Power Loss Evaluation of 5 Level Multilevel Inverters connected to Solar Sourced Stand alone Micro Grid System

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Abstract

Power electronic converters were developed to integrate solar panels to the electric grid. Inverters are required to convert the direct current power of the PV array into the alternating current required for loads. Multilevel inverters are now frequently used in solar systems. Multilevel inverters have various advantages over conventional inverters to use in high power applications. The performance of the Active Neutral Clamped Inverter (ANPC) multilevel inverter (MLI) is evaluated in order to improve power quality. The simulation results presented show that the comparison with the Diode Clamped Multilevel Inverter (DCMLI), Capacitor Clamped Multilevel Inverter (CCMLI) and the proposed ANPC Multilevel inverter which generates less harmonics, less losses and better efficiency in the micro grid system. A simulation is performed on the MATLAB 2018b version system.

*Key Words**: CCMLI, DCMLI, Losses, Multi level inverter, SPWM, Power losses, THD.*

1. INTRODUCTION

The usage of renewable energy resources (RES) has increased rapidly compared to non renewable sources [1-2]. When compared to other options utilized in power applications, photovoltaic generation is becoming a more significant renewable resource [3] because it produces no noise, pollution, fuel costs, or maintenance requirements.

In heavy duty industries and high voltage applications, the use of multilevel inverters are becoming common since many of the machinery uses electrical drives. The advantages of multilevel converters is their smaller output voltage step, which results in high voltage capability, lower harmonic components, lower switching losses, better electromagnetic compatibility, and high power quality [4]. Also it can operate at both fundamental switching frequency and high switching frequency Pulse Width Modulation. It must be noted that lower switching frequency usually means lower switching loss and higher efficiency [5]. Today, multilevel inverters are extensively used in medium voltage levels with high-power applications. The field of applications includes use in

laminators, pumps, conveyors, compressors, fans, blowers, and mills Uninterruptable Power Supply (UPS), DC power source utilization, induction heating, high voltage direct current power transmission, variable frequency drive, etc. One clear disadvantage of multilevel power conversion is the great number of power semiconductor switches needed. Another disadvantage of multilevel power converters is that the small voltage steps are typically produced by isolated voltage sources or a bank of series capacitors. Isolated voltage sources may not always be readily available and series capacitors require voltage balance. Multilevel inverters are more popular than conventional two-level inverters [6-7]. This is due to two-level limitation when handling high voltage and power. Transformerless multi-level inverter topologies replace power losses and act as voltage source inverters. The output of the multilayer inverter simulation will be compared in order to see an improvement in power quality, with a focus on losses, efficiency and total harmonic distortion (THD).

2. Overview of Multilevel Voltage source Inverter Topologies

2.1 Multilevel Voltage-Source Inverters

Multilevel voltage-source inverters (VSIs) are power electronic converters used in many different applications, including as motor drives, renewable energy systems, and high-voltage direct current (HVDC) transmission. These inverters create stepped or layered waveforms by synthesizing an output voltage waveform from a variety of DC voltage sources. Multilevel inverters [8-9] have an advantage over traditional two-level inverters in that they can produce an output voltage that is almost sinusoidal, with less harmonic content and less voltage stress on the switching components. As a result, they work particularly effectively in situations that call for high voltage levels and excellent voltage waveforms. The different multilevel inverters are

Diode-Clamped Multilevel Inverter (Neutral-Point Clamped Inverter): Firstly in his kind of multilayer inverter connects many DC voltage sources in series using clamping diodes and diodes. The number of voltage sources employed and the clamping diode [10] design control the voltage levels at the output. Inverters with two, three, and five levels are common configurations. They

have limited scalability while being reasonably easy to use and reasonably priced. Diode clamped inverter drawback is having higher switching losses and less efficiency. Due to the disadvantages furthermore in the next type, CCMLI is explained.

Flying Capacitor Multilevel Inverter: In this second type of MLI in order to establish intermediate voltage levels between the DC voltage sources, flying capacitor inverters employ capacitors. By dynamically modifying the capacitors' charging and discharging, the voltage levels are managed [11]. Multilevel Flying capacitor (FC) inverters are appropriate for medium-voltage applications because they can achieve a wide range of voltage levels. FC is not utilized in renewable energy sources because they require additional capacitors, which makes balancing procedures more difficult. Moreover FCMLI is not used in RES, so in the next type hybrid MLI is explained.

