Digital Simulation of Photo Voltaic Based Cascaded Boost Converter for Voltage Source Inverter fed Induction Motor Drive

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ABSTRACT: Solar energy is one of the important infinite source that maintains life on earth and is of clean energy. This energy can be converted to different forms as per our requirements. In this paper digital implementation of Photo Voltaic (PV) based cascaded boost converter (CBC)for voltage source inverter (VSI) fed induction motor is presented. The proposed PV model is based on a behavioral cell model that takes in to account of the environmental parameter of temperature and irradiance. And then its output is considered as input for CBC in which the low voltage is stepped up toa level that is required for the VSI fed drive. This kind of CBC system is implemented with only two switches and its synthesis will be explained in this paper. The comparison between SPWM and SVPWM is verified by using three phase VSI. The effectiveness of the proposed scheme is also presented through digital simulation using MATLAB Simulink.

Keywords: Cascaded boost converter (CBC), PV,* SPWM, SVPWM, *THD, MATLAB Simulink.

I. INTRODUCTION

The Conventional sources of energy are rapidly depleting. Moreover the cost of energy is rising and therefore photovoltaic (PV) system is a promising alternative among various renewable energy sources. They are abundant, pollution free, distributed throughout the earth and recyclable. The hindrance factor is its high installation cost and low conversion efficiency. Due to its manifold advantages mentioned earlier, PV based generating systems are gaining more importance throughout the world. PV modules are the basic power conversion units of a PV Generating System. The output of PV based systems is mainly dependent on solar irradiation and temperature. A conventional centralized PV array is a serial connection of numerous panels to obtain higher dc-link voltage for main electricity through a DC- AC inverter [1],[2]. There will be a significant reduction in system's energy when there is a partial shadow on some panels [3]. Hence there should not be a direct connection of load to the output of solar PV panels. In this context a DC-DC converter acts as an interface between the PV panels and the inverter which is in general a Boost converter that attains higher output voltages. Also it yields a constant output voltage across its output capacitors where loads are connected. It is also required that this constant voltage is to be supplied to the load irrespective of the variation in solar irradiance and temperature.

The main drawbacks of PV based system are its high cost of manufacturing and the low conversion efficiency. The present day technological developments in manufacturing the solar panels and efficient power converter designs are playing an important role in making the PV system a cost-effective. PV system is developed with PV array that consist of parallel and series combination of cells for electrical power generation depending upon the atmospheric conditions. The mathematical models of PV modules have been built using computer simulations over the past decades [4]-[6]. Many software packages are available and are popular in design and development of power electronics applications [7].

In this paper the PV array is interfaced with the boost converter using a controlled voltage source, for stepping up the voltage. Since this single boost converter is not able to drive the VSI fed Drive, another converter is cascaded to it which is named as Cascaded Boost Converter (CBC).The output voltage from the CBC is given to the inverter fed drive and then synthesized for comparing the performance of the drive with well-known Pulse width Modulation (PWM) techniques such as Sinusoidal PWM (SPWM) and Space Vector PWM (SVPWM).The Total harmonic distortion (THD) is obtained through digital simulation using Mat lab Simulink. Fig.1 is the simple block diagram representation of the proposed work presented in this paper. The detailed explanation is given in the next sections.

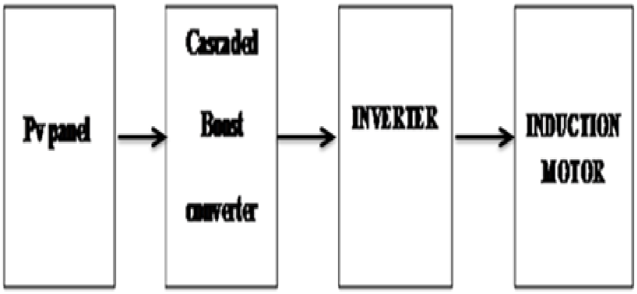

Fig .1 Block diagram of PV based Cascaded Converter

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II. RENEWABLE ENERGY

Renewable energy sources are also called non-conventional type of energy. These are the sources which are continuously replenished by natural processes. Such as, solar energy, bio-energy - bio-fuels grown sustainably, wind energy and hydropower etc. A renewable energy system convert the energy found in sunlight, water current, wind, sea-waves, geothermal heat, or biomass into a form, which we can use in the form of heat or electricity. Most of the renewable energy comes either directly or indirectly from sun and wind and can never be exhausted; hence they are noticed as renewable.

