SINGLE PHASE STAND-ALONE PHOTOVOLTAIC SYSTEM BASED ON Z SOURCE DC-DC CONVERTER

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Abstract

The Conventional sources of energy are rapidly depleting. Moreover the cost of energy is rising and therefore photovoltaic system is a promising alternative. They are abundant, pollution free, distributed throughout the earth and recyclable. The hindrance factor is its high installation cost and low conversion efficiency. Therefore our aim is to increase the efficiency and power output of the system. It is also required that constant voltage is supplied to the load irrespective of the variation in solar irradiance and temperature. PV arrays consist of parallel and series combination of PV cells that are used to generate electrical power depending upon the atmospheric conditions (e.g. solar irradiation and temperature). So it is necessary to couple the PV array with a converter. And to track the maximum power perturb and observe MPPT method is used. The MPPT is integrated into the Z source dc-dc converter's control system. An inverter is connected at the output of z source converter. The inverter switching control is by using sinusoidal PWM control and unipolar switching control is used. The power outputs from PV plants fluctuate due to variation in solar irradiance and hence needs to be backed up by dedicated battery storage. Battery storage helps to compensate for this power fluctuation and provides steady power to the load. The proposed system has applications on water pumping in remote areas, home power supply, swimming-pool heating systems etc.

Index Terms: *PV module, MPPT module, Z source converter, Inverter etc.*

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1. INTRODUCTION

In the recent years the power demand is increasing regularly and it can be fulfilled by the use of conventional or non-conventional energy power plants. So, renewable energy sources like photovoltaic panels are used today in many applications. 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 are now widely used[2]. 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 but their installation cost is high and, in most applications; they require a power conditioner (dc/dc or dc/ ac converter) for load interface. The solar photovoltaic energy is of the most decentralized nature among all the sources of energy in the world and harnessing power from solar energy is solely pollution free. India receives about 300 clear sunny days in a year. This is equal to over 5000 trillion kWh/year, which is far more than the total consumption of the country in a year. The daily average solar energy incident over India varies from 4-7kWh/m2, depending upon location. The output of photovoltaic cell is efficiently conditioned by power converters. The power converter must have high switching frequency in order to achieve small size, light weight, and low noise. In this work the power converters comprise of a Z source dc-dc converter and an inverter. Single phase stand-alone photovoltaic system based on z source dc-dc converter converts the light energy into electrical energy. Implementing stand-alone PV plants as distributed generation (DG) schemes provide many advantages such as providing power to remote load pockets which are difficult to supply from national utility grids. Since the output of the photovoltaic cell is clean and free of harmful emissions, demand for this kind of generation is increasing day by day.

2. MODELING AND SIMULATION OF PV CELL

An ideal PV cell is modelled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram below

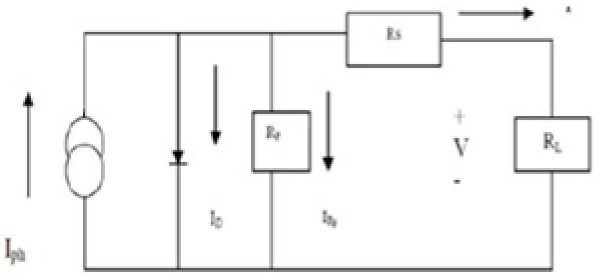

Fig-1: Equivalent circuit of a PV cell

RS is the intrinsic series resistance occurs as a charge carriers migrates from the semiconductor to electrical contacts whose value is very small. RP is the equivalent shunt resistance due to leakage current which has a very high value. Applying Kirchhoff"s law to the node where Iph, diode, Rp and Rs meet, we get

$$I_{ph} = I_D + I_{RP} + I \qquad (2.1)$$

We get the following equation for the photovoltaic current:

$$I = I_{ph} - I_{Rp} - I_D \qquad (2.2)$$

$$I = I_{PH} - I_0\left[\exp\left(\frac{V + I.R_s}{V_T}\right) - 1\right] - \left[\frac{V + I.R_s}{R_P}\right] \qquad (2.3)$$

Where, Iph is the Insolation current, I is the Cell current, I_0 is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel resistance, VT is the thermal voltage (KT/q). K is the Boltzmann constant, T is the Temperature in Kelvin, q is the charge of an electron.

