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Simulation of Single Phase 3-level Z-source NPC Inverter with PV System

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Abstract

This paper elucidates simulation of single phase 3-level z-source neutral point clamped (NPC) inverter with PV system. single phase NPC inverter employed due to its advantages like less voltage stress, reduced harmonic content, minimsed CMV and voltage stress is low. Z-source network is engaged to boost input voltage getting from the photovoltaic system, which is manoeuvre in shoot through and non-shoot through conditions. This proposed scheme utilized to enhance the output voltage, minimise THD and the leakage current can be avoided with help of split inductor connected with output of inverter system. sinusiodal pulse width modulation (SPWM) used as control technique for the proposed 3-level z-source NPC inverter. The simulation results of this scheme has been verified using matlab/simulink.

Keywords*: sinusiodal pulse width modulation (SPWM), -level z-source neutral point clamped (NPC) inverter, Z-source network, photovoltaic (PV) system*

1. Introduction

Electrical energy plays an imperative role in our daily life actions. Due to industrial and urbanisation increases the energy demand also increases day by day. The major causes for energy generations are coal, petroleum, gases and other things starts exhausting everyday [1]. So to meet the power demand of world, other alternative sources or renewable sources has to be developed. Photovoltaic system (PV) has less geographical restrictions compare to the non conventional energy sources, which accessible over the whole world [2]. Nowadays PV system source become more promising renewable energy source due to its availabilty and advantages [3]. PV system is the translation of incident solar light radiation to electrical energy source, which is the most exploitable outline of energy. This can be accomplished with the help of solar photovoltaic cell unit or with absorbed solar power plants. The grid connected solar scheme does not necessitate a battery, because the grid system can accumulate the power engendered by the PV array unit [4].

Generally inverter circuit is used to convert dc source into ac source. While using multilevel inverter circuit, which includes advantages like reduced EMI problems, minimsed capacitor balancing and common mode voltage, reduce the voltage stress and switching loss. And z-source network used to boost input voltage, which evades the tradition of dc-dc boost converters [5]. Split inductor neutral point clamped multilevel inverter evades the usage of transformer for connecting the inverter with grid system [6]. O. Lopez at el [7] while using transformer, leakage current should be escalating in the system, which causes grid current distortion and safety problems.

Topologies without a transformer generally have lower cost, size, and weight than topologies with transformers [8]. In transformerless PV systems that use the connection between the neutral of the grid and the central point of the dc link, the leakage currents have low values because the potential between the PV array and the ground is constant [9]. Power electronic converters are contolled by various PWM schemes like sinusoidal PWM, Space vector modulation, hysteresis contol, multicarrier sinusoidal PWM and nearest state vector sechem. Among these methods, every method has their own merits and demerits [10]. Based on these control schemes harmonic content of converter is minimised and shoot through states of z-source inverter also controlled.

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This proposed scheme gives simulation of single phase transformerless 3-level z-source neutral point clamped (NPC) inverter with PV connected system. In that z-source network utilised to boost input voltage arriving from the PV system. the various modes of opertion of z-source 3-level NPC inverter with shoot and non-shoot through state conditions are discussed. and the system has been controlled using sinusoidal pulse width modulation.

2. PV System Modelling

A photovoltaic (PV) cell unit or photoelectric cell unit is a power semiconductor device that exchanges light energy source to electrical energy source by PV effect condition [10]. If the energy source of photon of light is greater to the band gap subsequently the electron is unrestricted and the electron flow generates current source. Nevertheless a photovoltaic cell unit is divergent from a photodiode unit [11]. In a photodiode unit light source falls on n-channel semiconductor junction point and obtain renewed into current or voltage signal but a photovoltaic cell unit is forever forward biased condition [12], [13]. Figure 1 shows PV array modelling circuit

