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Using Incremental Conductance Algorithm with Dynamic Deviations in the Structure of Interleaved Fly-Back Converter Based on Power Source to Access Maximum Power in the Structure of Grid Independent Solar System

Mohsen Javadi Rad and Mehdi Radmehr
Department of Electrical Engineering, Islamic Azad University, Sari Branch, Sari, Iran

Abstract: Usually due to the unique characteristics of solar cells, they are not connected directly to the load. Instead a dc/dc converter is used as the interface between the solar panel and load. Low output voltage and high output current are some features of photovoltaic sources. Therefore, a converter that is inserted as the interface between the solar panel and load must be compatible with these features. Current-fed converters are compatible with characteristics of photovoltaic sources. Present thesis uses a current-fed dc/dc converter with an advantage of the interleaved technique for increasing the voltage. The converter must be controlled so that a solar cell operation point always to be put on the maximum power point. This is done by the MPPT algorithm. For tracking the maximum power point current research uses a MPPT algorithm based on incremental conductance. In this way, dynamic deviations are measured to speed up the maximum power point tracking. The results of the algorithm simulation on dc/dc converter represent efficiency of this method.

Key words: Conductance algorithm, dynamic, deviation, forward fly-back, solar systems

INTRODUCTION

Low output voltage and high output current are some features of photovoltaic sources. In addition, in order to achieve higher efficiency the output current ripple should be limited as much as possible. Therefore, a converter that is going to be inserted as the interface between the solar panel and load must be compatible with these features that is it must have high input current, low input voltag and limited input current ripple (Liu *et al*., 2011).

On the other hand, since the cost of solar cells manufacturing is high and their efficiency is about 20-15% it is needed to use the maximized potential of solar cells that is, operation point of the system should be on MPP. Usually due to the weather changes and lighting of solar cells, operating point of PV is not on MPP.

As a result, the output power of solar cells decreases. Thus, in order to have the required output power it is necessary to increase the number of solar cells; though, it increases the cost of the system. For this reason, a MPPT converter is used to track MPP point at any time and according to the conditions of light and temperature as well as transfer power point of solar system to MPP point (Balato and Vitelli, 2013).

In this study a new non-isolated current fed dc/dc converter with capability of high voltage increase and low current ripple is applied as the interface between the solar cell and the load. The major advantage of this converter is that it can be used for high power applications. In addition, due to the current sharing at input inductors, input current ripple is less.

Furthermore, compared to other converters, passive components are smaller. As a result, system reliability is increased and its transient response is faster than other converters (Li *et al*., 2012). In addition, a new algorithm named as variable step size incremental conductance MPPT algorithm is used to track the maximum power point of the solar cell. Compared to the previous methods response of this algorithm is faster and its precision is more than constant state and volatility around the MPPT point has been fixed in a permanent state (Abdourraziq, 2014).

Solar systems: Now photovoltaic systems are used widely for various applications with different capacities (from 5.0 kW-MWs). Due to the reliability and performance of photovoltaic systems the number of applications using of this energy is increasing rapidly.

Real model of a solar cell: The ideal equation in conjunction with voltage and current of solar cells, despite the series and parallel resistance is written as follows (Messenger and Ventre, 2003).

$$I_{pv} = I_{sc} - I_o \left[e^{\frac{q(V_{pv}+I_{pv}R_s)}{n_1 KT}} \right] - \left(\frac{V_{pv} + I_{pv}R_s}{R_p} \right) \quad (1)$$

Corresponding Author: Mehdi Radmehr, Department of Electrical Engineering, Islamic Azad University, Sari Branch, Sari, Iran

In the Eq. 1 RS represents series resistance of PV cell equating to the sum of connectors resistance and semiconductor materials. R_p is parallel resistance. Parallel resistance is much larger than the series resistance. n_i is ideality factor which usually has an amount between 1 and 2 (Harada and Zhao, 1993). Figure 1 shows the equivalent circuit of the actual solar cell which contains a light-controlled current fed a p-n type diode in parallel with the current fed and a resistance in parallel with a diode as well a series resistor.