The current source I_{ph} represents the cell photo current; R_j is used to represent the non-linear impedance of the p-n junction; R_{sh} and R_s are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of R_s 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 or PV generators. The PV mathematical model used to simplify our PV array is represented by the equation:

$$I = n_p I_{ph} - n_p I_{rs}[\exp(\frac{q}{KTA} * \frac{V}{n_s}) - 1] \qquad (2.4)$$

where I is the PV array output current; V is the PV array output voltage; ns is the number of cells in series and n_p is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current. The factor A in equation (2.4) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A=2.46.

The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs} = I_{rr}[\frac{T}{T_r}]^3 \exp(\frac{qE_G}{KA}[\frac{1}{T_r} - \frac{1}{T}]) \qquad (2.5)$$

Where Tr is the cell reference temperature, Irr is the cell reverse saturation temperature at Tr and EG is the band gap of the semiconductor used in the cell.The temperature dependence of the energy gap of the semi conductor is given by:

$$E_G = E_G(0) - \frac{\alpha T^2}{T + \beta} \qquad (2.6)$$

The photo current Iph depends on the solar radiation and cell temperature as follows:

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100} \qquad (2.7)$$

where Iscr is the cell short-circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mw/cm^2.

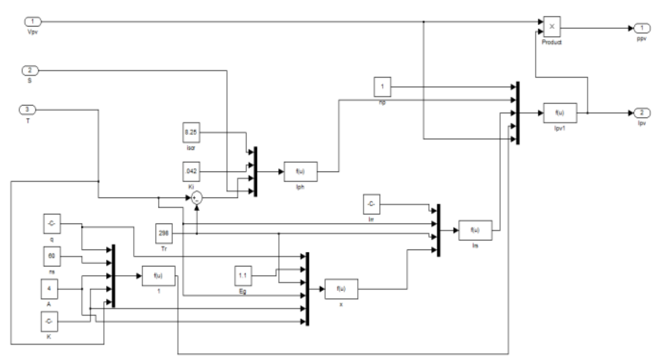

Fig-2: MATLAB/SIMULINK model of PV array

The current to voltage characteristics of a solar array is non-linear, which makes it difficult to determine the maximum power point. The figure below gives the characteristic I-V and P-V curve for a PV cell.

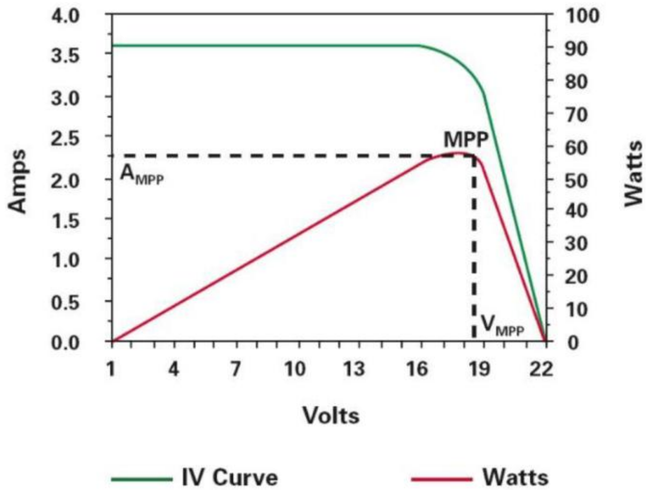

Fig-3: I-V and P-V curve characteristics

The characteristic I-V curve tells that there are two regions in the curve: one is the current source region and another is the voltage source region. In the voltage source region (in the right side of the curve), the internal impedance is low and in the current source region (in the left side of the curve), the impedance is high. Irradiance temperature plays an important role in predicting the I-V characteristic, and effects of both factors have to be considered while designing the PV system. Whereas the irradiance affects the output, temperature mainly affects the terminal voltage.

