1. shows a single-phase structure of a cascade inverter withSDCS's. Each SDCS is connected to a single-phase full bridge inverter. Each inverter level can generate three different voltage outputs, +Vdc , 0 and -Vdc, by connecting the dcsource to the ac output side by different combinations of the four switches, S1, S2, S3 and S4. To obtain +Vdc, switches S1and S4 are turned on. Turning on switches S2 and S3 yields. By turning on S1 and S2or S3 and S4, the output voltage is 0.The ac outputs of each of the different level full-bridge inverters are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels in a cascade inverter is defined by m=2s+1, where S is the number of dc sources[3].

II. STATCOM

The STATCOM (or SSC) is a shunt-connected reactive-power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM considered in this chapter is a voltage-source converter that, from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.

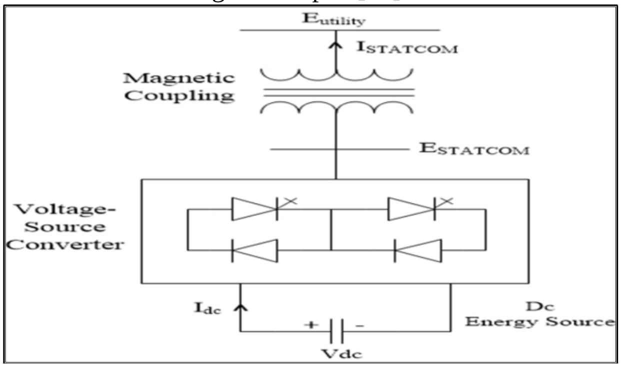
A STATCOM can improve power-system performance in such areas as the following:

- The dynamic voltage control in transmission and distribution systems;
- The power-oscillation damping in power-transmission systems;
- The transient stability;
- The voltage flicker control; and
- The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

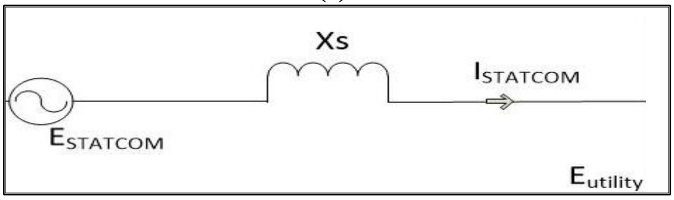
A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both capacitive and inductive) power [16].

III. CONSTRUCTION AND OPERATION

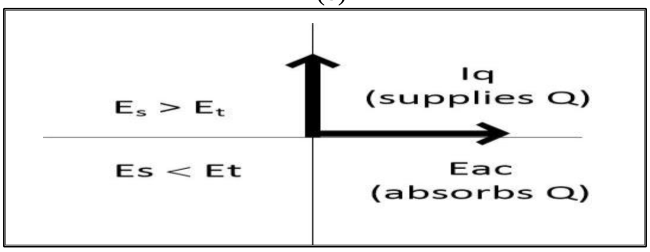
A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC). A single-line STATCOM power circuit is shown in (a), where a VSC is connected to a utility bus through magnetic coupling. In Fig.(b), a STATCOM is seen as an adjustable voltage source behind a reactance meaning that capacitor banks and shunt reactors are not needed for reactive-power generation and absorption, thereby giving a STATCOM a compact design, or small footprint, as well as low noise and low magnetic impact[17].



(a)



(b)



(c)

Fig. 2 The STATCOM principle diagram: (a) a power circuit; (b) an equivalent circuit; and (c) a power exchange [16]

The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, E_s, of the converter, as illustrated in Fig.(c). That is, if the amplitude of the output voltage is increased above that of the utility bus voltage, E_t, then a current flow through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system. If the amplitude of the output voltage is decreased below the utility bus voltage, then the current flows from the ac system to the converter and the converter absorbs inductive-reactive power from the ac system. If the output voltage equals the ac system voltage, the reactive-power exchange becomes zero, in which case the STATCOM is said to be in a floating state. Adjusting the phase shift between the converter output voltage and the ac system voltage can similarly control real power exchange between the converter and the ac system. In other words, the converter can supply real power to the ac system from its dc energy storage if the converter output voltage is made tolead the ac-system voltage. On the other hand, it can absorb real power from the ac system for the dc system if its voltage lags behind the ac- system voltage. A STATCOM provides the desired reactive power by exchanging the instantaneous reactive power among the phases of the ac system. The mechanism by which the converter internally generates and/or absorbs the reactive power can be understood by considering the relationship between the output and input powers of the converter. The converter switches connect the dc-input circuit directly to the ac-output circuit. Thus the net instantaneous power at the ac output terminals must always be equal to the net instantaneous power at the dc input terminals (neglecting losses). Assume that the converter is operated to supply reactive-output power. In this case, the real power provided by the dc source as input to the converter must be zero. Furthermore, because the reactive power at zero frequency (dc) is by definition zero, the dc source supplies no reactive power as input to the converter and thus clearly plays no part in the generation of reactive-output power by the converter. In other words, the converter simply interconnects the three output terminals so that the reactive-output currents can flow freely among them. If the terminals of the ac system are regarded in this context, the converter establishes a circulating reactive-power exchange among the phases. However, the real power that the converter exchanges at its ac terminals with the ac system must, of course, be supplied to or absorbed from its dc terminals by the dc capacitor[16].

