A new multilevel inverter with reduced switch count for renewable power applications

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Article Info	ABSTRACT

This paper proposes a new technique for a voltage source multilevel inverter (MLI) with reduced switch count, and it creates a smoother sinusoidal output waveform with reduced total harmonic distortion (THD). Therefore, the proposed technique identifies a better position in the list of multilevel converters used for power quality conditioners. Semiconducting devices are added to it if the number of levels increases. In this work, the topology of MLI with reduced number of switches is presented. A new MLI is proposed with lower number of switches and sources in order to achieve higher level. The proposed topology is framed out with the combination of three half bridge and a single H-bridge configuration. Detailed simulation results for 15-level inverter of single and three phase inverters are presented in this paper. Three phase 15-level inverter is developed by employing three isolated different renewable sources and 21 switches.

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1. INTRODUCTION

Nowadays, the electrical energy became an essential commodity and has a rapid demand for its generation. The modern electrical system contains conventional as well as renewable sources. The renewable sources are natural sources which are not depleted. To address the environmental concerns and for overall economic development, the addition of major renewable sources of energy, and transition from conventional energy to renewable energy is required. There are different types of renewable sources available such as solar, wind, tidal, geo thermal, bio mass, hydro electric energy. In the present paper, photo voltaic array (PVA) cell, fuel cell and battery are used as three isolated renewable souces [1]. The voltage of PVA totally relies upon sun oriented illumination and surrounding temperature. PVA is a blend of arrangement and parallel sun powered cells arranged in a cluster to produce required voltage and current. Fuel cell converts synthetic energy of crude materials into electrical energy. Batteries are the most widely recognized power hotspot for fundamental handheld gadgets to expansive scale mechanical applications. It is a blend of at least one electrochemical cells that are equipped for changing over put away synthetic energy into electrical energy [2]. Reversal of direct current into rotating current is a built up idea, however the nature of upset power is the principle worry behind each procedure centre around the power quality issues at the inverter end. Inverters can be voltage source and current source type. The power nature of inverter is totally relies on the inverter structure and control procedures. A definitive point is to coordinate the inverter for more smoother sinusoidal and subsequently to diminish the symphonious substance. There are various techniques accessible for structure and control of the inverter to get sinusoidal by reduction the THD [3]. Researches are

currently giving more consideration to spare electric energy by lessening the harmonics. By expanding the quantity of levels, the THD is diminished impressively, however it leads to an increase in number of switches and the relating exchanging misfortunes. Clearly the control and entryway driver circuit for the inverter get mind boggling and massive which results surprising expense and overwhelming size of the general system. It is hard to change the square wave into sinusoidal however conceivable with high esteemed filters and decrease in rms voltage [4]. Power quality increases linearly with semiconductor devices and is unbiased of the topology used [5]. The THD accomplished by way of multipulse converters for given levels is higher than that of multilevel converters but this advantage is misplaced if manipulate of ac voltage is to be made impartial of dc voltage. If commutation failure takes place in an IGBT multicell inverter, the failure may additionally both be a incorrect gate voltage or an intrinsic IGBT failure [6]. For an electric vechicle, hybrid cascaded multilevel inverter (MLI) is used and it enhances power to the device [7]. By this inverter, performance is enhanced in motor drives. The implementation of high step-up voltage conversion with automatic variation of duty ratio voltage clamping feature and by turns ratio of the coupled inductor is proposed in [8]. References [9, 10] present a comprehensive review of recently developed multilevel inverters with reduced power switch count. A new structure for a boost multilevel inverter (MLI) topology based on the concept of switched-capacitor is proposed in [11]. Two new topologies for staircase output voltage generations are proposed in reference [12] with a lesser number of switch requirement. A single-phase MLI topology to reduce the number of switches in the circuit and obtain higher voltage level at the output is proposed in [13].

From the available literature it is clear that, power quality is the major consideration to maintain proper conditioning of any device. Due to increase in harmonics in low level converters result in heat loss and also distortions in output voltage [14]. These problems may impact on functioning of devices. The major contributions of this paper are listed below.

−   A new voltage supply of multilevel converter is generated with smoother sinusoidal output waveform by lowering THD.
−   Semiconducting devices are also added as per the required levels. A new inverter is formed with maximum level using lesser number of switches and isolated renewable sources which will acquire most level.
−   The new topology is framed out by cascading three half bridge and a single H-bridge configuration. Three phase 15 level inverter is generated with lesser number of switches and DC sources
−   By taking the advantage of lesser number of switches and DC souces, a binary combination of renewable DC sources is chosen for every level to decrease the THD.

