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Comparison of Multilevel Inverters with T-type MLI: A Brief Review

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ABSTRACT

This paper gives a comparative analysis of different types of Multilevel Inverters with T-Type inverters. The principal aim of the work is to analyse the T-type multilevel inverter operation with different multilevel inverters such as Diode-Clamped Multilevel Inverter, Flying Capacitor Multilevel Inverter and Cascaded H-bridge Multilevel Inverter. All the inverters are compared and their advantages, disadvantages and usages are specified. The inverter used in our work runs on the multilayer bidirectional DC-DC converter. This can be used in Renewable Energy Sources and Electric Vehicle applications. The proposed design includes two power switches with an additional capacitor to balance the currents of the multilayer T-type (MLI) capacitor during an entire drive pattern or fault circumstances. In this design, the big capacitors being electrolytic in T-type Multilevel Inverter has been exchanged with longer-lasting film capacitors due to the high-frequency cycle-by-cycle current security between CN and CP. The converter's dimensions and weight would be lowered by 20% because of this topology, as the number of switches and the capacitors used for balancing is reduced in this proposed design. The simulation analysis for five-level conventional T-type inverter and proposed T-type inverter with capacitor voltage balancing is done. The line-to-line voltages, line currents, phase voltages, three-phase voltages, and voltage total harmonic distortions are compared for conventional T-type inverter and proposed T-type inverter with capacitor voltage balancing. The simulation results shows that the proposed T-type inverter gives better performance compared to conventional T-type multilevel inverter.

Keywords: Diode-Clamped Multilevel Inverter (DCMI), Flying Capacitor Multilevel Inverter(FCMI), Cascaded H-bridge Multilevel Inverter(CHMI), Total Harmonic Distortion (THD), T-type Multilevel Inverter, Capacitor Voltage Balance, Switching Losses.

INTRODUCTION

The devices that are designed to convert DC signals directly into AC signals are known as inverters. Power system solutions and continuously running energy businesses use inverters. General inverters used in industrial applications have three levels (Kouro et al. 2010; Rodriguez et al. 2002) As inductive loads are used by power systems more frequently, there are more power problems of higher quality. Therefore, a larger level inverter has been used. The large level, also known as the high-level inverter or multilevel inverter, aids in supplying electricity with fewer problems with power quality (Youssef et al. 2016; Kavousi et al. 2012; Can, E. 2019). Switches are utilised by multilevel inverters, which are frequently used with several inverters.

A significant component of these numerous multilevel inverters that could be divided into Diode clamped, Flying capacitor, and H-bridge cascaded multilevel inverters was developing day by day (Rodriguez et al. 2002; Li et al. 2008,; Lokeshwar Reddy Chintala et al. 2016). Current advancements for multilayer inverters use less expensive range switches, which reduces switching losses. Therefore, this paper depicts a multilayer inverter that is undoubtedly brand-new and has only six power switches (Praisuwanna et al. 2010). Additionally, a five-level output can be produced by using this inverter and a specific alteration in the procedure (Lakshmi et al. 2019; Rubanenko et al. 2020). As a result, this inverter is frequently referred to as a hybrid or crossbreed inverter (Can, E. 2020).. Pulse width modulation is used to control the switching of power energy devices (power electronic switches) (Can, E. 2022).The performance is high, and harmonics may be less when compared with other inverters. The cost is very less and requires a smaller number of switches. The operation and comparison of a bi-directional converter connected to a T-type multilevel inverter with other conventional inverters is shown in this paper. The voltage, current, and total harmonic distortions are compared with the conventional multilevel inverter (Can, E. 2019). The Total Harmonic Distortion (THD) for conventional T-type inverter and proposed T-type inverter with less number of switches with capacitor voltage balancing is compared.

MULTI LEVELINVERTER

Multilevel inverters may generate large voltages and currents with lower switching losses, making them ideal for high-power applications. Using a few adjustments, the output of these multilayer inverters is stepped. The crucial inverter mechanism is seen in Fig.1; it is unquestionably multilayer. The capacitor is employed due to the available DC source. Figure 1(a) illustrates a two-level inverter. The output levels can be obtained by adjusting the switching state positions. Figure.1. The quantity that may be distinguished from multilayer inverters by changing the switch locations is clearly defined in (b) and (c).

