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Harnessing Maximum Power from PV Module using DC-DC Converter

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Abstract: Solar energy is one of the most potent sources of energy. In the wake of depleting fossil fuel energy sources and growing environmental concerns, world is in a relentless drive towards utilizing natural resources like sun efficiently. The aim of the project is to make the solar module work in MPPT mode (Maximum Power Point Tracking) Mode. At this condition, the system is able to extract maximum power from the module without affecting the PV module. MPPT control here is obtained using boost converter. Applying PWM with proper controlling algorithm will vary the duty ratio of the converter such that system will run in MPP mode.
Keywords: Solar Energy, MPPT Mode, PV module, Boost Converter, PWM

I. INTRODUCTION

Solar Energy is an essential source of renewable energy. Solar energy, radiation from sun is capable of producing heat, causing chemical reactions or generating electricity. Solar is an inexhaustible source of energy apart from being clean and emission free. Energy can be harnessed from solar in many ways. Some of them are -Concentrated solar power plants (CSP), solar heater, solar heat generating system for cooking etc. But applications of these are limited and render less efficiency. Today, most efficient and widely used technology to harness solar energy is through PV cell.

PV or photo voltaic cell produces energy when photon (or light) of sufficient threshold energy falls on it, by producing electron-hole pairs (EHP) and movement of those EHP under the influence of electric field created by the junction. There is always a trade-off between selecting a photovoltaic material which has large band gap and the one with small band gap. For small band gap material, more photons from sun would have sufficient energy to excite electrons which is good in a sense that it creates charges that in fact enable the current to flow. Nevertheless, a small band gap means that many photons would have surplus of energy which is above the threshold required to make EHPs thus wasting their potential. On the other hand, large band gap material is having the opposite combination. A large band gap material indicates that only a smaller number of photons would have sufficient energy to overcome threshold energy to create EHP pairs, which in fact limits the generated current. It can be said that large band gap renders higher voltage with less surplus energy leftover. In other words, a large band gap results in higher voltage and less current while a low band gap energy gives less voltage with higher current It produces direct current. A PV cell is a simple P-N junction diode which is light sensitive.

The output power of a conventional silicon based solar cell is in milli watts range and terminal voltage would be less than or equal to one which will not be sufficient to drive a load or to connect with a distribution system. So many cells have to be connected in series and parallel in a sealed case with weather proof, which actually forms a module. Even this alone will not cater the need, so several modules are connected in series to increase the voltage produced thus forming a string.

One of the advantageous of solar PV is that anyone can install the panel on roof top or even on a flat ground where shading of sunlight does not exist. Also setting up of a solar panels in home is affordable to common man, unlike the wind which is exorbitant and practically not possible to fix on roof tops or even flat ground in urban areas.PV system is extremely modular and enables us to transport easily to any location. But wind turbines on the other hand, extremely difficult to transport to far locations because of its size and weight.

II. CONFIGURATIONS

There are different configurations available for solar energy extraction. As PV produces DC current and voltage, it cannot be directly connected to grid. Hence, a three-phase inverter is used to convert the DC voltage of the solar to three phase AC voltage. Based on applications, it can be mainly categorized into

A. Stand-alone PV system.

Stand-alone PV is used in residential applications or in remote, grassroot areas where electrical grid not practically easy to set up. They are used to feed local loads which can be either AC or DC. Battery is used to store and discharge energy whenever required.

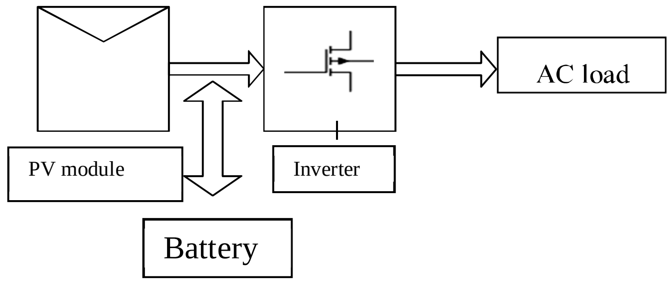

Fig. 1 Stand-alone system supplying AC load

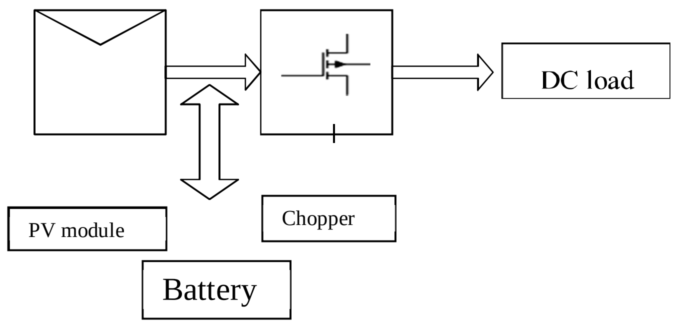

Fig. 2 Stand-alone system supplying DC load

B. Grid-Connected PV system

Here at the end of conversion power produced by PV system is going to grid. But it should be synchronized with grid, means voltage and frequency at the end should be same as that of grid. Mainly, there are two types of grid connected PV system- Single stage grid connected PV system and Dual stage grid connected PV system.

