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Space Vector of Three Phase Three level Neutral Point Clamped Quasi Z Source Inverter

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Abstract-- Space vector of three phase three level neutral point clamped quasi z source inverter is proposed in this paper. Space vector modulation is the pulse width modulation consists of number of switching states. Space vector pulse width modulation technique utilizes 15% more power from DC source. Harmonics are reduced by the presence of switching states. Quasi Z-source inverter is advanced topologies which performs both boost and buck operation of a converter. The proposed inverter obtains continuous input current and the boost converter is not needed. So, maximum voltage can be obtained in the load and system complexity is reduced. Maximum power can be obtained from the solar panel by using MPPT. The implementation of MPPT is to operate a PV array under constant voltage and power reference to modify the duty cycle of the inverter.The simulation of proposed topology is done in MATLAB/SIMULINK software.

Index Terms- Solar Photovoltaic (PV), Maximum Power Point Tracking, Space Vector Modulation (SVM), Quasi Z-Source Inverter (QZSI).

1 INTRODUCTION

Renewable energy sources play an important role in electricity generation. Solar energy is the most readily available sources of energy. Through Solar Photovoltaic (SPV) cells, solar radiation gets converted into DC electricity directly. The photovoltaic voltage–current (V-I) characteristics is nonlinear and changes with irradiation and temperature. In general, there is a point on the V-I or voltage-power (V-P) curves, called the Maximum Power Point (MPP), at which PV operates with maximum efficiency and produces its maximum output power. The state of the art techniques to track the maximum available output power of PV systems are called the Maximum Power Point Tracking (MPPT). Controlling MPPT for the solar array is essential in a PV system [1].

The three level diode clamped also known as the neutral point clamped (NPC) inverter has become an established topology in medium voltage drives and is arguably the most popular certainly for three-level circuits. The quasi z source inverter (QZSI) is a single stage power converter derived from the Z-source inverter topology, employing a unique impedance network. [2]-[5] The conventional VSI and CSI suffer from the limitation that triggering two switches in the same leg or phase leads to a source short and in addition, the maximum obtainable output voltage cannot exceed the DC input, since they are buck converter and can produce a voltage lower than the DC input voltage.

Both Z source inverter and quasi-Z-source inverters overcome these drawbacks by utilizing several shoot-through zero states. A zero state is produced when the three or lower three switches are fired simultaneously to boost the output voltage. Sustaining the six permissible active switching states of a VSI, the zero states can be partially or completely replaced by shoot through zero states depending upon the voltage boost requirement. Quasi-Z-source inverters (QZSI) acquire all the advantages of traditional Z source inverter. The impedance network couples the source and the inverter to achieve a voltage boost and inversion in a single stage. By using this new topology, the inverter draws a constant current from the PV array and is capable of handling a wide input voltage range. It also features lower component ratings, reduces switching ripples to the PV panels and reducedsource stresscomparedto thetraditional ZSI. [3]-[7]

2 MAXIMUM POWER POINT TRACKING

This technique is used to obtain maximum power from the solar panel. The Power point tracker converts high frequency DCinto DC. It takes the DC input from the solar panels, transform it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the load. Operation of MPPT is very high audio frequencies, usually in the 20-80 kHz. The main advantage of high frequency circuits is that they can be designed with high efficiency transformers and small components.Many techniques have been developed to executeMPPT, these techniques are different in their effectiveness, speed, hardware implementation, popularity, cost. Widely used one of the most techniques in MPPT is P&O due to its easy implementation andsimple. In this technique the controller adjusts the voltage by a small quantity from the array and measures power; if the power increases, more adjustments in that way are tried until power no longer rises. This method is called the perturb and observe method and is most common, although this method can result in oscillations of power output.[6] It is referred to as a hill climbing method, because it depends on the rise of the curve of power beside voltage below the maximum power point, and the fall above that point. Observe and Perturb is the most generally used MPPT method due to its ease of realization. Perturb and observe method may result in top-level efficiency, provided that anappropriate predictive and adaptive hill climbing approach is adopted.

