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Performance Analysis of 5-Level Diode Clamp Single Phase Inverter

Avishek Kumar[1], Vijay Anand Bharti[2]

[1]M.Tech, [2]Assistant Professor

Department of EE, Mittal Institute of Technology, Bhopal, India

Abstract—Many research works are focusing in the development of efficient multi level inverter for high performance of power conversion. Traditionally, switched capacitor multi level inverter with six switches has been commonly utilized for DC to AC power conversion. This involves the losses of the six switches as well as the complexity of the system. Thus the main issue of this work is to develop a cost effective, simple and efficient high performance single phase multi - level inverter. In this research work a single phase 5-level diode clamp inverter is used in which multi carrier pulse width modulation is done by means of sinusoidal reference signal and triangular carrier signal. In this pulse with modulation technique is used to reduce the total harmonic distortion which makes inverter more efficient. The advantage of this method is that the total harmonic distortion is less than 5% . Simulations have been done in MATLAB/ SIMULINK environment to explore the system response. The response obtained for the line current and line voltage (which shows very less THD in inverter). Result comparison has done which shows the better performance of the system.

Keywords— NPC, MLI, THD, MOSFET, VSC, EMC, PV, FC, DCI, MLC.

I. INTRODUCTION

The Inverter is an electrical device which converts direct current (DC) to alternate current (AC). In the early decade inverter was limited to two level inverter which implement a few semiconductors switch, however the with rapid growth in the industry and introducing the higher power application equipment which reaches the megawatt level the conventional two level inverter is not capable of handling high power application. Due to this reasons the need for introducing high level inverter(Multilevel inverter) become an essential to overcome the shortage of conventional two level inverter and efficiently high power loads besides these reasons multilevel inverter is aimed to replace the conventional two level inverter to gain good power quality, low switching losses, and high voltage capability.

Multilevel inverters have been under research and development for more than three decades and have found successful industrial applications. However, this is still a technology under development, and many new contributions and new commercial topologies have been reported in the last few years.

1.2 Power Converter

The DC/AC converter is one of the categories of power electronics technology that involves a conversion process and control in transferring electric power from an electrical DC source to an electrical AC output load, with a change in voltage magnitude, frequency, and number of output phases in a form that is suitable and efficient for the user electrical load. The advances of semiconductor power switch devices, such as the Bipolar Junction Transistor (BJT), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), and Insulated Gate Bipolar Transistor (IGBT) etc, have the capacity to improve power electronics DC/AC converter performance. Power electronics has emerged as a key technology in achieving the aforesaid. It involves application of solid state electronics for the conversion and control of electric power in a wide range (mill watts to hundreds of megawatts). Power electronic converters can be found anywhere wherever there is need to modify a form of electrical energy (i.e. change its current, voltage or frequency).

1.3 Concept of Power Converter

The principal function of a converter is to transform energy in a form of direct current (DC) or alternating current (AC) to either the same form or to the other i.e. DC to DC, AC to AC or DC to AC. Converters can also be operated in bidirectional mode, permitting the reduction of system components when used in certain applications such as starter generator drive systems. The use of power electronic semiconductors in such converters, alongside filtering components (inductors and capacitors), allows efficient conversion of electrical energy.

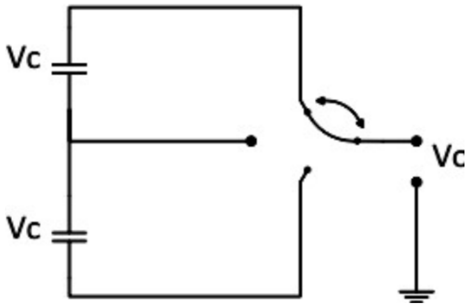


Figure 1.1: Basic Functional circuit of DC to AC Power Converter

For DC-DC conversion, the input voltage may be stepped up or down both with or without the use of a transformer. For the case of the DC to AC, a suitable sequence and ON time of the switching components is required to form the required output voltage.

1.4 Multi-Level Converter

The multi-level converter in the medium voltage energy management market provides a cost effective solution for industries. In multi-level converters, the desired output voltage is synthesized by combining one or more separate DC sources depending on the type of the multi-level converter. The most common independent sources used are photovoltaic panels, fuel cells, batteries and ultra-capacitors. The main advantages of multi-level converters are low harmonic distortion of the desired output voltage, low electromagnetic interference, high efficiency and the ability to operate at high voltages.