However, most of the world's energy sources came from conventional sources-fossil fuels such as coal, natural gases and oil. These fuels are often term non-renewable energy sources. Though, the available amount of these fuels are extremely large, but due to reduction in level of fossil fuel and oil level day by day after a few years it will end. Hence renewable energy sources demand increases. Another factor for its demand is it reduces the greenhouse effect.

A. SOLAR ENERGY

Solar has been accoutered by humans since centuries past using a variety of technologies. Solar radiation, along with secondary solar-powered resources such as, wave and wind power, hydroelectricity and biomass, account for most of the available non-conventional type of energy on earth. However, currently only a small fraction of the available solar energy is used.

Solar powered electrical generation banks on photovoltaic system and heat engines. Solar energy's applications are limited only by human creativity. To harvest the solar energy, the most adopted way is to use photo voltaic panels which will receive photon energy from sun and convert to electrical energy. Solar technologies are broadly classified into either passive solar or active solar depending on the way they detain, convert and distribute solar energy. Active solar techniques include the use of Photovoltaic panels and solar thermal collectors to strap up the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties and design spaces that naturally circulate air [8]. Solar energy has a wide area of application such as electricity generation for distribution, heating water, lighting, crop drying etc.

B. PHOTOVOLTAIC ARRANGEMENTS

A photovoltaic system is one which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the power output.

C. PHOTOVOLTAIC CELL

PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are linked to the positive and negative sides, creating an electrical circuit, the electrons can be captured in the form of an electric current that is nothing but electricity. This electricity can then be used to power a load [9]. A PV cell can either be circular or square in construction.

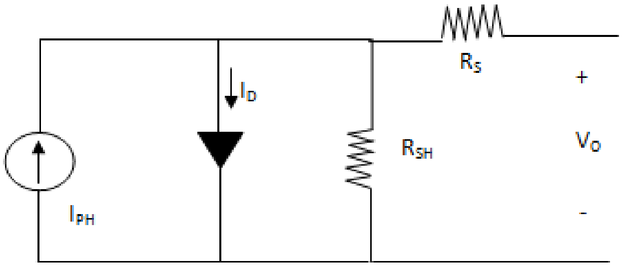

Fig. 2 Equivalent circuit model of a PV cell.

D. PHOTO VOLTAIC MODULE

Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be required to obtain reverse currents, in case of partial or total shading, and at night the p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics, which are not necessary. Reverse currents causes' power wastage and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.

E. PHOTO VOLTAIC ARRAY

The power that one module can produce is not sufficient to meet the requirements of domestic or industry. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first connected in series to get the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current [8].

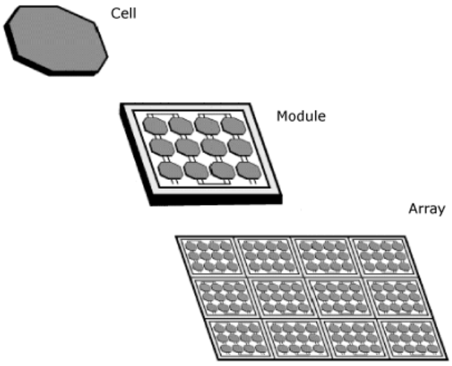

Fig.3 Basic construction of a photovoltaic panel

III. MODELLING OF PV ARRAY

The key element of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity; it has an equivalent circuit as shown in Figure 2.

The current source Iph represents the cell photo current, RSH and Rs are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of RSH is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays.