Let m be the number of levels; the voltage of capacitor V_c is offered by:

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

An m-phase inverter uses m-1 capacitors, and various modulation strategies and settings are typically used to control the inverter's multilevel operation. Ideal minimization refers to enhanced harmonic stepped waveforms, space vector modulation, and selective harmonic eradication PWM.

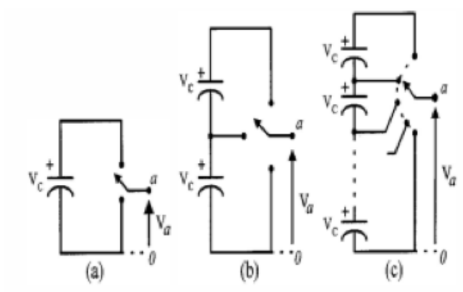

FIGURE. 1. (a). Two level, (b). Three level, and n-level inverter types.

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

1. They develop manufacturing voltages with notably less dv/dt and distortion; this is certainly the lowest.
2. The harmonics in voltage and current is quite low.
3. The output voltage and power are increased with the increased number of levels.
4. Multilevel inverter is typically used for higher energy solutions or high-power applications.

Three types of the multilevel inverter are in use are:

1. Diode Clamped Multilevel Inverter
2. Flying Capacitor Multilevel Inverter
3. Cascaded H-bridge Multilevel Inverter

DIODE CLAMPED MULTILEVEL INVERTER

A diode is used to clamp the DC bus voltage to stepped output voltage. Hence this inverter is termed as a diode-clamped inverter. This inverter certainly consists of a capacitor and clamped diodes to build the required levels of stepped voltages. They are produced to make three and five levels. The three-level design is called neutral point clamped and is mostly used in high and medium voltages. The below Figure. 2. shows the single leg of the diode-clamped multilevel inverter.

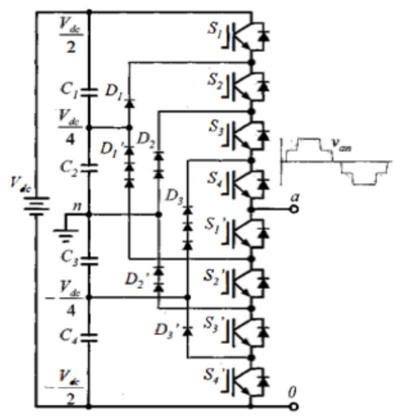

FIGURE.2. Single-leg of Five-level diode clamped MLI

For three-phase power output, three single legs are connected in series with a neutral point. The switches are increased for a higher number of levels. Let n be the levels then the number of switches required are given by 2(n-1) per phase and the number of clamped diodes required are given by (n-1)*(n-2) per phase. The number of capacitor required are given by (n-1) per phase. Therefore, the circuit complexity is increased for a higher level. The operation for five-level inverter is 4 switches should be turned switched on in a particular manner such that in each leg pair of switches like (s1,s1'),(s2,s2'),(s3,s3'),(s4,s4') are turned on.

DISADVANTAGES OF DIODE-CLAMPED MLI

1. Utilizesa single DC supply, but capacitors are increased with the increment of the 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 levels leads to circuit complexity and size, leading to high Total HarmonicDistortion (THD).

Therefore, cost is high in this type of the inverter.

FLYING CAPACITOR MULTILEVEL INVERTER

Meynard and Foch proposed it and is very similar to diode clamped MLI. The major advantage of flying capacitor MLI over diode clamped MLI are not all switches are turned on. The major difference is capacitors replace diodes in flying capacitor MLI. The voltage balance is applicable to only specific levels. The operation is similar to diode clamped MLI where the capacitors plays a key role to obtained desired output voltage levels in flying capacitor MLI.

Semiconductor devices like MOSFET,IGBT, SCR etc. can be found in series which are connecting clamped by extra capacitors. The capacitors used in n level flying capacitor MLI is given by (n-1)*(n-2)/2 ,where n is the number of levels. The below Figure. 3. shows the single-leg of a five level flying capacitor MLI.

