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A Review on Voltage Balancing Solutions in Multilevel Inverters

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Abstract

Multilevel inverters are used in high power and medium voltage applications. Employing multilevel inverter with renewable energy alone, the voltage balance cannot be made because the number of level increases in multilevel inverter the control gets complexity. So voltage imbalance problems are introduced. The voltage imbalance problems can be classified into two types; Midpoint unbalance and the central capacitor discharge. These problems can be solved by using voltage balancing solutions. The solutions are hardware based; software based, and combined solutions. By using these types of solutions the voltage balancing problems can be solved and the efficiency of multilevel inverter could be high. This paper reviews about various voltage balancing solutions in multilevel inverter.

Keywords*: Multilevel inverter, voltage imbalance problem, voltage balancing solutions, pulse width modulation (PWM), high efficiency. Midpoint unbalance*

1. Introduction

Multilevel inverter was introduced in 1975. Multilevel inverter is one of the most recent advancements in power electronics. Nowadays the multilevel inverters are preferred for high voltage and high power applications. The synthesize output voltage have more steps, because of increasing the number of levels in multilevel inverter and it generates a staircase waveform which reduces the harmonic distortion. Due to increasing the numbers of levels in multilevel inverter the control complexity are occurred and the voltage imbalance problem is introduced. It not only achieves high power rating and also enables the use of renewable energy source.

Multilevel inverters are easily interfaced with renewable energy source to produce high power and it is used in industries. It also used in medium voltage to high voltage industrial drive applications. Multilevel inverters have some advantages as they provide (i) low harmonic distortion, (ii) low voltage stress, (iii) high efficiency (iv) low switching frequency (v) ability to operate without magnetic components. There are three types of multilevel inverters, namely Diode clamped which is also called neutral point; capacitor clamped which is also called Flying capacitors and Cascaded H- bridge multilevel inverter [1- 3].

2. Voltage Balancing In Diode Clamped Multilevel Inverter

In diode clamped multilevel inverter, diodes are most commonly used. This inverter provides multiple voltage levels through different phases to the capacitor banks, where the capacitor banks are connected in series. A diode transfers a limited amount of voltage, so it will reduce the stress on the electrical devices. Diode clamped multilevel inverter provides high efficiency because fundamental frequency is being used for all the switching devices. The applications of diode clamped multilevel inverters are: (i) static var compensator (SVC), (ii) HVDC and HVAC transmission lines and (iii) variable speed motor drives. The number of level increases in multilevel inverter, the control of the inverter should be complex. So that voltage unbalance problem is being introduced.

There are two types of voltage unbalance problems. The problems are: (i) Midpoint unbalance and (ii) Central capacitors discharge. When the midpoint will be getting unbalanced due to the two upper capacitor voltage is exceeded than the two lower capacitors. Then the midpoint unbalance problem will be occurred. The central capacitor discharge states that, when

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the outer switching devices will be stressed and the central capacitors can get discharged [4]. The circuit diagram of Diode- clamped five level converter is shown in figure 1. In diode clamped five level converter dc link is made by four capacitors and the capacitors are connected in series. The dc link capacitors consist of C_1, C2, C3, and C4. For a dc bus voltage across each capacitor is Vdc/4. The complimentary switch pairs in each phase will be i.e., Sa_1-Sa'_1, Sa_2-Sa'_2, and Sa_4-Sa'_4.

