International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

PV Solar System fed Capacitor Start Induction Motor and DC Shunt Motor

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Abstract: ***This paper proposes the implementation of step-up converter implemented in the PV solar system, which is considered as the one of the fastest growing renewable energy sources. Here step-up converter is considered which can be designed to extend step-up gain and the switched capacitors can offer extra voltage conversion ratio thereby making it more beneficial than that of the existing converters. A conventional interleaved boost converter obtains high step-up gain without operating at extreme duty ratio. The configuration of the proposed converter not only reduces the current stress but also controls the input current ripple which decreases the conduction losses and extends the durability of the source. In addition, due to the lossless passive clamp performance, leakage energy is recycled at the output terminal. Hence, large voltage spikes across the main switches are elevated and the efficiency is improved. Here the low voltage stress encourages the adoption of low voltage-rated MOSFETs for the reduction of both conduction losses and cost. This proves that the proposed system is also cost effective and efficient. For the case here the system is considered with the motor load.***

Keywords: MPPT, PV solar system, Single phase asynchronous machine, Single phase inverter, DC-DC Converter.

1. Introduction

The need for energy in the present day scenario is never ending. This is certainly true in case of electrical energy, which stands as the largest one in total global energy consumption. The demand for electrical energy is increasing twice as fast as overall energy use and is likely to rise to 76% by 2030 from 12.5% in 2014.This situation can be managed only with the use of renewable energy sources as wind, tidal, solar etc[1]-[3]. Another concern is that in many overpopulated countries like India, there is a over usage of limited power generating resources and as a result many cities and towns are facing constant load shedding and black-outs. The existing power generation units are not sufficient to meet the continuously rising power demand. The wide gap between generation and distribution location lead to the inefficiency in supplying power to the rural areas. This can be eliminated only by the use of advanced techniques in power electronics by providing uninterrupted power supply to the users by providing flexibility in source by placing the inverters [4].Here the general PVsystem is as shown in figure.1

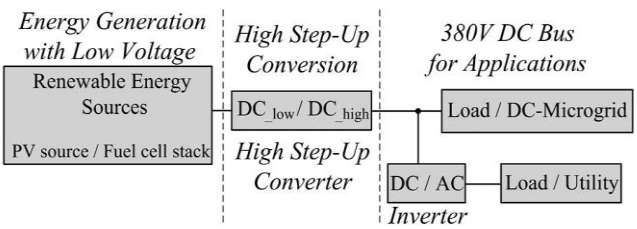

Figure 1: Typical Renewable Energy System

2. Photo-Voltaic Cell

Photovoltaic cells are solid-state semiconductor devices that convert the light energy into electrical energy directly. These cells are usually made of silicon with traces of other elements and are considered as first cousins to transistors, LED's and other electronic devices. Photovoltaic (PV) generation is becoming increasingly important as a renewable source because it is offering many benefits as incurring no fuel costs, not being polluted, requiring little maintenance and emitting no noise when compared to others. The amazing thing about solar power is that all the electricity that is generated from the material of the solar panels is the energy from the sun. The solar panels are mainly made out of semiconductor material, silicon being the most abundantly used semiconductor. The benefit of using semiconductor material is largely due to the ability of it to control its conductivity whereas insulators and conductors are not. The electrons of the semiconductor material can be located in any one of the two different bands as the conduction band and the valence band. The valence band is initially full with the electrons that the material contains. When the energy from sunlight known as photons strikes the electrons in the semiconductor some of these electrons will acquire some energy sufficient to leave the valence band andenter the conduction band. When this occurs, the electrons in the conduction band begin to move creating electricity. As soon as the electron leaves the valence band, a positively charged hole will remain in the location where the electron departed. When this occurs, the valence band is no longer full and able to play a role in the flow of current. This process describes the working principle of Photovoltaic (PV) system. Here the PV systems further enhance the rate at which the electrons are sent into the conduction band through the process of doping. Here the electrical equivalent circuit ofa single PV cell is as shown in following figure.2

