Multilevel Inverter using SVM for AC Drive Application

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***Abstract*— Multilevel inverter (MLI) technology has emerged recently as a very important alternative for energy control, especially in case of ac drive applications. However, these applications have several stability and performance issues. To overcome these problems, effective control techniques have been incorporated to enhance the harmonics, power factor, complex circuitry. This paper presents a new topology of inverter to get increased output levels along with reduced Total Harmonic Distortion (THD). System stability is associated with improvised power factor which is achieved using interleaved phase-shift boost converter (IBC) module. Switching control for the inverter module is given by space vector modulation (SVM) technique based upon the comparison of harmonic injected reference with carrier signals. A comparative study is performed for the analysis of THD by connecting the output of the MLI topology to a three-phase resistive load and a motor load. The multilevel inverter topology along with the interleaved phase-shift converter is simulated using MATLAB/SIMULINK software for nine levels of stepped voltage output.**

Index Terms* – *Multilevel Inverter (MLI), Inter leaved phase-shift Boost Converter (IBC), Space Vector Modulation (SVM) Technique, Power factor correction

I. INTRODUCTION

In recent times, the requirement for pure energy and the need to conserve power has stimulated the rapid growth of sustainable power generation used for high voltage applications. The demand for control of electric power for electric motor drive systems and industrial controls existed for many years, and this led to the early development of equipments that are employed to control motor drives [2]. Power electronics has revolutionized this concept of power control for power conversion.

Among the different solutions available, multilevel inverters provide a novel approach for reaching high voltage and reducing harmonics without the use of transformers. With no transformers and less switching frequency, multilevel inverters provide higher efficiency, smaller size and lower cost compared to the conventional solutions available [3]. For these reasons, this kind of topology has attracted a lot of attention both from the customers and the manufacturers.

The concept of multi-level converter structure was introduced in 1975 as alternative in high power and medium voltage situations. Multi-level inverters have been attracting in favor of academia as well as industry over the last three decades for high-power and medium-voltage energy control. In addition, they can synthesize switched waveforms with lower levels of harmonic distortion than an equivalently rated two-level converter [4]. The multi-level concept is used to decrease the harmonic distortion in the output waveform without decreasing the inverter power output. Multi-level inverters include an array of power semiconductors and capacitor voltage sources, the output of which generates stepped waveforms.

II. EXISTING TOPOLOGY

A. *Block Diagram*

The block diagram shown in Fig. 1 is used in the existing topology [1] to get the three-phase five voltage level output. The three-phase AC voltage source with a magnitude of fixed DC supply (V_{fix}=90V) is directly given to the multilevel inverter topology. The appropriate switching gate signals needed for the inverter circuit are fired from pulse generator.

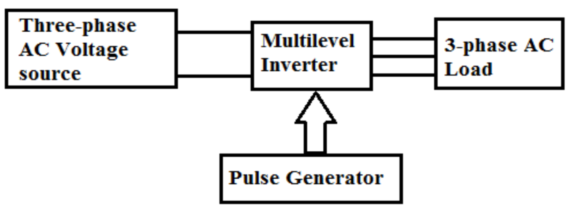

Figure 1. Block diagram of existing model

The three-phase AC output got from the inverter topology is given to a fixed three-phase series resistive-inductive load (23Ω-3mH/Phase) in start connection. A DSP controller was used to control the gate signals and to perform the other functions.

B. *Conventional Circuit Diagram*

Three bidirectional switches are used along with a multilevel DC link built by a single DC voltage supply with fixed magnitude. The Fig. 2 shows the typical configuration of a three-phase five-level inverter circuit used in the existing topology [1].

The main function of these bidirectional switches is to block the higher voltage and to ease the current flow to and from the three legs of the three-phase inverter topology. According to the desired number of output voltage levels, a number of cascaded H-bridge (CHB) cells are used. Here, two CHB cells are used and in each cell, two switches are turned ON and OFF under inverted conditions to get the output levels.

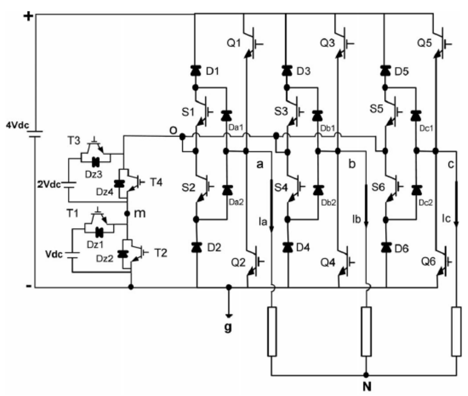

Figure 2. Circuit diagram of the existing multilevel inverter

C. *Switching Algorithm*

A particular type of switching algorithm was used to determine the magnitudes of utilized DC voltage supply. Fixed staircase modulation technique was implemented for the proposed inverter to generate the inverter's switching gate signals. In order to achieve the desired number of voltage levels, three algorithms or three methods were followed as enumerated below.