3. MAXIMUM POWER POINT TRACKING (MPPT)METHOD

In order to make photovoltaic arrays output more power in the same sunshine, temperature and other conditions, power electronic devices with maximum power point tracker control should be used in photovoltaic power generation system. MPPT play an important role in PV power generation systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. The output power of a solar panel is a function of the temperature, the sunshine and the position of the panel. It is also function of the product of the voltage by the current. By varying one of these two parameters, voltage or current, the power can be maximized. Several MPPT methods exist in order to maximize this output power and to fix its value, in steady-state, at its high level. MPPTs find and maintain operation at the maximum power point, using an MPPT. However, one particular algorithm, the perturb-and-observe (P&O) method, continues to be by far the most widely used method in commercial PV MPPTs. Perturbation and observation method and incremental conductance method commonly used in MPPT algorithms all change the duty ratio of the DC/DC converter by detecting the output voltage and current of the solar cells to get the maximum power. The parameters to be measured in the perturbation and observation method are fewer and the control is simple. Applying a variation on the voltage (or on the current) toward the biggest or the smallest value, its influence appears on the power value. If the power increases, one continues varying the voltage(or current)in the same direction, if not one continues in the inverse direction.

Fig.4 shows the block diagram of this MPPT method. In this figure, the duty cycle (αn) of the used chopper (or dc-dc converter) is calculated by the following expression:

$$\alpha_n = \alpha_{n-1} \pm \Delta\alpha$$

where $\Delta\alpha$ is the duty cycle step.

The different steps of the 'Perturb and Observe' method are:

2. If the power is constant, return to take new measurements,
3. If the power decreased or increased, test the voltage variation,
4. According to the direction of the voltage variation, modify the current.

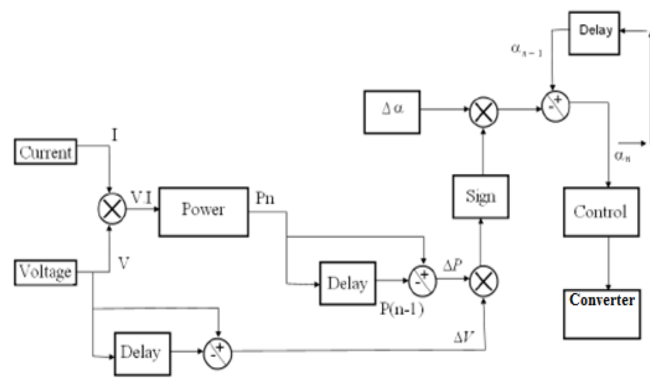

Fig- 4:Block diagram of the MPPT method, Perturb and Observe

Classical P&O algorithm is summarized as follows:
PV system controller change PV array output with a smaller step in each control cycle. The step size is generally fixed while mode can also be increased or decreased. Both PV array output voltage and output current can be the control object, so this process is called "perturbation"; then, by comparing PV array output power of the cycles before and after the perturbation. If power output is increased, "perturbation" will continue to work follow the direction in the previous cycle, else, if power output is decreased, "perturbation" will change the direction. In this way, the actual operating point of PV array can move closer to the maximum power point, and ultimately back and forth to reach steady state in a relatively small area.
Flow chart for P&O method is given below.