Single stage grid connected system configuration is similar to fig.1 while in dual stage there are two converters employed. Arrow indicates power flow direction. Chopper is stepping up the dc voltage of the solar module, after which inverter converts DC voltage to AC and then it's connected to grid. If the inverter voltage rating is low then a transformer is used to step up the inverter output to grid voltage.

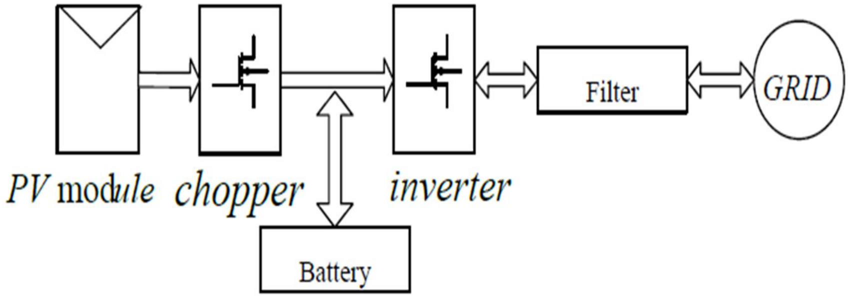

Fig.3 Dual-Stage Grid connected PV system

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III.MATHEMATICAL MODELLING OF SOLAR PV

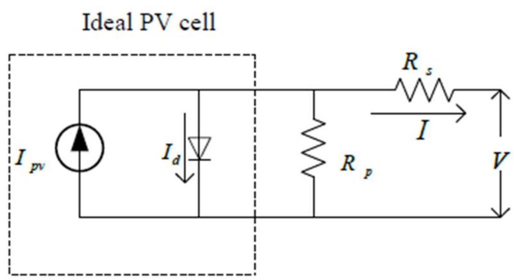

Fig.4. Si-Diode model of a conventional PV cell

In Fig4, I_{pv} is current produced by the incident light, which is directly proportional to intensity of the radiation. I_d is the diode current and let I be the load current. R_s is the series resistance of the device which basically depends upon[1] the contact resistance of the base of metal with ‘p’ layer of semiconductor, the resistance of ‘n’ and ‘p’ bodies and the top metal grid resistance on ‘n’ layer.

But generally, the value of R_s is very small and negligible. On the other hand, parallel resistance R_p is due to the leakage current at p-n junction and depends upon the method of fabrication of PV cell. In general, value of R_p is very high.

The light dependant current is directly proportional to irradiance and influenced by temperature and relation[1] is given by

$$I_{pv} = (I_{pv,s} + K\Delta S)\frac{G}{Gs}$$

Where

- $I_{pv,s}$ is the light generated current
- $\Delta T = T - T_s$ (T_s is te standard temperature and T is the actual temperature in Kelvin
- G and G_s are the actual and standard irradiance.

IV.MPPT OF SOLAR PV

Most desirable condition of a solar module is to make it work in MPPT mode. This is a condition at which the system is able to extract maximum power from the module without affecting the PV module. Here, the slope of the line that is $1/R_T$ where R_T is the effective resistance which is adjusted with the help of proper power controlling algorithm and PWM. R_T is depending upon the duty ratio so that change in duty ratio will vary the slope of the line. When the load line intercepts the MPP (Maximum power point) of PV curve, the system is said to work in MPPT mode.

