Study and Analysis of Distributed Maximum Power Point Tracking Under Partial Shading Conditions.

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Distributed Maximum Power Point Tracking Under Partial Shading Conditions.

A Thesis submitted in partial fulfilment of the requirements for the degree of
M.Tech Dual Degree in Electrical Engineering.

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CERTIFICATE

This is to certify that the dissertation report/thesis titled "**Distributed Maximum Power Point Tracking Under Partial Shading Conditions**", submitted to the National Institute of Technology, Rourkela by **Vadigi Chaitanya (Roll. No. 710EE3074)** for the award of **Master of Technology** in Electrical Engineering, is a bona fide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements. The dissertation report/thesis which is based on candidate's own work, has not submitted elsewhere for a degree. The draft report/thesis is of standard required for the award of a **Master of Technology** in Electrical Engineering.

Date:

Place: Rourkela

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ABSTRACT

Photovoltaic (PV) energy generation is becoming an increasingly widespread means of producing clean and renewable power. In PV systems, long strings of photovoltaic modules are found to be vulnerable to shading effects, causing significant reduction in the system power output. To overcome this, distributed maximum power point-tracking (abbreviated as DMPPT) schemes have been proposed, in which individual dc–dc converters are connected to each PV module to enable module-wise maximum power extraction. The development of a distributed maximum power point tracking (DMPPT) photovoltaic (PV) system enables us to compensate the shading effect and the PV module mismatching as well as to increase the overall output power. The two main concepts to implement DMMPT systems are series and parallel configuration which describes the connection of the output terminals of the converters. Both systems are studied intensively. Output side sensor based DMPPT system has also been studied. It is also proved that parallel configuration is virtually free of any cross coupling effects.

CONTENTS

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ABBREVIATIONS AND ACRONYMS

PWM	-	Pulse Width Modulation
AC	-	Alternating Current
DC	-	Direct Current
MPP	-	Maximum Power Point
MPPT	-	Maximum Power Point Tracking
DMPPT	-	Distributed Maximum Power Point Tracking
MATLAB	-	MATrix LABoratory
PV	-	Photo Voltaic
SCPVM	-	Self-controlled Photo Voltaic Module
P&O	-	Perturb and Observe
CC	-	Constant Current
CV	-	Constant Voltage
I	-	Current
V	-	Voltage
p	-	Power

CHAPTER **1**

Introduction

1.1 Introduction:

The increasing concern over environmental issues and the advantages that photovoltaic energy generation provides, if compared to other renewable energy sources, especially in terms of maintenance and reliability, attracted interest and remarkable investments in PV technology in the last decade. A PV field is comprised of a number of series connected strings that are arranged in parallel. Generally, cells in a PV field are assumed to be of the same type, or sometimes equal, but such a hypothesis is no longer valid when tolerances of manufacturing and aging-related parametric drift are accounted for. Moreover, due to possible different orientations of modules and to shadowing effects, the PV field very often works in mismatching conditions, and the possibility that some cells in a module or some modules in a string are potentially able to deliver strongly different currents is very high. To avoid one shadowed cell from narrowing the current path in a string, thus lowering the other ones in the series and reducing the overall power production of the whole string, bypass diodes are usually placed in antiparallel to small groups of series-connected cells. In case of mismatching, this arrangement helps to increase the power production of the PV field but makes its power versus voltage graph multimodal. The detection of the absolute maximum power point (MPP) of the PV field in such a characteristic makes much more complicated because of the presence of more than one peak. Operation in any other point of the characteristic, due to fault of the MPP tracking (MPPT) technique in presence of mismatch conditions, results in a consistent drop in the overall system's efficiency. In order to overcome such a setback, a switching converter connected to each module and performing the MPPT operation can be used. This method is referred to as distributed maximum power point tracking (DMPPT).

A number of PV modules are usually connected in series to supply the input voltage to the inverter within its operating range, and similar strings are connected in parallel to get the desired output power. As a first-order approximation, it is possible to model the dc–ac conversion stage as a voltage source with a series resistance. In fact, a PV inverter is capable of sinking any amount current in a certain range while keeping its input voltage regulated to a fixed average value. This hypothesis greatly simplifies system's analysis because each string forms an independent loop with the equivalent model of the dc–ac conversion stage, and the analysis of the circuit can be simplified by adopting to the analysis of a single string of *N* self-controlled PV modules (SCPVM).

1.2 Motivation:

As the time progresses, the demand of power is increasing gradually and on the contrary the fossil fuels used for power generation are decreasing rapidly. Alongside the reason of inadequate resources, the methods that are used for power generation by fossil fuels are not even eco-friendly and they are causing global warming and greenhouse effects. Now would be the proper time to initiate the usage of renewable energy resources on very large scale.

The renewable energy resources that are available to us are Solar Energy, Hydro Energy and Wind Energy. They are rich in quantity, pollution free, distributed all through the earth and recyclable. Hydro Energy generation, Wind Energy generation are of course two of the main sources of renewable energies, but the disadvantage in Hydro Energy is that, it is seasonal dependent and in Wind energy is that it depends on geographical location. On the contrary, Solar Energy is widespread all over the globe and all the time. Also most of the remote areas have not been connected to the grid and they do not have power supply. These areas can generate power on their own using renewable resources such as solar energy. The amount of irradiance and temperature vary from location to location and from time to time but under given conditions Solar Energy system can be installed. Photo Voltaic energy system is the most direct way to convert the solar radiation into electricity based on photovoltaic effect. Despite high initial costs, they have already been implemented in many areas. Research is going into this area to develop the efficient control mechanism and provide better control. Recent developments in the technology of batteries and solar panel efficiencies offers a better performance. So the overall installation cost of photovoltaic charging system reduces. And therefore, the time is not so far that almost any and every middle class person can afford a solar panel at home for at least some basic requirements.

In the light of above points, it is clear that Solar Energy plays an important role in the forthcoming future. So, it is our duty to learn, implement and improvise the idea as early as possible, so that it becomes a very useful tool to our future generations.

3.1 Thesis Objectives:

Objectives here in this project are:

- To study the solar cell model and observe its characteristics.
- To study the proposed DC-DC boost converter and its operation.
- To study MPPT algorithms and method to generate PWM wave according to the output of MPPT algorithm.

- To study how to use boost converter to implement the proposed MPPT and DMPPT systems.
- To study the comparison between the conventional MPPT method and the proposed DMPPT method in terms of efficiency improvement.
- Matlab Simulink implementation of solar panel, its interface with boost converter, using MPPT algorithms and generating suitable PWM wave for the control of Boost converter, its scaling to DMPPT.
- To observe the results of simulation, how the system is detecting the maximum power point, its improvement while using DMPPT under partial shading conditions.
- To implement output sensor based DMPPT and observe its operation.
- To prove that there are virtually no cross coupling effects in parallel connection of DMPPT systems.

1.4 Organisation of Thesis:

The thesis is partitioned into five chapters along with the chapter of introduction at the beginning. Each chapter is unique and is presented along with the required theory to encompass it.

Chapter 2. This section deals with PV Array Characteristics and its modelling. First, the equivalent circuit of the solar cell is made. Then power versus voltage and current versus voltage characteristics curves of solar panel are studied. This section discusses Boost converter, its circuit and its operation are presented along with the necessary illustrations. This chapter also deals with the Maximum Power Point Tracking (MPPT) systems and the algorithms used to implement it. . Here P&O algorithm is discussed for designing the MPPT controller to track the maximum power point and operate at this point.

Chapter 3. This section deals with Distributed Maximum Power Point Tracking (DMPPT) systems and how the efficiency of a solar panel is improved by DMPPT under partial shading condition. This section deals with analysis of DMPPT system with boost converter by State-Space modelling. Initially state space modelling of MPPT system is derived, thus obtaining A,B,C and D matrices for the later evaluations, which is further extended to parallel connected DMPPT system and proving that there are virtually no cross couplings in parallel connected DMPPT system. Results and discussion with DMPPT in parallel and series configuration has been presented.

Chapter 4. This section deals with output side sensor based PV system. It has been discussed about how this would allow reduction in the use of hardware thus affecting the installation cost. Implementation of this system in Simulink has been presented and corresponding results and discussions has been presented.

The final conclusion of the project is presented after these chapters concluded by the list of sources referred in the Bibliography.

CHAPTER **2**

Modelling of PV system

2.1 Characteristics of PV array:

The electrical equivalent model of a Photo-Voltaic cell consists of a current source and a diode connected in parallel (Fig. 1).The PV cell behaves as a highly nonlinear current source and its output voltage is limited. It is known from the PV-cell power versus voltage characteristics that the power generated reaches its maximum under a precise loading. A module consist of a number of solar cells which are arranged in parallel and series to increase voltage and current levels of module. The electrical equivalent circuit of a solar cell is shown in Figure 1. It is comprised of a series resistance, a parallel resistance, diode and light driven current source. Here I and V denote current and voltage generated by the solar cell, I_{ph}(A) denotes current generated by solar cell, R_s represents series resistance (Ω), and R_{sh} represents shunt resistance (Ω).

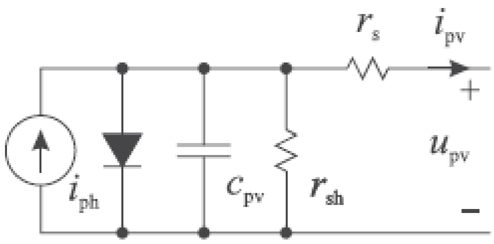

Figure 1 PV cell equivalent circuit

When load connected to panel is changed, then corresponding value of voltage and current changes. Temperature, irradiation and internal characteristic of module affects the P-V characteristics of the module. Irradiation on a module directly affect charge carriers of module. So current generated by the module changes according to irradiation of the module. When intensity of light changes, its corresponding temperature of module changes. So current generated by the module also influenced by temperature. The constant current region (CC), where the current of PV-cell stays almost constant from the voltage region (CV), where the voltage of PV-cell remains relatively constant is separated by the maximum power point (MPP). Since the terminal voltage and current of PV-cell are both proportional to ambient conditions, the loading must be controlled to extract maximum power under all operating conditions. This process is known as MPP tracking.