All cells have equal DC supply in magnitude.

$$V_{dc1} = V_{dc2} = \ldots = V_{dcn} = V_{dc} \quad (1)$$

Then, the magnitude of fixed DC supply can be chosen as,

$$V_{fix} = (N-1)V_{dc} = (1+n)V_{dc} \quad (2)$$

Where, n - number of utilized cells and $N = n + 2$

The magnitude of DC voltage supply used in each and every cell in a particular inverter is obtained as follows:

$$V_{dc1} = V_{dc} \quad (3)$$

$$V_{dc2} = 2V_{dc} \quad (4)$$

$$V_{dcn} = nV_{dc} \quad (5)$$

$$V_{fix} = (N-1)V_{dc} = [1 + \frac{n(n+1)}{2}]V_{dc} \quad (6)$$

Where, $N = 2 + \frac{n(n+1)}{2}$

By making binary (power of two) relationship between the DC supplies of the cascaded half-bridge structure as following:

$$V_{dc1} = 2^{(0)}(V_{dc}) \quad (7)$$

$$V_{dc2} = 2^{(1)}(V_{dc}) \quad (8)$$

$$V_{dcn} = 2^{(n-1)}(V_{dc}) \quad (9)$$

$$V_{fix} = (N-1)V_{dc} = [1 + \sum_{j=1}^{n} 2^{j-1}]V_{dc} = (2^n)V_{dc} \quad (10)$$

Where, $N = 1 + 2^n 2^n 2^n$

III. PROPOSED SYSTEM

The proposed system explains about the topology of a three-phase nine-level multilevel inverter using three bidirectional switches and cascaded half-bridges. The block diagram shown in Fig. 3 describes the function features of the proposed topology.

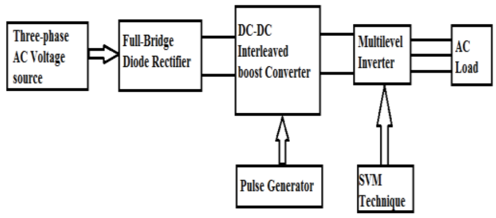

Figure 3. Block diagram of the proposed topology of multilevel inverter

The concept of space vector modulation is implemented to trigger the gate pulses and to regulate the switching pattern for the multilevel inverter. An interleaved phase-shift boost converter is used to improve the power factor correction and to measure the same. At the final stage, the system is connected to a three-phase induction motor load and operated.

A. *Power factor Improvement*

The ratio of the active power flowing to the load, to the apparent power in the circuit is referred to as power factor. It is a dimensionless number between 0 and 1. A low power factor reduces the power available from the utility grid, while a harmonic distortion of the line current causes electromagnetic interference problems and cross-interferences through the line impedance, between different systems connected to the same grid. [4] Different methods are employed for power factor correction including the use of active boost converters. The basic schematic diagram of a boost converter is shown in Fig. 4.

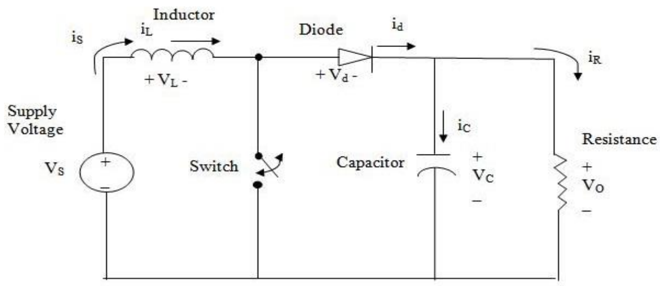

Figure 4. Basic schematic diagram of the Boost converter

The most popular topology in Power Factor Correction (PFC) applications is the boost converter topology, as it is very simple and allows low-distorted input currents and almost unity power factor with different control techniques [3]. A boost converter is a DC-DC power converter with an output DC voltage greater than the source DC voltage.

B. *Design of IBC for PF improvement*

Two or more boost converters connected in parallel, having the same frequency and phase shift and operating at 180 degree out of phase is referred to as Phase-shift converters [5]. They are controlled by phase-shifted switching function (interleaved operation) and hence are also referred to as interleaved boost converters (IBC).