3 QUASI Z-SOURCEINVERTER

All the advantages of traditional Z- source inverter are present in Quasi Z-source inverters (QZSI). Some more advantages when compared to Z-source inverter are also there in proposed inverter such as continuous input current,reduced switching stress andlower component rating it can be used insolar pv applications or in fuel cells. QZSI couples the DC source and the inverter.

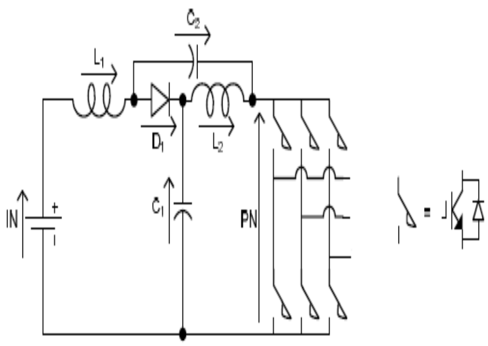

Fig. 1. Quasi Z source inverter

The single diode and LC network connected to the inverter circuitallows the shoot through stateand it modifies the operation. Once the shoot through statearises, this network will efficiently protect the circuit from damage. The proposed inverternetwork boosts the DC link voltage. PV array, battery,fuel cell, diode rectifier can be used as a DC source. In order to define the operating principle of the quasi Z source inverter, let us briefly examine the quasi Z source inverter structure shown in Fig.1.

The traditional three-phase V-source inverter has eightpermissible switching vectors (states) whereas the 3-phase 3-level quasi Z-source inverter bridge has nine. The three-phase V-source inverter has six active vectors while the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, correspondingly. [2],[3].

3.1 NON SHOOT THROUGH MODE

The QZSI switching pattern is similar to the VSI in the Non shoot through mode (Active mode). The DC link voltage is the input DC source voltage and the DC link voltage input is given to the inverter. The active mode equivalent circuit is shown in Fig.2.

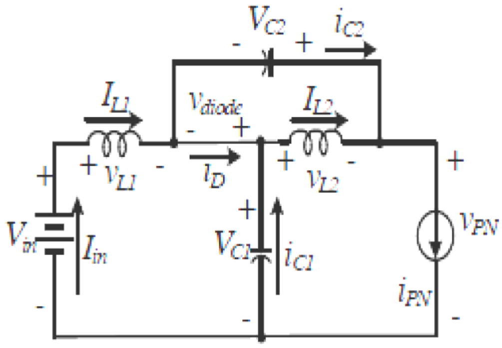

Fig.2. Non Shoot through mode equivalent circuit

3.2SHOOT THROUGH MODE

In shoot through mode, the switches of the same phase leg in the inverter are turned on instantaneously. On the time of shoot through state the output voltage become zero, the source cannot get shorted due to LC network, which offers boost capability. In the shoot through state, the DC link voltage boosted by a boost factor and its value depends onmodulation indexand shoot through duty ratio. The shoot through mode of QZSI equivalent circuit is shown in Fig. 3.

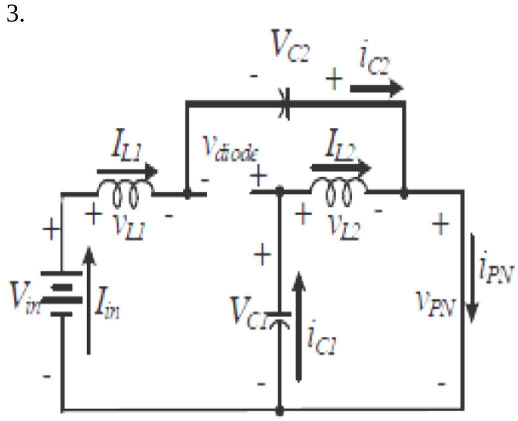

Fig.3. Shoot through mode equivalent circuit

During one switching cycle, T, the Shoot through state intervalis assumed as T_0 and the non-shoot-through state interval as T_1so one has $T = T_0 + T_1$ and the shoot-through duty ratio, $D = T_0 / T_1$. Through the interval of the non-shoot-through states, T_1

$$V_{L1}=V_{in}-V_{c1},\ V_{L2}=-V_{C2} \qquad (1)$$

During the interval of the shoot-through states, T0,

$$V_{L1}=V_{C2}+V_{in},\ V_{L2}=V_{c1} \quad (2)$$

$$V_{PN}=0,\ V_{diode}=V_{C1}+V_{c2} \quad (3)$$

At steady state, the average voltage of the inductors over one switching cycle is zero.