In this work, following the introduction part in section 1, section 2 is detailed on the presentation of proposed MLI with reduced number of switches. Afterward, in section 3, simulation results are presented. Finally, conclusive notes given in section 4.

2.   PROPOSED MULTILEVEL INVERTER (MLI) WITH REDUCED SWITCHES

This section presents the conventional systems, control strategies, logic in multi-level inverter, single phase inverter, three phase inverter, and types of conduction in an inverter. The output voltage is generated with MLI and control model [15]. The combination of MLI with reduced number of switches improves the performance of power quality conditioners.

2.1. Conventional systems

A cascaded MLI generates output of 5 levels with 8 switches, 7 levels with 12 switches, 9 levels with 16 switches, and so on. Using 4 switch and one dc source for each H-bridge, it produces one level of voltage output, and it is depicted in Figure 1. General expression for output voltage levels is $m = (n + 2)/2$, where n is number of switches in an inverter. Each bridge gives 3 output levels, i.e., $+V_{dc}$, 0 and $-V_{dc}$. Number of levels in three phase circuit means the output phase and line voltages are *2s+1* and *4s+1* respectively, where s is the number of H-MLI [16, 17]. The value of an ac output phase voltage is the sum of voltages produced by each H-bridges. The conventional cascaded n level MLI is depicted in Figure 1 with voltage sources, switches, and the inverters connected in cascading method. This cascaded inverter has 2(m-1) main switching devices, 2(m-1) main diodes, no clamping diodes, (m-1) (m-2)/2 number of DC bus capacitors and zero balancing capacitors [18].

Thinking about absolute three sources and three switches, single switch per source or two semiconductor gadgets for every source is considered. Seven reference signals are contrasted with the sine wave which produce the entryway signals for the half scaffold switches, and they are in charge of creating sinusoidal waveform. The recurrence of reference wave is the standard network recurrence (or) expected

inverter recurrence [19]. Consequently, the recurrence of door signals to the half extension switches will have double recurrence. To get reduced THD, it is required to change the progression estimate that coordinating with a unique required sine wave. For a perfect sinusoidal voltage, pulse width is adjusted as per the requirement. The sine wave is allowed to go through the midpoint of each reference voltage levels, which will make a lower least THD voltage [20, 21]. Control signals are created with the help of pulse generators and rationale entryways. The inversion of supply happening at the zero dimensions, it will diminish the exchanging pressure and hence dv/dt can be decreased enormously.
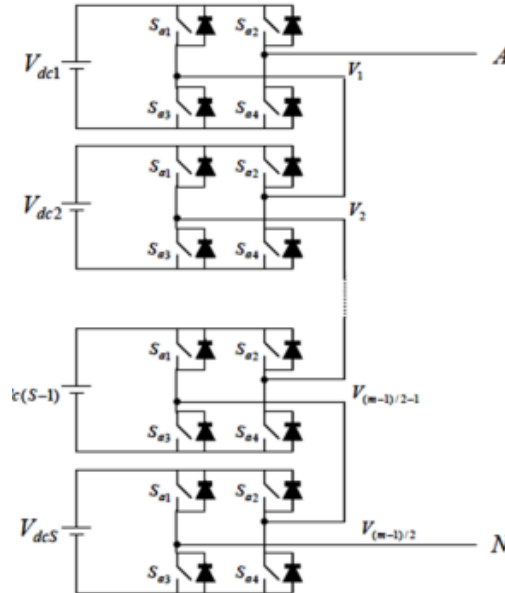

Figure 1. Conventional cascaded *n* level (multilevel) inverter

2.2. Inverters
An inverter alludes to a power electronic device that changes power in DC frame to AC shape at the required recurrence and voltage. Inverters are classified into two fundamental classes [22]:
− Voltage Source Inverter (VSI): It has firm DC source voltage that is the DC voltage has constrained or zero impedance at the inverter input terminals.
− Current Source Inverter (CSI): It is provided with a variable current from a DC source that has high impedance. The subsequent current waves are not affected by the load.

2.2.1. Single phase inverter
There are two sorts of single stage inverters available, and they are half scaffold inverter and full extension inverter [23]. The half scaffold inverter is the essential building square of a full scaffold inverter. It contains two switches and every one of its capacitors has a voltage yield equivalent to $V_{dc}/2$. Similarly, switches supplement each other, i.e., whether one is exchanged ON, then the other one goes OFF [24, 25]. Full extension inverter circuit changes over DC to AC. It accomplishes this by shutting and opening the switches in the correct grouping. It has four distinctive working states which depend on which switches are to be closed.

