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Implementation of Generalized Modular Structured Multilevel Voltage Source Inverter

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***Abstract*— A modified structure of two-stage SEPIC based cascade 7-level T-type inverter is presented for photovoltaic applications. The proposed topology consists of a frond-end SEPIC converter cascaded with three phase 7 level inverter. The proposed topology owns the merits of high boost output voltage level; modularity, reduced device parts, and better quality of supply Cascaded H-bridge Multilevel Inverters (CHBMLI) are having potential application in controlling the speed of Induction Motor Drives. This paper proposes a new modulation wave for PWM control strategy which improves the overall performance of the CHBMLI. The performance of 7-level CHBMLI with proposed PWM scheme is analyzed for three phase induction motor drive as load. The simulation is carried out on MATLAB/SIMULINK platform and the results were compared with conventional method to validate the proposed scheme.**

***Index Terms*— SEPIC, PWM, CHMLI, PI Controller, Induction Motor, THD.**

I. INTRODUCTION

In the evolution of electrical technology, the dc motors were widely used different industrial applications. After the invention of ac motors especially ac induction motors the view of industry become changed due to the wide advantage of induction motors. An induction motor has two main parts such as stationary part and rotating part. Two parts are interlinked by mutual induction.

In the present time, in the most of the applications, AC machines are preferable over DC machines due to their simple and most robust construction without any mechanical commentators’. Induction motors are the most widely used motors for appliances like industrial control, and automation; hence, they are often called the workhorse of the motion industry. As far as the machine efficiency, robustness, reliability, durability, power factor, ripples, stable output voltage and torque are concerned, three- phase induction motor stands at the a top of the order. Although various induction motor control techniques are in practice today, the most popular control technique is by generating variable frequency supply, which has constant voltage to ratio frequency ratio. This technique is popularly known as V/F control.

II. LITERATURE SURVEY

Umadevi et al[2019]A QBC (Quadratic-Boost-Converter) for -MLI (Multilevel-inverter) fed IM (Induction Motor) (QBCMLIIM) is proposed here. Quadratic boost-converter with multilevel-inverter is an alternative system in between the DC source and the motor. This work proposes quadratic boost converter between the DC

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source and inverter. [1]

Kore et al[2019]A simple simulation model of three-phase conventional inverter used for speed control of induction motor (two-level) and cascade H-bridge multilevel inverter(five-level) used for speed control of induction motor (closed loop) using sinusoidal PWM. [2]

Narsale et al[2018]Multilevel inverter emerged as a key factor in industrial drives to maintain speed and reduce THD for high power-medium voltage applications. Conventional inverter fed induction motor drives contain poor quality of voltage and current due to harmonic content which causes energy losses. To reduce THD content and improve power quality supply, a new topology of cascaded multilevel inverter is presented with minimum number of switches.[3]

Farivar et al [2016] proposed a cascaded H-Bridge (CHB) multilevel converter based Photovoltaic (PV) system with no voltage or current sensors at the dc-side. The main benefit of eliminating the dc-side sensors simplifies the hardware, leading to lower cost and higher reliability of the PV system.[4]

Coppola et al [2016] proposed an advanced control strategy for grid tied photovoltaic (PV) cascaded H bridge (CHB) inverter. The circuit topology consists of a proper number of power cells (H bridge configuration) connected in series and supplied by individual PV modules. [5]

Farivar et al [2016] introduced a cascaded H-bridge multilevel converter (CHB-MC) based StatCom system that was able to operate with extremely low dc capacitance values. The theoretical limit is calculated for the maximum capacitor voltage ripple, and hence minimum dc capacitance values that can be used in the converter. The proposed low-capacitance StatCom (LC-StatCom) was able to operate with large capacitor voltage ripples, which are very close to the calculated theoretical maximum voltage ripple. [6]

Napoles et al [2013] a new control strategy, based on the SHM-PWM technique that can tolerate different capacitor voltage levels for Cascaded H-Bridge Multilevel Converters. An example of an application which may benefit from such a scheme is in a multilevel UPS. [7]

Chavarria et al [2013] proposed an energy-balance control strategy for a cascaded single-phase grid-connected H-bridge multilevel inverter linking independent photovoltaic (PV) arrays to the grid. [8]

Comparison of the conventional CHB five-level inverters with other inverters is addressed in this literature survey Kouro et al [2010] presented a brief overview of well-established multilevel converters strongly oriented to their current state in industrial applications to then center the discussion on the new converters that have made their way into the industry.[9]