$$V_{PN} = V_{C1}-V_{L2} = V_{C1} + V_{C2} \quad (4)$$

$$V_{diode} = 0 \qquad (5)$$

By circuit analysis,

$$V_{c1} = \frac{1-D}{1-2D} V_{in} \; ; D = \frac{T_o}{T_s} (6)$$

T_0 - shoot- through timing per switching cycle; Ts – Time period of switching frequency.

In Non shoot-through mode,

$$V_{L2} = \frac{D}{1-2D} V_{in} (7)$$

The peak DC link voltage across the inverter bridge is expressed as

$$v_i = V_{c1} + V_{L2} \; (8)$$

$$v_i = \frac{1}{1-2D} V_{in} \; (9)$$

$$v_i = BV_{in} \; ; B = \frac{1}{1-2D} (10)$$

By converting the traditional zero states into shoot-through states we can obtain a higher output voltage in Quasi Z-source inverter without affecting output waveform quality.Though, the 3-phase quasi Z-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This particular shoot-through zero state (or vector) is not permissible in the traditional V-source inverter, as it would cause a shoot-through.

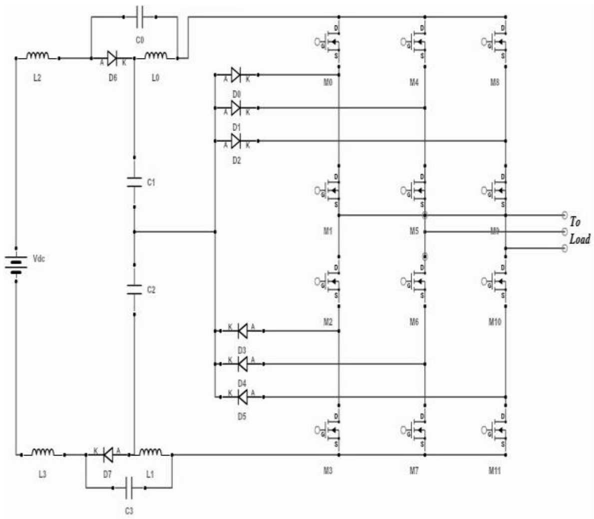

Fig.4. Topology of Quasi Z-source NPC Inverter

The third zero state (vector) is also known as the shoot-through zero state (or vector), which can be generated by three different ways such as shoot- through via any one phase leg, arrangements of any two phase legs, and all the three phase legs.

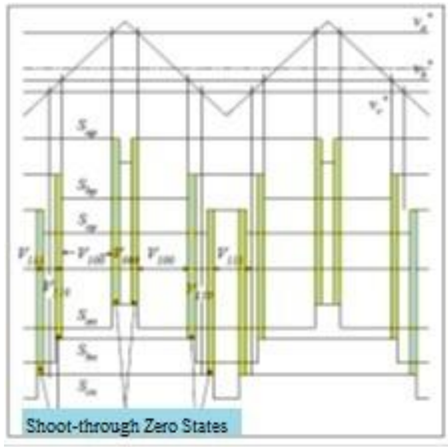

Fig. 5. Modified Carrier Based PWM With Shoot-Through Zero States

The quasi Z-source invertercan becontrolled byall the conventional PWM techniques and its theoretical connections maintains real. All switching cycle of the traditional PWM switching scheme based on the triangular carrier method has two non-shoot-through zero states along with two adjacent active states to synthesize the preferred voltage. The traditional PWM is used while the DC voltage is high enough to generate the desired AC voltage. In case the DC voltage is not sufficient to directly create a desired output voltage, a modified PWM with shoot-through zero states will be used to boost voltage as shown in Fig. 5. But,it is to be noted that each phase leg switches on and off, till once per switching cycle. Thereby, without changing the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. Hence, the active states are unchanged. On the other hand, the equivalent DC link voltage to the inverter is boosted because of the shoot-through states. Here it is noticeablethat the equivalent switching frequency viewed from the quasi Z-source network is three times the switching frequency of the inverter, thatsignificantly reduces the required inductance of the quasi Z-source network. [7],[8].

