Comprehensive Review on Modular Multi-level Inverters

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Abstract— Modular multilevel inverters (MMI) are in trends for high voltage and power applications since they can be easily extended to any number of levels with less no. of source requirement and reduced complexity to the control system. This paper presents an overview of control and applications of MMI. A brief overview on MMI topology is presented. With its control architecture. The switching topologies of the modules are presented to keep the capacitor voltage balanced. The detail discussion on voltage and current modulators are studied. This paper discusses brief principle of operation, carrier-based pulse width modulation for MMI.

Keywords: Modular multilevel inverters (MMI), Neutral point clamped inverter (NPCMLI), Flying capacitor inverter (FCMLI), Cascaded H Bridge inverter (CHBMLI), Grid tied solar system (GTSS)

I. Introduction

Modular multilevel inverters (MMI) are most advanced & latest type of power electronic converters that have replaced conventional 2-level Voltage source inverters (2LVSI) in grid connected operation of renewable sources. By taking sufficient number of dc sources, a nearly sinusoidal voltage waveform can be synthesized [1-3]. The unique structure of the MMI allows them to reach high voltage with low harmonics without the use of transformers. To synthesize multi level output ac voltage using different levels of dc inputs, semiconductors devices must be switched on & off in such a way that desired fundamental is obtained with minimum harmonic distortion [4] . There are different types of approaches for the selection of switching techniques for the MMI. When the 2LVSI topology have several disadvantages [5, 6]:

1) The arms of the converter have very high di/dt.
2) Over-voltages and great stress in the switching devices.
3) Emission of electromagnetic radiation.
4) With pulse-width modulation (PWM): great loss of power
5) Expensive passive filters.

Figure 1, presented for schematic of the MMI which improves these problems notably [7]:

1) The continuous flow of arm current avoids the high di/dt of the VSC switching.
2) Great reduction in power losses and filtering complexity.
3) The capacity is distributed among the modules of each arm.
4) High no. of level yield more relevant sine wave.

This paper presents an overview of control and applications of MMI. In section II presents MMI topologies. The control techniques are discussed briefly in section III.

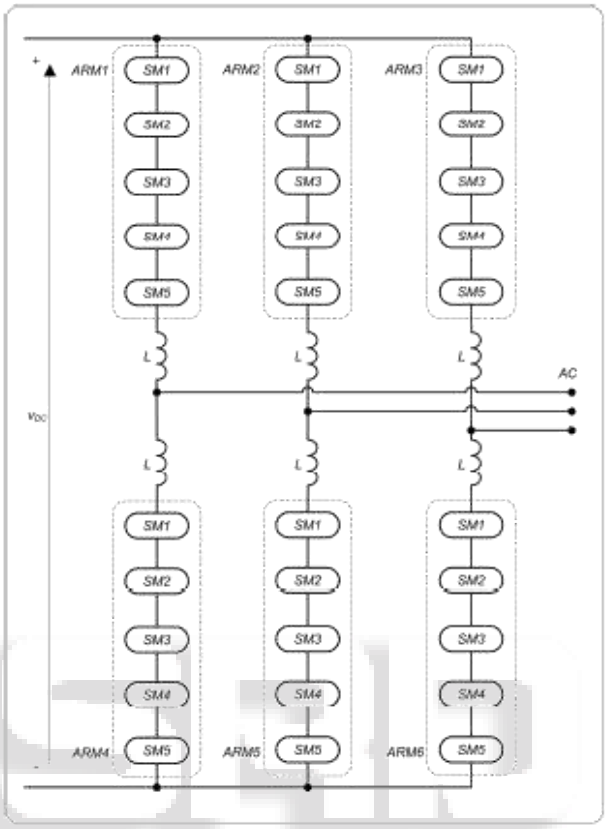


Fig. 1: Circuit topology of MMI

II. Modular Multilevel Inverter (MMI)

For ac/dc/ac conversion MMI are widely used MMI finds extensive applications in many high-voltage high-power applications. MMI are broadly of two types; one is diode/capacitor clamped as shown in figure 2 and another is bridge type as shown in figure 3. The diode clamped converter topology is mostly preferred due to its inherent due to its ease of regeneration and interconnection of the two ac ends via a common dc link. It also synthesize multi level output ac voltage using different levels of dc inputs. However, the proper use of this topology requires balancing of the dc link capacitor voltages during the exchange of non-zero real power between the two ac sides [8, 9].

