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Enhancement of Efficiency of a Photovoltaic Panelby Voltage Regulation using PI- Control Algorithm.

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Abstract: The growing demand for the renewable energy resources, especially the solar energy, has drawn the interest of the researchers. The need for extraction of maximum energy has called for innovation of newer techniques so that the PV panel can be efficiently operated at its peak power under partial shading and dynamic atmospheric conditions.

In this paper, we have discussed the regulation of the output voltage of the PV array. We have observed the characteristics of the PV Panel under different temperatures and solar irradiations. Maximum power point tracking algorithm has been employed to operate the panel voltage at its MPP.

Firstly, the panel peak voltage is obtained directly by varying the duty cycle of the converter. The direct duty Ratio control technique causes stress on the switch of the DC-DC converter besides loss of a significant amount of power.

Therefore a PI controller has been implemented to regulate the panel voltage. A study using both DC-DC buck converter as an interface between the PV Panel and the load has been presented. The PI controller prevents oscillation around the MPP apart from improving the steady state response and the settling time. A detailed analysis of the modeling of the PV array and DC-DC converters has been produced which helps in designing an efficient PI controller.

I. Introduction

With the reserve of fossil fuels diminishing and rise in the global temperature, the need to look for sustainable energy resources has become indispensable. The sustainable energy not only reduces the consumption of fossil fuels but also prevents the rising temperature of the earth besides diminishing the various pollutants emitted by it.

The main forms of renewable energy resources are Solar Energy, Wind Energy and Hydro Energy. The problem associated with hydro energy is that it is seasonal dependant where as the main factor that has caused researchers' inclination for solar energy a little more than wind energy is that it is plentily available throughout the globe whereas establishing a wind farm is significantly costlier and depends on geographical locations. Moreover solar energy can be converted directly into electrical energy with the implementation of some power electronic devices. Dynamic atmospheric conditions and partial shading reduces the efficiency of a PV Panel [11]. So a need for extracting maximum energy from the photovoltaic panel arises [2],[18]. This problem has been attended by the introduction of various MPPT methods. MPPT techniques help in faster tracking and locking of photovoltaic panel MPP which increases its efficiency. The growing research in this field has also reduced the cost of solar energy. Therefore Solar Energy has gained a lot of importance even in the rural areas.

II. Analysis & Modelling of a PV based system

The non-linear characteristics of the I-V curve of a PV panel can be divided into a current source region and a voltage source region. In this section we have linearized the PV panel at the MPP and a equivalent model of the PV panel is designed. The performance of a closed loop system can be improved by using a PI controller. The Parameters of a PI controller can be obtained by various methods like Frequency domain Analysis, Ziegler-Nichols criteria, Computational approach etc., for which modelling of a Converter is essential. The aim of modelling a converter for controlling the voltage is to derive a Small-Signal transfer function that gives a relation between the small signal voltage and the control variable. The negative sign indicates decrements in duty cycle causes increments in the input voltage [5]. The transfer function is then derived from the A, B, C and D matrices which is elaborated in the following section.

PV Module Modelling

The non-linear I-V characteristics of a photovoltaic device is define in Fig 3.1.The I-V curve of the PV Module is shown in Fig. 3.1.I-V characteristics are defined as [3]

$$i_{PV} = I_{PV} - I_0\left[e^{\left(\frac{v_{PV}+R_S i_{PV}}{V_t a}\right)} - 1\right] - \frac{v_{PV}+R_S i_{PV}}{R_P} \quad [3]$$

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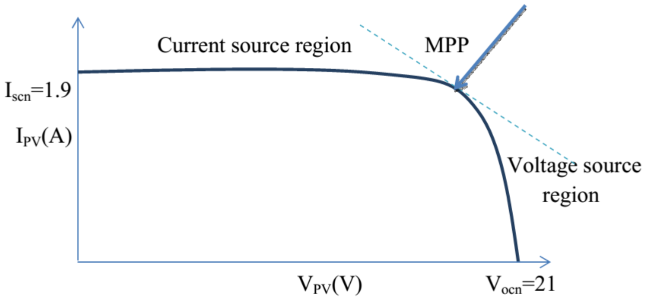


Fig 3.1 PV Modules Non-linear I-V Characteristics

It can be represented by a current source. It has avery high parallel resistance and a low series resistance. In Fig. 2.2 the equivalent circuit of a photovoltaic cell is shown [3].