Interleaved fly-back forward converter: Figure 2 shows an interleaved fly-back forward converter with interest factor of high-voltage and soft switching capability with bumpers circuits. In order to access to higher levels of voltage, 2 coupled inductors are used so that each coupled inductor will be at fly-back state if the connected power switch is on and will operate as a fly-back forward converter if the connected power switch is off. As a result, all of nuclear magnetic capacity is used and converter power density will increase.

Moreover by using of bumper circuits access to soft switching for power and auxiliary switches will be achieved. In addition, the problem of output diode reserve recovery impact will be fixed. Therefore, power devices switching losses decrease and converter efficiency increase. Input current also is divided between input coupled inductors resulting in decrease on input converter ripple due to the converter performance on interleaved state. Because of all above mentioned features, fly-back forward converter is an appropriate choice for applications with interest rate of high voltage, suitable efficiency and high power density (Lee *et al*., 2012).

To access a high input current S_1 and S_2 power switches of the converter operate as interleaved. Bumper circuit consist of S_{c1} and S_{c2} switches and C_{c1} and C_{c2} bumper capacitors which are used for restoring the energy stored at leakage inductance, limiting voltage tensions on power switches and accessing to initial ZVS soft switching for all power switches. Signal gate of S_{c1} and S_{c2} auxiliary switches complement signal gates S_1 and S_2.

Two coupled inductors of L_1 and L_2 are used in the structure of above converter. L_{1a} and L_{2a} primary inductance are coupled with L_{1b} and L_{2b} secondary side inductor. Dotted coupled inductors are specified by * and • (Masoum *et al*., 2002).

Primary rewind of coupled inductor has n1 rounds and secondary rewind has n2 rounds. In order to access to high voltage interest rate, coupled inductors secondary rewinds make a series. In addition Llk is the sum of coupled inductors leakage inductance which has been transferred to the secondary side. Magnetizing inductance of coupled inductors are indicated by Lm1 and Lm2.

To access ZVS soft switching C_{s1} and C_{s2} parallel capacitors are applied. As the need for high voltage conversion ratio, voltage double supplier is inserted at secondary side including output diodes of D_{01} and D_{o2}. Each output capacitor can tolerate half of dc bus voltage (Li *et al*., 2012).

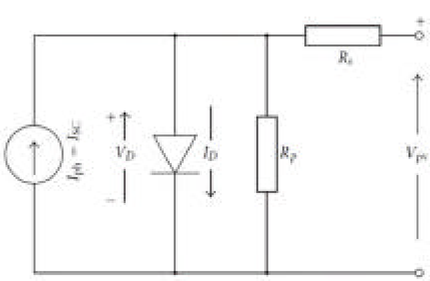

Fig. 1: Real model of a solar cell (Onat, 2010)

Incremental conductance algorithm of dynamic deviations size: In incremental inductance algorithm, deviations size of solar system output voltage and converter pulse width is constant. As a greater deviation size, system dynamic speed increases but instead fluctuations around MPP increases, too and system overall efficiency decreases. In this case, it is necessary to choose an optimized state between deviations size and dynamic speed. However, some methods have fixed this problem by selecting dynamic deviations (Bodur and Ermis, 1994).

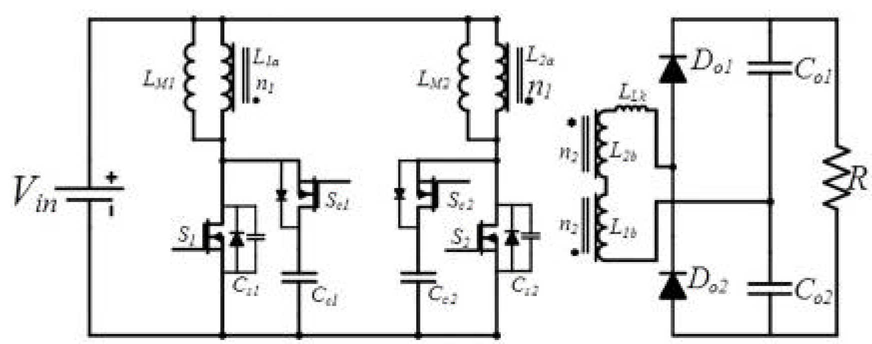

Fig. 2: Interleaved fly-back forward converter (Li *et al*., 2012)