The first topology of MMI presented was the half bridge (HB) topology (Figure 2) [10]. It consists of two switches (S), two diodes, and one capacitor. The S is ON when T1 is ON and T2 is OFF (Table 1), while S is OFF when T1 is OFF and T2 is ON. In ON state, the bridge voltage is the same as the capacitor voltage, and when OFF the voltage is zero. According to the S state and the direction of the S current, the current circulates through the capacitor producing its charge/discharge.

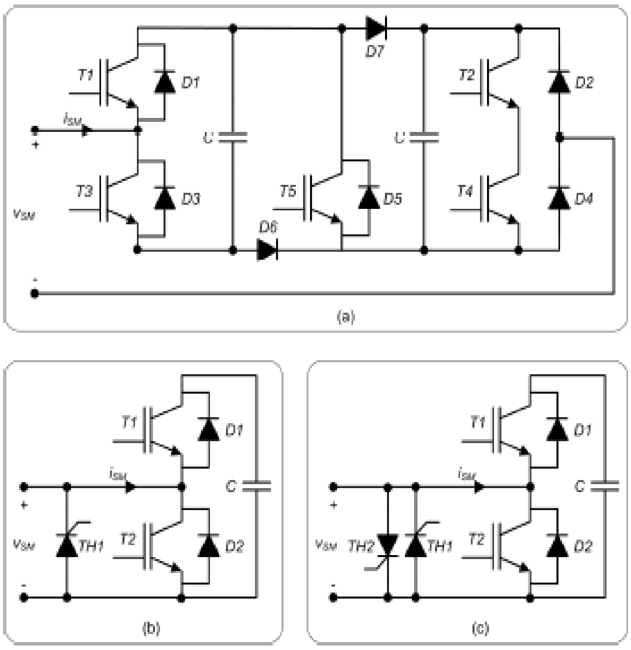


Fig. 2: MMI topologydiode clamped type

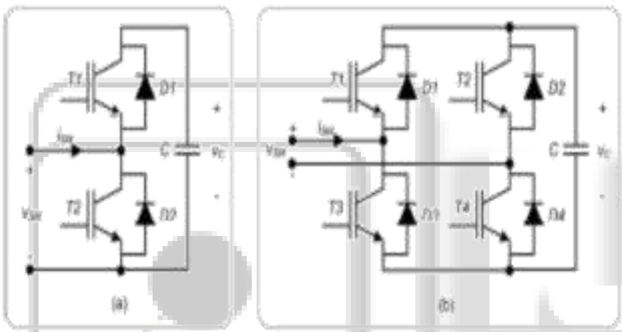


Fig. 3: MMI topology bridge type: (a) half bridge; (b) full bridge.

MMI State	T1 State	T2 State	V_{MMI}
ON	ON	OFF	V_C
ON	ON	OFF	V_C
OFF	OFF	ON	0
OFF	OFF	ON	0

Table 1: States of MMI-HB

III. Control Strategies

The inverter control strategy as shown in figure 4 includes two types of control: linear and non-linear [11-14].

