REVIEW ON MULTILEVEL INVERTER BASED THREE PHASE INDUCTION MOTOR DRIVES

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ABSTRACT

High power induction motor drives using classical three-phase converters have the disadvantage of poor voltage and current qualities. To improve these values, the switching frequency has to be raised which causes additional switching losses. Another possibility is to put a motor input filter between the converter and motor, which causes additional weight. A further inconvenience is the limited voltage that can be applied to the induction motor determined by the blocking voltage of the semiconductor switches. For high power semiconductors, the switching frequency is limited by the maximal power loss.
Traditional two level high frequency pulse width modulation inverters for motor drives have several problems associated with their high frequency switching which produce common mode voltage and high voltage changes dV/dt rates to motor winding. Multilevel inverter solve this problems because their devices switch at much lower frequency. Two different topology for multilevel inverter was identified for use as a converter for electric drives, a cascade inverter with dc drive and back to back diode clap inverter.
In this paper different techniques was presented for controlling three phase induction motor using three phase multilevel inverter circuit technologies. This study will be useful in future for students and researcher in the field of electric drive controlling.

Keyword: - *Multilevel inverter, three phase induction motor.*

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1. INTRODUCTION

Multilevel voltage-source inverters provide a costeffective solution in the medium-voltage energy management market [1]. These converters have been widely applied to chemical, oil, and liquefied natural gas (LNG) plants, water plants, marine propulsion, power generation, energy transmission, and power-quality devices [2]. Nowadays, there exist three commercial topologies of multilevel voltage-source inverters: neutral point clamped (NPC) [3], cascaded H-bridge (CHB) [4], and flying capacitors (FCs) [5]. Among these inverter topologies, cascaded multilevel inverter reaches the higher output voltage and power levels (13.8 kV, 30 MVA) and the higher reliability due to its modular topology. Cascaded multilevel inverters are based on a series connection of several single-phase inverters. This structure is capable of reaching medium output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. These converters also feature a high modularity degree because each inverter can be seen as a module with similar circuit topology, control structure, and modulation [6]. Therefore, in the case of a fault in one of these modules, it is possible to replace it quickly and easily. Moreover, with an appropriated control strategy, it is possible to bypass the faulty module without stopping the load, bringing an almost continuous overall availability [7].

2. DIFFERENT TECHNIQUES FOR MULTILEVELE INVERTER BASED INDUCTION MOTOR DRIVE

Pulse-width modulated (PWM) inverters are known to generate common mode voltages which cause motor bearing currents in the induction motor drives. They also result in leakage currents which act as sources of conducted electromagnetic interference in the drive system. The common mode voltage generated by a conventional three-level inverter can be eliminated by switching only the voltage space vectors which do not produce the common mode voltage. In one of the presents a PWM switching strategy to eliminate common mode voltage using the open-end winding configuration for the induction motor [1]. The switching strategy presented in this paper, does not generate any alternating common mode voltages in the drive system and hence the electrostatic coupling of the common mode voltage, which results in the bearing currents and the leakage currents, is avoided. The proposed scheme is devoid of neutral point voltage fluctuations and does not require neutral point clamping diodes, when compared to the common mode elimination scheme based on the conventional three-level inverter topology. Also, the present scheme uses a single dc-link with half the voltage compared to the conventional three-level inverter based scheme.