Hybrid Multilevel Inverter: In the third type of MLI the profit from the unique features of each of the aforementioned topologies, hybrid multilevel inverters integrate two or more of them. For instance, to achieve a balance between complexity, cost, and performance, a hybrid inverter might include a cascaded H-bridge inverter and a diode-clamped inverter [12-13]. The utilization of separate DC sources for every Hybrid bridge is the primary drawback. Hence the following system is proposed as a research objective.

In the proposed system simulation work done on one dc source of 90kw solar photovoltaic system is connected to grid through unified power quality conditioner (UPQC). The unbalanced load and non linear load (100 ohms) is connected to proposed system. Further diodes in the diode clamped multi level inverter is been replaced by active semiconductor devices. In the proposed Active Neutral Clamped MLI, less number of semiconductor switches is used to get the desired output voltage and to show good efficiency. The phase shifted Sinusoidal pulse width modulation technique is utilized to generate the gate pulse. The technique is continued in next discussion.

2.2. Sinusoidal PWM technique

The main objective of the SPWM [14] is to control the inverter output voltage and frequency. SPWM consist of two signals, first one is sinusoidal signal and second is triangular signal. Sinusoidal signal is also called as reference signal and triangular signal is called as carrier signal. Reference signal compared with carrier signal to produce pulses. These generated pulses are given to switches of multilevel inverters to produce desired output voltage through the LC filters. Phase-Shifted Pulse Width Modulation (PS-PWM), often referred to as Phase-Shifted Sinusoidal Pulse Width. Hence SPWM is applied to inverter to generate the pulses. Likewise parameters of the different multilevel inverter are explained in next section.

3. Measurable Parameters of different types of MLI

3.1. Total Harmonic Distortion (THD)

THD is a measurement of the harmonic distortion is characterized as the ratio of the sum of the powers of all harmonic components to the power of fundamental frequency. Total Harmonic Distortion can be determined by the expression (1) is

$$THD = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots + I_\infty^2}}{I_1} \quad (1)$$

In the expression (1) I_1 is the fundamental component of signal and I_2 to I_∞ is the harmonics of same signal. THD is used to characterize the linearity of systems and the power quality of electric power systems.

According to IEEE standard of THD limits, total harmonic current distortion shall be less than 5% of the fundamental frequency current at rated inverter output.

3.2. Switching device Losses

The total power losses of switching devices consist of two parts such as conduction losses and switching losses.

$$P_{losses} = P_{conduction} + P_{switching} \quad (2)$$

Where $P_{conduction}$ is calculated as multiplication of collector emitter voltage drop ($V_{CE(ON)}$) and collector current ($I_{C(on)}$) during ON state and $P_{switching}$ is ON and OFF state of power switch. Usually in many literature P_{losses} are calculated based on simulation results and they don't consider theoretical results [15]. More the switching frequency increases losses, the proposed system working in fundamental frequency percentage of losses occur in inverter is less.

3.3. Efficiency

Efficiency is a measurable concept that may be calculated by the output to input ratio. The system's input power comes from the power delivered by the PV arrays, while its output power comes from the grid.

4. Switching States and Modes of operation of multilevel inverters

4.1. Diode Clamped Multi-Level Inverter

Diode clamped MLI is shown in Fig. 1. Number of DC bus capacitor in a multi level inverter is decided by (n-1), Number of switches in Multilevel inverter is decided by 2*(n-1), Voltage source is decided by Vdc/(n-1) & clamping diode is given by (n-1)*(n-2). Where 'n' is number of level of an inverter.
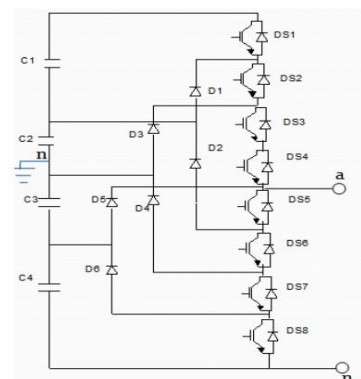

Fig. 1: DCMLI-5L converter

The DC bus voltage is split up in to three levels as shown in Fig. 1. Five-level diode-clamped converter in which the DC bus consist of four capacitor C1,C2,C3,C4 for DC bus voltage Vdc, the voltage across each capacitor is Vdc/4 and each device voltage stress will be limited to one capacitor voltage levels Vdc/4 through clamping diodes.