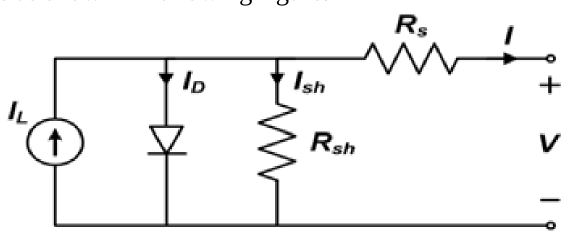

Figure 2: Electrical Equivalent of PV cell

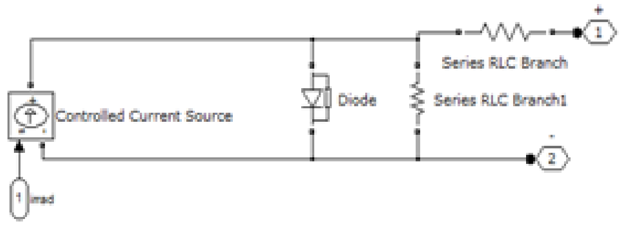

Figure 3: Equivalent PV cell implemented in simulink

In the above equivalent circuit, I and Vare the PV current and voltage of a single cell respectively. $R_s$and R_{sh} are the Series and shunt resistances respectively. Here the value of R_{sh} is maintained as low value where as R_s is at a very higher value. Now the current to the load by a number of PV cells connected as per the requirement is given by.

$$I=N_P\, I_{PV} - N_P\, I_S\left[\exp\left[\frac{q\,(V+Rs\,I)}{nNs\;KT} - 1\right]\right] - \frac{V+Rs\,I}{Rsh} .. \qquad (1)$$

(or)

$$I=I_{ph}-I_0\left[\exp\left(\frac{q(V+R_S I)}{Ak_B T}\right) - 1\right] - \frac{V+R_S I}{R_{sh}} \;\ldots\ldots \qquad (2)$$

In this equation, I_{pv} is the photocurrent, $I_s$is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, n is the ideality factor of the diode, and Rs and Rsh are the series and shunt resistors of the cell, respectively. N_s and N_p are the number of cells connected in series and parallel respectively. As mentioned earlier PV current is a function of temperature and solar irradiation.

$$I_{pv}= [I_{sc}+ K_I(T\text{-}298)]\frac{\beta}{1000} \qquad \ldots\ldots\ldots (3)$$

Where K_I=0.0017 A/◦C is the cell's short circuit current temperature coefficient and β is the solar radiation (W/m2). The diode reverse saturation current varies as a cubic function of the temperature and it can be expressed as follows

$$I_s(T) = I_s\left[\frac{T}{T\,nom}\right]^3 exp\left[\frac{T}{Tnom} - 1\right]\frac{Eg}{nVt} \qquad \ldots\ldots. (4)$$

Where $I_s$is the diode reverse saturation current, T_{nom} is the nominal temperature, E_g is the band gap energy of the semiconductor and V_t is the thermal voltage. The power output of a solar cell is given by