Malinowski et al [2010] presented a survey of different topologies, control strategies and modulation techniques used by cascaded multilevel inverters. [10]

Khoucha et al [2010] proposed hybrid cascaded H-bridge multilevel motor drive direct torque control (DTC) scheme for electric vehicles (EVs) or hybrid EVs. The control method was based on DTC operating principles. Therefore, a high performance and also efficient torque and flux controllers are obtained, enabling a DTC solution for multilevel-inverter-powered motor drives.[11]

Vazquez et al [2010] proposed several control and modulation techniques for multilevel cascaded H-bridge (CHB) power converter topology. In this paper, the steady-state power balance in the cells of a single-phase two-cell CHB is studied. [12]

III. SEPIC CONVERTER

A SEPIC is a cascaded boost/buck-boost converter, with its input stage similar to that of a basic boost converter, and its output stage is similar to that of a basic buck-boost converter. Overall, a SEPIC function is similar to a buck-boost converter, but has the additional advantages of having its output voltage polarity non-inverted with respect to its input voltage, having a true shutdown mode – i.e. when switch S turns off, the converter's output voltage reduces to 0V, and having isolation between the input and output.

A. Basic SEPIC Operation

The basic SEPIC performs DC-DC voltage conversion through energy exchange between its coupling capacitor and switching inductors (C_{in}, L_1 and L_2). The switch controls the energy exchange amount between the capacitor and inductors. Maximizing energy exchange efficiency and overall converter efficiency requires this SEPIC design operating in continuous conduction mode (CCM).

B. Design of SEPIC Converter

Designing the SEPIC for proper operation under the proposed specifications requires selecting the proper component values.

Components in the SEPIC are inductors L_1 and L_2, switching transistor S, diode D and capacitor C_{in}. The input and output filter capacitors, C_s and C_o, also need to be large enough in capacitance to minimize input and output voltage ripple. One major disadvantage with the SEPIC topology is that its output voltage ripple is inherently large because a pulsating diode (D) connects to its output. As mentioned, D conducts when switch S turns off and does not conduct when switch S turns on; resulting in a pulsating current fed to the converter's output. Hence C_o needs to be large in capacitance to effectively quell any output voltage ripple that results from diode pulsating current. Regarding switch, a MOSFET is preferable over a BJT because MOSFETs offer higher input impedance and lower voltage drop across its main current path compared to BJTs. Furthermore, a BJT needs to be biased with additional resistors as current differences control BJT switching, unlike MOSFETs, in which voltage differences control switching. The formulas used in the design of the SEPIC converter are as per the equations from 1 to 4 as follows.

$$\text{Inductor Current } I_L = \frac{I_{OUT} \times V_0 \times 40\%}{V_{IN\,(min)}} \quad (1)$$

$$\text{Inductor } L_1 \& L_2 \quad L_1 = L_2 = \frac{V_{IN\,(min)} \times D_{max}}{\Delta I_L \times F_{SW}} \quad (2)$$

$$\text{Output Ripple Voltage} \quad \Delta V_{CIN} = \frac{I_{OUT(max)}}{C_{IN} \times F_{SW}} \times \frac{V_{OUT}}{V_{IN} + V_{OUT} + V_D} \quad (3)$$

$$\text{Output Capacitor } C_{OUT} = \frac{I_{OUT} \times D_{max}}{V_{RIP} \times 0.5 \times F_{SW}} \quad (4)$$

Based on the above equations, the design parameters are calculated which help to control the input of commutation circuit in Brushless DC motor.

The proposed topology is verified through MATLAB simulation and experimental prototype model. The parameters considered for the simulation. The simulated waveforms of the input voltage, dc-link capacitor voltages, five-level inverter output voltage and their corresponding load currents respectively. It can be noticed that the input voltage is maintained constant and boosted to an output voltage by SEPIC converter and further stepped up. The voltage across the capacitors is maintained at generate five-level output voltage waveform. It can be noticed that the output voltage is always maintained constant during load transitions. By employing a suitable controller the output voltage can be regulated for both step changes in load as well as input voltage changes.

