Vandana Publications
IJEMR

Volume-5, Issue-3, June-2015
International Journal of Engineering and Management Research
Page Number: 518-524

Analysis of Photovoltaic Micro-Inverter System using MPPT

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ABSTRACT

In this paper a grid connected step up photovoltaic micro inverter system is analysed using maximum power point tracking technique. To maximize power output of the photovoltaic system using MPPT, the system components need to be optimized. Considering this the conventional central inverter is replaced by micro-inverters connected to each PV array. Micro inverters acts as power optimizers and increases the overall output power transferred to the load. As a result the efficiency of the system increases. The main focus of this paper is to connect a DC-DC converter in between the PV module and the load. Among the various converter topologies and MPPT methodology the most suitable combination has to be chosen. A compromise between cost and reliability is made and a step up three state switching converter is selected along with perturb and observe MPPT methodology. Simulation work is carried out using Powersim software.

Keywords— Maximum power point tracking, micro inverters, photovoltaic system, step up converters.

I. INTRODUCTION

The day by day rapid increase in the electricity demand along with the changing environmental conditions like global warming, has come up with a need for a new source of energy. Considering cost and sustainability with low carbon emission solar energy is one of the energy sources which has offered promising results. Solar energy being available abundantly becomes easy to harvest and utilize. It can be used as a generating unit and can be connected to the nearby grid. Solar energy being portable, can be used whenever and wherever necessary for example it can be used to power those areas where grids are not available like rural areas. The increasing demand of PV system is because of the fact that solar radiations are converted into electric power without hampering the environment. The only problem is that solar energy is never constant and keeps on varying throughout the day. Our concern at this point is to deliver a constant voltage to the grid. For this we need a control mechanism which can extract maximum power from the incomingsolar radiations at all times. The need of power control mechanism has led to a new control mechanism known as Maximum power point tracking (MPPT) technique which has resulted in appreciable increase in efficiency [1].

In this paper instead of using a single central inverter several micro inverters are used. In general for a PV system inverters are composed of DC-DC step upconverters with multi stage topologies and DC link. Low cost, high efficiency and easy control mechanism are the major concerns. Also, micro inverters need high step up voltage gain. In order to achieve these conditions step up converters are used to interface the low voltage photovoltaic module. The transformer used must be high frequency since current is DC. For this full bridge inverters are used and the secondary is rectified back to DC.

There are various types of algorithm proposed for the maximum power point tracking –The perturb and observe algorithm, incremental conductance algorithm, pilot cell algorithm, reduced current sensor algorithm etc., each of the above methods result in high efficiency, transient tracking speed and complexity in control mechanism.

There are several topologies of converter circuits and MPPT algorithm. The cost factor and reliability are needed to be balanced when choosing a converter and an algorithm to produce the most efficient system. In this paper a three state switching cell converter is used which is basically a step up converter with a transformer, two switches, an inductor, a few diodes and capacitors. This combination result in high voltage gain. MPPT algorithm used is based on perturb and observe method.

For simulation powersim software is used. Powersim enables the simulation to perform with one of the most realistic PV panel characteristics(sharp NU235 PV panel). The dynamic test on MPPT control circuits are also carried out for guiding MPPT design. In this paper the powersim utility simulates a real PV panel reproducing its I-V curve related to the irradiation and temperature.

II. PHOTOVOLTAIC CELL MODEL

Photovoltaic cell (PV cell) is the basic building block of a solar panel. Various solar cells which generate low voltage are connected in series (high voltage) and parallel (high current) to form a PV module to get the desired output. The basic solar cell model consists of a current source, diode and two resistors. This type of model is single diode PV cell model. In a double diode model of a PV cell two diodes are present. At lower irradiation levels double diode model is more accurate [2].