Switching states of the 5L DCMLI is given in table 1.

Table 1: Switching states of the 5L DCMLI

Switching States	Output Voltages	DS 1	DS 2	DS 3	DS 4	DS 5	DS 6	DS 7	DS 8
+1	Vdc/2	1	1	1	1	0	0	0	0
+2	Vdc/4	0	1	1	1	1	0	0	0
0	0	0	0	1	1	1	1	0	0
-2	-Vdc/4	0	0	0	0	1	1	1	1
-1	-Vdc/2	0	0	0	0	1	1	1	1

Modes of operation
   a. For voltage levels Van= Vdc/2 all upper switches S1-S4 are turned ON.
   b. For voltage level Van= Vdc/4, turn on three upper switches S2-S4 and lower switch S5.
   c. For voltage level Van=0, turn on two upper switches S3 and S4 and two lower switches S5 and S6.
   d. For voltage levels Van= -Vdc/4, turn on one upper switch S4 and three lower switches S5-S7.
   e. For voltage levels Van= -Vdc/2, turn on all lower switches S5-S8.

3.2. Capacitor Clamped Multilevel Inverter

The DC bus voltage is split up in to three levels as shown in Five-level capacitor-clamped converter in which the DC bus consist of four capacitors C1,C2,C3,C4 for DC bus voltage, the voltage across each capacitor is Vdc/4 and each device voltage stress will be limited to one capacitor voltage levels Vdc/4 through clamping capacitor. Capacitor clamped MLI is shown in Fig. 2.
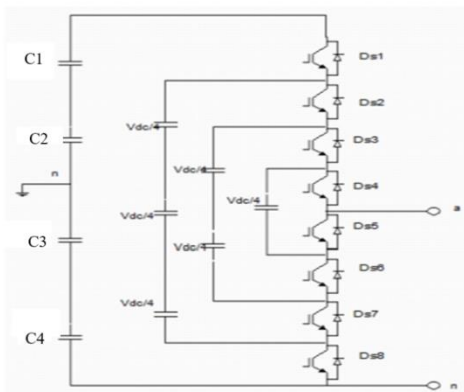

Fig. 2: CCMLI-5L converter

Main switches=2(n-1) =8,
DC bus capacitor = (n-1) = 4
Balancing capacitor= (n-1) (n-2)/2=6.
Switching states of the 5L CCMLI is given in table 2.

Table 2: Switching states of the 5L CCMLI

Switching States	Output Voltages	DS 1	DS 2	DS 3	DS 4	DS 5	DS 6	DS 7	DS 8
+1	Vdc/2	1	1	1	1	0	0	0	0
+2	Vdc/4	1	1	1	0	1	0	0	0
0	0	1	1	0	0	1	1	0	0
-2	-Vdc/4	1	0	0	0	1	1	1	0
-1	-Vdc/2	0	0	0	0	1	1	1	1

Modes of operation
   a. For voltage levels Van= Vdc/2 turn on all upper switches S1-S4.
   b. For voltage level Van= Vdc/4, turn on three upper switches S1-S3 and lower switch S5.
   c. For voltage level Van=0, turn on two upper switches S1 and S2 and two lower switches S5 and S6.
   d. For voltage levels Van= -Vdc/4, turn on one upper switch S1 and three lower switches S5-S7.
   e. For voltage levels Van= -Vdc/2, turn on all lower switches S5-S8.