$$P_{PV} = V_{PV} * I_{PV} \qquad \ldots\ldots\ldots\ldots\ldots (5)$$

3. Maximum Power Point Tracker

A maximum power point tracker (MPPT) is device that looks for the maximum power point of a source and keeps on operating at that point. The MPPT tries to match the power source to impedance that demandsthe maximum power out of it. This variable impedance is usually a DC-DC converter to maintain very low losses in the system. The PV is not always operating in its maximum power point, but with the use of an MPPT it is possible to force the PV to give the maximum power at the given irradiance. There are many techniques [5] used for implementing MPPT. Some are more complex than others [6]. For the proposed system the Perturbation and Observation (P&O) [7] technique is used because of its simplicity and can be easily implemented. This technique is not being used in real time, but considering that it will be implemented in a microcontroller and the internal cCalculations are done at high speed, it is almost real time. This technique can be easily implemented basing on an algorithm using the power-voltage characteristics of the PV module. Knowing that at the right and the left of the maximum power point the power decreases. Therefore the converter's duty cycle is changed depending on the last change in power as if the duty cycle has to be increased or decreased. To implement P&O technique the power needs to be read at a time k and the voltage is to be changed. These readings are stored in memory. Next the power at time k+1 is also read, if this power is increasing we have to increase the duty ratio. In the case if the power in k+1 is lower than at the time k we have to decrease the duty ratio and there by consequent change in the voltage. This technique is to be operated in the boundaries of the MPPT. The algorithm of the P&O is presented in the fig. 4

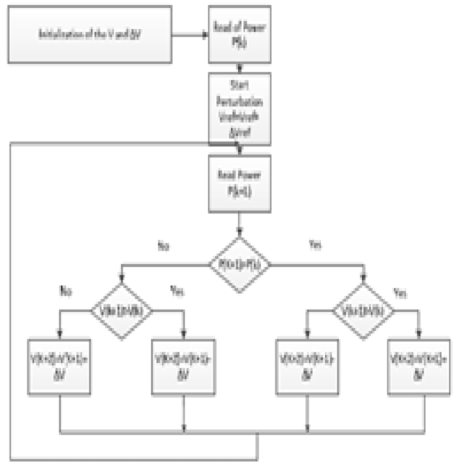

Figure 4: the Perturbation and Observation Algorithm

The power vs. voltage graph showing the MPPT is as shown in figure.5

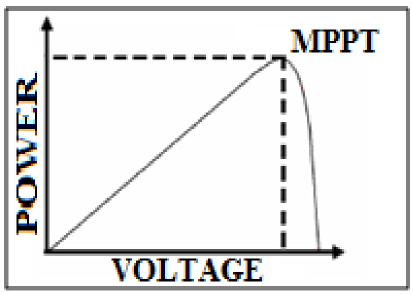

Figure 5: showing the Power vs Voltage graph

4. Invereter

Inverter in general refers to a class of power conversion circuits that operate from a dc voltage source or a dc current source and convert it into a symmetric ac voltage or current. It does reverse of what ac-to-dc 'converter' [11] does. The input to the inverter is a direct dc source or dc source derived from an ac source. For example, the primary source of input power may be utility ac voltage supply that is converted to dc by an ac - dc rectifier with filter capacitor and then 'inverted' back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply.

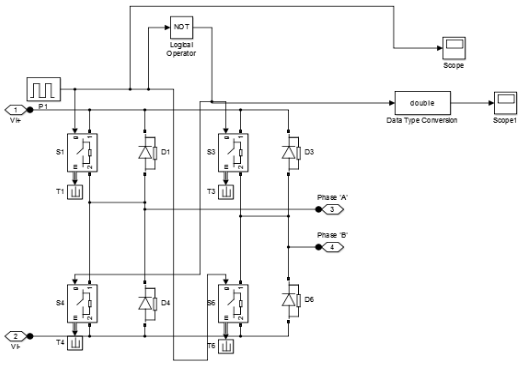

Figure 6: Simulink model of inverter (VSI)

Fig.5 shows the power circuit diagram for single phase bridge voltage source inverter. In this four switches (in 2 legs) are used to generate the ac waveform at the output. Any semiconductor switch like IGBT, MOSFET or BJT can be used. Four switches are sufficient for resistive load because load current i_o is in phase with output voltage v_o. However this is not true in case of RL load where the i_o is not in phase with v_o and diodes connected in anti-parallel with switch will allow the conduction of the current when the main switch is turned off. These diodes are called as Feedback Diodes since the energy is fed back to the dc source.If the input dc is a voltage source, the inverter is called a Voltage Source Inverter (VSI). One can similarly think of a Current Source Inverter (CSI), where the input to the circuit is a current source. The VSI circuit has direct control over 'output (ac) voltage' whereas the CSI directly controls 'output (ac) current'.