II. LITERATURE REVIEW

2.1 Introduction

DC to AC power conversion is a major technology in the new generation, transmission and distribution of electric power. DC to AC power converters play a crucial role in variable frequency drives, air conditioning, uninterruptible power supplies, induction heating, high voltage DC power transmission, electric vehicle drives, static VAr compensators, active filters, flexible AC transmission systems and DC power source utilization (such as electricity obtained from batteries, solar panels or fuel cells) [1,2]. With the advent of recent power electronics devices, digital controllers and sensors, the role of power inverters is also increase and acknowledged in futuristic grid connection with application of non-conventional energy sources like solar, wind, biogas, etc[3].

On the basis of the output generated by the inverter they are classified as: square wave inverter, quasi-square wave inverter, two-level inverter, and multilevel inverter [4]. The multilevel inverter (MLI) structure has been introduced as an alternative in high power and medium voltage situations. The elementary concept of an MLI to achieve higher power is to use power semiconductor switches along with several lower voltage DC levels to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple input DC levels. Power switches are controlled so as to aggregate these multiple input DC levels to achieve high voltage at the output, while the rated voltage of the power semiconductor switches depends on the rating of the DC voltage sources to which they are connected. Thus, in general, the voltage stress on a power switch is much lower than the operating voltage.

2.2 Review Based On Diode Clamped MLI

Baker and Bannister [5] in the mid-1970s, a first patent file which describing a converter topology capable of producing multilevel voltage from various DC voltage sources was published. In another patent by Baker [6] in 1980, a modified multilevel topology was introduced, for which three-level and five-level versions are illustrated. In contrast to the CHB inverters, this converter can produce multilevel voltage from a single DC source with extra diodes connected to the neutral point. This topology is now widely referred to as the neutral point clamped (NPC) inverter and/or diode clamped topology.

In 1980, Nabae et al [7] demonstrated the implementation of NPC inverter using a pulse width modulation scheme. In the 1980s much of the research was focused only on three-level inverters.

The so called flying capacitor (FC) was introduced in the 1990s by Meynard and Foch [8] and Lavieville et al. [9]. Much of the literature published in past few decades have shown intense focus in studying the diode clamped, flying capacitors and cascaded Hbridge topologies with regards to their respective pros and cons and these topologies are now widely referred to as the “classical topologies”.

Agelidis et al. [10] presented a multilevel PWM single-phase voltage-source inverter topology for photovoltaic applications, which utilizes a combination of unidirectional and bidirectional switches of different ratings along with the use of phase-opposition carrier disposition multicarrier PWM switching technique.

Manjrekar and Lipo [11] have presented a hybrid inverter based on the cascaded Hbridge topology for a 500 HP, 4.5 kV Induction Motor Drive, with investigations on design optimization, capacitor voltage balancing and harmonic profile of the output wave form.

Xioming and Barbi [12] presented a modified diode-clamped structure with a view to solve the problem of series-connected diodes in the conventional diode clamped inverter. In this structure, apart from the clamping of the main switches with clamping diodes, there is mutual clamping amongst the clamping diodes themselves.

Cheng and Crow [13] have proposed to employ an additional circuitry, integrated with the diode clamped inverter for implementing a static compensator with battery energy storage system (STATCOM/BESS) using a diode clamped structure, so as to achieve effective balancing of the DC link capacitors.

Mariethoz and Rufer [14] proposed a topology to reduce the number of DC-DC converters supplying the cells of reversible multilevel converters, combining in series a 3-phase 6-switch voltage source inverter with single phase

H-bridges, resulting in advantages in terms of voltage resolution and energetic efficiency.

Veenstra and Rufer [15] proposed an innovative topological structure using a three phase three-level integrated gate commutated thyristor inverter (main inverter), with a two level IGBT H-bridge (sub-inverter) in series with each phase by along with asymmetric source configuration to obtain a nine-level waveform for implementation of a medium voltage drives.

Chen et al. [16] proposed a fault tolerant topology to obtain uncompromised multilevel voltage waveform in the event of partial failure(s) in the power circuit, which maintains the output voltage waveform utilizing control signal modification along with redundancy offered by multi switching states application.