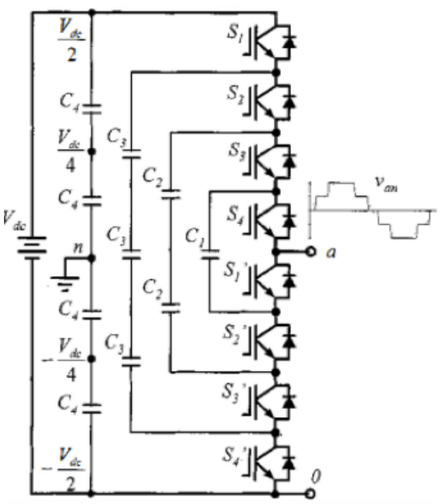

FIGURE 3. Single-leg Five level flying capacitor MLI

The drawbacks of this inverter are as 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

Cascaded H-Bridge Multilevel Inverter

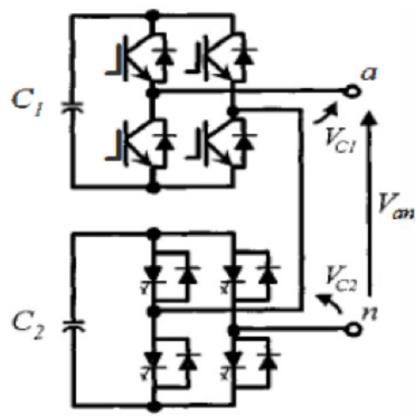

FIGURE 4. Single-leg of a Five level cascaded H-bridge MLI

General H-Bridges increases with number of levels. For n level the bridges required are n-1 in Cascaded H-Bridge MLI This inverter consists of several H-Bridge cells (Full-bridge inverters) connected in series. One lower-body cascaded inverter that is shown that is multilevel. This is certainly specific inside the figure it is possible to take notice of the framework of 1 cell. Depending on the voltage sources they are broadly classified as cascaded H-Bridge equal voltage sources and cascaded H-Bridge unequal voltage sources. The Figure. 4. shows the single- leg of a five level cascaded H-bridge MLI.

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

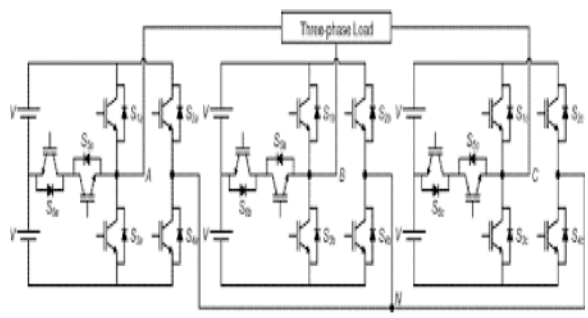

FIGURE 5. Five-level T-type topology

T-type topologies are the most workable and generalised, with reduced switch count compared to traditional topologies. The T-type topology is made up of bidirectional and unidirectional switches. As indicated in Figure.5, four unidirectional switches (S1, S2, S3, and S4), one bidirectional switch, and two DC sources are required per phase 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 generating 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.

PROPOSED T-TYPE SYSTEM CONFIGURATION

Conventionally, through the propulsion program development perspective, the DC input power had been attached to the bidirectional converter that is DC-DC which manages the relating to the creation of the DC-DC converter;therefore the feedback through the inverter this is certainly multilevel. The DC energy supply (such as electric batteries in EV) is truly connected to a bidirectional multilevel DC-DC converter as revealed in Figure.6. Their individual productivity capacitors supply the multilevel inverter happens to be the sub-level voltages requires constructing its ac production current in comparison, within the suggested arrangement. The added capacitor CM from inside the multilevel bi-directional converter that is DC-DC an electrical energy storing that is advanced. It transfers the vitality that is additional is electrical the larger capacitor CP to CN and vice versa. Hence, the converter can perform all-natural voltage between CP and CN without any included controls pattern.