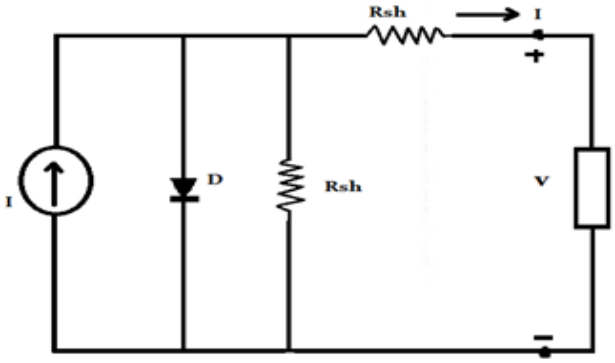

Figure 1. PV array modelling circuit

A PV array unit contains of abundant photovoltaic cells in series connections and parallel connections. Series associated schemes are responsible for escalating the voltage of the system while the parallel connected schemes are accountable for escalating the current in the system [15]. In generally a solar cell scheme can be premeditated by a current source and an inverted diode allied in parallel to system. It has its own series resistance and parallel resistance to progress the system voltage and current [16]. Series resistance is due to obstruction in the path of electrons flow from n-channel semiconductor to p-channel semiconductor junction point and parallel resistance is due to the leakage current, the system output current from the photovoltaic array unit depends on,

$$I = I_{scg} - I_{dd} \quad (1)$$

$$I_d = I_p(e^{yv_{dd}/wQ}\text{-}1) \quad (2)$$

Where I_p is the reverse saturation current of the diode, y is the electron charge, V_{dd} is the voltage across the diode, w is Boltzmann constant and Q is the junction temperature, from equations 1 and 2.

$$I = I_{scg} - I_p(e^{\frac{yv_{dd}}{wQ}} - 1) \quad (3)$$

$$I = I_{scg} - I_p(e^{q(\frac{V+IR_s}{nwQ})} - 1) \quad (4)$$

In instruct to representation the solar panel unit, it necessitates two diode scheme models but in the projected performance, it is inadequate to the single diode model. Also, the shunt resistance is very elevated and can be deserted during the path of the discussion [13].

3. 3-level Z-source NPC Inverter

The neutral point clamped multilevel inverter has expanded greatly additional concentration in modern years and is extensively established by researchers today, which is also called as diode clamped multilevel inverter. It generates staircase output volatege levels, which is depends on dc link capacitors. Figure 2 shows circuit of single phase 3-level z-source NPC inverter

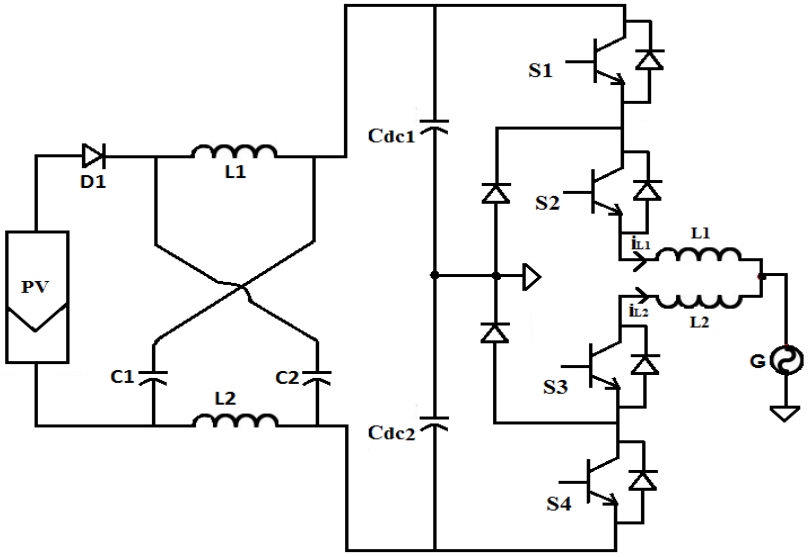

Figure 2. Circuit of single phase 3-level z-source NPC inverter

Generally when using transformer for synchronising 2 systems, which leads to more cost, bulky in size and more leakage current, these are evading by the use of coupled inductor, which can do the same function of transformer.

a. Modes of operation

Single phase 3-level z-source neutral point clamped (NPC) inverter with PV system can be operated using shoot through and non shoot through condition. While using shoot through condition, the output voltage can be boosted 2 times of applied input voltage.

b. Non shoot through condition

The operation of single phase 3-level z-source neutral point clamped during non shoot through condition its acting as typical NPC inverter. During this process the output voltage of inverter is less than the input voltage.