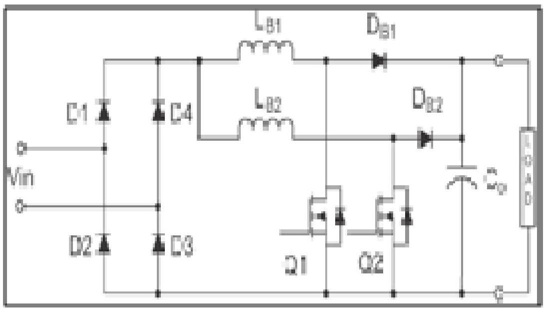

Figure 5. Schematic diagram of the interleaved phase-shift boost converter

A schematic diagram of the interleaved phase-shift boost converter is shown in Fig. 5. These are mainly used for applications related to renewable energy sources. These IBCs are distinguished from the conventional boost converters by critical operation mode (COM), discontinuous conduction mode (DCM) and continuous conduction mode (CCM) [6].

C. Design of Multilevel Inverter

The concept of multi-level inverter (MLI) structure was introduced in 1975 as an alternative in high power and medium voltage situations. In addition, they can synthesize switched waveforms with lower levels of harmonic distortion than an equivalently rated two-level converter without decreasing the inverter power output [6]. The Fig. 6 shows the circuit diagram of MLI used in the proposed model.

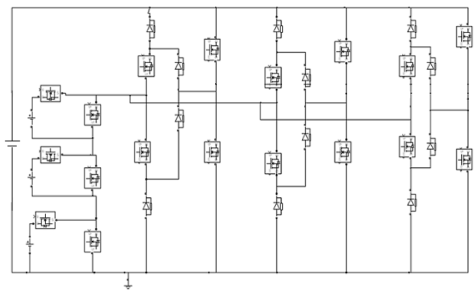

Figure 6. Circuit diagram of MLI used in the proposed model

The MLI used in the proposed model has three bidirectional switches along with six diodes. Since the proposed inverter is designed to achieve an output voltage of nine levels, there are three series CHB cells having three unequal voltage supplies. In each cell, at inverted conditions, the two switches are turned on and off to output different voltage levels. The final output is given to the star connected resistive-inductive load.

D. Space Vector Modulation Technique

Space Vector theory uses a particular concept to calculate the duty cycle of the switch which is imperative implementation of digital control theory of PWM modulators [7]. “Space Vector Modulation” (SVM) concept is mainly used for controlling the current and flux in analysis of electrical machines [8]. The technique has greater flexibility to reduce switching losses.

The principle of SVM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon. A circle can be inscribed inside the state map, corresponding to the sinusoidal operation. The area inside the inscribed circle is called the linear modulation region or under-modulation region [6]. The concepts in the operation of linear and nonlinear modulation regions depend on the modulation index (M), which indirectly reflects on the inverter utilization capability. The equation to calculate the modulation index is shown in (11).

$$\text{Modulation Index (M)} = \frac{A_r}{A_c} \qquad (11)$$

Where, A_r – Amplitude of rectangular reference signal

A_c – Amplitude of triangular reference signal

A special switching sequence is followed to turn-on and turn-off the upper three power transistors of a three-phase multilevel power inverter. In the proposed topology, a total of 50 switching patterns are needed to obtain a nine-level output in both the positive and the negative cycles. The Fig. 7 shows the basic block diagram of SVM technique employed in the proposed topology to fire the gate signals in the multilevel inverter.

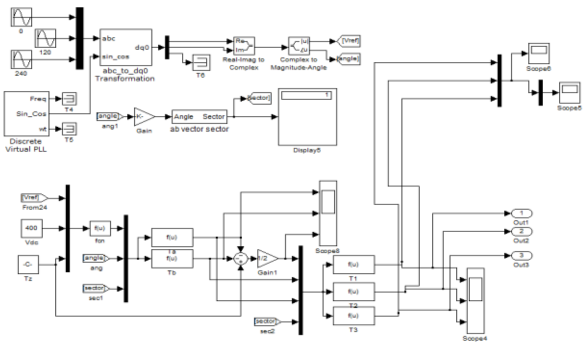

Figure 7. Block diagram of SVM technique employed in the proposed topology

There are six sectors with an angular difference of 60° between each sector. This can be assigned as shown in the table 6.2. Using Park’s transformation, the ABC reference frame is converted to DQ reference frame i.e. from three-phase to two-phase.