IV. SIMULATION WORK

Simulink model, results and FFT analysis of third level inverter using ideal switch without PWM:

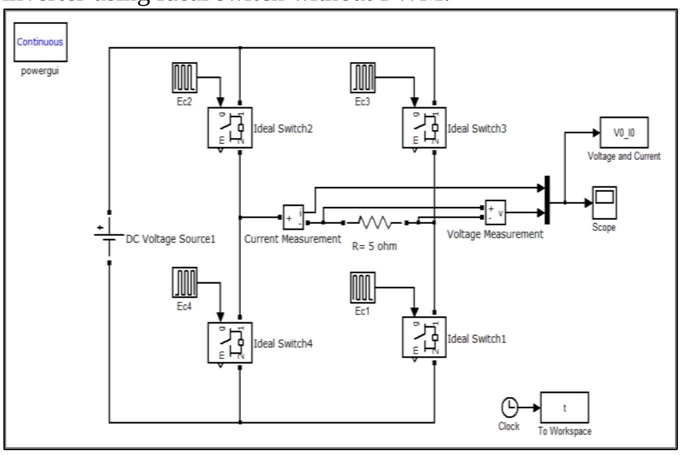


Fig3. Simulink model of third level inverter using ideal switch without PWM

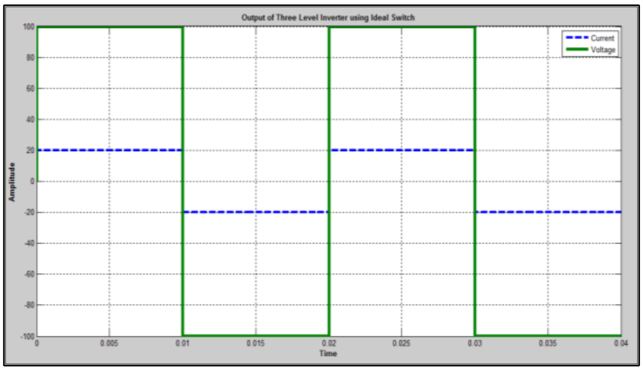


Fig 4. Output of third level inverter using ideal switch without PWM

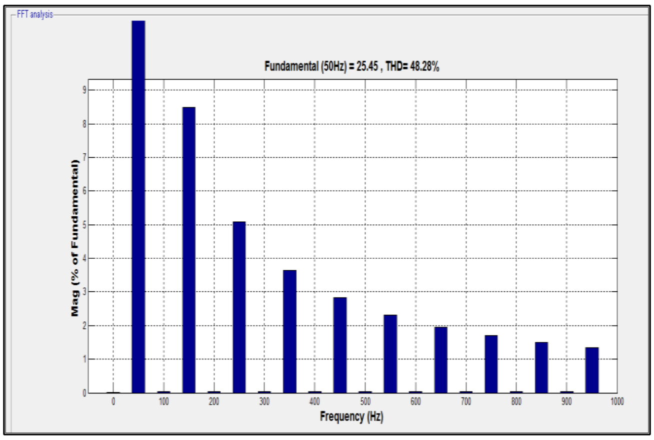


Fig 5. FFT Analysis of third level inverter using ideal switch without PWM

Simulink model, results and FFT analysis of third level inverter using ideal switch with PWM:

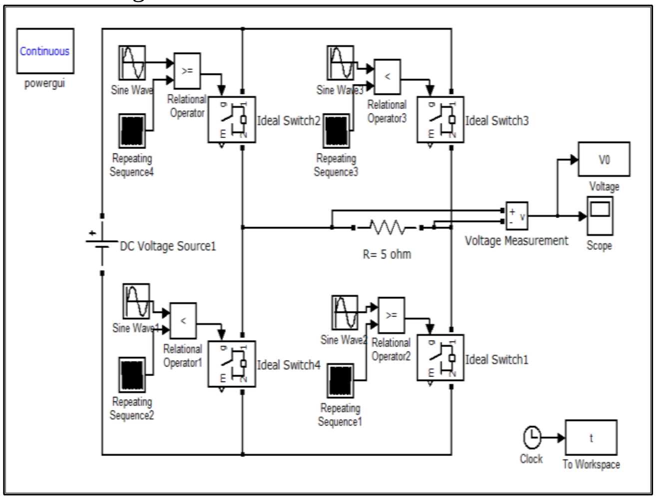


Fig 6. Simulink model of third level inverter using PWM for ideal switch

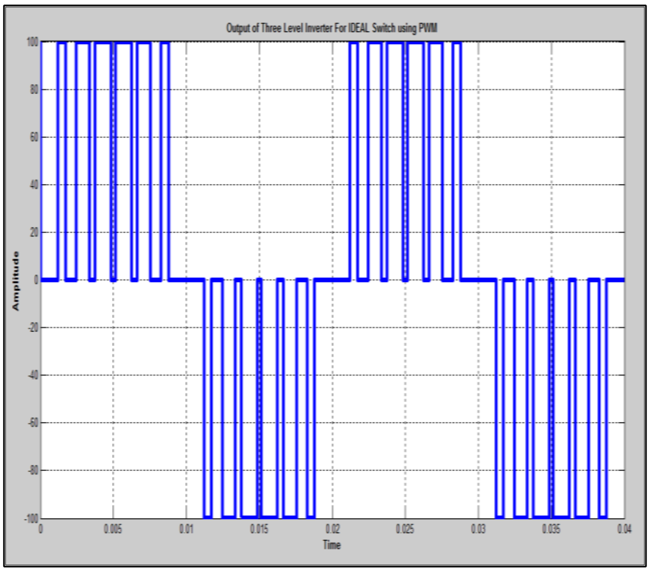


Fig 7. Output of third level inverter using PWM for ideal switch (Instantaneous carrier)

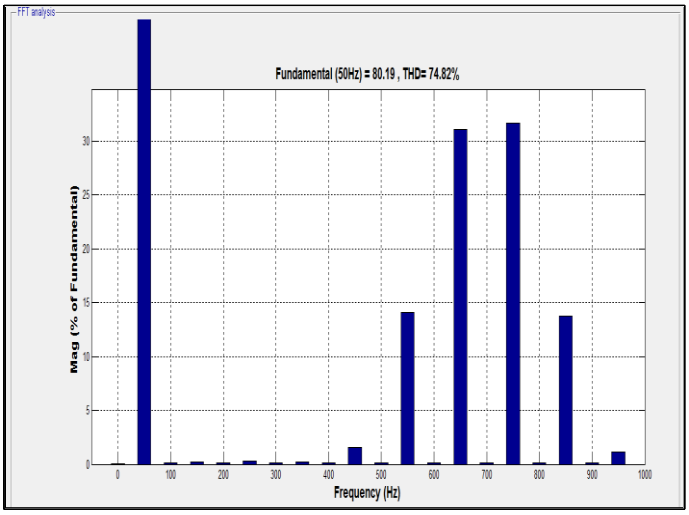


Fig 8. FFT Analysis of third level inverter using PWM for ideal switch
(Instantaneous carrier)

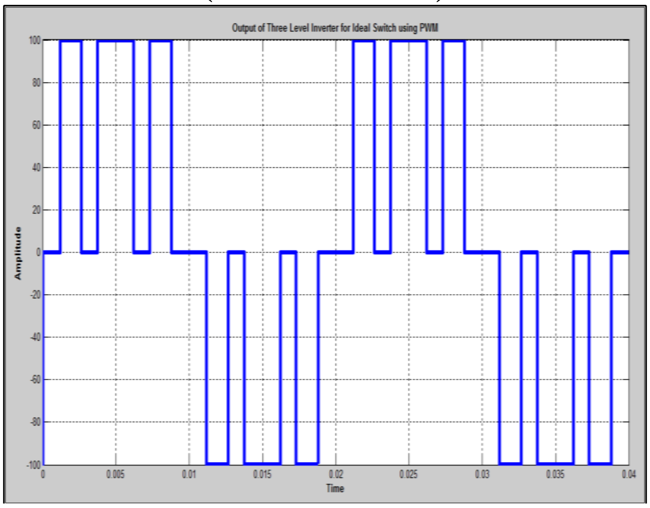


Fig 9. Output of third level inverter using PWM for ideal switch (Unidirectional carrier)

