SOLAR POWERED MOTOR APPLICATION WITH Z-SOURCE INVERTER

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ABSTRACT

With the increased usage of renewable energy resources, it is essential to efficiently use the energy produced from them. Such energy can be produced using solar panels as the solar energy is very abundantly available. This paper is to achieve high converter conversion efficiency, reduced switching and conduction losses, reduced transformer winding losses, reduced EMI in low-voltage high-power isolated boost DC-DC converter using Z-Source converter. The Impedance Source (Z-source) Power Converter performs both buck and boost conversion and one of DC/DC, AC/DC, DC/AC or AC/AC conversion. The converter efficiency is increased with less stresses on the motor and increase in the output power while maintaining the desirable traits of prior converters (Voltage Source Converter, Current Source Converter). MATLAB/Simulink is used to simulate the experiment.

Keyword : - *Renewable Energy, Solar Energy, Z-Source, Voltage Source Converters, Current Source Converters.*

1. INTRODUCTION

Renewable energy includes solar energy, wind energy, bio-fuel, geothermal energy, hydrogen and fuel-cells, etc. These energy sources are renewable and utilization of these energy sources creates zero or little emissions. Due to environmental concerns, more effort is now being put into clean distributed power like geothermal, wind power, fuel cells, and Photo Voltaic (PV) that directly uses the energy to generate electricity. Distributed Generation (DG) systems using renewable energy have great potential to increase the grid reliability.

Currently, renewable energy systems are still relatively expensive and therefore the cost is higher than using fossil fuel. For this reason, renewable energy sources have captured only a small share of the total energy market. However, with the continued development of technology, the cost of photovoltaic cells is decreasing steadily and it will become more cost effective. Therefore, one can foresee a large future market for Photo Voltaic (PV) systems [1]. As people are much concerned with the fossil fuel exhaustion and the environmental problems caused by the conventional power generation, renewable energy sources and among them photovoltaic panels and wind-generators are now widely used. Photovoltaic sources are used today in many applications such as battery charging, water pumping, home power supply, swimming-pool heating systems, satellite power systems etc. They have the advantage of being maintenance and pollution-free.

To efficiently use PV systems, they are the most expensive part of the power generation system. Reducing cost, increasing efficiency and improving reliability of power electronics are the technical challenges facing wider implementation of PV power generation.

This paper presents a Z-Source Inverter [2] system and control for DC motor drives. The Z-source inverter system employs a unique LC network in the dc link. By controlling the shoot-through duty cycle, the Z-Source can produce any desired output AC voltage, even greater than the line voltage. As a result, the new Z-source inverter system provides ride-through capability during voltage sags, reduces line harmonics, improves power factor and reliability, and extends output voltage range.

Operating DC motors from photovoltaic solar panels comes with some requirements in order for the motors to operate efficiently. DC motors require a stable power supply, which can only be achieved by installing some sub-systems into the overall motor system.

Fang Zheng Peng. suggested Z-source converter employs a unique impedance network to couple the converter main circuit to the power source, thus providing unique features that cannot be observed in the traditional voltage-source and current-source converters where a capacitor and inductor are used, respectively.

Miaosen Shen, Alan Joseph, Jin Wang, Fang Zheng Peng, Donald. J. Adams compared Traditional Inverters with the Z-Source Inverter. The comparison results show that the Z-source Inverter has better conversion efficiency than the two existing systems. It can also minimize stresses and size of the motor and increase output power greatly. Along with these promising results, the Z-source Inverter offers a simplified single stage power conversion topology and higher reliability because the shoot-through can no longer destroy the inverter. The existing two inverter systems suffer the shoot through reliability problem. The Z-source Inverter was found to be very useful for fuel cell vehicles.

R. Samuel Rajesh Babu, Joseph Henry proposed DC-DC converter achieved high efficiency in low-voltage high-power isolated boost DC-DC converter. High-power low-voltage transformers required an extensive interleaving of windings to keep AC resistances low. Extremely low primary leakage inductances were achieved, allowing the dissipation of stored leakage energy. The proposed converter had advantages such as fast current switching, low parasitic circuit inductance, high efficiency, reduced switching losses, reduced switching stresses, reduced EMI, increased power density.