2.2.2. Three phase inverter
A three-stage inverter changes over a DC contribution to a three-stage AC. Its three arms are regularly deferred by an edge of 120° to create a three-stage AC supply [26]. Exchanging of inverter switches happens after each T/6 of time T (60° point interim). The switches Sw1 and Sw4; Sw2 and Sw5; Sw3 and Sw6 supplement each other. Figure 2 depicts three stage inverter circuit. It is only three single stage inverters put over a similar DC source. The shaft voltages in a three stage inverter are equivalent to the post voltages in single stage half extension inverter [27, 28].
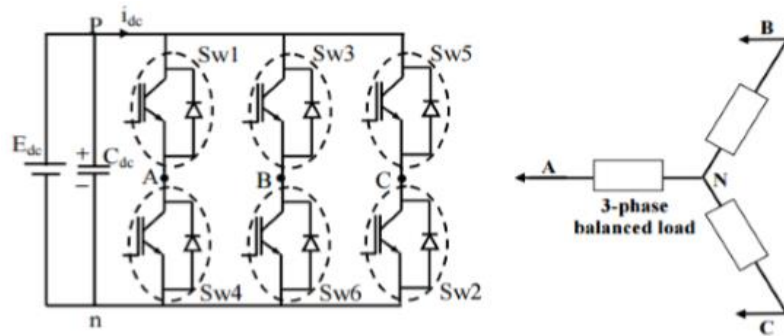
Figure 2. Three phase inverter

2.2.3. Types of conduction

There are two methods of conduction, and they are 180° method of conduction and 120° method of conduction. In 180° method of conduction, each gadget is in conduction state for 180° where they are exchanged ON at 60° interims [29]. The terminals A, B and C are the yield terminals of the scaffold that are associated with three-stage delta or star association of the load. The task of an adjusted star associated load is clarified in the graph beneath. For the period (0° - 60°), the focuses Sw1, Sw5 and Sw6 are in conduction mode. In 120° method of conduction, each electronic gadget is in a conduction state for 120°. It is appropriate for a delta association in a load since it brings about a six-advance sort of waveform over any of its stages [30]. In this way, at any moment just two gadgets are leading on the grounds that every gadget conducts at just 120°. Detailed inverter circuit is depicted in Figure 3. The terminal A on the load is associated with the positive end while the terminal B is associated with the negative end of the source. The terminal C on the load is in a condition called coasting state [31]. The fundamental 3-stage inverter is a six-advance inverter. A stage is characterized as an adjustment in the terminating arrangement.
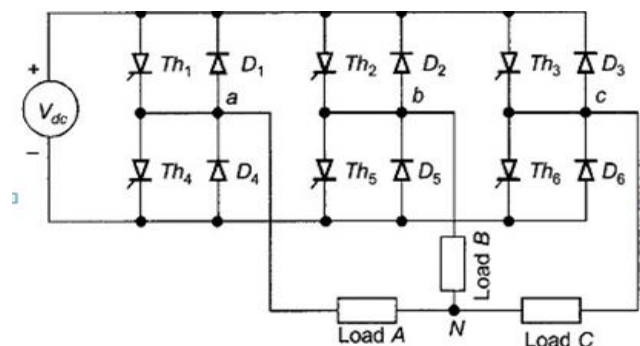

Figure 3. Detailed inverter circuit

Th1 to Th6 are the six load-conveying thyristors while D1 to D6 are the free-wheeling diodes. Each match of thyristors in a branch (Thl and Th4; Th2 and Th5; Th3 and Th6) are gated for T/2 and are out-of-stage with each other, i.e., they are never gated all the while. Th1, Th2 and Th3 are fired out-of-stage continuously by 120° as are Th4, Th5 and Th6 [32]. This is an absolute necessity to acquire three yield voltages out-of-stage by 120°.

3.   RESULTS AND DISCUSSION

The utilization of MLI is held and the proposed system is recreated in the MATLAB Simulink programming. An ideal air conditioning voltage can be taken structure the H-connect yield side of the proposed new double cross breed fell H connect multilevel converter for air conditioning power applications, for example, utilizing in active filters, or to associate with the power framework. The air conditioner of converter is multi-level voltage, and a proficient energy the executives' calculation is created for exchanging

battery units as indicated by the parallel example [33]. Thus, the quantity of voltage levels are more noteworthy than the absolute number of battery units. It will decrease absolute symphonious substance of the converter yield. By suitable exchanging of the dc sources, it can get various strides in the yield voltage waveform. The results of output voltage, THD of single phase and three phase inverter were obtained.