5. Single-Pulse-Width-Modulation

In single pulse width modulation control, there is only one pulse per half cycle and the output rms voltage is changed by varying the width of the pulse. The gating signals and output voltages of single pulse-width modulation are shown in fig 4(b). The gating signals are generated by comparing the rectangular control signal of amplitude V_c with triangular carrier signal V_{car}. The frequency of the control signal determines the fundamental frequency of ac output voltage. The amplitude modulation index is defined as:

$$ma = \frac{Vc}{Vcar}$$

The rms ac output voltage

$$Vo = \left\{ \frac{2}{T} \int_{\frac{T}{4}-\frac{ton}{2}}^{\frac{T}{4}+\frac{ton}{2}} Vs^2 \, dt \right\}^{\frac{1}{2}} = V_s\sqrt{\frac{2ton}{T}} = V_s\sqrt{\delta}$$

Where

$$\delta = \text{duty ratio} = \frac{t_{on}}{T}$$

By varying the control signal amplitude V_c from 0 to V_{car} the pulse width ton can be modified from 0 secs to T/2 secs and the rms output voltage V_o from 0 to V_s. In multiple PWM control, instead of having a single pulse per half cycle, there will be multiple number of pulses per half cycle, all of them being of equal width.

6. Single Phase Induction Motor

An induction motor is an asynchronous AC (alternating current) motor that consists of a stator and a rotor. In the induction motor a sinusoidal voltage is applied to the stator, this results in an induced electromagnetic field. This field induces a current in the rotor that creates another field that tries to align with the stator field causing the rotor to spin. The least expensive and most widely used induction motor is the squirrel cage motor. The interest in sensor less drives of induction motor (IM) has grown significantly over the past few years due to some of its advantages as mechanical robustness, simple construction and less maintenance. These applications include pumps, fans, paper and textile mills, subway and locomotive propulsions, electric and hybrid vehicles, machine tools and robotics, home appliances, heat pumps and air conditioners, rolling mills, wind generation systems etc. So, with the development in the field of vector control technology. Induction motors have been used more in the industrial variable speed drive system. There are four types of induction motors available in general of which the type of induction machine considered here is of capacitor start type. The induction motor considered is of the ratings as shown in the Table.1.

Table 1

S.No.	Parameter	Value
1	Type	Single phase
2	Power	0.25 HP
3	Voltage	110V
4	Frequency	50Hz
5	Current	2.5 A
6	Speed	1200 Rpm
7	Capacitance	10µF

7. DC-DC Converter

In this project the model is not only designed for AC systems but also for DC systems which are specifically used for certain applications. For convenience dc-dc converter [12]-[17] is employed by considering that there may exists DC loads at the utility side. But more emphasis is given on the AC systems

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. The following is a summary of some of the popular DC-to-DC converter topologies as Buck converter, Boost converter and Buck-Boost Converter

High efficiency is invariably required, since cooling of inefficient power converters is difficult and expensive. The ideal dc-dc converter exhibits 100% efficiency; in practice, efficiencies of 70% to 95% are typically obtained. This is achieved using switched-mode, or chopper, circuits whose elements dissipate negligible power. Pulse-width modulation (PWM) allows control and regulation of the total output voltage. This approach is also employed in applications involving alternating current, including high-efficiency dc-ac power converters (inverters and power amplifiers), ac-ac power converters, and some ac-dc power converters (low-harmonic rectifiers).Off these types buck type converter is used in this model. Its simulink block is as shown in figure (7).

The current at the output is continuous or not is decided by the value of filter inductance. The ripple content in the output voltage is decided by the capacitor. The minimum value of inductance for maintaining continuous conduction decided by the values of frequency, duty ratio, load current and the input voltage.

