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PV Fed Modified SEPIC Converter for Fast-Converging MPPT Technique

Engineering

KEYWORDS: Fast converging, incremental conductance, maximum power point tracking (MPPT), photovoltaic (PV) system, single-ended primary-inductor converter (SEPIC), modified single-ended primary-inductor converter.

Vineeth N K, Prajith J.M Department of Electrical Engg., Veda Vyasa Institute of Technology

ABSTRACT

In this paper, Modified Single Ended Primary Inductance Converter (SEPIC) used for the control of photovoltaic power using Fast-Converging Maximum Power Point Tracking (MPPT) control is presented. Under fast-varying solar irradiation and load resistance, a fast-converging maximum power point tracking (MPPT) system is required to ensure the photovoltaic (PV) system response rapidly with minimum power losses. Traditionally, maximum power point (MPP) locus was used to provide such a fast response. However, the algorithm requires extra control loop or intermittent disconnection of the PV module. Hence, this paper proposes a simpler fast-converging MPPT technique, which excludes the extra control loop and intermittent disconnection. In the proposed algorithm, the relationship between the load line and the I-V curve is used with trigonometry rule to obtain the fast response. Fast-Converging MPPT is liable for extracting the maximum possible power from the photovoltaic and feed it to the load via the SEPIC converter which steps up the voltage to required level. Voltage multiplier technique is applied to a traditional SEPIC converter. The multiplier technique provides new operation characteristics and a high static gain. The theoretical analysis, design procedure and simulation results are shown in this paper.

I. INTRODUCTION

One of the major concerns in the power sector is the day-to-day growing power demand but the absence of enough resources to meet the power demand using the conventional energy sources. Demand has enlarged for renewable sources of energy to be employed along with conventional systems to meet the energy demand. Renewable sources such as solar energy and wind energy are the foremost energy sources which are being employed in this regard. Solar energy is plentifully available that has made it possible to harvest it and utilize it correctly [1]. Solar energy can be a standalone generating unit or canbe a grid connected generating unit depending on the obtainability of a grid nearby. Thus it is used to power rural areas where the obtainability of grids is very low. The advantages of solar power, such as no air pollution, no fuel costs, noiseless, and low maintenance [2]-[3]. However, the high expense in acquiring the photovoltaic (PV) module has slowed down the adoption of PV system in electricity generation. Furthermore, the power of PV modules is unstable and strongly dependent on solar irradiation and load [5]. Hence, the maximum power point tracking (MPPT) controller is introduced to ensure the PV system always provide high efficiency despite the variation in solar irradiation and load resistance.

Many MPPT algorithms have been introduced to improve the efficiency of the PV system, including fractional open circuit voltage, fractional short circuit current, fuzzy logic, neural network, hill climbing or perturbation and observation (P&O), and incremental conductance. Among those algorithms, P&O and incremental conductance are the most popular algorithms [1]-[2]. If a dc–dc converter is connected in between the PV module and the load, the switching duty cycle of the dc–dc converter is regulated to ensure the PV system always operates at the maximum power point (MPP). SEPIC converters is used as the dc-dc converter with fast converging algorithm which is derived from voltage gain equation. Fast converging algorithm is a modified algorithm have been introduced to improve the converging speed during the variation in solar irradiation level and load [3]-[4]. Since SEPIC converters has less static gain, it is replaced by modified SEPIC converter which is having high static gain.

In this paper proposes a modified MPPT algorithm, i.e., able to provide fast response without the requirement of an extra control loop. Other than that, the proposed system also does not require the intermittent disconnection. The proposed PV system simply consists of a dc–dc converter which connected in between the PV module and load. Then, the current and voltage of the PV module are sensed by a PIC controller, which is also used to execute the modified MPPT algorithm.

II. I-V CHARACTERISTCS OF PV MODULE

Due to the low voltage produced in a PV cell, several PV cells are coupled in series (for high voltage) and in parallel (for high current) to form a PV module for preferred output. Fig 1 shows the I–V characteristics of PV module under different solar irradiation level and a straight line connecting the MPPs. A load line which imposed on the I-V curve when the PV module supplies power to the load. At the intersection point between the load line and the I–V curve the PV module generate power as the product of the voltage and current of PV module.

