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COMPARATIVE STUDY OF MULTI LEVEL INVERTERS BASED ON THE OUTPUT TOTAL HARMONIC DISTORTION

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Abstract - *The power converters are utilized to change one type of electrical energy to another. The class of power converter that produce AC power from DC power is known as inverter. Because of high THD and losses, the conventional two-level inverters are not appropriate for high power applications. So multilevel inverters have attracted huge significance power industries. This thesis presents different types of multilevel inverters and their significances.*
In this work three cases of power electronic inverters are taken into consideration for comparison to analyses the performance in terms of total harmonic distortion in their output voltage and output current. A 5 and 7 level H-bridge inverter is simulated with SPWM technique to generate the gating pulses for the switches. The same switching techniques are used for 5 and 7 level Flying Capacitor Type inverter and Diode Clamped Inverter is designed. The FFT analysis is performed to understand the total harmonic distortion of output current and output voltage of all the three cases. A comparison study is made between all the three inverters total harmonic distortion of their output current and output voltage by keeping the load resistance and inductor value as constant and vice versa.

Key Words*: *cascaded H-bridge, diode clamped, flying capacitor multilevel inverter (FCMLI), Multilevel inverter (MLI) topology, THD, cascaded H-bridge. SPWM.

1.INTRODUCTION

The amount of energy production and distribution systems has increased significantly in recent years. World electricity energy consumption is steadily increasing which specifically requests more electricity generation from renewable energy resources (wind and solar). As a statistical approach total electricity consumption will be 61% higher in 2030 than in 2011. In addition, renewable energy reaches 6% of global energy production by 2030, up from 2% in 2011. Renewable energy resources play an important role in generating electricity due to green energy and reduced environmental impacts. However, their output is not usable by consumers and to provide the desired power to the grid with less harmonics it needs to be boosted and converted into a smoother AC waveform requiring higher power inverters with higher efficiency. In addition, industries demand high-power devices that exceed MW levels. So, to overcome this problem certain solution takes place in existing inverter such that levels can be improved more than two so that pure sinusoidal waveform is produced at the output voltage and harmonics inside the output can be suppressed and percentage of losses may be decreased and this topology is named as multilevel inverter topology. The multilevel inverter topology concept has been introduced in the early 1975 with three level converters. Multi-level inverters are widely used as stationary power converters for very high-power operations such as FACTS devices, HVDC light transmission and AC drives. One of the powerful benefits of multi-level modeling is the minimal harmonic in the output waveform without reducing the inverter power output and controlling the speed of a single-phase induction motor for low dissipation of electrical energy. Thus, the inverter is known as a multi-level inverter that starts at 3-levels and as the number of levels of the inverter increases, the total harmonic distortion (THD) decreases.

2. MULTILEVEL INVERTER

As in figure 1, Conventional two-level inverters normally generate an output AC voltage from an input DC voltage. Pulse Width Modulation switching scheme is used to generate the AC output voltage.
In the Multilevel Inverter topology (MLI), numerous DC voltage levels are added together to create a smoother output waveform. The acquired output waveforms have decrease harmonic distortions and dv/dt. The circuit design is more complicated with the increase in voltage levels due to addition of the valves. And complex control circuit is also required.

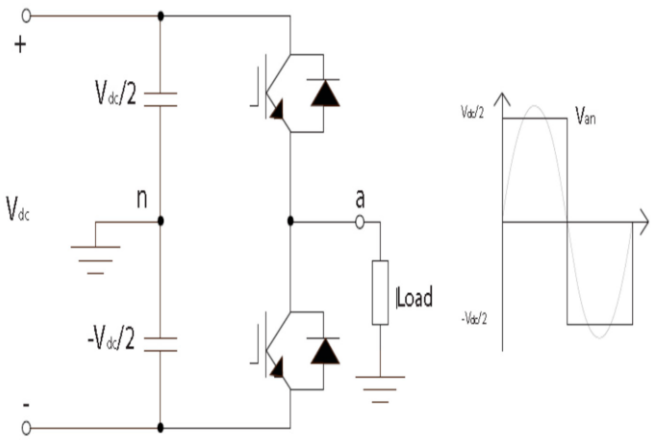

Figure 1: - Two level inverter and its output waveform without PWM

3. Advantages of Multi-Level Inverter over conventional two-level Inverter

A multilevel inverter has many advantages over a standard two-level inverter that uses high switch frequency pulse width modulation (PWM). the foremost attractive options of a multilevel inverter are as follows:

- It generates output voltages with very low distortion and lower dv/dt.
- It draws input current with terribly low distortion.
- They generate smaller common-mode (CM) voltage.
- They will operate with a lower switch frequency.

4. DIFFERENT MULTI LEVEL INVERTER TOPOLOGIES

There are basically three types of multilevel inverter categorized according to the voltage source used in the inverter. The Figure 2 below indicates the topologies of multilevel inverter.

