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Highly Efficient Pure Sine-Wave Inverter for Photovoltaic Applications with MPPT Technique

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***Abstract*—with the increase in the utilization of solar energy there is a need for renewable energy sources. A low frequency transformer is used to make project cost effective and sinusoidal pulse width modulation technique is employed for control circuit to obtain single phase pure sine wave inverter for PV applications. Distortion in the output waveform is minimized for both inductive and capacitive load by considering closed loop control PIC microcontroller is used to generate PWM pulses. The simulation is carried out using MATLAB to verify the presented approach.**

***Index Terms*— Solar panel, Boost converter, Maximum power point tracking (MPPT), Sinusoidal pulse width modulation (SPWM), Perturb and observe , Total harmonic distortion.**

1. INTRODUCTION

The world is moving towards use of non-conventional energy sources since continuous use of conventional energy sources like fossil fuels has caused the reduction of fossil fuel deposit and drastically affected the environment, depleting the biosphere and cumulatively adding to global warming. Requirement has increased for renewable sources of energy to be utilized along with conventional system to meet the energy demand. There are many alternative sources of energy such as solar, wind, ocean thermal, tidal, biomass, geo-thermal, nuclear energy etc. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. Solar energy is one among the alternative clear energy sources which are paid close attention by humans. This solar energy can be converted into electricity with the help of solar panel that are made up of silicon photovoltaic cells. DC-AC power inverters are a key part of PV power generation. The inverter is needed to convert the DC voltage from the PV array. Into

line frequency AC voltage used in standalone mode or grid connected application [1].With a well-designed application solar

can provide large amounts of power at low cost .DC-AC power inverters are a key part of PV

power generation. The inverter is needed to convert the DC voltage from the PV array into line frequency AC

voltage used in standalone mode or grid connected application. Available inverter choices are often costly and produce poor quality output. Quality of inverter output waveform is characterized by harmonic contents present. Square wave inverters are simple to construct but they are inferior to sine wave inverters in performance. The objective is to make a cost effective inverter to provide pure sine wave AC voltage while maximizing efficiency and reducing the total harmonic distortion (THD). Fig. 1 shows the block diagram of the proposed PV inverter system, the construction of which contains H-bridge configuration [3], closed-loop SPWM technique[4] controlled by microcontroller, DC-DC converter to utilize power between solar panel and inverter, a low frequency transformer, and passive low pass L-C filter.

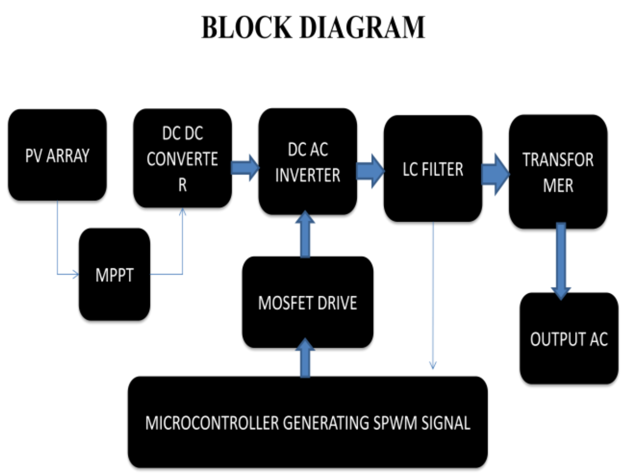

Fig 1BLOCK DIAGRAM

2. INVERTER DETAILS

2.1 *Photovoltaic Panel*

A photovoltaic cell or photoelectric cell is a semiconductor device that converts electrical energy by photovoltaic effect. When light falls on a PV cell, it may be reflected, absorbed, or pass right through. However, only absorbed light generates electricity. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell semiconductor material. When enough photons are absorbed by the negative layer of the photovoltaic cell, electrons are freed from the negative semiconductor material. Each individual solar energy cell produces only 1-2 watts of power. To increase the power output, cells are combined called a solar module.