3.3. Proposed Active Neutral Point Clamped-Five Level converter

Fig. 3 shows that ANPC-5L converter. In Fig. 3 each leg consist of 6 semiconductor switches, one dc source with two separate capacitors and totally for 5-level ANPC inverter of 3 leg need 18 switches to operate.
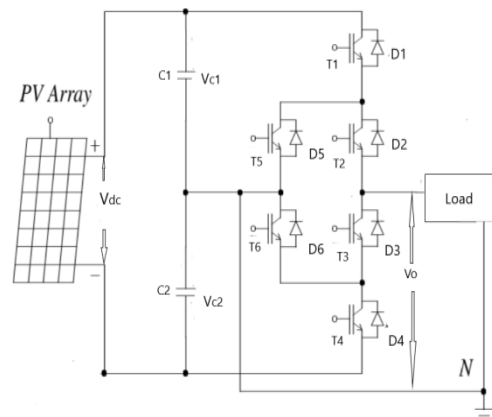

Fig. 3: ANPC-5L converter

PV array connected to load through proposed inverter. The gate pulse given to power switches are T1, T2, T3, T4 is responsible for levels and inverse pulse of T1, T4 given to T5, T6 respectively to avoid the DC-link short circuit, actively control switching angles and reduce harmonics.

Vc1 and Vc2 represent the two split capacitor voltages has same balanced voltage. Vdc represent the input voltage. Vo is the output voltage. Switching states of the 5L MLI is given in table. 3.

Table 3: Switching states of the 5L MLI

Mode	Voltage level	T1	T2	T3	T4	T5	T6	Load Voltage
1	+2	1	1	0	0	0	0	Vdc
2	+1	0	1	0	0	1	0	Vdc-Vc1
3	0	0	0	0	0	0	0	zero
4	-1	0	0	1	0	0	1	-(Vdc-Vc2)
5	-2	0	0	1	1	0	0	-Vdc

4. Simulation, Results and Discussions

Modes of operation

a. Mode 1 (+2): In this, the switches T1 and T2 are turned ON and the load voltage is Vdc. The current flows through Vdc-T1-T2-load.

b. Mode 2 (+1): In this, the switches T5 and T2 are turned ON and the load voltage is +(Vdc-Vc1). The current flows through C1-T5-T2-load.

c. Mode 3 (0): In this all the switches are OFF and the voltage around load is zero shown in Fig. 3(c).

d. Mode 4 (-1): In this, the switches T3 and T6 are turned ON and the load voltage is –(Vdc-Vc2). The current flows through load-T3-T6-C2.

e. Mode 5 (-2): In this, the switches T3 and T4 are turned ON and the load voltage is –Vdc. The current flows through load-T3-T4-(-Vdc).
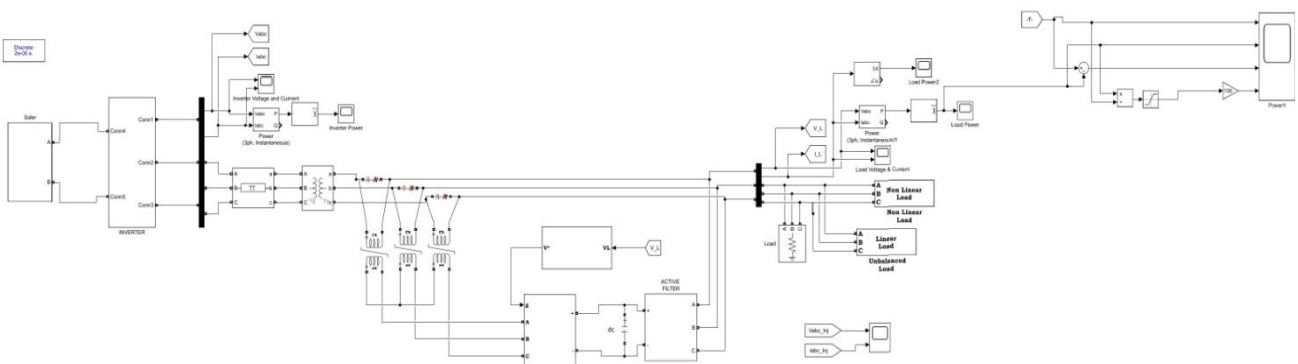