The PV mathematical model used to simplify our PV array is represented by the equation:

$$I = I_{PH} \square I_S \left[exp\left(\frac{q(V+IR_S)}{kT_C A}\right) - 1\right] - (v + IR_s)/R_{SH} \qquad (1)$$

Where

I =PV array output current

V = PV array output voltage;

Ns = number of cells in series;

Np = number of cells in parallel;

q = charge of an electron;

k = Boltzmann's constant;

A = p-n junction ideality factor;

T = cell temperature (K);

I_{RS} = cell reverse saturation current.

The factor A in equation (1) determines the cell deviation from the ideal p-n junction characteristics; Here A is dependent on PV technology.

The photo current I_{PH} value depends on the solar radiation and cell temperature as follows

$$I_{PH}=[I_{sc} + k_i(T_c - T_{Ref})]\lambda. \qquad (2)$$

Where

Iscr = cells short-circuit current with reference temperature and radiation, K_i = short circuit current temperature coefficient, and S = solar radiation in MW/cm^2.

The approximate model PV solar cell with suitable complexity so equation (1) can be written as

$$I=I_{PH}-I_S\left[exp\left(\frac{q(V+IR_S)}{KT_C A}\right) - 1\right] \qquad (3)$$

After neglecting R_S& R_{SH} .The above equation can be written as:

$$I=I_{PH}-I_S\left[exp\left(\frac{q(V)}{KT_C A}\right) - 1\right] \qquad (4)$$

The cell saturation current I_{RS} varies with temperature according to the following equation.

$$I_S=I_{RS}\ (T_C/T_{Ref})^3\ exp\left[qE_G\ \left(\frac{1}{T_{Ref}} - \frac{1}{T_C}\right)/kA\right] \qquad .(5)$$

Where,

T_{REF} = cell reference temperature,

I_{RS} = cell reverse saturation temperature at T_r

E_G = Band gap of the semiconductor used in the cell.

The reverse saturation current at reference temperature can be approximately obtained as

$$I_{RS}=I_{sc}\ /[\exp\left(\frac{qV_{OC}}{kAT_C}\right) - 1] \qquad (6)$$

The PV power can be calculated using equation as follows:

$$P=V_{max}I_{MAX} \qquad (7)$$

Where V_{MAX} and I_{MAX} are terminal voltage and output current of PV module.

IV. DC-DC CONVERTERS

DC-DC converters can be used as switching mode regulators to convert an unregulated DC voltage to a regulated DC output voltage. The regulation is normally accomplished by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time, to boost the efficiency. This limitation is because of the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereafter, the efficiency decreases. The main loss of the inductors limits the high frequency operation. Control voltage VC is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the control voltage VCR.

The PWM control signal for the DC converter is generated by comparing V_{CR} with a saw tooth voltage V_r . There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter, and cuk converter. However for the current case of our experiment we deal with the boost regulator and further discussions will be concentrated towards this one.

A. CASCADED BOOST CONVERTER AND ITS OPERATION

The figure (4) below shows a step up or PWM cascaded boost converter. It consists of a DC input voltage source Vg; boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor boosts linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit [10].

B. STEADY STATE ANALYSIS OF THE BOOST CONVERTER

(a) *Off state*

In the off state, the sum total of inductor voltage and input voltage appear as the load voltage.

(b) *On state*

In the ON state, the inductor is charged from the input voltage source V_{IN} and the capacitor discharges across the load. The duty cycle= $\frac{T_{ON}}{T}$ where T= $\frac{1}{f}$.