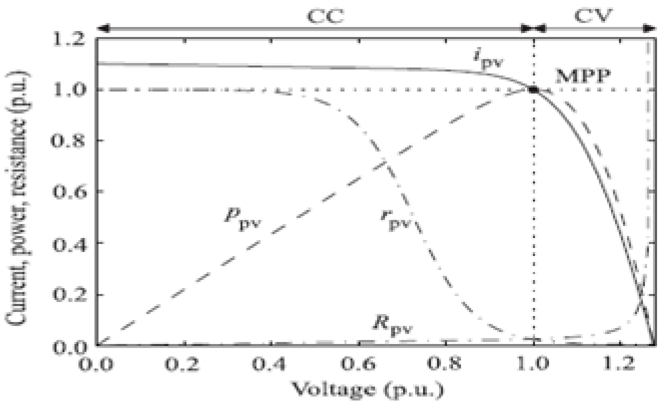

Figure 2 PV cell P-V, I-V characteristics

2.2 Operation of Boost Converter:

It has been noted that the output characteristics of any solar module are nonlinear and depends highly on the solar irradiation and temperature. To maximize the power extracted from solar module, it has to be operated at fixed value of voltage and current representing a definite value of load. For this DC-DC converter circuit is needed to operate our intended load and extracting maximum power from the panel. Here in this project a boost converter is used.

There are particularly, two modes of operation of a boost converter which are based on the operation of the switch of boost converter. The first mode is when the inductor is charging when the switch is closed. The second mode when the inductor is discharging when the switch is open.

In this operation mode, the switch is closed. The inductor is charged from the source through the switch. The charging current is actually exponential but for our simplicity it is assumed to be linear. The diode helps restricting the flow of current from the source to the load and power supply to the load is provided by the discharging of the capacitor.

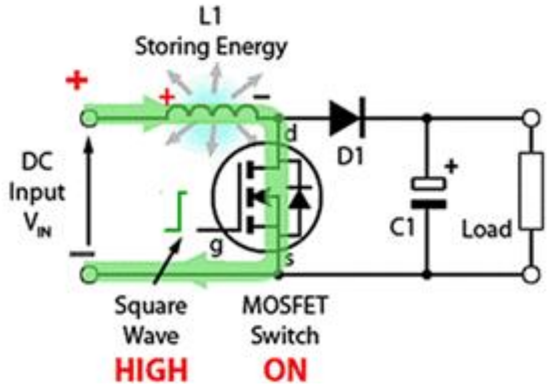

Figure 3 Boost converter when the switch is closed

In discharging operation mode, the switch is closed and the diode is forward biased. The inductor is now discharged. The discharging inductor and the source charges the capacitor and supplies the load demand too. The load current variation is usually very small and which is assumed constant throughout the two modes.

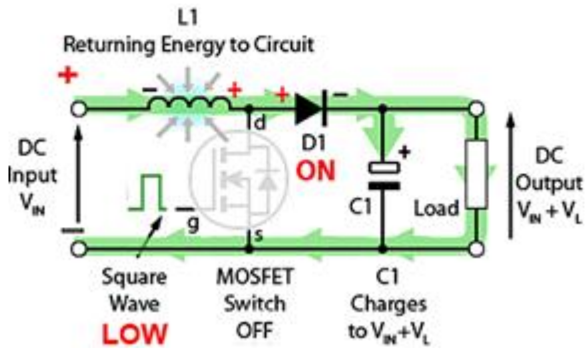

Figure 4 Boost converter when the switch is open

For a boost converter,

$$V_{out} = \frac{V_{in}}{1-D}$$

Where V_{out} is the output voltage of boost converter, $V_{in}$is the input voltage of boost converter and D (0< D <1) is the duty ratio of boost converter.

If load R_L is connected on the output side of boost converter, then the output power drawn is

$$\frac{V_{out}^2}{R_L} = \left(\frac{V_{in}^2}{1-D}\right)\frac{1}{R_L}$$

$$= \frac{{V_{in}}^2}{R_L(1-D)^2}$$

Which must be equal to the power delivered by the solar panel $V_{in}I_{in}$.

$$\Rightarrow \; V_{in}I_{in} = \frac{{V_{in}}^2}{R_L(1-D)^2}$$

$$\Rightarrow \frac{I_{in}}{V_{in}} = \frac{1}{R_L(1-D)^2}$$

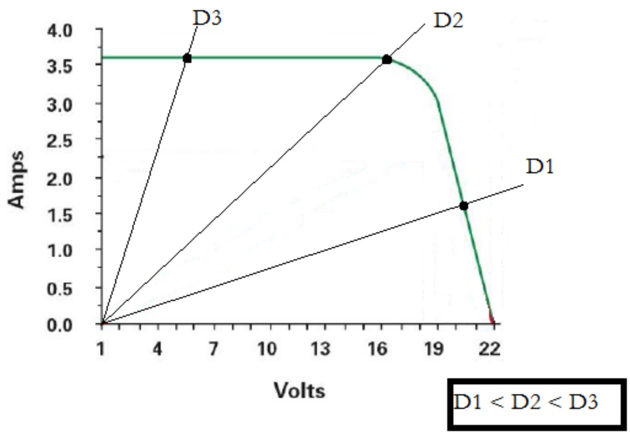

Figure 5 Operating Point control using Duty cycle

Value of $\frac{I_{in}}{V_{in}}$ represents the slope of operating point in I-V characteristics graph. Thus by above equation, it can be controlled by controlling the duty ratio considering load resistance at a fixed value.

Hence with the increase of the duty ratio, voltage of solar panel (i.e. input voltage of DC-DC boost converter) decreases and current from the panel increases. Also with the decrease of the duty ratio, voltage of panel increases and current from the panel decreases.

This is the method to control the boost converter for attaining the required maximum power point (MPP).

2.3 Maximum Power Point Tracking:

The method that any grid connected inverter and solar battery chargers adopt to get the maximum possible power from the photovoltaic (PV) modules is called Maximum power point tracking (MPPT). Analysis based on the I-V curve shows that photovoltaic cells have a complex relationship among irradiance ($watt/m^2$), temperature and resistance of the panel that introduces non-linear output efficiency. The intention of the MPPT system is to monitor the output of the module and apply the proper resistance (load) to obtain maximum possible power from the ambient environmental conditions. Generally, MPPT devices are integrated into the power conversion systems. Whenever AC power is needed, install inverters that convert the DC-power to AC-power. The voltage and current corresponding to MPP are called as MPP voltage (V_{mpp}) and MPP current (I_{mpp}) respectively.

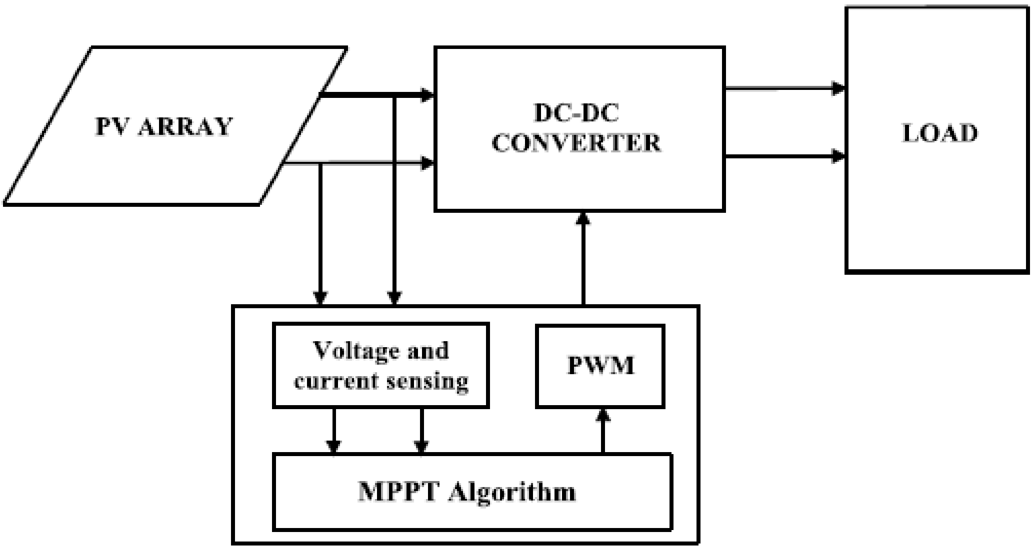

Figure 6 PV system implementing MPPT

For a given value of ambient operational conditions, PV cells have a particular operating point which gives the values of the current (I_{mpp}) and Voltage (V_{mpp}) of the cell that result in maximum power output. From circuit theory it can be shown that the power delivered from the panel is at optimal level when the derivative ($\frac{dI}{dV}$) i.e., the slope of the I-V curve is equal to the negative ratio of $\left(\frac{I}{V}\right)$ where$\frac{dP}{dV} = 0$. This is known as the maximum power point (MPP) of module at those conditions and occurs at the knee point of I-V curve.

MPPT controllers follow any one of the methods to detect the MPP. Various algorithms are available that can be implemented to detect this point and the choice may depend on the operating conditions of solar array. Some of the MPPT algorithms are Perturb and observe algorithm, Incremental conductance algorithm, Current Sweep method, Constant Voltage method etc.