3.1. Results of single phase multilevel inverter (MLI)

MATLAB simulation model of single phase MLI is depicted in Figure 4. Three battery sources, i.e., 12V, 24V, 48V are connected to single phase MLI. This single phase MLI consists of three half bridge and single H-bridge configuration. By using this configuration, 15 level inverter is generated as output voltage of 84V.
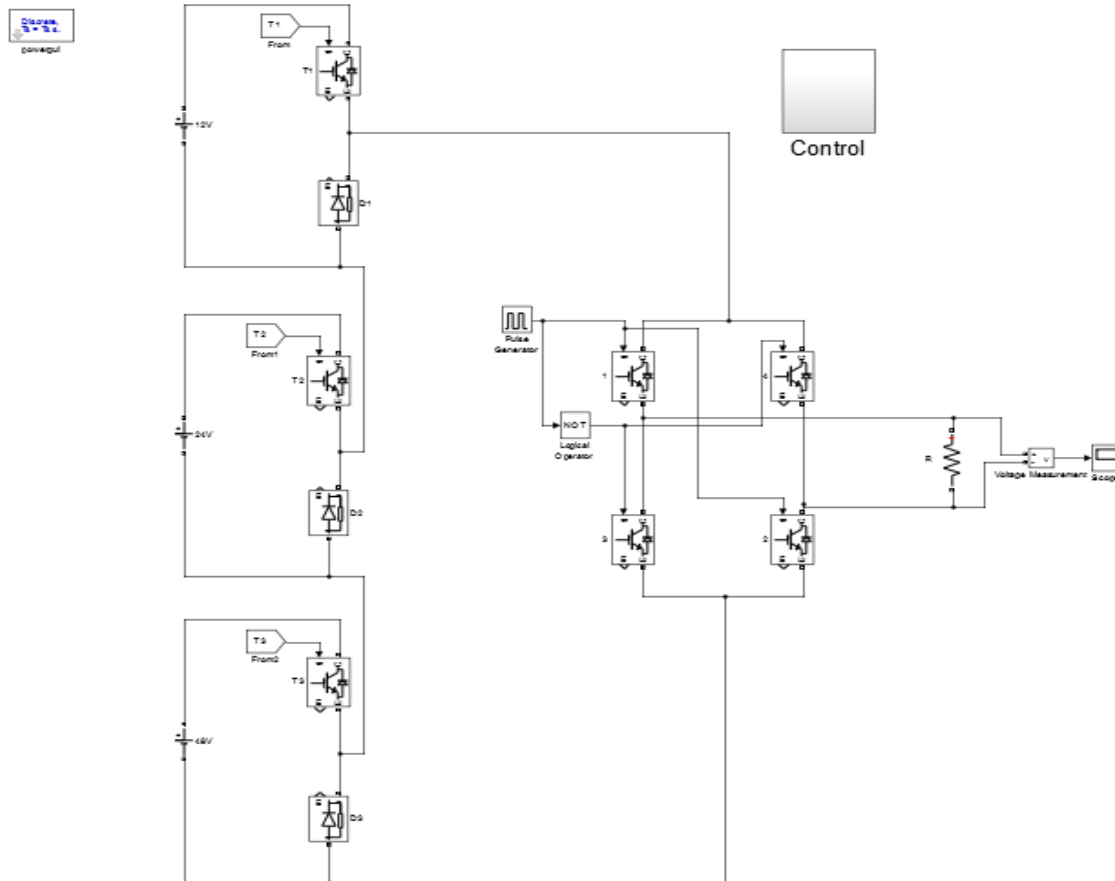

Figure 4. Single phase multilevel inverter (MLI)

3.1.1. Control model

The control model is used to generate control signal pattern. By using this control signal pattern, the output voltage of 15 level multi-inverter is generated. The control model of MLI is depicted in Figure 5.