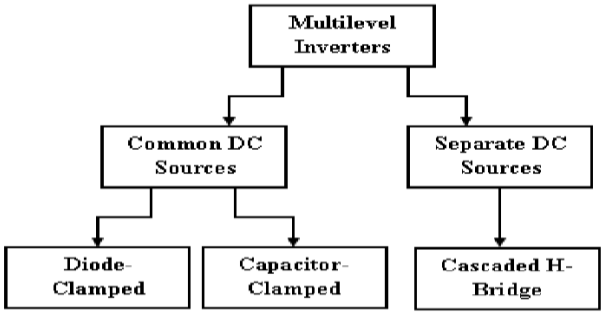

Figure 2: Classification of multilevel inverter

4.1 DIODE CLAMPED MULTILEVEL INVERTER

5-level diode clamped multilevel inverter. Diode-clamped inverters are one of the earliest designed topologies of multilevel inverters. Figure 3 shows a single phase five-level diode-clamped inverter. The two capacitors connected in the circuit split input voltage Vdc to obtain the midpoint voltage of the input. In a three-level topology, the common point of capacitors is connected to the ground. Therefore, this circuit can also be called the neutral point clamped inverter. Diodes D1 and D2 present in the circuit help with clamping dc voltage Vdc to obtain different output voltage levels. There are nine allowable switching states for the given circuit to obtain five different output voltage levels +Vdc, +Vdc /2, 0, -Vdc/2, and –Vdc. It has to be noted that switch pairs Sa1 and Sa1', and Sa2 and Sa2' are complementary to each other. Similarly, switch pairs Sb1 and Sb1', and Sb2 and Sb2' are complementary to each other.

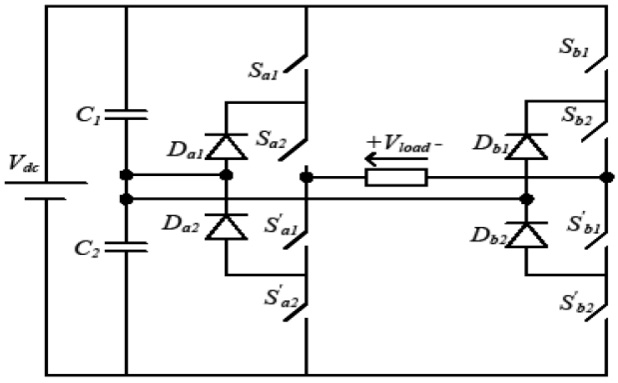

Figure 3: 5-level Diode Clamped Inverter.

The number of switches, capacitors, and diodes required in the circuit increases with the number of output voltage levels desired. For every additional level of voltage, it requires an extra pair of complementary switches is required in each limb of the circuit and also additional capacitors and clamping diodes. However, in such cases, voltage balancing of the capacitors and the cost of diodes become a practical problem.

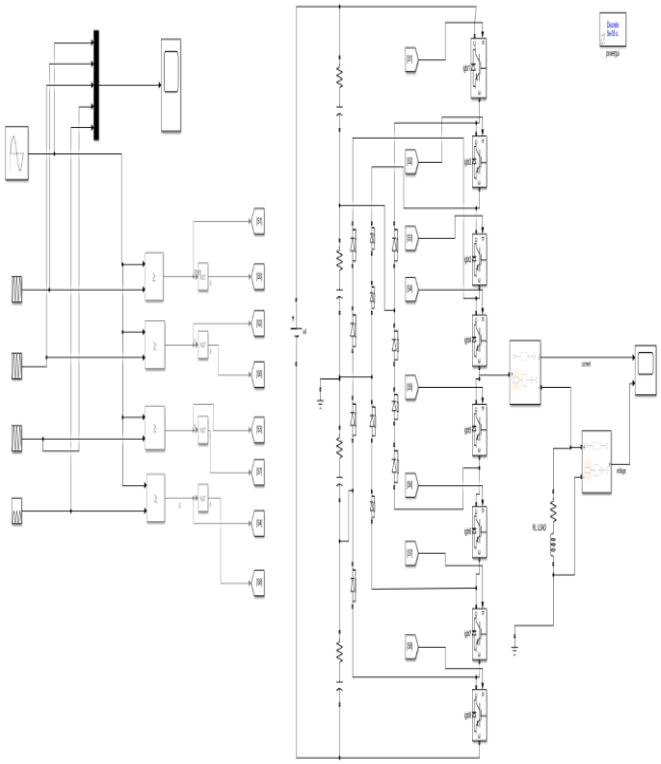

Figure 4: Simulation Model for 5-level Diode Clamped multi-level inverter with SPWM