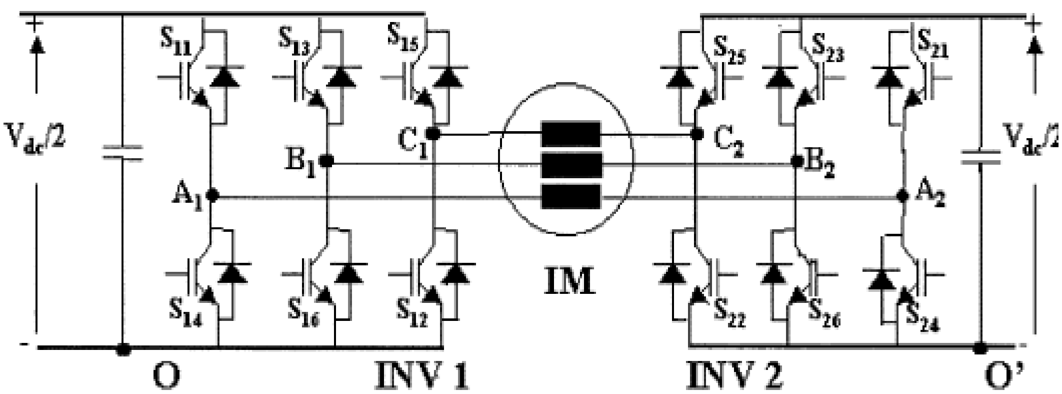

Fig 1:- Schematic of dual inverter fed open end winding induction motor drive with isolated dc-links [1].

A space vector based PWM to eliminate alternating common mode voltage in the dual inverter fed open end winding induction motor drive. With the proposed scheme, the zero sequence currents do not flow in the machine phase windings as no common mode voltage exists in the phase windings and the dual inverter can be operated from a single power supply. The individual inverters do not generate any alternating common mode voltage and hence possibility of common mode voltage coupling is avoided. The proposed drive does not experience any neutral point fluctuations compared to the common mode voltage elimination scheme based on conventional neutral point clamped three-level inverter. The proposed drive has a simple power circuit consisting of two standard two-level inverters, and does not require the neutral point clamping diodes. The proposed scheme uses a single dc-link with half the voltage of the common mode elimination scheme based on the conventional three-level inverter.

A dual two-level inverter fed open-end winding induction motor drive with a single DC power supply is proposed [2]. The proposed scheme produces voltage space vector locations identical to those of a conventional three-level inverter. In the conventional neutral-clamped three-level inverter, the series-connected DC link capacitors carry the load current, resulting in a fluctuating neutral point. Also, a three-level inverter requires bulky DC link capacitors. In the proposed scheme, the DC link capacitors carry currents of higher frequency and hence the neutral point fluctuations are reduced. A PWM switching strategy to suppress the zero sequence currents for all the voltage space phasor combinations is also proposed. This strategy is an improvisation of the one that uses a switched neutral to eliminate the triplen harmonic currents and results in an improved DC bus utilization.

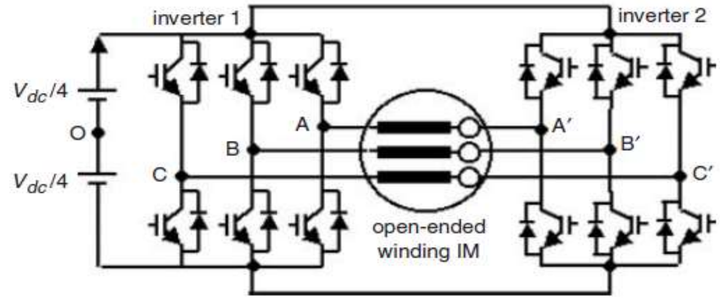

Fig 2:- Dual inverter fed induction motor with open-end winding [2].

A PWM switching strategy to suppress the triplen harmonic currents is highlighted without the need for bulky harmonic filters or isolation transformers. The triplen harmonic current suppression is achieved by alternately connecting one of the inverters to the DC link by toggling the bidirectional auxiliary switch pairs. The modified switching strategy could enhance the DC bus utilization by a factor of 15% compared to the earlier scheme reported in. The neutral point fluctuations are expected to be smaller in the proposed scheme, when compared to a three-level inverter.

The frequency of the ripple current of the individual DC link capacitors is determined by the switching frequency of the auxiliary switch pair and not by the frequency of the fundamental component of the load current, as for a conventional neutral clamped three-level inverter. The switching frequency of each inverter is half of the motor phase switching frequency. The proposed space phasor based PWM scheme requires only the instantaneous sampled values of the reference phase voltages as inputs for gate drive signal generation, in the entire speed range. The switching patterns are implemented in such a way that minimum inverter switch transitions are only needed during a sampling period Ts.