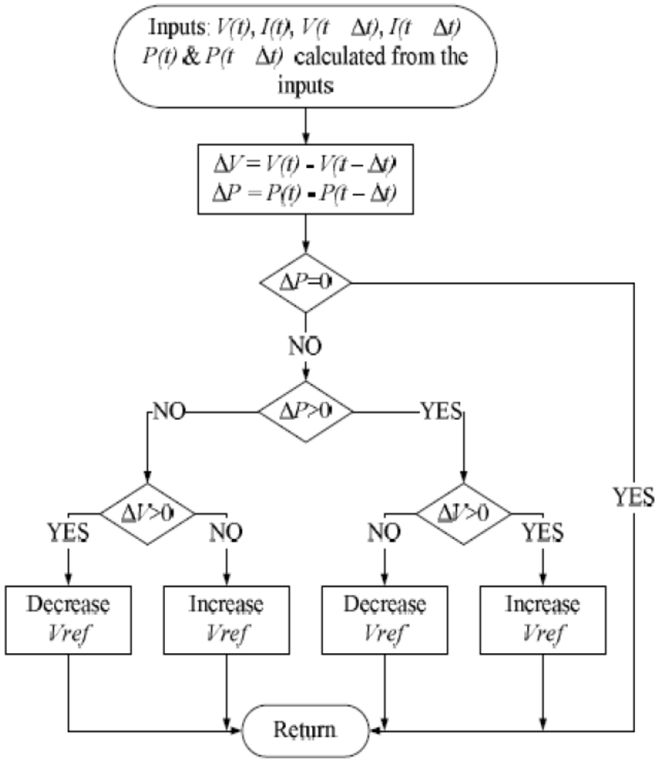

Fig-5: Flow chart of Perturb and Observe method

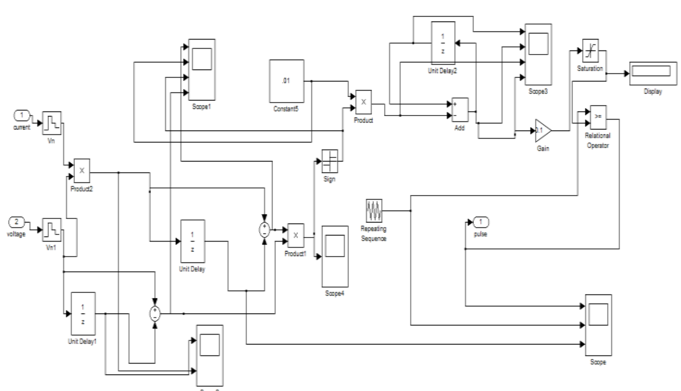

Fig-6: MATLAB/SIMULINK model of P&O MPPT method

4.OPERATION AND SIMULINK MODEL OF Z SOURCE DC-DC CONVERTER

System involving power converters are being often used in applications like alternative energy sources and hybrid electric vehicle (HEV). Major objective for power electronics designers are efficiency, low cost & reliability. New topologies in power conversion like Z-source converter are invented to give better results in some applications.ZSC is very promising new topology in power conditioning of alternative energy sources and applications like HEVs & utility interfacing. Z source converters can be grouped into Z source DC-DC converters, Z source rectifiers and Z source inverters (ZSI).Unique buck-boost capability of Z source DC-DC converter allows a wider input voltage range & eliminates the usage of traditional converter .In ZSC the shoot-through state is allowed. In this state both upper & lower switches of the same phase leg are turned on. Shoot-through state is forbidden in traditional converter like VSI or CSI.

Fig.7 shows the general Z-Source converter structure, which consists of inductors (Lz1 & Lz2) connected in X shape to couple the inverter to the dc voltage source, which may be a battery,diode, rectifier or fuel cell. The Z-Source converter can produce a desired dc voltage regardless of dc source voltage.

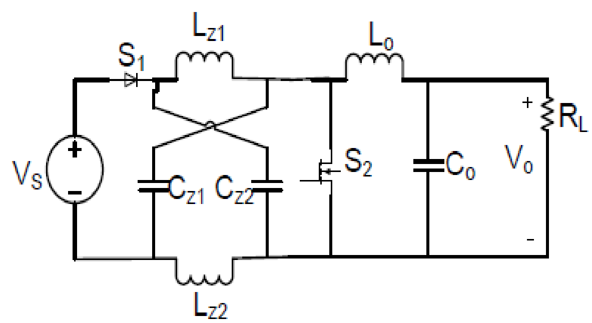

Fig-7: General Z-Source converter structure

The ZSC has two operating modes: Non shoot through mode and Shoot through mode. Figure 3 shows the equivalent circuit of ZSC at the non-shoot through mode and shoot through mode respectively.

In non shoot through mode as shown in Fig.8 switch S2 is off in this mode where Z-source inductor LZ, transfer the stored energies on them to load also the input current is transferred to Z- source capacitor CZ and load. Inductor Lo is energized during this mode. In this mode as diode is forward biased switch S1 is closed. In shoot-through mode as shown in Fig.9 switch S2 is switched on. In this mode Lz are energized by CZ. By applying Kirchhoff's voltage law voltage across diode (switch S1) comes out to be negative value. Diode becomes reversed biased and hence switch S1 becomes open .The load is meanwhile fed by filter inductor Lo and Co.

