Research Article

A Novel Review on Modular Multilevel Converter for Induction Motor Drive Applications

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Abstract: Variable speed drive applications in the industrial vicinity playing a vital role in nation development. The majority of the industries are engaged with AC induction machine drives due to easy, smooth and reliable drive operations for its various variable drive applications. Recent advances in power electronic technologies makes the efficient control schemes to obtain a smooth and reliable variable speed drives. Modular multilevel converter (MMC) technique plays a significant role in applications of high power rating such as HVDC. The application of these modular multilevel converter techniques now extended to various variable induction machine speed drive applications in industrial services due to its superior benefits of investment and life cycle cost. Modular multilevel converters designed in number of modules to obtain ripple and harmonic less voltage out puts of the induction machines. Different topologies and control strategies of modular multilevel converters are observed and employed by the various researchers elsewhere in the world. This paper presets a novel review on applications of modular multilevel converters used in different drive applications. Also, this paper presents a detail review on different topologies and control schemes used elsewhere in the world and made suggestion on application of efficient modular multilevel converter technique configuration to obtain effective performance of induction machine at different drive applications

Keywords: Modular multilevel converter, Voltage source converter, induction machine, drive

1. Introduction

Rapid growth in population coerces the enhanced production in industrial items to meet the increased demand. This dictates that, industries pays more attention on the application of AC drives in support of various power electronic based control topologies in cost effective mode. In order to meet the required demand in industrial applications, it is necessary to switch high power voltage applications of the AC drives [1]-[4]. Also, it is necessary to obtain the operation of these AC drives at high power voltage applications industries in cost effective with high efficiency and reliable. Different multilevel converters with various control techniques are available elsewhere in the world to obtain desired AC drive operations [5]-[11]. Multilevel converters employing in operations are either voltage source converters or current source converters and both converter applications in some applications. In order to reduce voltage ripples and total harmonic distortions in output voltages and currents different topologies are also designed and used [12]-[18]. Different multilevel converter topologies such as neutral point clamped converter, flying capacitor converter, cascaded H-bridge and modular multilevel converter etc. are designed and utilizing elsewhere in the world [19]-[22]. Each converter topology has its merits and demerits compared to each other. Converters of neutral point clamped converter, flying capacitor converter are best suitable for output voltage with lower dv/dt stresses and lower harmonic content [23]-[27]. But these two converters are limited to operate at high power voltage drive applications. Therefore, compared to these converter topologies, modular multilevel converters are best suitable to high power voltage drive applications. The control strategies in this modular multilevel converter are designed to operate in number of modules to obtain modularity, scalability, and output voltage quality [4-7].

2. Backgroud Works

Many researchers are proposed modular multilevel converters (MMC) for medium to high power voltage AC drive applications with their own control strategies to obtain the efficient performance of variable AC drives. Multilevel converters such as neutral point clamped converter [1] and flying capacitor converter [2] are employed to AC drive applications to obtain lower dv/dt stresses and harmonics in output voltages. But these converters are limited to number of levels only [3]. In recent years many authors [4]-[7] proposes the application of MMCs for medium and high power voltage AC drive applications. They confirmed that MMCs performs improved benefits of modularity, scalability, less failure management and low cost and life cycle compared to the other conventional multi converter designs. In [8], the authors are proposed a conventional Half-Bridge Sub Module (HBSM)-based MMC design to obtain the reduced voltage ripples of sub module capacitor in the structure. This method of structure was suffered with discontinuity in input current. Also, the authors from [9] are considered same HBSM-based MMC design for loaded induction motor drive from stand still to rated speed conditions. In this configuration, they considered an additional arm connected in cross sectional between the upper and lower arms of the circuit to achieve energy balance between arm legs. This method of configuration uses many HBSMs, makes the complex and sensitive design. In order to overcome this problem, authors in [10] are proposes same configuration was utilized by replace of FBSMs with HBSMs.

It is also observed that from [11] [12], the back-to-back FBSM based MMC i.e MMC connects on both grid side and motor side design structures. This configuration controls the AC drives from zero speed to full-load speed with balanced and bounded capacitor voltages, but a large number of FBSMs are engaged. In [13], the energy equalization modules concept has been introduced to obtain assured energy balance between the lower and upper leg arms of MMC at low-frequency conditions. From [14] [15], the authors are proposed dual active bridge equalization channels concept for various types of AC drives, while the shared capacitor SM concept has been proposed in [16] for open-winding machine drives. Coming to the software based simulation approaches the authors of [17] - [22] are proposed the concept of high frequency circulating current injection in to MMC arm legs. In [23], the authors are proposed an optimal assortment of the average capacitor voltage of MMC based AC drive at rated torque and base speed condition. From [24], it is observed that, the complex design of variable speed control scheme for arm capacitor voltage of MMC circuit for improving the low speed control capabilities. Also, it is observed from [25], asymmetric control scheme for MMC based induction drives and not suitable for high power voltage applications. A limited multi level output using quasi-two-level PWM of MMC-based drive was presented in [26]. A multi multi-phase MMC-based induction drives was proposed in [27] to obtain balanced capacitor voltage during zero-/low-speed operation and this method of scheme was not supported to three phase AC drive applications.