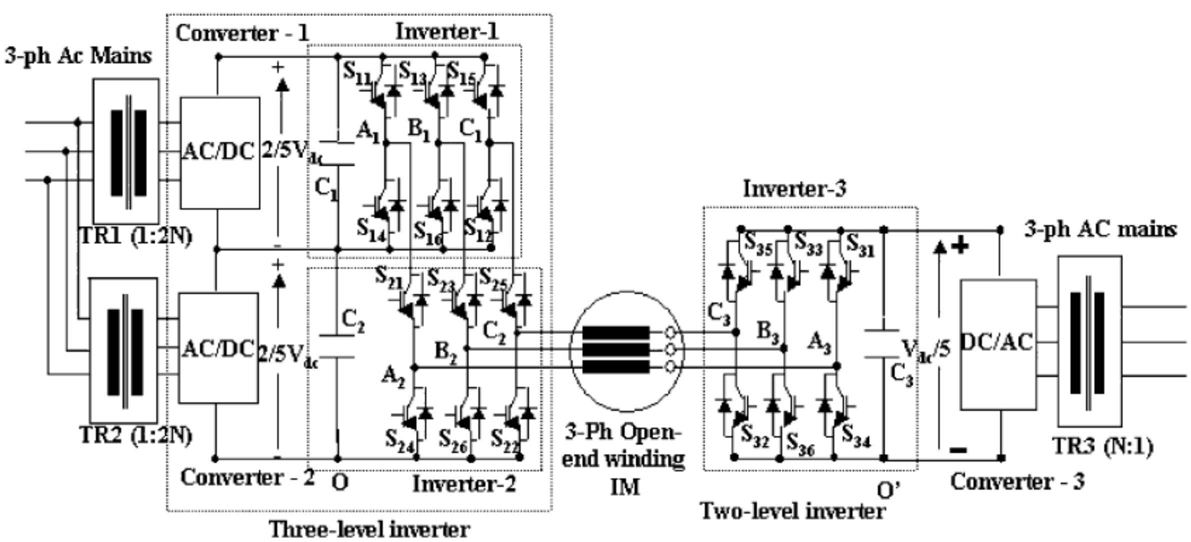

Fig 3:- Schematic circuit diagram of the proposed inverter scheme [3].

In one of the paper, a multilevel inverter system for an open-end winding induction motor drive is described [3]. Multilevel inversion is achieved by feeding an open-end winding induction motor with two two-level inverters in cascade (equivalent to a three-level inverter) from one end and a single two-level inverter from the other end of the motor. The combined inverter system with open-end winding induction motor produces voltage space-vector locations identical to a six-level inverter. A total of 512 space-vector combinations are available in the proposed scheme, distributed over 91 space-vector locations. The proposed inverter drive scheme is capable of producing a multilevel pulse width-modulation (PWM) waveform for the phase voltage ranging from a two-level waveform to a six-level waveform depending on the modulation range. A space-vector PWM scheme for the proposed drive is implemented using a 1.5-kW induction motor with open-end winding structure.

In the proposed scheme, a total of 512 voltage space-vector combinations are present, distributed over 91 space-vector locations. The three-level inverter is realized by connecting two two-level inverters in cascade. This three-level inverter structure does not show the voltage fluctuations of the neutral point, as isolated power supplies are employed to power the individual inverters. Also, it can easily be synthesized by retrofitting two existing two-level inverters. This three-level configuration does not require the clamping diodes. In the lowest modulation range, only one of the three inverters is switched. In the medium modulation range two inverters are switched and in the higher modulation range all three inverters are switched. This feature ensures that the switching losses are reduced in the lower and the middle ranges of modulation. The motor phase voltage shows a two-level waveform in the lowest modulation range, a three-level or a four-level waveform in the medium modulation range, and a five-level or a six-level waveform in the higher modulation range. This configuration needs three isolated power supplies.

Current source inverter (CSI) fed drives are employed in high power applications. The conventional CSI drives suffer from drawbacks such as harmonic resonance, unstable operation at low speed ranges, and torque pulsation. In one of the paper presents a novel CSI drive which overcomes all these drawbacks and results in sinusoidal motor voltage and current even with CSI switching at fundamental frequency [4]. The proposed CSI drive uses a three-level inverter as an active filter across motor terminals replacing the bulky ac capacitors used in the conventional drive. A sensorless vector controlled CSI drive based on proposed configuration is developed. The simulation and experimental results are presented. Experimental results show that the proposed drive has stable operation even at low speeds. Comparative results show that the proposed CSI drive has improved torque ripple compared to the conventional configuration.

