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Comparison of Multilevel Inverters with T-type Inverter

Abstract. *This paper provides a comparison analysis of various types of multilevel inverters with T-Type inverters. The primary goal of this work is to examine the operation of T-type multilevel inverters with various multilevel inverters. The inverter used in our paper is based on a multilayer bidirectional DC-DC converter that can be used in EV applications. The proposed design incorporates two power switches as well as an additional capacitor to balance the currents of the multilayer T-type (MLI) capacitor over the course of a drive pattern or during fault conditions. Due to the high-frequency cycle-by-cycle current security between CN and CP, the large electrolytic capacitors in T-type MLI have been replaced with longer-lasting film capacitors in this design. Because of this, the dimensions and weight of the converter would be reduced by 20%.*

Streszczenie. *Artykuł zawiera analizę porównawczą różnych typów falowników wielopoziomowych z falownikami typu T. Podstawowym celem tej pracy jest zbadanie pracy falowników wielopoziomowych typu T z różnymi falownikami wielopoziomowymi. Falownik zastosowany w naszym artykule oparty jest na wielowarstwowej dwukierunkowej przetwornicy DC-DC, która może być wykorzystana w aplikacjach EV. Proponowany projekt obejmuje dwa przełączniki zasilania, a także dodatkowy kondensator do równoważenia prądów wielowarstwowego kondensatora typu T (MLI) w trakcie wzorca napędu lub w warunkach awarii. Ze względu na zabezpieczenie prądowe cykl po cyklu o wysokiej częstotliwości między CN i CP, duże kondensatory elektrolityczne w MLI typu T zostały w tym projekcie zastąpione trwalszymi kondensatorami foliowymi. Dzięki temu wymiary i waga konwertera zostałyby zmniejszone o 20%.* (***Porównanie falowników wielopoziomowych z falownikiem typu T***)

Keywords: Total Harmonic Distortion (THD), Multilevel Inverter, Capacitor Voltage Balance, Switching Losses.
Słowa kluczowe Współczynnik THD, przekształtnik wielopoziomowt, straty przełączania

Introduction

Inverters are devices created to convert DC signals into AC signals directly. Inverters are used in energy enterprises that operate continuously and for power system solutions. Three levels are present in common inverters used in industrial applications. Power difficulties of higher quality are more prevalent as inductive loads are used by power systems more frequently. Hence, a bigger level inverter has been employed. The large level, often referred to as the high level inverter or multilayer inverter, aids in the provision of energy with fewer power quality issues. Multilevel inverters, which are typically used in conjunction with other inverters, use switches [1, 2].

These various multilevel inverters, which are further classified as diode clamped, flying capacitor, and H-bridge cascaded multilevel inverters, were becoming an increasingly important component. Switching losses are decreased by the use of less expensive range switches in multilayer inverter advances today. As a result, the multilayer inverter shown in this article is unquestionably brand-new and has only six power switches. Additionally, by employing this inverter and a precise modification to the process, a five-level output can be created. This inverter is sometimes referred to as a hybrid or crossbreed inverter as a result. The switching of power energy devices is controlled by pulse width modulation (power electronic switches). As compared to other inverters, the performance is excellent and there may be fewer harmonics. A lesser number of switches are needed; therefore the price is relatively low. This study illustrates the operation of a bi-directional converter linked to a T-type multilevel inverter and compares it to other traditional inverters [3, 4]

Multi-Level Inverter

Multilevel inverters are the best choice for high-power applications because they have lower switching losses and can produce big voltages and currents. The output of these multilayer inverters can be stepped by making a few modifications. The image below shows the essential inverter mechanism, which is obviously multilayer. Because of the available DC resources, the capacitor is used [5, 6]. A two-level inverter is depicted in Figure 1(a). By changing the positions of the switching states, the output levels can be achieved. Figure 1. (b) and (c) both clearly describe the quantity that can be separated from multilayer inverters by altering the switch locations (c).Let m be the number of levels, the voltage of capacitor V_c is offered by:

(1) $$V_c = \frac{V_{dc}}{m-1}$$

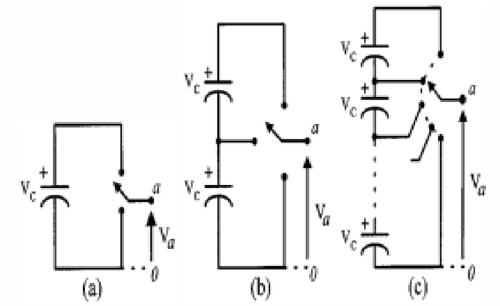

Fig.1. Two, three and n-level inverters

The multilevel operation of an m phase inverter is commonly managed using a variety of modulation techniques and settings, which employ m-1 capacitors. In order to achieve ideal minimization, enhanced harmonic-stepped waveforms, space vector modulation, and finally selective harmonic eradication PWM are used.