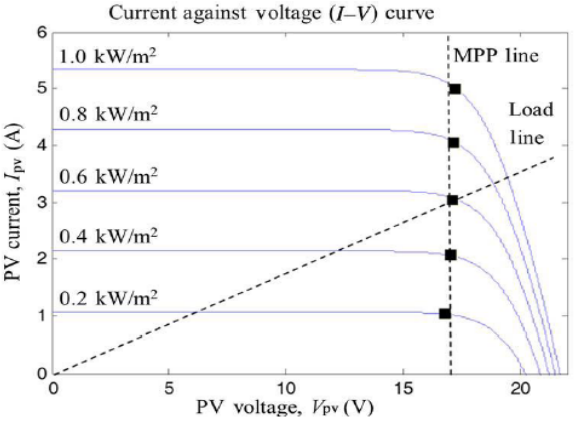

Fig. 1. MPP line and load line on the I-V curves for different levels of solar irradiation

So output power of PV module varies with load resistance (load line) and solar irradiation. A SEPIC(DC-DC converter) is connected between PV module and load. To regulate the duty cycle of the SEPIC to ensure the load line always cuts through the I–V curve at MPP by a MPPT controller. When the duty cycle of SEPIC is fixed variation in solar irradiation and load variation will increase or decrease the voltage and current of PV module. Variation in the voltage and current are always in the opposite direction under load variation. The MPPT controller should only regulates the duty cycle of SEPIC converter after the variation in solar irradiation or load is determined.

A fast-converging algorithm is used for MPPT controller these algorithm adopts the relationship between the load line and the I-V curve. In the SEPIC the relationship between the voltage and current in the input and output side equation is developed from the voltage gain equation of SEPIC. The equations are (1) and (2) respectievely.

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

$$I_{in} = \frac{D}{1-D} I_{out} \quad (2)$$

Equation (1) is then divided by Equation (2),

$$R_{in} = \frac{(1-D)^2}{D^2} R_{out} \quad (3)$$

Equation (3) shows that the duty cycle can be regulated to force the input resistance (load line). Where Vin is the input voltage of the converter or the voltage of the PV module (V_{pv}), I_{in} is the input current of the converter or the current of the PV

module (Ipv), Rin is the input resistance of the converter Rout is the output resistance of the converter or load resistance Rload.

In the PV system, (3) can be rewritten to obtain (4) and (5) as follows:

$$\frac{V_{pv}}{Ipv} = \frac{(1-D)^2}{D^2} R_{load} \quad (4)$$

$$R_{load} = \frac{D^2}{(1-D)^2} \frac{V_{pv}}{Ipv} \quad (5)$$

For calculating load resistance substituting the duty cycle, voltage, and current of PV module in equation (5). After the value of load resistance obtained, equation (5) can be rewritten in equation (7). Then, the duty cycle can be calculated by substituting the desired voltage (*V*mpp) and current (*I*mpp) of PV module into equation (7) as follows:

$$\frac{D^2}{(1-D)^2} = \frac{Ipv}{V_{pv}} R_{load} \quad (6)$$

$$D = \frac{\sqrt{a}}{1+\sqrt{a}} \quad (7)$$

where $a = \frac{Ipv}{V_{pv}} R_{load}$.

For fast-converging algorithm using in equation (5), the load resistance is calculated and operates nearer to the new MPP in equation (7) and is used under the variation in solar irradiation. In the case of load variation, equation (5) is used to calculate new load resistance, by substituting *V*mpp and *I*mpp in equation (7), so the new duty cycle can be calculated.