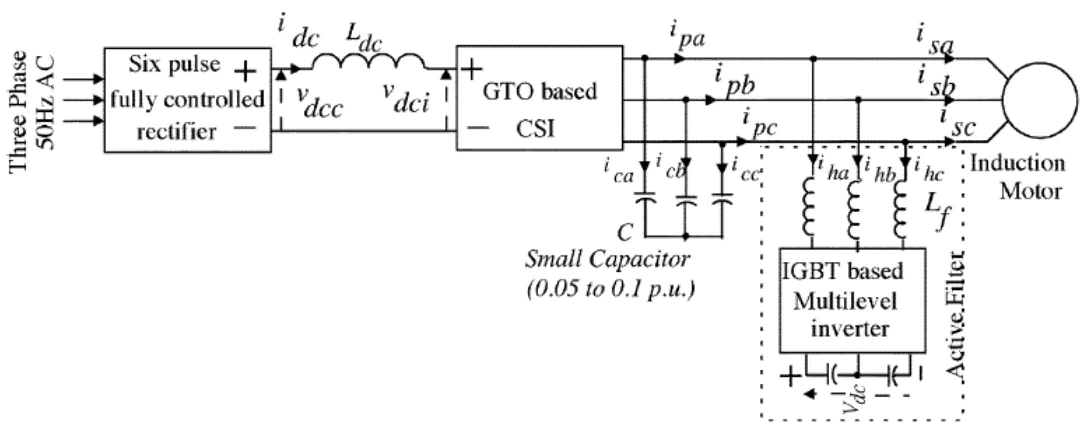

Fig 4:- Functional block diagram of proposed CSI fed drive [4].

A novel CSI-fed induction motor drive with sinusoidal motor current and voltage waveforms is proposed. A vector controlled drive based on the proposed CSI configuration has been simulated and verified experimentally. Excellent waveforms for the motor voltage and current can be obtained with sufficient bandwidth of the active filter current controller loops. In the experimental drive, because of the limitations of the DSP based controller used, the bandwidth of active filter current controllers is restricted to 6283 rad/s. Even with this low bandwidth, the active filter is able to filter out most of the low order harmonics and the resulting current and voltage waveforms are near sinusoidal. Moreover compared to the conventional CSI drive, the proposed drive results in near sinusoidal motor current and voltage waveform in the entire speed range of the drive including low speed because of the uniform filtering action of the active filter. Since motor voltage and current waveforms are sinusoidal, high voltage stress due to reflected waveforms in long cables are avoided, hence conventional motors can be retrofitted with the proposed drive. Also, the common mode voltage problem is reduced. The CSI is switched at fundamental frequency with simple switching logic. Hence, design of the power circuit is simple. Also, the power loss in the CSI will be reduced.

A dc link capacitor voltage balancing scheme along with common mode voltage elimination is proposed for an induction motor drive, with open-end winding structure. The motor is fed from both the ends with three-level inverters generating a five level output voltage space phasor structure [5]. If switching combinations, with zero common mode voltage in the pole voltage, are used, then the resultant voltage space vector combinations are equivalent to that of a three-level inverter. The proposed inverter vector locations exhibit greater multiplicity in the inverter switching combinations which is suitably exploited to arrive at a capacitor voltage balancing scheme. This allows the use of a single dc link power supply for the combined inverter structure. The simultaneous task of common mode voltage elimination with dc link capacitor voltage balancing, using only the switching state redundancies, is experimentally verified on a 1.5-kW induction motor drive.