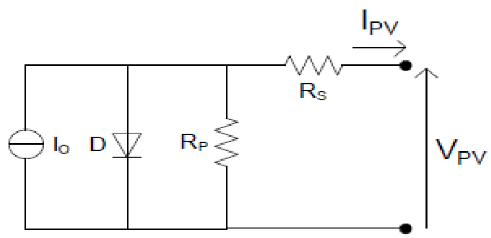

Fig.1: Single diode model of a PV cell

Applying Kirchoff's law to the node where I_O, diode, Rp and Rs meet.
We get,

$$I_O = I_D + I_{RP} + I_{PV} \;................(1)$$

$$I_{PV} = I_O - I_D - I_{RP} \;................(2)$$

$$I_{PV} = I_O - I_{DS}\left[\exp\left(\frac{V_{PV} + I_{PV} * R_s}{n * V_T}\right) - 1\right] - \left[\left(\frac{V_{PV} + I_{PV} * R_s}{R_P}\right)\right] \;..................(3)$$

Where,

I_{PV} = photovoltaic cell output current,
I_O = source current,
I_{DS} = reverse saturation current of thediode,
V_{PV} = PV cell voltage,
R_S = series resistance,
R_P = parallel resistance,
V_T = thermal voltage of module,
n = diode modified factor.
I_{RP} = current through the shunt resistor,

The shunt resistance is very high, so the current through it may be neglected. As a result equation 3 becomes,

$$I_{PV} = I_O - I_{DS}\left[\exp\left(\frac{V_{PV} + I_{PV} * R_s}{n * V_T}\right) - 1\right]................(4)$$

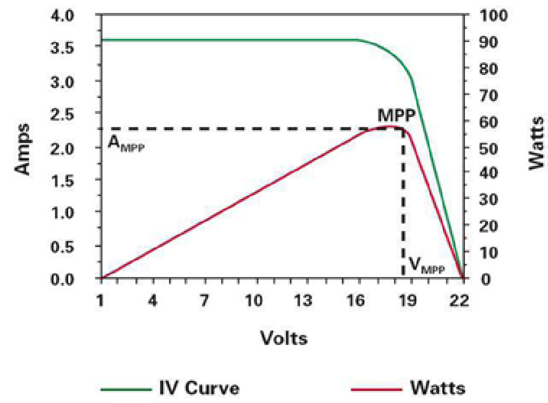

Fig.2: Characteristic curves of PV module :– I-V curve and P-V curve.[3]

The IV characteristic of a PV cell mainly depends upon the applied voltage and sunlight.

The variation in the power curve is due to temperature and current insolation.The power available at PV array terminal is directly proportional to current insolation and indirectly proportional to temperature.

III. DC – DC CONVERTORS

A DC- DC convertor is used toconvert DC voltage from a certain voltage level to another voltage level. When the convertor converts a high voltage level to low voltage level then it is called step-down converter or buck converter. On the other hand if it converts voltage from low level to high level then it is called a step-up converter or boost converter.

An example of DC-DC conversion technology is a voltage divider, potentiometer, etc. but they have resulted in poor efficiency. For the last 60 years there have been more than 500 DC- DC converters [4]. As per requirement new topologies and more developed designs are coming up day by day. Example of modern day DC-DC converters are buck converter or step-down converter, boost converter or step-up converter, buck- boost converter, zero voltage switching (ZVS) converter, zero current switching (ZCS) converters etc.

DC-DC converters are also used along with some other device like maximum power point tracker (MPPT) for PV module [5]. With the help of DC-DC converter the output voltage can be converted to the desired voltage level. In PV system we usually use the DC-DC step-up converter along with a DC-AC inverter. Therefore we can say that converters of a PV system are included with multi stage topology and DC link.There are some losses due to high switching current in the diodes and high voltage across the switches [6].

IV. BOOST CONVERTER

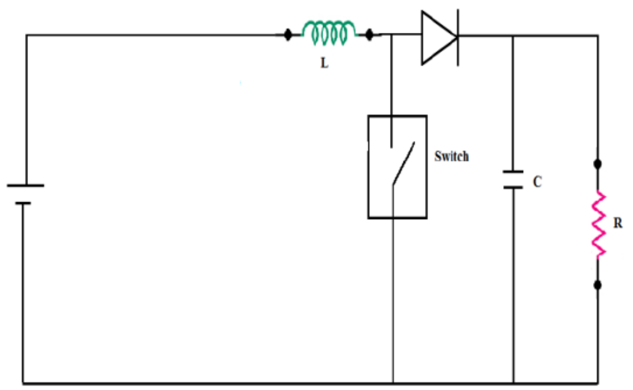

Fig.3: Boost converter.