Fig. 4. Grid connected standalone solar PV system

Grid connected solar pv system is shown in Fig. 4. In Fig. 4 solar system connected to standalone grid through multilevel inverter and UPQC. Moving forward to that the different types of multilevel inverters simulink models is discussed further.
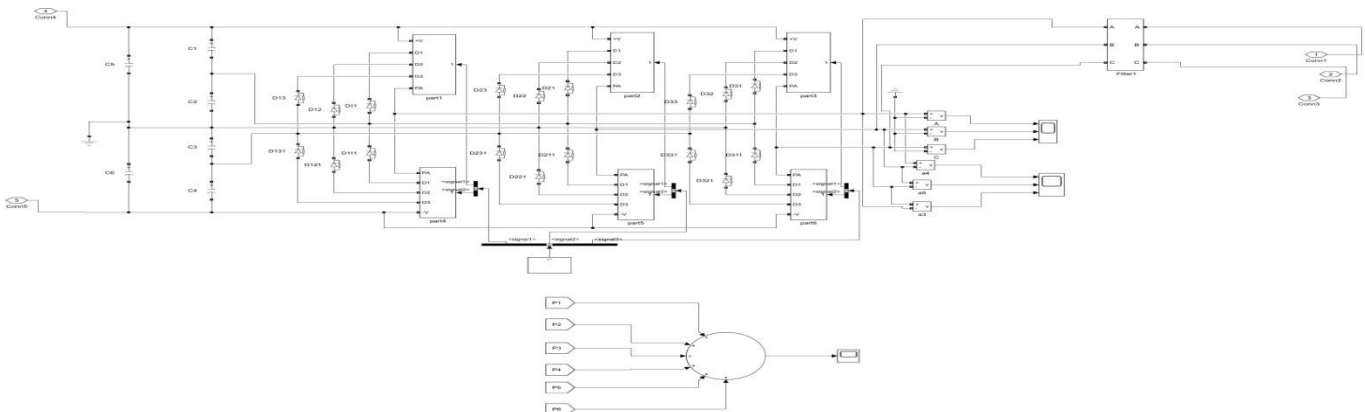