The inverter can operate in 3 differnet switching conditions like when top 2 switches are ON the output voltage Vo=+Vdc/2, when bottom 2 switches are ON the output voltage Vo=-Vdc/2 and when middle 2 switches are ON the output voltage Vo=0, which is shown in Figure 3a, 3b & 3c respectively and Modes of operation during non shoot through conditions are shown in Table 1.

Table 1. Modes of Operation during non Shoot through Condition

Different Modes	Switches Position	Output voltage (Vo)
Mode 1	S1, S2 ON & S3,S4 OFF	Vo=+Vdc/2
Mode 2	S3, S4 ON & S1,S2 OFF	Vo=-Vdc/2
Mode 3	S2, S3 ON & S1, S4 OFF	Vo=0

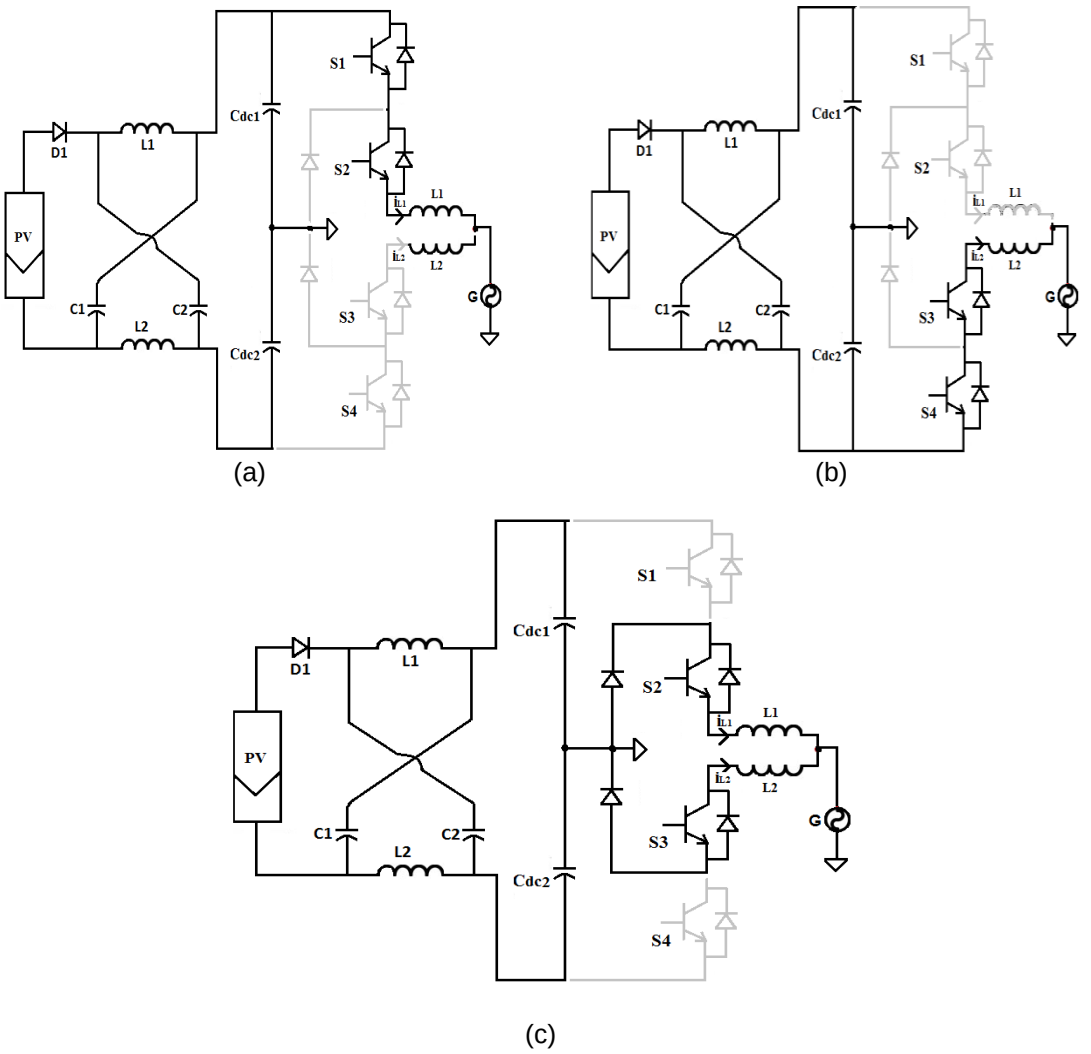

Figure 3. Non-shoot through states of proposed system (a) Mode1 Vo=+Vdc/2 (b) Mode2 Vo=-Vdc/2 (c) Mode3 Vo=0

c. Shoot through condition

The main disadvantage of traditional 3-level NPC inverter is all switches placed in a leg cannot switched ON simultaneously. But during shoot through condition, all the switches in a leg can be switched ON with damaging any power semiconductor switches. The input supply will cut off, when the diode is reverse biased condition and at this time the capacitor and inductor placed in z-source network starts to discharging.

Then during next mode both input source and capacitor charged voltages adding to boost the output voltage of the inverter circuit. The shoot through states of single phase 3-level NPC inverter has operated in 3 modes of operation, in that when all switches S1, S2, S3 & S4 are switched ON (full shoot through), when top 3 switches S1, S2 & S3 are switched ON (upper shoot through) and when lower 3 switches S2, S3 & S4 are switched ON (lower shoot through), which is shown in Figure 4a, 4b & 4c respectively. Modes of operation during shoot through condition is shown in Table 2.

Table 2. Modes of Operation during Shoot through Condition

Different Modes	Switches Position	Condition
Mode 1	S1, S2, S3 ON S4 OFF	Upper shoot through
Mode 2	S1, S2, S3, S4 ON	Full shoot through
Mode 3	S1, S2, S3, S4 ON	Lower shoot through