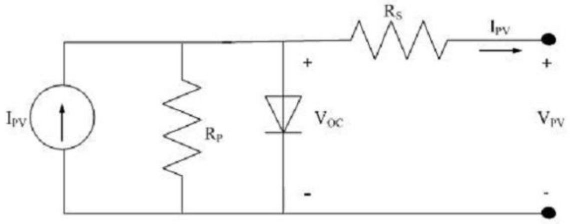


Fig 3.2: Equivalent Circuit of a Photovoltaic Cell[3]

Where

Table 1: Parameters of the PV Module

'I_{PV}' is represented as the photovoltaic current,
'I_O' represents reverse saturation current,
'V_t' represents the thermal voltage,
'k' is represented as the Boltzmann constant(1.381e-23 J/K),
'q' represents electron charge(1.602e-19 C),
'T' represents junction temperature in K,
'R_s' represents equivalent Series Resistance,
'R_p' represents equivalent Shunt Resistance,
'a' represents ideality constant of the Diode(1-1.3),

I_O	$9.825*10^{-8}$A
I_{scn}	1.9A
a	1.3
R_P	210
R_S	0.221 Ω
V_{ocn}	21V

We need to linearize the PV array model at its MPP in order to analyze. The nominal I-V curve is linearzed at the MPP as shown in Fig 2.1.The slope of the non-linear I-V curve at a certain point(V,I)is given by [5]

$$g(V,I) = -\frac{I_o}{V_t N_s a} e^{\left(\frac{V+IR_S}{N_S V_t}\right)} - \frac{1}{R_P} \quad [5]$$

The linear model is given by the tangent to the point at the linearization point (V,I) [5]

$$i_{PV} = (-gV + I) + g v_{PV}$$

The equivalent circuit is represented by Fig 2.3 [5] where Req 1/g=and $V_{eq} = V - I/g$

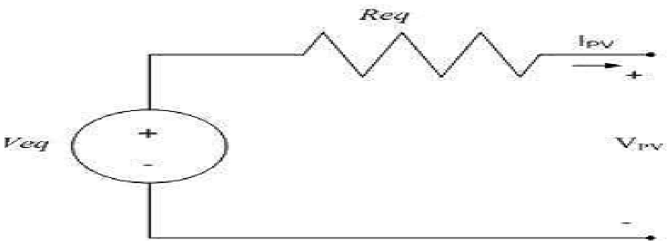


Fig.3.3: Linear equivalent circuit at the linearization point.[5]

State Space Modelling of Buck Converter

a) With Resistive Load

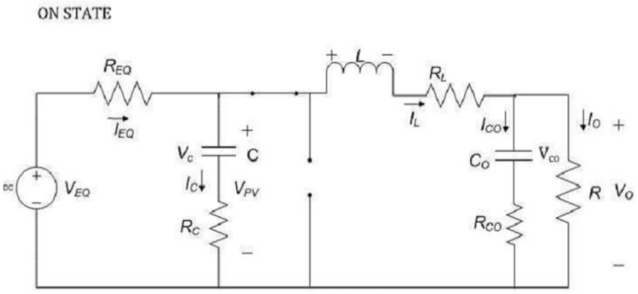


Fig 3.4: On-State Circuit diagram of Buck Converter with Resistive Load

ON STATE EQUATIONS

$$\frac{V_{PV} - V_{EQ}}{R_{EQ}} + I_C + I_L = 0$$

$$V_{PV} = R_C I_C + V_C$$

$$V_{PV} = \begin{bmatrix} -\frac{R_{EQ}R_C}{R_{EQ}+R_C} & \frac{R_{EQ}}{R_{EQ}+R_C} & 0 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \\ V_{CO} \end{bmatrix} + \begin{bmatrix} \frac{R_C}{R_{EQ}+R_C} \end{bmatrix} V_{EQ}$$