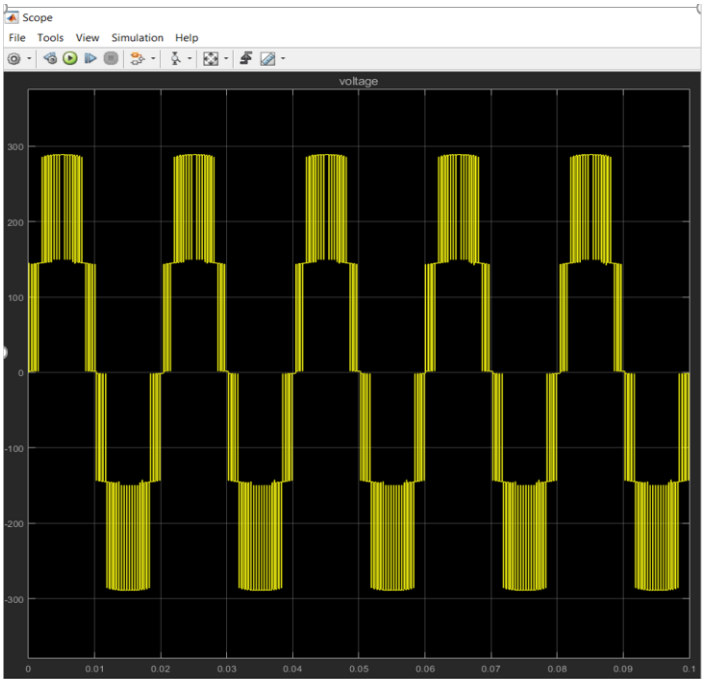

Figure 5: Output waveform of 5 level diode clamped MLI

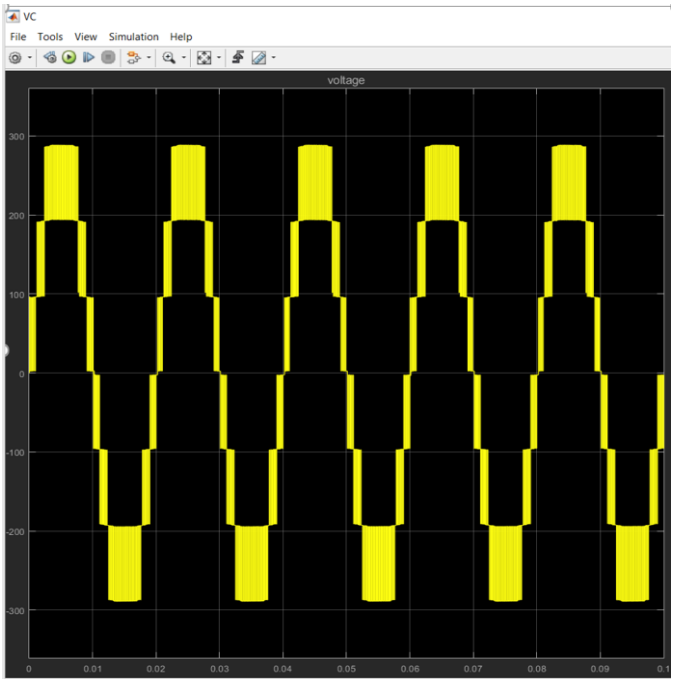

Figure 7: Output waveform of 7 level diode clamped MLI

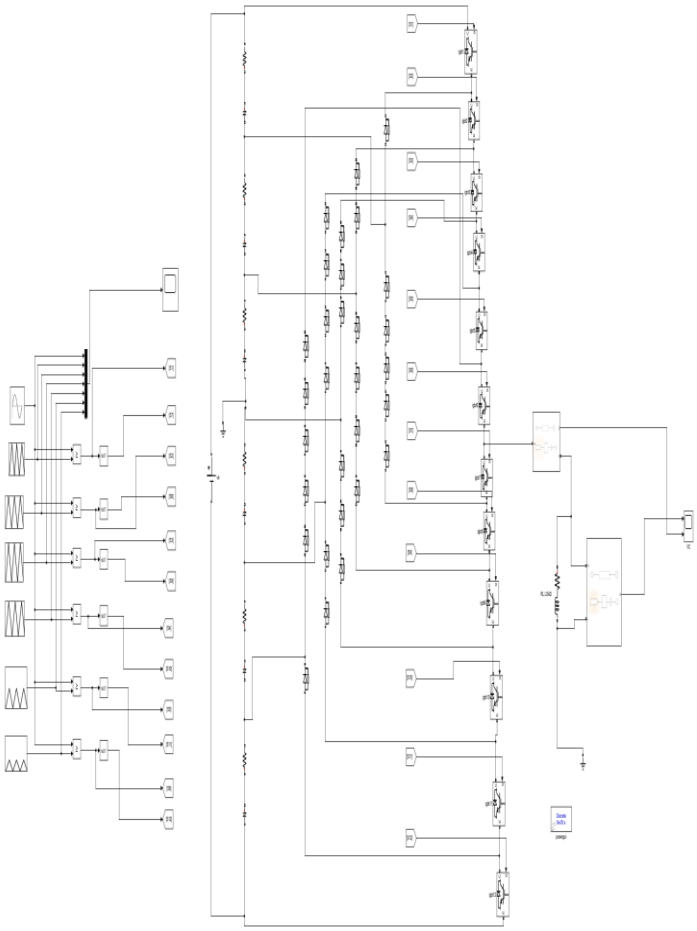

Figure 6: Simulation Model for 7-level DIODE CLAMPED multi-level inverter with SPWM

ADVANTAGES:

- Voltage across the switch is only half of the dc-link voltage.
- Entire phase shares a common dc bus, which minimize the capacitance requirement of the converter
- Capacitance of the capacitor is low and they are recharged.
- Back to back inverters are used.
- Efficiency is high at fundamental frequency.