2.3.1 Perturb and Observe algorithm:

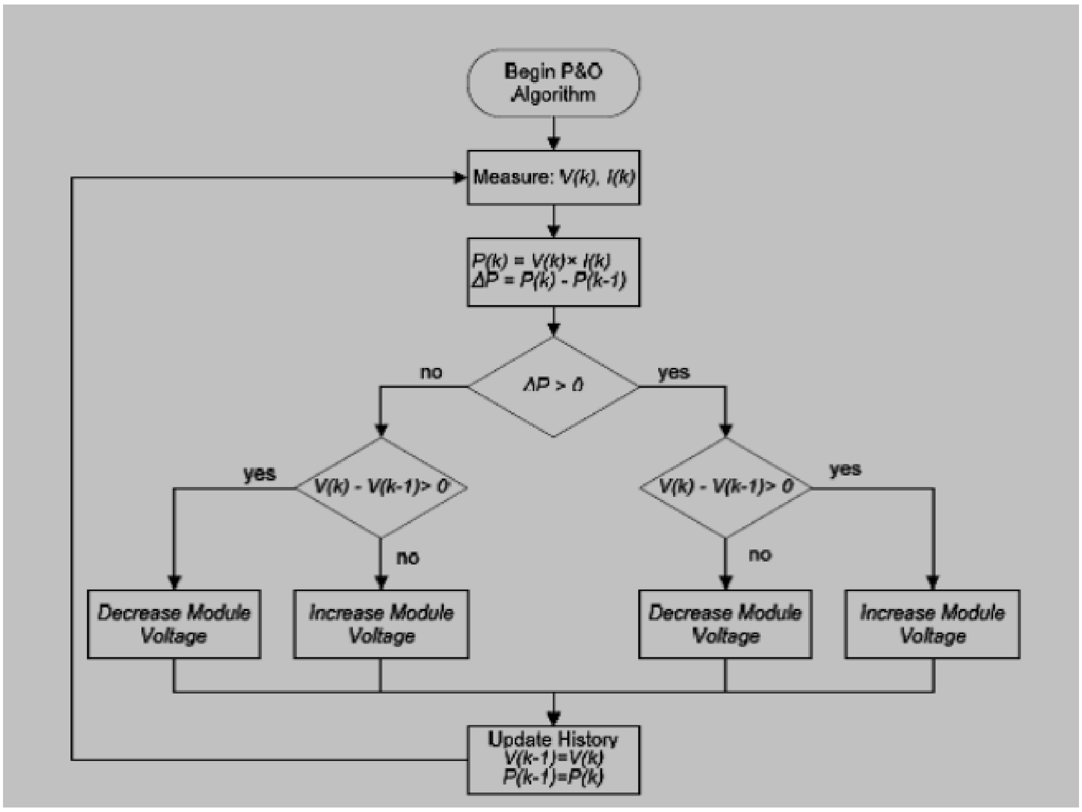

Figure 7 Flowchart of P&O algorithm

For the development of MPPT in this project, Perturb and Observe algorithm has been used. The working of algorithm is as follows: voltage and current of the solar panel is measured initially. After some time, by measuring the change in voltage and change in current, change in power is measured. Depending on whether the change in power is positive or negative, increase or decrease the module voltage as given in the algorithm is followed. If both the change in power and change in voltage is positive the panel voltage is increased. If change in voltage is negative and change in power is also negative, increase the module voltage. If either change in voltage or change in power is positive and the other one is negative, then decrease the module voltage. Overall algorithm is presented in figure 7.

Using the signal given by the Perturb and Observe algorithm, the duty ratio of the boost converter is controlled, there by controlling the increase and decrease of voltage of the solar panel. So when the insulation level changes, as the maximum power point changes from the point the module is operating at, this algorithm detects the change and accordingly gives the signal to the boost converter to reach the maximum power point.

CHAPTER 3

DMPPT and Mathematical Analysis of Cross-Coupling Effects

3.1 Distributed Maximum Power Point Tracking:

Utilising a switching converter between the PV panel and the load is a general method to implement MPP tracking. The converter is useful in changing the levels of voltage and current for transferring power between the PV panel and the intended load. A converter which would transfer power from low voltage to high voltage is needed while interfacing any individual PV module, since the PV module voltage is most usually insufficient for the suitable operation of the inverter. Moreover, occurance of non-uniform illumination especially in constructed environment is quite frequent, causing partially shaded PV modules of whose global maximum power point occur at a significantly lower voltage than that of uniform illumination condition. Each string of a panel contains a number of PV modules connected in series, thus increasing the voltage of string which would be enough for the operation of inverter. These strings have been seen to be potentially vulnerable to the mentioned shading effects whence the generated power of the string is limited by shaded module e.g., by obstacles nearby or clouds. Each module has to carry equal current due to the series connection which forces the operating point of some modules away from the MPP. To overcome this, DMPPT systems have been proposed. Here each individual PV module has a dedicated interfacing DC-DC converter.

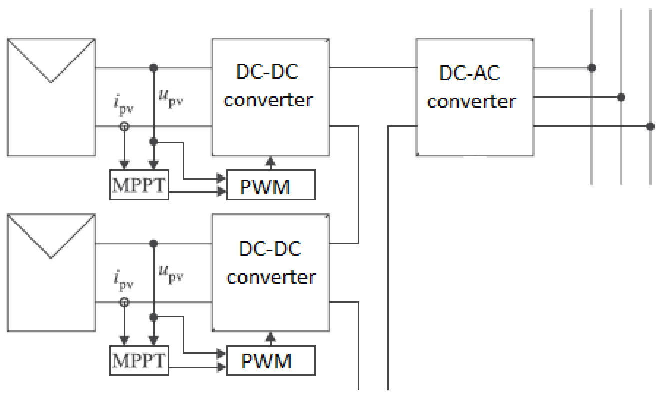

Figure 8 PV system in series DMPPT configuration

DMPPT converters are the front part in a two-stage conversion. Here the DC power produced by the PV modules is transferred into the AC utility grid by means of an inverter. The two stage structure thus contains a high-voltage dc-link between the DC-DC converters and the inverter. There would be a number of individual converters that would transfer power into the common dc-link. There are two general structures of DMPPT systems that are used. They are presented in figure 8 and figure 9 representing the series configuration and the parallel configuration respectively. In the series configuration, the outputs of individual DC-DC converters are connected in series. Thus the dc-link voltage is spread between the converter output terminals. While in the parallel configuration, the output terminals of the DC-DC converters are connected parallel to the input of an inverter.

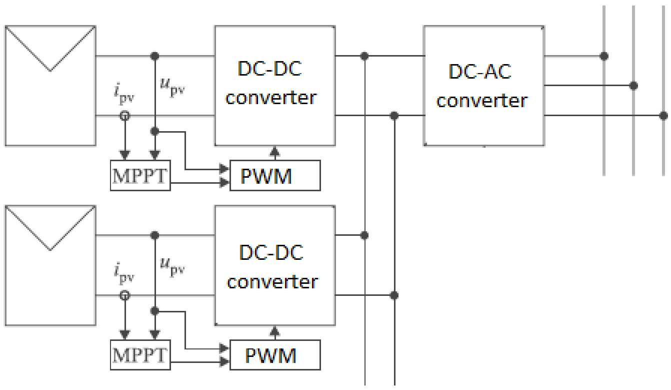

Figure 9 PV system in parallel DMPPT configuration

As observed in figures 8 and 9, although each module is independently connected to a dedicated converter, they in turn are sharing either a common voltage (in parallel connection) or a common current (in series connection). This result in a cross coupling effect. When the current or duty ratio of second module is changed, it results in turbulence of voltage of first panel. Vice versa, when the current or duty ratio of first module is changed, it ends up effecting the voltage of second module. These cross couplings are undesirable and there are methods to eliminate these cross couplings. These cross couplings are usually prominent in series DMPPT configuration. Where as in parallel configuration, the effect of cross couplings is much less as the system doesn't introduce the cross couplings but only the load does. While in series configuration, the system itself introduces cross couplings. Hence one could say that parallel configuration is virtually free of these cross coupling effects.

3.2 Mathematical analysis of Cross-Couplings:

A linear model of a converter is needed in order to analyse the switched-mode converter operation suitably. In general the State-Space averaging technique usage is quite common to obtain a small-signal model explaining the operation of the circuit.

In this technique of State-Space averaging, each of the sub circuits obtained from switching process are analysed separately and by using the Kirchoff's laws, the equations required are developed. In this State-Space model a function is developed to relate the output variables and input variables and state variables. In order to get an averaged State-Space model, it is needed to average these equations over the switching periods according to the active time of sub-circuit. The time invariant model is thus obtained. When the averaged equations are subjected to linearization at specific operating point, final linear model is obtained. Depending on the value of resistances, inductance and capacitance values, and the circuit, obtaining the matrices A, B, C, D.

$$SX(s) = AX(s) + BU(s)$$

$$Y(s) = CX(s) + DU(s)$$

The output variable can be solved from the above two equations as

$$Y(s) = [C(sI - A)^{-1}B + D]U(s)$$

$$Y(s) = G(s)U(s)$$

The equations are linearized around

$$U_{in} = (r_L + r_{ds} + D'r_d)I_{L_1} + D'(U_o + U_D)$$

$$I_{L_1} = I_{in} \ , \ I_o = D'I_{in}$$

$$U_{C_1} = U_{in} \ \ , \ U_{C_2} = U_o$$

The averaged equations obtained from the Kirchoff's laws are manipulated to get the State-Space model.

$$G = [C(sI - A)^{-1}B + D] =$$

$$\begin{bmatrix} \frac{1}{\Delta L_1 C_1}\left(R_{eq} + sL_1 - r_{C_1}\right)(1 + sr_{C_1}C_1) & \frac{D'}{\Delta L_1 C_1}(1 + sr_{C_1}C_1) & -\frac{U_{eq}}{\Delta L_1 C_1}(1 + sr_{C_1}C_1) \\ \frac{D'}{\Delta L_1 C_1}(1 + sr_{C_1}C_1) & -\left[\frac{D'^2 s}{\Delta L_1} + \frac{sC_2}{1 + sr_{C_2}C_2}\right] & -\frac{I_{PV}}{\Delta}\left[s^2 + s\left(\frac{R_{eq}}{L_1} - \frac{D'U_{eq}}{L_1 I_{PV}}\right) + \frac{1}{L_1 C_1}\right] \end{bmatrix}$$

3.2.1 Analysis of parallel configuration:

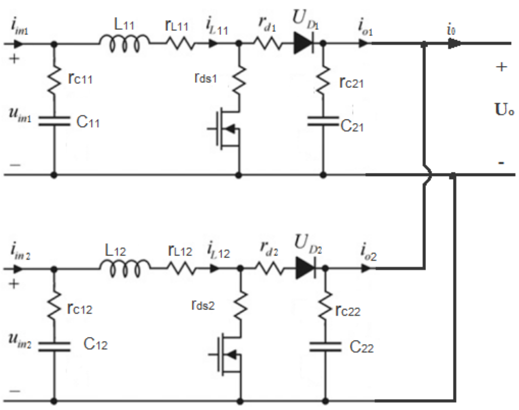

Figure 10 Equivalent circuit for a parallel DMPPT system

Writing in State-Space form,

$$\dot{X} = AX + BU$$

$$Y = CX + DU$$

Solving the equations, we get,

$$\begin{bmatrix} u_{in1} \\ u_{in2} \\ i_o \end{bmatrix} = \begin{bmatrix} b_1 & 0 & b_2 & b_3 & 0 \\ 0 & b_4 & b_5 & 0 & b_6 \\ b_7 & b_8 & b_9 & b_{10} & b_{11} \end{bmatrix} \begin{bmatrix} i_{in1} \\ i_{in2} \\ u_o \\ \widehat{d_1} \\ \widehat{d_2} \end{bmatrix}$$