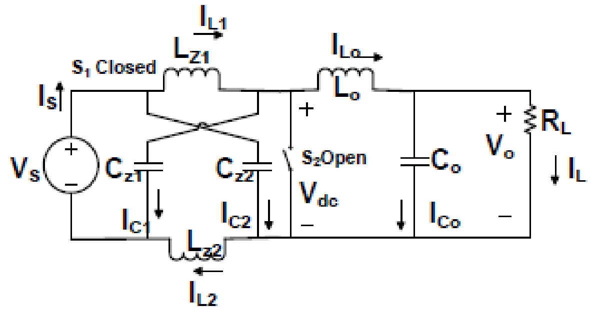

Fig-8: Non -shoot through mode

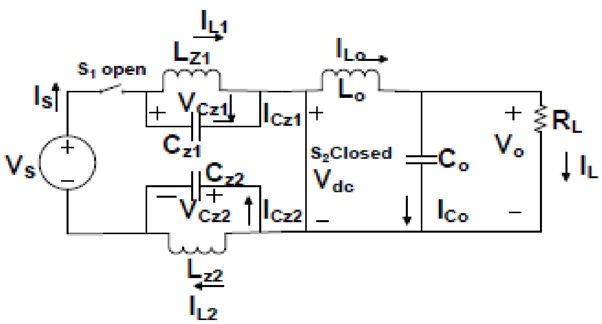

Fig-9: Shoot-through mode

Assume the Z-source inductors (L Z1 & L Z2) & capacitors (C Z1 & C Z2) respectively. From the equivalent circuit, we have $V_{LZ1} = V_{LZ2} = V_{LZ}$, $V_{CZ1} = V_{CZ2} = V_{CZ}$ When the ZSC is in the non-shoot through state for a period1 T from Figure 2(a) the inductor voltage and input voltage of the inverter can be expressed as:

$$V_{LZ} = V_S - V_{CZ} \ , \ V_{DC} = V_{CZ} - V_{LZ} = 2V_{CZ} - V_S$$

When the ZSC is in the shoot through state for a period o T from Fig 2(b), the voltage Vdc becomes zero. The inductor voltage can be expressed as:

$$V_{LZ} = V_{CZ}$$

As the average of the inductor voltage over one switching period T becomes zero in steady state, the capacitor voltage can be derived as:

$$V_{CZ} = \frac{T_1}{T_1 - T_0} V_S = \frac{1-D}{1-2D} V_S$$

Where $T = T_1 + T_0$ is the switching period & $D = \frac{T_0}{T}$ is the shoot through time duty ratio.

Vcz is the steady state (dc) value of capacitor voltage & Vs is the steady state value of the input voltage. . Similarly output voltage Vo can be derived as:

$$V_0 = \frac{1-D}{1-2D} V_S$$

As equation (4) and (5) has equal right hand side hence left hand side should be same. Hence

$$V_0 = V_{CZ}$$

The peak value (Vdcn) of the capacitor voltage is dependent on shoot through time & can be stepped up by increasing the shoot-through time. The peak value of the pulsating dc link voltage (Vdc) is given as:

$$V_{DCN} = 2V_{CZ} - V_S = \frac{T}{T_1 - T_0} V_S = \frac{1}{1-2D} V_S = BV_S$$

Where B is known as boosting factor on D.