The below points can be utilized for crucial well-known features of multilevel inverter;

(i). They develop manufacturing voltages with notably less dv/dt and distortion this is certainly lowest.

(ii). The information this is certainly harmonic is quite low,

(iii). The output voltage and power are increased with the increased number of levels.

(iv). Multilevel inverter is typically used for higher energy solutions or high-power applications.

Three sorts of multilevel inverter are in use:

a) Diode clamped inverter
b) Cascaded inverter
c) Flying capacitor inverter

Diode Clamped Multilevel Inverters

The dc bus voltage is clamped to step output voltage using a diode. This inverter is referred to as a diode clamped inverter as a result. This inverter undoubtedly uses clamped diodes and capacitors to create the necessary stepped voltage levels. They are created to create stages 3, 4, and 5. Neutral point clamped, often known as the three-level design, is frequently utilised in high and medium voltage applications. Figure 2. Below illustrates a multilayer inverter with a single leg that is diode clamped [7].

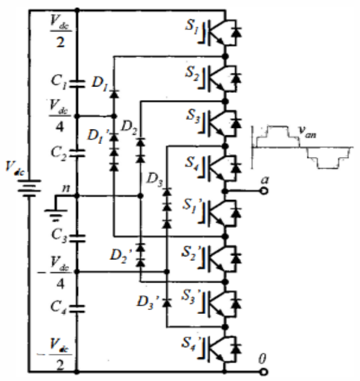

Fig.2. Diode Clamped five level inverter

Three single legs connected in series with a neutral point produce power in three phases. As the number of levels rises, the switches get bigger. If n is the number of levels, the number of switches needed is 2(n-1) per phase, and the number of clamped diodes needed is (n-1)*(n-2) each phase. Using (n-1) for each phase, you can calculate how many capacitors you'll need. As a result, with increasing levels, the intricacy of the circuit increases. When using a five-level inverter, four switches must be turned on in a specific way so that a pair of switches like (s1,s1'), (s2,s2'), (s3,s3'), and (s4,s4') are turned on for each leg [8].

Disadvantages of diode clamped MLI

1. Utilizes single DC supply but capacitors are increased with increment of number of levels.
2. It has 8 switches and 12 diodes and 4 capacitors per leg.
3. Its output voltage is nearly 0.5 times of the input voltage.
4. The number of levels is limited to three level due to its issues of capacitor balancing.
5. Increasing of levels leads to circuit complexity and size which further leads to high Total Hormonic Distortion (THD). Therefore, cost is high in this type of the inverter.

Flying Capacitor Multilevel Inverter

It was proposed by Meynard and Foch. It is very similar to diode clamped MLI. The main advantage of flying capacitor MLI over diode clamped MLI is that no all switches are turned on. The main difference is that diodes are replaced by capacitors in flying capacitor MLI. Only certain voltage levels are affected by voltage balance. The operation is similar to diode clamped MLI in that the capacitors play an important role in obtaining the desired output voltage levels in flying capacitor MLI. Semiconductor devices such as MOSFETs, IGBTs, and SCRs can be found in series, which are connected by extra capacitors. The capacitors used in n level flying capacitor MLI are given by (n-1)*(n-2)/2, where n is the number of levels. Figure 3 depicts the five levels of flying capacitor [9].

Drawbacks of this inverter are follows,

1. Utilizes single DC.
2. Uses 8 diodes and 6 capacitors per leg for five level inverters.
3. The output voltage is 0.5 times of the input voltage.
4. Rating of the capacitor should be high.
5. It has high switching losses.
6. This type of inverter is expensive
7.

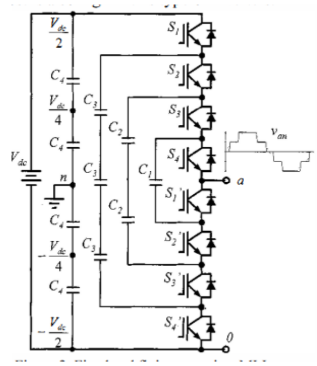

Fig.3. Flying capacitor five level inverter

Cascaded H-Bridge Multilevel Inverter

The number of levels of general H-bridges increases. In Cascaded H-Bridge MLI, the bridges required for n level are n-1. This inverter is made up of several H-Bridge cells (Full-bridge inverters) connected in series. A multilevel lower body cascaded inverter is shown. In the figure, you can see the framework of one cell. Depending on the voltage sources, they are broadly classified as cascaded H-Bridge equal voltage sources or cascaded H-Bridge unequal voltage sources [10, 11].