Where,

$$b_1 = \left[-\left(\frac{sr_{C_{11}}}{\Delta_1} + \frac{1}{C_{11}\Delta_1}\right)\frac{r_{C_{11}}}{L_{11}} + \left(s + \frac{R_{eq1} - r_{C_{11}}}{L_{11}}\right)\frac{1}{C_{11}}\right] + r_{C_{11}}$$

$$b_2 = \frac{D_1'}{L_{11}\Delta_1}\left(sr_{C_{11}} + \frac{1}{C_{11}}\right)$$

$$b_3 = \frac{-U_{eq1}}{L_{11}\Delta_1}\left(sr_{C_{11}} + \frac{1}{C_{11}}\right)$$

$$b_4 = \left[-\left(\frac{sr_{C_{12}}}{\Delta_2} + \frac{1}{C_{12}\Delta_2}\right)\frac{r_{C_{12}}}{L_{12}} + \left(s + \frac{R_{eq2} - r_{C_{12}}}{L_{12}}\right)\frac{1}{C_{12}}\right] + r_{C_{12}}$$

$$b_5 = \frac{D_2'}{L_{12}\Delta_2}\left(sr_{C_{12}} + \frac{1}{C_{12}}\right)$$

$$b_6 = \frac{-U_{eq2}}{L_{12}\Delta_2}\left(sr_{C_{12}} + \frac{1}{C_{12}}\right)$$

$$b_7 = \frac{D_1'}{L_{11}\Delta_1}\left(sr_{C_{11}} + \frac{1}{C_{11}}\right)$$

$$b_8 = \frac{D_2'}{L_{12}\Delta_2}\left(sr_{C_{12}} + \frac{1}{C_{12}}\right)$$

$$b_9 = -\left(\frac{sD_1'}{L_{11}\Delta_1} + \frac{D_2'}{L_{12}\Delta_2} + \frac{sC_{21}}{1 + sr_{C_{21}}C_{21}} + \frac{sC_{22}}{1 + sr_{C_{22}}C_{22}}\right)$$

$$b_{10} = \frac{sD_1'U_{eq1}}{L_{11}\Delta_1} - I_{L_{11}}$$

$$b_{11} = \frac{sD_2'U_{eq2}}{L_{12}\Delta_2} - I_{L_{12}}$$

Where,

$$U_{eq1} = u_o + U_{D_1} + \left(r_{d_1} - r_{ds_1}\right)I_{in1}$$

$$R_{eq1} = r_{L_{11}} + r_{C_{11}} + Dr_{ds_1} + D'r_{d_1}$$

$$U_{eq2} = u_o + U_{D_2} + \left(r_{d_2} - r_{ds_2}\right)I_{in2}$$

$$R_{eq2} = r_{L_{12}} + r_{C_{12}} + Dr_{ds_2} + D'r_{d_2}$$

Hence, from the above zeroes, it is observed that u_{in1} is independent of i_{in2} and $\widehat{d_2}$. Similarly u_{in2} is independent of i_{in1} and $\widehat{d_1}$. Any change in i_{in2} and $\widehat{d_2}$ doesn't affect u_{in1} and any change in i_{in1} and $\widehat{d_1}$ doesn't affect u_{in2}. Hence, virtually there are no cross couplings in parallel connected DMPPT system.

3.3 Results and Discussions:

The voltage and current signals are sampled using zero order hold. Then change in voltage and change in power is measured. If both the change in power and change in voltage is positive then D state is decreased. If change in voltage is negative and change in power is also negative, it will decrease the D state. If either change in voltage or change in power is positive and the other one is negative, then it increases the value of D state. Now this signal is compared with a repeating sequence which produces the required pulse width modulated (PWM) wave through which the switch of boost converter is controlled.

The distributed maximum power point tracking (DMPPT) under partial shading conditions is simulated in parallel configuration and the shading condition is generated by providing different insulation levels to the modules. Now each MPPT tracker connected to the modules detect the required maximum power point and generate corresponding PWM signals which controls the respective boost converters. Hence different points will be detected independently by each module. Input voltage of both modules will be different and the currents flowing through each modules will also be different from each other so that each will be detecting their corresponding maximum power point. Both the converters are finally connected together in parallel DMPPT configuration and it is connected to an inverter which in turn is either connected to the grid or a load can be connected after smoothening the waveform. Thus DMPPT is used to get more efficiency from the panel, the downside being more usage of equipment, in turn effecting the economy of installation. DMPPT system in parallel configuration is presented in fig.11

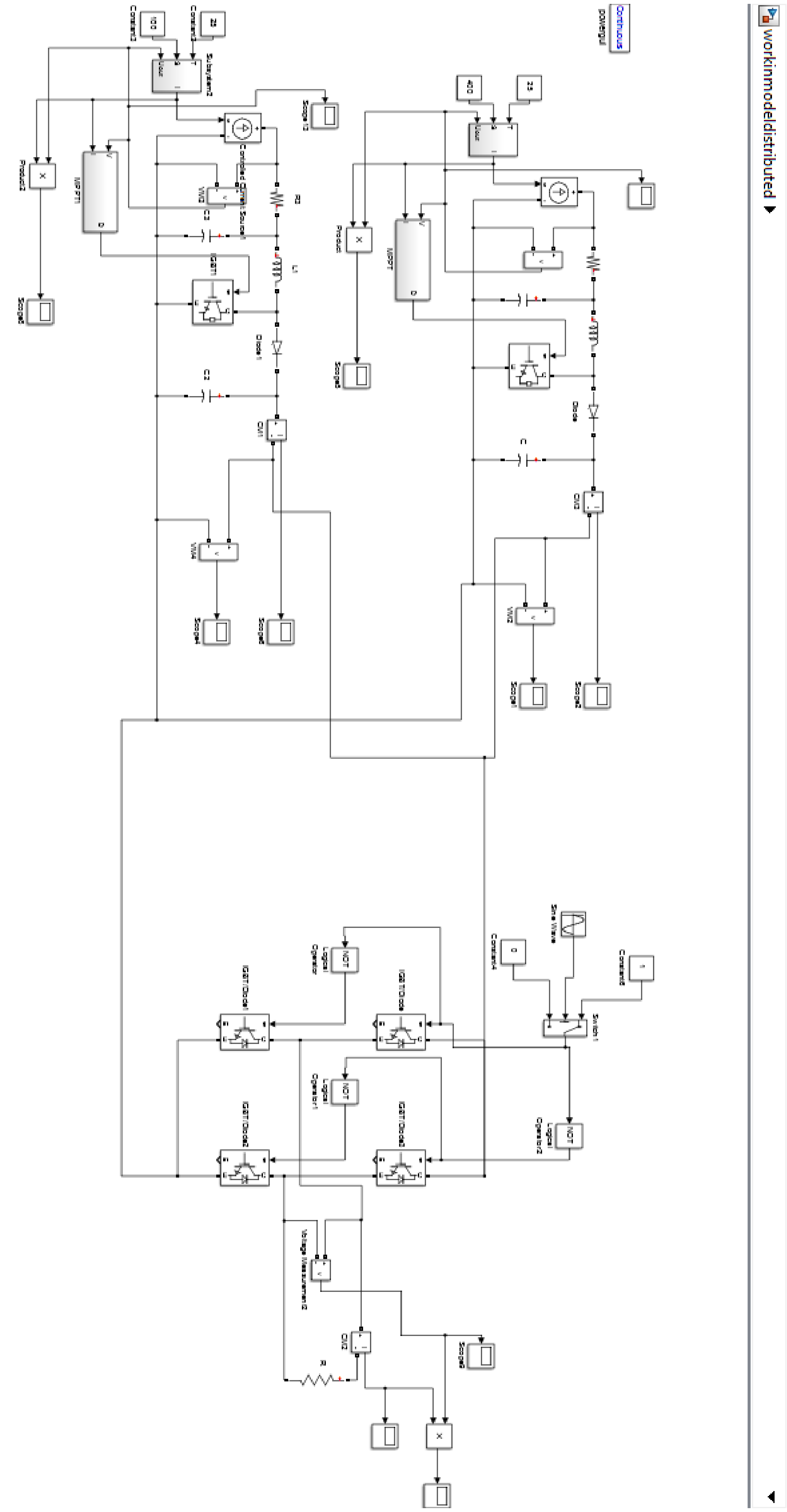

Figure 11 DMPPT system in parallel configuration

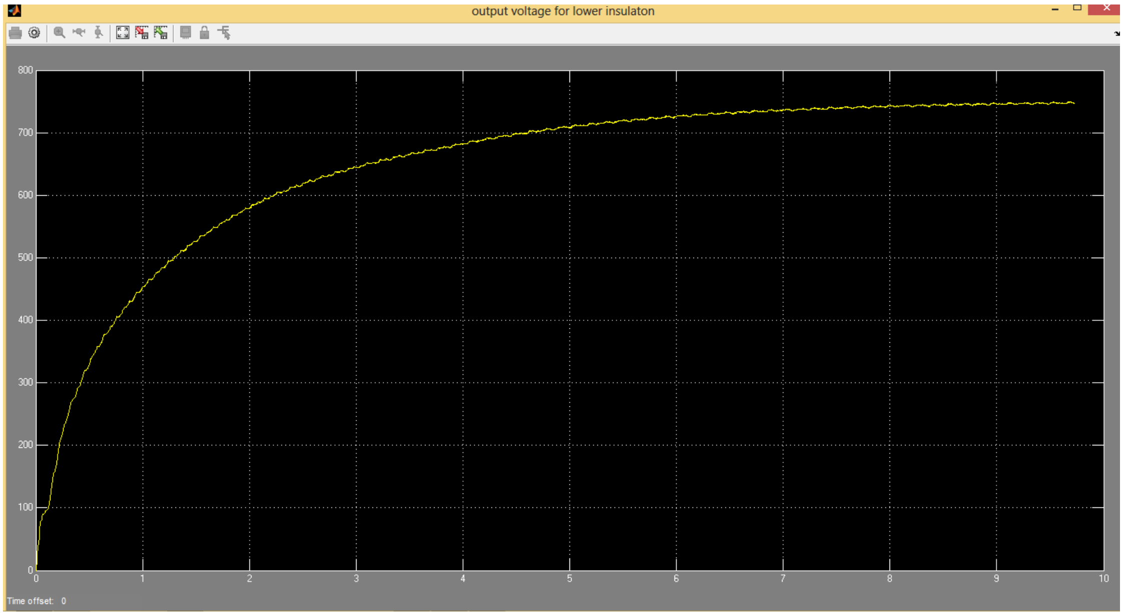

Figure 12 output voltage after boosting for lower insulation

The input voltage is being controlled by the corresponding MPPT algorithm for tracking of maximum power point. The input voltage is controlled while the output voltage after boosting is reaching its value corresponding to the power that is produced by both the modules.