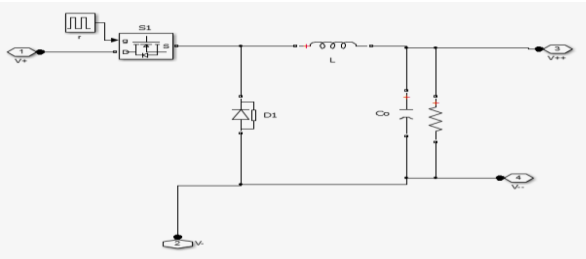

Figure 7: Simulink model of the Buck Converter

Here the DC load considered is of DC motor of parameters as 5HP, 1750Rpm and voltage of 240V for the same the waveforms of torque, speed and armature current are as shown in fig.13.

8. Simulink blocks

The following figure shows the simulink model of the single phase induction motor fed with voltage multiplier module based PV solar system

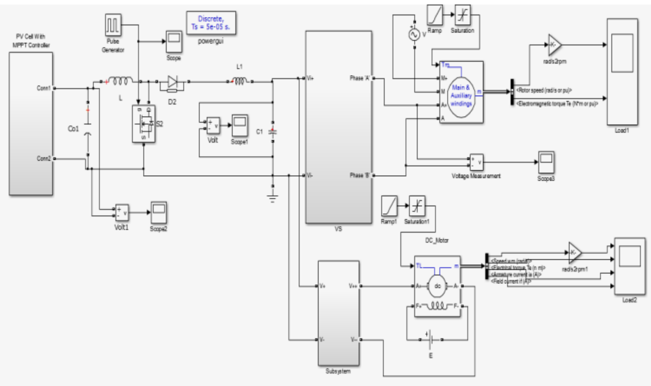

Figure 8: Simulink of the proposed model

9. Simulation Results

The wave forms considered here are of gate pulses of the single phase inverter in fig.9, PV cell Voltage is shown in Figure.10, output voltages of the inverter as in fig.11 and 11(a). The Speed andElectromagnetic Torque waveforms for the induction machine are as shown in the figure.12. And the output waveforms as Speed, Armature, field Currents and Torque Characteristics of the DC motor load are shown in figure.13.

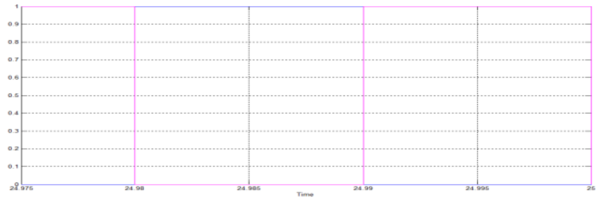

Figure 9: Gate Pulses for the Single Phase Inverter

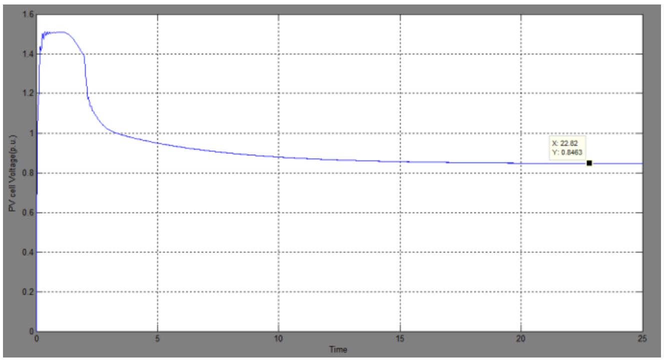

Figure 10: PV Cell Voltage in p.u.