III. PROPOSED MODIFIED SINGLE –ENDED PRIMARY-INDUCTOR CONVERTER

The equation for the duty cycle and the load resistances in the fast-converging algorithm, is developed from voltage gain equation of SEPIC. In the proposed modified SEPIC, the voltage gain is higher compared to SEPIC, so the output voltage and output power is very high compared to SEPIC for the same input. Modified SEPIC operate in continues-conduction mode and may be different for other converter. Voltage multiplier technique is a applied to a traditional SEPIC converter. The multiplier technique provides new operation characteristics and also high static gain.

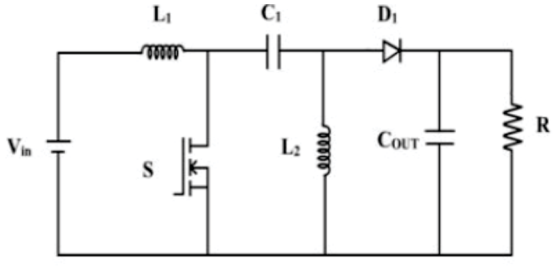

Fig. 2. Traditional SEPIC

The modified SEPIC converter is obtained by placing a capacitor C_2 and a diode D_2. Design parameters and the static gain of the traditional SEPIC converter are changed with this modification on topology.

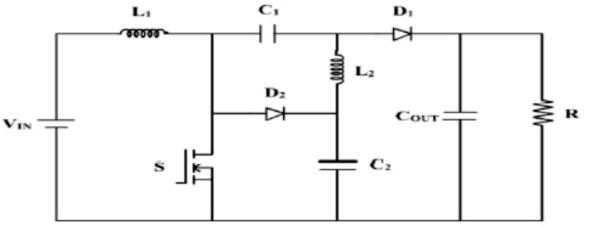

Fig. 3. Modified SEPIC

In the modified SEPIC converter, the capacitor C_2 is charged with the output voltage. Therefore, when the switch is conducting, the voltage applied to the inductor L_2 is higher than the voltage obtained from a traditional SEPIC converter. The voltage gain equation of SEPIC and modified SEPIC is given in the equations (8) and (9) respectively.

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D} \quad (8)$$

$$\frac{V_{out}}{V_{in}} = \frac{1+D}{1-D} \quad (9)$$

So the relationship of the voltage and current in modified SEPIC between the input and output side are different from SEPIC as follows:

$$V_{in} = \frac{1-D}{1+D} V_{out} \quad (10)$$

$$I_{in} = \frac{1+D}{1-D} I_{out} \quad (11)$$

$$R_{in} = \frac{(1-D)^2}{(1+D)^2} R_{out} \quad (12)$$

where is the input voltage of the converter or the voltage of the PV module V_{pv}, *Iin* the input current of the converter or the current of the PV module (I_{in}), R_{in} the input resistance of the converter or the resistance seen by the PV module, and *Rout* is the output resistance of the converter or load resistance R_{load}.

In the PV system, (12) can be rewritten to obtain (13) and (14) as follows:

$$\frac{V_{pv}}{Ipv} = \frac{(1-D)^2}{D^2} R_{load} \quad (13)$$

$$R_{load} = \frac{D^2}{(1-D)^2} \frac{V_{pv}}{Ipv} \quad (14)$$

For calculating load resistance, substituting the duty cycle, voltage, and current of PV module in (14). After the value of load resistance obtained, equation (14) can be rewritten in (16). Then, the duty cycle can be calculated by substituting the desired voltage (V_{mpp}) and current (I_{mpp}) of PV module in equation (16) as follows:

$$\frac{(1+D)^2}{(1-D)^2} = \frac{Ipv}{V_{pv}} R_{load} \quad (15)$$

$$D = \frac{\sqrt{a}-1}{1+\sqrt{a}} \quad (16)$$

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where $a = \frac{Ipv}{V_{pv}} R_{load}$

For fast-converging algorithm used in equation (14), the load resistance is calculated and operates nearer to the new MPP. Equation (16) is used under the variation in solar irradiation. In the case of load variation, equation (14) is used to calculate the new load resistances, by substituting *V*MPP and *I*MPP in equation (16), so we can calculate the new duty cycle.

