Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 10 April-June (2015) pp. 81-86

http://www.krishisanskriti.org/areee.html

Smart and Efficient Way of Rural Electrification with Solar Panel

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Abstract—*This paper presents a smart way of getting maximum solar energy out of solar arrays with the help of MPPT technique. Energy requirement has led to various researches in the field of renewable energy and installation of a large number of solar panels worldwide. Since solar panel gives maximum power only once in 24 hours so with the help of "perturb and observe" technique maximum power can be achieved. DC Power received from solar panel is further connected to boost converter and VSC for smooth regulation at desired voltage and connection to grid of Solar Farm.*

1. INTRODUCTION

Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts. The global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) are being adopted by organizations all across the globe.

Studies show that a solar panel converts 30-40% of energy incident on it to electrical energy. A Maximum Power Point Tracking algorithm is necessary to increase the efficiency of the solar panel. There are different techniques for MPPT such as Perturb and Observe (hill climbing method), Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPP and several other economic reasons.

Under abruptly changing weather conditions (irradiance level) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiance and sometimes ends up in calculating wrong MPP. However this problem gets avoided in Incremental Conductance method as the algorithm takes two samples of voltage and current to calculate MPP. However, instead of higher efficiency the complexity of the algorithm is very high compared to the previous one and hence the cost of implementation increases. So we have to mitigate with a trade off between complexity and efficiency.

It is seen that the efficiency of the system also depends upon the converter. Typically it is maximum for a buck topology, then for buck-boost topology and minimum for a boost topology.

When multiple solar modules are connected in parallel, another analog technique TEODI is also very effective which operates on the principle of equalization of output operating points in correspondence to force displacement of input operating points of the identical operating system.

2. PV MODULE

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current.However a photovoltaic cell is different from a photodiode. In a photodiode light falls on n-channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased. Usually a number of PV modules are arranged in series and parallel to meet the energy requirements. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small scale desalination plant requires a few thousand watts of power. A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array.

2.1 PV modeling

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

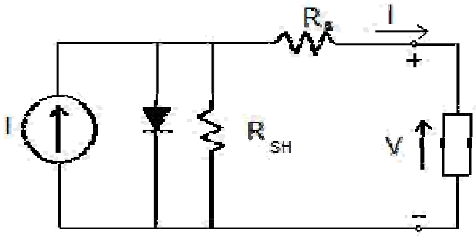


Fig. 1: (a): Single diode model of a PV cell

In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$$I = I_{sc} - I_d$$

$$I_d = I_o\,(e^{qV_d/kT} - 1)$$

where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant ($1.38 * 10^{-19}$ J/K) and T is the junction temperature in Kelvin (K).

$$I = I_{sc} - I_o\,(e^{qV_d/kT} - 1)$$

Using suitable approximations,

$$I = I_{sc} - I_o\,(e^{q((V+IRs)/nkT)} - 1)$$

where, I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n is the diode ideality factor

In order to model the solar panel accurately we can use two diode model but in our project our scope of study is limited to the single diode model. Also, the shunt resistance is very high and can be neglected during the course of our study.

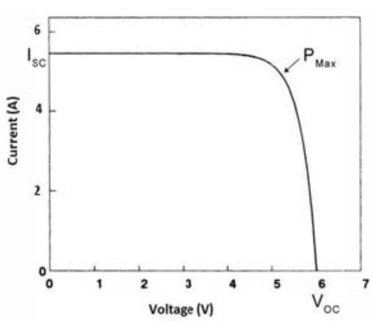
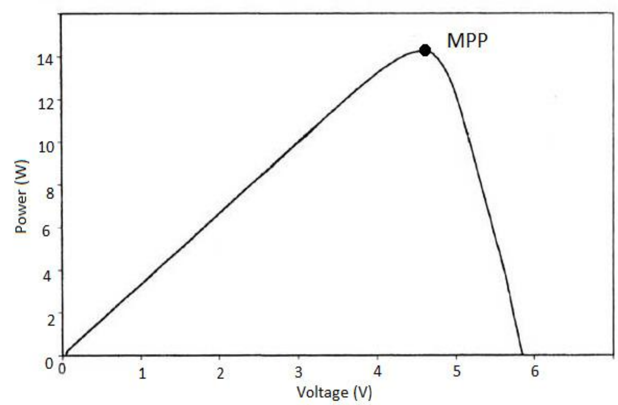


Fig. 1(b): I-V characteristics of a solar panel

When the voltage and the current characteristics are multiplied we get the P-V characteristics as shown in Fig. 3.3. The point indicated as MPP is the point at which the panel power output is maximum.