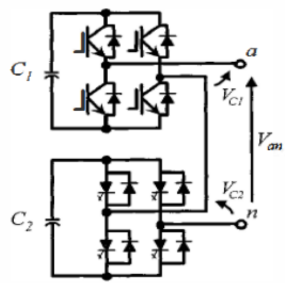

Fig. 4. Cascaded H-bridge five level inverter

Disadvantages of this inverter,

1. Used DC source that is single.
2. Made up of 8 switches and 2 capacitors per leg.
3. H-Bridges circuit complexity becomes hard on increasing of number of levels.

Thus, still price is actually expensive in this kind or sort of the inverter.

Conventional T-Type Multilevel Inverter

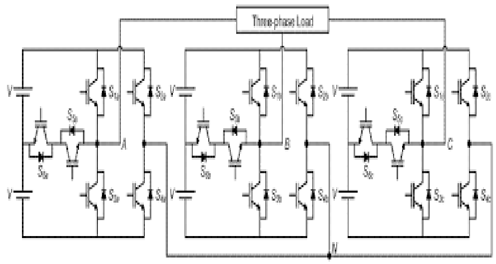

Fig. 5.Five-level T-type topology

When compared to traditional topologies, T-type topologies are the most workable and generalised, with fewer switches. The T-type topology is made up of bidirectional and unidirectional switches. As shown in Figure 5, each phase requires four unidirectional switches (S1, S2, S3, and S4), one bidirectional switch, and two dc sources to provide five levels of phase voltage.

A bidirectional switch is illustrated by two unidirectional switches linked back-to-back (S5 and S6). The four unidirectional switches create an H-bridge, and the bidirectional switch connects the isolated dc supply to the H-bridge. The operation includes to generate five levels of phase voltage, namely 2V, V, 0, V, and 2V, two dc sources (of each V volt) are required in each phase. Switching S4 - S2 and S1 - S3 in each phase generates 2V and 2V levels, respectively. Switching S5 - S4 and S6 - S3 provides + V and V levels, respectively.

The main disadvantage of this T-type topology is the voltage balance is unstable and the circuit needs an extra voltage controlling device. Thus, the proposed T-type is implemented to overcome these disadvantages.

Table 1. Comparison of different multilevel inverters with T-type inverter

S.No	Topology	Diode Clamped Multilevel Inverter	Flying Capacitor Multilevel Inverter	Cascaded H-Bridge Multilevel Inverter	T-type multilevel inverter
1	No.of levels	Five	Five	Five	Five
2	Switch count	More switches are used	More number of switches and capacitors are used	Number of switches depends on the number of levels	Less number of switches are used
3	Switching losses	High	High	High	Less
4	Construction and size	Complex construction and has heavy size	Complex construction and has heavy size	complex construction and has less size	Simple construction and has less size
5	Flexibility	Less flexible	Less flexible	More flexible	More flexible
6	Soft switching	Not available	Not available	Not available	Available
7	Bidirectional operation	Not available	Not available	Not available	Bidirectional operation is a key aspect in T-type multilevel inverter
8	Applications	Medium And High-Power Transmission Line	Motor drive systems, statcom	Active filters, Power factor compensators	Solar grid, pv cell, electric motors, electric vehicles
9	Capacitor voltage balancing	Small	Average	Small	High
10	No. of Voltage Sources Required	1	1	2	1
11	No. of Uncontrollable Devices Required	24 diodes+ 4 split capacitors	12capacitors+4 split capacitors	2 capacitors	3 capacitors

A Proposed T-Type System Configuration:

Traditionally, the dc input power was connected to the bidirectional converter that is dc-dc, which manages the s electric batteries in an EV) is physically connected to a bidirectional multilevel dc-dc converter. Within the recommended arrangement, their individual productivity capacitors supply the multilevel inverter with the sub-level voltages required for constructing its ac production current. Advanced electrical energy storing is provided by the additional capacitor CM from the multilevel bidirectional dc-dc converter. The larger capacitor CP receives greater electrical energy, which is transferred to CN, and vice versa. Hence, without any added control scheme, the converter may produce a natural voltage between CP and CN. Although a multilayer converter is unquestionably a dc-dc two change, it also functions as a capacitor, which affects the size and expense of an electrical train. In addition, they offer a bonus of doubling the voltage-boosting gain for the same amount of work as the traditional improve converter. Without increasing the reverse voltage, which is being prevented by all energy changes, it is complete. In comparison to the old-fashioned boost converter, the multilevel converter that is dc-dc power switches with one-half of the preventing voltage Vb and works in half of the job pattern D.