2.1.1 *Mathematical Model for a Photovoltaic Module*

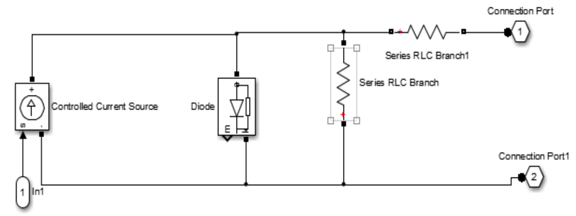

Fig 1.2 PV cell modeled as diode circuit

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor [10]. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation.

The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and Series resistances 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.

Module photo current

Iph= [Isc+Ki(T-298)]*λ/1000..................................(1)

Module Reverse Saturation current

Irs=Iscr/[exp(q.Voc/Ns.k.A.T)]....................................(2)

The Module saturation current I0 varies with the Cell temperature which is given by

I0=Irs*[T/Tr]3exp[q*Ego{(1/Tr)-(1/T)}]......................(3)

The Current of the PV module is

Ipv=Np*Iph-Np*I0[exp{(q*Vpv+Ipv*Rs)/NsAkT}]….(4)

Where,Vpv=Voc, Np=1,Ns=1

Nomenclature

Vpv is output voltage of a PV module (V),
Ipv is output current of a PV module (A),
Tr is the reference temperature = 298 K,
T is the module operating temperature in Kelvin,
Iph is the light generated current in a PV module (A),Io is the PV module saturation current (A),
A = B is an ideality factor = 1.6,
k is Boltzman constant = 1.3805 × 10-23 J/K,
q is Electron charge = 1.6 × 10-19 C,
Rs is the series resistance of a PV module,
Iscr is the PV module short-circuit current at 25 ^{o}C And1000W/m^{2} = 2.9A,
Ki is the short-circuit current temperature coefficient atIscr = 0.0017A / oC,
λis the PV module illumination (W/m2) =1000W/m2,
Ego is the band gap for silicon = 1.1 eV,
Ns is the number of cells connected in series,
Np is the number of cells connected in parallel

2.1.2 *SPWM*

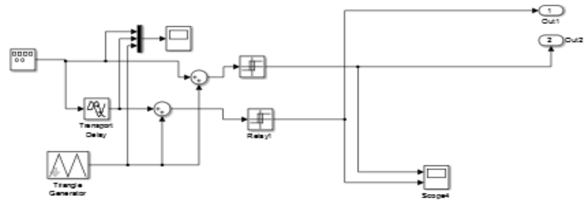

Fig 1.3 Model of SPWM in MATLAB simulink

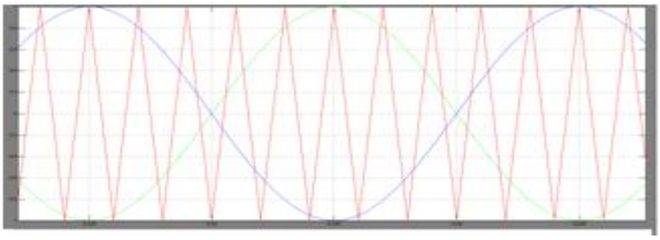

Fig 1.4 Generating technique of SPWM signal

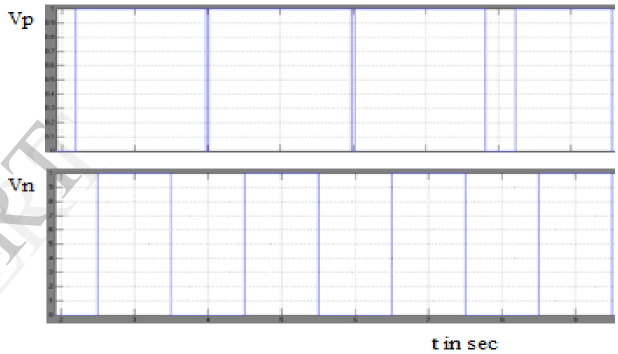

Fig 1.5 Output of SPWM signal from control circuit, Vp for Q1 and Q2&Vn for Q3 and Q4