The above figure depicts a conventional boost converter. As the name suggests boost converter steps-up the input voltage to a required output voltage. A basic boost converter comprises of a diode, an inductor and a high frequency like MOSFET. This combination results in an increased output voltage magnitude.

The output voltage is controlled by manipulating the duty cycle of the switch. A boost converter operates in two different modes which depend on closing and opening of switch. The modes are – charging mode of operation which means that the switch is closed and the other one is the discharging mode of operation which means the switch is open.

DC-DC boost converter is connected in between the photovoltaic module and the grid or the load. The converter is controlled by the switch i.e., MOSFET. The closing (ON) and opening (OFF) of the MOSFET controls the output voltage. It does so by changing the voltage of the inductor. As a result maximum power is transferred to the load from the PV module. The conventional boost converters have some limitations which does not allow it to result in higher efficiency.

When the switch is ON energy is stored in the inductor. When the switch is OFF, current flows from inductor to the load. This results in a voltage gain which is given by –

$$\frac{V_O}{V_{in}} = \frac{1}{1-D} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

Where,

V_O = output voltage,
V_{in} = input voltage,
D = duty cycle.

Therefore,

$$D = 1 - \frac{V_{in}}{V_O} \ldots\ldots\ldots\ldots\ldots(6)$$

Micro-inverters require high step-up voltage gain which cannot be achieved by conventional topologies [7]. Some examples of boost converters used in MPPT are – Flyback topology converter, tapped inductor boost converter, high step-up converter with switched capacitors, high step-up converter with multi-level cell. High step-up interleaved boost converter with coupled inductor and switched capacitor. In this paper a 3 stage DC-DC step-up converter is considered.

V. MICRO-INVERTERS

Micro-inverters are small electronic devices used to convert direct current(DC) generated from a single photovoltaic module in alternating current(AC). In the conventional system all the PV arrays are connected to one central bulky converter but in this design one micro inverter is connected per PV array and theoverall power combined from each PV array is fed to the load.

There are several advantagesof using micro-inverters in place of conventional string inverter. The main advantage is that if due to any reason a solarmodule is partially covered or even complete failure occurs then also the supply is not affected. This is because each module has separate micro-inverter installed and each micro-inverter harvests maximum power with the help of maximum power point tracker.

Advantages of micro-inverters:-

- Installing converters into the module reduces cost.
- Converter temperature is reduced so no need of fan.
- Reliability has increased over the past years.
- Hard switching techniques are replaced by soft switching techniques which reduces heat dissipation. As a result system becomes more efficient.
- Electrolytic capacitors are eliminated and non-electrolytic capacitors are introduced.

VI. MAXIMUM POWER POINT TRACKING (MPPT)

Maximum power point means the point at which a system work with its highest possible efficiency, which results in maximum power output. A maximum power point tracker is basically a DC-DC converter with high efficiency. For a PV cell it acts as an optimal electrical load and converts the voltage level to the desired voltage level. There is a single operating point in each PV cell where the voltage and current values result in a maximum power output[8].

Maximum power point tracker is an electronic system which is used to control the duty cycle of the converter. This helps the PV module to operate at maximum operating point all the time without the help of any mechanical system used to rotate the PV module in the direction of sun light. This technique gives greater efficiency during climatic conditions like cloudy or hazy days, cold weather or some time when battery is completely discharged.

Tracking methods consists of various algorithms which sets the system to maximum power point so that it can give maximum efficiency. When efficiency is maximum, overall cost is also reduced.

Various MPPT methodologies are listed below–

1) Perturb and observe algorithm,
2) Incremental conductance algorithm,
3) Pilot cell algorithm,
4) Fuzzy logic algorithm,
5) Artificial neutral network algorithm,
6) Temperature algorithm, etc.

In this paper we are concentrating on perturb and observe algorithm. However, there are other models in which different methodology is adopted [9].