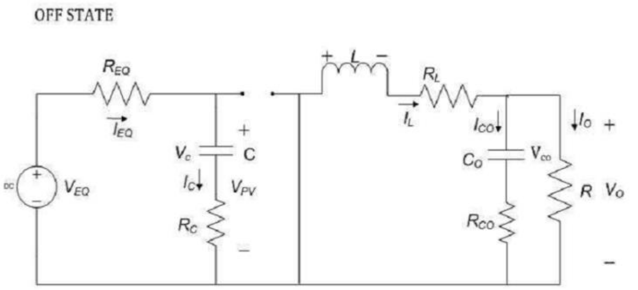


Fig 3.5: Off-State Circuit diagram of Buck Converter with Resistive Load

OFF-STATE EQUATIONS

$$\frac{V_{EQ}-V_{PV}}{R_{EQ}} = I_C$$

$$I_C = \frac{V_{EQ}}{R_{EQ}+R_C} - \frac{V_C}{(R_{EQ}+R_C)}$$

$$V_{PV} = \begin{bmatrix} 0 & \frac{R_{EQ}}{R_{EQ}+R_C} & 0 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \\ V_{CO} \end{bmatrix} + \begin{bmatrix} \frac{R_C}{R_{EQ}+R_C} \end{bmatrix} V_{EQ}$$

With Battery Load

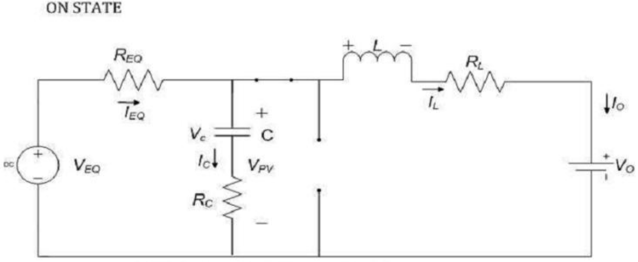


Fig 3.6: On-State Circuit diagram of Buck Converter with Battery Load

ON STATE EQUATIONS

$$I_{EQ} = I_C + I_L$$

$$V_{PV} = I_C R_C + V_C$$

$$\frac{V_{EQ}-V_{PV}}{R_{EQ}} = I_C + I_L$$

$$I_C = \frac{V_{EQ}}{R_{EQ}+R_C} - \frac{V_C}{R_{EQ}+R_C} - \frac{I_L R_{EQ}}{R_{EQ}+R_C}$$

$$V_{PV} = \begin{bmatrix} -\frac{R_{EQ}R_C}{R_{EQ}+R_C} & \frac{R_{EQ}}{R_{EQ}+R_C} \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{R_C}{R_{EQ}+R_C} & 0 \end{bmatrix} \begin{bmatrix} V_{EQ} \\ V_O \end{bmatrix}$$

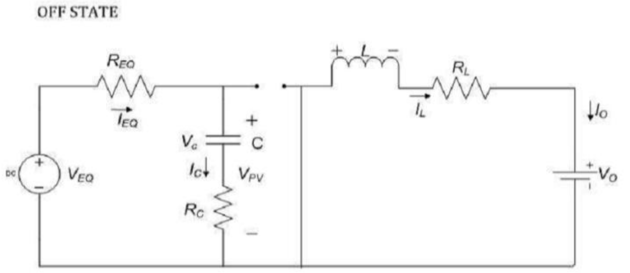


Fig 3.7: Off-State Circuit diagram of Buck Converter with Battery Load

OFF STATE EQUATIONS

$$I_C = \frac{V_{EQ}-V_{PV}}{R_{EQ}}$$

$$I_C = \frac{V_{EQ}}{R_{EQ}+R_C} - \frac{V_C}{R_{EQ}+R_C}$$

Maximum Power Point Tracking Algorithms

When we install a solar panel or a array of solar panels without a MPPT technique, it often leads to wastage of power, which ultimately requires more number of panels for the same amount of power requirement. Also whenever a battery is connected directly to the panel, it results in premature failure of battery or loss capacity owing to lack of a proper end-of-charge process and higher voltage. So, absence of a MPPT method results in higher cost. The main aim of a MPPT technique is to automatically find the operating voltage of the panel that delivers maximum power to the load. When a single MPPT is connected to large number of panels,it will yield a good result but in case of partial shading, the combined power output curve will have multiple maxima which might confuse the algorithm.