2. BLOCK DIAGRAM

The source of DC power in the above block diagram is a Solar Panel. Direct current (DC) is generated in the panels. The Solar Panels have arrangement to store the power generated in the connected batteries. This setup could be very useful during conditions or times when there is not enough sunlight. Such conditions could arrive because of rainy or cloudy conditions or during night.

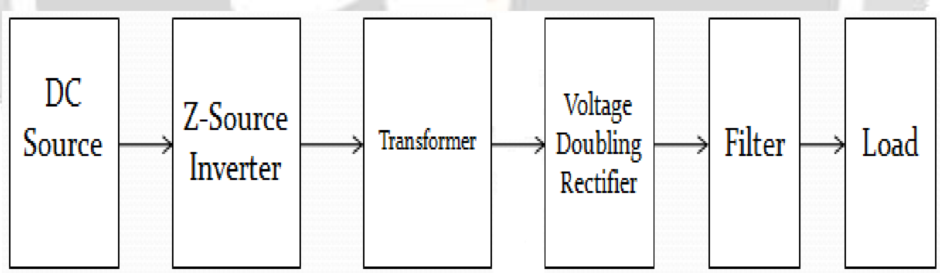

Fig- 1 Block Diagram of Renewable Energy using Z-Source

The Z-Source (impedance-source or impedance-fed) power converter performs both boosting of voltage and DC-to-AC power conversion in a single stage. Both boosting of voltage and DC-to-AC conversion in a single stage is the main attraction of a Z-Source converter.

The Transformer provides isolation to the components in the secondary side from getting damaged, if any problem arises.

The Rectifier converts back from AC-to-DC. A voltage-doubling rectifier includes an AC full-bridge diode rectifier and a DC-to-DC converter having two output boost circuits. One of the output boost circuit is coupled with the rectifier and a DC link, and the other boost circuit is coupled, with opposite polarity, between the rectifier and the circuit common. Two series-connected filter capacitors are also coupled between the DC link and the circuit common. In a preferred embodiment, the two output boost circuits each compromise either a series, parallel, or a combination series/parallel resonant circuit and a rectifier, A switch is coupled between the junction joining one pair of diodes of the rectifier and the junction joining the two filter capacitors. For a relatively high AC line voltage, the switch is open, and the circuit operates in a high boost, or voltage-doubling mode.

After the conversion of AC-to-DC there are still some elements of AC left or present. A simple capacitive filter is used to remove the leftover AC. The simple capacitor filter is the most basic type of power supply filter. The application of the simple capacitor filter is very limited. It is used on extremely high-voltage, low-current power supply. The capacitor filter is also used where the power-supply ripple frequency is not critical. After the filtration DC is allowed to pass through and then it is fed to the load (DC Motor). This then serves its purpose for high power applications.

3. CIRCUIT DIAGRAM

3.1 DC Source (Solar Panel)

Commonly called solar panels, photovoltaic cells are the heart of any solar power supply system. A photovoltaic system typically includes an array of solar panels. The use of solar powered motors reduces greenhouse gas emissions, which leads to the global warming phenomena, especially when the application is used in an industrial, manufacturing environment. The electricity produced depends greatly on the efficiency of the cells and the availability of direct sunlight.