VII. THE PERTURB AND OBSERVE ALGORITHM

As the name suggests, in this algorithm the voltage is perturbed and the resulting power output is measured. If change in power has the same sign as that of voltage then it means that the operating point has moved closer to the MPP. On the other hand if change in power has different sign of that of voltage then it means that it has moved away from MPP. As a result, opposite change in voltage need to be applied. This algorithm is very easy to understand and implement. After reaching the MPP the power starts decreasing and hence perturbation reverses. Perturbation size is taken very small so that power variation is very small. With the help of this method a reference voltage is set corresponding to the peak voltage. The drawback of this method is that small changes and rapid change in irradiation is very difficult to read. This method is also not suitable during constant irradiation as because it is always perturbing the voltage no matter what the case is.

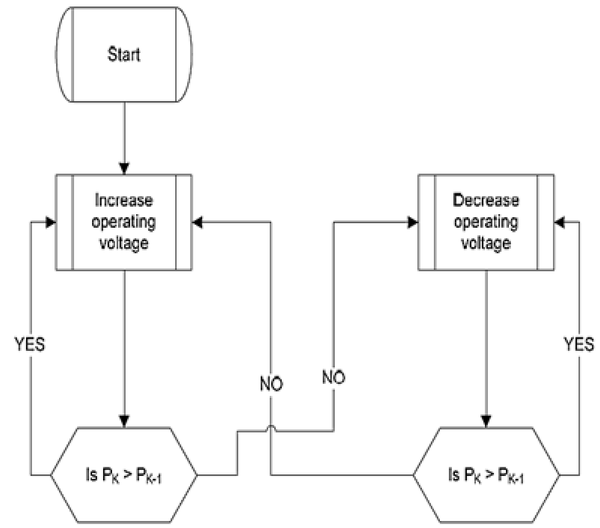

Fig.4: Flowchart of the Perturb and Observe algorithm

VIII. SIMULATION RESULTS

In this paper the simulation model is carried out using powersim. The simulation model is shown in figure.4. The DC-DC boost converter which is connected in between the PV module and load,need input voltage and current. The input voltage and current fed to the boost converter is supplied from the PV module. Initially the PV cell generates 30V voltage by using MPPT method. Then it is fed to the DC-DC boost converter so that it can be raised to the desired voltage level. Now depending upon the duty cycle of the boostconverter, voltage is stepped up to a voltage level 400V. Next it is converted into AC by a single phase or three phase inverter to the same voltage level and is fed to the grid. The duty cycle of the boost converter is controlled by varying the PV module voltage.

ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

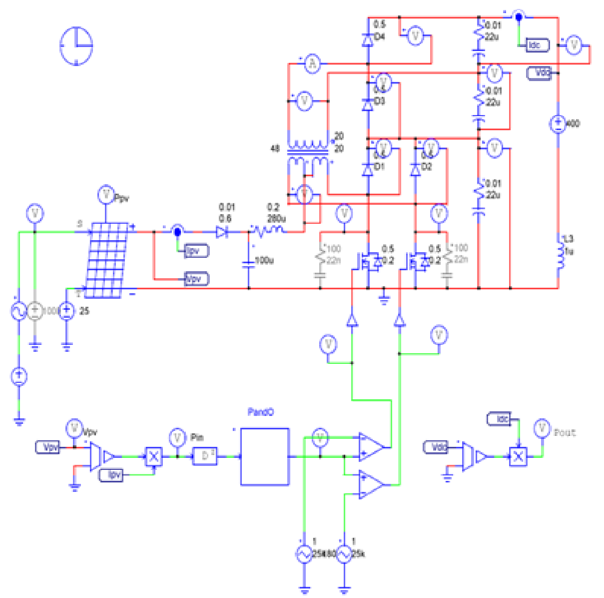

Fig.5: complete simulation power and control circuit.

All the dimensioning work is carried outkeeping in mind the desired specifications like voltage gain, power and response fastness. Turns ratio of the transformer depends upon the duty cycle of the boost converter and is 2.33.

Table.1.

PV panel	Sharp NU235
Input voltage to the converter(V_{PV})	30V
Output voltage of the converter(V_O)	400V
Working frequency	25Hz
Maximum input current(I_{PV})	8A
Maximum power	235V
Admissible input current ripple (ΔI_{Lb})	1.2A
Admissible output voltage ripple (ΔV_o)	4V

Simulation results for constant irradiation:

Initially standard light intensity (SLI) is taken 250 W/m^2 and then a step for 1000 W/m^2.