The control pattern is generated by using control model of MLI. Logic gates are used in control model, and the control signal pattern is generated from control model to yield single phase output voltage. The output voltage of 15-level inverter is depicted in Figure 6 (x-axis is taken as time (in s) and y-axis is taken as output voltage (in V). The obtained ouput voltage of this single phase MLI is 84V. Figure 6 also depicts the FFT analysis of output voltage (x-axis is taken as frequency (in Hz) and y-axis is taken as magnitude (in % of fundamental), and it calculates the THD of output voltage. The obtained THD of output voltage is 7%.
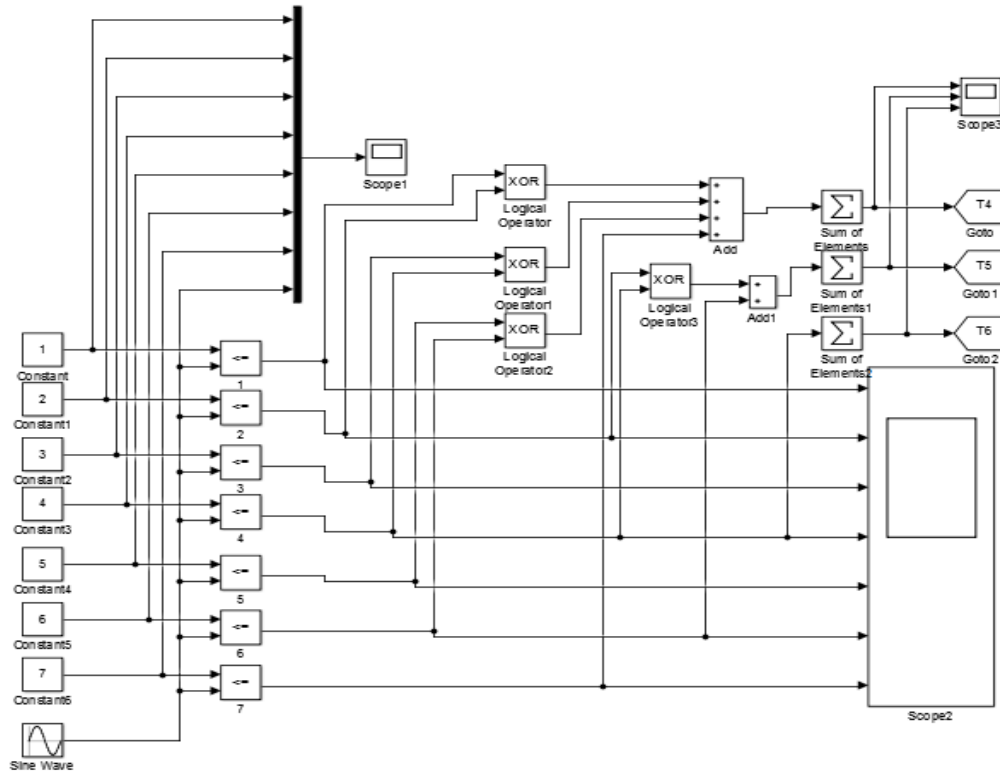
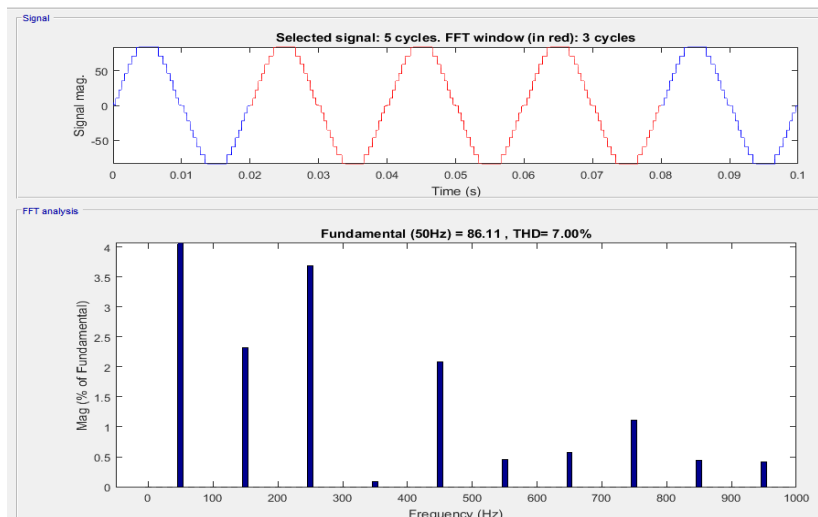Figure 5. Control model of multilevel inverter (MLI).