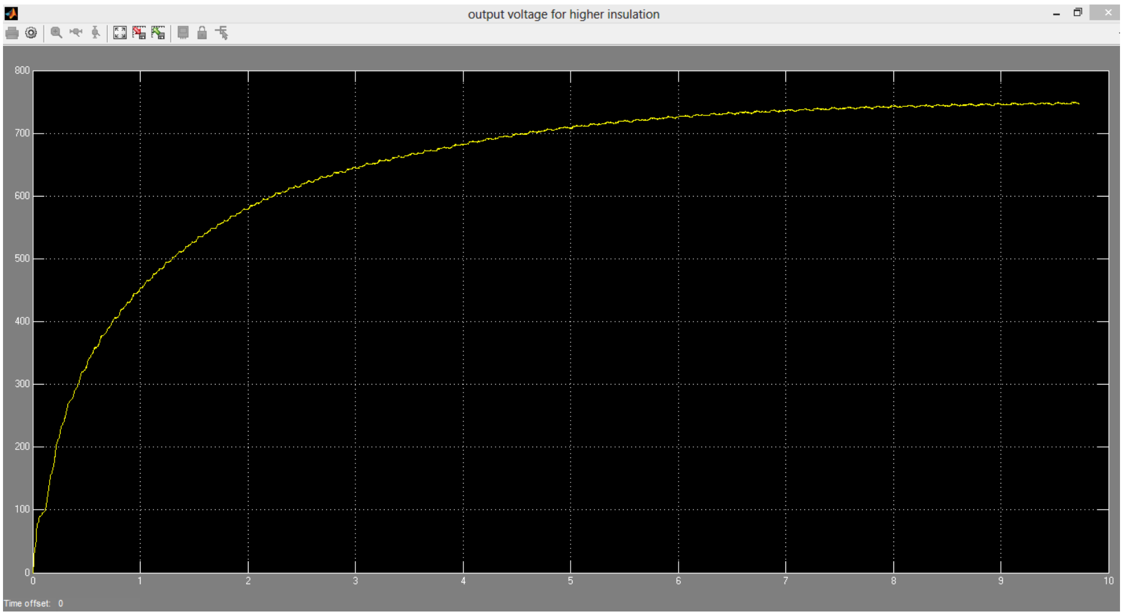

Figure 13 Output voltage for higher insulation

Here it is seen that the output voltage after boosting is similar to the output voltage of lower insulation. It is because they both are connected in parallel. Whereas input voltage of both modules doesn't seem similar because each one is operated by different boost converters so as to extract maximum power from each module.

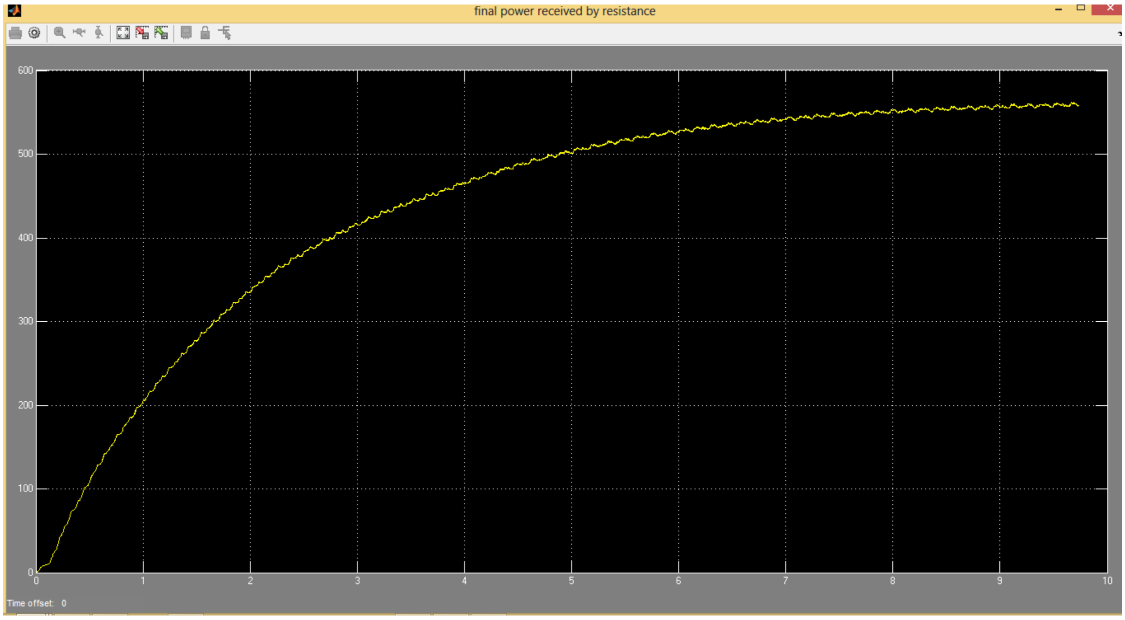

Figure 14 Final power obtained by parallel connected DMPPT modules

Finally after tracking MPP from each module and converting it by boost converter and connecting them in parallel, the tracking of final maximum power from the panel is observed in figure 14. DC-AC conversion is done if the load needs alternating current. Otherwise load can directly be connected to the output of DC-DC converter.

