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MPPT with Inc.Cond method using conventional interleaved boost converter

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Abstract

This paper presents maximum power point tracker (MPPT) with incremental conductance (Inc.Cond) method with implantation of two different topologies of boost converter. Conventional and conventional interleaved boost converters are chosen. These two systems are compared together in the case of efficiency and speed. For both topologies MATLAB-SIMULINK is applied to model the system. Final results and discussions are represented to make the comparison much easier.

Selection and peer-review under responsibility of KES International

Keywords; Maximum power point tracker (MPPT), Incremental conductance, boost converter.

1. Introduction

The inevitable costs of using fossil fuels to generate electricity have led to attracting lots of interests to the green energy sources recently. Among these green energy sources the solar energy may be the most important one because it is available almost everywhere unlike wind, geothermal, sea waves, etc. Due to high initial investment of solar power plant it is necessary to increase return of investment's rate by increasing the efficiency as much as possible. The efficiency can be increased by developing the material used in photovoltaic (PV) cells as well as improving the energy management of the system in order to absorb maximum available power from the PV. Maximum Power Point Tracking (MPPT) usually is implemented with power electronic converters which act as an interface between PV array and consumption point in the power system. Generally a PV system may be a standalone system or grid connected. In the first case it is necessary to keep the output voltage of the system in the standard range and avoiding of power cut[1].

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Nomenclature:	
I_{PV}	Output current of PV
V_{PV}	Output Voltage of PV
I_o	Reverse saturation current
α	Diode ideality factor
V_T	Thermal voltage of PV module
K	Boltzmann Constant
q	Electron charge
T	Temperature
G	Irradiation
V_{oc}	Open circuit voltage
I_{sc}	Short circuit current
$C_v(t)$	Variable step size
D	Duty cycle
R_s	Series resistance
R_p	Parallel resistance
Abbreviations:	
PV	Photovoltaic
PCU	Power Conditioning Unit
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
Inc.Cond.	Incremental Conductance
PWM	Pulse Width Modulation
CVT	Constant Voltage Tracker

There are many methods proposed in the literature for MPPT. [2-4] used perturb and observe (P&O) method to do the MPPT, in this method an increase in voltage or current is done then the power is measured, if there is an improvement in measured power over the last state the next step of increasing would be perturb, otherwise the converter starts decreasing the voltage/current and the same procedure is done until the MPP is achieved. The main disadvantage of this method is failing to track MPP when the irradiation changes are too fast. The incremental conductance (Inc.Cond) suggests a faster method to track the MPP which is studied by [5, 6]. This method tracks the MPP by changing the voltage and current supplied to the load and measuring the instantaneous and incremental conductance periodically to reach the minimum value of the two parameters [7, 8]. Moreover, the converter topology is one of the important issues which changes the efficiency and speed of the system. Artificial intelligence methods such as fuzzy logic and neural network for MPPT are investigated as well [9-11]. However Fats tracking and good performance under varying atmosphere conditions are reported for these methods, high complexity is the major drawback for such strategies.

This paper steps through two different topologies for Inc.Cond method. Conventional boost converter is one of the most popular topologies which is using in order to control the position of operating point alongside MPPT. On the other hand, changing the topology might change the speed and efficiency. In this manuscript first, characteristics of PV module is taken into consideration. Then, conventional and interleaved boost converters are topics of discussion. Finally, obtained results by implantation of two different topologies of converters are represented and studied.

2. PV module and MPPT method

2.1. PV module characteristics

There are two common models for PV cell: one-diode model and two diode model. Although two-diode model is more accurate, its disadvantages outweigh the advantages; it is because, the number of variable which should be calculated is more than one-diode model[12]. Hence, for simulation in this paper one-diode model is used.

Solar cell consists of one diode parallel with a photo current source. To have more accurate model series resistance and parallel resistance added to this combination. Figure 1 displays equivalent circuit of one-diode model [13-15].

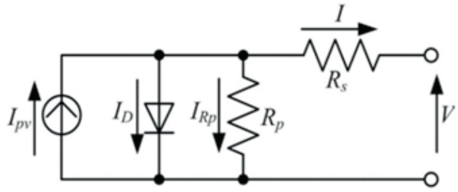

Figure 1: One-diode model equivalent circuit

According to equivalent circuit output current of one PV cell is calculated as follows:

$$I = I_{PV} - I_D - I_{R_P} \quad (1)$$

$$I = I_{PV} - I_0\left(e^{\left(\frac{V+IR_s}{\alpha V_T}\right)} - 1\right) - \frac{V+IR_s}{R_P} \quad (2)$$

Where I_{PV} is the current producing by light radiation, I_0 is reverse saturation current, α is diode ideality factor. V_T which is thermal voltage of PV module can be computed from equation below:

$$V_T = \frac{N_s KT}{q} \quad (3)$$

Where N_s is number of cells in series, K is Boltzmann constant, q is electron charge, and T is the temperature of p-n junction in ^{o}Kelvin[12].