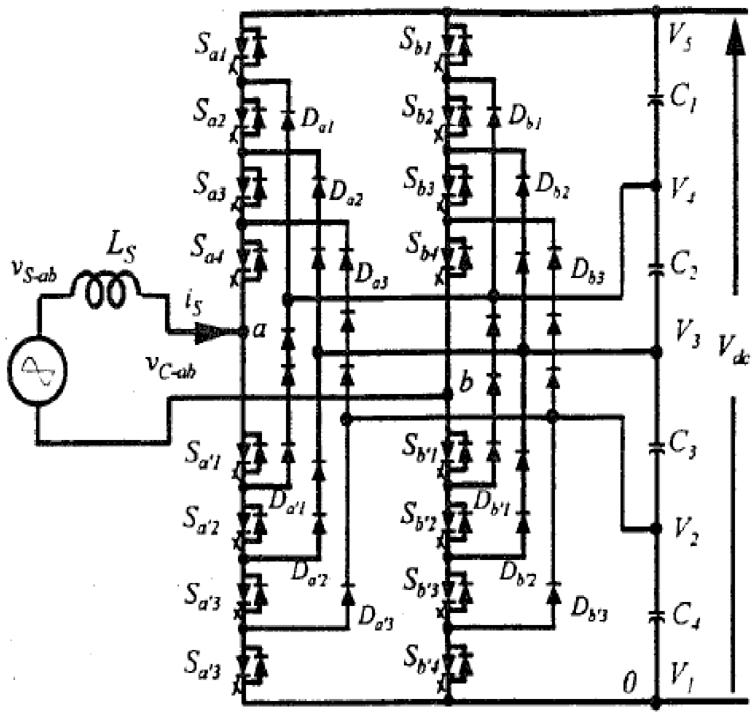

Figure 1. Circuit Diagram of Diode- Clamped 5- Level Converter

3. Solutions of Voltage Balancing Problem

There are three types of solutions to solve the voltage unbalance problem,
(i) Hardware based solutions
(ii) Software based solutions
(iii) Combined solutions.

3.1. Hardware Based Solutions

The hardware based solutions are used to solve the central capacitor discharge. There are three types of hardware based solutions,
(1) Back to Back connection of diode clamped converters
(2) Feeding the capacitors with independent DC sources and
(3) The use of clamping converters in the DC-side [4].

3.1.1. Back to Back Connection of Diode Clamped Converters

Julio C. Rosas-Caro, et al, proposed a method that can generate nearly sinusoidal input current and achieves unity power factor. In back-to-back connection two converters have to be used. Where, the two converters should have same power rating. This forms one of the drawbacks in back-to-back connection because this will be increasing the total cost in twice. The solution is most suitable for unified power flow controller (UPFC) in back-to-back connection [4].

Natchpong Hatti, et al, proposed a transformerless motor drives using two five level diode clamped PWM converters that are connected in back-to-back system. In this system, voltages can be balanced by the voltage balancing circuit using two bidirectional buck and boost converters that are operated independently. When the switching frequency is lower, then large ripple current to flow in the inductor, this ripple current will not affect the voltage balancing circuit because it's absorbed by the four split dc capacitors [5]. Leon M.Tolbert, et al, proposed a back-to-back connection of diode-clamped converters which is interfaced with the source of ac power and it will meet high-power and high-voltage requirements of the driven motor. The capacitor voltage balance method is used to perform voltage balance in back-to-back configuration. In back-to-back connection, proportional switching patterns are used for both portions of rectifier and inverter [6].

Diego E. Soto-Sanchez et al, proposed a back-to-back configuration in which DC link voltage balance could be adjusted by setting commutation angles in the case of steady state operation. High harmonic distortions are produced due to voltage control of series converter. In order to overcome this problem series converter is divided into two half power rated converters and the output voltage can be controlled by using phase displacement between series converter into half power rated converter [7].

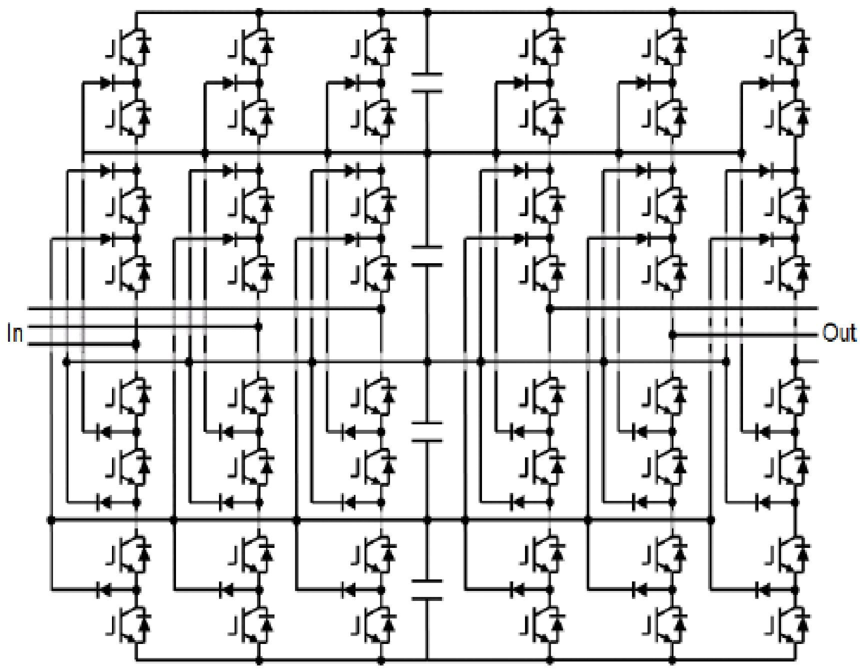

Figure 2. Circuit diagram of back to back connection for two diode clamped Multilevel converters

Mario Marchesoni, et al, proposed a fact that capacitor voltage is not balanced in all operating conditions, when the multipoint clamped converter carry a passive front end. Further in ac-dc-ac power conversion, the back-to-back connection grants the balance of the dc link voltage. Multipoint clamped converter requires the effective balancing strategy, which is used to balance the dc link capacitor voltages [8]. Zhiguo Pan, et al, proposed a balancing theory which is used to generate the switching angles and hence balancing of capacitor voltage is built in the modulation control. The modified PWM control method is used to reduce the total harmonic distortion and produce good harmonic performance. The control methods have some features such as low harmonic content and unity power factor operation [9].