DISADVANTAGES:

- Diode clamped MLI have a practical limit on the number of levels, because it required clamping diode.
- If the control and monitoring are not precise, Dc level will discharge.

APPLICATIONS:

1. Static VAR compensation
2. Variable speed motor drives
3. High voltage system interconnections

4.2 FLYING CAPACITOR MULTILEVEL INVERTER

5-level flying capacitor multilevel inverters. The diodes in the diode-clamped topology can be replaced by clamping capacitors or floating capacitors to clamp the voltages. Such a topology is called flying capacitor multilevel inverter (FCMLI). FCMLI topologies are relatively new compared to the diode-clamped the cascaded H-bridge cell inverter topologies. Redundancy in the switching states is available by using flying capacitors instead of clamping diodes. This redundancy can be used to regulate the capacitor voltages and obtain the same desired level of voltage at the output. Figure 8 shows a single phase five-level FCMLI topology. The voltage across the capacitors is considered to be half of Dc source voltage Vdc. The output voltage consists of five different voltage levels + Vdc, Vdc/2, 0, -Vdc/2, and - Vdc.

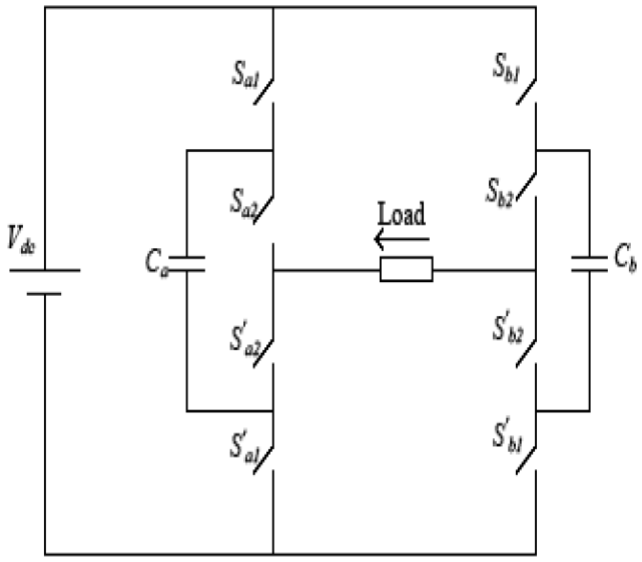

Figure 8: 5-level Flying capacitor multilevel inverter

Similar to the other multilevel converter topologies, FCMLI also has complementary switch pairs. In the present considered circuit, switches Sa1 & Sa1', and Sa2 & Sa2' are complementary to each other. Similarly, on the other limb, switch Sb1 & Sb1', and Sb2 & Sb2' are complementary to each other. The switching states available for such a topology are higher than that of the diode clamped. The number of voltage levels at the output can be increased by adding a pair of complementary switches and a capacitor. However, all the capacitors used in such topologies must be rated identically which can prove to be expensive and bulky in size.