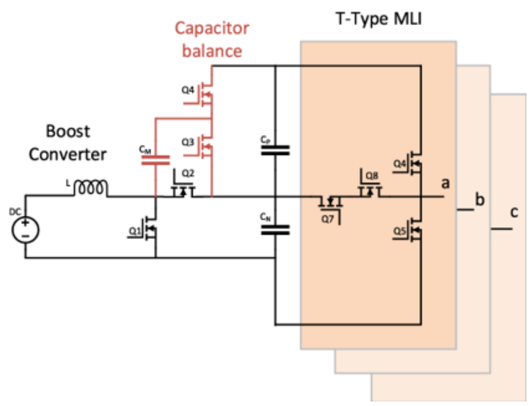

FIGURE 6. The proposed configuration, a multilevel bidirectional DC-DC converter connected to the T-type MLI.

Although multilevel converter is certainly DC-DC two changes that are extra well as a capacitor that has an impact on electricity train cost and dimensions. They present a bonus of enhancing the voltage boosting gain by two when it comes to duty this is certainly same in old-fashioned improve converter. It's total without boosting the reverse voltage that is prevented by any vitality modifications. Multilevel converter DC-DC power switches with 1 / 2 of the preventing voltage V_b, and works in half of the job pattern D compared to the boost converter that is old-fashioned.

CIRCUIT OPERATION

The procedure about the recommended converter arrangement is divided according to the two settings of operation into:

1. Step-up mode in device motoring; and
2. bucking setting in device breaking (regenerative) state.

It's important to observe that the boost converter tend to be functioning in continual conduction indicates where the average inductor current has ended its ripple.

The ability this is certainly electric through the input DC voltage aided by the diminished capacitor CN on the CM additionally to top of the capacitor CP a lot more than a period that is flipping is complete. In such a case, the inverter is certainly multilevel in a typical problem where the charged power given by each capacitor CN and CP become equal.

Thus, the increase converter constantly forces the ability to CN that will be used in CP via CM.

ADVANTAGES OF PROPOSED T TYPE CONFIGURATION

1. Compared to more multilevel inverters, lower components are needed, which reduces the weight and cost by a significant amount.
2. Switching is decreased since multilevel switching claims have lower losses.
3. The arrangement was simple, easy functioning, and versatile, greater effectiveness.
4. The capacitor current is balanced and operates efficiently.
5. This method of managing easy and comfortable flipping is applicable.
6. Compared to other types of multilevel inverters, it raises its voltage build, increasing the same responsibility period.
7. It reduces the usage this is certainly further of converter much more acts a charged power storage that is advanced.
8. Total Distortion is certainly harmonic really low into the production waveform with no filtration program.

APPLICATIONS

1. Induction motor controls
2. Solar inverter
3. Energy phone converter that is mobile
4. Static generation this is certainly var
5. Significant grip drive-in electric vehicles
6. Used in medium and high-power transmission

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

RESULTS OF CONVENTIONAL T-TYPE INVERTER & PROPOSED 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, 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, and three-phase voltages are shown. The phase voltage of convetional T-type inverter is of five-level voltages as shown in the Figure. 9. The load connected is of R-load with load resistance of 100 ohms. The current drawn by the conventional T-type inverter is shown in the Figure. 8. The proposed inverter with less number of switches and the capacitor voltage balancing inverter output phase voltage also have five-levels as shown in the Figure 13. The output current of the proposed T-type inverter is shown in Figure 12. having less harmonics with R-load compared to the conventional T-type inverter. The voltage THD for the conventional T-type inverter is around 39.03% as shown in the Figure. 15. The voltage THD for the proposed T-type inverter as shown in Figure 16. is having 37.19%. The Figure. 7. Shows the line-line voltage of the conventional T-type inverter. The Figure 10 shows the three-phase voltages of conventional T-type inverter. The Figure.11 shows the line-line voltage of the proposed T-type inverter. The Figure 14 shows the three-phase voltages of the proposed T-type inverter.