C. DESIGN OF THE BOOST CONVERTER

From the inductor voltage balance equation, we have:

To calculate switch current:

$$D=1-(V_{in\,(min)} * n)/\ V_{out} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

To calculate Inductor ripple current:

$$\Delta I_L = \frac{V_{in(min)} * D}{f_S * L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where,

$$L= (V_{in} * (V_{out} - V_{in}))/\Delta I_L * f_s * V_{out} \ \ldots\ldots\ (10)$$

To calculate capacitor maximum output voltage:

$$C= (I_{out} * D)/\ f_S * \Delta V_{out} \ \ldots\ldots\ldots\ldots \quad (11)$$

To calculate ripple current:

$$\Delta I_L = (0.2 +0.04) * I_{out} * V_{out}/V_{in} \ \ldots\ldots \quad (12)$$

(1) CURRENT RIPPLE FACTOR (CRF)
$\Delta I_{1/I_1}$=30%

(2) VOLTAGE RIPPLE FACTOR (VRF):
$\Delta {}^{V_O}/_{V_O}$ = 5%

(3) SWITCHING FREQUENCY (fs):
F_S= 50 KHZ.

V. INTERFACING OF THE PV ARRAY WITH CASCADED BOOST CONVERTER

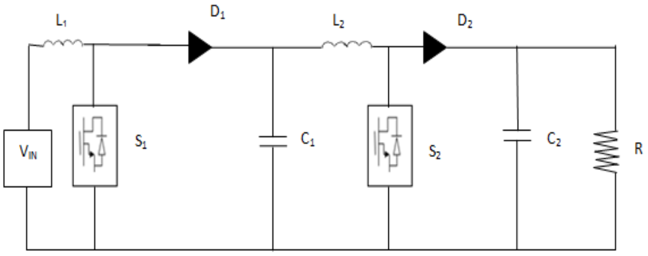

Fig.4 Cascaded boost converter with PV Array

The PV array has been interfaced with the cascaded boost converter using a controlled voltage source. The PV array has been designed taken into consideration its dependence upon the irradiance, temperature, number of PV cells connected in series and parallel are shown in m-file. The M-file for IRS function has been developed using the equation (6) and that for the Iph function using equation (2). The PV array has been modeled using the equation (1). The interfacing of the PV array with the cascaded boost converter has been achieved by using a voltage controlled source.

A. PWM TECHNIQUE

Pulse-width modulation (PWM) is a technique where the duty ratio of a pulsating waveform is controlled by another input waveform. The intersections between the reference voltage waveform and the carrier waveform, give the opening and closing times of the switches. PWM is generally used in applications like motor speed control, converters, audio amplifiers, etc. For example, it is used to reduce the total power delivered to a load without losses, which commonly occurs when a power source is limited by a resistive element. PWM is used to adjust the voltage applied to the motor. Changing the duty ratio of the switches changes the speed of the motor. The longer the pulse is closed compared to the opened periods, the higher the power supplied to the load is, The change of state between closing (ON) and opening (OFF) is rapid, so that the average power dissipation is very low compared to the power being delivered. PWM amplifiers are more efficient and less bulky than linear power amplifiers. In addition, linear amplifiers that deliver energy continuously rather than through pulses have lower maximum power ratings than PWM amplifiers.

There is no single PWM best relevant method is for all applications along with advances in solid-state power electronic devices and microprocessors, various pulse-width modulation (PWM) techniques have been developed for industrial applications. For these reasons, the PWM techniques have been the subject of intensive research since 1970s.

PWM strategy plays a major role in the minimization of harmonics and switching losses in converters, especially in three-phase applications. The main objective of any modulation technique is to yield a variable output with a maximum fundamental component and minimum harmonics [11].

Initially the carrier-based PWM methods were developed and were widely used in most applications. One of the earliest modulation signals for carrier-based PWM is sinusoidal PWM (SPWM). The SPWM technique is based on the comparison of a carrier signal and a pure sinusoidal modulation signal[12].

B. SVPWM TECHNIQUE

SVPWM was first introduced in the mid 80's and was greatly progressed by Van DerBroeck in 1988. With the development of microprocessors, SVPWM has become crucial PWM methods for three-phase inverters [13].

The motto in each modulation strategy is to lower the switching losses, reduce harmonic content, and to achieve precise control. The SVPWM technique utilizes the DC bus voltage more efficiently and generates less harmonic distortion against the SPWM technique. The maximum peak fundamental magnitude of the SVPWM technique is about 90.6% of the inverter capacity. This represents a 15:5% increase in the maximum voltage against conventional sinusoidal modulation [14].