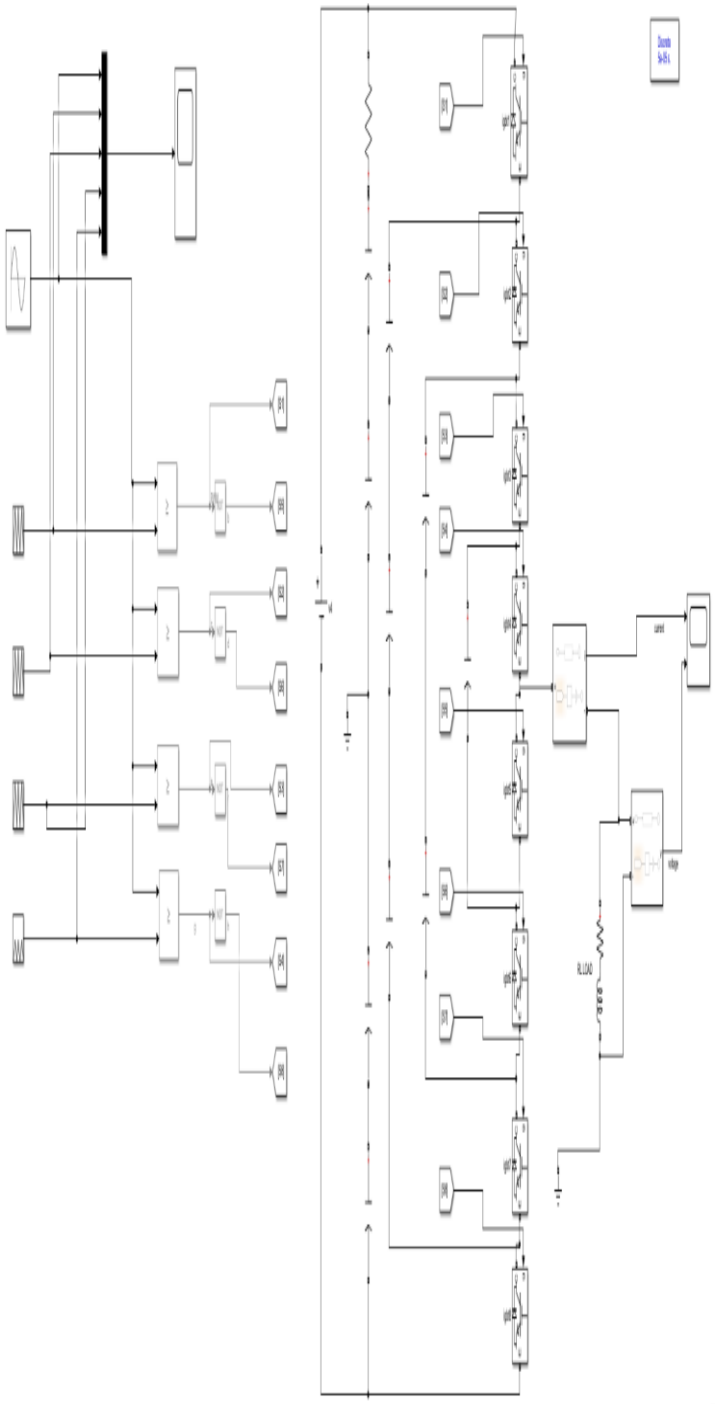

Figure 9: Simulation model for 5-level Flying Capacitor multi-level inverter with SPWM

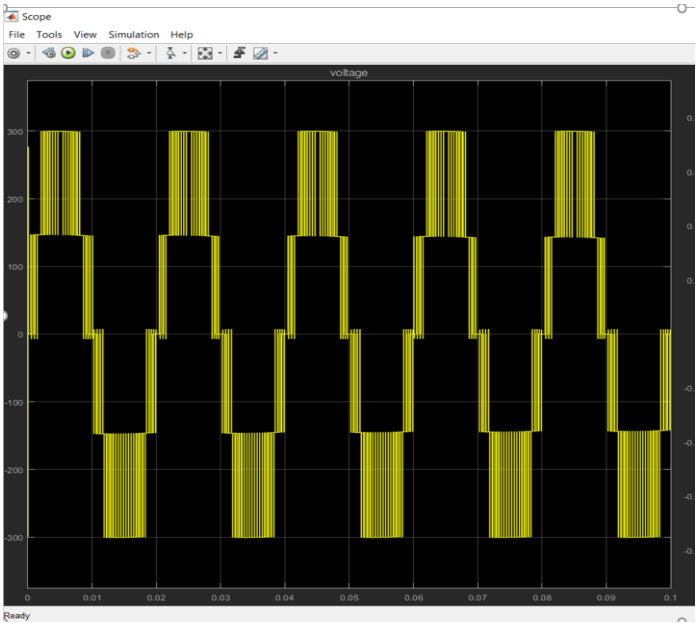

Figure 10: Output waveform of simulation circuit of 5 level Flying Capacitor MLI

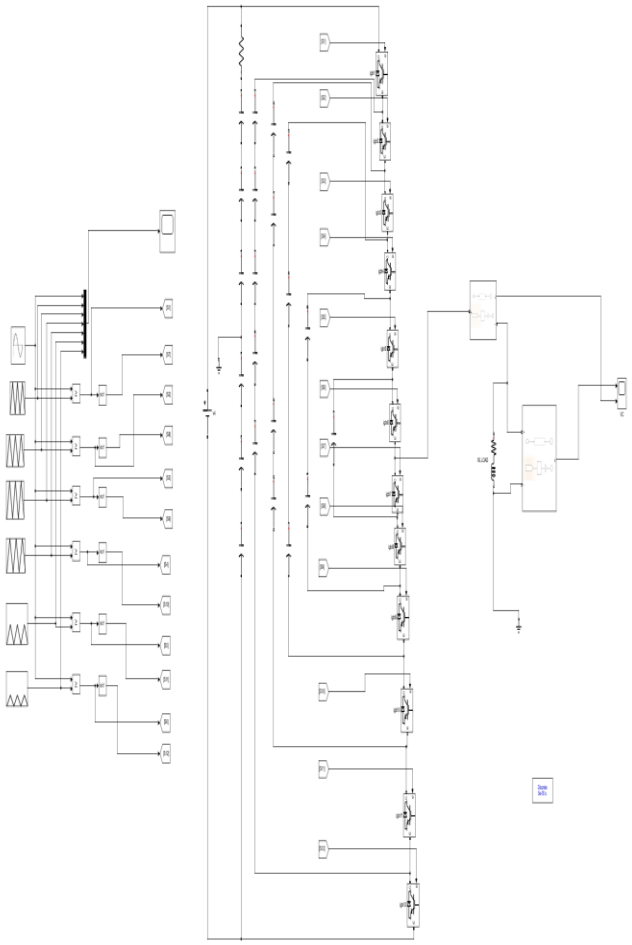

Figure 11: Simulation Model for 7-level Flying Capacitor multi-level inverter with SPWM