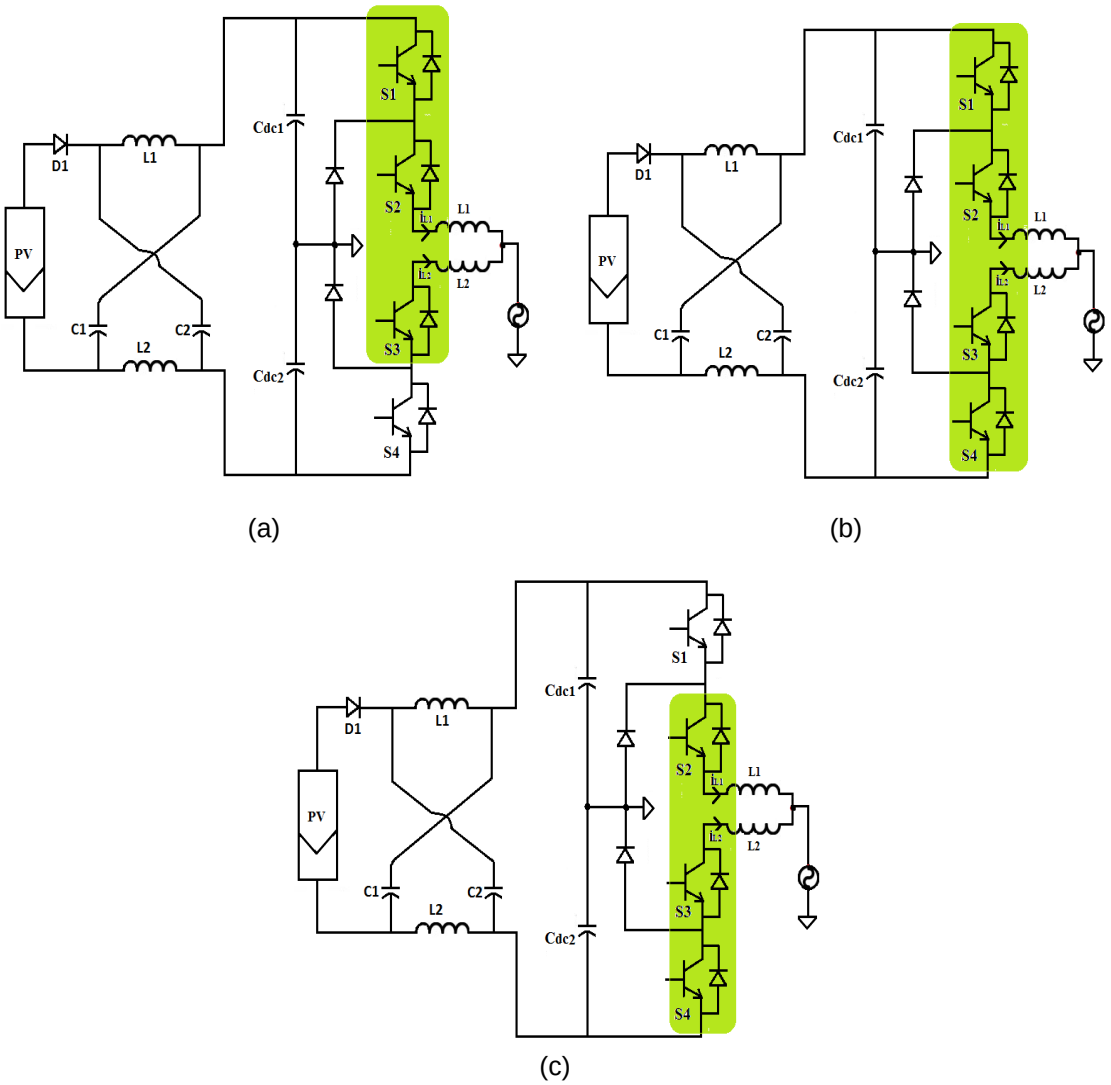

Figure 4. Shoot through states of system (a) mode1 upper shoot through, (b) mode2 Full shoot through, (c) mode3 lower shoot through

4. Sinusoidal PWM (SPWM)

Among various pulse width modulation (PWM) schemes sinusoidal Pulse Width Modulation (SPWM) method is one of the method to control power semiconductor devices, which engender the switching pulses by evaluating the reference signals (sinusoidal) with carrier signals (triangular). At this point the sinusoidal waveform perform as reference signal and triangular waveform perform as carrier waveform, by comparing these above two signals the obligatory switching pulses created. Every switching pulse thickness assorted direct proportionally to the amplitude of the sinusoidal wave measured at the interior of the equivalent pulse is shown in Figure 5.