Current producing by each cell is something between 2A to 10A and output voltage is less than 1V and depends on its material, for silicon is approximately 0.6V. Usually the cells are arranged to sort the output voltage increment of 12 V. Therefore, the output voltages of PV panels which are available in marketplace are 12V, 24V or 36V.

The same equation is used to model PV module, the only difference is about output voltage and current, in the case of voltage the total output voltage should be divided by the number of series cell and current is generated by the number of parallel strings multiply by current of each one.

2.2. Incremental conductance method

Incremental conductance method has been proposed in 1993 and expected to overcome the problems of previous method specially P&O. Perturb and observation which was the most common method for tracking the maximum power point has some problems such as weakness in tracking during rapid variation of isolation[16, 17].

Inc.Cond method is based on the differentiation of power with respect to voltage, due to this fact that this value in maximum power point is equal to zero.

$$\frac{dP_{PV}}{dV_{PV}} = \frac{d(I_{PV} \times V_{PV})}{dV_{PV}} = I_{PV}\frac{dV_{PV}}{dV_{PV}} + V_{PV}\frac{dI_{PV}}{dV_{PV}} = 0, \quad (4)$$

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}}. \quad (5)$$

Besides, $\frac{I_{PV}}{V_{PV}}$ is called instantaneous conductance and $\frac{dI_{PV}}{dV_{PV}}$ is incremental conductance, the place where these two values are equal the MPP will be there.

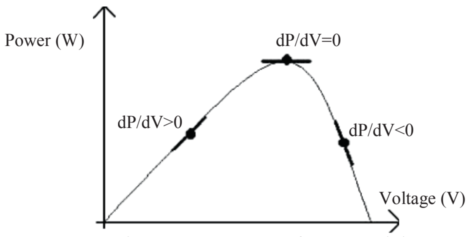

Figure 2: P-V curve of a PV module

Thus, meeting the MPP requires checking the operating point in each sample; generally operating points in a P-V curve are classified into three groups:

$$\frac{dP_{PV}}{dV_{PV}} > 0 \rightarrow V_{PV} < V_{MPP}, \quad (6)$$

$$\frac{dP_{PV}}{dV_{PV}} = 0 \rightarrow V_{PV} = V_{MPP}, \quad (7)$$

$$\frac{dP_{PV}}{dV_{PV}} < 0 \rightarrow V_{PV} > V_{MPP}. \quad (8)$$

Besides, the incremental variations can be stated approximately due to subtracting of actual value of V_{PV} and I_{PV} in two following sampling time.

$$dI_{PV} \approx \Delta I_{PV} = I_{PV}(t_1) - I_{PV}(t_2), \quad (9)$$

$$dV_{PV} \approx \Delta V_{PV} = V_{PV}(t_1) - V_{PV}(t_2). \quad (10)$$

Analysis of data values is much easier with this approximation. Algorithm flow chart of Inc.Cond method has been drawn in Figure 3.

Practically, it is impossible to achieve exact MPP $(\frac{dP_{PV}}{dV_{PV}} = 0)$. Consequently, more experimenting format is:

$$\frac{dP_{PV}}{dV_{PV}} = \pm E. \tag{11}$$

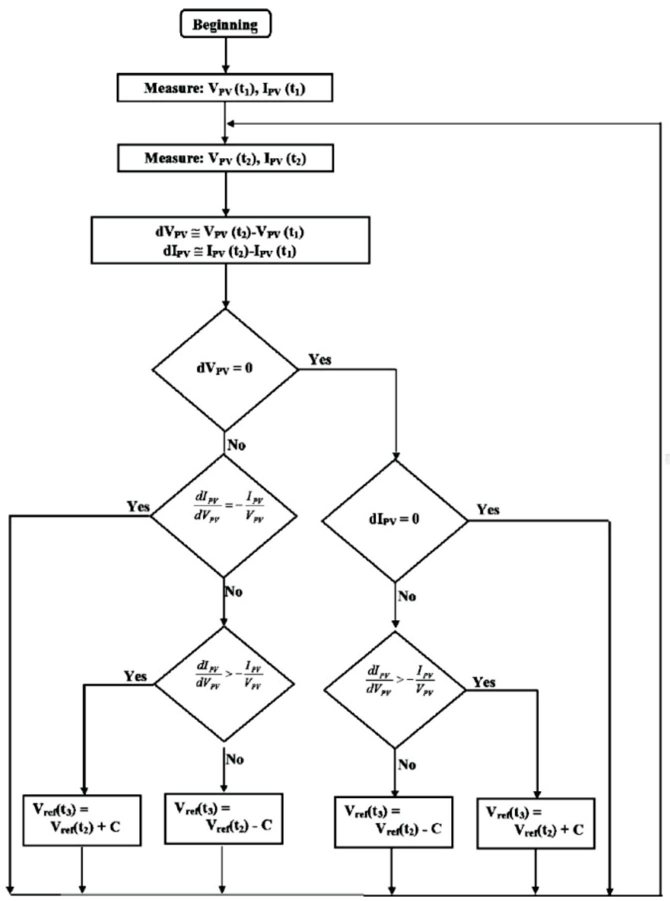

Figure 3: Algorithm flowchart of Inc.Cond *[16]*

The main advantage of this method is that it is compatible with rapidly changing of irradiance; furthermore it has less oscillation around MPP in comparison with P&O. previously implementation of control unit of this method was difficult and expensive, but recently there are some options to do it more cost effective[16].

2.3. Converter selection

The main part of MPPT is a switching-mode DC-DC converter, power electronic circuit that converts a DC voltage to a different DC voltage level. DC-DC converters are usually used to regulate output voltage, but MPPT system uses the DC-DC converter in order to regulate the output voltage of PV array, converter input voltage, by means of load matching[18].

Generally topologies of DC-DC converters classified into two main groups: isolated and non-isolated topologies.

In isolated topologies a small-size high frequency transformer not only has a role of isolation between input and output, but also steps up and down the output voltage due to its turns ratio [19]. In the case of safety is an important factor in designing of electrical system these topologies are widely implemented, fly-back, half bridge, and full bridge are frequently applied converter in this group.

Due to some facts, it is better not to implement the isolated topologies. First, as the input current is pulsed, it has bad effects on PV modules duration of life. Second, bigger input ripple leads the designer to have bigger value capacitor, that is not cost effective. Third, voltage stress of diode is higher than output voltage, which restricts the efficiency of current for high voltage output [20]. Non-isolated topologies make the systems much cheaper and more efficient.

2.4. Two topologies of boost converter

A conventional boost converter is figured in Figure 4, output voltage the same as all switching-mode converters generates by opening and closing the switch, it might be either an IGBT or a MOSFET.

Having analysis about output voltage of this converter the output will be represented as following equation:

$$V_0 = \frac{V_s}{1-D}, \quad (12)$$

Where V_0 is output voltage, V_s is input voltage, and D is duty cycle.

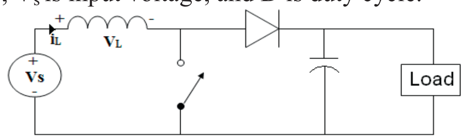

Figure 4: Circuit of conventional boost Converter

According to (12) the smaller the duty cycle the bigger value for output voltage will be drawn out.

In [20] almost all topologies of DC-DC converters which are appropriate for PV systems are covered. According to this study the important problems of PV systems in the case of converter selecting is related to either cost issues or efficiency.

Due to the following facts conventional boost converter might be replaced by some new topologies. First, the ripple in the conventional boost converter is large and makes power losses. Second, the voltage stress of switch is equal to the output voltage; therefore, more expensive switch should be selected because a high voltage stress switch is required. Figure 5 shows the proposed topology of conventional interleaved boost converter.

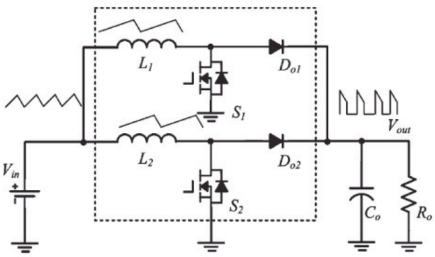

Figure 5: Conventional interleaved boost converter

In this paper both topologies of conventional boost and conventional interleaved boost converter are applied and compared in a standalone PV system.

3. Results and discussion

In this section obtained results from simulation of a standalone PV system with two different topologies of boost converter will be represented and finally a comparison between these two different topologies will be expressed. The general connection between PV panel, converter and load is displayed in following figure.

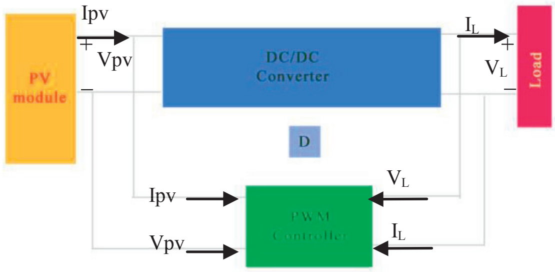

Figure 6: General connections

For each topology two different step size check and results compare together. First the step size of C=0.7 and second C=0.21. Tracking time, average output power and output power curves will be represented by following sections. Sampling time for all simulations is 50μs. all data are tabulated in Table 3.1 to make the comparison much easier.