A. ***Decrease in Solar Irradiation Level***

Consider the PV module operates on a solar irradiation of 1.0 kw/m2 with load line 1, with a voltage and current of PV module are *V*mpp and *I*mpp as shown in Fig. 5(a). When the solar irradiation decreases to a value 0.4 kw/m2 ,but the duty cycle of modified SEPIC is remains same operating point of PV module is at A(*V1,I1*) of load line which far away from MPP point of irradiation 0.4 kw/m2 (from point C).

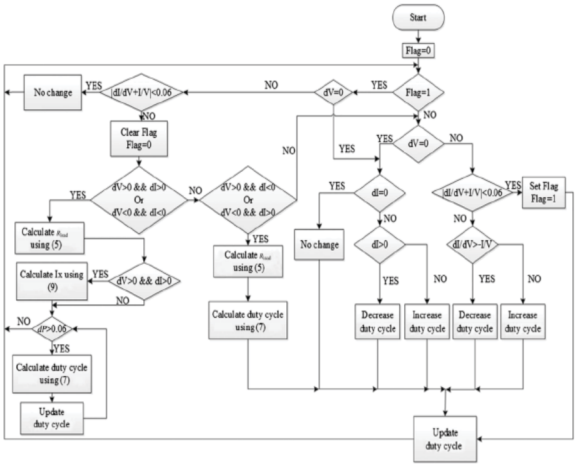

Fig.4. Flow chart for MPPT algorithm

In order to shift the operating point of PV module to new MPP by using equation (16). So the voltage and current of new MPP is required. In Fig5(a) the current I_1 is close to short circuit current of 0.4 kw/m² irradiation and the current at MPP is approximated to 0.8Isc that is current I_1 is approximated to new MPP. The MPP voltage of all irradiation are closed one another, so the new V_{mpp} previous Vmpp as approximated. Previous V_{mpp} and I_1 are substituted in (16) to perturb the new operating point PV module to load line -3 at point B(V_2,I_2) which is close to the new MPP. Finally through conventional incremental conductance algorithm are used to track the new MPP point C.

B. ***Increase in Solar Irradiation Level***

Consider the PV module operates at load line 2 with solar irradiation of 0.4 kw/m² the corresponding voltage and current of PV module are $_{Impp0}$.4 and V_{mpp0}.4 respectively as shown in Fig 5(b). When solar irradiation increases to1.0 kw/m², where the duty cycle of modified SEPIC remains unchanged. After that, the approximated values are substituted in equation (16) to guarantee the PV module operates near to the new MPP.

The operating point D(V_1,I_1) far away from MPP of 1.0 kw/m² as shown in the fig 5(b). From the fig 5(b), point E, $V_{oc1.0}$ and $V_{mpp/0}$.4 form a right-angled triangle. As per trigonometry rule in equation (17) of the operating current Ix which is near to the I_{sc} of 1.0 kw/m_2 is obtained. The open circuit voltage V_oc in equation (9) is approximated to open circuit voltage obtained in $V_{mpp}/0.8$. Where V_{MPP} is the voltage of MPP before the variation in solar irradiation. V_1s the voltage of PV module after the variation in solar irradiation

$$\frac{V_1 - V_{mpp}}{I_x - I_1} = \frac{V_{oc} - V_{mpp}}{I_x} \qquad (18)$$

$$I_x = \frac{V_1 - V_{mpp}}{I_x - I_1} I_1 \qquad (19)$$

After that, current I_x and voltage V_{mpp0}.4 of previous MPP are substitute in equation (16) to get new duty cycle. So the PV module operate at point F(V_2,I_2) of load line 4 which is close to new MPP.