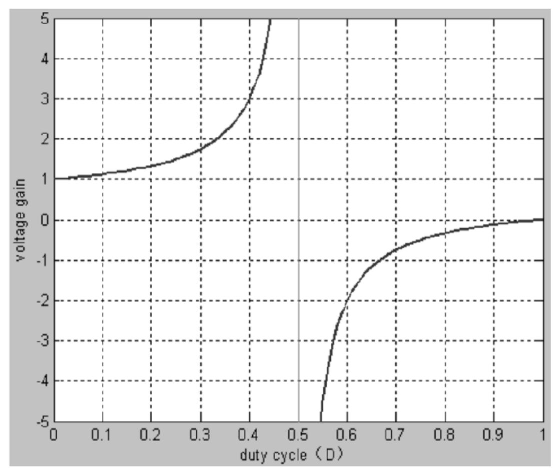

Fig-10: Voltage gain versus duty cycle

By controlling the duty cycle D, the output voltage of the double input dc-dc converter can be bucked or boosted. Fig.10 shows the voltage gain versus the duty cycle of the dc-dc converter. It clearly shows that there are two operating regions. When the duty cycle is greater than 0.5, the converter enters negative gain region, i.e., the polarity of the output voltage is reversed, and the converter operates in the buck/boost mode mathematically, but in practice it needs bipolar capacitor. When the duty cycle is less than 0.5, the output voltage is in phase with the input voltage, and the converter operates in the boost mode.

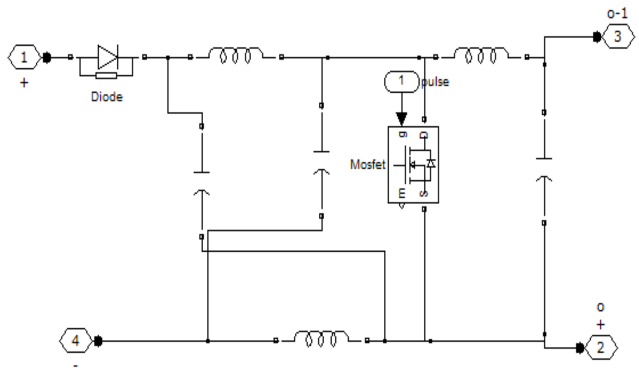

Fig-11: MATLAB/SIMULINK MODEL of Z source dc-dc converter

5.INVERTER

An inverter is basically a device that used to converts Direct Current into Alternating Current. The purpose of DC-AC inverter is to take DC power from a battery source and converts it to AC. The DC-AC inverters usually operate on Pulse Width Modulation (PWM) technique. The PWM is a very advance and useful technique in which width of the Gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user's choice) irrespective of the output load .In a conventional inverter the output voltage changes according to the changes in the load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC depends on the switching frequency and pulse width which is adjusted according to the value of the load connected at the output so as to provide constant rated output. The inverters usually operate in a pulse width modulated (PWM) way and switch between different circuit topologies, which means that the inverter is a nonlinear, specifically piecewise smooth system.

A full bridge inverter is shown in fig.12. In PWM with unipolar voltage switching, the switches in the two legs of the full-bridge inverter are not switched simultaneously. Here the legs of A and B of the inverter are controlled separately by comparing V_{tri} with $V_{control}$ and $-V_{control}$, respectively. As shown in fig.13, the comparison of $V_{control}$ with the triangular wave results in the following logic signals to control the switches in leg A:

$V_{control} > V_{tri}$: T_{A+} ON and $V_{AN} = V_d$

$V_{control} < V_{tri}$: T_{A-} ON and $V_{AN} = 0$

The output voltage of inverter leg A with respect to the negative dc bus N is shown in fig 13.For controlling the switches in leg B, $-V_{control}$ is compared with the same triangular wave form, which yields the following:

$(-V_{control}) > V_{tri}$: T_{B+} ON and $V_{BN} = V_d$

$(-V_{control}) < V_{tri}$: T_{B-} ON and $V_{BN} = 0$

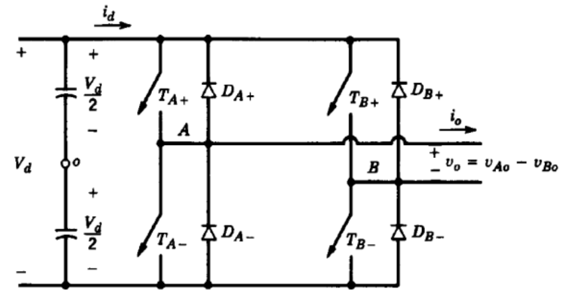

Fig-12: Single phase full-bridge inverter

The waveforms of fig.13 Shows that the there are four combinations of switch on-states and the corresponding voltage levels:

T_{A+}, T_{B-} ON : $V_{AN} = V_d$, $V_{BN} = 0$; $V_0 = V_d$

T_{A-}, T_{B+} ON : $V_{AN} = 0$, $V_{BN} = V_d$; $V_0 = -V_d$

T_{A+}, T_{B+} ON : $V_{AN} = V_d$, $V_{BN} = V_d$; $V_0 = 0$

T_{A-}, T_{B-} ON : $V_{AN} = 0$, $V_{BN} = 0$; $V_0 = 0$

When both the upper switches are on, the output voltage is zero. The output current circulates in a loop through T_{A+} and D_{B+} or D_{A+} and T_{B+} depending on the direction of i_o. During this interval, the input current i_d is zero. A similar conditions occur when bottom switches T_{A-} and T_{B-} are on.

In this type of PWM scheme, when a switching occurs, the output voltage changes between zero and $+_{Vd}$ or between zero and $_{-Vd\ voltage}$ levels. For this reason this type of PWM scheme is called PWM with a unipolar voltage switching, as opposed to the PWM with bipolar voltage switching scheme. This scheme has the advantage of "effectively" doubling the switching frequency as far as the output harmonics are concerned, compared to the bipolar voltage switching scheme

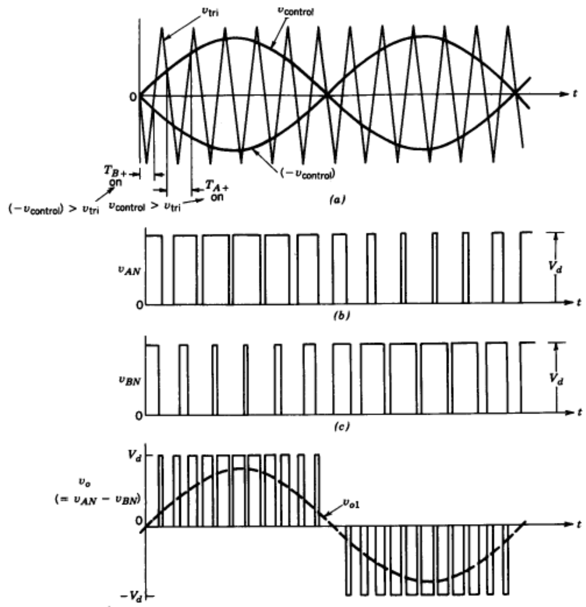

Fig-13: PWM with unipolar voltage switch

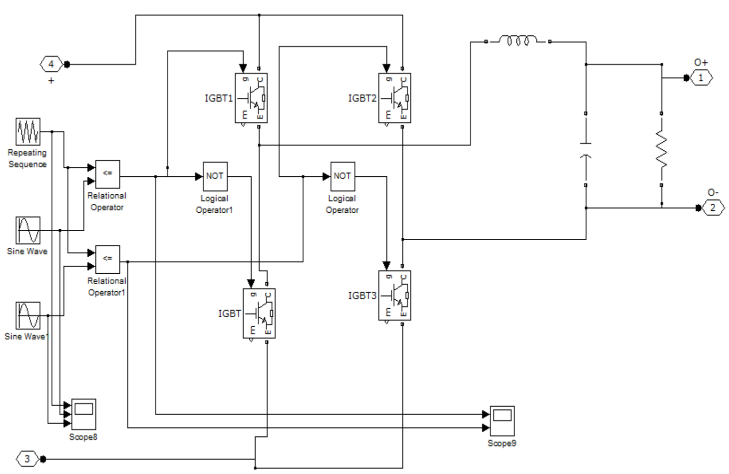

Fig-14: MATLAB/SIMULINK model of PWM inverter

6. THE COMPLETE SIMULATION MODEL

The figure given below shows the complete simulation model of the system. The system consists of a subsystem of photovoltaic array, perturb and observe maximum power point tracking method, z source dc-dc converter, a PWM inverter and a flooded battery.