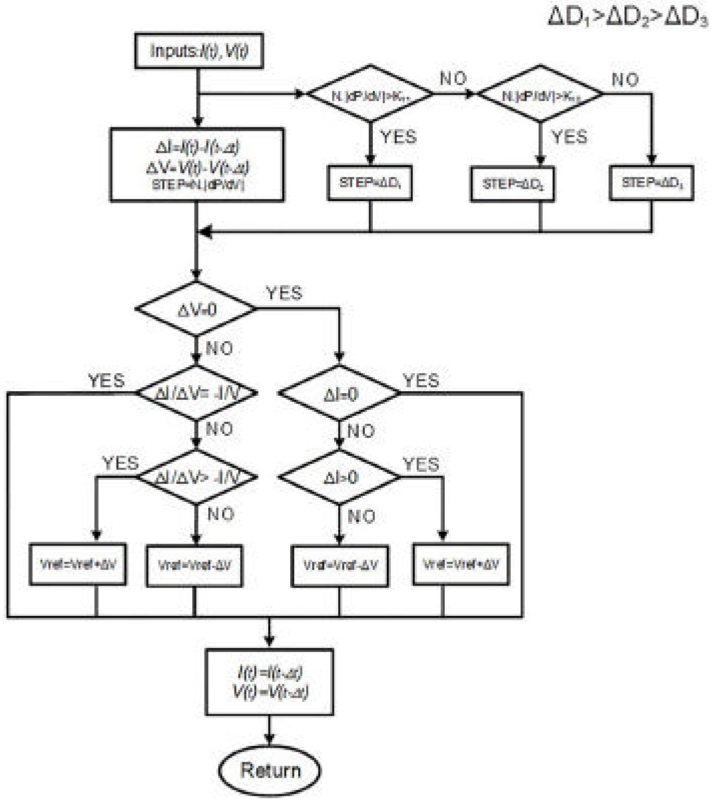

Fig. 3: Overall diagram block of the incremental conductance algorithm of new dynamic deviations

The research (Abdourraziq *et al*., 2014) has proposed a new algorithm based on incremental conductance of dynamic deviations size through which maximum power point with a high precision and appropriate speed will be achieved. Figure 3 shows the diagram block of the proposed algorithm.

MATERIALS AND METHODS

Principles of the proposed method: Figure 4 shows $(N\times\Delta P/\Delta V)$ curve in terms of solar cell output voltage. We mark the impact point of fixed and direct lines K_{11} and K_{12} with deviation level curve $(N\times\Delta P/\Delta V)$ as P_1 and P_2 and assume that impact point of load line with the curve is the system operation point (L).

If the power operating point difference compared to P_1 is positive, the operating point will be on area 1. In this case, to access the maximum power point a small deviation is considered which increases the speed for accessing the point (Midya *et al*., 1996).

But if the difference is negative compared to P_1 and positive relative to P_2, system operation point will be at area 2. In this case, to access the maximum power point a moderate deviation is considered which increases the speed for accessing the point.

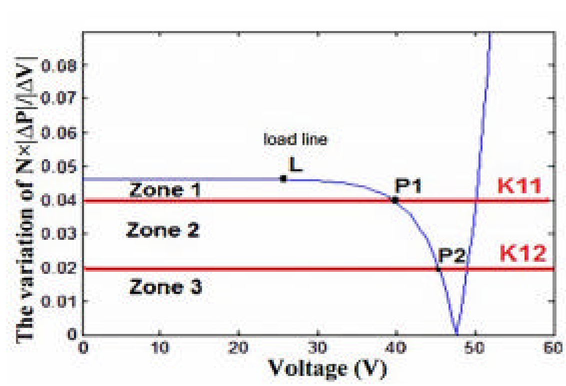

Fig. 4: Operation principles of incremental conductance method with new dynamic deviations size

Finally, if the difference is negative compared to P_1 and P_2 the operation point is at area 3. In this case, deviation is considered small in order to the speed for accessing the maximum power point to be increased.

Fly-back forward converter design: Designing means to obtain values of circuit different elements such as magnetizing inductance, bumper capacitors, output capacitors and finding power switches and appropriate diodes so that it can tolerate voltage tension of the circuit.