IV. PWM INVERTER

An Inverter is a circuit which converts a DC power input into an AC power output at a desired output voltage and frequency. Inversion is the change of dc power to ac power at a desired output voltage or current and frequency. A static semiconductor inverter circuit does this electrical energy inverting transformation. The terms voltage-fed and current-fed are used in relation with the output from inverter circuits. This conversion is achieved by controlled turn-on and turn-off devices like IGBT's or MOSFETS. Ideally, the output voltage of an Inverter should be strictly sinusoidal. However the outputs are usually rich in harmonics and are almost always non-sinusoidal. Square-wave and quasi-square-wave voltages are acceptable. The DC power input to the inverter may be a battery, a fuel cell, solar cell or any other DC source. Most industrial applications use a rectifier which takes AC supply from the mains and converts it into DC to feed it to the inverter.

C. Voltage Source Inverter

A VSI is one in which the dc input Voltage would have to keep constant and independent of the load current drawn. The Inverter dictates the load voltage while the drawn current shape is specified by the load. These topologies are widely used because they behave as voltage sources naturally as required in many industrial applications, such as adjustable speed drives (ASDs), which are the most famous application of inverters. Similarly, these structures can be used as CSIs, where the independently controlled ac output is a current waveform. These structures are widely used in medium-voltage applications, where good-quality voltage waveforms are required. Static power converters, mainly inverters, are constructed from power switches and the ac output waveforms are therefore constructed of discrete values. This leads to the formation of waveforms that features fast transition rather than smooth ones.

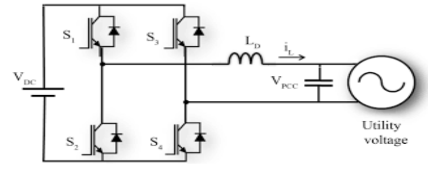

Figure 4.1: Traditional VSI

V. PROPOSED 7 LEVEL MOTOR DRIVE

Figure 5.1 depicts the SEPIC with a changed structure based on a seven-level inverter for photovoltaic application was proposed.

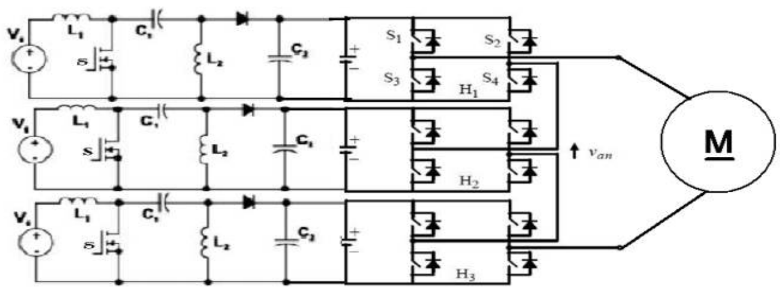

Figure.5.1 Proposed SEPIC Based Single Phase Seven-Level Inverter Based Speed Controller

Multilevel inverters are the alternative for medium voltage applications. Within the inverters types there are symmetric and asymmetric topologies. The asymmetric inverters have different DC voltage values. The most common topology is when the different cells are implemented in cascade arrangement, where the DC voltage are in multiples of 3, obtaining an AC voltage with 3n = 7 levels (n = 5 cascaded inverters). This topology provides a load voltage with low harmonic content, THD <; 3%. However, this high quality voltage has a no negligible drawback, which is the presence of regeneration in some of the inverters, independent of load type. This phenomenon is due to the modulation technique (Nearest Level Modulation) used by this inverter. In this work, the asymmetric 7 level inverter is presented. This inverter is designed to avoid the regeneration problem - power flow from the load to the inverter - in some of the power cells. This is achieved by obtaining the firing angles associated with the power cells considering a minimum load voltage THD. Finally, a power flow analysis is accomplished and simulated results show the feasibility of this approach.

D. V/F Control of Induction Motor Drive

An Introduction There is various methods for the speed control of an Induction Motor. They are:

- Pole Changing
- Variable Supply Frequency Control
- Variable Supply Voltage Control
- Variable Rotor Resistance Control
- V/f Control
- Slip Recovery
- Vector Control

Of the above mentioned methods, V/F Control is the most popular and has found widespread use in industrial and domestic applications because of its ease-of-implementation. However, it has inferior dynamic performance compared to vector control. Thus in areas where precision is required, V/F Control are not used. The various advantages of V/F Control are as follows:

- It provides good range of speed.
- It gives good running and transient performance.
- It has low starting current requirement.
- It has a wider stable operating region.
- Voltage and frequencies reach rated values at base speed.
- The acceleration can be controlled by controlling the rate of change of supply frequency. It is cheap and easy to implement.