4 SPACE VECTOR PULSE WIDTH MODULATION CONCEPT

In Space Vector based PWM, a rotating voltage vector is used as the referencevoltage vector. In every sub cycle,Ts, voltage reference vector is sampled. Space Vector diagram for a three-level inverter shown in Fig.6.In two-level inverter the reference vector is given with the help of three voltage vectors.[9] In the three-level inverter each sector is again divided into 4 regions, specifying the output even more. The voltage vectors can be defined based on the magnitude:

- Zero Voltage Vectors (ZVV): V=0 (redundant switching states)
- Small Voltage Vectors (SVV): V_1, 4,7,10,13,16 (redundant switching states)
- Medium Voltage Vectors (MVV): V_3, 6,9,12,15,18.

- Large Voltage Vectors (LVV): V_2, 5,8,11,14,17.

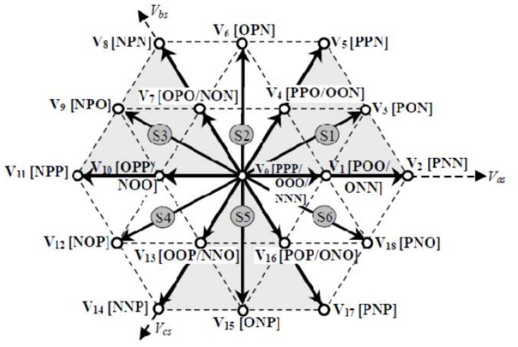

Fig.6. Space Vector diagram for a three-level inverter

4.1 TIME CALCULATION FOR EACH VECTOR

In the three levelNeutral Point Clamped (NPC) inverter, there are 27 switching states corresponding to 19 space vectors having fixed positions. These space vectors can be grouped into 4 namely, large voltage vectors (V_2, V_5, etc.) of magnitude 2VDC/3, medium voltage vectors (V_3,V_6, etc.) of magnitude VDC/√3, small voltage vectors (V_1, V_4, etc.) of magnitude VDC/3, and zero voltage vector (V_0) having zero magnitude. The plane can be divided into 6 major triangular sectors (S1 to S6) enclosed by large voltage vectors (solid lines) and zero voltage vector. Each major section represents 60° of the fundamental cycle and within each major sector, there are 4 minor triangular sectors (denoted as the dotted lines). In the plane,there are totally 24 minor sectors and the voltage vectors are represented as thevertices of these sectors. Each small voltage vectorshave 2redundant switching states andzero voltage vector has 3 redundant switching states., When the rotating voltage vectors falls into one certain sector in three-phase three-level inverter, the adjacent voltage vectors are chosen to synthesize the preferred rotating voltage vector based on the vector synthesis principle which results in generating three-phase PWM waveforms. By examining the magnitude of a rotating reference voltage vector $V_{ref}$and the phase angle, the sectorcan be easily located where in V_{ref}exists. Consider figure.7 of sector 1, suppose if the rotating vector falls in region three bounded by the vertices V_1, V_{13} and V_7, the vectorsV_1, V_{13} and V_7 are selected to synthesize V_{ref}. Here the duty ratios of these vectors are denoted as D_1, D_2 and D_3, correspondingly. The modulation law with a sequence of the nearest three vectors based on the volt–second product is then as follows:

$$D_1.V_1+D_2.V_7+D_3.V_{13}=V_{ref} \quad (12)$$

$$D_1+D_2+D_3=1 \quad (13)$$

Solving above equations,

$$D1 = 2 - 2 * m * (\cos\theta + \frac{\sin\theta}{\sqrt{3}}) \quad (14)$$

$$D2 = -1 + 2 * m * (\cos\theta - \frac{\sin\theta}{\sqrt{3}}) \quad (15)$$

$$D3 = 4 * m * (\frac{\sin\theta}{\sqrt{3}}) \quad (16)$$

The same way is used for calculating the duty ratios of the selected voltage vectors in all the other triangles. In order to complete the modulation process, the selected voltage vectors are applied to the output based on the switching sequence. At the same time, a switching sequence is formed in such a way that a high-quality output waveform is obtained with minimum number of switching transitions.