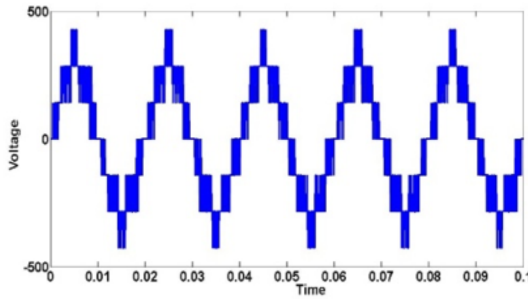

FIGURE 7. Line to Line voltage (V_{ab}) of Conventional T-Type Inverter

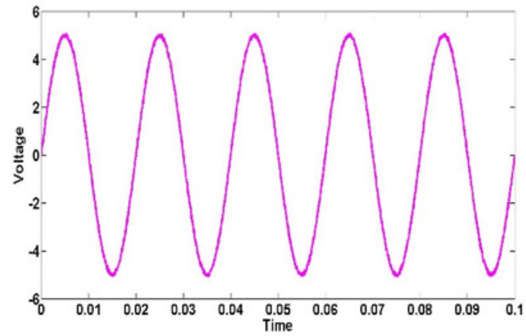

FIGURE 8. Line current of conventional T-type inverter

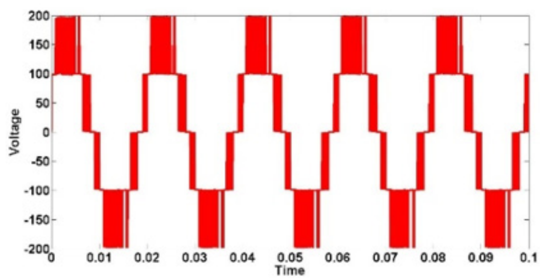

FIGURE 9. Phase Voltage of Conventional T-Type Inverter

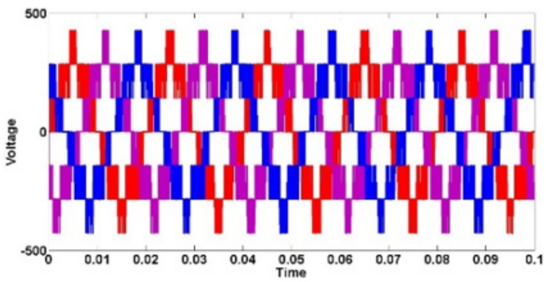

FIGURE. 10.Three-phase voltages of Conventional T-Type Inverter

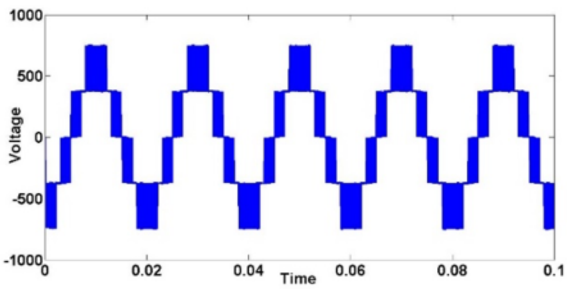

FIGURE. 11.Line to Line voltage (V_{ab}) of Proposed T-Type Inverter

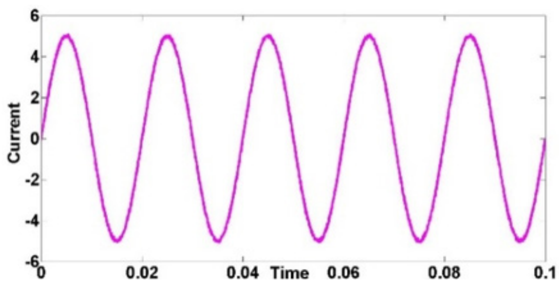

FIGURE. 12.Line current of Proposed T-type inverter

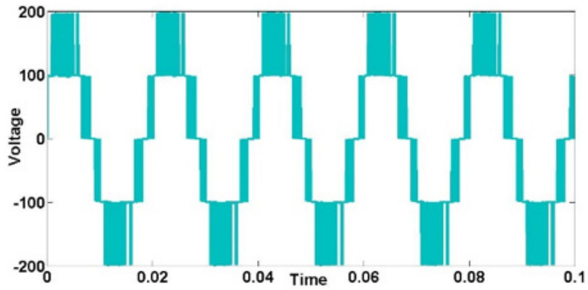

FIGURE. 13.Phase voltage (V_{ab}) of Proposed T-Type Inverter

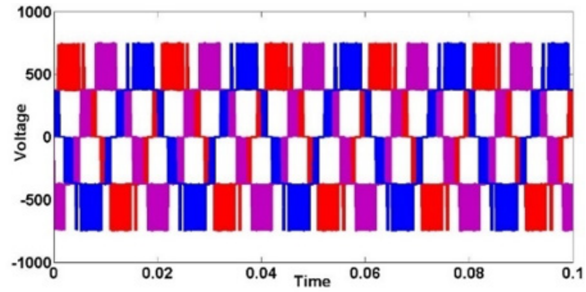

FIGURE. 14.Three-phase voltages of the Proposed T-Type Inverter

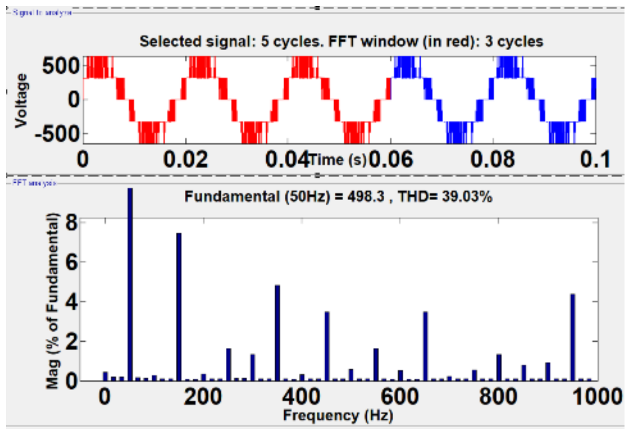

FIGURE. 15.Voltage THD of Conventional T-Type Inverter

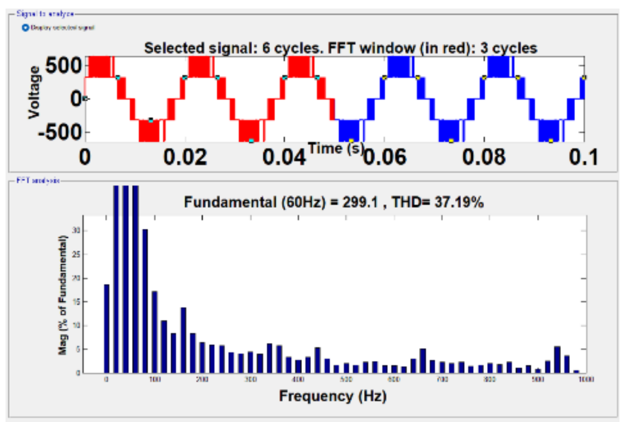

FIGURE. 16.Voltage THD of Proposed T-Type Inverter

CONCLUSION

This paper describes a novel integration of a five-level T-type multilevel inverter, a modified bi-directional DC-DC converter, for electric vehicle applications. Compared to the existing traditional resource inverter, the T-type MLI makes use of additional energy adjustments. The development of a lot better range that is wide of current phases is brought about by the use of power switches with 1 / 2 of the peak inverse voltage. However, when it comes to a coach that is DC, the power alterations for the converter must be built to resist the complete current. The converter is undoubtedly paired with a vintage DC-DC converter that is bidirectional. Additionally, the voltage balance of the DC capacitors must be adequately ensured.

The voltage balance of the DC capacitors also needs to come to be fully guaranteed by adding a stability this is certainly current or having a flipping that is unique with recommendations and legislation loops alternatively, the recommended structure utilizes the higher frequency cycle-by-cycle voltage balance between the DC capacitors CN and CP. These capacitors developed for the 180Hz high regularity ripple for the DC-DC comments duration, maybe not the range low frequency ripple (multiple the rated frequency). The capacitance that is essential reduced from several hundred uF capacitors to tenth uF capacitors, enabling the application of film capacitors instead of electrolytic capacitors as a result.