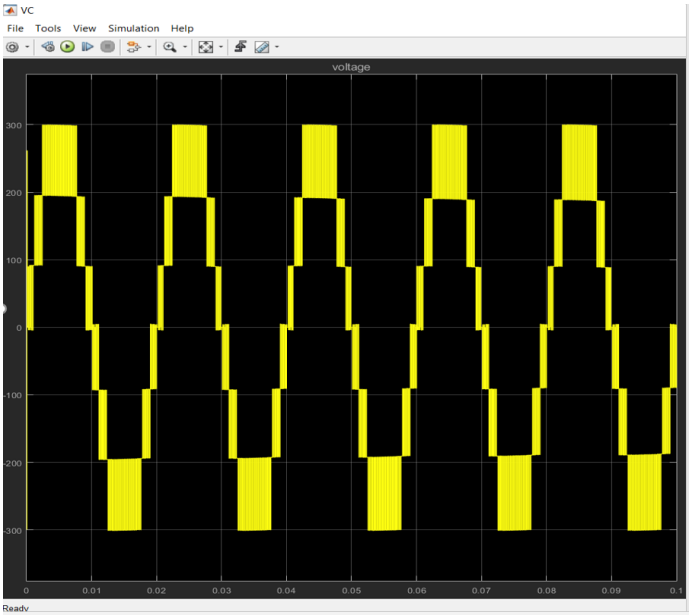

Figure 12: Output waveform of simulation circuit of 7 level Flying Capacitor MLI

ADVANTAGES:

- Eliminates the clamping diode problems
- Phase redundancies are available for balancing the voltage levels of the capacitors, real and reactive power flow controlled.
- The large number of capacitors enables the inverter to save from short duration outage and deep voltage sags

DISADVANTAGES:

- Complex start-up
- Lower Switching efficiency
- Capacitors are expensive than diodes
- Voltage control across all the capacitors is difficult

APPLICATIONS:

1. Induction motor control using DTC circuit
2. Static VAR generation
3. Both AC-DC and DC-AC conversion applications
4. Converters with Harmonic distortion capability
5. Sinusoidal current rectifiers

4.3 CASCADED H-BRIDGE MULTILEVEL INVERTER

5-level Cascaded H-bridge multilevel inverter. Cascaded H-bridge multilevel inverter topology is a series connection of two or more individual full bridge inverters. Figure 13 shows a single-phase, five-level cascaded H-bridge cell inverter realized by connecting two three level conventional full bridge inverters in series. Switch pairs Sa1 and Sa1', and Sa2 and Sa2' are complementary to each other. Similarly, switch pairs of the other full bridge inverter Sb1 and Sb1', and Sb2 and Sb2' are complementary to each other. The different voltage levels that can be obtained at the output terminals are +2Vdc, +Vdc, 0, Vdc, -2Vdc. If the dc voltage sources in both the inverter circuits connected in series are not equal to each other, then nine levels can be obtained at the output terminals.

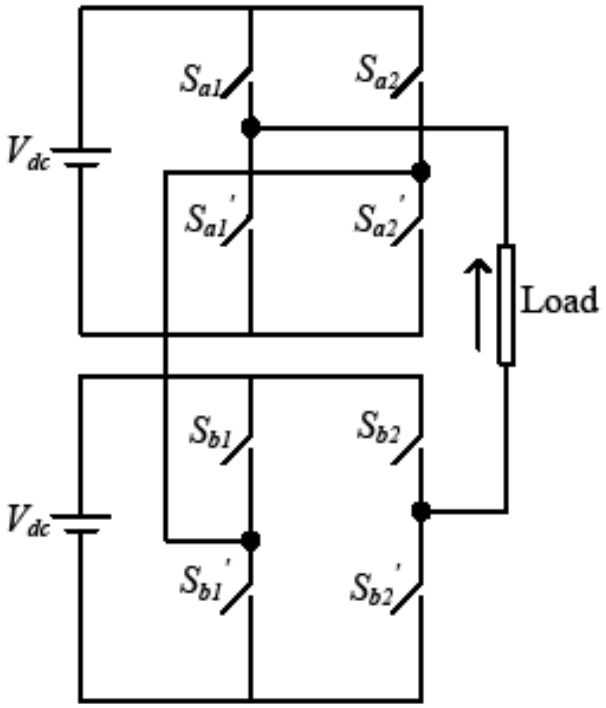

Figure 13: 5 level cascaded H-bridge multilevel inverter

The number of levels in the output voltage can be increased by two by adding an identical inverter in series. Cascaded H-bridge cell inverters use the least number of power electronic devices when compared to any other topology. However, they require isolated power sources in each cell which in turn requires a large isolating transformer.