The output frequency (fo) of the Z-source inverter can be ascertain by using the frequency of the reference signal (fr). The rms output voltage (Vo) can be inhibited by modulation index (M) and in turn modulation index is controlled by peak amplitude (Ar). The voltage can be embarrassed by the generate gating pulses from the controller. The number of pulses per half cycle depends on the carrier frequency.

$$M_a = \frac{V_{ref}}{V_{car}}$$

Where, Vref–Maximum amplitude of reference sinusoidal control signal, Vcar- Maximum amplitude of carrier triangular signal.

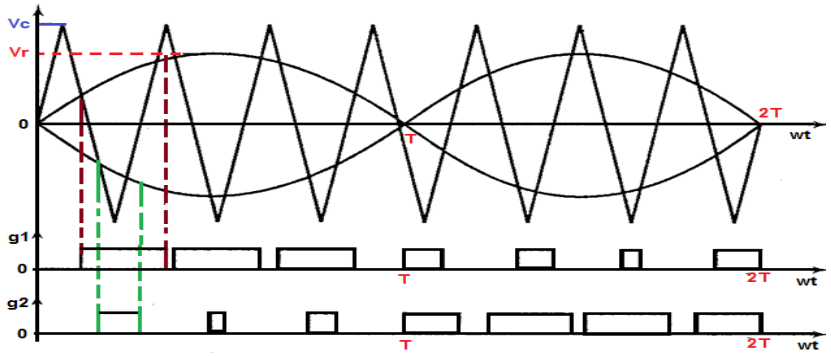

Figure 5. Switching pulse generation using SPWM scheme

5. Simulation Results and Discussion

The recital of the single phase 3-level z-source neutral point clamped (NPC) inverter with PV system authenticated by using MATLAB simulation under different PV array operating situations. The performance of the system is tested with various solar radiations from 400W/m^2 to 800W/m^2 and various temperatures (0-38) C. And z-source NPC inverter operated under shoot through and non shoot through mode conditions.