relating to the creation of the dc-dc converter and thus the feedback through the multilevel inverter. As shown in Figure.6, the dc energy supply (such a

Circuit operation

The procedure for the recommended converter arrangement is divided into two stages: 1) step-up mode in device motoring; and 2) bucking mode in device breaking (regenerative) state. It is important to note that the boost converter typically operates in continuous conduction, indicating where the average inductor current has ended its ripple.

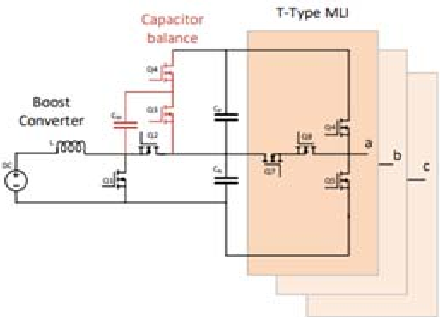

Fig. 6. Proposed T-type multilevel inverter

Electricity is generated from the input dc voltage with the help of the reduced capacitor CN on the CM as well as the top of the capacitor CP after the flipping period has ended. In this instance, the inverter is undoubtedly multilayer in a typical issue where the charged power provided by each capacitor, CN and CP, actually becomes equal. As a result, the increase converter continuously forces the ability to CN that will be used in CP via CM.

Advantages of proposed T-Type configuration
Compared to more multilevel inverters, lower components are needed, which reduces the weight and cost by a significant amount.

1. Switching is decreased since multilevel switching claims have lower losses.
2. The arrangement was simple and easy functioning that is versatile greater effectiveness.
3. The capacitor current is balanced and operates in an efficient manner.
4. The method this is certainly managing easy and comfortable flipping is applicable.
5. When compared to other types of multilevel inverters, it raises its voltage build, which increases the exact same responsibility period.
6. It reduces the usage this is certainly further of converter much more acts a charged power storage that is advanced.
7. Distortion that is total is certainly harmonic really low into the production waveform with no filtration program.

Applications

a) Induction motor controls
b) Solar inverter
c) Energy phone converter that is mobile
d) Static generation this is certainly var
e) Significant grip drive-in electric vehicles
f) Used in medium and high-power transmission