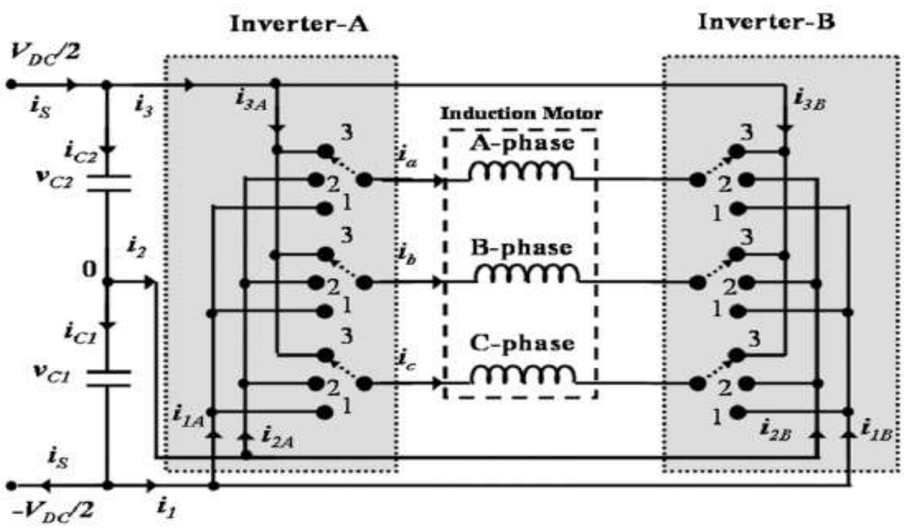

Fig 5:- Inverter-induction motor system model [5].

An open end winding induction motor drive, fed by three-level inverters from both sides, is used for the proposed scheme. The three-level structure is realized by cascading the conventional two two-level inverters, resulting into simple power bus structure for the proposed scheme. Thus, the proposed inverter structure does not require any clamping diodes which are required in NPC inverter topology. The proposed scheme has more multiplicity in the inverter voltage vector locations as compared to conventional single inverter fed drive which are effectively used to balance the dc link capacitor voltages without disturbing the SVPWM modulation. Thus, a single front-end rectifier of rating nearly half to that of a conventional two-level inverter can be used, with two capacitors for splitting the dc link voltage. The proposed capacitor voltage balancing scheme is based on altering the switching combinations of the inverter voltage vectors, having exactly opposite effect on the capacitor voltages, for consecutive sampling durations. A simple closed loop hysteresis controller is used to balance the dc link capacitor voltages throughout the modulation range of the drive.

One of the methodology presents a high-performance torque and flux control strategy for high-power induction motor drives [6]. The control method uses the torque error to control the load angle, obtaining the appropriate flux vector trajectory from which the voltage vector is directly derived based on direct torque control principles. The voltage vector is then generated by an asymmetric cascaded multilevel inverter without need of modulation and filter. Due to the high output quality of the inverter, the torque response presents nearly no ripple. In addition, switching losses are greatly reduced since 80% of the power is delivered by the high-power cell of the asymmetric inverter, which commutates at fundamental frequency. Simulation and experimental results for 81-level inverter are presented.

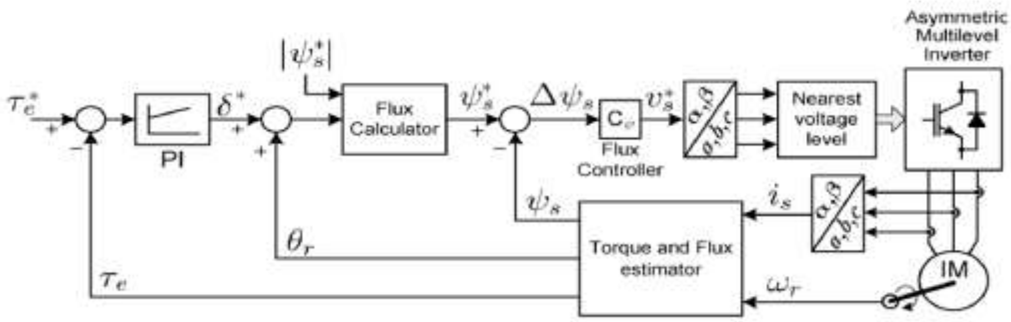

Fig 6:- DTC scheme for multilevel inverter-fed induction motor drive [6].