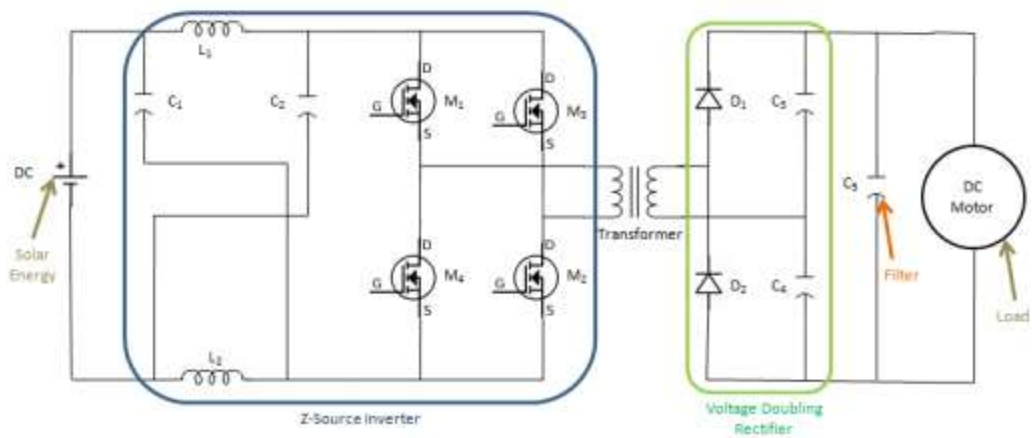

Fig- 2 Circuit Diagram of Renewable Energy using Z-Source

3.2 Z-Source Converter

It consists of a split-inductor L1 and L2 and capacitors C1 and C2 connected in X-shape is employed to provide an impedance source coupling the converter (or inverter) to the dc source, load, or another converter. The dc source can be either a voltage source or a current source or load. Similarly, the load can be either a voltage source or a current source or load. Therefore, the dc source can be a battery, diode, rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes. The inductance L1 and L2 can be provided through a split inductor or two separate inductors. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the PV voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional Voltage Source and Current Source Inverters cannot provide such feature.

For the traditional Voltage Source Inverter, the dc capacitor is the sole energy storage and filtering element to suppress voltage ripple and serve temporary storage. For the traditional Current Source Inverter, the dc inductor is the sole energy storage/filtering element to suppress current ripple and serve temporary storage. The Z-source network is a combination of two inductors and two capacitors. This combined circuit, the Z-source network is the energy storage/filtering element for the Z-source inverter. The Z-source network provides a second-order filter and is more effective to suppress voltage and current ripples than capacitor or inductor used alone in the traditional inverters. Therefore, the inductor and capacitor requirement should be smaller than the traditional inverters.

When the two inductors (L1 and L2) are small and approach zero, the Z-source network reduces to two capacitors (C1 and C2) in parallel and becomes a traditional Voltage Source Inverter. Therefore, a traditional Voltage Source Inverter's capacitor requirements and physical size is the worst case requirement for the Z-source network. Considering additional filtering and energy storage provided by the inductors, the Z-source network should require less capacitance and smaller size compared with the traditional Voltage Source Inverter.

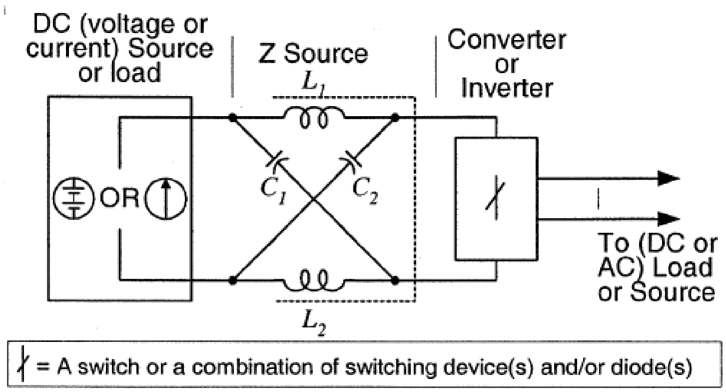

Fig- 3 General Structure of the Z-source Converter

Similarly, when the two capacitors (C1 and C2) are small and approach zero, the Z-source network reduces to two inductors (L1 and L2) in series and becomes a traditional Current Source Inverter. Therefore, a traditional Current Source Inverter's inductor requirements and physical size is the worst case requirement for the Z-source network. Considering additional filtering and energy storage by the capacitors, the Z-source network should require less inductance and smaller size compared with the traditional Current Source Inverter [2].

3.3 Voltage Doubling Rectifier

A voltage doubler is an electronic circuit which charges capacitors from the input voltage and switches these charges in such a way that, in the ideal case, exactly twice the voltage is produced at the output as at its input. The simplest of these circuits are a form of rectifier which take an AC voltage as input and output a doubled DC voltage. The switching elements are simple diodes and they are driven to switch state merely by the alternating voltage of the input. The Delon circuit uses a bridge topology for voltage doubling. This form of circuit was, at one time, commonly found in cathode ray tube television sets where it was used to provide an extra high voltage supply. The circuit consists of two half-wave peak detectors. Each of the two peak detector cells operates on opposite half-cycles of the incoming waveform. Since their outputs are in series, the output is twice the peak input voltage.