Fig. 5. Simulink Model of Diode clamped MLI

Simulink model of Diode clamped 5 level MLI connected to Grid is shown in Fig. 5. The DCMLI is simulated in MATLAB/Simulink 2018b version software where DCMLI of Fig. 5 includes elements given in table 4.
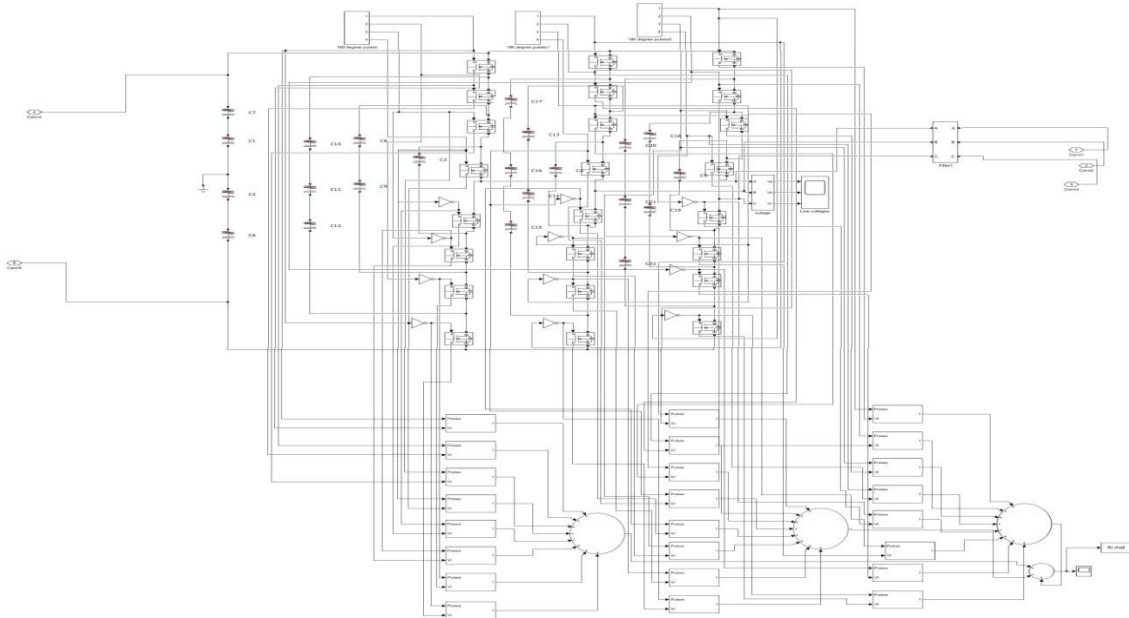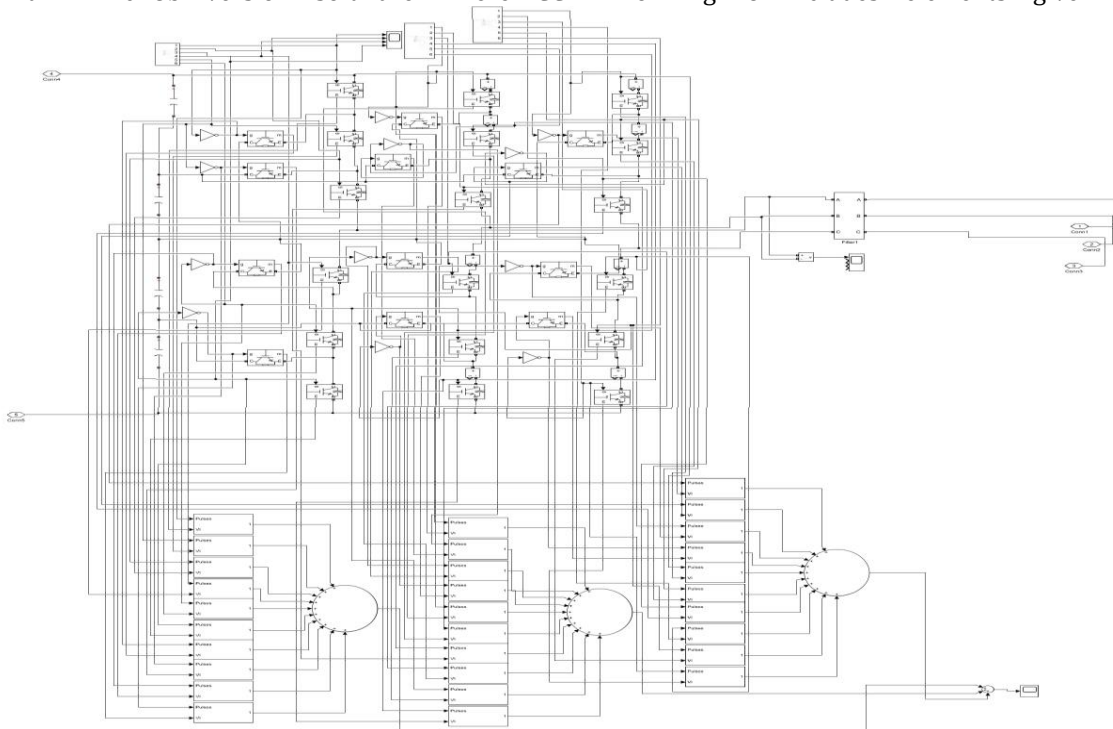

Fig. 6. Simulink Model of capacitor clamped MLI

Simulink model of Capacitor clamped 5 level MLI connected to Grid is shown in Fig. 6. The CCMLI is simulated in MATLAB/Simulink 2018b version software where CCMLI of Fig. 6 includes elements given in table 4.