Grandi et al. [17] proposed a topology for photovoltaic medium and high power range with grid connection of two isolated photovoltaic generators, utilizing dual two level voltage source inverter so as to obtain a multilevel waveform thereby reducing grid current harmonics and mitigating output voltage derivatives.

Lezana et al. [18] have proposed a modification in the classical cascaded H – bridge topology with an active front end with the objectives of problem-free regenerative mode of operation for loads (such as laminators and downhill conveyors) demanding regeneration capability on the converter and effective control of the input current and output voltage waveforms.

Daher et al. [19] presented a solution for standalone applications requiring few kilowatts of power with single battery storage with a multilevel inverter topology utilizing multi-winding transformer with appropriate turn-ratios and an array of bidirectional power switches.

Du et al. [20] have shown implementation of a cascaded multilevel boost inverter for electric vehicle and hybrid electric vehicle applications without the use of inductors and multiple power supplies and utilizing a fundamental switching frequency modulation scheme.

III. PROBLEM FORMULATION

The current energy arena is changing. The feeling of dependence on fossil fuels and the progressive increase of its cost is leading to the investment of huge amounts of resources, economical and human, to develop new cheaper and cleaner energy resources not related to fossil fuels. In fact, for decades, renewable energy resources have been the focus for researchers, and different families of power inverters have

been designed to make the integration of these types of systems into the distribution grid a current reality. Besides, in the transmission lines, high-power electronic systems are needed to assure the power distribution and the energy quality. Therefore, power electronic converters have the responsibility to carry out these tasks with high efficiency. The increase of the world energy demand has entailed the appearance of new power converter topologies and new semiconductor technology capable to drive all needed power. A continuous race to develop higher-voltage and higher-current power semiconductors to drive high-power systems still goes on. However, at present there is tough competition between the use of classic power converter topologies using high-voltage semiconductors and new converter topologies using medium voltage devices. Power inverters are an amazing technology for industrial practice powered by electric drive systems. They are potentially helpful for a wide range of applications: transport (train traction, ship propulsion, and automotive applications), energy conversion, manufacturing, mining, and petrochemical, to name a few. Many of these processes have been continuously raising their demand of power to reach higher production rates, cost reduction (large-scale economy), and efficiency.

The power electronics research community and industry have reacted to this demand in two different ways: developing semiconductor technology to reach higher nominal voltages and currents (currently 8 kV and 6 kA) while maintaining traditional converter topologies (mainly two-level voltage and current source inverters); and by developing new converter topologies, with traditional semiconductor technology, known as multilevel inverters. The first approach inherited the benefit of well known circuit structures and control methods. Adding to that, the newer semi-conductors are more expensive, and by going higher in power, other power-quality requirements have to be fulfilled, thereby there may be need of additional power filters. Therefore it will be quite feasible to choose to build a new converter topology based on multilevel concept. This is the challenging issue right now.

IV. PROPOSED METHODOLOGY

5.1modulation Technique

Modulation is that the method within which the ability switches of an influence converter square measure controlled to modify from one state to a different. Modulation techniques for inverters needed to beat input voltage changes and meet the necessity of voltage/frequency management. With the appearance of MLI topologies, power electronic researchers centered on extending the standard two-level modulation to structure case. Whereas it gave rise to enhanced complexness so as to regulate additional power switches, additional flexibility was provided by the extra switching states generated by these topologies. As a result, an outsized range of schemes are developed and tailored relying upon the appliance and electrical converter topology, every having distinctive advantage and demerit. Figure 4.1 depicts the classification of the modulation schemes on the premise of the typical switching frequency with those MLIs operate. Techniques that operate with high switching frequency have several commutations of the ability switches per cycle of the elemental output voltage whereas the low switching frequency schemes usually have one or two commutations in one cycle of the fundamental output voltage. It ought to be noted here that for prime power applications, high shift frequency refers to frequency over 1 kHz [4].