Synchronous speed can be controlled by varying the supply frequency. Voltage induced in the stator is $E1 \propto \Phi f$where Φ is the air-gap flux and f is the supply frequency. As we can neglect the stator voltage drop we obtain terminal voltage $V1 \propto \Phi f$. Thus reducing the frequency without changing the supply voltage will lead to an increase in the air-gap flux which is undesirable. Hence whenever frequency is varied in order to control speed, the terminal voltage is also varied so as to maintain the V/f ratio constant. Thus by maintaining a constant V/f ratio, the maximum torque of the motor becomes constant for changing speed.

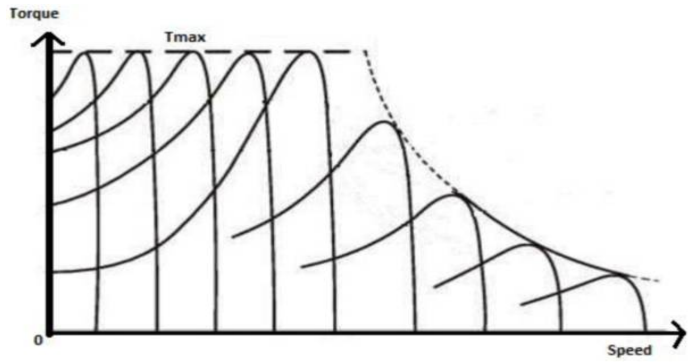

Figure 5.2 Torque-Speed Characteristics For V/F Controlled Induction Motor

It can be seen, when V/F Control is implemented, for various frequencies inside the operating region, the maximum torque remains the same as the speed varies. Thus, maintaining the V/F ratio constant helps us to maintain a constant maximum torque while controlling the speed as per our requirement.

E. Closed-Loop V/F Control Of Induction Motor

In closed-loop V/F Control the speed of the rotor is measured using a sensor and it is compared to the reference speed. The difference is taken as the error and the error is fed to a Proportional controller. The P controller sets the inverter frequency. The frequency is taken as input for the Voltage Source Inverter which modifies the terminal voltage accordingly so as to keep the V/F ratio constant. The frequency at which the motor should be started so as to operate in the stable zone is calculated. The corresponding voltage is determined. The speed of the rotor is incremented from 0 to the Synchronous speed and the values of the torque were stored. The actual speed of the rotor was ascertained and compared with the reference speed. The resulting difference was taken as the error and original frequency was corrected. The terminal voltage is also modified accordingly, keeping the V/F ratio constant and the process is repeated. Thus here it can be observed that as the frequency is varied, the maximum torque on the rotor remains constant across the speed range. This is the result of keeping the flux constant by maintaining a constant V/f ratio. Thus the speed of the rotor is measured and compared with the reference speed. This generates an error that is processed by the Proportional Controller which modifies the supply frequency accordingly. As the P Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/f ratio remains constant. This keeps the flux value constant which in turn ensures a constant maximum torque throughout the speed range. Hence Speed control is achieved in the Induction motor.

VI. System Analysis And Overview

Induction motors are used in many drives because they are simple and very easy to maintain. Speed of an induction motor is related to its frequency. So speed can be easily by using converters which gives variable frequency output. An inverter is a type of power converter which converts dc ac power. Thus inverter is used in the areas where ac power is required. But practical inverters give non sinusoidal output waveform. Usually they contain harmonics. The harmonics can be eliminated with pulse width modulation. By using some modulation we can obtain the required amplitude and frequency with good quality outputs. Control of an induction motor (V/F) is become easy by using pulse width modulation. PWM is a simple method which used for controlling output of inverter. By adjusting the ON time and OFF time of inverter switches, a required ac output voltage is obtained. So PWM helps in reducing total harmonic distortion. Three phase power converters using pulse width modulation have a wide range of applications for ac machine drives. It is understood that the induction motor is going to become the main part of industrial purposes. As compared to the DC machine, it has a better power by mass ratio, simpler maintenance and low cost. However, the process of controlling of the induction is more difficult. Advantage of using an ac-dc-ac system to drive AC motor in place of simply plugging into power is that, it allows better speed control. An available method of power converter circuit to obtain the three phase variable voltage and frequency output from single phase supply is a full bridge diode rectifier and three phase inverter system. This circuit is of simple structure and low cost. But it has more current distortion and poor power factor. Whenever, the power requirement in the low power range low cost drive is relevant. The circuit proposed in this work has a modified SEPIC rectifier.