It is undoubtedly advantageous that the proposed converter has the ability to switch between step-up and step-down modes when starting and halting the electric engine, respectively. The rated current of all the capacitors is fixed at 50% of the top AC result voltage in order to further decrease current stress and allow the use of more effective energy switches on the T-type MLI side. The peak inverse voltage of all power switches is also fixed at this level.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

S. Kouro, M., Malinowski, K., Gopakumar, J., Pou, L,. G. Franquelo & B. Wu. 2010. Recent Advances and Industrial Applications of Multilevel Converters *IEEE Transactions on Industrial Electronics* 57(8): 2553-2580, Aug.

J. Rodriguez, J.-S. Lai & F. Z. Peng. 2002. Multilevel inverters: a survey of topologies, controls, and applications *IEEE Transactions on Industrial Electronics* 49(4):724-738. Aug.

M. Z. Youssef, K. Woronowicz, K. Aditya, N. A. Azeez & S. S. Williamson. 2016. Design and Development of an Efficient Multilevel DC/AC Traction Inverter for Railway Transportation Electrification. *IEEE Transactions on Power Electronics* 31,(4): 3036-3042, April.

AyoubKavousi, BehroozVahidi, Reza Salehi & Mohammad Kazem Bakhshizadeh. 2012. Application of the Bee Algorithm for Selective Harmonic Elimination Strategy in Multilevel Inverters. *IEEE Transactions on Power Electronics* 27(4) April.

Jose Rodriguez, Jih-sheng lai, Fan zhengpeng & senior Cl. 2002. FFT analysis for five level hybrid cascaded multilevel inverter 10 member IEEE, Multilevel inverter: A survey of topologies, controls, and applications. *IEEE transactions on Industrial Electronics* 49 (4).

Haiwen Liu, Leon M & SurinKhomfoi. 2008. Hybrid cascaded multilevel inverter with PWM control Method 978-1-4244-1668-4/08. IEEE.

Surin Khomfoi, Nattapat Praisuwanna & Leon M.Tolbert. 2010. A hybrid multilevel inverter application for renewable energy resources including a reconfigureuration technique. 978-1-4244-5287- 3/10/2010 IEEE.

S. Khomofi & AChatrchai. 2009. A 5-level cascaded hybrid multilevel inverter for interfacing with renewable energy resources. Proceedings of the 2009 electrical engineering/ electronics. *Computer telecommunications,and information technology* Chonburi May 6-9 :284-287.

Praisuwanna & S.Khomfoi. 2010. A hybrid cascaded multilevel inverter. Proceedings of the 2010 electrical engineering/ electronics. *Computer telecommunications, and information technology* Chonburi May 19-21:1041-1044.

S. Lakshmi Gundebommu. 2019. Five-Level and Seven-Level DCMI fed to IPMSM. 2019 *International Conference on Electrical Engineering Research & Practice (ICEERP).* 2019:1-6, DOI: 10.1109/ICEERP49088.2019.8957001.

G. S. Lakshmi, O. Rubanenko, M. L. Swarupa & K. Deepika. 2020. Analysis of ANPCI & DCMLI fed to PMSM Drive for Electric Vehicles. 2020 *IEEE India Council International Subsections Conference* (INDISCON), 2020:254-259, DOI: 10.1109/INDISCON50162.2020.00059.

Can, E. 2020. The levels effect of the voltage generated by an inverter with partial source on distortion. *International Journal of Electronics* 107(9): 1414-1435.

Can, E. 2022. Investigation of the effect of the gap at the zero-crossing point of PWMs creating the first level voltage in a multi-level inverter . *Journal of Engineering Research*.

Can, E. 2019. The load performance of multi-level alternating voltage provided by upgrade effect. *Journal Kejuruteraan* 31(2).

Can, E. 2019. The application of multi-phase power distribution line with pure energy Conversion. *Journal Kejuruteraan* 31(2).

Lokeshwar Reddy Chintala. 2016. Improvement in Performance of Cascaded Multilevel Inverter Using Triangular and Trapezoidal Triangular Multi Carrier SVPWM