3. Modular Multilevel Converter

A. Lesnicar and R. Marquardt are designed and introduced the modular multilevel converters due to its superior benefits of modular realization, extension of multi levels to decrease output harmonics, possibility for redundancy, minimum failure management and low investment and life cycle cost [28]. The most common three phase modular multilevel converter configuration is shown in figure 1.

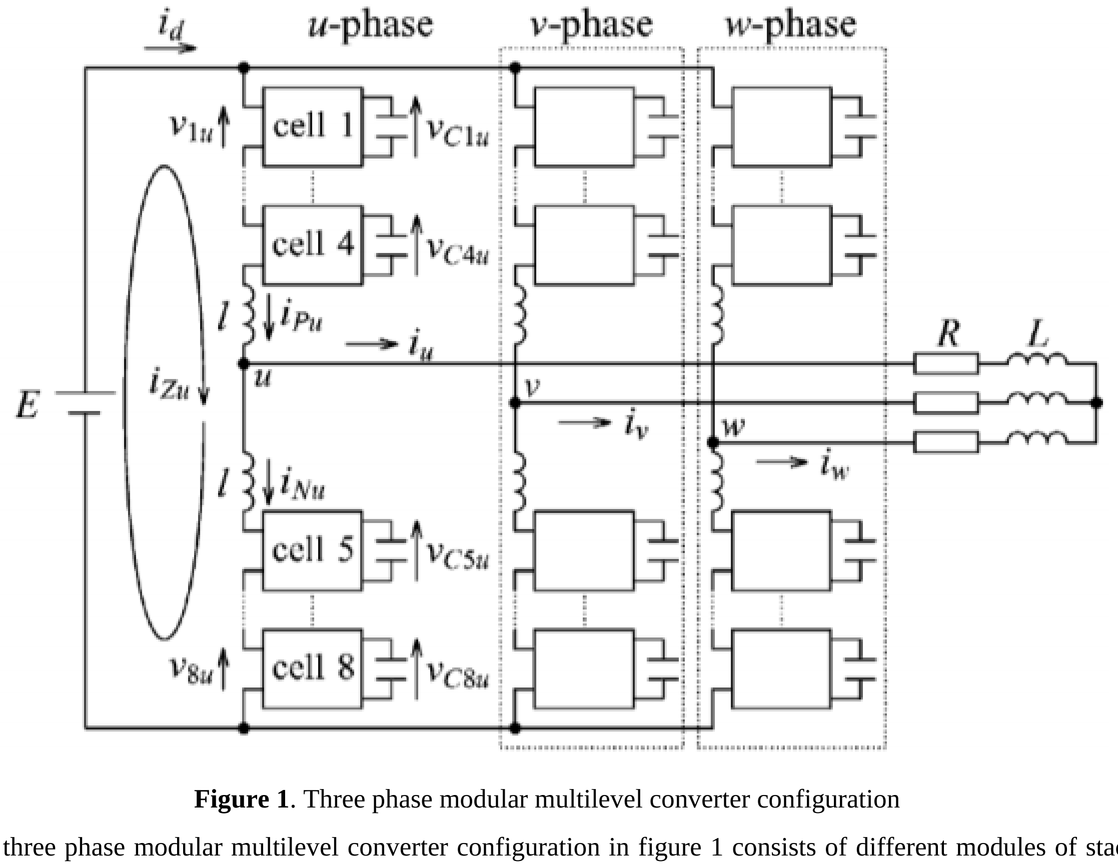

Figure 1. Three phase modular multilevel converter configuration

The three phase modular multilevel converter configuration in figure 1 consists of different modules of stack of cells called as arms on each phase of leg. Also, a controllable DC voltage source connected to a each module can be observed from the figure 1.It is also possible to design in modular multilevel converters in different configurations and the figure 1 illustrates the type of double-star configuration. Figure 1 illustrates clearly, number of cell modules are designed to operate the converter at right time of switching results in reduced harmonic less desired sinusoidal outputs. It is also possible to increase the number or levels of the converter to obtain desired outputs for meticulous applications. The major challenge observed in modular multilevel converter configurations are its sub module capacitors, in which voltage ripples are observed due to fluctuations of circulating currents in each leg of arms. This confirms that, it is a key challenge to design modular multilevel converters operations at lower frequencies which causes voltage stresses on semiconductor devices in design. Hence, suppression of these capacitor voltage ripples during fluctuations pays more attention to electrical design engineers. Also, it is tedious process to obtain the optimized solution to suppress the capacitor voltage ripples in conducting practical design and conducting the tests. In view of this simulation based study results supports to