(3.1)

3. BOOST CONVERTER

As stated in the introduction, the maximum power point tracking is basically a load matching problem. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required.

(3.2)

It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter but as we intend to use our system either for tying to a grid or for a water pumping system which requires 230 V at the output end, so we use a boost converter.

(3.3)

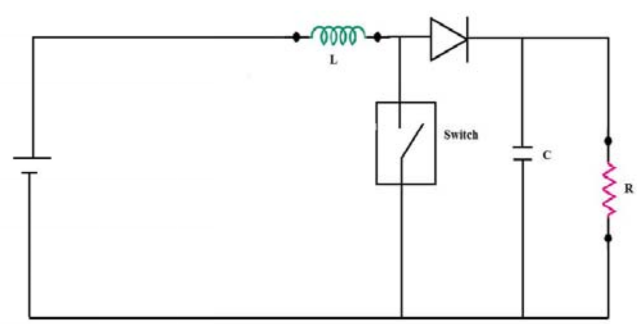


Fig. 2(a) : Circuit diagram of a Boost Converter

3.1 Mode 1 operation of the Boost Converter

When the switch is closed the inductor gets charged through the battery and stores the energy. In this mode inductor current rises (exponentially) but for simplicity we assume that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor.

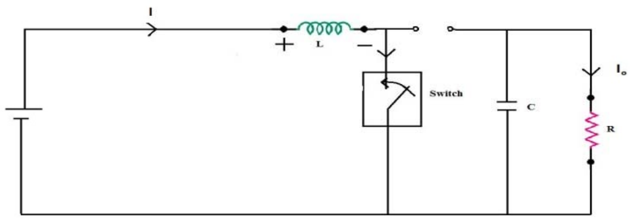


Fig. 2: (b) Mode 1 operation of the Boost Converter

In mode 2 the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation. The waveforms for a boost converter are shown in Fig. 3.7.

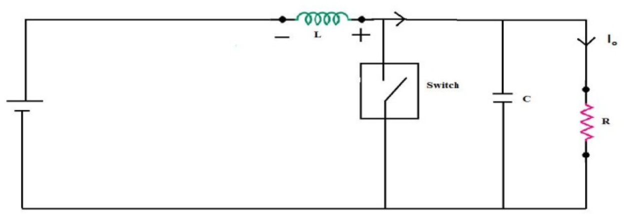


Fig. 2: (c) Mode 2 operation of Boost Converter

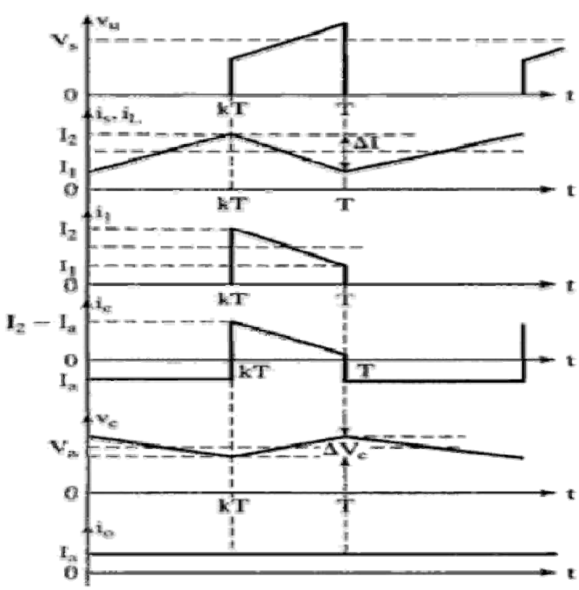


Fig. 2: (d): Waveform Of Boost Generator

4. MAXIMUM POWER POINT TRACKING ALGORITHMS

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem.