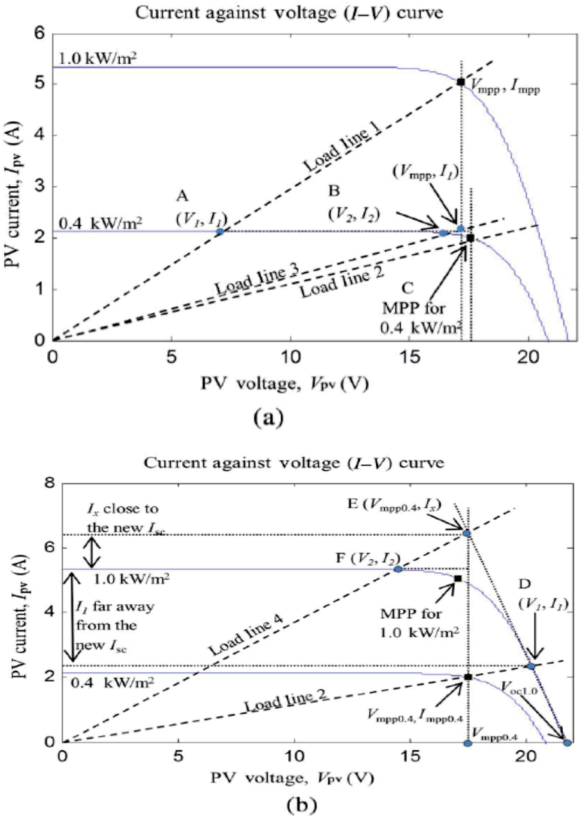

Fig. 5. Load lines on I–V curves for solar irradiation level of 0.4 and 1.0 kW/m2 during (a) decrease of solar irradiation and (b) increase of solar irradiation.

C. Load Variation

When variation in load , the operating point of PV module diverts from the MPP. To get new duty cycle for ensure the PV module operates at the MPP again. The variation only occur in load, but the voltage and current at the MPP should be the same. To obtain new resistance equation(14) is used. And to obtain new duty cycle substituting voltage and current at the MPP in to equation (16). With the new duty cycle the operating point of PV module is close to the MPP and using incremental conductance to track MPP.

IV. SIMULATION RESULTS

Fig. 6. shows the MATLAB Simulink model of the MPPT controller and modified SEPIC, The values of the components in the modified SEPIC are as follows: Cin =100 μF and Cout = 1000 μF, L1 and L_2 = 247 μH, C1 = 1 μF, C2=1 μF and the load is a 58 Ω resistance.

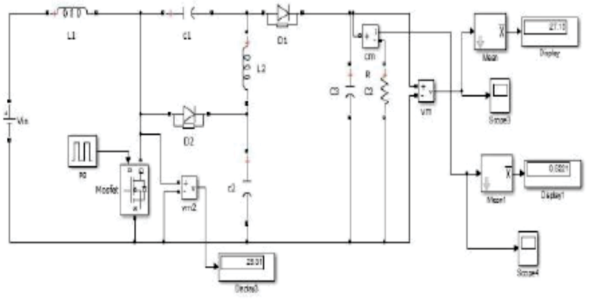

Fig. 6. Shows the MATLAB Simulink model of the MPPT controller and modified SEPIC

A. Decrease in Solar Irradiation Level

The irradiation on PV module is .8 kw/m^2 through incremental conductance it track a MPP and at a duty ratio of 0 .21 remains constant at a time t =1s and power produce by PV module is 17w. When the irradiation decreases to 0.5 kw/m^2 it track MPP and the power of PV module become 6w.