many industries to over this problem. Therefore, different control strategies are designed to suppress the capacitor voltage ripples of modular multilevel converter elsewhere in the world are discussed in the following sections to obtain efficient modular multilevel converter technique configuration to obtain effective performance of induction machine at different drive applications.

4. Modular Multilevel Converter (MMC) Control Topology

Different modular multilevel converter control strategies are used elsewhere in the world in order to obtain the efficient performance of AC induction drive applications. The following sections discuss the some of the major control strategies of in modular multilevel converters.

4.1 MMC with Arm Interchange Control

The modular multilevel converter with arm interchange control technique [29] is observed in figure 2.

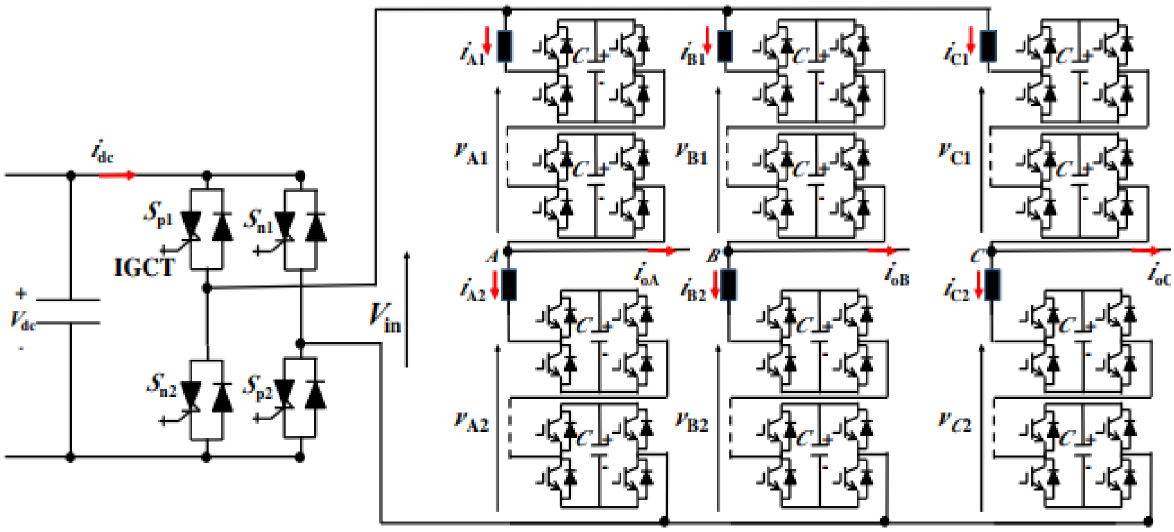

Figure 2. Three phase hybrid MMC

The above configuration consists of two stage of designs. The first step involves design of front-end IGCT-based H-bridge converter and its input was connected to the DC-link voltage, The output of this DC link voltage is fed to input to the second stage. The second stage of design involves a conventional three-phase FBSM-MMC. The major equation considered to minimize the voltage ripples of the switching module capacitors is

$$v_c(t) = V_{co} + \frac{1}{C} \int i_c \, dt$$

$$= V_{co} + \frac{1}{C} \int i_{arm} \; (v_{arm} / V\,dc) \; dt$$

It is reported in literature that, this method of design operates under zero/ low frequency operational mode to obtain balanced and bounded capacitors voltages with guaranteed low capacitor voltage ripples in outputs. Also, it is concluded that this type of design have low voltage stresses in output voltages.

4.2 Cascaded Control System Of The Modular Multilevel Converter

The design structure of cascaded control strategy of the modular multilevel converters [30] is shown in figure 3 below.