Fractional Open Circuit Voltage

A linear relation with the open circuit voltage is maintained by the maximum power point voltage under different temperature and irradiance conditions.

$$V_{MPP} = K_V V_{OC}$$

Constant KV is always dependable on the type and configuration of the Solar Panel. The open circuit voltage. For FOCV the open circuit voltage of the panel has to be measured first in order to determine the MPP voltage. One way of doing it is the system periodically disconnects the system from the load to measure the open circuit voltage and calculate the MPP. Clearly this procedure leads to wastage of power. Another method could be by using one or more monitoring cells but they must also be chosen and placed very carefully to measure the correct open circuit voltage. Even though the method is simple and robust, we can only make a crude approximation of the MPP. The value of KV has been experimentally found out to be between 0.7-0.8.

Fractional Short Circuit Current

The MPP can also be calculated from the short circuit current of the panel because IMPP is linearly dependent on the short circuit current under varying atmospheric conditions

$$I_{MPP} = K_I I_{SC}$$

Incremental Conductance

It is based on concept that the slope of the power versus voltage curve is zero at MPP, positive on the left side and negative on the right side of the MPP.

Equation 1

$$\frac{dP}{dV} = 0, at\ the\ MPP$$
$$\frac{dP}{dV} > 0, left\ of\ MPP$$
$$\frac{dP}{dV} < 0, right\ of\ MPP$$

Equation 2

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

Equation 3

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

The concept behind this is to make a comparison between the incremental conductance to the instantaneous conductance. It is operated by this logic until the MPP is reached by increasing or decreasing voltage

Direct Duty Ratio Control

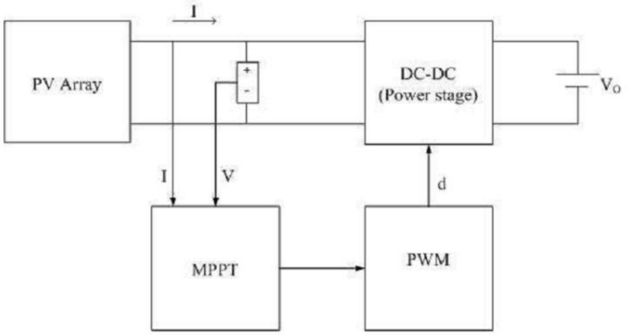
In this method the duty cycle of the converter is varied based upon different MPPT methods which measures the small variations inthesolar array input voltage 'dV' and input power 'dP', in a direction to reach towards the MPP of the solar array.

The duty cycle perturbation at (k+1)th sampling time can be represented by

$$d((k+1)T_a) = d(kT_a) + (d(kT_a) - d((k-1)T_a)).sign(P((k+1)T_a) - P(kT_a))$$

The oscillations of i(jkl)around the MPP can be minimized if the sampling interval Tais properly chosen. Minimizing Δd reduces the steady state losses caused due to the continuous oscillation of the Module operating point about the MPP.

The Fig. 3.8 gives a schematic representation of direct duty cycle control method.



In this type of control no proper voltage regulation can be achieved. And the power stage is subjected to increased switching stresses and losses. Therefore a PI compensator is used for regulating the converter voltage or current. Apart from reducing stresses and losses owing to the bandwidth constrained regulation of the duty cycle, a compensator reduces the settling time, avoids oscillation a, which eases the functioning of MPPT algorithm [5].

PI Control

In this scheme of Fig.3.9 MPP technique generates the reference voltage signal which is then compared with the input voltage of the converter. The input voltage Vpvis regulated by a PI compensator, the output of which acts on the converter duty cycle.