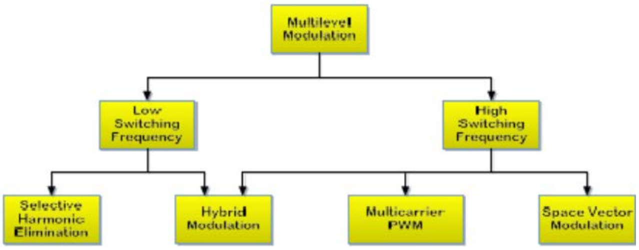


Figure 4.1: Classification of multilevel modulation methods

Neutral point clamped five-level inverter schemes discussed in literature are associated with inherent capacitor voltage balancing issues. The unequal voltage distribution across the capacitors will damage the semiconductor devices as well as generate harmonics at inverter output. The classical modulation schemes cannot utilize the more number of levels, redundant voltage vectors and zero common mode voltage vectors available in five-level DCI for achieving switching frequency reduction, common mode voltage elimination, capacitor voltage balance and reduction in THD, etc. The clamping diodes in five-level DCI share unequal voltages for a given switching state and to distribute voltage stress equally among the diodes, 12 clamping diodes of equal voltage ratings ($V_{ds}/4$) are required. Converter topology which minimizes the series connected devices and shares the total voltage equally among the devices during a valid switching state is required for achieving improved efficiency.

V. PROPOSED SINGLE PHASE MULTILEVEL INVERTER

Neutral point clamped five-level inverter schemes discussed in literature are associated with inherent capacitor voltage balancing issues. The unequal voltage distribution across the capacitors will damage the semiconductor devices as well as generate harmonics at inverter output. The classical modulation schemes cannot utilize the more number of levels, redundant voltage vectors and zero common mode voltage vectors available in five-level DCI for achieving switching frequency reduction, common mode voltage elimination, capacitor voltage balance and reduction in THD, etc. The clamping diodes in five-level DCI share unequal voltages for a given switching state and to distribute voltage stress equally among the diodes, 12 clamping diodes of equal voltage ratings are required. Converter topology which minimizes the series connected devices and shares the total voltage equally among the devices during a valid switching state is required for achieving improved efficiency.

The objective of this chapter is to propose an multicarrier-based voltage balancing strategy for a new five-level single phase NPC-MLI topology which uses lower number of clamping diodes compared to classical five-level DCI. A simple switching function model of the new topology is derived which predicts the dc-link capacitor currents by sensing load currents for given switching state. Here, the redundant voltage vectors present in five-level inverter are utilized to provide a balanced voltage across the four dc-link capacitors and the need for balancing circuit is eliminated. 5.2 Single Phase NPC-MLI

VI. SIMULATION RESULTS

6.1 Simulation

In this chapter discuss about the simulation of the proposed system which discussed in previous chapter. MATLAB is the software which is used for simulation of the proposed system. The main objective of simulation is to check the performance of the proposed neutral phase clamped multilevel inverter (NPC-MLI) with the application of various load in domestic application. For simulation of the proposed work here simpower system tool box of MATLAB is used. Figure 6.1 shows the Simulink model of the proposed system.

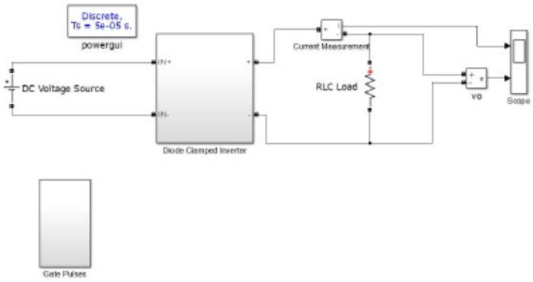


Figure 6.1: SIMULINK model of proposed NPC-MLI

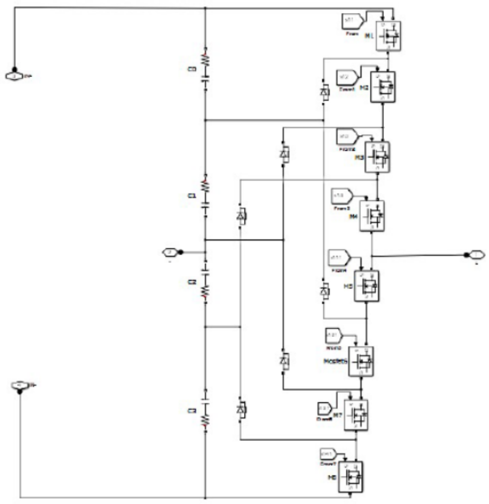


Figure 6.2: Proposed New Diode Clamped Circuit for Generation of 5 level Output

Figure 6.2 shows the inner block of the proposed diode clamped inverter system. In the proposed system eight switches is used for generating output voltage with two groups as discussed in chapter 5. In the proposed multilevel inverter six diodes are used for clamping action. The voltage is balancing with the help of four capacitors which is connected in series to produce the output voltage from the single source application.