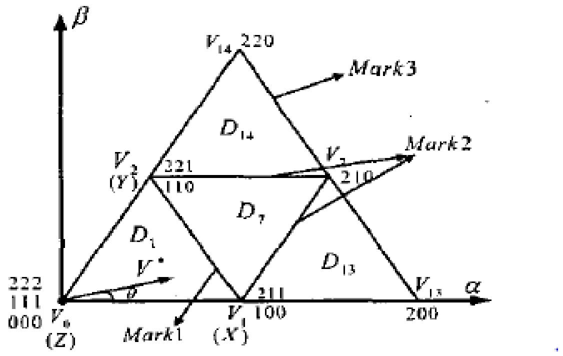

Fig.7. Space Vector Diagram of Sector 1

4.2 INSERTING SHOOT THROUGH STATE IN THE INVERTER

To achieve the minimal number of switchesthat changes between two adjacent states, a seven-segment switching sequence shown in Table I. is implemented in SVM. If the reference vector stay in triangle 3 shown in Fig.8. using the decomposition method, where the null state is shifted from{PPP/OOO/NNN} to {POO/ONN}, the Equivalent Null states are V_1 {POO} and V_1 {ONN}, while the Equivalent Active (E-Active) states are V_7 {PON} and V_{13} {PNN}, respectively.

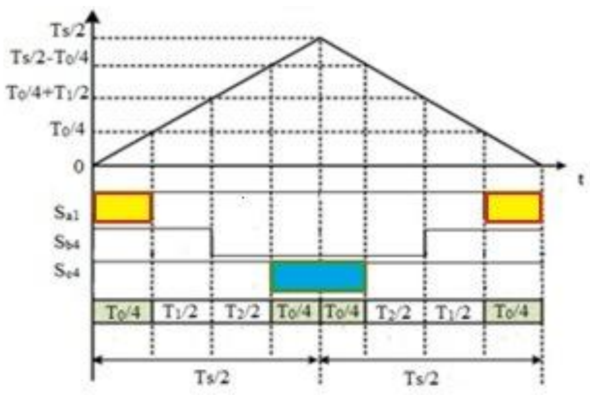

Fig.8. Implementation of Shoot through

The shoot through implementation using a seven segment table is shown in Fig.8. Theoretically, a shoot-through state can be introduced on any phase which is switched to the zero level (O) without affecting that phase voltage. However, the effect on the line-to-line voltages must also be considered. Instead of Full shoot-through which means a phase leg is completely shorted by turning on all the four switches, Upper (upper three switch turned-on) and Lower

(lower three switch turned-on) shoot-through states(UST and LST) are used to make shoot through as it produces an output voltage with enhanced waveform quality with minimum number of switching. Thisallowed shoot-through states are given in Table II and based on the above theory, simulation had been done in Matlab 7.1.

Table II

Permissible Shoot-through States

UPPER SHOOT-THROUGH	LOWER SHOOT-THROUGH
UNN	PLO
UON	POL
OUN	PPL
NUN	LPO
NUO	OPL
NOU	LPP
NNU	LOP
UNO	OLP
ONU	PLP

5 SIMULATION RESULTS

The quasi z source inverter topology is verified using MATLAB/SIMULINK. The input voltage of the Quasi Z source network is VDC=200V and L=7mH and C=1000 µF. The inductor and capacitor value are chosen based on the current ripple and voltage ripple. Quasi Z-source NPC inverter with voltage buck and boost capability is shown. The Specifications of the proposed system is shown in Table III.

Table III

Specifications Of the Proposed System

PARAMETERS	VALUE
INPUT VOLTAGE	200V
DUTY RATIO	0.29
L_1,L_2	7Mh
C_1,C_2,C_3,C_4	1000 µF
SWITCHING FREQUENCY	3-5KHZ
MODULATION INDEX	0.7

The proposed control circuit model is shown in Fig.9. The input voltage given V_{DC}=200V. The output boosted voltage obtained is 300V. The output voltage of Quasi Z source inverter is shown in Fig.10.

