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Solar Photovoltaic (PV) Array under Partial Shading Conditions

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ABSTRACT: *This paper intended to investigate a schematic to draw out maximum attainable solar power from a PV panel for use in a DC application. The concept of Maximum Power Point Tracking is to be implemented which results in a noticeable growth in the efficiency of the Photovoltaic System. Therefore, the MPPT algorithm proposed would identify the appropriate duty ratio in which the DC-to-DC converter should be operated to get the maximum power output.*
Keywords: *About five key words in alphabetical order, separated by comma*

I. INTRODUCTION

It is a well-documented fact that the output power capacity will be reduced by a partial shading of a photovoltaic array; however, the reduction in energy production cannot be determined in a direct method, as it is frequently not proportional to the shaded area. Some of the previous studies supposed that the decrease in power production is proportional to the shaded area and reduction in solar irradiance as well. In actuality, this concept is valid for just a single cell. The power reduction at the array level is predominantly far away from linearity with the shaded portion [2]. Numerous factors can influence the performance of a photovoltaic (PV) system. One of the most significant factors is shading. Shading indicates a shadow on the PV modules on the outer surface that will decrease the system energy yield. As a consequence, the three fundamental PV module characteristics of power, voltage, and current will be affected [1]. With changing irradiation during the day, the array output varies in a wide range. This variation of array output is expected. However, uniform lighting concentration in a panel is not roughly satisfied due to unexpected shading effects caused by dust, clouds, trees, buildings, atmosphere fluctuation, an existence of clouds, and daily sun angle changes causing shading on cells or side of modules as shown in Figure 3.10. Shade impact depends on module type, fill factor, bypass diode placement gravity of shade, and string configuration. Power loss happens from the shade as well as current mismatch within a PV string and voltage mismatch between parallel strings [5].PV solar panels are very sensitive to shading. In PV systems, it is virtually impossible to utterly avoid shading. Looking at the electrical characteristics of PV solar panels, partial shading effect results in a distortion of the overall I-V and P-V curves of the PV solar panels. As a result, the I-V and P-V characteristics of the solar panels become more complex with existing multiple maximum power points (MPP) under the non-uniform irradiance conditions.

The total output power of a PV module will be reduced by a shadow falling on it from two mechanisms, which are reducing the energy input and increasing energy losses. Even though only one cell is shaded in the PV module, around 30% power loss will happen. The power losses will increase proportionally to the number of shaded cells. A partial shading problem results in a deformity of the overall I-V curve, and this impact can be illustrated by the mismatch between the individual modules' I-V curves [7].

II. CHARACTERISTIC OF SOLAR PV ARRAY

1. Open Circuit Voltage

The open circuit voltage (V_{OC}) has occurred when there is no current passing through the cell.
At I = 0, Voltage = V_{OC}
V_{OC} is the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant. For forward-bias power quadrant, $V_{OC} = V_{MAX}$

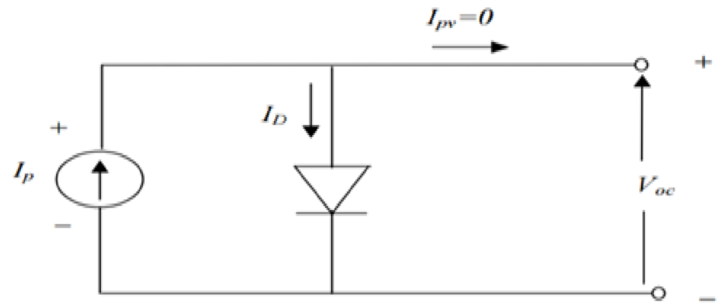

Fig.1: Open circuit voltage.

Under the open circuit voltage $I_{PV} = 0$

$$I_P - I_0\left[e^{\frac{qV_{OC}}{nKT}} - 1\right] = 0$$

$$\frac{I_P}{I_0} = \left[e^{\frac{qV_{OC}}{nKT}} - 1\right] \Rightarrow \ln(e^{\frac{qV_{OC}}{nKT}}) = \ln\frac{I_P}{I_0} + 1$$

$$V_{OC} = \frac{nKT}{q}\ln\left[\frac{I_P + I_0}{I_0}\right]$$

2. Short Circuit Current

The short circuit current (I_{SC}) has occurred when the voltage equals zero.

At V=0, I = ISC

I_{SC} happens at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For forward-bias power quadrant, $I_{SC} = I_{MAX}$

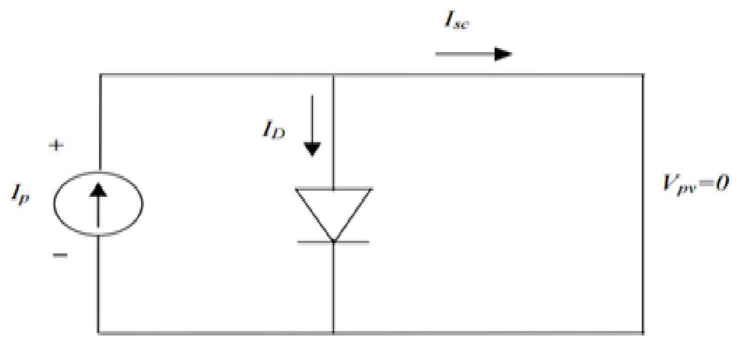

Fig.2: Short Circuit Current.