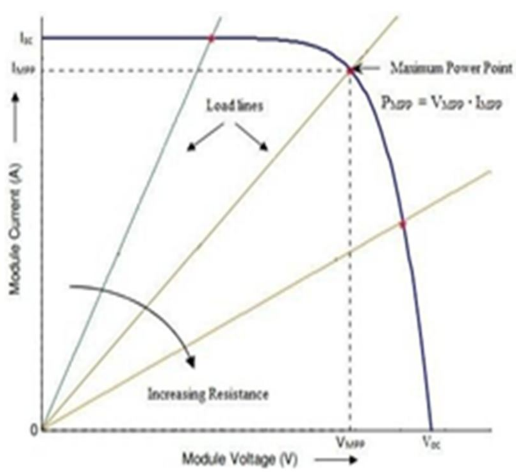

Fig 5. MPPT and load line characteristics

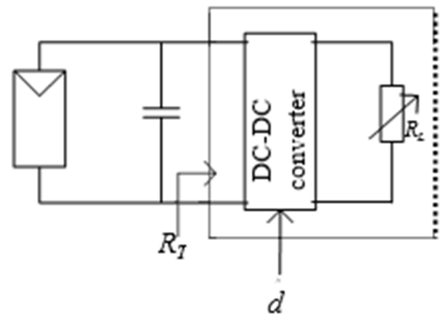

Fig 6. MPPT control using a chopper

Here is the combined resistance the circuit after chopper, and the effective resistance of dc-dc converter is the function of its duty ratio 'd'.

'd' is the output of the inner control loop which is compared with carrier signal of quite high frequency and generate pulse which is then given to IGBT. In this work carrier frequency is set at 5kHz.

The boost converter used as the power electronic converter which, in this work has a different topology. That is, after the capacitor, the branch is split into three with equal impedance in each branch. This is a one directional converter. The carrier used in each leg is phase shifted by 120° which ensures that the actual current, which is tracking the reference current produced by the MPPT voltage control loop (outer loop) is also having a phase difference of 120°.Finally when these three branches merge into one branch, the net current will have less ripples because it is the summation of three 120 phase-shifted currents. This configuration is called interleaved topology (Fig.7).

The advantages of interleaved converters is that

1) It reduces harmonics in current as well as duty ratio.
2) Size of the inductor used in branch and the capacitor connected at the input of the boost converter is reduced.
3) As the current ripple is reduced, switching frequency chosen is lower than that of a conventional boost converter.
4) even if one or two branches gets open circuited the 3rd branch will still work

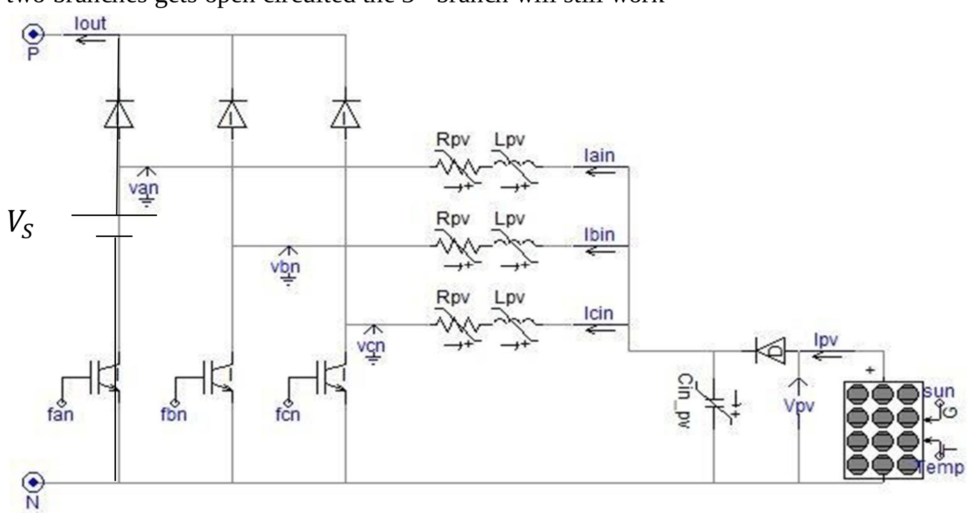

Fig.7 Implementation of three-phase boost converter

V. P &O ALGORITHM

This is the most widely used and accepted method for implementing MPPT of PV system. This hill climbing algorithm involves continuous search process for the reference voltage to attain MPP [2]. It is done by perturbing the voltage reference and then observing system response to find out the direction of next perturbation. The voltage reference perturbations are done in a direction at which the power is increasing.

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Here power is sampled at a particular rate. This sampling time and the time interval at which reference voltage is updated are to be properly chosen. The time interval must be adequate to allow the converter to reach steady state around the voltage reference before the next perturbation is given [2].