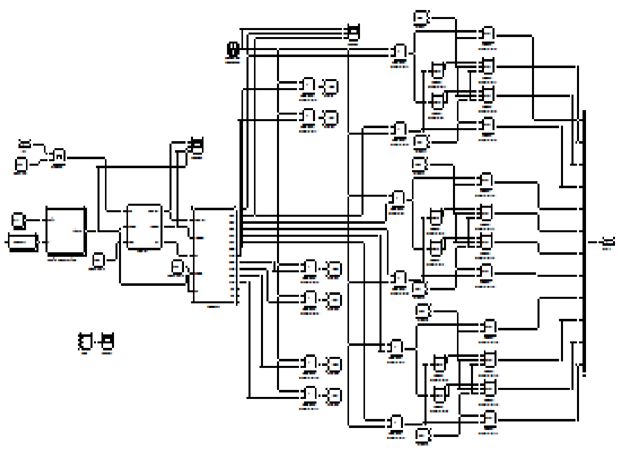

Fig.9. Model of the Control Circuit

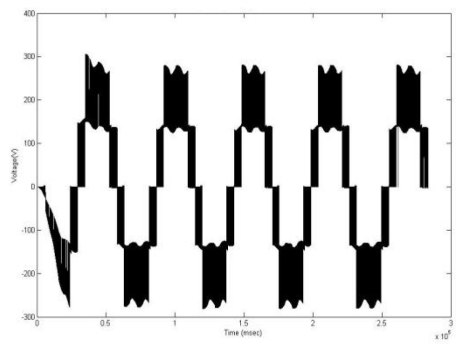

Fig.10. Quasi Z-Source inverter Output Voltage waveform

The input current of the Quasi Z source inverter is shown in Fig.11. The input current is continuous.

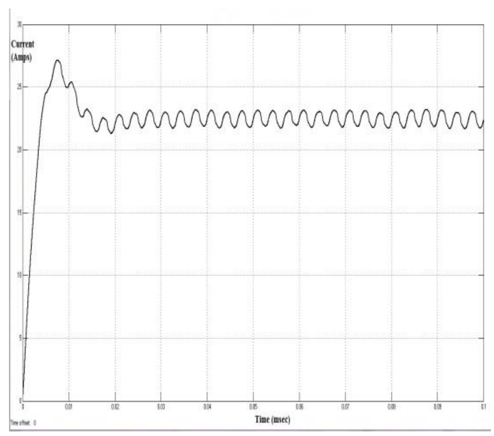

Fig.11. Quasi Z-Source inverter Input Current waveform

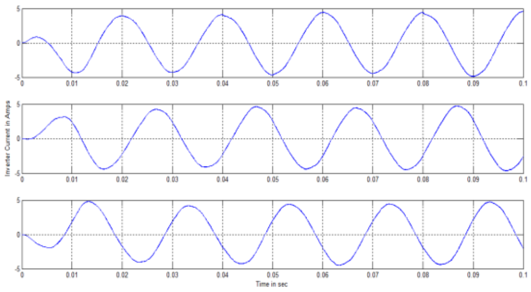

Fig.12. Quasi Z-Source inverter Output Current waveform

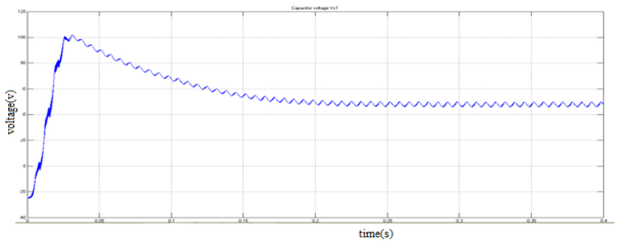

Fig.13. Capacitor voltage V_{C1}

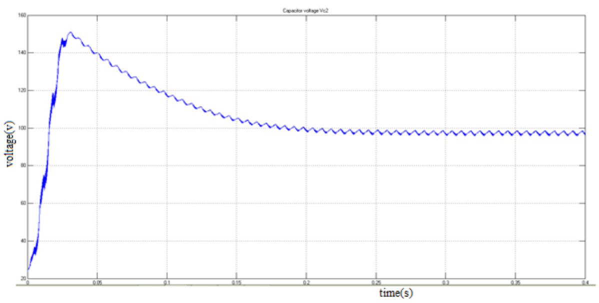

Fig.14. Capacitor voltage V_{C2}

Fig.15. represents the MPPT voltage waveform. It increases to 300v and maintains in the constant value.