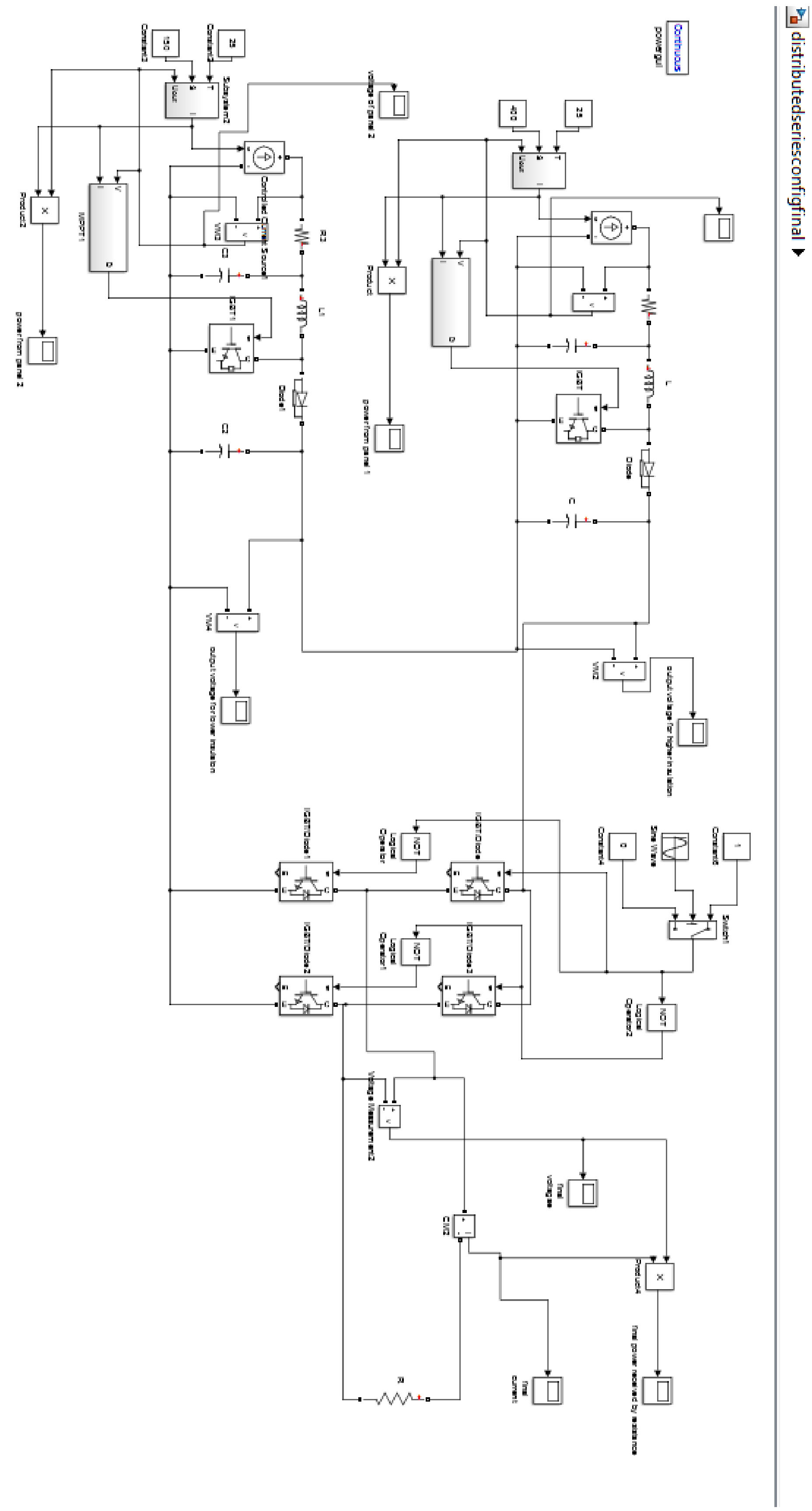

Figure 15 DMPPT in series configuration

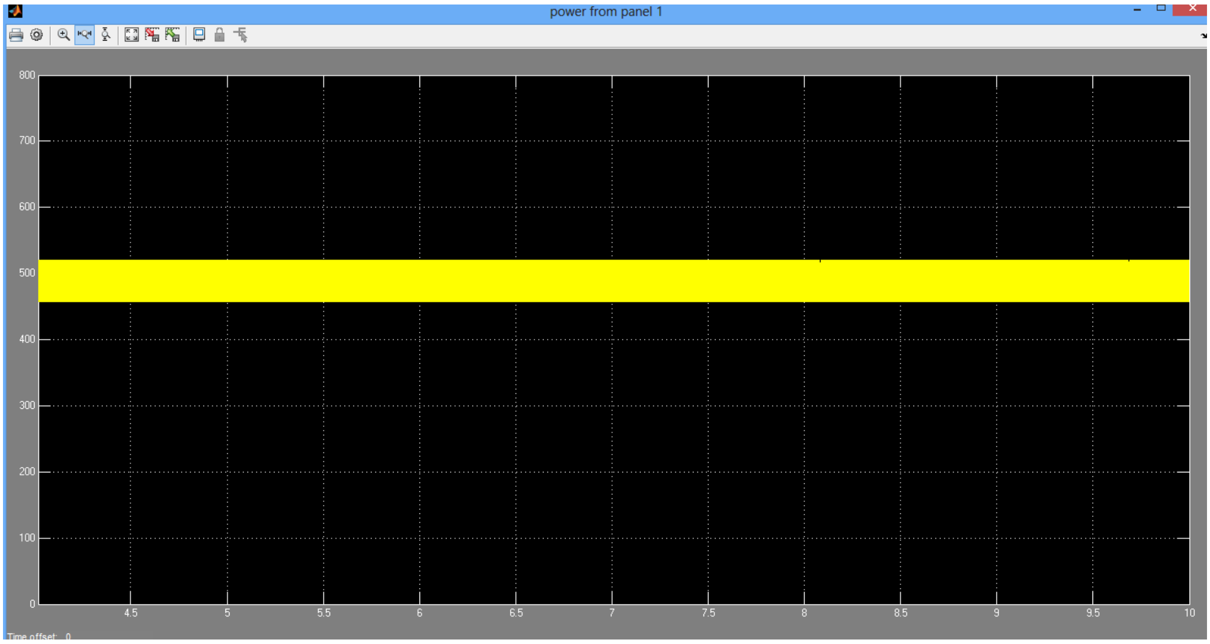

Figure 16 power obtained from higher insulation module at steady state

Figure 15 shows the DMPPT system in series configuration. Hence output voltage will be different for different modules but output current remains same. Power obtained from higher insulation modules is shown in fig.16

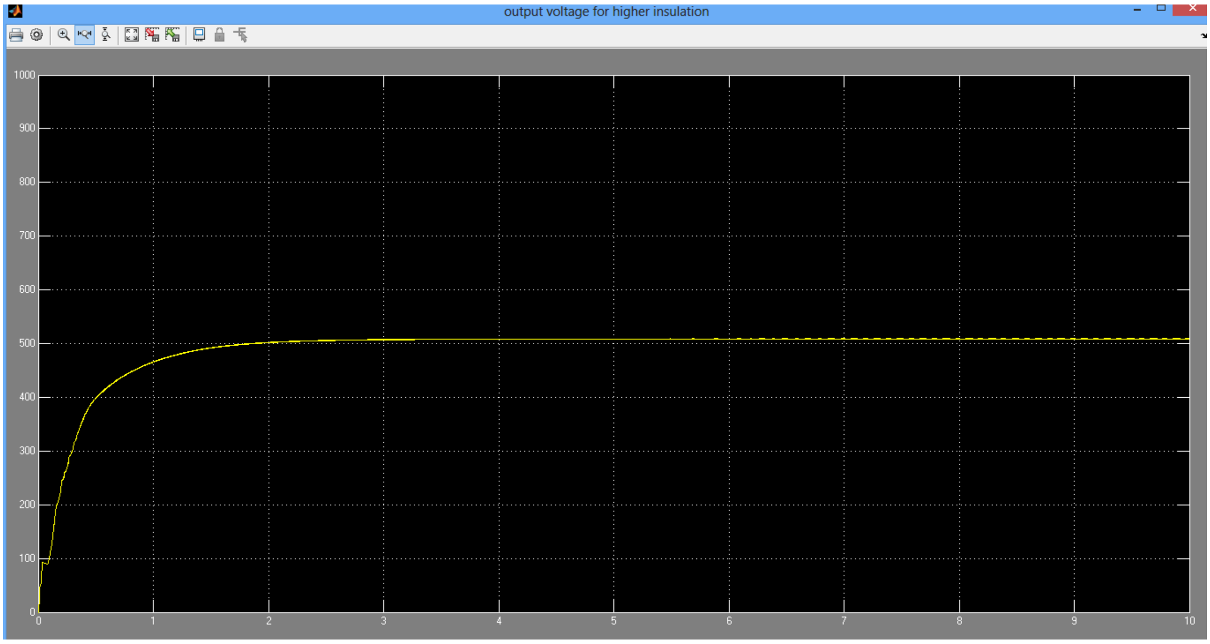

Figure 17 output voltage for module 1

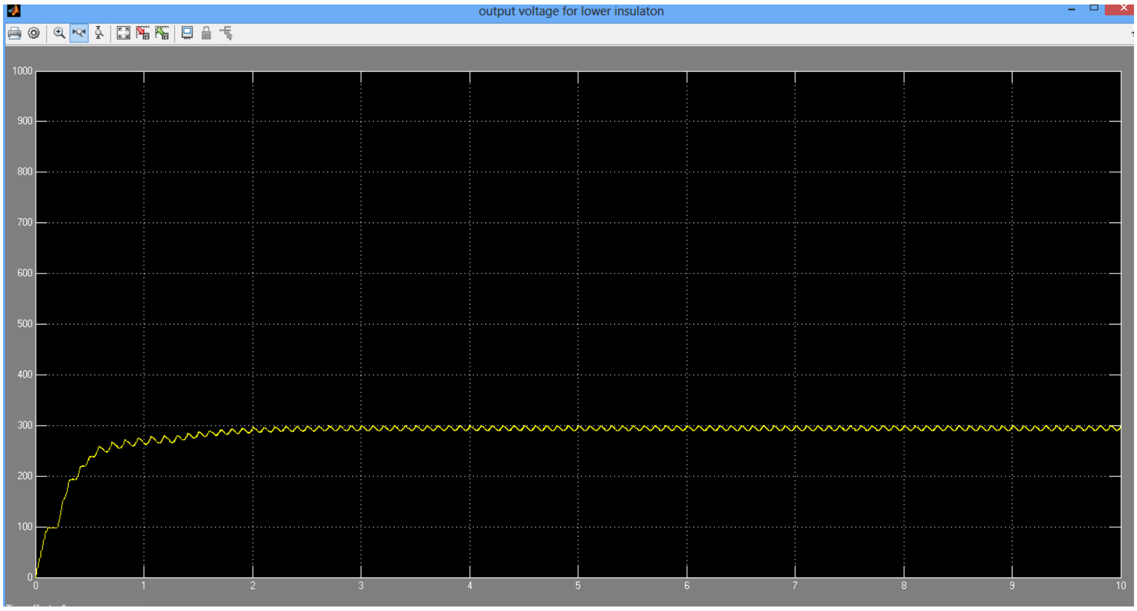

Figure 18 output voltage for module 2

Output voltage for higher insulation is shown in fig.17 and the output voltage for lower insulation is shown in fig.18

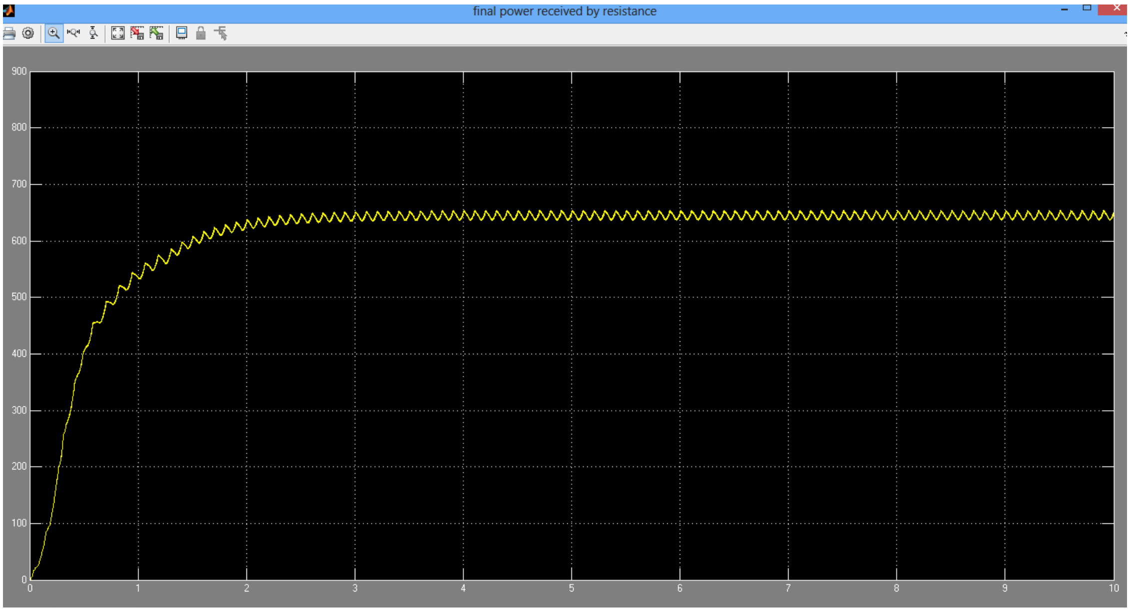

Figure 19 power received by load

Power received by the load is the aggregate of the power received from both converters. Its plot is shown in fig.19

CHAPTER **4**

Output side sensor based DMPPT

4.1 Output side sensor based MPPT:

Conventional method is tracking the maximum power point by taking the voltage of module and current of the module as inputs to the MPP tracker. This chapter presents another way to detect the maximum power point of the module i.e., by having an MPP tracker based on sensing the output of converter rather than sensing the output of solar module.