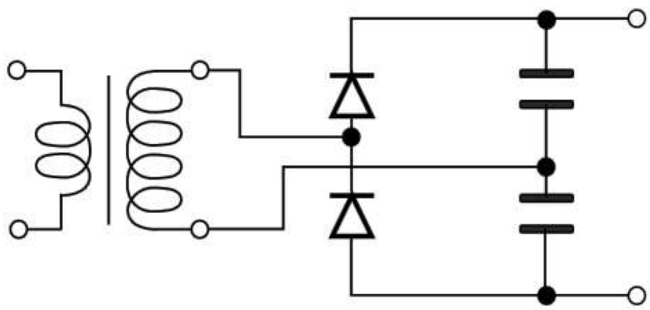

Fig- 4 Delon Circuit

4. METHODOLOGY

The Z-source inverter has the unique feature that it can boost the output voltage by introducing shoot through operation mode, which is forbidden in traditional voltage source inverters. The Z-source inverter outputs a required voltage by adjusting the shoot through duty cycle with the restriction to keep the voltage across the switches not to exceed its limit.

For the Z source inverter, the current through the inverter switches consists of two elements, one is the current to the load and the other is the current through them during the shoot through state. Because of the symmetrical structure of the inverter, the current during shoot through in terms of average is evenly distributed in three parallel paths. The current through the inverter during shoot through is twice of the inductor current.

When the dc voltage is high enough to generate the desired ac voltage, the traditional PWM is used. While the dc voltage is not enough to directly generate a desired output voltage, a modified PWM with shoot-through zero states will be used to boost voltage. It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states. It is noticeable here that the equivalent switching frequency viewed from the Z-source network is six times the switching frequency of the main inverter, which greatly reduces the required inductance of the Z- source network.

The three-phase Z-source inverter bridge has nine permissible switching states unlike the traditional three- phase Voltage Source Inverter that has eight. The traditional three-phase Voltage Source Inverter has six active states when the dc voltage is impressed across the load and two zero states when the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z-Source Inverter bridge has one extra zero state 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 shoot-through zero state is forbidden in the traditional Voltage Source Inverter, because it would cause a shoot-through. We call this third zero state the shoot-through zero state, which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter.

Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance (L) and capacitance (C), respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuits, we have

$$V_{C_1} = V_{C_2} = V_C \qquad v_{L_1} = v_{L_2} = v_L$$

Given that the inverter bridge is in the shoot-through zero state for an interval of T0, during a switching cycle, T and from the equivalent circuit, we have,

$$v_L = V_C \quad v_d = 2V_C \quad v_i = 0$$

Now consider that the inverter bridge is in one of the eight non shoot-through states for an interval of T1, during the switching cycle, T. From the equivalent circuit, we get

$$v_L = V_0 - V_C \quad v_d = V_0 \quad v_i = V_C - v_L = 2V_C - V_0$$

Where, V0 is the dc source voltage and T = T0 + T1.

The average voltage of the inductors over one switching period (T) should be zero in steady state,

$$V_L = \overline{v_L} = \frac{T_0 \cdot V_C + T_1 \cdot (V_0 - V_C)}{T} = 0$$

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}$$

Similarly, the average dc-link voltage across the inverter bridge can be found as follows:

$$\widehat{v_i} = V_C - v_L = 2V_C - V_0 = \frac{T}{T_1 - T_0} V_0 = B \cdot V_0$$

The peak dc-link voltage across the inverter bridge is expressed in (3) and can be rewritten as

$$V_i = \overline{v_i} = \frac{T_0 \cdot 0 + T_1 \cdot (2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C$$

Where,

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_1}{T}} \geq 1$$

B = Boost factor resulting from the shoot-through zero state.

The peak dc-link voltage is the equivalent dc-link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as

$$\widehat{v_{ac}} = M \cdot \frac{\widehat{v_i}}{2}$$

Where,

M = Modulation Index

$$\widehat{v_{ac}} = M \cdot B = \frac{V_0}{2}$$

This shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor,

$$B_B = M \cdot B = (0 \sim \infty)$$

The capacitor voltage can expressed as

$$V_{C_1} = V_{C_2} = V_C \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0$$

Where,

M = Modulation Index

T = Switching Period

To = Shoot-through interval

The buck–boost factor BB is determined by the modulation index M and boost factor B. The boost factor can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over the non shoot-through states of the inverter PWM.

