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Novel Seven- Level Flying Capacitor based Active Neutral Point Clamped Converter using Photovoltaic Energy Generation

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Abstract: ***Multilevel converters are the attractive solution for medium and high-power applications, especially for the renewable energy conversion. Developing high voltage rating converters of more than 6.6kV is a key goal for solar energy based industries. The maximum power capacity of the photovoltaic plants has highly increased over the past few years and it is expected to continue its growth over the next decade due to the increasing demand of renewable energy and distributed generation systems. This paper presents a seven-level active neutral point clamped (ANPC) inverter for the minimization of total harmonic distortion of voltage. The seven level active neutral point clamped converter is simulated using MATLAB software.***

Keyword: Active Neutral Point Clamped (ANPC), Flying Capacitor (FC), multilevel inverter, Photo Voltaic (PV) systems, grid connected converters.

I. INTRODUCTION

Multilevel inverters are the important one which is mainly needed in the power industry .It may be easier to produce a high power and high voltage to control the voltage stresses in their structure[i]. when the number of voltage levels in the inverter is increased, then considerably power ratings can also improved. Multilevel voltage source inverters allows them to reach high voltages by increasing the levels and decreasing the harmonics[ii].The main drawbacks in power electronic converter are switching loss, harmonics and voltage stress in the switches ,which are overcome by the advanced multilevel inverters. Although the multilevel inverters are initially introduced to reduce the harmonic content, it is found that the DC bus voltages could be increased beyond the voltage ratings of an individual power device by the use of voltage clamping network consisting of diodes[iv]. Multilevel inverters also improve the harmonic performance greatly without having to resort to PWM techniques.

The classic multilevel inverter topologies have serious problems when the inverter is used to obtain five or more levels. An NPC converter of more than three voltage levels has problem in balancing the bus capacitor voltages even for a back-to-back connection of capacitors. Many modulation techniques and controls have been proposed to solve these kind of issues but it has been proven that extra hardware components or special modulating signals are required to balance the DC bus capacitors' voltage. The FC converters are usually limited to four levels of voltage due to the large size of the FCs . Finally, the CHB need some isolation to transfer active power.

In this paper active neutral point clamped converter can be discussed for five level and new seven level describes section III.

II. CONVENTIONAL FC BASED FIVE- LEVEL ANPC SYSTEM

The conventional five level active neutral point clamped converter is the combination of three level ANPC and two level FC cells. The phase leg of five level FC based active neutral point clamped converter is shown in fig.2.The basic requirement of FC based ANPC converter is to operate the outer switches (S5,S6,S7 and S8) at the fundamental frequency of the output voltage[vi]. The five-level FC based ANPC converter consists of eight switching states which generate the five different voltage levels at the output shown in Table 1. The voltage withstand capacity of the outer switches is twice that of the S1,S2,S3 and S4.

The voltage across FC should be maintained at Vdc which is affected by the switching states by the switching states V2,V3,V6 and V7. During the switching states V3 and V6 the neutral point is connected to the load through the flying capacitor. By utilizing these switching states, the neutral point voltage can be controlled.

TABLE I

Switching States of Five level ANPC Converter

	S3	S4	S5	S6	S7	S8	Sa1	Sa2	Voltage
V1	0	1	0	1	0	1	0	1	-2Vdc
V2							1	0	-Vdc
V3	1	0	0	1	0	1	0	1	-Vdc
V4							1	0	0
V5	0	1	1	0	1	0	0	1	0
V6							1	0	Vdc
V7	1	0	1	0	1	0	0	1	Vdc
V8							1	0	2Vdc

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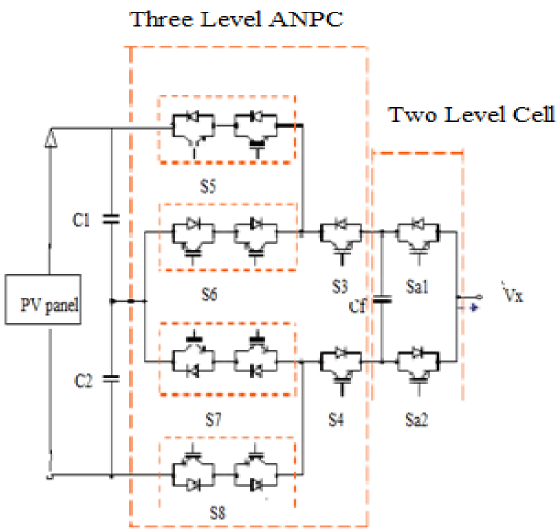


Fig 1 : Phase leg of Five Level ANPC

The flying capacitor voltage can be controlled by the controller techniques by SFO(switching Frequency optimal) methods .