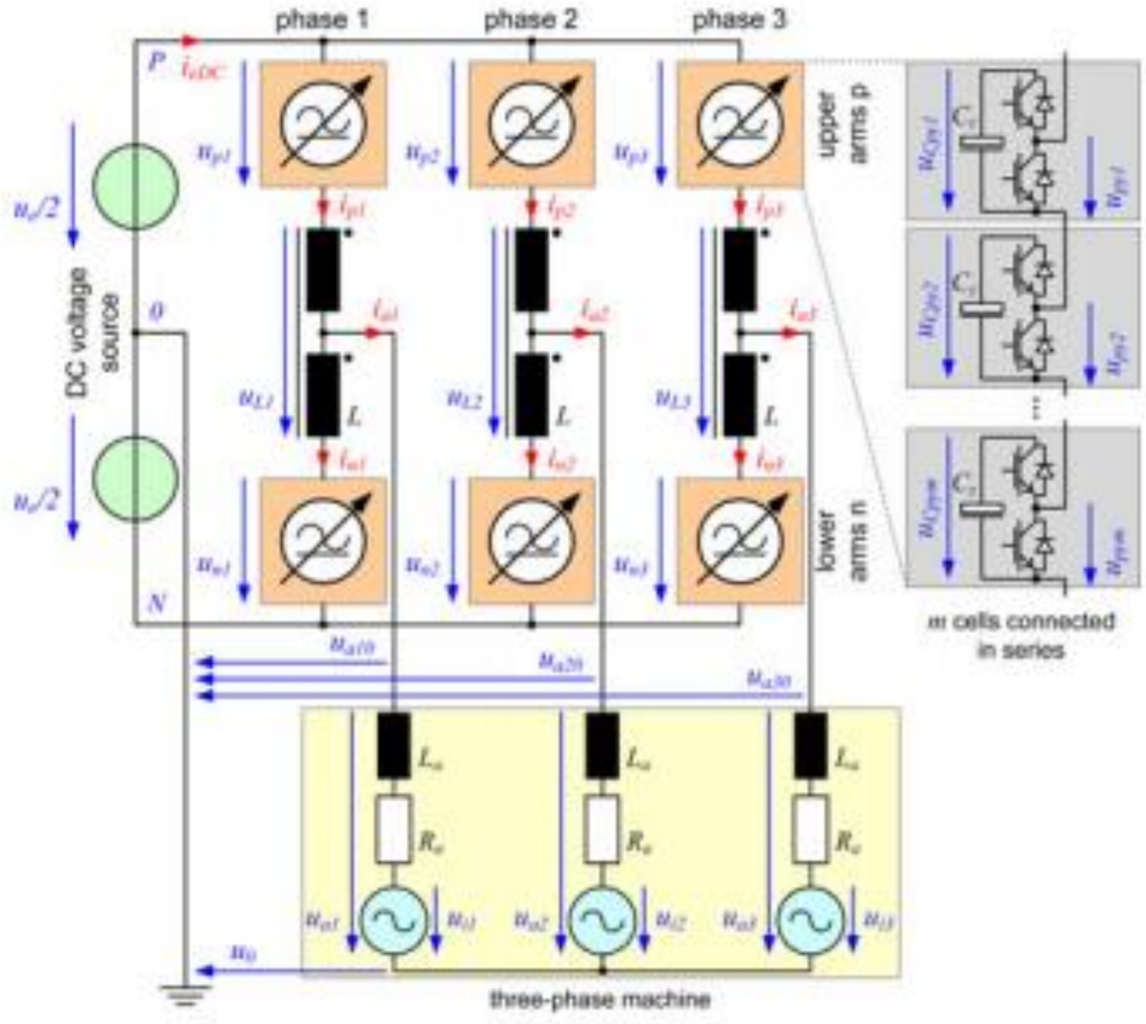

Figure 3. Design of cascaded modular multilevel converter

The cascaded type of control modular multilevel converter consists of two major design considerations. First design consideration is concentrated to current control design for the independent adjustment of several current components and which is derived from the equivalent circuit analysis. The other consideration is to obtain the balancing the energies in the leg arms of the MMC for the current and voltage components and systematically identify by the investigation of the transformed arm power components. These design considerations are lead to the design of the structure of cascaded control, which allows the balancing task in the whole operating range of a three-phase machine. Also, this control strategy ensures that, it necessities minimum internal currents over the complete frequency range by the dynamic balancing of the energies in the modules of the MMC. Concurrently, all other circulating current components are avoided to reduce the current stress and added voltage pulsations.

4.3 Control Stratagy On Energy Balance Of MMC

Many research works are reported on control strategies for obtaining the energy balance problems in arm legs of the three phase MMC circuit configurations at low frequencies and at starting of the AC drives [31]. The differences in energies supplying from upper arm to lower arms during the circulating currents generates voltage stresses and increased harmonic concentrations. The circuit configuration to obtain this energy balance control scheme is shown in figure 4 below.