TABLE I SECTOR SEPARATION ACCORDING TO DEGREE OF ANGLE

Sectors	Angle
I	0 to 120
II	120 to 240
III	240 to 360

After the Park’s transformation, the real and imaginary parts are converted to complex form. The reference voltage (V_{ref}) and the angle (α) are obtained using the corresponding equation (12).

$$\text{Angle } (\alpha) = \frac{1}{\tan}\left(\frac{\beta}{\alpha}\right) \qquad (12)$$

For the reference voltage (V_{ref}), an input voltage of 400V is given as V_{dc} along with a particular time constant (T) as given in equation (13).

$$Tc = \frac{\sqrt{3T}}{Vdc} Vref \quad \text{where } T = 1/10^4 \qquad (13)$$

Using a combination of AND gate signals and relational operators, the needed sectors are automatically choosen according to the rotating reference voltage vector.

III. CLOSED-LOOP STRUCTURE

A closed-loop control system is one in which an input forcing function is determined in part by the system response. The measured response of a physical system is compared with a desired response and the difference between these two responses initiates actions that will result in the actual response of the system to approach the desired response [8].

In this section, the proposed system with closed-loop structure is explained. The Fig. 8 shows the block diagram of the closed-loop structure. The reference speed and current are considered from the three-phase series resistive-inductive induction motor load. These are converted to actual speed and current using an integrator.

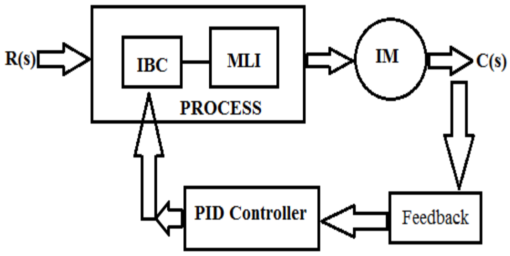

Figure 8. Block diagram of Closed-loop structure

In the block diagram, a feedback component is used to get the reference output. The difference between the input and feedback signals is applied to the PID controller. In response to this difference, the controller acts on the process forcing controlled output to change in the direction that will reduce the difference between the input signal and the feedback component [9]. This will reduce the input to the process and result in a smaller change in controlled output. This chain of events continues until a time is reached when controlled output approximately equals reference input.

IV. SIMULATION RESULTS

MATLAB simulation software is widely used in Industries to model and simulates different electrical and electronic equipments. The simulation part of this paper is done by the help of Sim Power System and Simulink packages [10]. The proposed system is explained in Fig. 9 which shows the overall operation of the proposed model. The aim is to design a 240V multilevel inverter with 9-levels of output voltage.

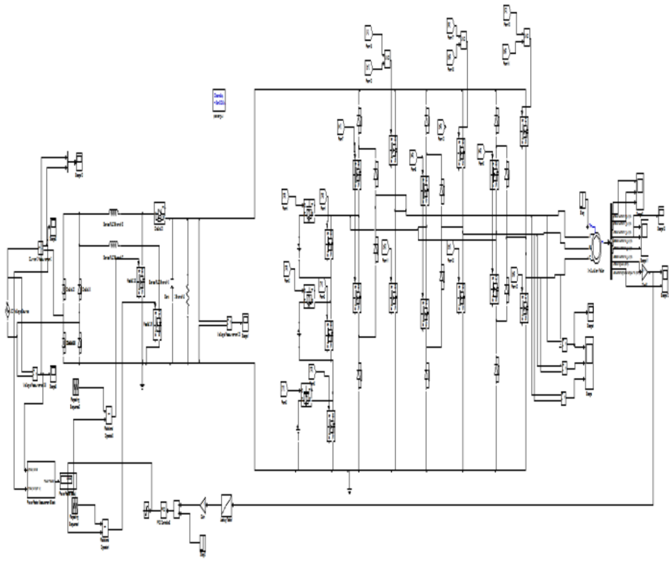

Figure 9. Circuit diagram of the proposed model

The input AC voltage supply given to the full-bridge rectifier is 120V. Fig. 10 shows the input voltage waveform of the proposed circuit. The output from the DC-DC converter got is 240V DC supply which is directly fed as the inverter input voltage. Fig. 11 shows the output voltage waveform of the proposed circuit.