A high-performance torque and flux control strategy for high power induction motor drives is presented. The main achievements of the proposed control method are: significant reduction in the torque ripple, sinusoidal output voltages and currents, lower switching losses and a high-performance torque and flux regulation. In addition, this approach simplifies the application of DTC principles to multilevel inverters-fed drives. Particularly, there is no need of multiple hysteresis comparators, particular sector divisions and more complex lookup tables, which are too difficult to extend to inverters with a higher number of levels.

The asymmetric multilevel inverter enables a DTC solution for high-power motor drives, not only due to the higher voltage capability provided by multilevel inverters, but mainly due to the reduced switching losses and the improved output voltage quality (small 's dV/dt and common mode voltages), which provides sinusoidal current without output filter. Future work on this topic can be the extension of this method to grid inverter interfaces. In this case, the direct power angle control should replace the torque angle control, and the inverter should be considered as an active filter for reactive power compensation.

One of the methodologies presents the operating principle of each topology and a review of the most relevant modulation methods, focused mainly on those used by industry [7]. In addition, the latest advances and future trends of the technology are discussed. It is concluded that the topology and modulation-method selection are closely related to each particular application, leaving a space on the market for all the different solutions, depending on their unique features and limitations like power or voltage level, dynamic performance, reliability, costs, and other technical specifications.

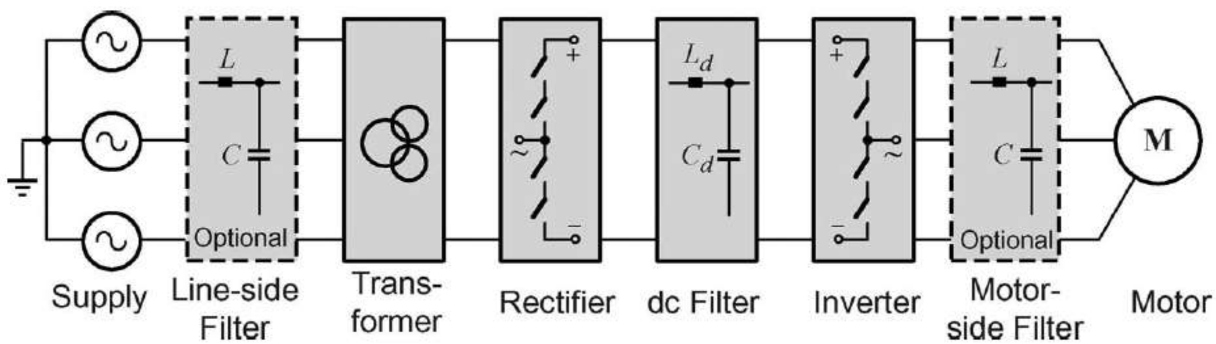

Fig 7:- General block diagram of the MV drive [7].

The analyzed operating principles, relevant characteristics, established modulation methods, and latest developments of these converters show that all described topologies (2L VSCs, NPC, CHB, and FC multilevel VSCs) feature specific technical advantages and disadvantages which justify their existence on the market. The growing market size and increasing technical requirements of MV high-power drives for a large variety of applications will require substantial efforts and research in the future.

One of the method presents a fundamental frequency modulated diode-clamped multilevel inverter (DCMLI) scheme for a three-phase stand-alone photovoltaic (PV) system [8]. The system consists of five series-connected PV modules, a six-level DCMLI generating fundamental modulation staircase three phase output voltages, and a three-phase induction motor as the load. In order to validate the proposed concept, simulation studies and experimental measurements using a small-scale laboratory prototype are also presented. The results show the feasibility of the fundamental frequency switching application in three-phase stand-alone PV power systems.