The SPWM technique is the easiest modulation scheme to understand and apply in software or hardware; however this technique is unable to fully utilize the DC BUS supply voltage available to the voltage source inverter. The application of the conventional SVPWM is especially difficult because it requires complicated mathematical operations. Here we synthesize and compare the three-phase generation of SPWM, and SVPWM. These two techniques are used to generate their respective output PWM signals, which are then compared, upon harmonic content and distortion by using the total harmonic distortion (THD) measure of various output voltages.

The peak of the sine modulating waveform is always lower than the peak of the triangle and carrier voltage waveform. When the sinusoidal waveform is greater than the triangular waveform, the upper switch is turned on and the lower switch is turned off. Similarly, when the sinusoidal waveform is less than the triangular waveform, the upper switch is off and the lower switch is on. Depending on the switching states, either the positive or negative half DC bus voltage is applied to each phase. The three phase inverter is connected to induction motor as load.

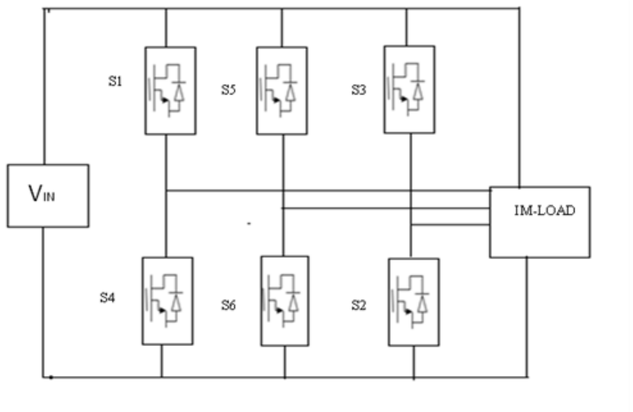

Fig.5 Three phase full bridge inverter.

VI. MATLAB/SIMULINK RESULTS

The Mat lab /simulink results are shown below for the Mat lab circuit and waveforms are executed. The designed converter consists of two active mosfet switches with two capacitors, two inductors and a resistor to step up with high voltage level.

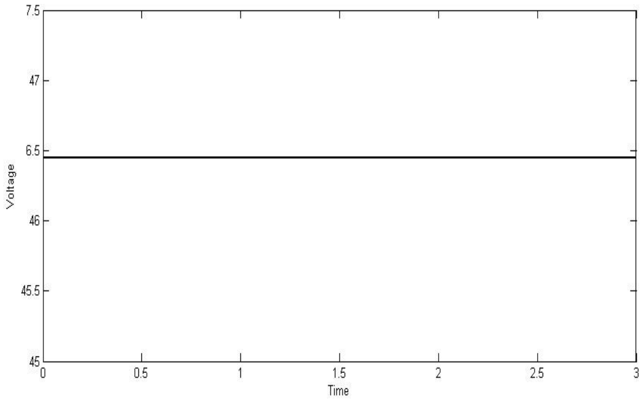

Fig.6 Dc voltage of a PV panel.

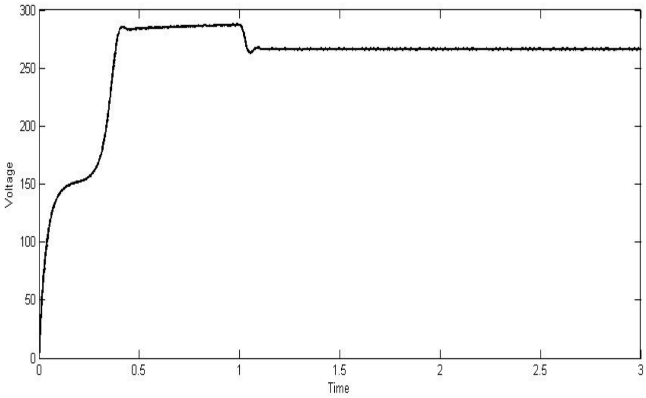

Fig.7 Output Voltage of a Cascaded Boost Converter.