In commonly conventional pulse width modulation (PWM) technique is used but in this a SPWM technique is used to generate a sine wave from DC input. To generate SPWM signal a high frequency triangular wave is used as carrier signal and this signal is compared with the sinusoidal signal which is a reference signal

2.2 DC-DC Converter

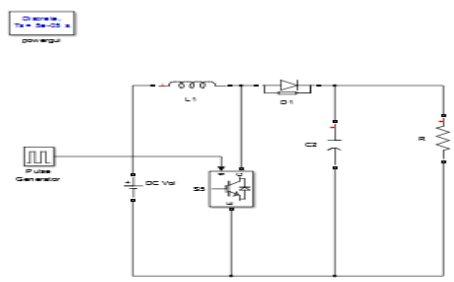

Fig 1.6 DC DC converter

Switch mode DC-DC converters are used to convert unregulated DC input voltage into controlled DC output voltage that ensures constant DC power supply to the inverter input at desired voltage level. These converters basically consist of capacitors, inductors, diode and transistors to step-up or down an input voltage. There are three basic topologies :buck (step-down), boost (step-up), and buck-boost (step up or down). DC-DC converters are controlled by the PWM duty cycle of the transistor, so that output of the converter depends on the state of the transistor switch. By varying the duty cycle, the optimal load impedance of the photovoltaic module can be achieved. In our design we preferred boost converter in case of steady environmental condition that successfully amplify PV arrays voltage into required level. DC-DC converters are used as switch mode power supplies for optocouplers, which electrically isolate the H-bridge inverter circuit.

2.3 H-Bridge Inverter

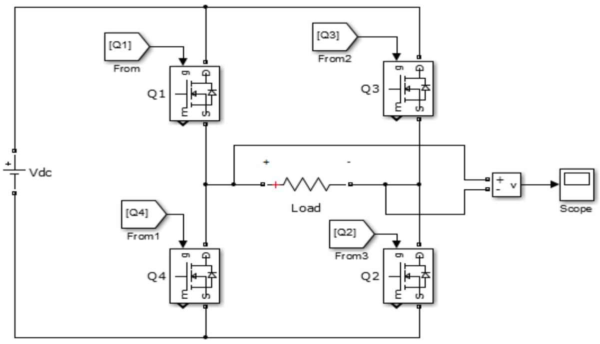

Fig 1.7 Inverter Circuit

Typical circuit diagram of the single phase bridge inverter is shown above .The configuration of single phase full bridge inverter consists of DC voltage source, four switches, and load. In my work I considered resistive and inductive load. As per the circuit switches Q1 and Q2 will turn on for half cycle, other two switches Q3 and Q4 will turn on for another half cycle. Control signals or triggering of the switches should be in such a way that Q1 and Q4 or Q3 and Q2 do not conduct together to prevent short circuit of the input DC supply.

3. SIMULINK MODELS

3.1. Solar panel

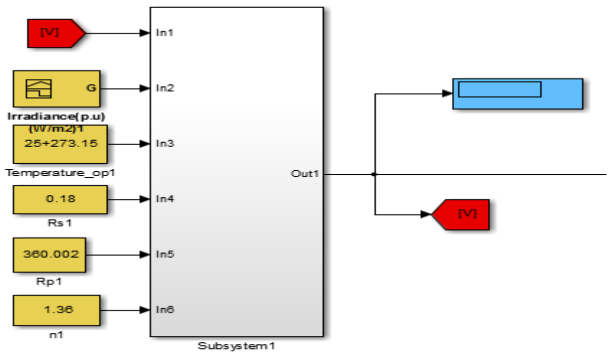

Fig 1.8 solar panel

PV array is interconnection of solar cells in series and parallel. Solar cell can converter the energy of sunlight directly into electricity. A simplified equivalent circuit of a solar cell consist of a current source in parallel with a variable resistor is connected to the solar cell generator as a load.