In the source side we are using a boost convertor connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance.

Techniques of Maximum Power Point Tracking Algorithm (MPPT)

- Perturb and Observe (P&O)
- Incremental Conductance(INC)
- Fuzzy logic Control
- Artificial Neural Network (ANN)

4.1 Perturb and Observe (P&O)

Operating voltage is periodically perturbed by a small increment which changes the output power. Output power increases due to perturbation then the perturbation will continue in the same direction to reach MPP. Otherwise if the perturbation decreases the output power direction reverses to move the operating point towards MPP.Main advantage of this technique is simple to implement . with only disadvantage of oscillation around MPP causes a waste of energy and long tracking time or Miss-tracking of accurate MPP under rapidly changing of irradiations

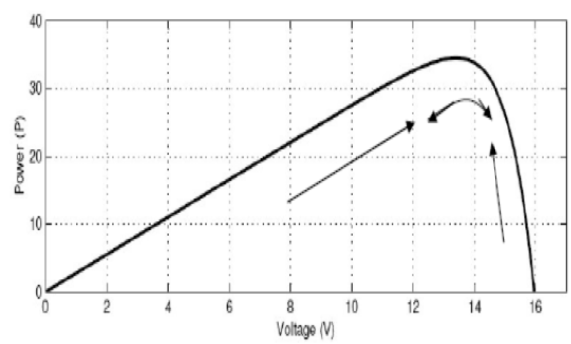


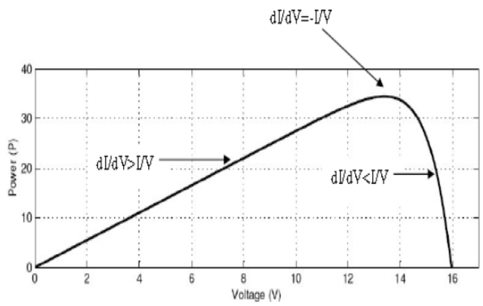
Fig. 3: (a): Maximum Power Point Tracking

4.2 Incremental Conductance(INC)

$$\begin{cases} \dfrac{dP}{dV} = 0, & at\ MPP \\ \dfrac{dP}{dV} > 0, & left\ of\ MPP \\ \dfrac{dP}{dV} < 0, & right\ of\ MPP \end{cases}$$

Since

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \approx I + V\frac{\Delta I}{\Delta V}$$



$$\begin{cases} \frac{\Delta I}{\Delta V} = -\frac{I}{V}, & at\ MPP \\ \frac{\Delta I}{\Delta V} > -\frac{I}{V}, & left\ of\ MPP \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V}, & right\ of\ MPP \end{cases}$$

Advantages of this technique are that oscillations around the Maximum PowerPoint (MPP) stops when MPPT system reaches MPP. It tracks Maximum PowerPoint (MPP) under fast changing atmospheric conditions whereas it has disadvantages like fast MPP tracking can only be achieved with bigger increments while using smaller increments time taken to reach MPP is larger .

4.3 Fuzzy Logic Control

Inputs of the fuzzy logic controller are the error, e and change in error e at sampled times k defined by :

$$E = \frac{P(k) - P(k-1)}{V(k) - V(k-1)}$$

$$\Delta E = E(k) - E(k-1)$$

Where P(k) is the instantaneous power of the photovoltaic generator. The Fuzzy inference is carried out by using Mamdani’s method. The defuzzication uses the centre of gravity method to compute the output of fuzzy logic controller i.e. duty cycle

$$d\alpha = \frac{\sum_{j=1}^{n} (d\alpha_j) - d\alpha_j}{\sum_{j=1}^{n} \mu(d\alpha_j)}$$

Where α is duty cycle

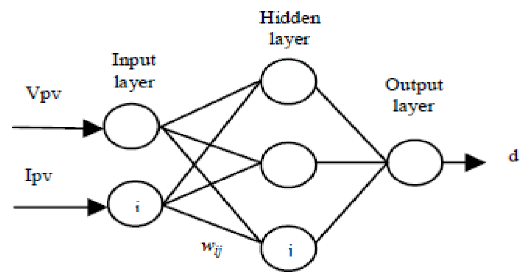
Table I - Rule Base.