The upper four switch produce positive output voltage and the lower four switch produce negative output voltage with the help of capacitors. A multi carrier PWM technique is used for operating the switch. Here in this simulation four carrier wave the sinusoidal wave to produce the pulse for the switch as the table 5.1 discussed in chapter 5. Figure 6.3 shows the internal circuit of the PWM generator.

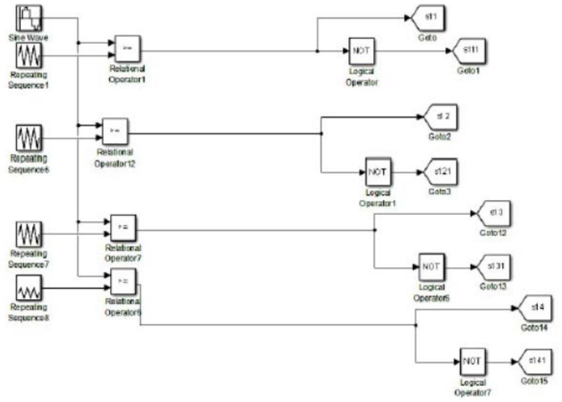


Figure 6.3: SIMULINK model of Multicarrier PWM used for pulse generation

6.2 Result & Discussion

In this section the result generated by the running of the proposed system in MATLAB is discussed. For simulation of the proposed work the DC voltage is taken 500 V, DC link capacitor capacita is 2 kHz. The switch is used here in MOSFET.

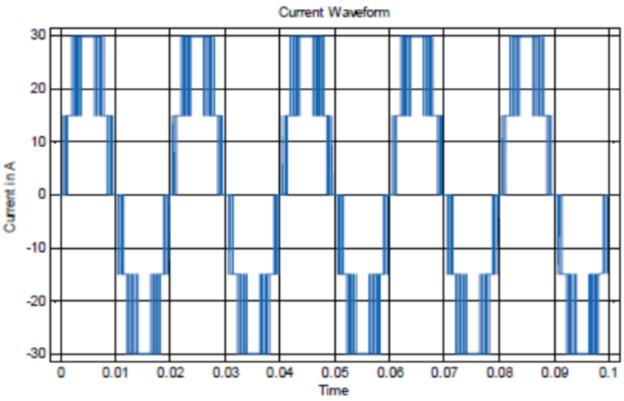


Figure 6.4: Current output of Resistive load in Proposed Single phase NPC-MLI

6.2.1 Performance of Analysis of R Load

For domestic load it is clear that it is either resistive or inductive in nature. For checking performance of the proposed system here we take a resistive load of 220 V, 5kW is connected to the system. Figure 6.4 shows the current response of the system. It is clearly seen that the output in 5 level output.

Figure 6.5 shows the THD analysis of the current output of the proposed system.

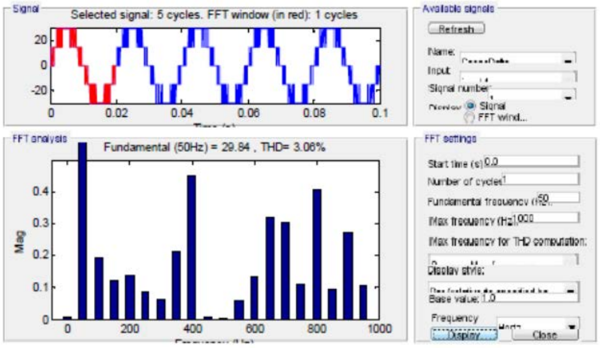


Figure 6.5: FFT Analysis of current waveform of the proposed single phase NPC-MLI

From the figure 6.5 it is clearly seen that the total harmonic distortion of the proposed system is about3.06%. Figure 6.6 and 6.7 shows the voltage output and FFT analysis of the proposed system with resistive load.

