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REVIEW OF INVERTER AND MULTILEVEL INVERTER: FEATURES, TECHNIQUES, TOPOLOGY AND LATEST DEVELOPMENTS

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Abstract

Inverter is an important topology in modern power electronic system which provides a solution to convert the average power flow from DC power to AC power. Inverter employs different soft switching techniques to solve the problems faced in industrial applications such as harmonic reduction, stress reduction and switching power loss minimization. This paper presents the detailed study and comparative analysis of inverter and multilevel inverter.

***Key Words*:**Adjustable Speed Drives (ASD), Pulse Width Modulation (PWM), Multi-level Inverter (MLI), Harmonic Factor (HF), Total Harmonic Distortion (THD), Weighted Total Harmonic Distortion(WTHD)

1 Introduction

Inverter is a power electronic device which transforms the DC voltage into AC voltage. Before 1960s inverter technology was not been widely used in industrial applications because of the cost and their system complexity. Later on tremendous improvement in inverter technology which created applications in modern industrial revolution. Multilevel inverter was first proposed by Nabae in 1980 and presented in IEEE international conference [20] and same concept was published in IEEE Transactions on Industry Applications [17] which proposed different approach to construct DC/AC inverters. Input DC source used in inverter is usually battery or controlled rectifier output. Output voltage of the inverter is basically controlled by switches which generate AC power supply in form of square wave, quasi-square wave or sine wave [2-3].

During 1980s development of semiconductor devices played a vital role in shaping the inverter technology to next level. Inclusion of IGBTs and MOSFETs in the inverter made the circuit to operate at higher frequencies from few KHz to MHz. These were generally used for constant regulated power supply and Adjustable Speed Drives (ASD) such as induction motor drives, voltage compensation, flexible AC transmission systems (FACTs), reactive power compensations, passive series/parallel filters and synchronous machine drives. SCRs, GTOs and triacs were used for lower frequency switching [1,3,4].

Despite of its growing importance, one of the major setbacks is the presence of significant amount of unwanted harmonics in its output voltage and current. Generally harmonics tend to exhibit severe effects on electrical and mechanical components [9]: switches losses are increased in the semiconductor switches, overall system performance will reduce considerably causing ripples in induction motor (torque) and reduces the life span of the system due to vibration, torque pulsation and mechanical fatigue [19].

To overcome these problems, research has been carried out to control or mitigate the effects of harmonics in inverters. The most important aspect is to device an appropriate switching scheme for the power switches that can synthesize the AC waveform with the lowest total harmonic distortion (THD). Harmonic Elimination PWM (HEPWM) has gained prominence among researchers due to several benefits compared to other PWM techniques [1,2,3,4,12,18]. Soft switching techniques are employed to handle transitions occurring during switching in order to reduce switching losses, low EMI with reduced switching stress and thermal stability [1]. Inverter mostly works on pulse width modulation (PWM) and multilevel modulation (MLM) techniques which chop the reference waveform vertically to attain different levels based on output voltage waveform (sine wave). Output voltage of the inverter contains harmonics which can be reduced based on different control techniques. PWM techniques can be implemented for high output voltage and frequency which in turn reduces THD.

2 INVERTERS

Inverters are mainly classified based on the sources used. They are

- Voltage source inverter (VSI)
- Current source inverter (CSI)
- Impedance source inverter (ZSI)

A voltage source inverter (VSI) is supplied from a DC voltage source which provides output voltage value lower than DC link voltage (Buck). Large capacitors are needed to maintain the DC link voltage constant. In VSI, proper placement of capacitors across DC voltage source should be done otherwise the device will be short circuited which is shown in Fig, 1(a).

A current source inverter (CSI) is supplied from a DC current source which provides output voltage value higher than DC link voltage (Boost). Large inductors are needed to maintain the supply current constant. In CSI, proper placement of inductor across DC current source should be done otherwise the device will be open circuited. In Adjustable speed drives (ASD), the DC current source is AC/DC rectifier with series inductor which is shown in Fig. 1(b).

An impedance source inverter (ZSI) is supplied from voltage or current source with x-shaped impedance circuit formed by two capacitors and two inductors called z-source inverter which provides output voltage value higher/lower than DC link voltage (Boost/Buck) which is shown in Fig. 1(c). Large inductors and capacitors are needed.