Since, a tracker on the output side has been used, the MPP tracker which is used in earlier chapters cannot be used here, because the variation of duty cycle is not same as that of earlier one. Hence, in order to determine how to design the MPP tracker, power obtained at the output of converter versus duty cycle of converter graph has been drawn.

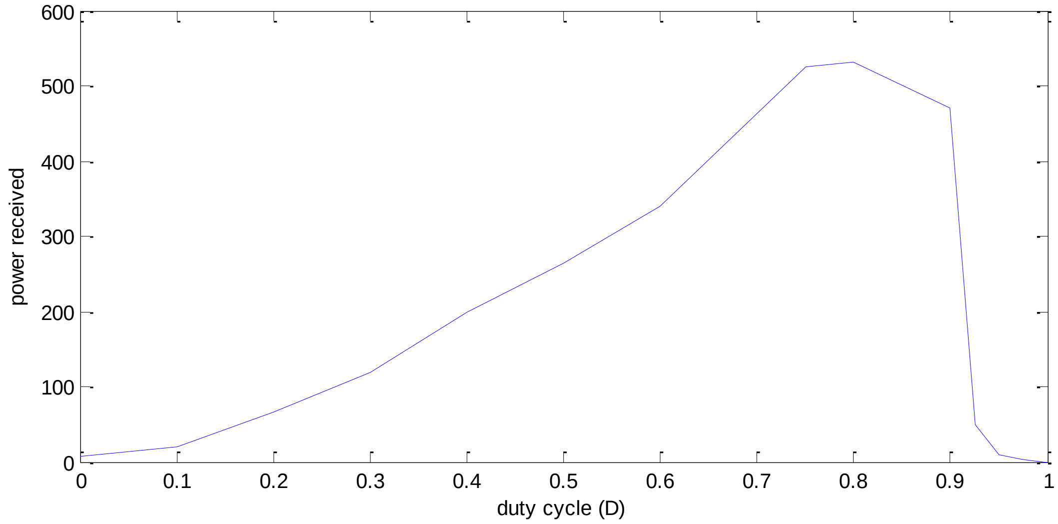

Figure 20 Power vs Duty cycle characteristics

From the obtained graph, it is evident that as the duty cycle is increased, the power obtained keeps on increasing until one point and from then on power obtained keeps deducing until zero. So, by properly keeping the value of duty cycle at the optimum point, the maximum power point can be tracked. The description of the algorithm used to detect the maximum power point is as follows: measure the change in power and change in D i.e., finding out whether ΔP , ΔD

are positive or not. If both are positive or both are negative then ΔD is increased for the next duty cycle. If one of them is positive and the other is negative then ΔD is decreased for the next duty cycle. Thus it keeps on increasing or decreasing the duty ratio depending on the algorithm and finally the MPP point is obtained as steady state is reached.

The remaining system that is used will remain same as the one that is used in previous chapters. The solar panel is connected to the boost converter which adjusts the duty ratio according to the load and the maximum power point. The difference comes in the algorithm used in the MPP tracker and the position of MPP tracker which is placed at the output side of boost converter thus sensing the output voltage and output current and changing the duty cycle accordingly.

4.1.1 Results and discussion:

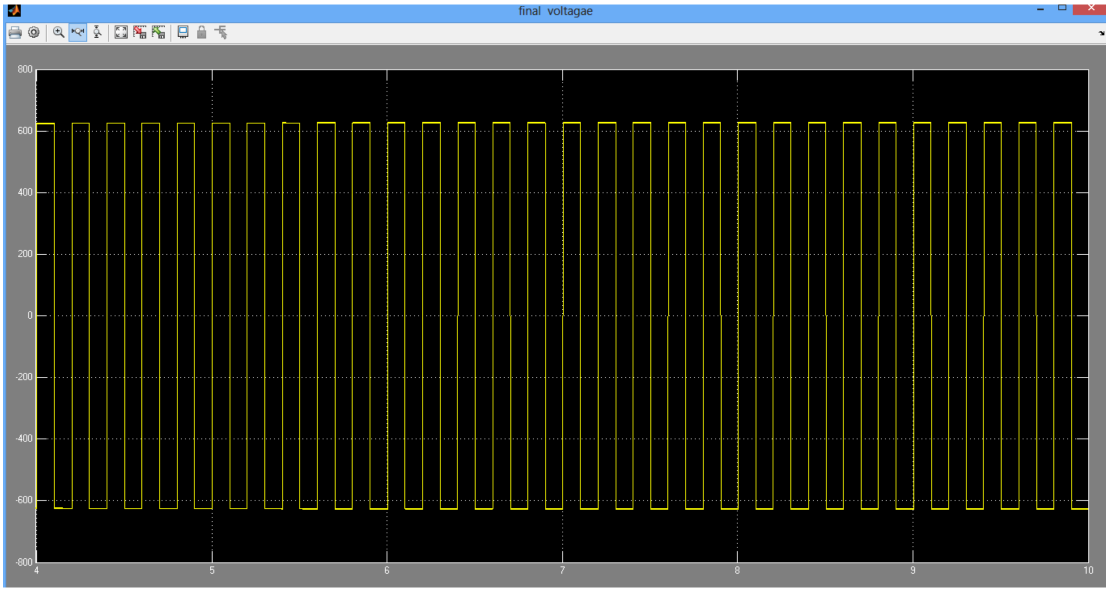

Figure 21 Output voltage at steady state after DC-AC conversion

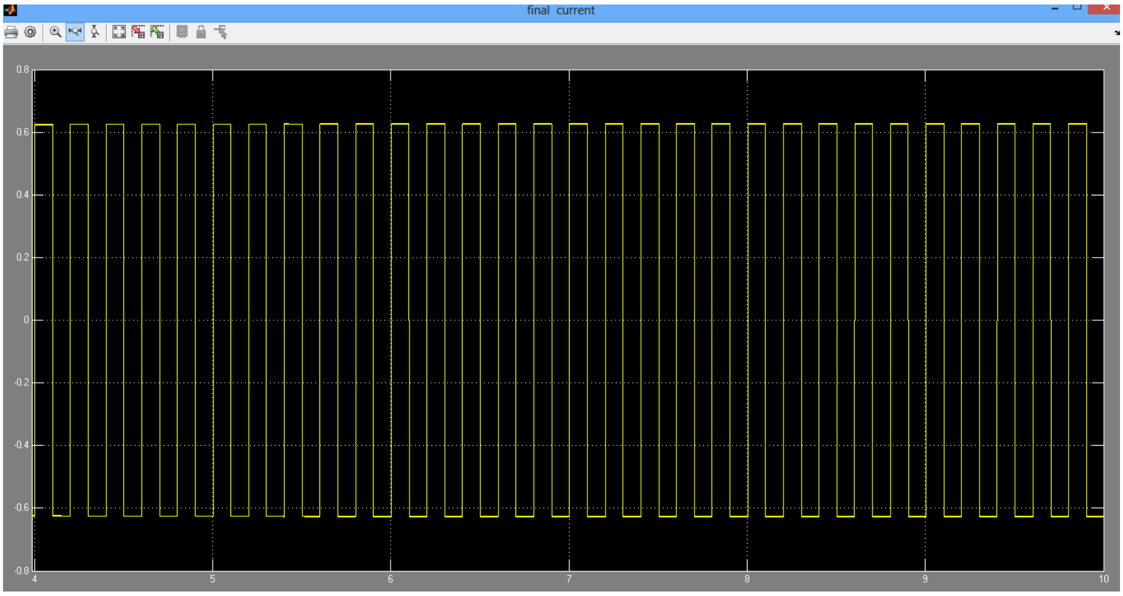

Figure 22 Output current at steady state after DC-AC conversion

The output voltage and the output current shown in the figures 21 and 22 are obtained after DC-AC conversion. The MPP tracker tracks the MPP point and correspondingly adjusts the duty cycle necessarily thus boosting the input voltage.