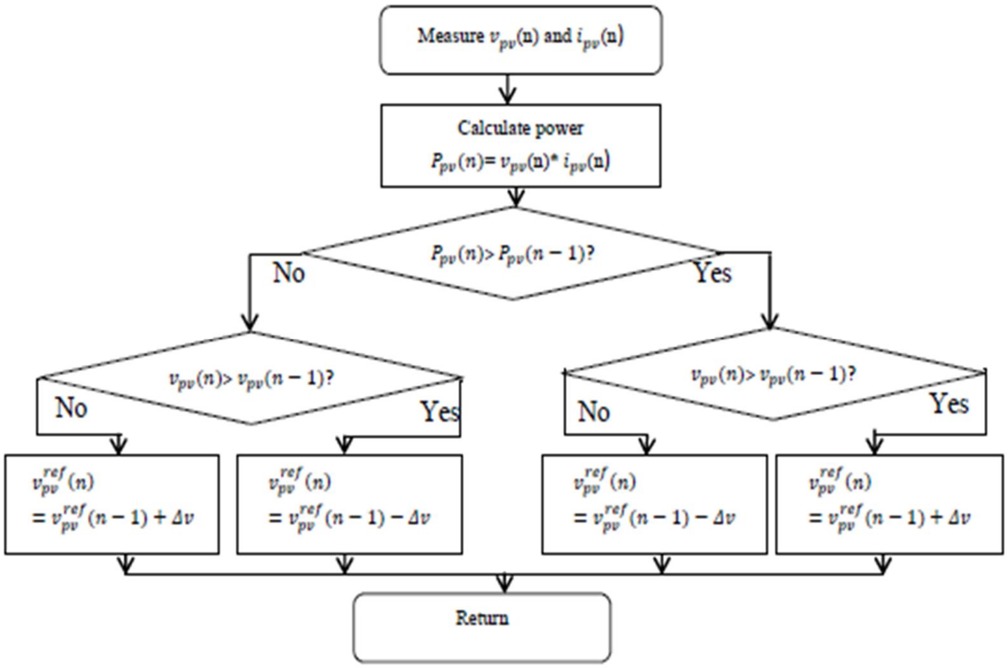

Fig 8. P&O Algorithm

However, it will never reach exact MPP, in fact it will oscillate about MPP with negligible voltage difference from the MPP voltage ΔV. There is always a trade-off between the accuracy and speed of response of MPPT algorithm. If we chose very low value for ΔV such as 0.1mV, speed of response will be low. On the other hand, a high value for ΔV will reduce its accuracy leading to large oscillations about MPP. One of the drawbacks of the P&O to be emphasized is that it will fail under rapid change in environmental conditions such as solar irradiation. The reason for this can be the variation in power due to operating conditions is higher than the changes caused due to perturbation produced by algorithm [2].

VI. CONTROL LOOPS

The outer loop shown in Fig.8 produces total input inductor current which is to be divided by three to get input current for each branch. This input current for one inductor is the input for the inner loop, i.e current controller loop shown in Fig.10.

Fig.10 is the control loop for branch ‘a’, for branch ‘b’ and ‘c’. Output of this control loop is duty ratio of IGBT of the upper leg of branch ‘a’. Subtract that from one to get duty ratio of bottom switch and which is compared with high frequency carrier and produced pulse ‘fan’ as can be seen from fig.7 is given to bottom switch. Similar procedure is done for branches ‘b’ and ‘c’ to get pulses for other two-legs. The purpose of second limiter to restrict the value of duty ratio between zero and one.