Table 1 gives the basic information about the design of the converter. According to Table 1, if we take the output V = 400 V and input voltage equal to 50 V (Salas *et al*., 2006).

The values of circuit elements are calculated from the following equations: The following equation calculated with KVL/KCL laws in Fig. 4's circuit:

$$M = \frac{{}_2N}{1-D} \quad (2)$$

$$V_{Co1} = V_{Co2} = \frac{NV_{in}}{1-D} \quad (3)$$

$$V_{Cc1} = V_{Cc2} = \frac{V_{in}}{1-D} \quad (4)$$

$$R = \frac{V_o^2}{p_o} \quad (5)$$

$$C_{CC1} = C_{cc2} = \frac{I_{LM_1} D}{8\Delta V_{Co1} f_S} \quad (6)$$

$$C_{Co1} = C_{co2} = \frac{V_o D}{2R\Delta V_{Co} f_S} \quad (7)$$

$$L_M = V_{Cc2} = \frac{V_{in} D}{2\Delta i_{LM1} f_s - D} \quad (8)$$

Table 1: Basic information of the converter design

Title	Symbol	Value	Unit
Output power	Po	1	kW
Output voltage	Vo	400	V
Input voltage	Vi	50	V
Switching frequency	f	100	kHz
The ratio of magnetizing inductance conversion	n2/n1	13/21	-

$$L_{LK-pri} = \frac{L_{Lk} - \max}{{}_2N^2} \quad (9)$$

RESULTS AND DISCUSSION

To investigate the operation precision of tracking by incremental conductance algorithm with dynamic eviations, it is simulated by the software MATLAB. Figure 5 indicates the overall structure of the simulated system which includes the solar cell, interleaved fly-back forward dc/ds converter and incremental conductance algorithm with dynamic deviations.

Solar cell: To simulate a solar cell associated relations are used. Fig. 6 displays power-voltage and current-voltage characteristics of a simulated solar cell where:

Vmpp = 30; Impp = 7; Voc = 5/37; Isc = 8/7;
Pmpp = Vmpp. Impp = 210

Fly-back forward converter: Values of dc/dc converter elements including leakage inductor and magnetizing coupled inductor, bumper capacitors C_{c1} and C_{c2}, output capacitors C_{o1} and C_{o2} and output resistance R_o are calculated. Using these values, dc/dc converter is simulated by MATLAB. Figure 7 shows structure of the simulated converter.

Interleaved fly-back forward converter with maximum power point tracking algorithm: Then, according to the presented model of the solar cell we simulate a solar cell and connect it to a fly-back forward dc/dc converter input as the power supplier. Power-voltage and current-voltage wave forms of the solar cell are illustrated in Fig. 6. To track maximum power point of a solar cell, incremental conductance algorithm of constant deviation on interleaved fly-back forward converter is used at first stage, then incremental conductance algorithm of dynamic

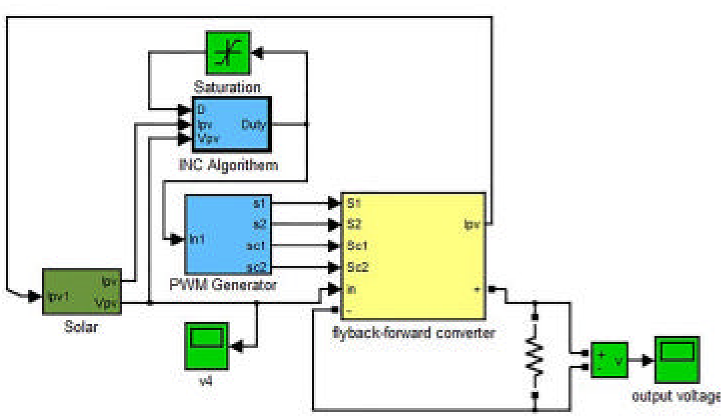

Fig. 5: Overall structure of the simulated system

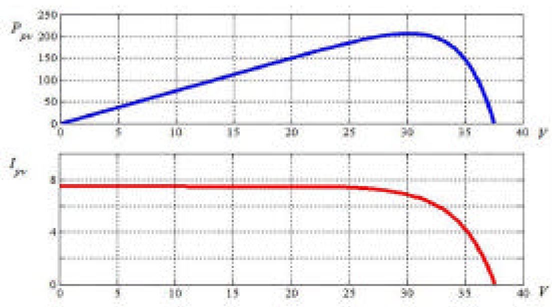

Fig. 6: Power-voltage and current-voltage characteristics of simulated solar cells

deviation on interleaved fly-back forward converter is used at the next stage. Thus, we are going to examine efficiency of the new algorithm (Le and He, 2011).