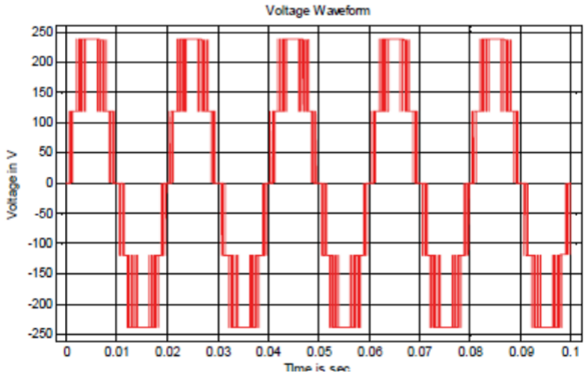


Figure 6.6: Voltage output of Resistive load in proposed single phase NPC-MLI

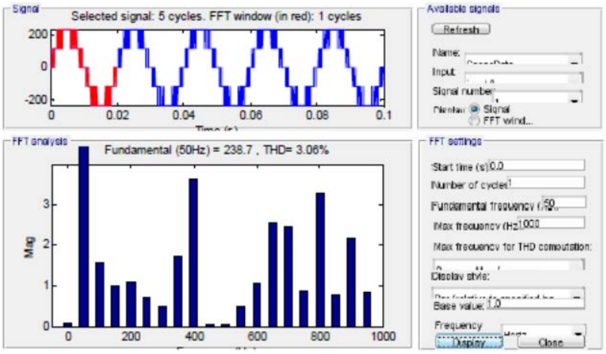


Figure 6.7: FFT Analysis of Voltage waveform of single phase proposed NPC-MLI

The output is clearly seen that it is 5 level output of maximum voltage 240. Because of the resistive load the output current and voltage is in phase it is clearly seen from figure 6.4 and 6.6. The THD of the voltage is 3.06%. Figure 6.7 shows the multicarrier PWM technique which is used for pulse generation in this simulation.

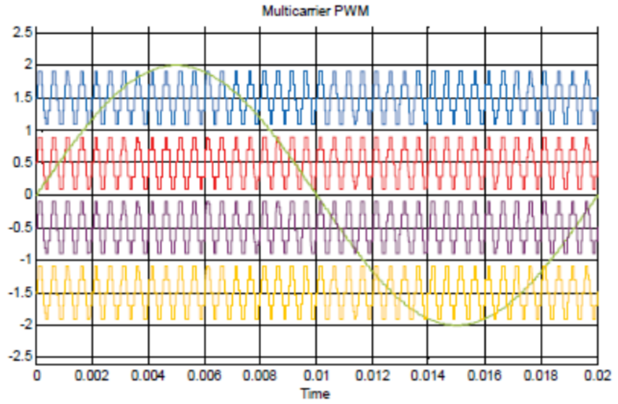


Figure 6.7: Multicarrier PWM simulation for Pulse generation

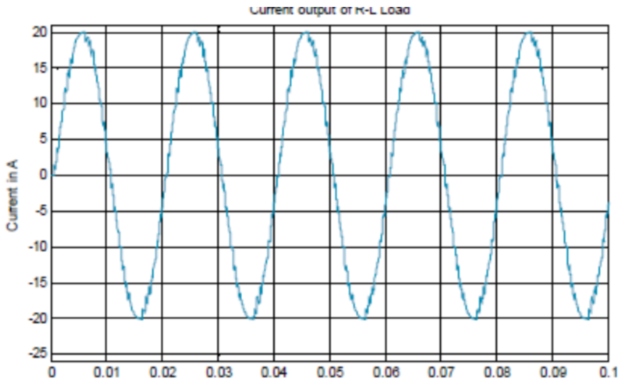
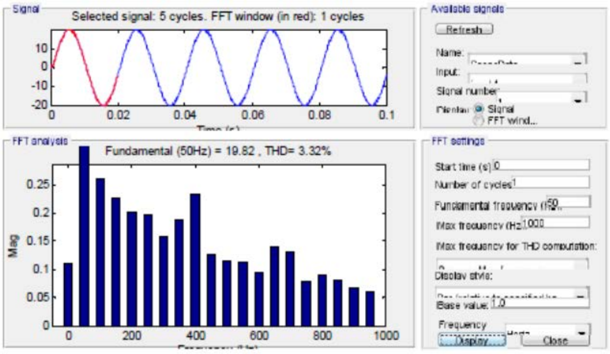


Figure 6.8: Current output of R-L Load for single phase Proposed NPC-MLI

As discussed in chapter 5 there are four carrier signals are superimposed in the sinusoidal signal to produce pulse for all positive group switch. And negative group is connected with not gate for complementary action.