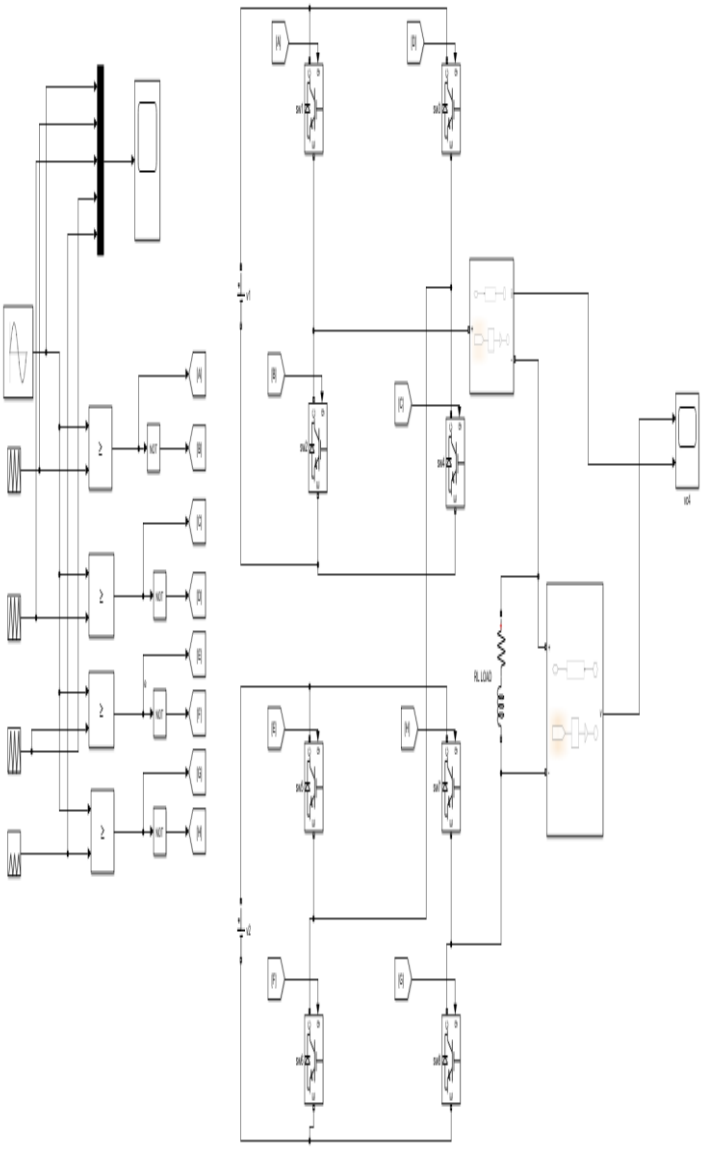

Figure 14: Simulation Model for 5-level H-Bridge multi-level inverter with SPWM

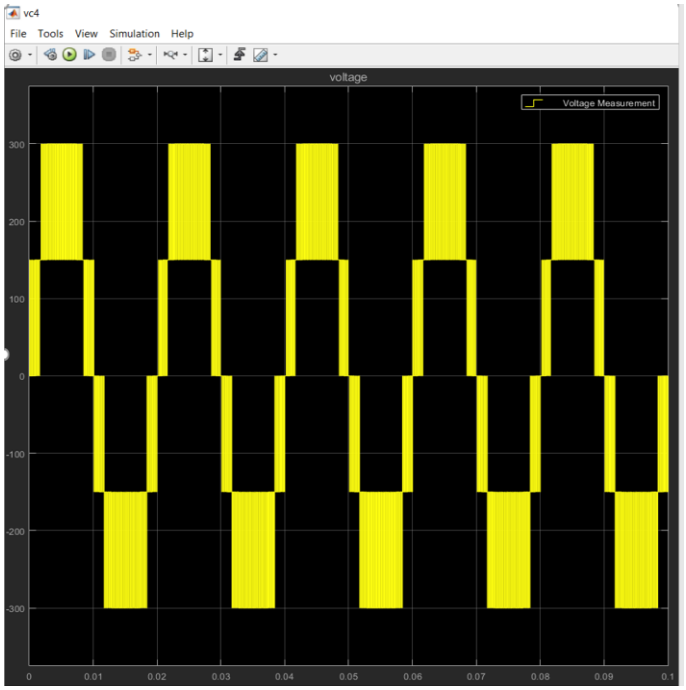

Figure 15: Simulation circuit of cascaded H- Bridge 5 level inverter

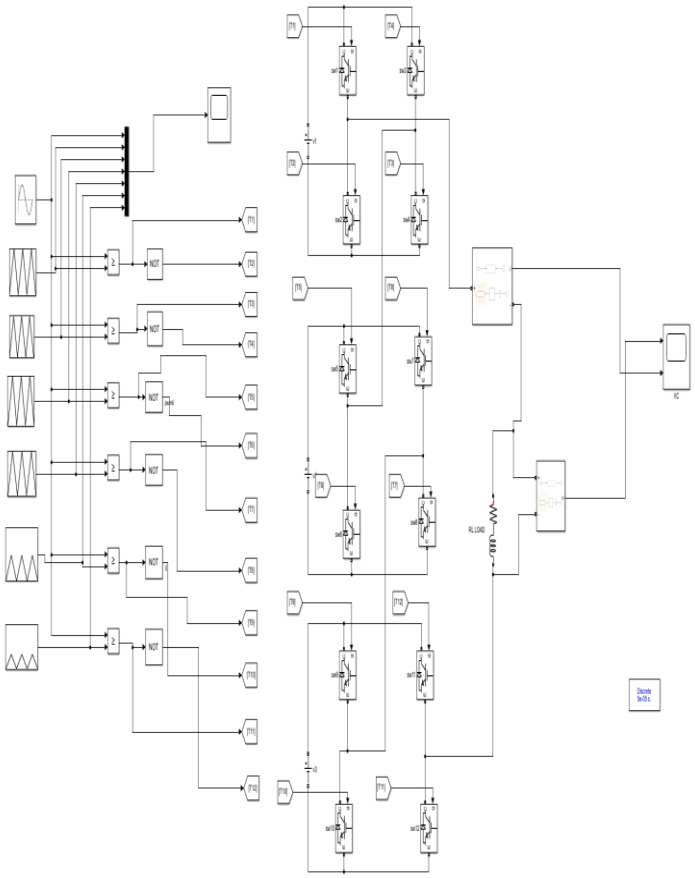

Figure 16: Simulation Model for 7-level H-Bridge multi-level inverter with SPWM

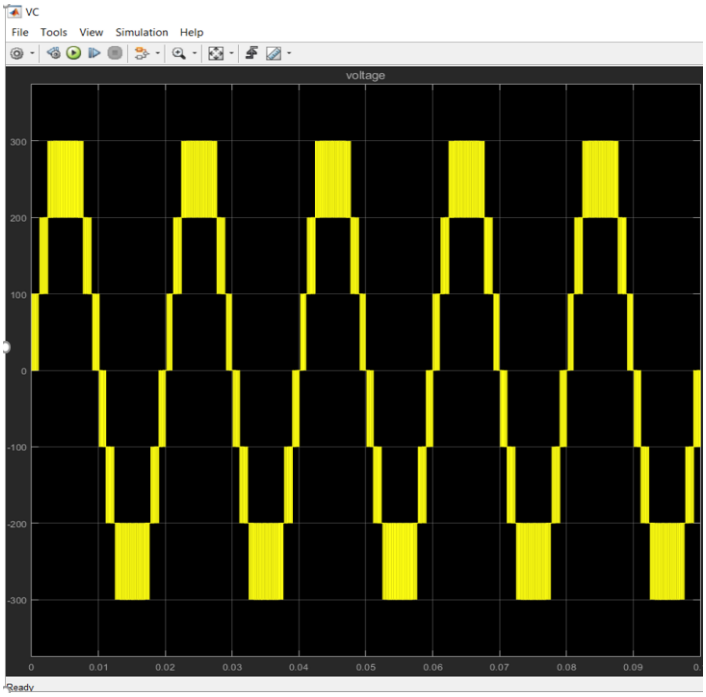

Figure 17: Simulation circuit of cascaded H- Bridge 7 level inverter

ADVANTAGES:

- Total harmonic distortion is very low in the output waveform without any filter circuit
- Operates at both fundamental switching frequencies
- Easy packaging and storage
- Produce common mode voltage, stress is reduced
- Low distortions in the input current

DISADVANTAGES:

- Separate DC sources or capacitor are required for each module but it is more suitable for Photovoltaic application since each photovoltaic array can act as a separate DC source.
- Y- connected cascaded MLI are suited for STATCOM, power line conditioning but it can't be used for compensation & connecting unbalanced current

APPLICATIONS:

1. Motor drives
2. Electric vehicle drives
3. DC power source utilization
4. Power factor compensators
5. Back to back frequency link systems
6. Interfacing with renewable energy resources.

5. TOTAL HARMONIC DISTORTION ANALYSIS

From FFT analysis of the three topologies we get the total harmonic distortion (THD) as follows:

Topology	*Voltage THD %*	*Current THD %*
5-LEVEL H-BRIDGE INVERTER	33.98	32.02
7-LEVEL H-BRIDGE INVERTER	22.04	22.77
5-LEVEL FLYING CAPACITOR INVERTER	34.11	32.04
7-LEVEL FLYING CAPACITOR INVERTER	24.84	22.31
5-LEVEL DIODE CLAMPED INVERTER	28.61	27.58
7-LEVEL DIODE CLAMPED INVERTER	21.81	20.56

6. CONCLUSIONS

The use of multilevel inverter in PV system was accepted in power system since it gave a lot of advantages. More number of levels of multilevel inverter will give better performance in the system. In this paper, A detailed Multi-Level Inverter is presented and from the simulations and the results, 7-level multilevel inverter had given more efficient performance in terms of the power factor, THD and its efficiency than 5-level multilevel inverter and the Cascaded H-Bridge Inverter topology has advantage over the other two as it requires less number of components as compared to the other two types of inverters and so its overall weight and price is also less and as the level of voltage and current increases DCMLI is superior in case of THD compared to CHMLI and FCMLI in which the DCMLI produce 21.81% THD while CHMLI and FCMLI produce 22.04% and 24.84% respectively for output voltage in case of 7 level inverter. It also is more suitable for the purpose of integrating PV arrays and grid system.

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