Figure 6 shows the electric power generation using photovoltaic system, which is obtained maximum as 700W, which 98 V generated from PV system. This generated PV voltage is boosted as 160 V with help of z-source network, which is shown in Figure 7 and output voltage of 3-level z-source NPC inverter under is 157.1 V, which is operated under shoot through & non shoot through conditions is shown in Figure 8. In Figure 9 shows output current of 3-level z-source NPC inverter with photovoltaic system.

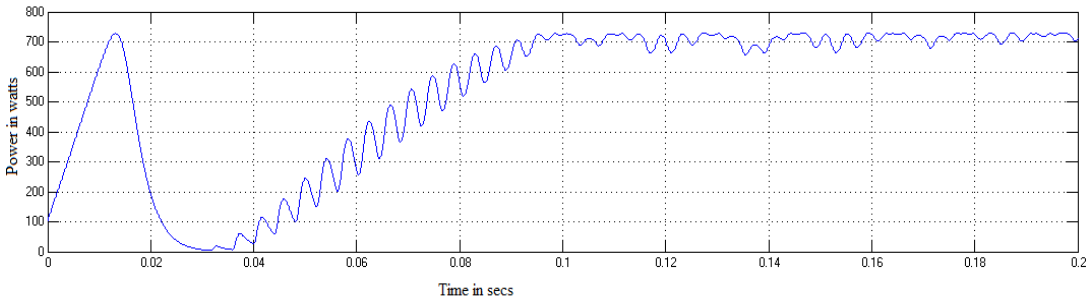

Figure 6. Electric power generation using photovoltaic system

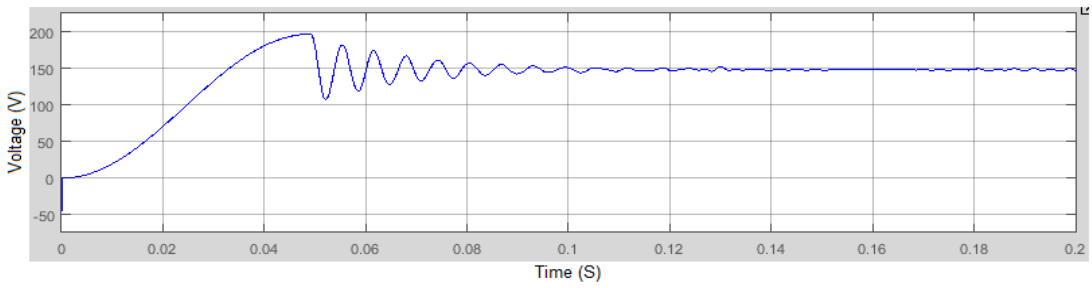

Figure 7. Boosted input voltage using z-source network

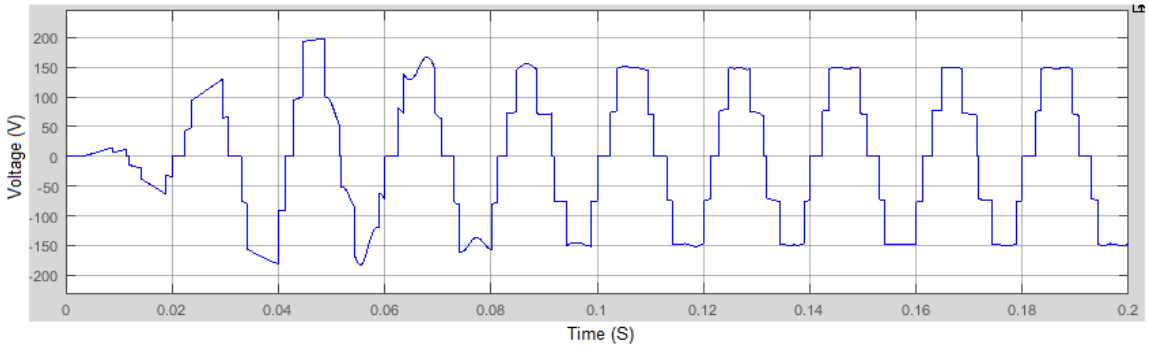

Figure 8. Output voltage of 3-level z-source NPC inverter

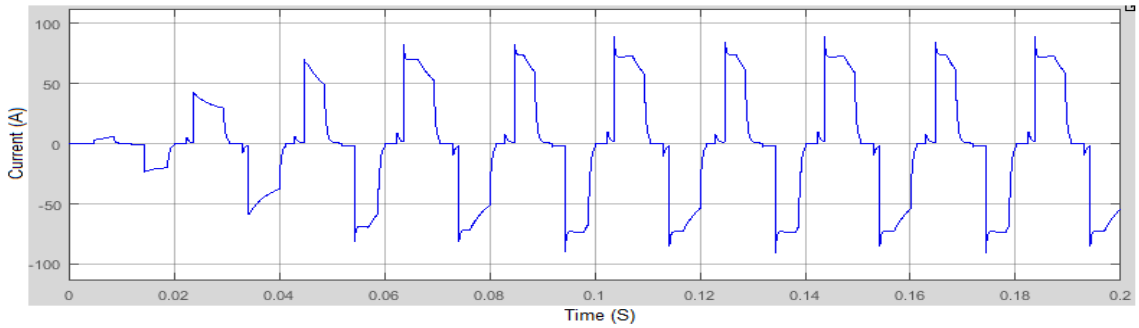

Figure 9. Output current of 3-level z-source NPC inverter

In Figure 10 shows harmonic analysis for voltage of 3-level z-source NPC inverter, which minimised up to 20.78 % with fundamental voltage magnitude of 157.1 V. And Figure 11 shows the switching pulse generation using SPWM to control proposed NPC inverter power switches. And the staircase output voltage from NPC inverter is synchronised with ac load or ac applications through coupled inductor, which is shown in Figure 12.