Fig. 7. Simulink Model of 7 level clamped ANPC MLI

Simulink model of seven level ANPC MLI connected to Grid is shown in Fig. 7. The ANPC MLI is simulated in MATLAB/Simulink 2018b version software where ANPC MLI of Fig. 5 includes elements given in table 4.
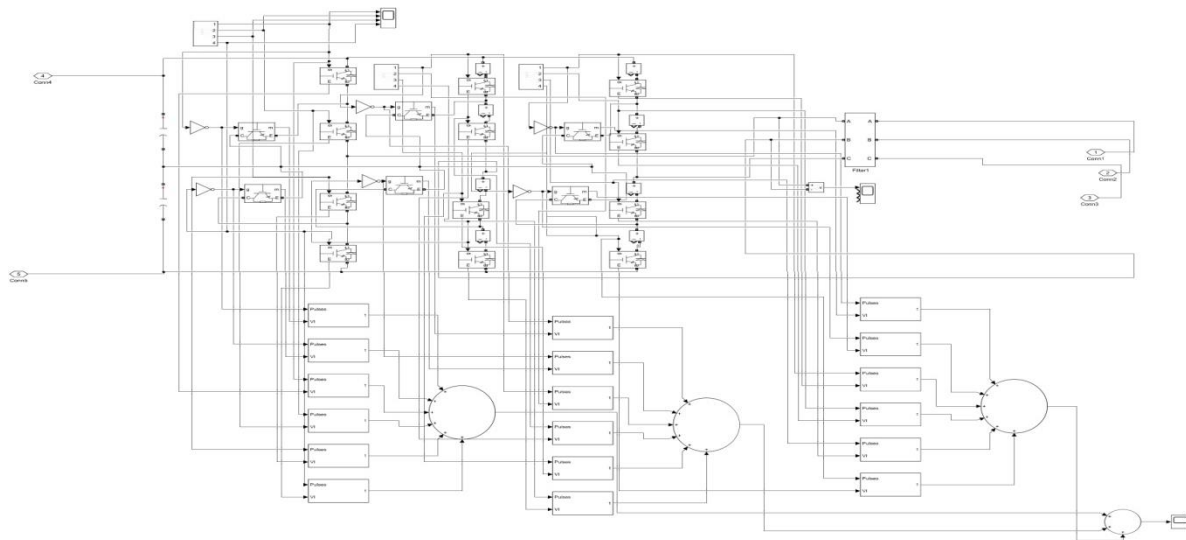
Fig. 8. Proposed Simulink Model of 5 level ANPC MLI

Proposed Simulink model of five level ANPC MLI connected to Grid is shown in Fig. 8. The ANPC MLI is simulated in MATLAB/Simulink 2018b version software where ANPC MLI of Fig. 8 includes elements given in table 4. Table. 4 shows the Parameters comparison of different types of multilevel inverters

Table. 4. Parameters comparison of different types of multilevel inverters

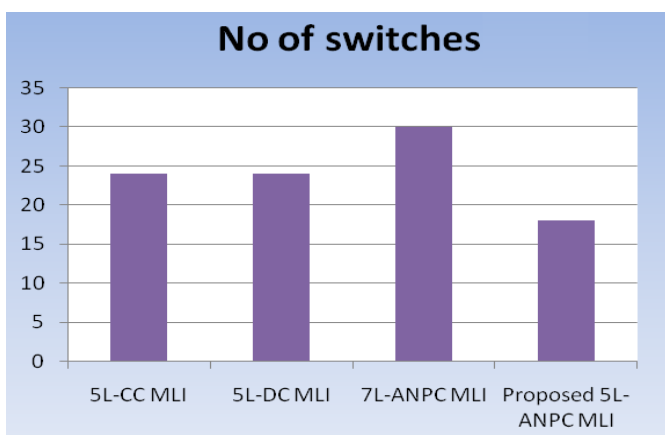| Inverter Type	No of diodes	No of dc link capacitors	No of flying capacitors	No of levels	No of switches	THD%	Losses(W)	Efficiency (%)
2L-VSI	-	1	-	2	6	1.01	5030	78
5L-Flying Capacitor	-	4	18	5	24	0.92	4750	79.25
5L-Diode clamped	18	4	-	5	24	0.35	4280	80.4
5L-Active Neutral point clamped	-	2	-	5	18	0.31	3827	81.4
7L-Active Neutral point clamped	-	4	-	7	30	0.25	5240	77.5

Fig. 9. Comparison of switches for different types of inverter

The comparison of switches for different types of inverter is shown in Fig. 9. In Fig. 9, y-axis shows number of switches and x-axis shows the different types of MLI. In