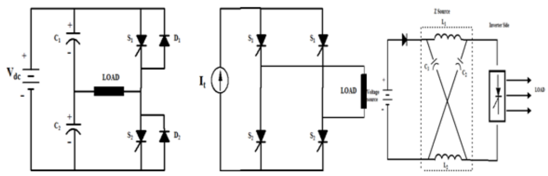

Fig 1. (a) Voltage source inverter (b) Current source inverter (c) Z source inverter

3 MULTILEVEL INVERTER

Multilevel Inverter (MLI) gives the solution to the basic structure of inverter by modifying the parameters, size and components in order to achieve different levels (m-level) by adding output voltages to produce stepped waveform. Each level is attained due to commutation of switches. It has overcome the drawbacks faced by PWM technique which has been for more than 25 years. By increasing the levels in the MLI, the system complexity increases which in turn creates voltage imbalancing problem which is considered to be the only major problem regarding MLI. But it reduces the harmonic content based on number of levels.

There are different topologies proposed for MLI which is shown in Fig. 2. They are diode/capacitor clamped topology, H-bridge topology, laddered topology, soft switching topology. MLI can be based on number of DC sources. Diode Clamped (Neutral Clamped) and Flying Capacitor Clamped (Capacitor Clamped) MLI requires only single DC source [22] whereas Cascaded H-bridge, Quasi- linear, Binary hybrid and Trinary hybrid MLI requires multiple DC source.

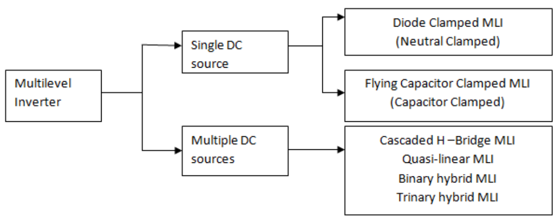

Fig 2. General types of MLI topology

Diode Clamped MLI (Neutral Clamped):

Diode clamped MLI has been proposed in 1981. Till then its popularity gained in making the circuits using diodes. The desired voltage levels are obtained by connecting the switching devices in series to obtain number of levels (M). The name clamped is denoted because diodes are used as clamping devices. DC voltage points are clamped (centered) by two diodes (Additional) or one capacitor with high frequency is added to it.

- Main switching devices required = 2(M-1)
- DC link capacitors required = (M-1)
- Diodes required = M(M-1)
- Total components required = (M-1) (M+1)
- Voltage across each DC link capacitor = Vdc / (M-1) where Vdc is DC link voltage
- *Application :* Variable drive high speed motor, power transmissions, static VAR compensation
- *Advantages:* Less components, High efficiency at fundamental frequency, back to back connections
- *Disadvantages:* real power flow calculation is difficult, voltage imbalancing problem, output voltage is limited based on levels

For three level diode clamped inverter, number of switches and DC link capacitors required is 4 and 2 respectively. The number of clamped diodes used in MLI is 4 and its voltage across each DC link capacitor is Vdc/2.in Fig 3.

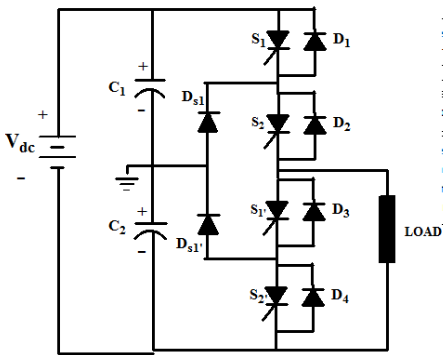

Fig 3. Three level Diode clamped MLI

Capacitor Clamped MLI (Flying Capacitor Clamped):

Capacitor clamped MLI is also called flying capacitor clamped because of the clamped capacitor is dependent on the device voltage to one capacitor voltage level. The clamping capacitor C1 is charged when S1 and S1 are turned ON and discharged when S2 and S2 are turned ON.

- Main switching devices required = 2(M-1)
- Capacitors required = 0.5M (M-1)
- Diodes required = (M-1)
- Total components required = (M-1)(0.5M+3)
- Voltage across each DC link capacitor = Vdc / (M-1) where Vdc is DC link voltage
- *Application :* Induction motor control using direct torque control, sinusoidal current rectifiers, static VAR generation and DC-AC and DC-AC conversion application
- *Advantages:* power outrages, use of filters is reduced due to reduced harmonic content, both real and reactive power flow can be controlled
- *Disadvantages:* switching frequency and switching losses are high during power transmission[21]

For three level capacitor clamped inverter, number of switches and capacitors required is 4 and 3 respectively. Number of diodes required is 2.

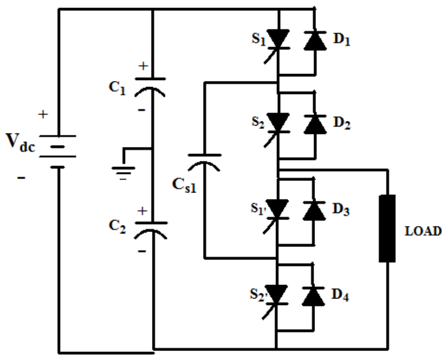

Fig 4. Three level Capacitor clamped MLI

Cascaded H Bridge MLI:

The structure of cascaded H- Bridge resembles the shape of H when connected to MLI. Each H-bridge requires separate DC source. If the DC link voltages of H-bridge are identical then the multilevel inverter is called cascaded multilevel inverter. If the DC link voltages of H-bridge are different then the multilevel inverter is called Hybrid multilevel inverter.