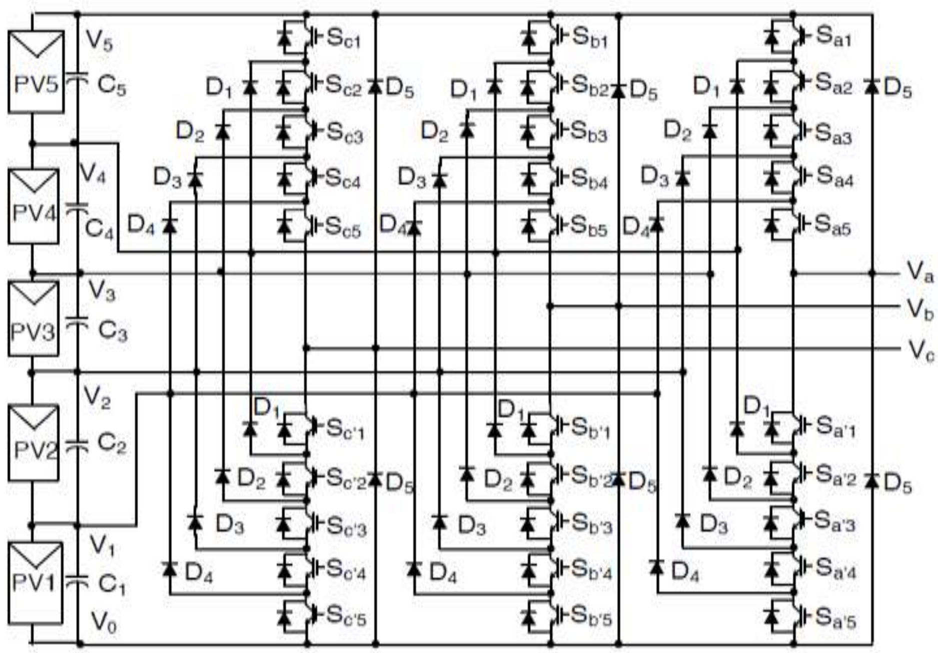

Fig 8:- PV-connected to a three-phase six-level diode-clamped multilevel inverter topology [8].

It is dedicated to rural areas where there is no connection to the utility network. High efficiency converters are desirable for renewable energy systems, especially those related with photovoltaic applications. The aim is to have a simple, robust, free maintenance and highly efficient PV system. The maximum overall efficiency of the multilevel inverter experimentally verified by a prototype stand-alone PV power system is about 98.5%, which is comparatively higher than conventional inverters. The proposed six-level diode-clamped multilevel inverter has been applied in a three-phase stand-alone photovoltaic system and presents several promising advantages. First, it can convert power for ac utility from relatively low dc voltage sources by itself. Second, it increases output voltage levels without any transformer so that it has higher efficiency and lower weight for the overall system. Third, in case of a six level multilevel inverter, it does not require an output filter because high-order harmonics are effectively filtered off, owing to the reactance of the induction motor load; therefore, it can produce a staircase voltage waveform with lower harmonics eliminated such that higher order harmonics can be easily filtered if needed for that particular application. Finally, it reduces stresses on power switching devices, resulting in low audio and radio frequency (RF) noise, EMI, or less electromagnetic compatibility (EMC) problems, since the multilevel inverter operates with a low switching frequency.

A new five-level inverter topology for open-end winding induction-motor (IM) drive is proposed [9]. The open-end winding IM is fed from one end with a two-level inverter in series with a capacitor-fed H-bridge cell, while the other end is connected to a conventional two-level inverter. The combined inverter system produces voltage space-vector locations identical to that of a conventional five-level inverter. A total of 2744 space vector combinations are distributed over 61 space-vector locations in the proposed scheme. With such a high number of switching state redundancies, it is possible to balance the H-bridge capacitor voltages under all operating conditions including over modulation region. In addition to that, the proposed topology eliminates 18 clamping diodes having different voltage ratings compared with the neutral point clamped inverter. On the other hand, it requires only one capacitor bank per phase, whereas the flying-capacitor scheme for a five-level topology requires more than one capacitor bank per phase. The proposed inverter topology can be operated as a three-level inverter for full modulation range, in case of any switch failure in the capacitor-fed H-bridge cell. This will increase the reliability of the system. The proposed scheme is experimentally verified on a four-pole 5-hp IM drive.