Figure 5 shows structure of the incremental conductance algorithm with dynmic deviations Interleaved Fly-back forward dc/dc converter input voltage with incremental conductance algorithm of constant deviations size.

According to power-voltage and current-voltage solar cell simulation waveforms in Fig. 6, the solar cell output power reaches to the maximum level at 30 V and 7 A (Fig. 7 and 8).

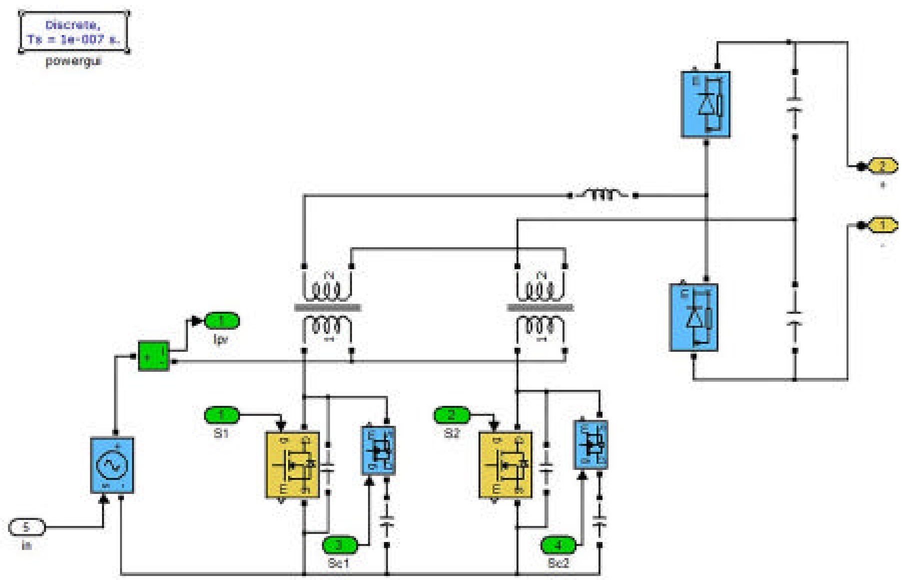

Fig. 7: Structure of the simulated converter

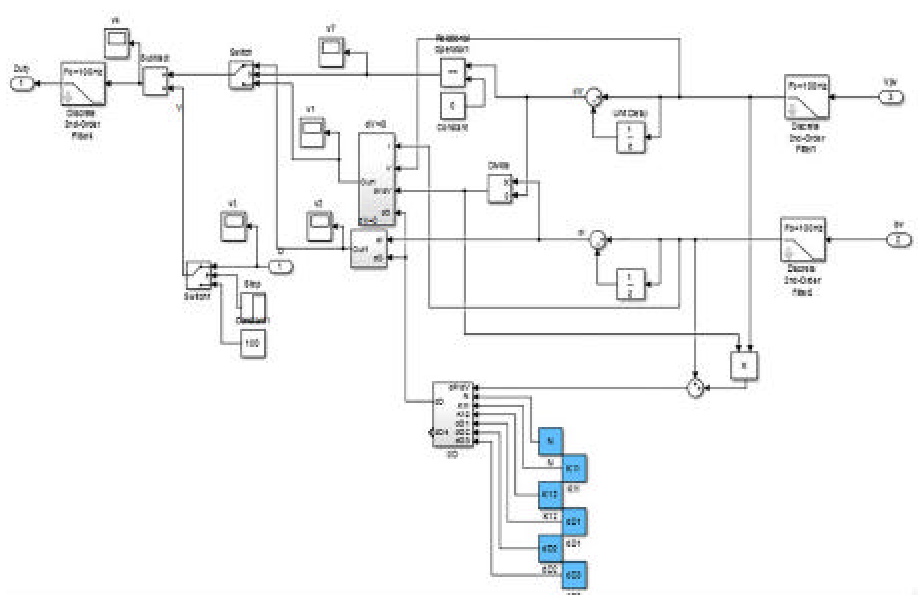

Fig. 8: Shows structure of the incremental conductance algorithm with new dynmic deviations