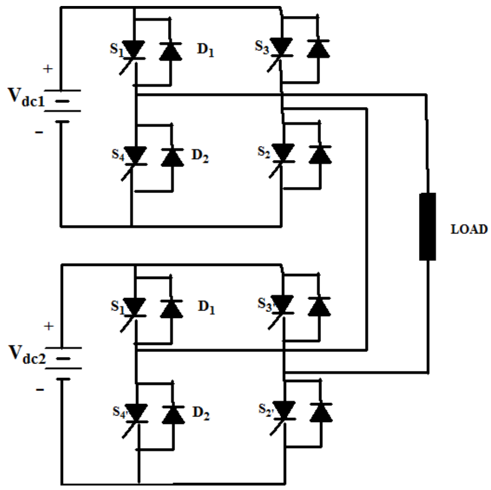

Fig 5. Three level cascaded H-bridge MLI

If the DC link voltages of H-bridge are identical and equal then the multilevel inverter is called Cascaded Equal Voltage MLI (CEMI).

$$V_{dc1} = V_{dc2} = V_{dc3} = E \tag{1}$$

where E is unit voltage

If the DC link voltages of H-bridge(V_{dci})is $2i - 1$E, then the multilevel inverter is called Binary Hybrid MLI (BHMI). For three H-bridge one phase leg,

$$V_{dc1} = E, V_{dc2} = 2E, V_{dc3} = 4E \tag{2}$$

If the DC link voltages of H-bridge (V_{dci})is $3^{i-1}E$, then the multilevel inverter is called Trinary Hybrid MLI (THMI). For three H-bridge one phase leg,

$$V_{dc1} = E, V_{dc2} = 3E, V_{dc3} = 9E \tag{3}$$

(Common for CEMI, BHMI and THMI)

- Main switching devices required = 2(M-1)
- Capacitors required = (M-1)/2
- Diodes required = 2(M-1)
- Total components required = 4.5 (M-1)
- *Application :* Electric vehicle drives, Motor drives, Active filter, Power factor compensators

• *Advantages:* less components, switching losses and device stresses are reduced using soft switching techniques

• *Disadvantages:* Separate dc sources adds additional cost and size

4 CONTROL STRATEGIES

Pulse Width Modulation (PWM) technique:

Pulse width modulation is a method that is widely used for switching pulses to turn on and off the switches to produce alternating waveform at the output of an inverter circuit. It is a technique which has adjustable widths with constant amplitude and phase. The modulation ratio [ma] is obtained from the amplitude of reference signal [V_{ref}] with the amplitude of carrier signal [V_c] (Triangular signal).

$$M_a = \frac{V_{ref}}{V_c} \tag{4}$$

The output voltage can be controlled by varying the ma value for different amplitude of reference signal. When m_a is less than or equal to 1, the range is linear region where the amplitude of fundamental frequency varies linearly with modulation ratiom_a. When ma lies between 1 to 3.24, then the range is over modulation region where the amplitude of fundamental frequency does not varies linearly with modulation ratio m_a.. Over modulation causes harmonics in the output voltage in sidebands. When m_a is greater than 3.24, then the range is square wave region in which each inverter switch is (1/2) cycle of the desired output frequency (180 degree).

Parameters used for comparison:

The output waveform of an inverter should be a square-wave which contain harmonics (from 3rd harmonics). 3rd harmonics is located very close to the fundamental frequency, so it is very difficult to filter it. Designing of high order filter is required in order to reduce the total distortion. Other harmonic parameters used in PWM operation are Harmonic Factor (HFn), Total Harmonic Distortion (THD) and Weighted THD (WTHD).

$$HF_n = \frac{V_n}{V_1} \tag{5}$$

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1^2} \tag{6}$$

$$WTHD = \frac{1}{V_1}[\sum_{n=2,3,\cdots}^{\infty}(\frac{V_n}{n})^2]^{1/2} \tag{7}$$

5 CONCLUSION

This paper gives a summary of inverter and multilevel inverter with its classification and control strategies. General concepts on MLI and its techniques were discussed. Its primary focus is about the general outline about multilevel inverter and its applications in present scenario. Day to day applications are being developed based on multilevel inverter concept. So it is necessary for researchers who wants to work in this domain to learn the basic skill set about MLI. Whenever the researchers thinks about MLI, they should always remember to work with reduced switching devices as far as possible and should be capable of producing high output voltage with reduced switching frequency.

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