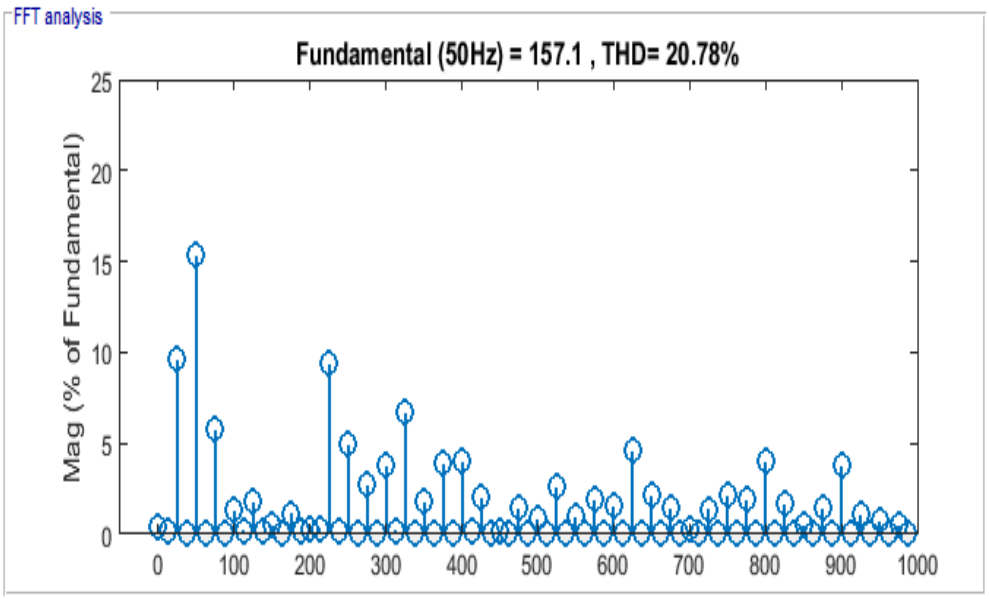

Figure 10. Harmonic analysis for voltage of 3-level z-source NPC inverter

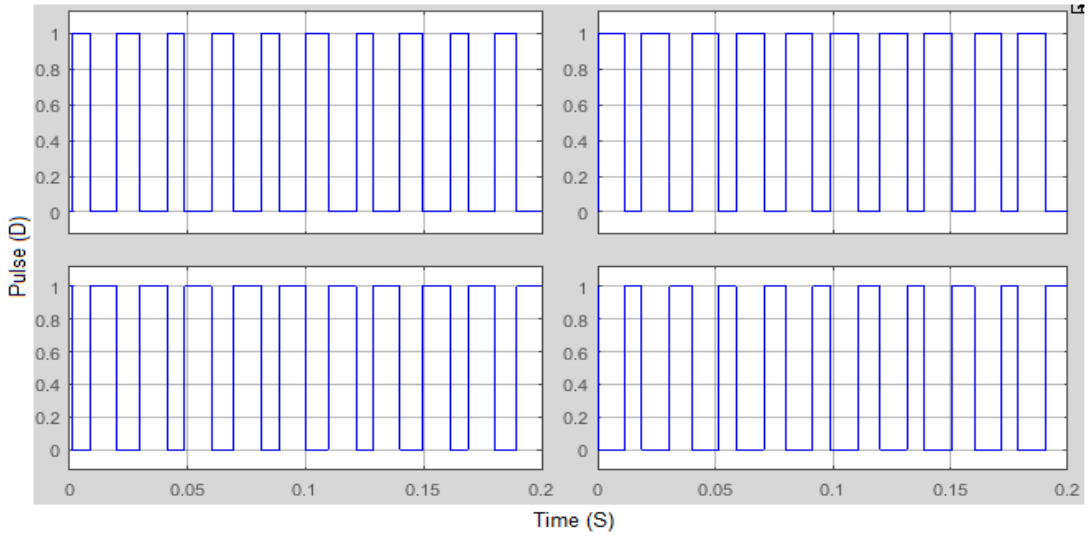

Figure 11. Switching pulse generation using SPWM

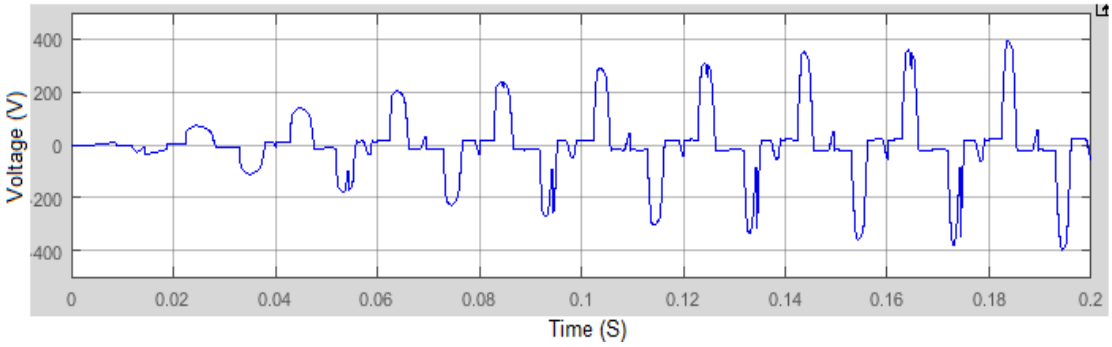

Figure 12. Output voltage of 3-level z-source NPC inverter with split inductor

6. Conclusion

This projected method furnishs simulation of single phase coupled inductor based 3-level z-source neutral point clamped (NPC) inverter with PV connected system. z-source network used to boost input voltage from the photovoltaic system, which is operted under shoot through and non shoot through state conditions. Based on this proposed scheme the THD is minimised and output voltage improved. The simulation results of the projected scheme verified using matlab/simulink tool. The following results are obtained from the projected scheme,

a. Using z-source network the PV system voltage is boosted from 98V to 160 V.
b. THD of proposed system is 20.78% with variable PV system.
c. Coupled inductor is used to synchronise with ac load or ac applications, which avoids leakage current problem and economically good system.

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