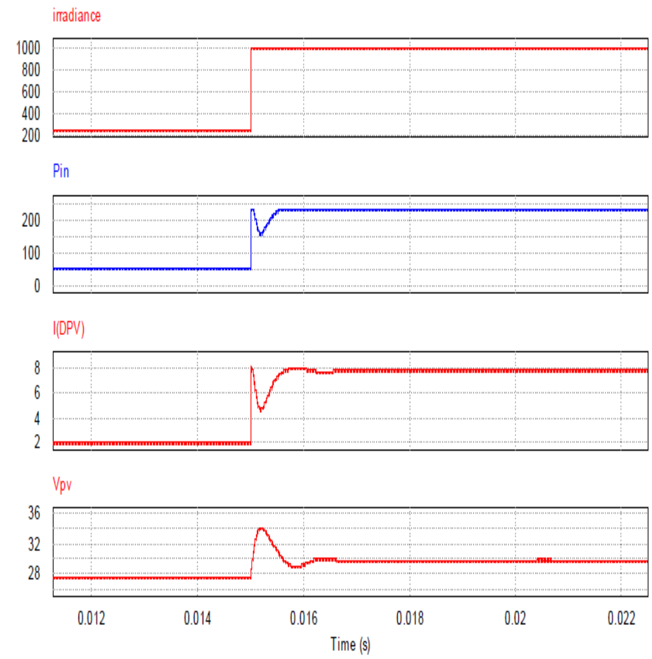

Fig.6:Pin - actual power from panel, I(DPV) - input current across the inductor, Vpv - voltage at PV terminal.

Simulation results for sinusoidal irradiation :

Here a sinusoidal irradiation variation of 50 Hz from 0 to 1000W/m^2 is considered.

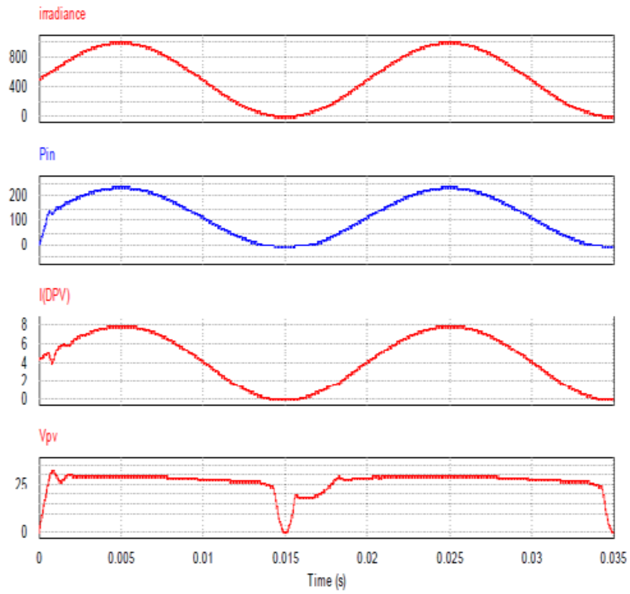

Fig.7: irradiance, Pin-the actual power from the panel, I(DPV)-current across panel, Vpv-voltage across panel.

The speed of 50Hz is superior to the speed of solar radiation changes even in case of cloudy and hazy days. This proves that if our system can perform good in this weather condition than it will do better in normal weather conditions.

Simulation results for step variable irradiation:

Rapid changes in irradiation is considered, with frequency 50Hz and duty cycle is taken 50% that is 500 to 1000W/m^2.