3.1.2. Feeding the Capacitors with Independent Dc Sources

P. N. Tekwani, et al, presented an open loop control method which is used to balance the dc-link capacitor voltage. This method uses only the redundant switching states for inverter voltage vectors. Additional power circuit not required for the open loop control [10]. The closed loop control method is used to maintain the balance of the dc-link capacitor voltage. During different dynamic operating conditions the capacitor voltage gets unbalanced. Additional power circuits are required for the closed loop control to achieve the capacitor voltage balance and to eliminate the common mode voltage for the entire system [11].

Sanjay Lakshminarayanan, et al, proposed a 12 sided polygonal voltage space vector based PWM method used for a open end winding induction motor drive. This method gives the zero common mode voltage for a motor operation which is used to eliminate the common mode voltage variation problems. The advantage of this method is to reduce the inverter switching losses and efficiency is increased in the overall drive system [12].

S.Figarado, et al, proposed a dual fed open ended winding induction motor drive with PWM modulated inverter scheme where three level common mode voltages is eliminated with reduced number of switches. No isolation is needed between two inverters as the system is free from triplen harmonic contents and hence only two DC links are needed. Common mode voltage variations are zero for pole voltages as well as phase voltages and hence the problems of bearing currents and shaft voltages are eliminated [13].

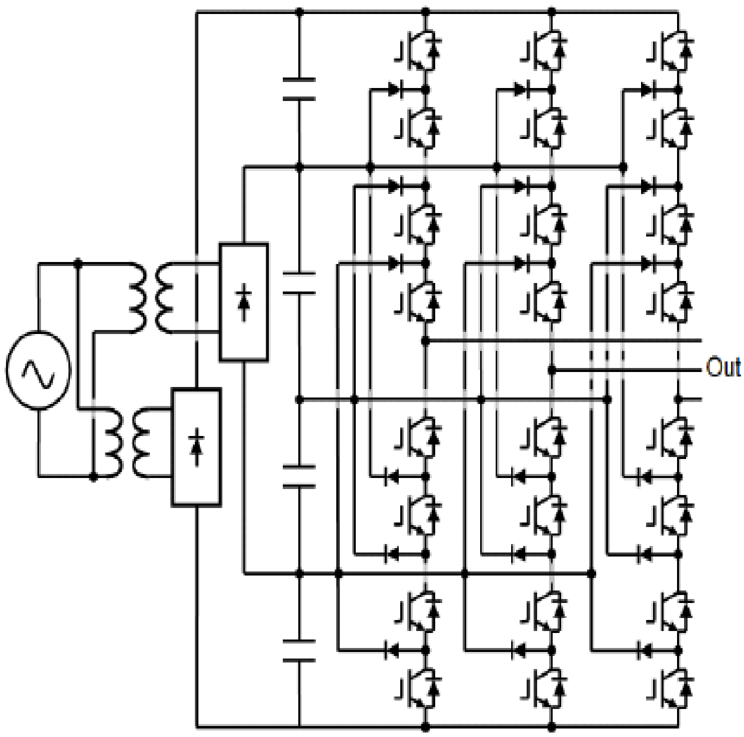

Figure 3. Circuit Diagram Of Diode Clamped Multilevel Converter Feeding The Capacitors With Independent DC Sources.

3.1.3. Clamping Converter in the Dc-Side

Natchpong Hatti, et al, proposed a 6.6kv transformerless five level diode-clamped PWM inverter with a diode rectifier at the front end, which has been used for pump/blower drives. Voltage balancing circuit along with the power conversion system consists of five level diode-clamped PWM inverter and front-end diode rectifier. In any operating conditions, voltage balancing controller works properly even in over modulation [14].

Yiqiang Chen, et al, proposed multilevel converter which is used in the application of STATCOM and UPFC. In UPFC two converters are connected in the dc sides and the multilevel converters are fed from the ac side by shunt and series transformers. Unfortunately inherent voltage stability problem existing in the multiple level dc links could be solved by equalizing the dc link capacitor voltages by dc choppers [15]. Narendrababu A, et al proposed a diode clamped converter operating in rectifier mode. Various control techniques are used to balance the capacitor voltages. In this system the space vector modulation technique is proposed. The converter works as the high power factor rectifier and the PWM wave shape is nearer to the sinusoidal wave which is also used to draw the sinusoidal current [16].