Results of Conventional T-Type Inverter & Proposed T-Type Inverter

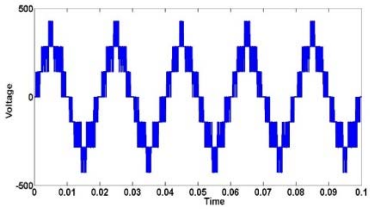

Fig. 7. Line to Line voltage (V_{ab}) of conventional T-Type Inverter

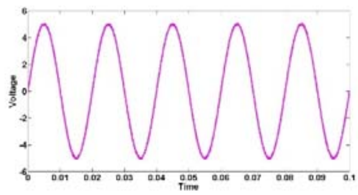

Fig. 8. Line current of conventional T-type inverter

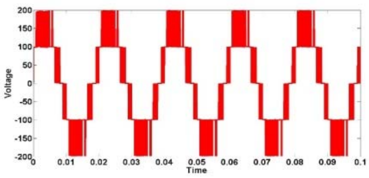

Fig. 9. Phase Voltage of conventional T-Type Inverter

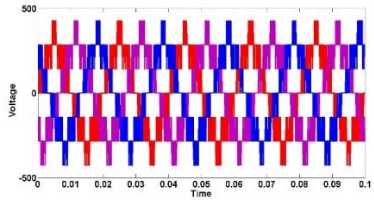

Fig.10.Three phase voltages of conventional T-Type Inverter

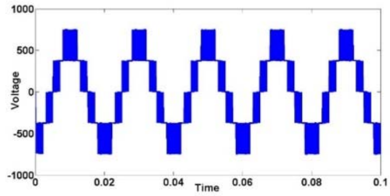

Fig. 11.Line to Line voltage (V_{ab}) of proposed T-Type Inverter

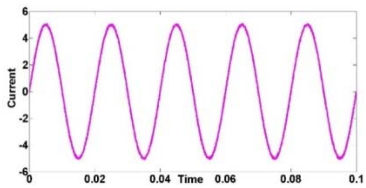

Fig. 12.Line current of proposed T-type inverter

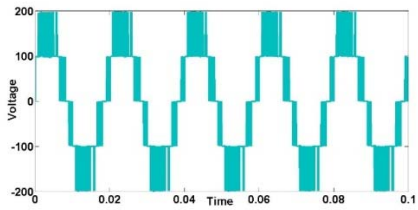

Fig.13. Phase voltage (V_{ab}) of proposed T-Type Inverter

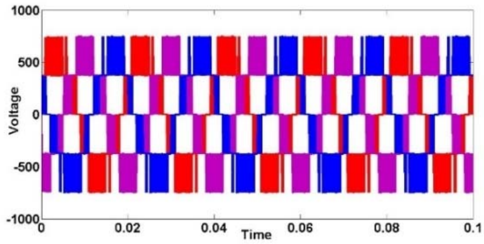

Fig. 14.Three phase voltages of proposed T-Type Inverter

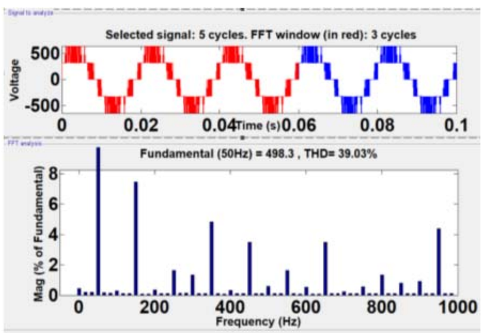

Fig. 15.Voltage THD of conventional T-Type Inverter

The simulation results of five level conventional T-type inverter and proposed T-type inverter with capacitor voltage balancing is shown below. The line-to-line voltage, line current, phase voltage and three-phase voltages and voltage THDs are compared with both types of the inverters. The conventional T-type inverter output line voltage, line current, phase voltage, three-phase voltages are shown in Figure.7, Figure. 8, Figure. 9, Figure. 10. proposed T-type inverter output line voltage, line current, phase voltage, three-phase voltages are shown in Figure.11, Figure. 12, Figure. 13, Figure. 14. The voltage THDs of conventional T-type inverter and proposed t-type inverter is shown in Figure. 15. and Figure. 16.

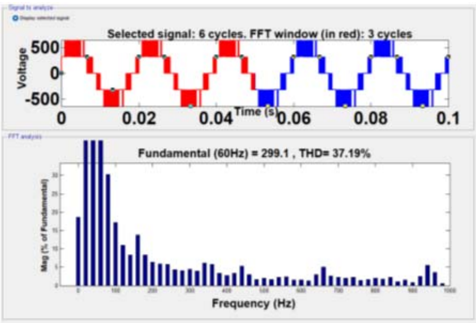

Fig. 16.Voltage THD of proposed T-Type Inverter

Conclusion

This paper describes a novel integration of a modified bi-directional dc-dc converter that is multilevel and a five-level T-type multilevel inverter for use in electric vehicle programmes. In addition to the existing resource inverter, the t-type MLI employs additional energy modifications. Using power switches with one-half of the peak inverse voltage results in the generation of a much wider range of current phases. However, when it comes to dc coach, the converter power modifications must be developed to resist the entire current. The converter is clearly connected to an old-fashioned bi-directional converter that is undoubtedly dc-dc. By using a current stabiliser or using a flipping that is unique with guidelines and law loops, the voltage balance of the dc capacitors must also be properly ensured. Alternately, the suggested arrangement makes use of the higher frequency cycle-by-cycle voltage balancing between the dc capacitors CN and CP. These capacitors weren't necessarily designed to withstand the range low frequency ripple, but rather the 180Hz high regularity ripple for the duration of dc-dc remarks (multiple the rated frequency). As a result, film capacitors were able to be used in place of electrolytic capacitors since the necessary capacitance decreased from several hundred uF capacitors to tenth uF capacitors.

The recommended converter's ability to use step-up mode when running and step-down mode when shutting down the electric engine unaffected by this aspect is undoubtedly advantageous. On the side that is dc-dc to those who work in the T-type MLI side, the rated current of all of the capacitors is fixed to 50% of the top ac result voltage in order to further reduce current stress and permit the use of better effectiveness energy switches. An experimental prototype and a simulation model are both used to investigate and validate the proposed arrangement. The results are analysed and compared to demonstrate the numerous advantages of the suggested configuration over the standard one in the marketplace.

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