3.2 *Effect of cell temperature and cell radiation*

When the sun is brighter, module current is higher and vice versa. Since sunlight intensity and cell temperature vary throughout the day and the year, array MPP current and voltage varies. So the inverter and system design also get affected. The terms full sun or one sun are ways to describe the irradiance conditions at STC(1000W/m^2)

Temperature affects the characteristic equation in two ways: directly, via *T* in the exponential term, and indirectly via its effect on *Irs*. While increasing T reduces the magnitude of the exponent in the characteristic equation, the value of *Irs* increases exponentially with *T*. The net effect is to reduce *Voc* (open circuit voltage) linearly with increasing temperature. The photo generated current *Iph* slightly increases with the increase in temperature due to the increase in the number of thermally generated carriers in the cell.

3.3*Open loop simulink model*

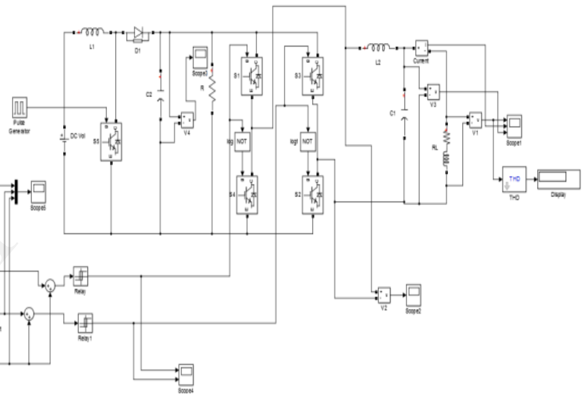

Fig 1.9 open loop model

As shown in the above fig1.9 open simulink model we used boost converter between PV array and inverter. As we get 24V DC from PV array which is to be boosted up to 300 voltages and this voltage given to the inverter and along with filter circuit we get the pure sine wave as output. As we know in inverter circuit the switches going to conduct complementarily. In this model we connected the SPWM model to each switch of inverter circuit. And here we used NOT logic gates which are giving opposite signal to other switches. And also LC filter is used to reduce harmonic and bring out the pure sine wave output at the load side. And also there is a display for total harmonic distortion (THD).

3.4*MPPT with Perturb and observe method*

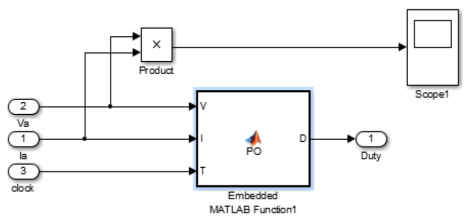

Fig 2 MATLAB function

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The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is

Varied by using a M PPT algorithm. This method is the most common. In this method very less number of sensors are utilized and. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples dP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until $dP/dV$is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point(MPP). In MATLAB function we have to write the coding for perturb and observe method. As from above model we can see the duty cycle which is given to the MOSFET switch of the BOOST converter.

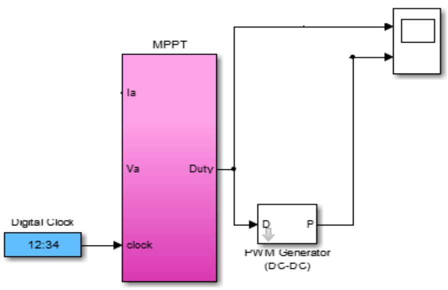

Fig 2.1 MPPT block in simulink

In above Fig2.1 as we see the MPPT block inside we have the block which is shown in Fig2. In Fig 2.1 we used PWM Generator to produce the pulses which is given to the input to the BOOST converter. We can see the output of MPPT in scope as shown above. And also there is an Digital clock for output current simulation time at the specified rate.