E\dE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Its advantages are that its implementation does not require the knowledge of the exact mathematical model of the PV array. Convergence speed is fast and minimum oscillations around the MPP happens whereas its disadvantages are that it does not have right error computation and it comes up with the appropriate Rule base.

4.4 Artificial Neural Networks(ANN)

A simple NN has three layers : input, hidden and output layers .Layers are connected by weights to pass signals forward to other layers .Learning of NN is performed by frequently changing the weights in training process, for which set of input and output data is required .The inputs can be PV array parameters such as PV voltages and PV currents or environmental data like solar radiation and temperature. Output of the neural network is the duty cycle or dc link reference voltage used to operate the dc-dc converter at MPP. Data of Patterns between inputs and outputs are recorded over lengthy period of time so the MPPT can be tracked accurately.



5. SOLAR FARM

A solar Farm can be created with the help of solar arrays,MPPT module, Boost converter and other requisite transformers for stepping up/down voltage.Switching and Measuring devices can be installed depending upon requirement and user’s aesthetic needs. MPPT models connected in parallel give good results.

6. RESULTS OF SIMULINK MODELS

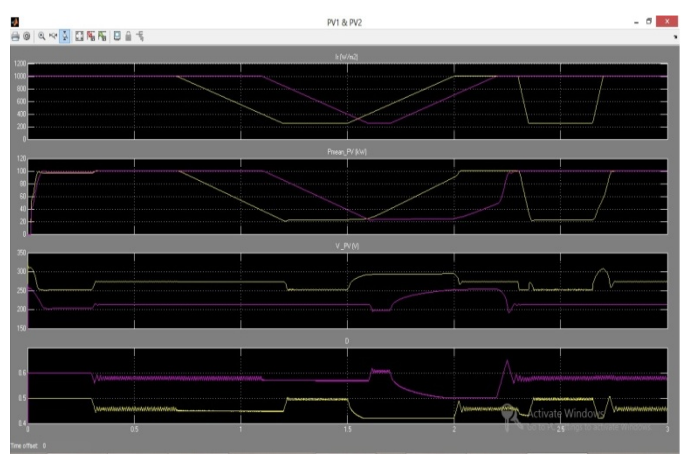


Fig. 4: Simulation result for two PV panel connected in parallel giving 200KW power

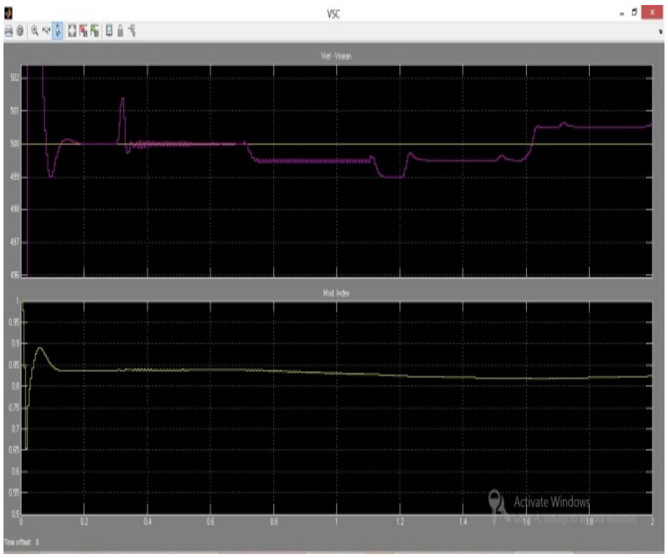


Fig. 5: Simulation result of Voltage regulation achieved

The simulink model contains two PV arrays delivering each of maximum 100KW at 1000 w/m2 irradiance. Boost converter increases voltages to 500V DC. Two MPPT controller uses the “Perturb and Observe” technique.VSC converts the 500V DC to 260 V AC and keeps unity power factor.20 Kvar capacitor bank filtering harmonics produced by VSC and 200 KVA 260/250KV three phase coupling transformer has been used. The simulation was first run with the switch on no MPPT mode, bypassing the MPPT algorithm block in the circuit. It was seen that when we do not use an MPPT algorithm, the power obtained at the load side was less. The simulation was then run with the switch on MPPT mode. This included the MPPT block in the circuit and it was seen that conversion efficiency has increased.