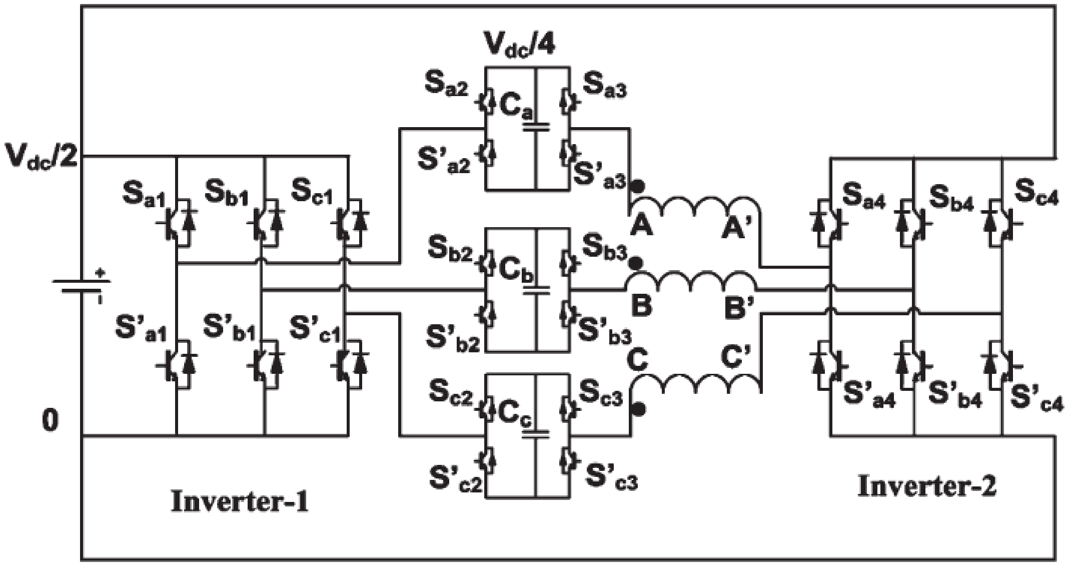

Fig 9:- Proposed five-level inverter power circuit [9].

The concept of open-end winding structure has been extended by adding a capacitor-fed H-bridge cell in series with the motor phase winding. This results in a five-level inverter topology. It does not require any clamping diodes as in a conventional five-level NPC inverter. It requires only one capacitor bank for each phase, whereas the five level flying-capacitor topology requires six additional capacitor banks with a voltage rating of *V*dc/4 for each phase. Therefore, the proposed topology reduces the power circuit complexity compared with NPC or flying-capacitor topologies. In case of any switch failure in the H-bridge cell, the proposed inverter topology can be operated as a three-level inverter for full modulation range (by appropriately clamping the H-bridge cell). Inherent H-bridge capacitor voltage balancing eliminates the need for additional dc-power supplies and hence, increases the reliability of the power circuit and also reduces the power circuit complexity.

Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Variable voltage and frequency supply to ac drives is invariably obtained from a three-phase voltage source inverter. Here is used three-phase voltage source inverter which is carrier-based sinusoidal PWM (Sinusoidal PWM) with power IGBTs is described [10]. In ac motor drives, SPWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to a motor. As a result, PWM inverter-powered motor drives are more variable and offer in a wide range better efficiency and higher performance when compared to fixed frequency motor drives. Three phase voltage-fed PWM inverters are recently showing growing popularity for multi-megawatt industrial drive applications. Here open loop and close loop simulation and analysis of PWM Inverter fed Induction motor is carried out.

The variations in modulation index also affect the speed of induction motor drive. There are fluctuations in the starting of rotor currents, electromagnetic torque but this is absent in speed. This is because of machine's inertia. This is clearly visible in scopes.

3. CONCLUSION

The cascaded multilevel inverters have evolved from a theoretical concept to real applications due to several remarkable features like a high degree of modularity, the possibility of connecting directly to medium voltage, high power quality, both input and output, high availability, and the control of power flow in the regenerative version. This paper has reviewed the recent developments and applications of these inverters, including new proposed topologies, modulation techniques, and control strategies. In this paper different techniques was presented for controlling three phase induction motor using three phase multilevel inverter circuit technologies. This study will be useful in future for students and researcher in the field of electric drive controlling.

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