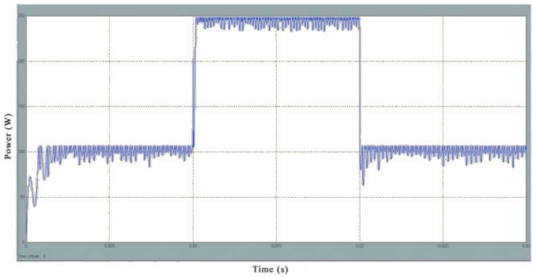

Figure 7: Output power for step size of C=0.7 by implementation of ordinary boost converter

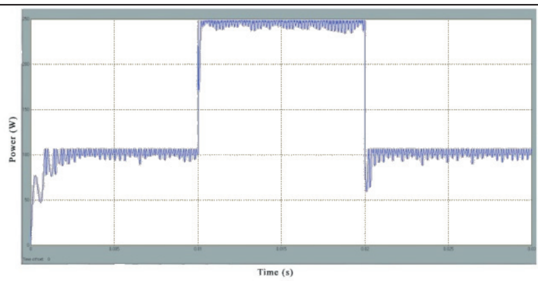

Figure 8: Output power for step size of C=0.21 by implementation of ordinary boost converter

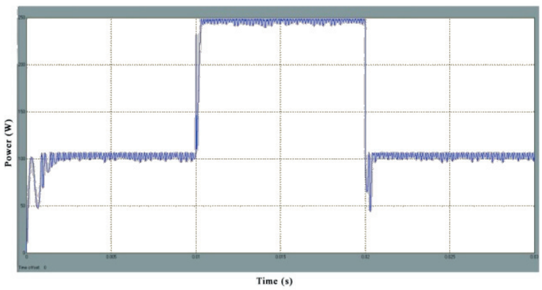

Figure 9: Output power for step size of C=0.7 by implementation of conventional interleaved boost converter

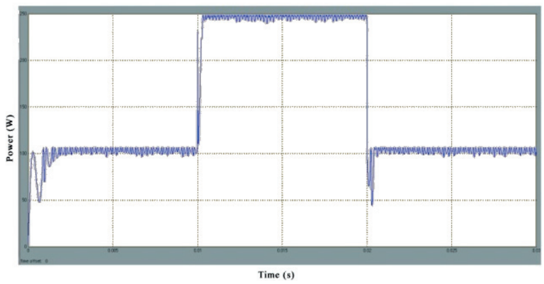

Figure 10: Output power for step size of C=0.21 by implementation of conventional interleaved boost converter

In the case of conventional boost converter implementation, for constant isolation of G=1KW/m^2 the average output power is 244 W and 244.7 for step sizes of C=0.7 and C=0.21 respectively. On the other hand, to have a better idea about this simulation, isolation has been varied from 0.4KW/m^2 to 1 KW/m^2 at t=0.01 s and suddenly fall down again to 0.4KW/m^2 at t= 0.02; Figures 7 and 8 show the output power for two different step sizes.

Table 1: comparison between two topologies

Converter	**Step size**	**Average power**	**Tracking time**	**Tracking time**
			For 1KW/m^2→0.4KW/m^2	For 0.4KW/m^2→1KW/m^2
conventional interleaved boost converter	C=0.21	246.4W	0.5ms / 10 cycle	0.4ms / 8 cycle
	C=0.7	245.9W	0.4ms / 8 cycle	0.2ms / 4 cycle
conventional boost converter	C=0.21	244.7W	0.7ms / 14 cycle	0.5ms / 10 cycle
	C=0.7	244W	1ms / 20 cycle	0.7ms / 14 cycle

On the other hand, when conventional interleaved boost converter is applied the average power for constant irradiation of G=1KW/m^2 is 246.4 W and 245.9 W for C=0.21 and C=0.7 respectively. Figures 9 and 10 represent the output power for mentioned condition.

Furthermore, tracking time for different topologies with different values of step sizes are tabulated in Table 1. According to this table it is clear that, implantation of conventional interleaved boost converter make the system more efficient and faster.

4. Conclusion

In this paper maximum power point tracker with incremental conductance method was introduced. One-diode model for simulation of PV module was selected. Conventional boost converter and conventional interleaved boost converter topologies were studied and applied to test the system efficiency and speed of the system. Obtained results for both topologies in two different step sizes were expressed and compared together.

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