The inductors are designed based on the current ripple limit, and the capacitors are designed based on the current ripple capacity requirement and capacitance requirement due to voltage ripple range.

For the Z-source inverter, during the shoot through interval, the capacitor charges the inductor and gives out current. The voltage ripple across the capacitors can be estimate as

$$\Delta V_C = \frac{I_L T_0}{C}$$

Where,

$$T_0 = \left(1 - \frac{\sqrt{3}}{2}M\right)T_s$$

And

$$I_L = \frac{P_0}{V_i}$$

We have,

$$\Delta V_C = \frac{\frac{P_0}{V_i}\left(1 - \frac{\sqrt{3}}{2}M\right)T_s}{C}$$

When the inverter is in a shoot through state, the voltage across the inductor is the voltage across the capacitor. Therefore the current ripple of the inductor can be calculated as

$$\Delta I = \frac{V_C}{L}T_0$$

Where VC is the voltage across the capacitor C

$$V_C = \frac{V_i}{2}(1 + B) = \frac{V_i}{2}\frac{\sqrt{3}M}{\sqrt{3}M - 1}$$

We have

$$\Delta I = \frac{V_i\sqrt{3}M}{2L\left(\sqrt{3}M - 1\right)}\left(1 - \frac{\sqrt{3}}{2}M\right)T_s$$

Based on above equations, we can design inductors with requirement of current ripple level. The capacitors are designed to take the ripple current through them based on the ripple current level, which can be calculated by certain programs.

5. RESULTS

The below are the results obtained. Figure 5 shows the input voltage, PV voltage and output voltage waveforms. Figure 6 shows the pulse generator waveforms. Figure 7 shows Transformer Primary & Secondary Waveforms and Diode Voltage & Current Waveforms.