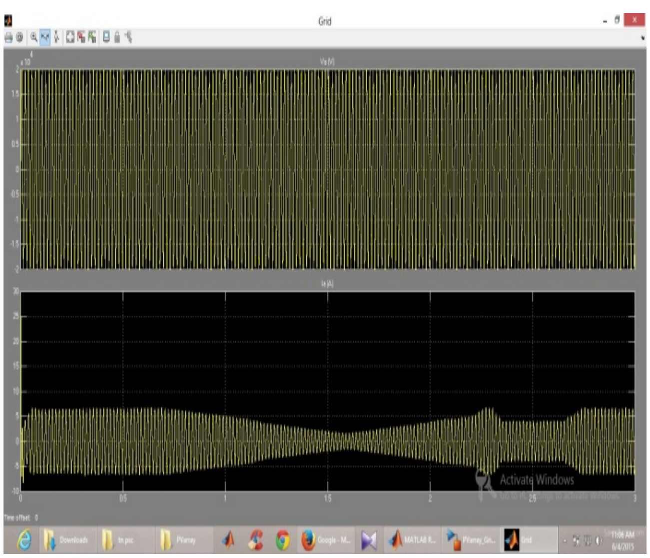


Fig. 6: Simulation result of voltage and current at receiving end of solar grid panel

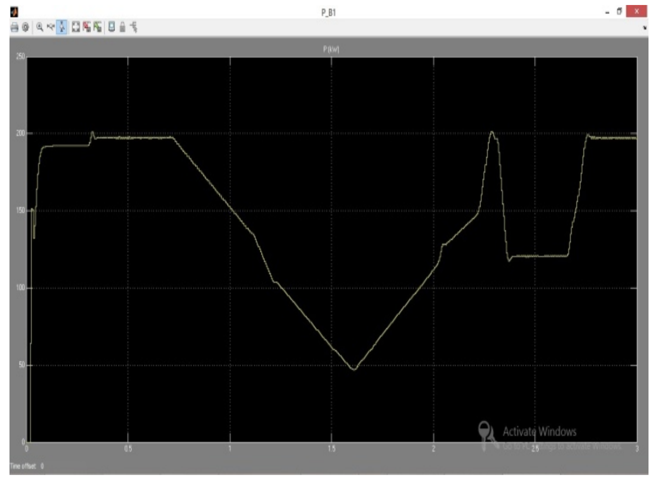


Fig. 7: Power measured at Receiving end of solar grid

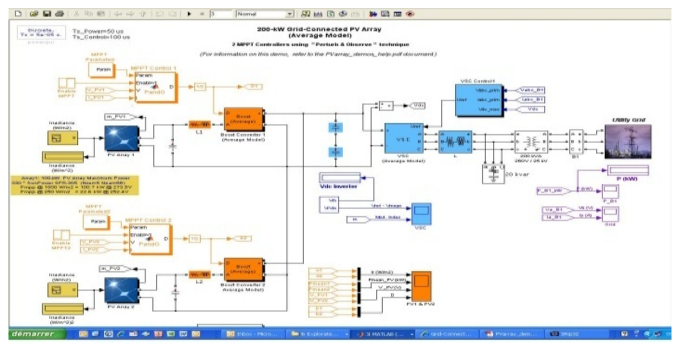


Fig. 8: Simulink model for 200 kw solar grid with MPPT and good voltage regulation features

7. CONCLUSION

Solar farm of varying capacity depending upon requirement of consumer can be achieved with the help of implementation of maximum power point tracking as discussed in the paper .A rising country like India is in acute need of power in rural area with vast availability of land where Solar farm can be installed .As shown in the Mat lab results voltages achieved are well regulated. through this paper, we would like to propose an efficient way to electrify the streets of all the city corporations under the prevailing “Solar Photovoltaic-Powered LED (light-emitting diode) Street Lighting” project through some modifications which will help to implement the project within the budget and thereby reducing pressure on conventional power use and current generation. Although it seems costly initially but in the long run it will be much more

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