Selected signal: 5 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 19.82 , THD= 3.32%

Start time (s) 0
Number of cycles 1
Fundamental frequency (Hz) 50
Max frequency (Hz) 1000
Max frequency for THD computation:
Base value: 1.0

Figure 6.9: FFT Analysis of Current waveform of single phase proposed NPC-MLI

6.2.2 Performance Analysis of R-L load

Here in this section discuss the performance of the R-L load of the proposed single phase NPC-MLI. A 220V, 5kW, 1kVAr R-L load is connected to the proposed NPCMLI. The figure 6.8 and 6.9 shows the current output and FFT analysis of the proposed system.

Here from the figure 6.8 it shows the current is sinusoidal in nature. This is because the inductor present in the load. From the figure 6.9 gives the total harmonic distortion of the current is 3.32%.

Figure 6.9 shows the voltage output of the R-L load with proposed single phase NPCMLI and figure 6.10 shows its FFT analysis.

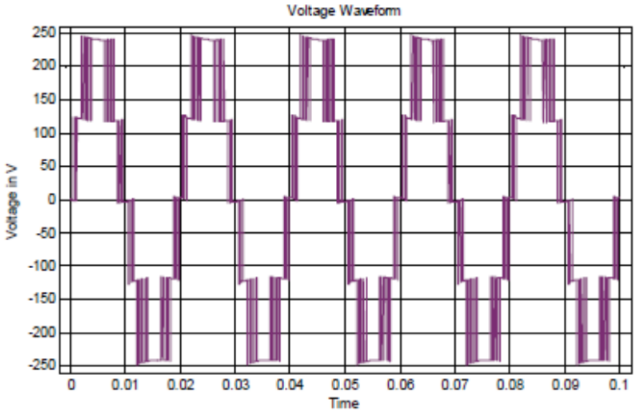
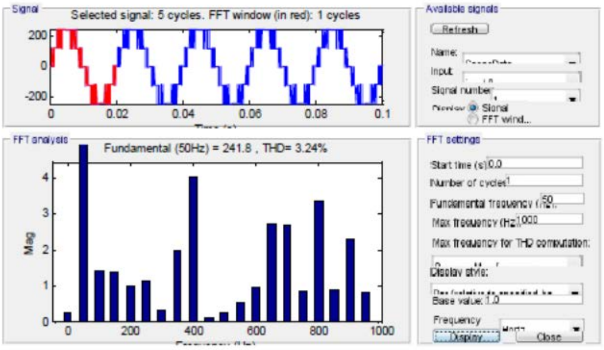


Figure 6.9: Voltage Output of R-L Load with proposed single phase NPC-MLI



Selected signal: 5 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 241.8 , THD= 3.24%

Start time (s) 0.0
Number of cycles 1
Fundamental frequency (Hz) 50
Max frequency (Hz) 1000
Max frequency for THD computation:
Base value: 1.0

Figure 6.10: FFT Analysis of Voltage waveform of single phase proposed NPC-MLI From the figure 6.10 it is clearly seen that the total harmonic distortion of the output voltage is 3.24%.

VI. CONCLUSION & FUTURE WORK

6.1 Conclusion

Power inverter plays major role in the conversion of the DC power to AC power. Now a day due to increasing application of non-conventional energy sources the requirement of power inverter is also increase. Conventional power inverter produces harmonics in the appliances. This harmonics decay the life of the domestic appliances. Traditionally there is two stage of conversion used for power conversion. It’s making circuit more complex and costlier. On the basis of this here required a new type of power inverter which having less complex circuit and also produce low harmonics to the system.

6.2 Future Work

The thesis is based on the application of NPC-MLI for single phase supply system. The research is only based on the improving harmonics profile of the system. There are following future aspect of this thesis:

- Thesis is based on diode clamped inverter in which voltage balancing is more in concern. Here in the future flying capacitor technology may be used for improving the voltage balancing system.
- The proposed system is utilized in future for compensating the harmonics present in the distribution system as a FACT device.
- In the future DSP is applied in the generation of multilevel inverter system for enhancing the behavior of the system.
- In future hardware application of the proposed system can be modeled.
- In future full bridge implementation work is also implemented.

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