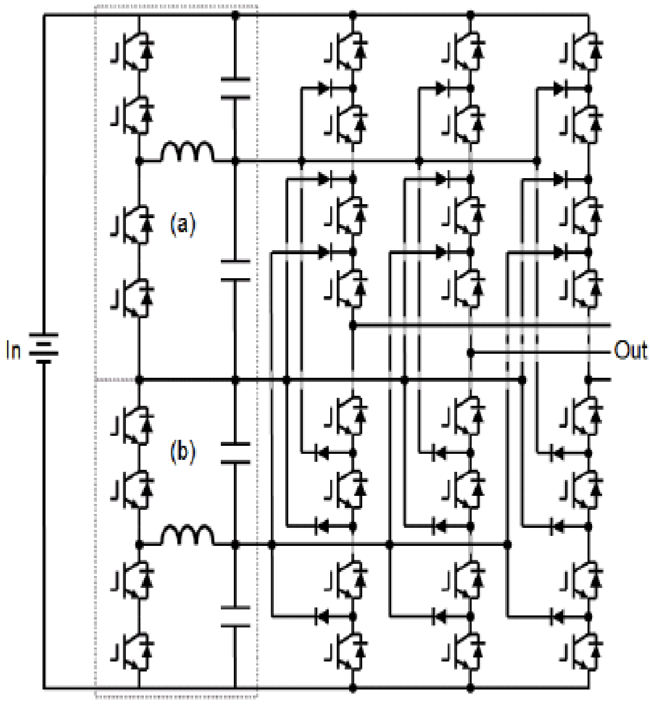

Figure 4. Circuit Diagram Of Diode Clamped Converter With Clamping "Insiders" DC-DC Converters To Balance The DC Link (A) Buck Type (B) Boost Type

3.2. Software Based Solutions

In a diode clamped converter, four split DC capacitors are present, of which upper two stages forms buck-type converter and lower two stages forms boost-type converter. When buck-type voltage exceeds the boost type voltage, at that condition, midpoint unbalance occurs. Using redundant switching states, the problem of midpoint unbalance can be solved [17-19]. A sophisticate PWM method is used to balance the DC link, and then the problem can be solved. But then it is limited in the operating conditions [19-23]. Redundant switching states enables to determine the capacitors that is to be charged or discharged during switching period, where the output voltage can be generated by more than one switch combinations. For more redundant switching states, modulation index is too decreased [24].

3.3. Hybrid Based Solutions

By using the internal circuit the dc link capacitor voltage can be balanced without using the external circuit. The active and passive devices are clamped in this topology and it can be used in real and reactive power conversion applications. The drawback of hybrid clamped multilevel inverter is it requires more number of devices [25]. Amin ghazanfari, et al, proposed a hybrid optimal modulation strategy. It is used for a cascaded H bridge multilevel inverter. There are two main parts of the hybrid optimal modulation strategy. One is the optimal modulation and another one is pattern exchange. The optimal modulation strategy is used to reduce the total harmonic distortion and the pattern exchange technique is used to balance the dc capacitor voltages. The hybrid optimal PWM strategy can be extended for any level of cascaded H bridge multilevel inverter and it produces high quality output signals [26].

For a hybrid clamped multilevel inverter a novel PWM control method is used. The control method is also known as Higher and Lower Carrier Cells Alternative Phase Opposition PWM (HLCCAPOPWM) method. This method is used to improve the output harmonic performance and to reduce the switching losses. Then the active and passive devices are clamped and it can be used in real and reactive power conversion applications [27]. Zhong Du, et al, proposed a hybrid cascaded H-bridge multilevel inverter using only a single DC sources and capacitors. In order to increase the number of output levels, it provides high quality power, then the result is high conversion efficiency and low thermal stress. A fundamental frequency switching method [28-29] and triplen harmonic compensation method were developed to extend the modulation index range for which capacitor voltage can be balanced [30].

4. Conclusion

The different types of voltage balancing solutions are discussed in this paper. The voltage unbalance problems are solved by using the solutions of hardware based; software based and hybrid based. Using these types of solutions the voltage balancing problems can be solved and it is used to balance the capacitor voltage, then the efficiency of multilevel inverter should be improved. The multilevel inverters are used in high power and medium voltage applications such as motor drives, power distribution, power quality, and power conditioning applications.

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