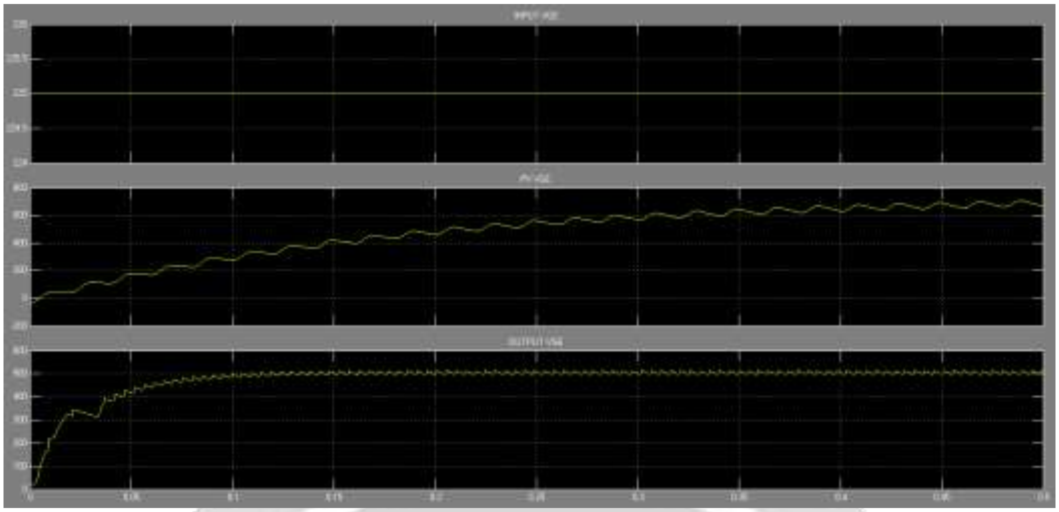

Fig- 5 Input, PV, Output Voltage Waveforms

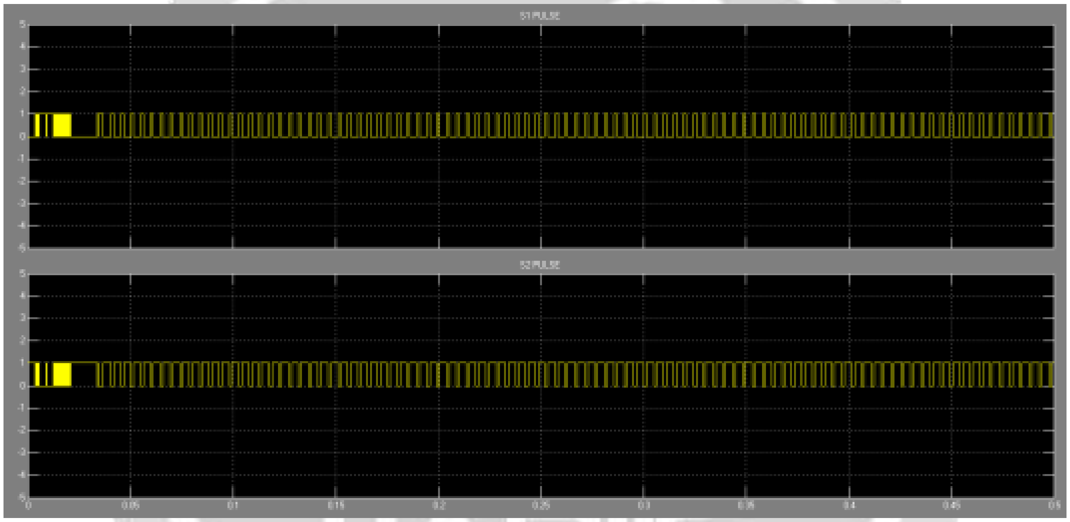

Fig- 6 Pulse Generator Waveforms

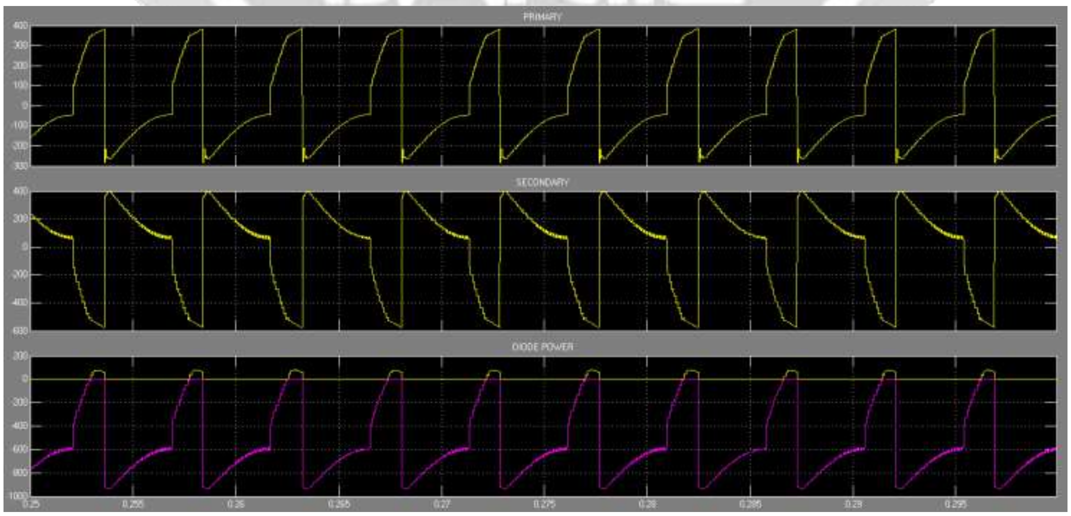

Fig- 7 Transformer Primary & Secondary Waveforms and Diode Voltage & Current Waveforms

6. CONCLUSION

The objective of this paper was to use the Solar Energy generated from solar panels for running a DC Motor using a Z-Source Inverter. The Z-Source inverters were found to be much advantageous than the traditional Voltage Source and Current Source Converters. Of all the sources of renewable energy available to mankind in its pursuit of a sustainable future, solar power is a pivotal one. Plentiful, free and absolutely clean, the main challenge to fully tap its huge potential is to harness and distribute it. We have made considerable progress with solar power, but future uses of solar energy will be spawned by innovations still to come.

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