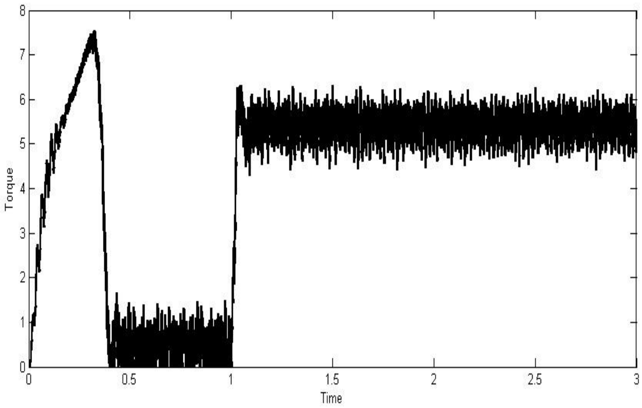

Fig.8 Output Torque of an Asynchronous Machine on load.

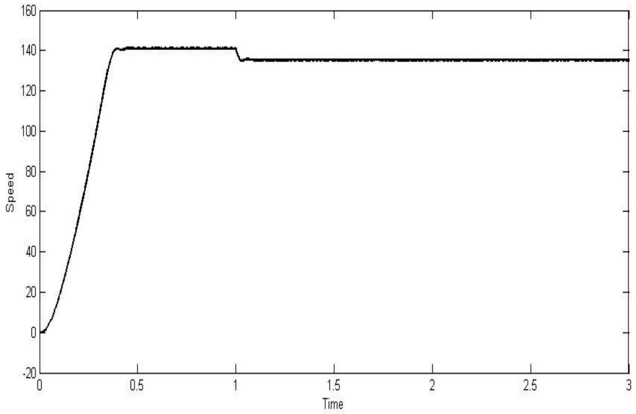

Fig.9 Output Speed for an Asynchronous Machine on load.

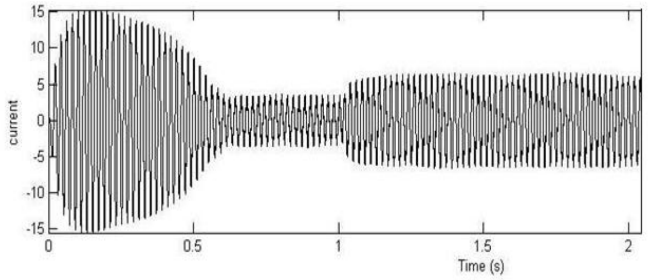

Fig.10 Output Current for a Three Phase Inverter.

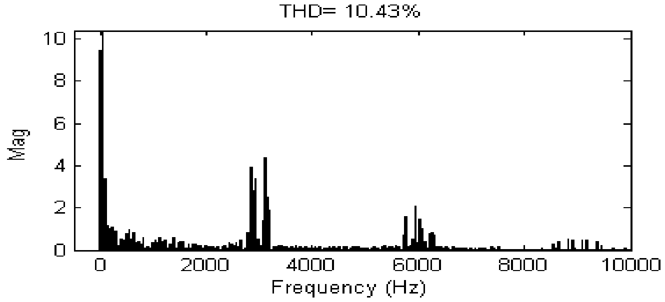

Fig.11 THD Measurement of current for SVPWM Inverter without load.

VII. CONCLUSION

In the proposed topology it is shown that the voltage source inverter fed induction motor drive is driven by low voltage PV based cascaded boost converter. That is from low voltage PV system it is possible to drive an induction motor of 5hp.Also the cascaded boost converter used less number of switches and capacitors. The total harmonic distortion for the current waveforms of the drive is reduced when Svpwm is employed compared to sinusoidal pulse width modulation. At the outside it can be concluded that low cost solar PV panels can be used to drive a three phase induction motor instead of using high rating, high cost PV panels

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