III. MAXIMUM POWER POINT TRACKING METHOD FOR PV ARRAY UNDER PARTIAL SHADING CONDITIONS

The use of the recently developed power control mechanisms, called Maximum Power Point Tracking (MPPT) algorithms, has led to increasing the efficiency of operation of the solar modules. Therefore, MPPT is efficient in the field of exploitation of renewable sources of energy [MPPT technics]. Maximum power point tracking is a DC-to-DC converter that optimizes the match between the solar array (PV modules) and the battery bank or utility grid. It converts a higher voltage DC output from solar PV arrays or modules down to the lower voltage needed to charge batteries and vice versa. Maximum Power Point Tracking is an electronic arrangement that routinely finds the voltage (V_{MPP}) or current (I_{MPP}) at which PV modules should operate to achieve maximum power output (P_{MPP}) under partial shading condition. It runs the PV modules in a way that allows the modules to generate all the power they are capable of producing [3].

Solar radiation that hits the photovoltaic modules has a variable character depending on the position, the direction of the solar field, the season, and the hour of the day. During the trajectory of a day, a shadow may be decanted on the cell, which may be contemplated, as in the case of a building near the solar field, or unforeseeable as those created by clouds. The breakthrough of PV systems as distributed power generation systems has increased drastically in the last few years. Because of this Maximum Power Point Tracking (MPPT) is becoming more and more substantial as the amount of energy generated by PV systems is increasing. A MPPT technique must be used to track the maximum power point since the MPP depends on solar irradiation and cell temperature. In general, when the impedances of the load and source are matched, the maximum power is transferred to the load from the source only. The generated energy from PV systems must be maximized, as the efficiency of solar panels is low. For that reason to get the maximum power, a PV system is repeatedly equipped with an MPP tracker [4].

IV. DC-DC CONVERTERS

DC-DC converters are used for converting one level of DC input voltage to another level of DC output voltage. The DC-DC converter contains an inductor, capacitors, and switches. A DC-DC converter interfaced with a PV system is extremely important because we needed a good converter. These converters play a significant role in the charge controller, MPP trackers, and PV interface with the load [6].

V. BUCK-BOOST CONVERTER WITH MPPT

Maximum power from the PV panel can be accomplished by incorporating an intelligent mechanism to change the load resistance noticed from the PV panel. Power converters are used to modify operating conditions to achieve the maximum power point. Figure 4.10 represents the incorporation of a buck-boost converter into a PV system. Adjusting the duty ratio of the power switches of the converter controls the input voltage. The relationship of the voltage and current at the load terminal and those at the PV panel under steady-state conditions are listed below in the case of buck-boost converter is operating in the continuous conducting mode with 100% efficiency [10]-[8].

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$$V_o = \frac{D}{1-D} V_{PV} \; ; \; I_o = \frac{1-D}{D} I_{PV}$$

The load resistance will be expressed based on Ohm's law as:

$$R_L = \frac{V_o}{I_o} = \left(\frac{D}{1-D}\right)^2 \frac{V_{PV}}{I_{PV}}$$

Thus, the equivalent resistance observed from the PV panel, denoted as R_{PV}, is:

$$R_{PV} = \frac{V_{PV}}{I_{PV}} = \left(\frac{1-D}{D}\right)^2 R_L$$

This equation implies that for a particular load resistance R_L, the equivalent resistance R_{PV} counts on the duty ratio of the buck-boost converter. Therefore, we may adjust the duty ratio D to attain maximum power transfer from the PV panel through an optimal mechanism. Figure 4.11 depicts the power characteristics of the PV system. Also, it shows the power received at the load terminal with different duty ratios for the power switches of the converter.

The power developed at the load terminal is:

$$P_L = \frac{V_o^2}{R_L} = \frac{\left(\frac{D}{1-D}V_{PV}\right)^2}{R_L} = \left(\frac{D}{1-D}\right)^2 \frac{V_{PV}^2}{R_L} = \frac{V_{PV}^2}{R_{PV}}$$

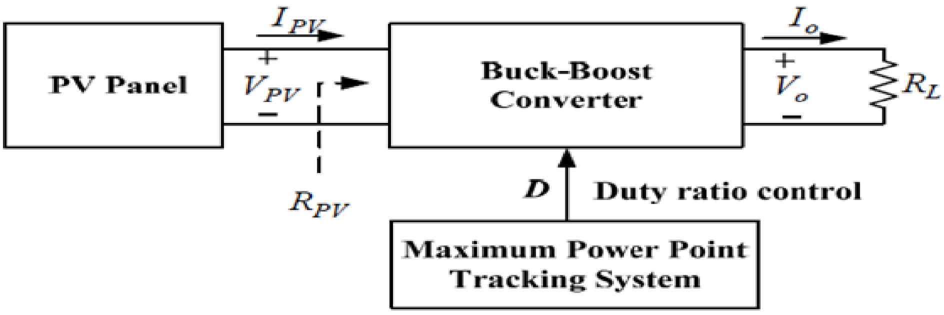

Fig.3: PV system with buck-boost converter incorporated.

VI. CONCLUSION

This paper has presented detailed solar photovoltaic power system technology. Based on this research and judging from the outstanding breakthroughs that have been made in the technology of solar PV array in the last couple of decades, the future trend looks optimistically bright for solar photovoltaic applications. The ongoing technology and research will no doubt transform solar energy from niche to mainstream in the very near future. Other factors that are catalysts to transforming this renewable source of energy are the increasing cost of fossil fuel and climate change awareness. In partially shaded conditions, as there are several local maxima values on the P-V curve, a conventional MPPT algorithm usually tends to follow less than the real MPP, and it causes significant power loss. A PV system model was established. It has a quick response and good performance. Even if some parts of the PV module are under partially shaded conditions or sunlight is rapidly changing the circumstances, a PV system can quickly work at MPP.

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