Figure 6. Output voltage and FFT analysis of single phase MLI

3.2. Results of Three Phase Multilevel Inverter (MLI)

Figure 7 depicts the MATLAB model of three phase MLI and it is connected to an induction motor. Three sources, i.e., fuel cell, battery and PVA cells are connected to the combination of cascaded three half bridge and H-bridge configuration each leg of topology. Fuel cell, battery, PVA cells constitute voltages of 60V, 120V and 240V. They produce the maximum voltage of three phase 420V. The resultant voltage is used to run three phase 400V induction motor.
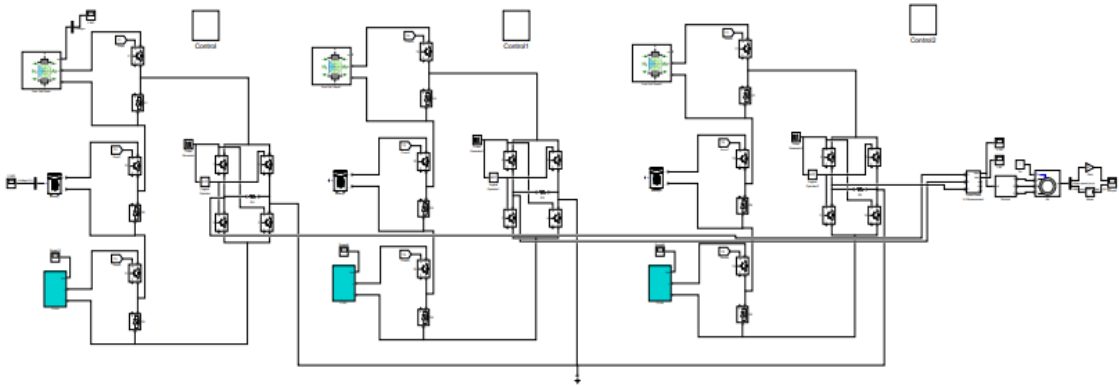
Figure 7. Three phase multilevel inverter (MLI)

Figure 8 depicts the output voltage of three phase inverter (x-axis is taken as time (in s) and y-axis is taken as output voltage (in V)), and the obtained maximum voltage is 420V. Figure 8 also depicts the THD of output voltage (x-axis is taken as frequency (in HZ) and y-axis is taken as magnitude (in % of fundamental), and the THD obtained is 6.52%.
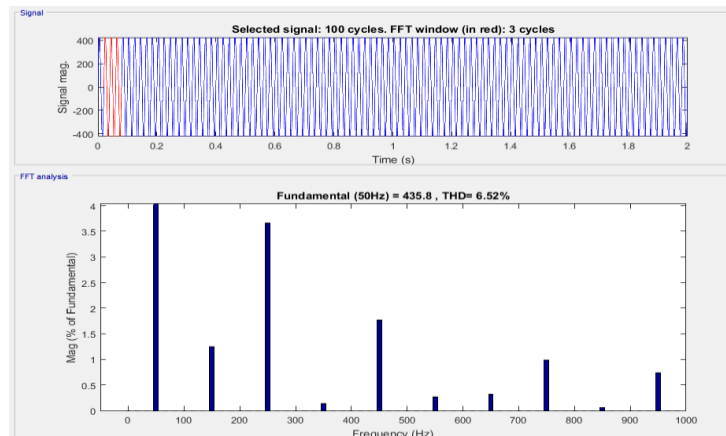

Figure 8. Output voltage and FFT analysis of three phase MLI

The conventional method of cascaded inverter consists of 2(m-1) switches. For example, 15-level conventional topology has 28 switches for single phase and 84 switches for three phase. But by using the proposed topology, the number of switches, levels and THD obtained for single phase MLI are 7, 15 and 7%, respectively; whereas for three phase MLI are 21, 15 and 6.52%, respectively. Comparing with conventional method, the proposed topology has less number of switches, and this reduces the switching stress.

4. CONCLUSIONS

In this paper, a new topology is proposed for a three phase 15-level inverter with reduced number of switches and sources. The proposed topology is formed with cascading three half bridge and H-bridge configuration. This configuration comprises of three isolated different renewable sources (i.e., photovoltaic array cell, fuel cell and battery) and twenty-one switches. The total harmonic distortion of acquired yield three phase voltage is 6.52% which is adequate in a multilevel inverter utilized for active filters. Multilevel voltages with decreased harmonics are useful to improve the exhibition power quality conditioners. Successful utilization of the sources can be guaranteed by utilizing this topology and maximum blend accomplishment is the primary fascination of the converter.

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