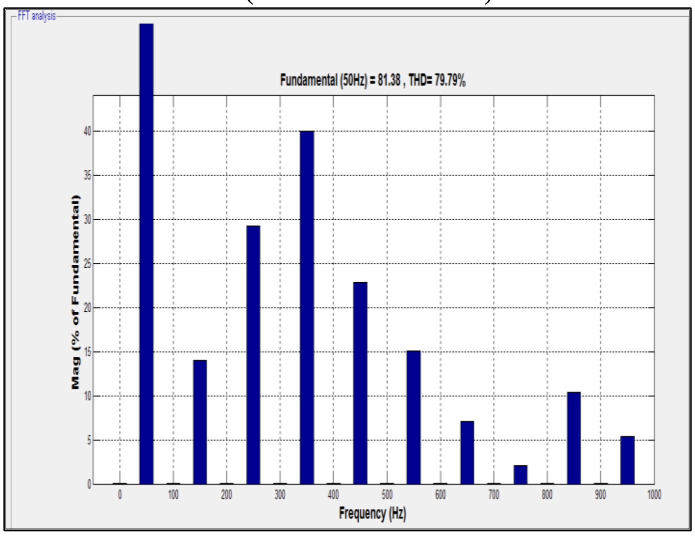


Fig 10. FFT Analysis of third level inverter using PWM for ideal switch
(Unidirectional carrier)

Simulink model, results and FFT analysis of third level inverter using IGBT without PWM:

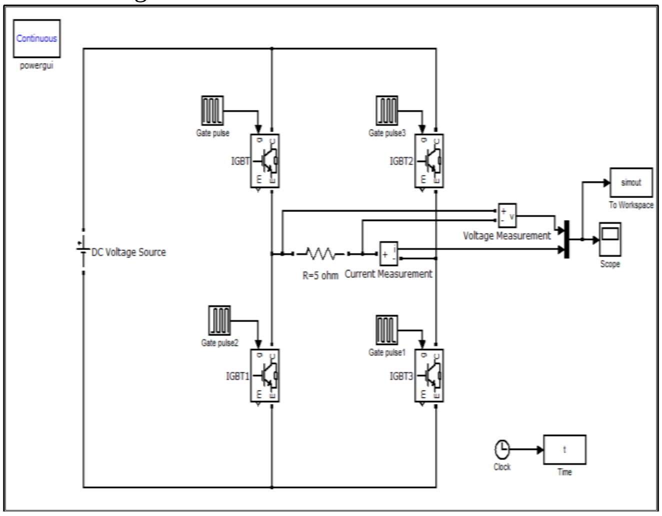


Fig 11. Simulink model of third level inverter using IGBT without PWM

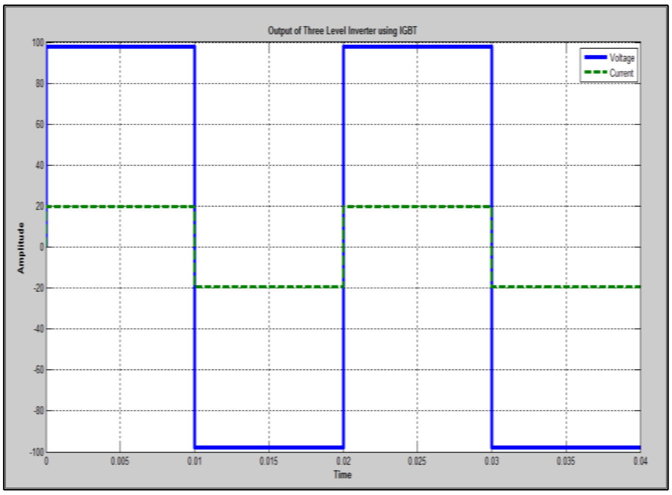


Fig 12. Output of third level inverter using IGBT without PWM

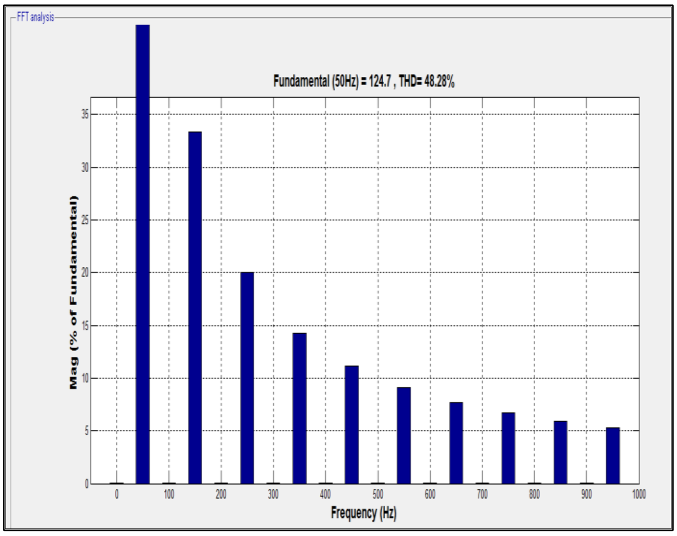


Fig 13. FFT Analysis of third level inverter using IGBT without PWM

Simulink model, results and FFT analysis of third level inverter using IGBT with PWM:

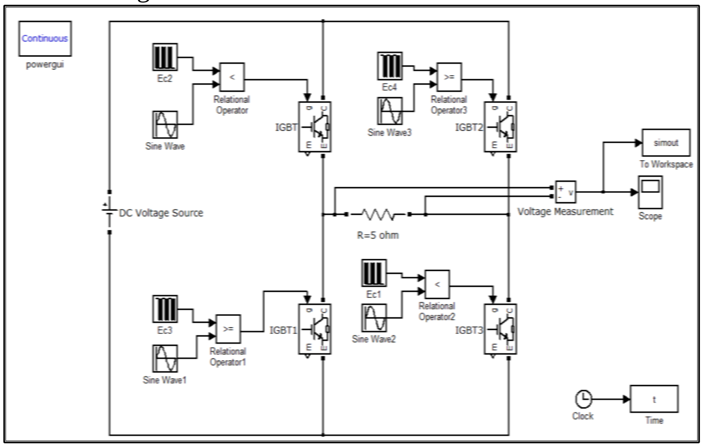


Fig 14. Simulink model of third level inverter using PWM for IGBT
(Unidirectional carrier)

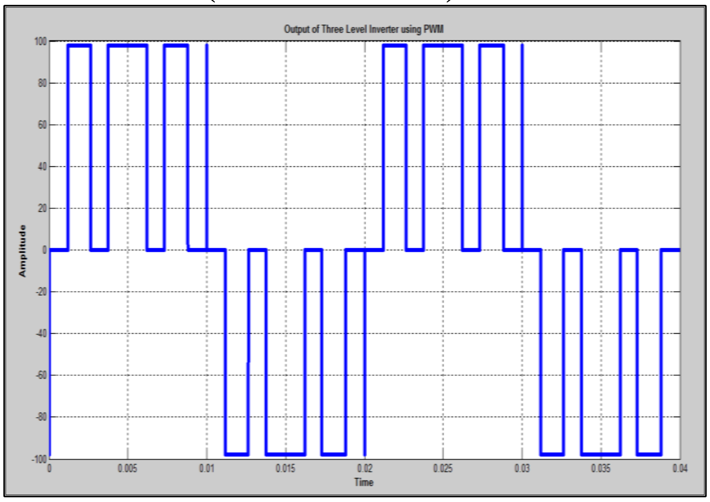


Fig 15. Output of third level inverter using PWM for IGBT
(Unidirectional carrier)

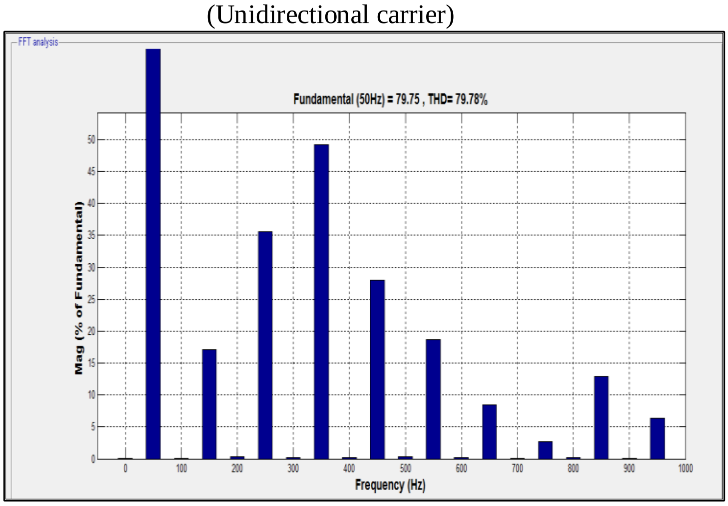


Fig 16. FFT Analysis of third level inverter using PWM for IGBT
(Unidirectional carrier)

V. CONCLUSION

Multilevel inverter have most promising device for the high power application. Among the all multilevel inverter, the cascade multilevel inverter requires less number of diode and capacitor with respect to other multilevel inverter to achieve desired output. Also using cascade multilevel inverter the harmonics distortion of the output waveform can be decrease and get desired output.

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