A. *Linear controller*

The linear controllers used in MMI are categorized as:

– Feed-forward
– Feedback
– Composite

B. *Non –Linear controller*

The power semiconductor switches introduce non-linearity in the MMI circuit which could transverse in the circuit of inverter. For proper operation of MMI an appropriate nonlinear controller must be designed. Some non-linear controllers are:

– Fuzzy Logic (FL) based controller
– Artificial Neural Network (ANN) based controller
– Space Vector Pulse Width Modulation (SVPWM) based controller

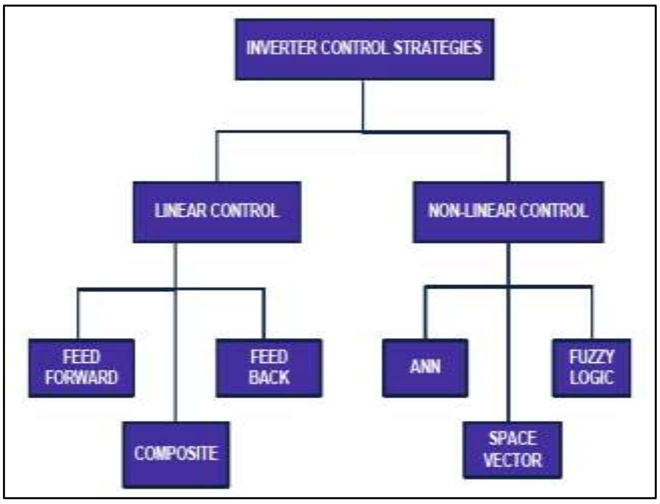


Fig. 3: MMI control strategies

IV. Dynamic Voltage Restorer

To develop a controller for MMI generally PI regulators as mentioned in figure 4 is used. Several strategies can be used to implement the inner voltage/current controller based on harmonic compensation schemes. Among them, two strategies capable of tracking sinusoidal reference signals are explained below. Both strategies employ resonant filters tuned at the frequencies to be compensated:

1) Control in αβ − dq axes: In this, Proportional Resonant (PR) regulators are used to eliminate the voltage/current errors in αβ axes (eαβ) also it tracks the fundamental reference signal. While the compensation of the harmonics is exerted on the current errors in the dq axes (where the αβ → dq transformation is applied), surging several resonant filters tuned to these harmonic frequencies. After the application of the inverse transform dq → αβ, all the αβ signals are added to obtain the reference output voltages as shown in Figure 5.
2) Control in αβ axes: in this, two PR regulators are used for the current errors (eαβ) to track the reference signal with the fundamental frequency ω1, and several resonant filters tuned to the harmonics to be compensated. The output of both the PR regulators and the resonant filters in the αβ axes are added to obtain the reference output voltages (voα ∗ , voβ ∗) needed to

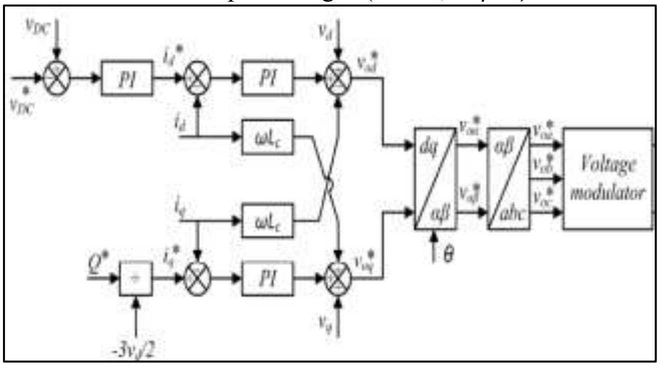


Fig. 4: PI controller Circuit Topology of MMI.