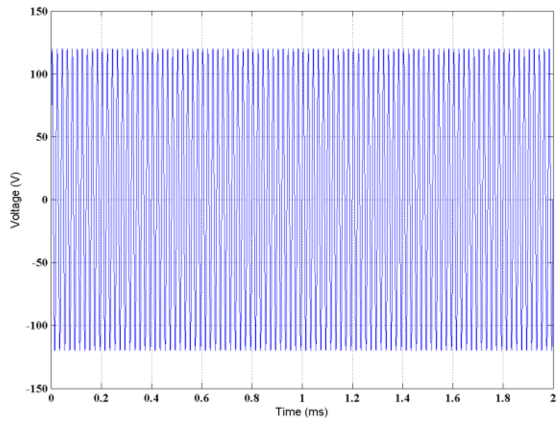

Figure 10. Input voltage waveform

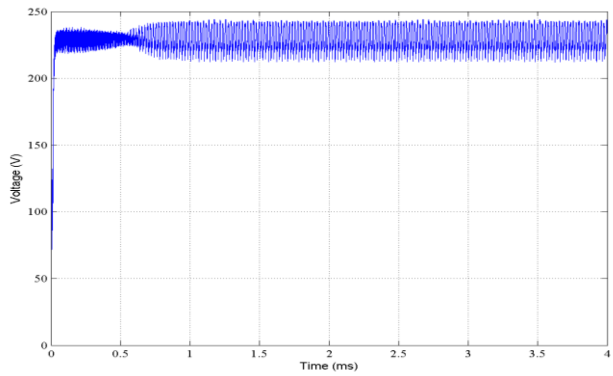

Figure 11. Output voltage waveform

The table 7.1 gives the overall plan of the components used and the specifications.

TABLE II SPECIFICATION OF COMPONENTS

S. NO	PARAMETERS	SPECIFICATIONS
1.	Input voltage V_{in}	120V
2.	Frequency f_s	50Hz
3.	Number of CHB cells	3
4.	Capacitor C_1	2.2mf
5.	Resistor R_1	100
6.	Inductor L_1	1mH
7.	Load resistance	100
8.	Motor load	3-phase Induction Motor
9.	Output voltage v_o	240V

Fig. 12 shows the nine-level voltage output of the proposed model.

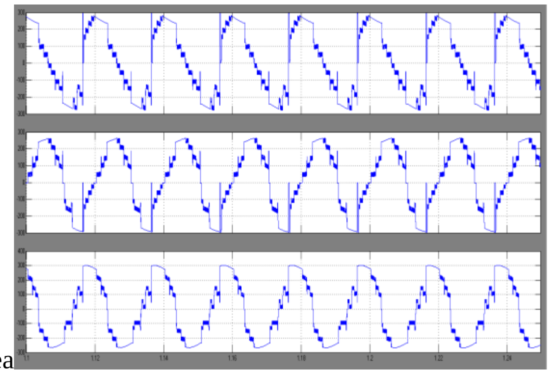

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Figure 12. Nine-level output voltage of the proposed model

V. APPLICATION IN RURAL DEVELOPMENT

Rural Development is a process of improving the quality of life and financial well-being of people living in relatively isolated and sparsely populated areas [11]. The main aim of this whole process is to increase access to modern energy services and technologies like grid extension programs, renewable resources' usage, etc. in rural areas.

In terms of innovation and engineering, rural development deals [12] with: 1. Use of improvised methods to increase efficiency of already available resources 2. Conserve natural resources by eliminating negative environmental effects 3. Produce quality output and provide energy management solutions to ensure good outcome of products.

Rural electrification is one of the main matters of concern even today, especially in villages and less-developed towns. In [13] these places, electricity is not only needed for household purposes, but also to operate farming equipments like motors, pumps, turbines, etc. Due to the increase in the need of pure voltage and current for electrical appliances and devices used in rural areas, electricity consumption is taking a toll as these equipments are high power equipments and they need pure current for a longer life [14].

Multi-level Inverters, like the ones proposed in this paper are used to reduce the ripple factor, distortion and the harmonic levels of the current [15]. This therefore improves the quality of the input current supplied to the electrical devices, thus resulting in reduced overall power consumption. The total life of the equipments which are being used for a particular function is extended and this brings down the burden of the government to install new electrical equipments from time and time again [16]. Also, due to the use of a particular type of 'Interleaved boost Converter' in this project, there is a significant improvement in the power factor levels [17]. This reduces the overall cost of electricity and helps to achieve economic optimization (i.e.) reduced losses in cables, reduced voltage drop, and increase in the available power.

Improving the quality of power in these areas can revolutionize the methods [18] of power conservation as it increases the longevity of the electrical devices, which in turn results in the decline of the cost of power.

IV. CONCLUSION AND FUTURE SCOPE

The proposed circuit topology includes a new interleaved phase-shift boost converter circuit which is used to improve the overall power factor of the circuit. The Total Harmonic Distortion is also improved using the SVM technique. In order to verify the performance, the proposed configuration was simulated and verified using MATLAB. The simulation results have been presented for a 9-level inverter using SVM technique. THD results are also analyzed along with the power factor for various loads.

The consequent works in the future may include an extension of the proposed system to higher level with improvisations in the system stability and performances.

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