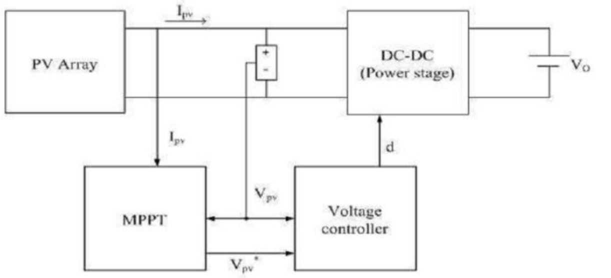


Fig. 3.9: PV Array regulated by PI controller

The open loop transfer function relating the converter input Voltage Vpv to duty cycle d is represented by Gvd which can be obtained through the procedure given in [2].,the feedback gain of the input voltage is Hvand the compensator transfer function is Cvd. The block diagram representation of the single feedback loop.

PI Tuning

The MPPT measures the PV voltage and current and then the Perturb and Observe algorithm decides the reference voltage. The aim of PI is to decide the value of Vpv*only and it is done at certain intervals time. The PI control loop tries to reach the input voltage of the converter. It reduces the error between V_{PV*} and Vpvby varying the converter's duty cycle. The PI loopcontrol works at a much faster rate and gives a faster response.

III. RESULTS

The PV Module has been interfaced to a load resistance through DC-DC converters. The simulation results have been obtained for both Boost and Buck converters. The PV module characteristic has been shown under different irradiations. Secondly, Power and voltage curves have been obtained under two different irradiations using the direct duty ratio control technique. Lastly we have shown the input regulated power and voltage curves of the PV Module with both Buck and Boost converters using PI controller.

Voltage Reference Control using PI Controller

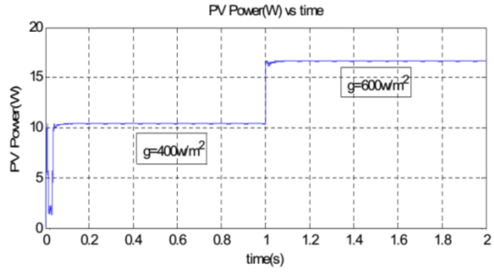


Fig. 4.1: PVPower of a Buck converter using PI.

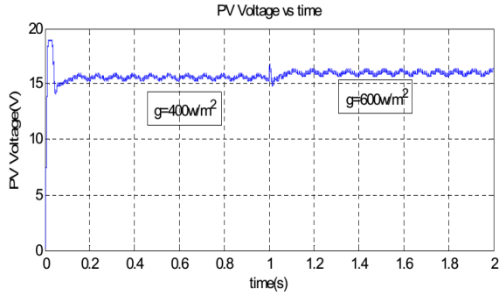


Fig. 4.2: PV Voltage of a Buck converter using PI.

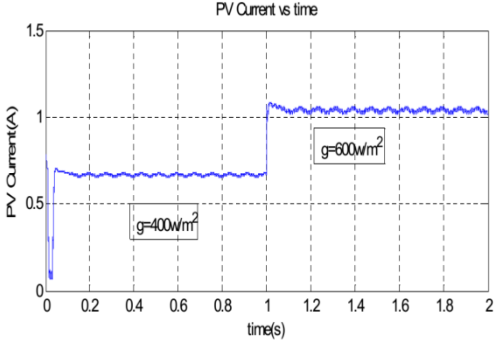


Fig. 4.3: PV Current of a Buck converter using PI.

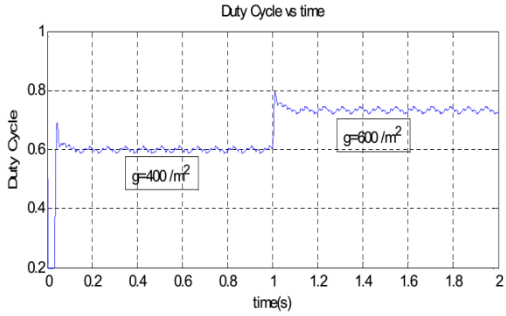


Fig. 4.4: Duty Cycle of a Buck converter using PI.

IV. CONCLUSION

The results were obtained in the MATLAB-Simulink environment. From the curves obtained both in the direct duty ratio control and the voltage reference control in which a PI controller is used to regulate the voltage of the PV array, it is evident that a PI controller helps in achieving a faster steady state response and avoids oscillations and overshoot as compared to direct duty ratio control. We have also made a comparative analysis of the different MPPT techniques which guides us to choose the best among the available techniques in a particular environmental condition.

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