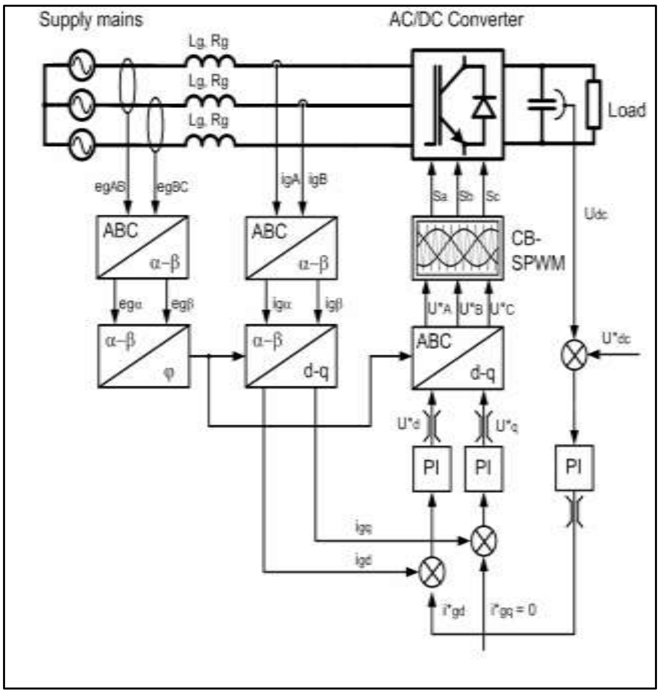
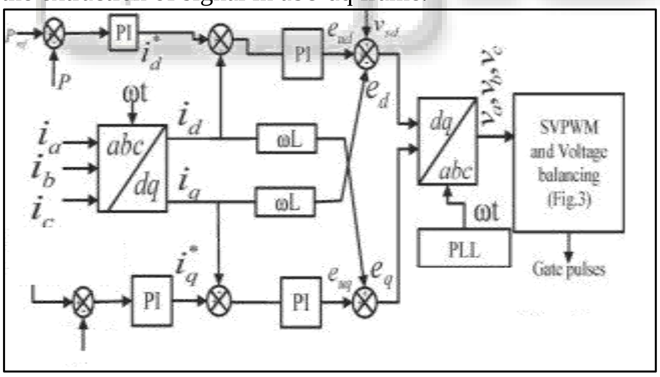


Fig. 5: Circuit Topology of STS.

From figure 5 it can be observed that firstly reference signals of three phase voltage is tracked and fed to the abc-dq transform and processed in the PI controller to obtain the control signal in d-axis and q-axis frame. The dq-axis simplify the control generation. For positive sequence, active power Pp must be zero, so the reference of the positive sequence current on the d axis must be zero, $i_{dp}* = 0$. A PI regulator is used to try to reset the positive sequence grid voltage to its nominal value Vp which is controlled by the positive sequence current in the q axis. Figure 6 presents the extraction of signal in abc-dq frame.



V. CAPACITOR BALANCING

The capacitors of the MMIs change their voltage depending on the current flowing though. The voltage of the MMI should be maintained to its theoretical value V_{DC}. For this, the MMI voltage must be measured and the appropriate controls to maintain the voltages to the constant value must be taken. Else, the capacitor voltages will become unbalanced and the AC output voltage cannot be controlled. Different types of algorithms have been used to balance capacitor voltages. One proven technique is the combination of the averaged control and the balanced control method. By its use, it is possible to balance the voltage of the capacitors without using any external circuit [19]. A predictive control, based on minimizing a cost function, allows the capacitor voltages to be balanced, circulating currents to be minimized and the AC currents to be controlled, jointly, under various operating conditions [20]. A method that does not need to measure the current in each arm eliminates current sensors, reducing costs and simplifying the voltage balance control algorithm [21]. The most commonly used algorithm measures the voltages of the capacitors and chooses the SMs that must be ON depending on the direction of the current [7,18]. The voltages of the upper arm will be balanced, while the lower arm will be balanced in the same way. In the upper arm, three SMs must be set to ON, chosen according to the SM current [illegible] direction. Depending on whether it is positive/negative, it increases/reduces the voltage of the SMs it circulates. When it is positive, SMs that have less voltage are turned ON to charge, while if negative, the SMs that have the highest

VI. CONCLUSION

The paper presents the comprehensive review on various CPD topologies to improve the performance efficiency the network connected with non-linear loads, unbalanced loading and source unbalanced leading to sag/swell events of voltages. This paper presents an overview of control and applications of MMI. A brief overview on MMI topology is presented. With its control architecture. The switching topologies of the modules are presented to keep the capacitor voltage balanced.

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