3.5 *Closed loop simulink model with MPPT feedback*

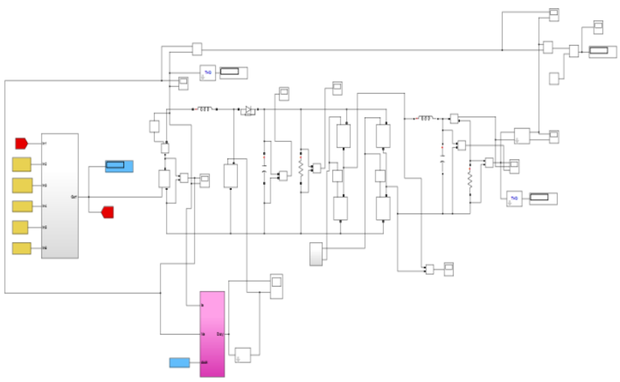

Fig 2.2 Closed loop simulunk circuit with MPPT block

Above Fig2.2 shows the closed loop simulink circuit with solar panel and MPPT block. The advantage is the total harmonic distortion (THD) of output is lower than the input THD.

4. SIMULATION RESULTS

Fig 4.1 shows non sinusoidal output voltage waveform and it has excessive harmonica and at the end of circuit we employ LC filter circuit to reduce the harmonics.