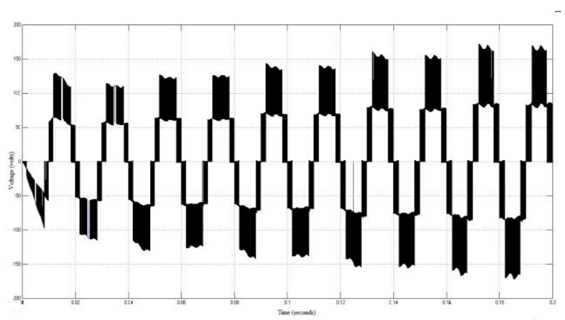

Fig.15. MPPT Voltage waveform

PV Panel output power waveform is shown in Fig.16. The power increases up to 600 watts.

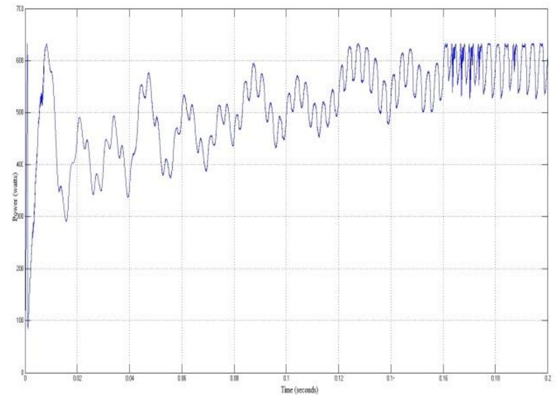

Fig.16. PV Panel Output Power waveform

The temperature and irradiance of the PV panel is shown in Fig.17. The irradiance is based on the amount of sunlight falls on the panel. And the temperature increase baeds on the irradiance.

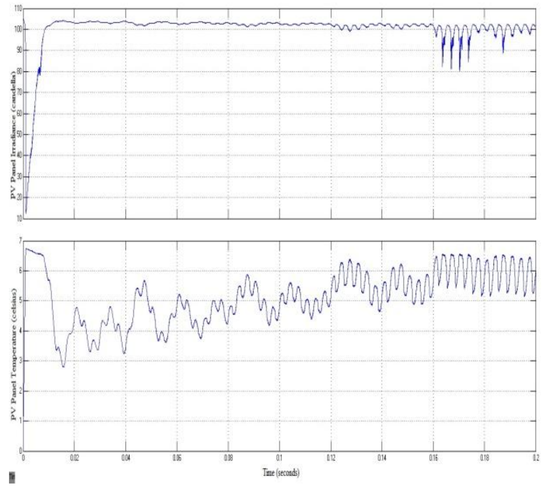

Fig.17. PV Panel Irradiance and Temperature waveform

Fig.18. shows tha THD waveform of the proposed inverter. The THD value is 2.59% i.e less than 5%.

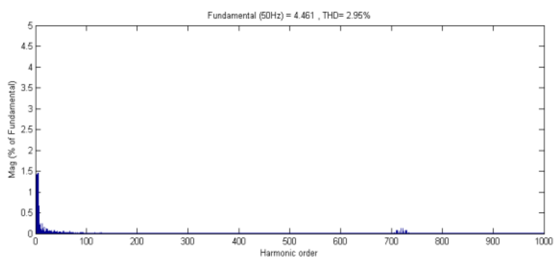

Fig.18. THD waveform

6 CONCLUSION

In the traditional NPC inverter, by carefully inserting LST and UST states maximum output voltage is obtained. Insertion of shoot through zero state improves the efficiency and the output voltage is improved with respect to constant output current. Total harmonic distortion occurred in the system due to the switching states is also reduced to less than 5%. Switching stress is low because numbers of switches are more. Low rating switches can be used to operate under high voltage conditions.

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