III. PROPOSED SEVEN- LEVEL ANPC CONVERTER

The circuit diagram for seven level FC based ANPC converter is shown in fig 2. The seven-level ANPC converter is the combination of two FC with a three-level ANPC converter at the output side. Two flying capacitor voltages are kept at Vdc and 2Vdc respectively to get the seven level output voltage. For simplification, last capacitor is maintained at Vdc .
At the same time two DC link capacitor voltages are maintained at 3Vdc, the total voltage taken as 6Vdc. Switches Sc1, Sc2 and Sc3 has to withstand the voltage equal to Vdc, where the outer switch S1 need to withstand three times of this voltage due to voltage stress.

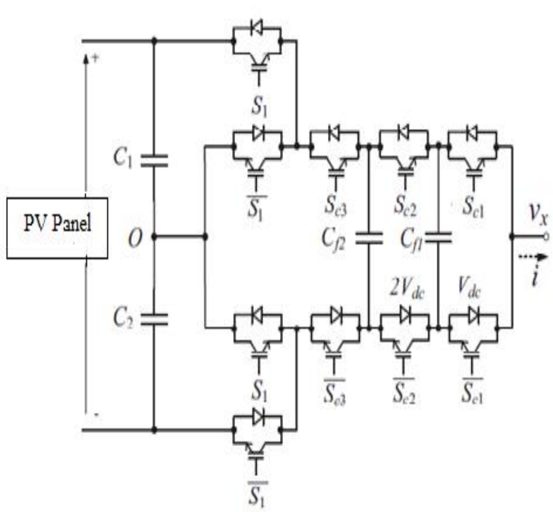
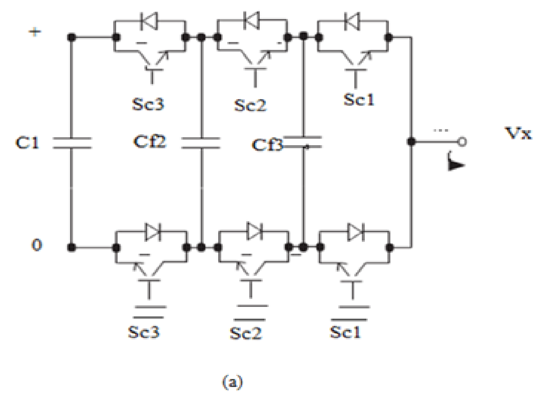
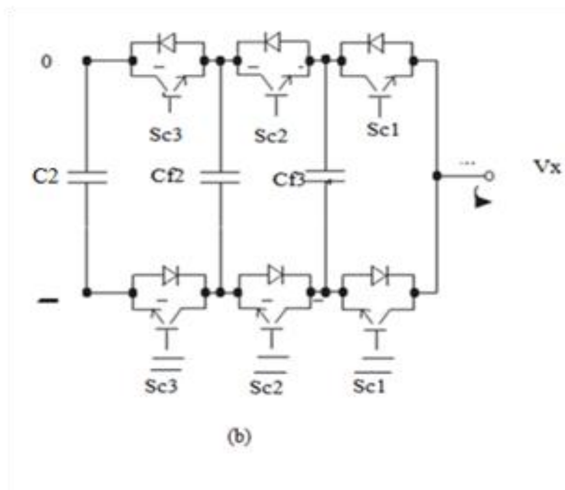


Fig 2 : Proposed Seven level ANPC

The seven level converter operates in two distinct half periods. During positive half period upper DC link capacitor(c1) is connected to a phase and during negative half period where the lower DC link capacitor (c2) is used to be connected. During these half-periods, the topology simplifies to a four-level FC converter [10] and for which the FC balancing requirements can be identified [14]. The equivalent circuits for one phase of the converter during the two half-periods of operation are given in Fig.3.

To reduce the stress across the switches and to limit the losses in the outer switches, fundamental frequency is used as switching frequency.





(a) Positive half period (b) negative half period

Fig 3: Equivalent circuit during Half period of operation

This fundamental frequency operation on outer switch S1 limits the operating states of the three level ANPC from six modes to four modes and this is combination with the two states of the two flying capacitor cells, total switching states of the converter is sixteen for seven level FC based ANPC inverter. The switching states are given in the table. The voltage levels of ±2Vdc and ±Vdc can be designed with three different switching combinations and the required switching states to acquire these levels shows a way to balance the voltages across the neutral point and FCs voltage. Two states will provide the zero voltage state, due to its fundamental switching frequency at the outer

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switches, it will provide the zero voltage level at positive (V9) state and negative (V8) state of the waveform, respectively.

Flying Capacitors are based on selection of the proper switching state to maintain both FC to their individual reference values. It is important for the proper control operation of the converter .Selection of switching cells used in the converter will affect the FC voltage and the neutral point voltage (difference between the lower and upper DC link capacitor voltages VC1 - VC2). The proper voltage regulation of the converter can be observed using simulation circuits. The tabulation consists of various switching states to represent the voltage of different states of various voltage levels .the upper levels are represented using positive levels and the lower levels are represented by their negative voltages.