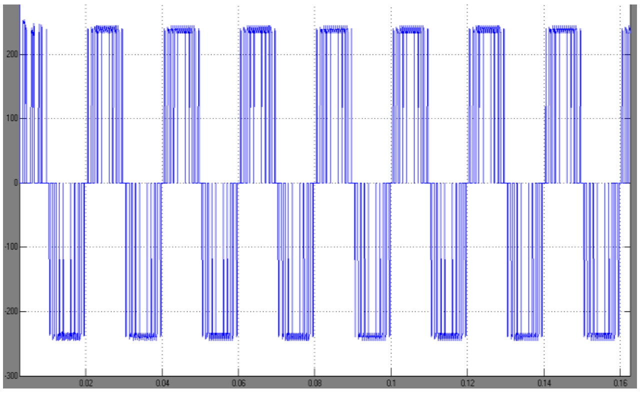

Fig .2.3 Output voltages without filtering

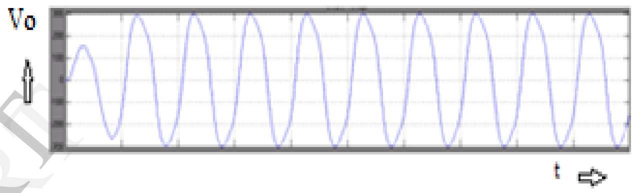

Fig 2.4 Output voltage with filter

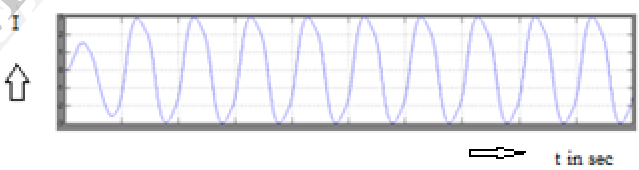

Fig 2.5 Output current waveform

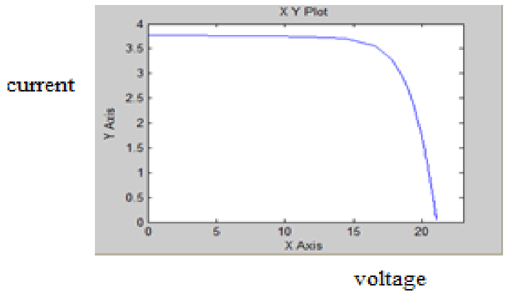

Fig 2.6 IV characteristic curve with irradiance= 1000W/m^2 and T=25 ^{0}C

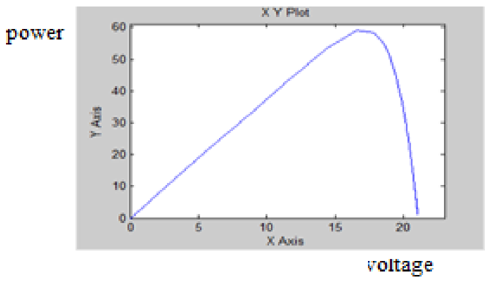

Fig 2.7 PV characteristic curve with irradiance= 1000W/m^2 and T=25 ^{0}C

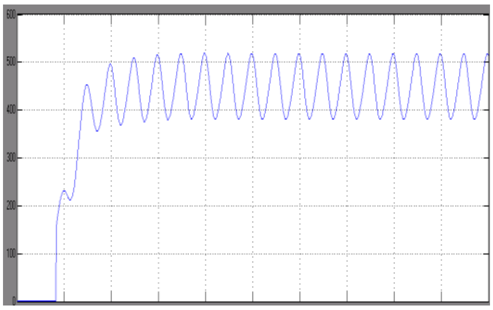

Fig 2.8 power improve foe without MPPT

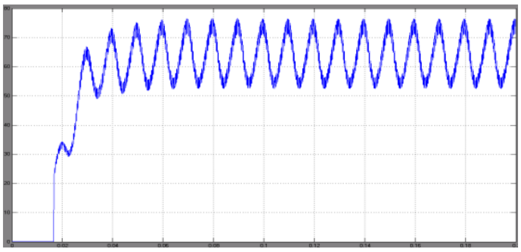

Fig 2.9 efficiency without MPPT

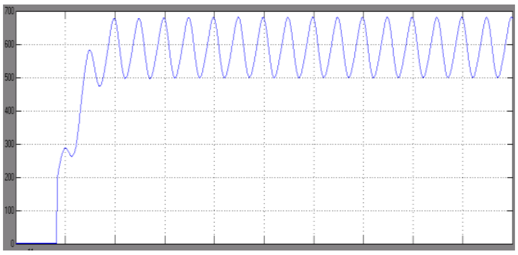

Fig 3 power improve with MPPT

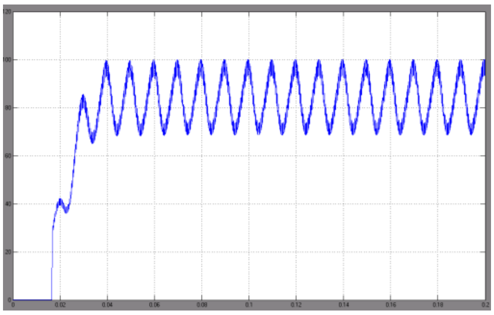

Fig 3.1 efficiency with MPPT

As below Table 1 shows the comparison between without MPPT block and with MPPT block. Data has been collected like voltage (V), current (A), power (W) and efficiency.

Table 1

Sr.no	MPPT technique	Voltage(V)	Current (A)	Power (W)	efficiency
1	Without MPPT	265V	2.6A	400 W	67%
2	With MPPT	305V	3.1A	525 W	90%

After filtering we get 300 V(rms), 50 Hz pure sine wave output voltage and in this we make use of SPWM technique. And also we used low pass LC filter. As from Table 1 we can greatly improve the system performance by introducing MPPT block. So closed loop simulation with MPPT greatly provide the good efficiency and a maximum power. Circuit insulation is needed for the safety of users.

5. CONCLUSION

This paper presents the design and simulation of pure sine wave inverter with MPPT technique. Various advantages exist like low switching losses, cost less, small size. And from this we can achieve the efficiency up to 90% and total harmonic distortion less the 0.3019% with around 300V rms, 50Hz pure sine wave inverter. This can be mainly used in residential purpose.

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