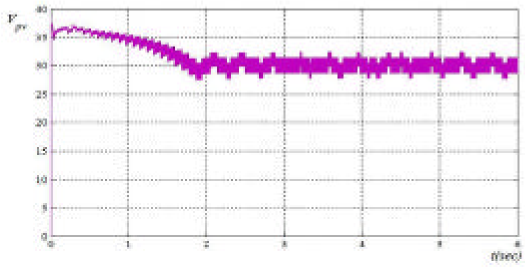

Fig. 9: Fly-back forward dc/dc converter input voltage with incremental conductance algorithm of constant deviations size

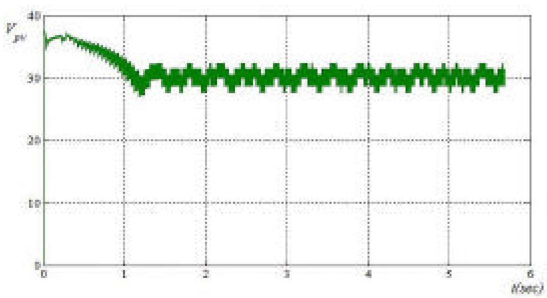

Fig. 10: Fly-back forward dc/dc converter input voltage with incremental conductance algorithm of dynamic deviations size

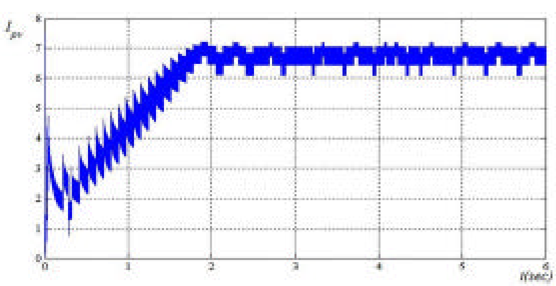

Fig. 11: Fly-back forward dc/dc converter input current with incremental conductance algorithm of constant deviations size

Therefore, incremental conductance algorithm with constant deviations will operate properly if voltage and current of the solar cell reach to 30 V and 7A, respectively; since in this case the solar cell maximum power point is extracted.

Figure 9 shows the solar cell voltage wave form, in other words it illustrates fly-back forward dc/dc converter input voltage. As indicated by Fig. 9 initially solar cell voltage is on open circuit voltage of V_{oc} that is 37.5 V. Over the time, incremental conductance algorithm of constant deviations changes input current by making a deviation at switching pulse width of power switches, then changes the input voltage of fly-back forward dc/dc converter directing it towards a voltage and current that the solar cell maximum power point is extracted. As shown in Fig. 9, output voltage is fixed on maximum power voltage that is 30 V.

Maximum power point tracking time is important and remarkable. At Fig. 9 the maximum power point tracking by incremental conductance algorithm of constant deviations size lasts about 2 sec.

Fly-back forward dc/dc converter input voltage with incremental conductance algorithm of dynamic deviations size: At Fig. 10, incremental conductance algorithm of dynamic deviations size tracks maximum power point during about 1 sec.

Therefore, it might be concluded that maximum power point tracking speed by incremental conductance of dynamic deviations size is more than incremental conductance of constant deviations size. Maximum power point tracking speed by incremental conductance of variable deviations size compared to the incremental conductance of constant deviations size has been doubled or increased by 100%.

Fly-back forward dc/dc converter input current with incremental conductance algorithm of constant deviations size: Figure 11 shows the solar cell current waveform. In other words it illustrates fly-back forward dc/dc converter input current. According to the figure, initially soar cell current is zero A. Over the time, incremental conductance algorithm of constant deviations changes fly-back forward dc/dc converter input current by deviating switching pulse width of power keys and directs it towards a current where solar cell maximum power point is extracted.