F. Proposed Topology

The proposed system uses SEPIC based cascaded inverter topology for induction motor drive. The system uses SEPIC converter to regulate the DC supply and feed it to the seven level inverter. This new seven-level inverter is bridge power converter, connected in a cascade. The power electronic switches of capacitor selection circuit determine the discharge of the two capacitors while the two capacitors are being discharged individually or in series. Because of the multiple relationships Cascaded H-bridge Multilevel Inverters (CHBMLI) are having potential application in controlling the speed of Induction Motor Drives. This paper proposes a new modulation wave for PWM control strategy which improves the overall performance of the CHBMLI. The performance of 7-level CHBMLI with proposed PWM scheme is analyzed for three phase induction motor drive as load. The proposed modulation scheme results in increased output of 13% compared to conventional method and also reducing the harmonics. The simulation is carried out on MATLAB/SIMULINK platform and the results were compared with conventional method to validate the proposed scheme. The detailed operation of each part is as follows.

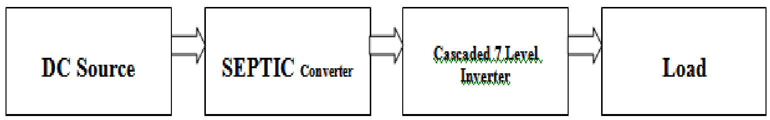

Figure.6.1 Proposed Topology Architecture

G. Circuit Description

In this proposed system we have series Connected seven-level CHB to lessen or reduce the switch count and minimize THD. The main of the proposed device is inverter presents higher quality output with reduced strength loss as compared to the other conventional inverters when compared with same output quality. The overall block diagram for the proposed inverter is shown in fig.6.1 and the waveform of the proposed method is also shown. Inverter topology is as shown in fig.6.2. When comparing with the existing multi stage inverters, the new MLI inverters can successfully reduce the switch count and also the number of gate drivers as the number of voltage degrees or levels increases. For a given number of voltage Degrees (level) m, the new inverter requires m+3 active switches. Demanding higher power, higher power quality, lower switching loss, and eliminating interface transformers in industrial applications caused significant attention toward multilevel converters. This paper presents current control of a seven-level topology for medium-voltage high-power applications. This topology has fewer active switches and components, and less control complexity in comparison to the other existing classic and advanced seven-level topologies.

TABLE 1: SWITCHING PATTERN

Levels	S_1	S_2	S_3	S_4	S_a	S_b	S_c	S_d	VR_L
1	on	off	off	on	on	off	off	on	V_{dc}
2	off	on	on	off	on	off	off	on	$2V_{dc}$
3	off	on	off	on	on	off	off	on	$3V_{dc}$
4	off	off	off	off	off	off	off	off	0V
5	on	off	off	on	off	on	on	off	$-V_{dc}$
6	off	on	on	off	off	on	on	off	$-2V_{dc}$
7	off	on	off	on	off	on	on	off	$-3V_{dc}$

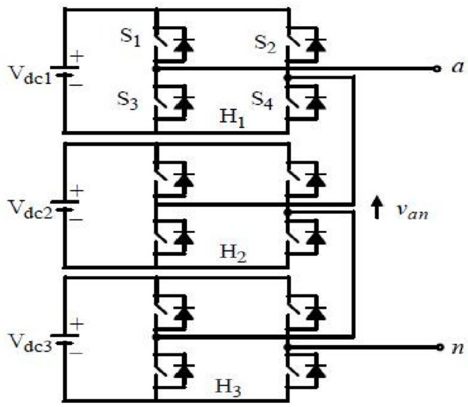

Figure.6.2 Cascaded Seven Level Inverter

VII. SIMULATION AND RESULTS

The proposed work is carried out using MATLAB simulation. The SIMULINK of the proposed system is shown in Figure 7.1.