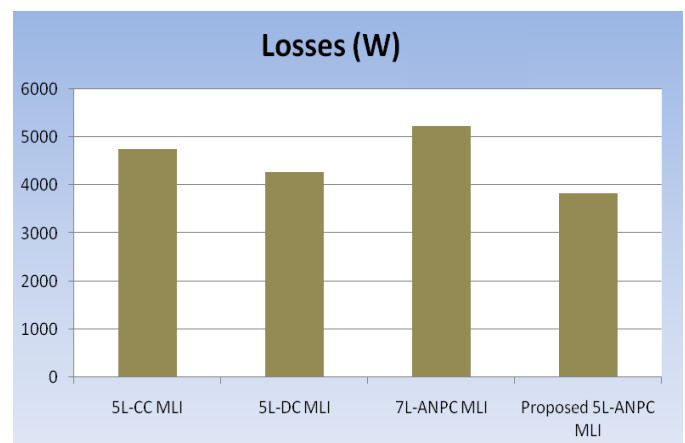Proposed 5 level ANPC MLI, less number of switches used to reduce losses.

Fig. 10. Comparison of losses for inverter

Further in the comparison of losses for different types of inverter is shown in Fig. 10. In Fig. 10, y-axis shows losses

in watts and x-axis shows the different types of MLI. Fig. 10 shows that VSI suffers more losses (5030 W) due to PWM switching frequency (1KHz) and ANPC have lower loss (3827 W) inspite of more number of switches than VSI as it operates under modulation frequency (50Hz) but the losses are increased to 5240 W as the number of levels increases to 7. The proposed system will increase the efficiency of system due to reduced losses. In the next section efficiency parameter is discussed.
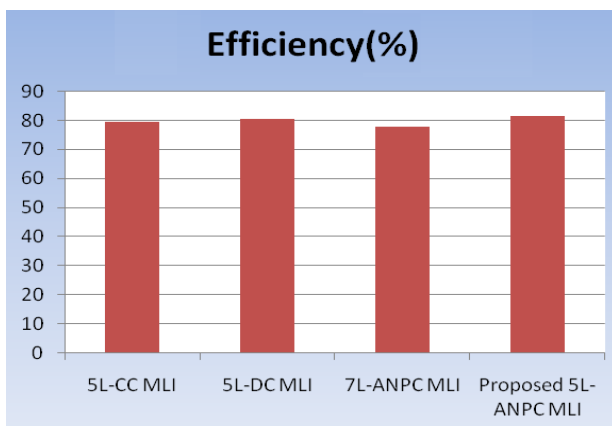

Fig.11. Comparison of Efficiency for different MLI

Likewise comparison of efficiency for different MLI is shown in Fig. 11. The ANPC with 7 level shown in Fig. 11 offers low efficiency (77.5%) while ANPC with 5 level offers more efficiency (81.4%) where diode clamped inverter (80.4%) is next to ANPC which is followed by flying capacitor MLI (79.25%) and VSI (78%).
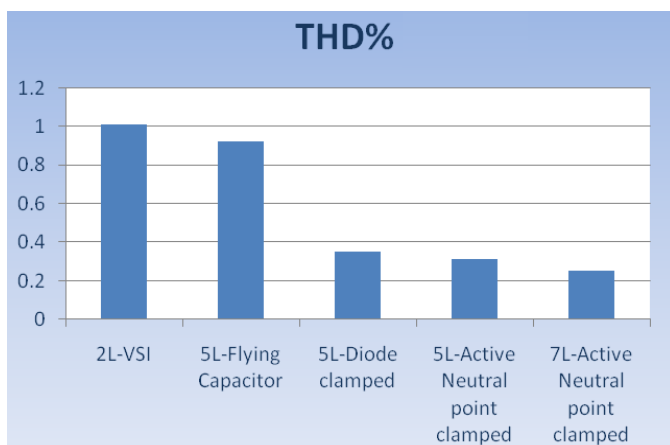

Fig.12. Comparison of THD% for different types of MLI

Comparison of THD% for different types of MLI is shown in Fig. 12. In Fig. 12, THD% is less in 7 level inverter compared to proposed ANPC five level Multilevel inverter but more switches increases losses and reduces efficiency in 7 level MLI as shown in Fig. 10 and Fig. 11.

5. Conclusion

This paper presented new active neutral clamped five level multilevel inverter topology for the MLI is the best topology. The main concept of this inverter is to use less power electronic switches instead of diodes which reduce losses and improve efficiency. The effectiveness of five level active neutral point clamped inverter based SPWM is validated through the simulations in terms of losses, efficiency and THD.

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