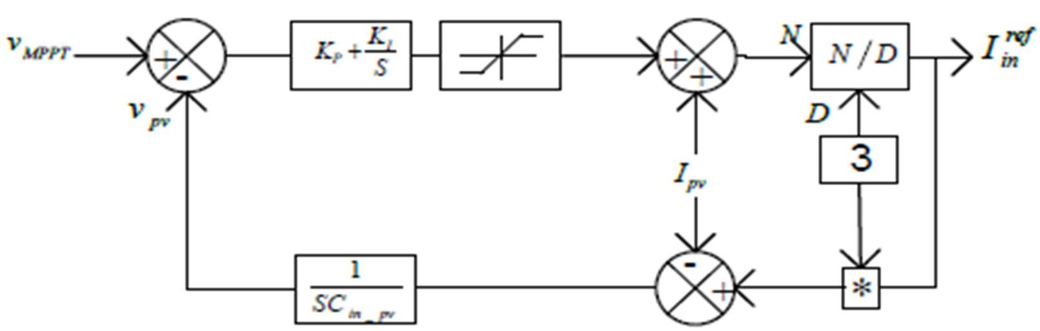

Fig.9.Input capacitor voltage controller

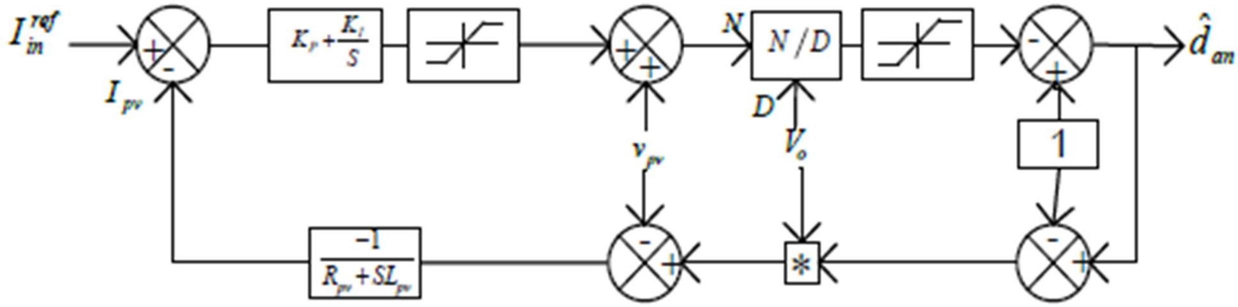

Fig.10.Inductor current controller of branch 'a'

The value of Kp and Ki for both the controllers are designed using conventional techniques.

VII. RELEVANT SOLAR MODULE RESPONSES

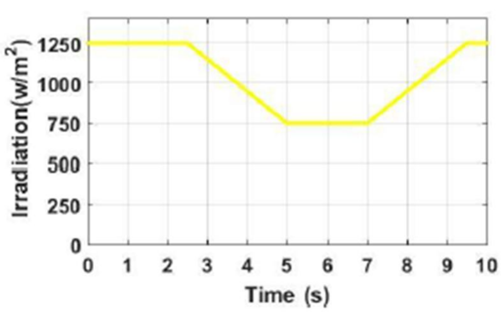

Fig.11 Variation of solar irradiance given (Rated intensity is 1250W/m^2 and reference is 1000W/m^2)

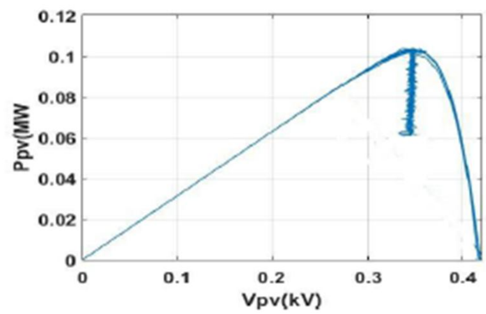

Fig.12 PV curve obtained for a given intensity

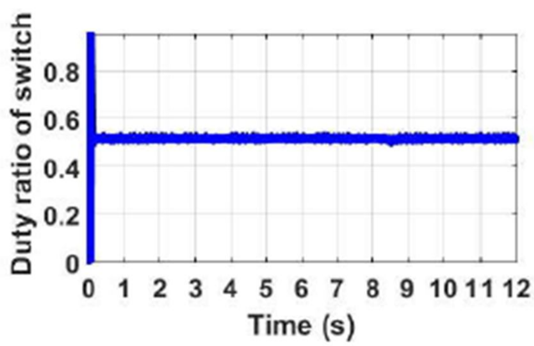

Fig.13 Duty ratio of switch on leg 'a'

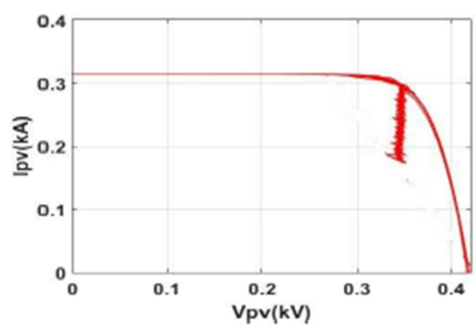

Fig.14 IV curve of solar obtained for a given intensity

It can be observed from above figures that voltage is oscillating about the nominal MPP which is approximately 345V.When the intensity is first decreasing and then increasing as in fig.14 peak of power is coming down as can be seen in fig.15 so is the current. But there is not much variation in MPP voltage. As the peak power is decreasing, voltage is still oscillating about the new MPP voltage (approximately same as nominal MPP voltage).

VIII. CONCLUSION

It can be concluded that we can track the MPP of solar PV system using the proper controlling algorithm and PWM. Converter will ensure that PV system is at it's MPP.

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