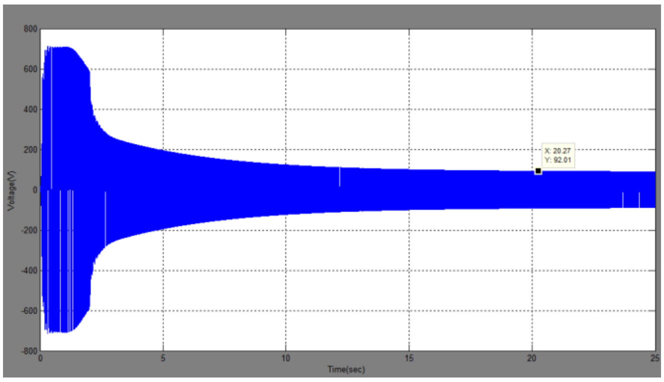

Figure 11: (a) Voltage waveform of the Inverter

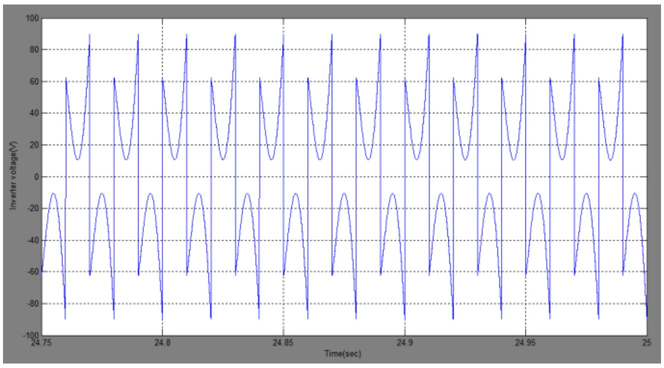

Figure 11: Voltage waveforms of the Inverter

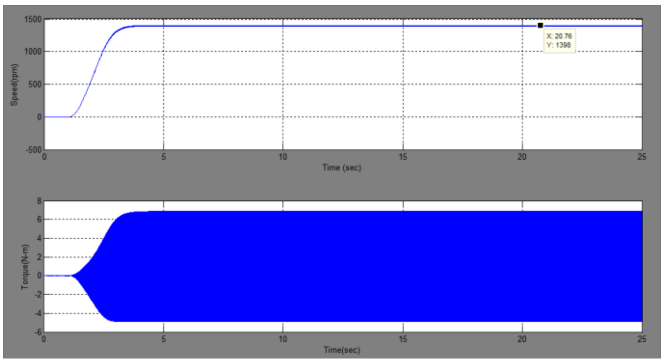

Figure 12: Output Speed and Torque of single phase induction motor

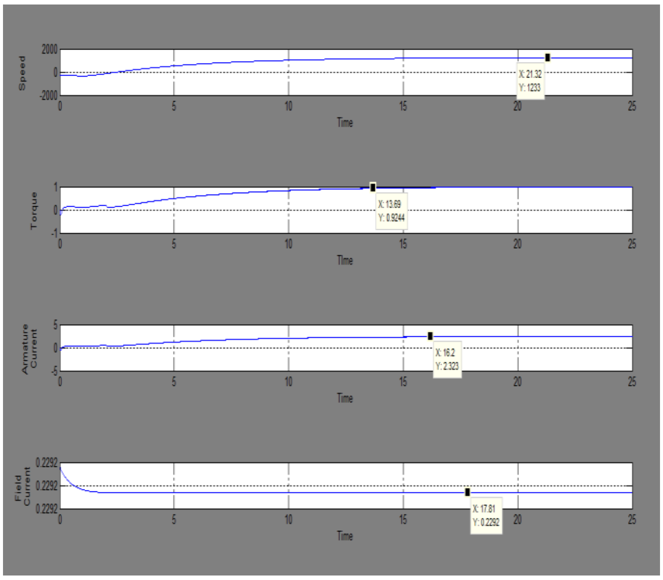

Figure 13: Speed, Torque, Armature& Field Current of D.C.Motor

10. Conclusion

Here the proposed model with step up converter using voltage multiplier module has the advantages as high step-up gain, low current ripple and low conduction losses making it suitable for high load applications when compared to the existing converters. This may be extended as implementing the model in real time and making it suitable for 3 phase applications with suitable modifications by the use of phase transformer or with the use of three phase inverter at the place of single phase inverter.

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