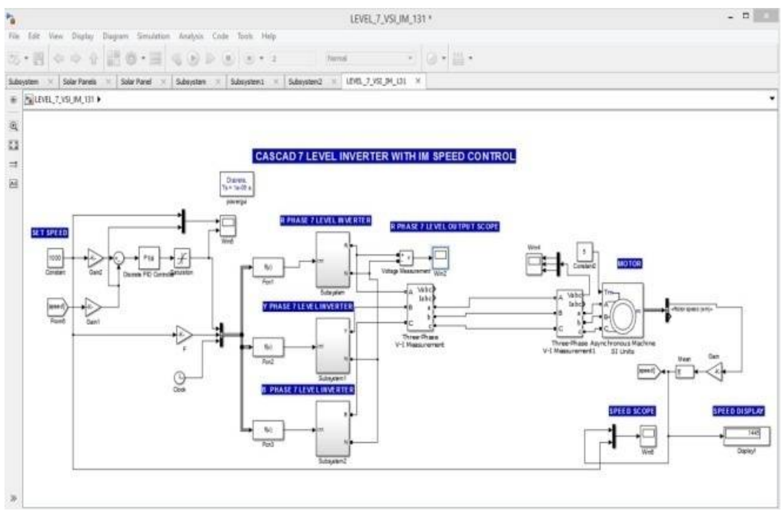

Figure.7.1 Simulation Circuit Of Three Phase 7-Level CHBMLI Fed To Induction Motor

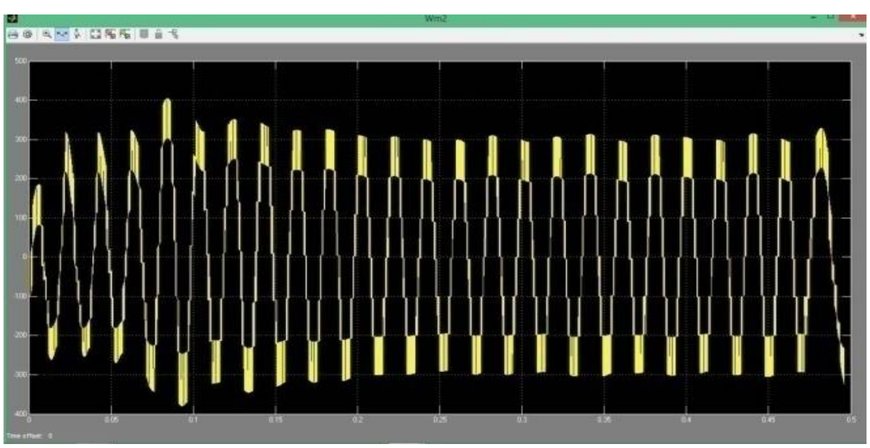

Fig.7.2 SIMUILINK Of Line Voltage Of Three Phase Induction Motor With Elliptical Modulating

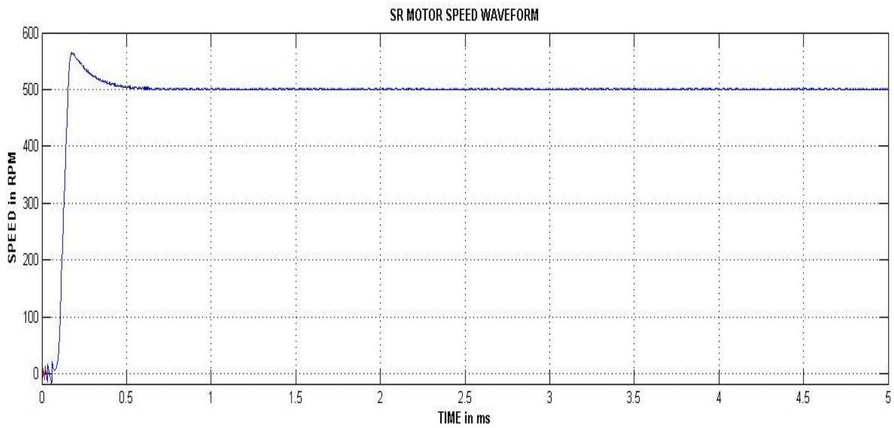

Figure.7.3 Motor Speed Waveform Using PI Controller

VIII. Conclusions

The investigation of three phase 7-level CHBMLI fed induction motor drive has been experimented and also PWM technique is used with a switching frequency. The performance of proposed PWM technique is further verified by carrying v/f method of speed control of induction motor. The error between the real rotor speed and the reference speed was processed using a proportional integral and used to vary the supply frequency in the closed loop v/f control. The magnitude of the terminal voltage was varied by the voltage source inverter to keep the v/f ratio constant. The maximum torque was found to be constant around the speed spectrum once more. As a result, the motor was completely utilized, resulting in a successful motor speed.

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