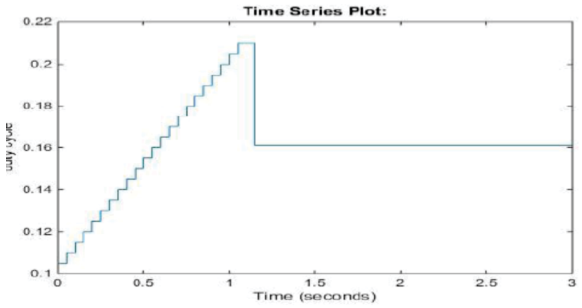

Fig. 7(a). Duty cycle variation with time

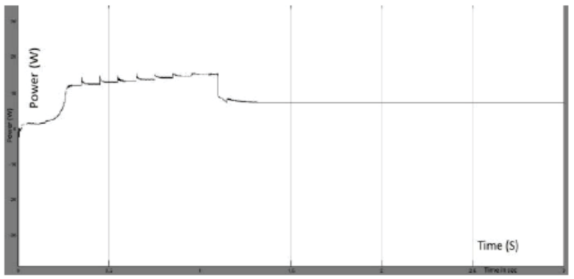

Fig. 7(b). Power variation with time

B. Increase in Solar Irradiation Level

When the solar irradiation is 0.5 kw/m2 through incremental conductance it track MPP at the time t = 0.4s and at a duty cycle of 0.135 and it remains constant, the power of the PV module is 6w at the time t =1.1s the irradiation change 0.8 kw/m2 through fast converging algorithm it attain a duty ratio 0.212 at time t =1.5s. The power produced by PV module is 17w.

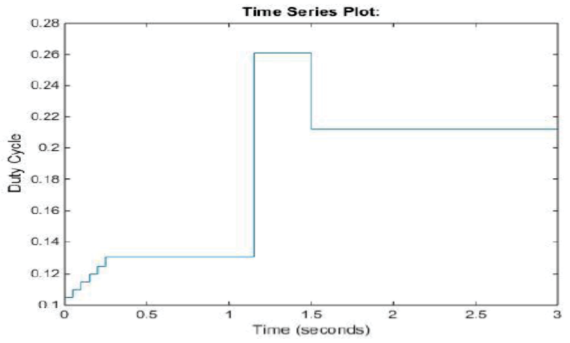

Fig. 8(a). Duty cycle variation with time

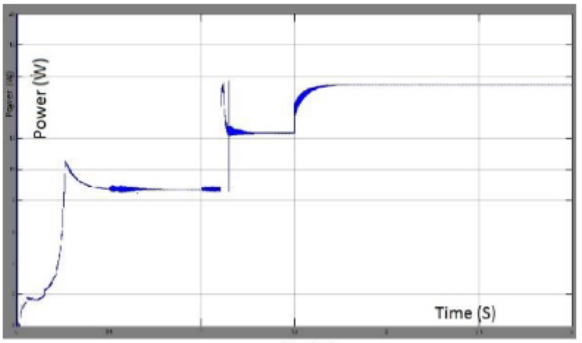

Fig. 8(b). Power variation with time

C. Load Variation

Initially load resistance is 50Ω it track MPP and reach a duty cycle of 0.18 and then at time t=1.1s the load resistance become 58Ω then duty ratio perturb to 0.195 it is close to MPP. At time t=1.3s track the new MPP and a duty cycle of 0.212.

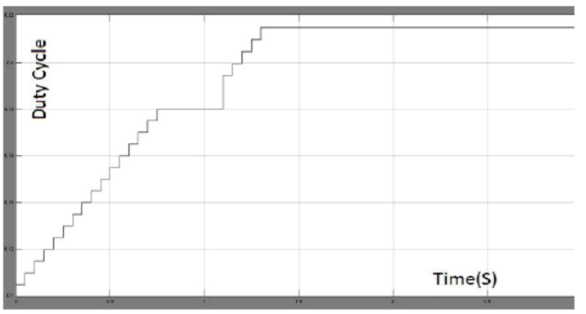

Fig. 9(a). Duty cycle variation with time

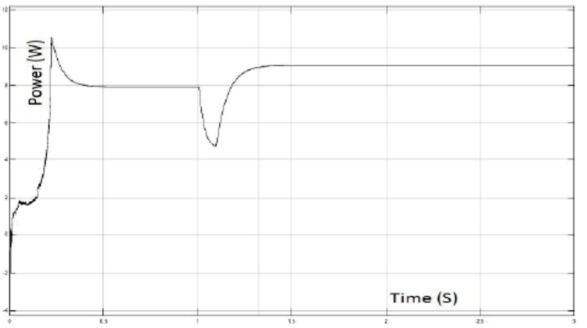

Fig. 9(b). Power variation with time

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