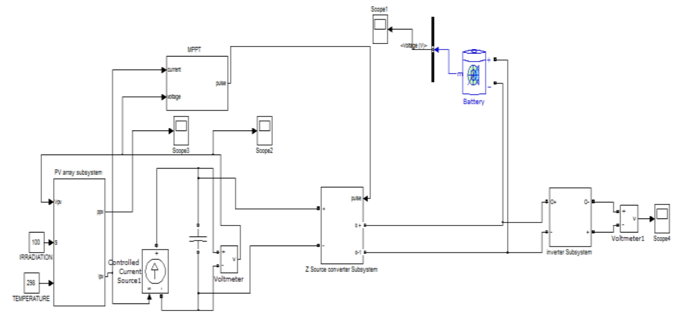

Fig-15: MATLAB/SIMULINK model of photovoltaic stand-alone system

Table-1: Simulation parameters

Parameters	Value
Inductor L_1	0.5e-3
Inductor L_2	0.5e-3
Capacitor C_1	100e-6
Capacitor C_2	100e-6
Capacitor C_3	100e-6
Inductor L	10e-3
Capacitor C	25e-6

7. SIMULATION RESULTS

Fig-16: PV array output power for an irradiation of 1000W/M^2

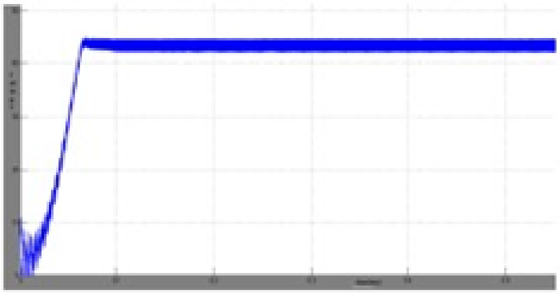

Fig-17: PV array output voltage for an irradiation of 1000W/M^2

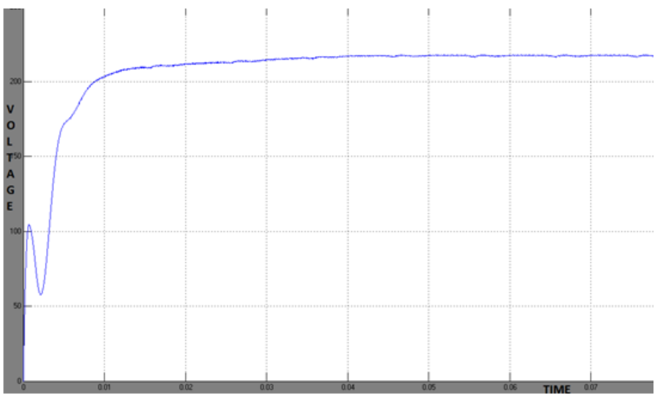

Fig-18: The output voltage of Z source converter

Fig-19: The output voltage of PWM inverter

The results shows that the output power obtained for an irradiation of 1000w/m2 is around 300watts.The output voltage obtained for an irradiation of 1000w/m2 is around 45Volts. The Z source converter gives 210volt of boosted voltage of, for a duty ratio of 40%. The result shows the output voltage of a PWM inverter of 170V and the total harmonic distortion obtained is 13%.

8. CONCLUSION

The cost of energy is rising and therefore photovoltaic system is a promising alternative. They are abundant, pollution free, distributed throughout the earth and recyclable. The PV array has been designed in MATLAB environment. The coupling of the photovoltaic array with the z source converter has been described .The maximum power point tracking is obtained by using perturb and observe method. An inverter is connected at the output of z source converter. The inverter switching control is by using sinusoidal PWM control and unipolar switching control is used. The controlled inverter output voltage can be step up or step down using a transformer as the load requirement. The battery model here is based on a lead acid battery model. The power outputs from photovoltaic plants fluctuate due to variation in solar irradiance and hence needs to be backed up by dedicated battery storage. Battery storage helps to compensate for this power fluctuation and provides steady power to the load. The proposed system has applications on water pumping in remote areas, home power supply, swimming-pool heating systems etc.

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