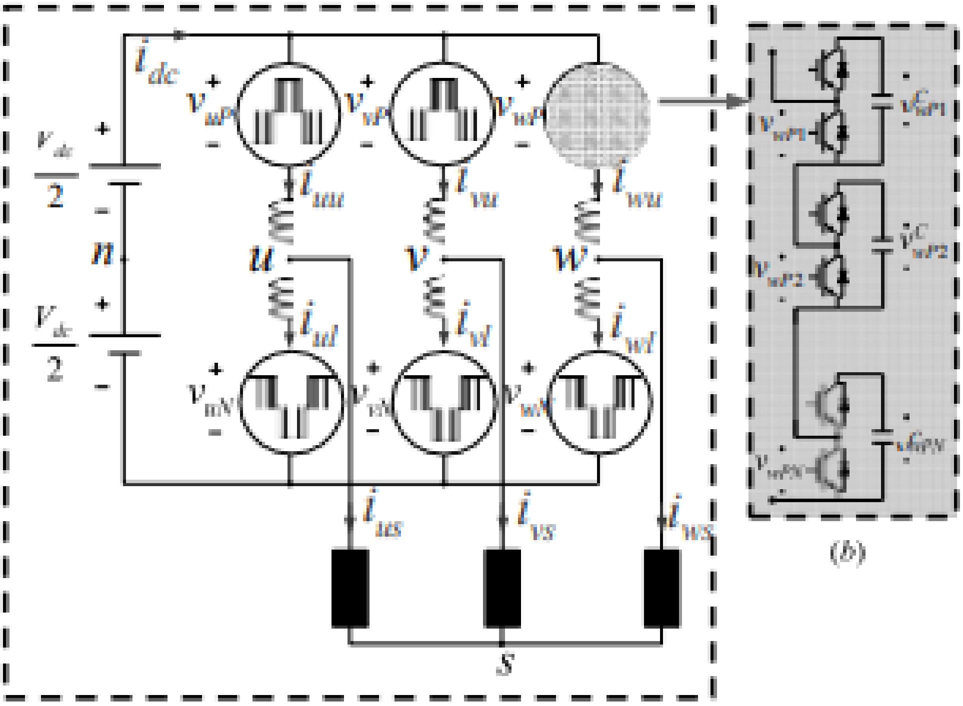

Figure 4. MMC control scheme for energy balance

The proposed control scheme initiates two operation modes. First mode is for start up of a AC drive at low frequency mode and for low speed operation. The second mode is to drive the AC machines at medium to higher speed operation for normal frequency ranges. The major approach for low frequency mode is to utilize leg arm offset voltages and common mode voltages with the high frequency component to suppress voltage ripples of the module cell capacitor. The use full mathematical equations to obtain the energy balance between upper arm leg to lower arm leg modules are

$$v_{xo} = \left(R + L\frac{d}{dt}\right) i_{xo}.$$

$$v_{xP}^{*} = \frac{V_{dc}}{2} - v_{xs}^{*} - v_{sn}^{*} - v_{xo}^{*}.$$

$$v_{xN}^{*} = \frac{V_{dc}}{2} + v_{xs}^{*} + v_{sn}^{*} - v_{xo}^{*}.$$

In this control strategy, square wave voltage instead of sinusoidal waveform voltage is used as the leg offset voltage, to obtain reduced circulating current peak.

5. Conclusion

A detailed review on modular multilevel converter techniques to obtain the efficient performance of the AC drive applications at low frequency and normal frequency has been presented in above sections. Existing multilevel techniques like neutral point clamped converter, flying capacitor converter, cascaded H-bridge and modular multilevel converter etc. are utilizing elsewhere in the world and each method having its own merits and demerits when compared to other. Among the existing techniques, neutral point clamped converter, flying capacitor converter, cascaded H-bridge converters are not suitable for high power voltage applications, where as modular multilevel converter is designed to operate for high power voltage applications compared other techniques. In view of enhanced power ratings of the AC drive applications, modular multilevel converters are the best suitable techniques due to its reliable operation in high power ratings, scaling, minimum failure management, low cost and life cycle operations etc. However, minimizing the module capacitor voltage ripples makes the key challenge to design engineers and many control schemes are designed by the researchers elsewhere in the world. It is also observed that, designing of modular multilevel converter with suitable control strategy up to 5 level showing the best performance. Therefore, designing of modular multilevel converter with energy balancing in arm legs control strategy with increased level of Sinusoidal Pulse Width Modulation technique may give the enhanced effective performance of AC drives.

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