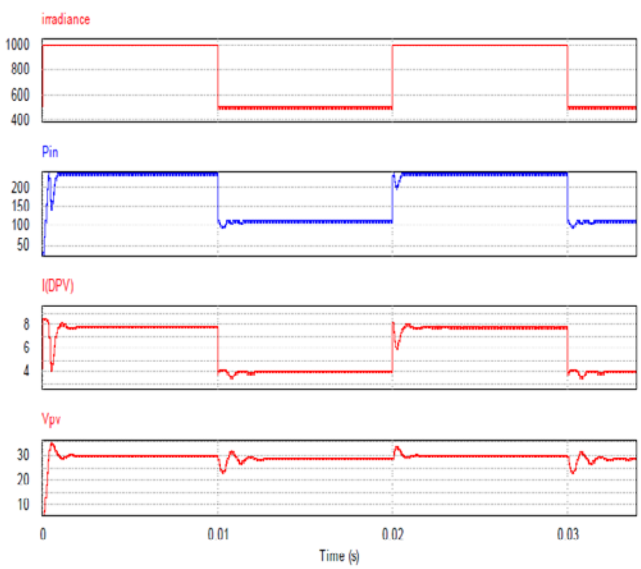

Fig.8: Irradiance level, actual power from the panel, input current across the panel terminal, voltage at PV terminal.

This proves that in case the system is covered by any obstacle the system will work normally.

Efficiency:

Considering maximum irradiance of 1000W/m^2, maximum power output and input power to the converter is 207W and 234.9W respectively. Which gives an efficiency of 88%.

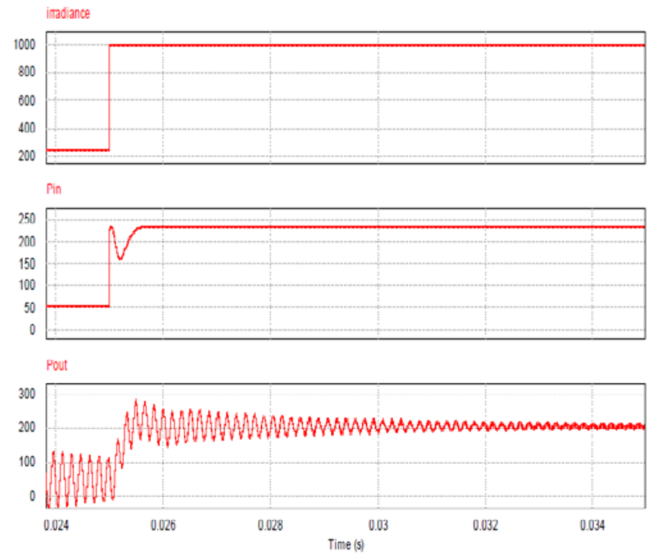

Fig.9:converter input and output power according to irradiance

With this topology better efficiency can be achieved if there is less loss across the transformer and inductor and the switches, diodes are of better quality.

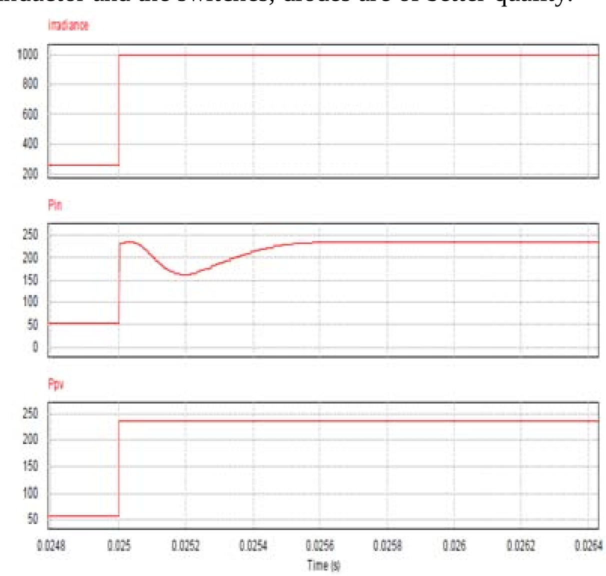

Fig.10:Simulation power curves from the PV panel and input of the converter

IX. DISCUSSION AND CONCLUSION

In this paper a new type of converter topology is presented and one large central inverter is replaced by several small inverters called the micro inverter. The system is exposedto various climatic conditions and outputs are observed. Use of micro inverter optimizes power output so it is called power optimizer. The system operates successfully with constant irradiation, sinusoidal irradiation and for step variable type irradiation. In this paper a combination of high efficiency inverter and peak power tracker is proposed considering overall cost. The converter operates very close to MPP and forms a DC to AC inverter. This system can be applicable to a wide operating range ofDC-AC power conversion so that we can utilize the tremendous amount of solar energy available naturally through the photovoltaic system.

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