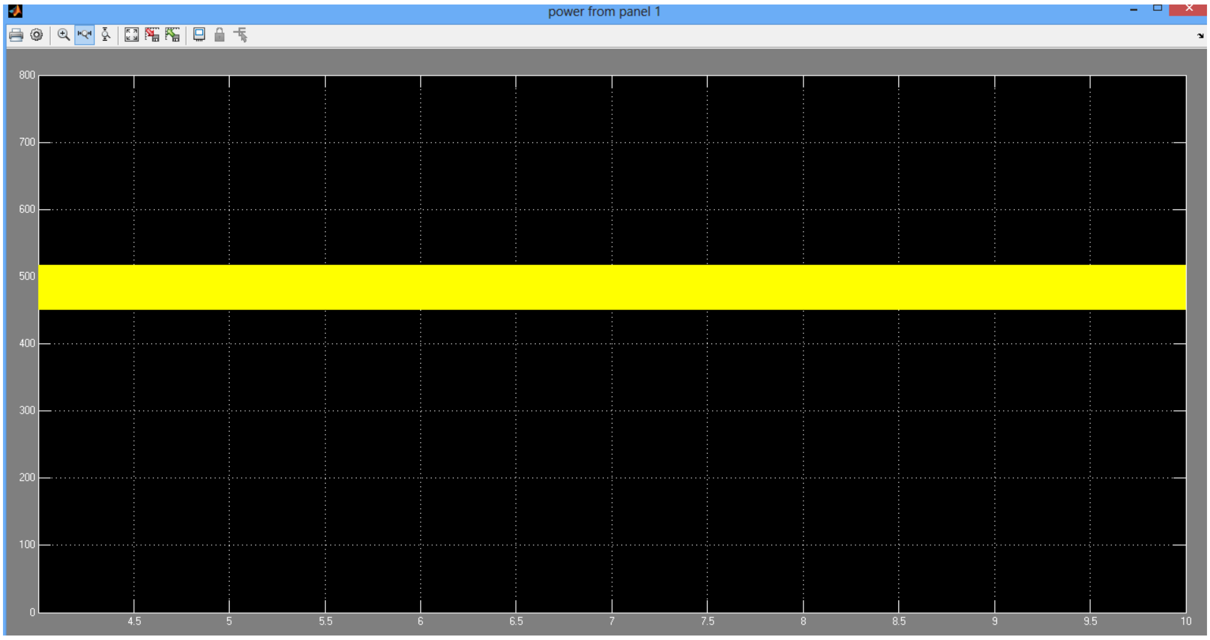

Figure 23 Power from the solar module after reaching steady state

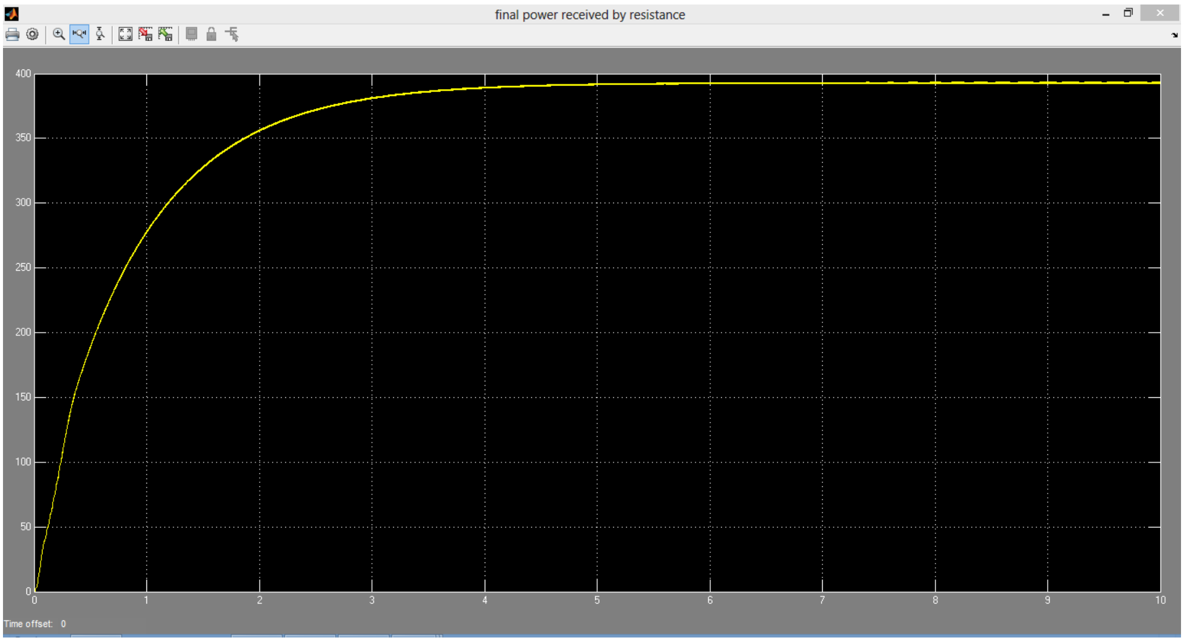

Figure 24 Power received by tracking the MPP by the load

The power obtained from the panel in the figure 23 is adjusted accordingly to get maximum power from the output sensing and the final power received by the load is shown in figure 24.

4.2 output side sensor based DMPPT:

Similar to that of output sensor based MPPT, here output sensor based DMPPT is implemented by sensing the output voltage of converter and output current of the converters. Here in DMPPT, each module is provided a separate converter so that even under partial shading conditions maximum power could be extracted from each module separately. Here in output sensor based DMPPT, the output of each converter is tracked and feed it to the corresponding output based MPP tracker. The tracker used in section 4.1 is used here also. The change in output power of each converter is measured and comparing it with the change in duty cycle, if both are positive then ΔD is increased for the next duty cycle. If both are negative then ΔD is increased for the next duty cycle. If one is negative and the other one is positive, ΔD is decreased for next duty cycle.

The benefit of using output sensor based DMPPT in parallel configuration is that since the output voltage of all the converters is same in parallel connected DMPPT system, the output voltage of any single module can be sampled and it would be given it to all the MPP trackers. So, the amount of hardware needed for this one is lesser when compared to the conventional DMPPT system. Thus hardware is saved in turn affecting the money needed to implement the system. In this system, one voltage sensor and more than one current sensor are needed, where as in conventional system, more than one voltage sensor and more than one current source are needed. Similarly, output sensor based MPPT can also be implemented for series configuration also where only one current sensor is needed and more than one voltage sensors are needed.

4.2.1 Results and Discussion:

Figure 25 Power obtained from lower insulation module after reaching steady state

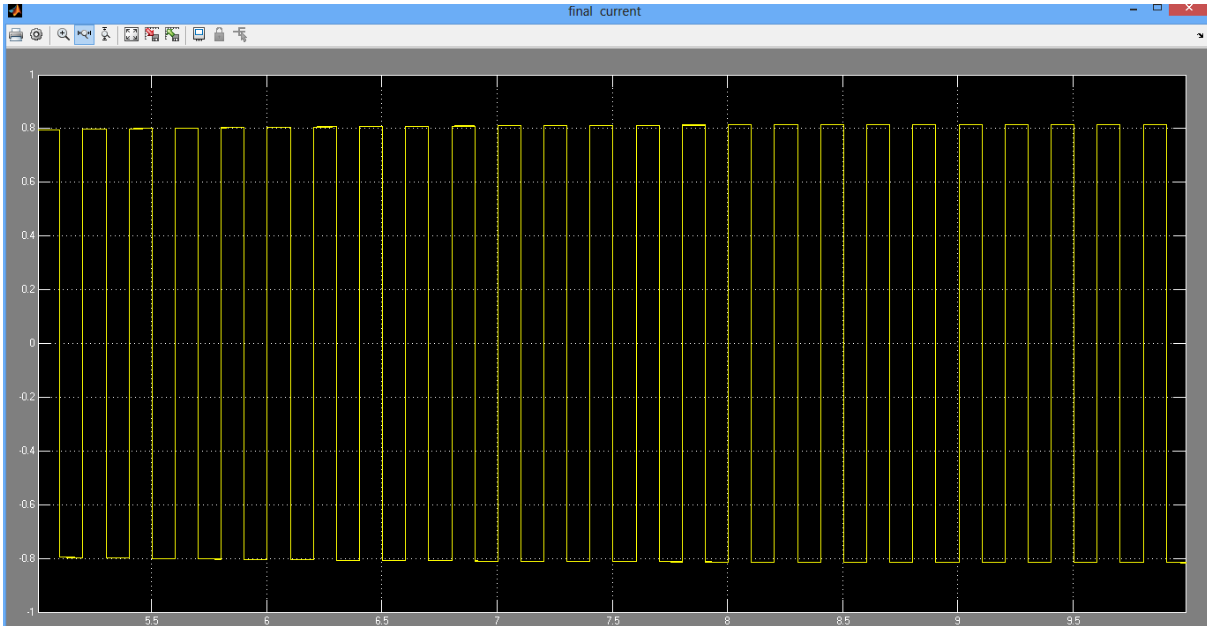

Figure 26 Output current at steady state after DC-AC conversion

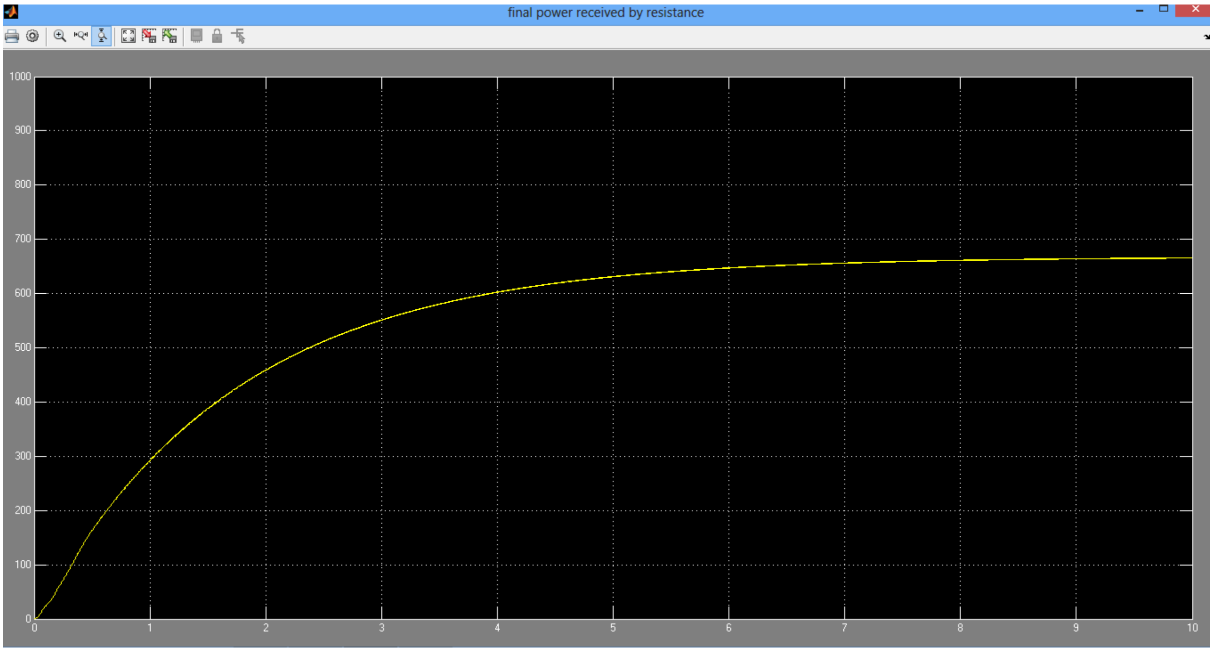

Figure 27 Output power of output sensor based DMPPT

The power obtained from the two modules is different from one another because the insulation level for one module is higher than that of the other module. The output voltage remains same to all the modules as they are connected in parallel. The power received by the load which is shown in fig.27 is the aggregate of power from both the modules. Thus current received by the load is the sum of currents provided by all modules. The voltage received by the load after DC-AC conversion is shown.

Conclusion
And
Bibliography

Conclusion:

- Some new trends in practice for improvising the solar energy production have been discussed.
- A special importance on perturb and observe method is being given.
- State Space modelling of boost converter is derived.
- An acceptable Mathematical analysis of why there are virtually no cross coupling effects in the parallel configuration of DMPPT is presented.
- How the DMPPT technique effectively improves the efficiency of solar power is discussed.
- Output side sensor based DMPPT system has been studied and how it helps in reducing the hardware thereby reducing the overall installation cost is discussed.
- Various simulation results have been presented and checked based on theoretical learning. The plots obtained have been shown accordingly.

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