TABLE 2

Sixteen switching states for seven level ANPC converter

	S1	**Sc3**	**Sc2**	**Sc1**	**OUTPUT VOLTAGE**
V1	0	0	0	0	-3Vdc
V2	0	0	0	1	-2Vdc
V3	0	0	1	0	-2Vdc
V4	0	0	1	1	-2Vdc
V5	0	1	0	0	-Vdc
V6	0	1	0	1	-Vdc
V7	0	1	1	0	-Vdc
V8	0	1	1	1	(-)0
V9	1	0	0	0	(+)0
V10	1	0	0	1	+Vdc
V11	1	0	1	0	+Vdc
V12	1	0	1	1	+Vdc
V13	1	1	0	0	+2Vdc
V14	1	1	0	1	+2Vdc
V15	1	1	1	0	+2Vdc
V16	1	1	1	1	+3Vdc

IV. SIMULATION RESULTS

Simulation results can be depicted using MATLAB simulation software. The Fig.4 shows the 7L-ANPC simulation circuit. Fig 5 shows the output voltage waveform of 7L-ANPC and Fig 6 shows the THD value of 7L-ANPC under the harmonic analysis of fast fourier transform and THD value is around 21%. The THD value has been improved from its conventional method .

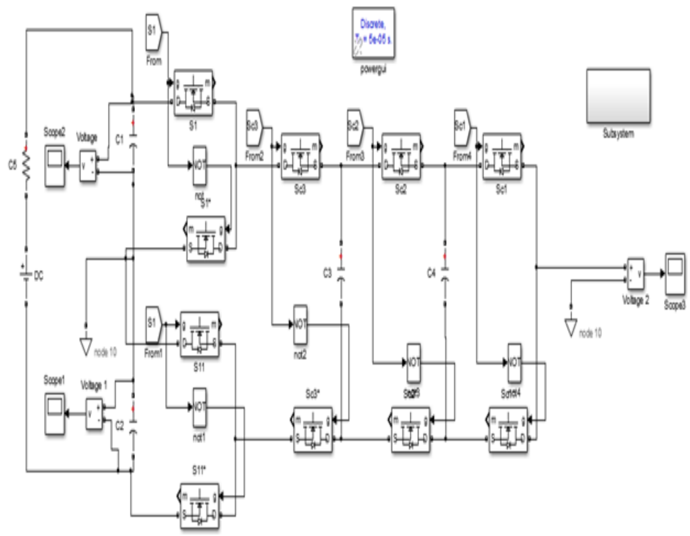

Fig 4: 7L-ANPC simulation diagram

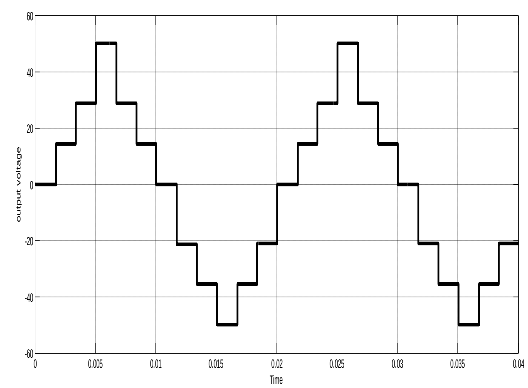

Fig 5 : Output voltages

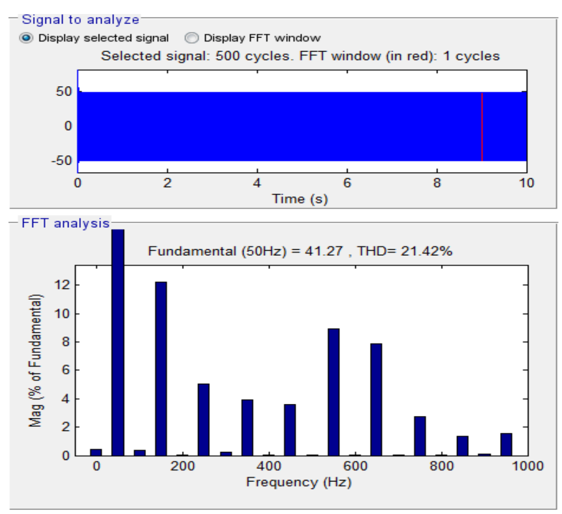

Fig 6: Harmonic Analysis

TABLE 3

Simulation results of seven level inverter

	7 level ANPC
THD	21%
Switches	10
Sources	1
Switching states	16

V. CONCLUSION

From this paper conventional 5 level FC-ANPC and proposed seven level FC-ANPC systems are discussed, and their harmonic values are compared. Total Harmonic Distortion for five level inverter output is 29% and THD value of seven level inverter is 21%. From this result, by increasing the number of level in the ANPC system will reduce the THD value. Simulation is simulated with MATLAB 12.0 and results are verified. Table 3 shows the simulation results of seven level ANPC system.

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