Figure 11 shows that output cell current is fixed on maximum power current that is 7 A. As it is clear incremental conductance algorithm of constant deviations size tracks maximum power point at <2 sec.

Fly-back forward dc/dc converter input current with incremental conductance algorithm of dynamic deviations size: As indicated by Fig. 13, output cell current has been fixed on maximum power current that is 7 A. In one hand, incremental conductance algorithm of dynamic deviations size tracks the maximum power point at 1 sec. It means that its speed is more than incremental conductance of constant deviations size method.

Fly-back forward dc/dc converter pulse width with incremental conductance algorithm of constant deviations size: Figure 13 displays wave form of fly-back forward dc/dc converter pulse width when incremental conductance algorithm is constant while tracking the

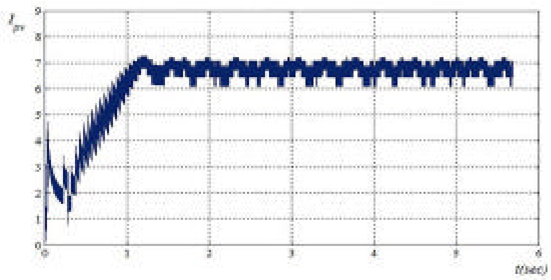

Fig. 12: Fly-back forward dc/dc converter input current with incremental conductance algorithm of dynamic deviations size

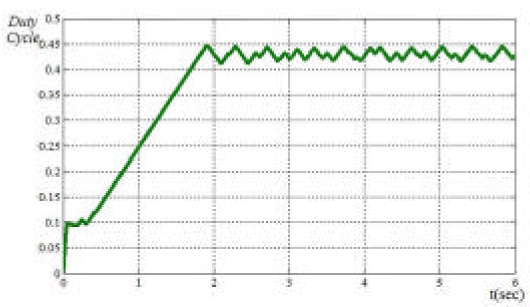

Fig. 13: Fly-back forward dc/dc converter pulse width with incremental conductance algorithm of constant deviations size

power point. As we know, the value of power converter pulse width is between 0 and 1. According to the figure, in order that solar cell operation point reaches its maximum power point as well as maximum productivity of the cell to be extracted, the value of power converter pulse width should be about 0.43 (Schoeman and van Wyk, 1982).

Fly-back forward dc/dc converter pulse width with incremental conductance algorithm of constant deviations size: According to Fig. 14, like incremental conductance algorithm of constant deviations size, in order that the solar cell power point reaches its maximum power point and maximum productivity of the cell to be extracted, the value of power converter pulse width should be at 0.43; though, the speed by which pulse width reaches to this value is different (Walker, 2001).

Fly-back forward dc/dc converter output voltage with incremental conductance algorithm of constant deviations size: Fly-back forward dc/dc converter output voltage wave form is shown by Fig. 15. According to the Fig. 15, after tracking the solar cell maximum power point via incremental conductance algorithm of constant

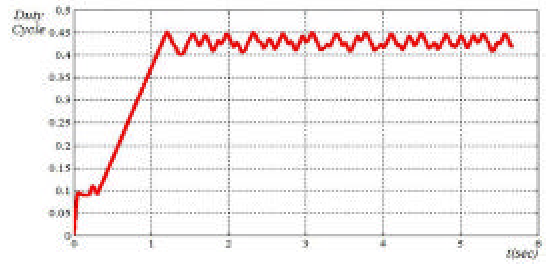

Fig. 14: Fly-back forward dc/dc converter pulse width with incremental conductance algorithm of dynamic deviations size

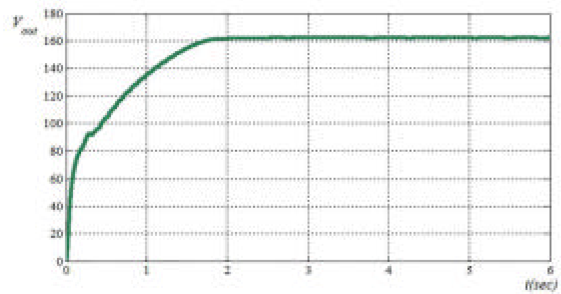

Fig. 15: Fly-back forward dc/dc converter output voltage with incremental conductance algorithm of constant deviations size

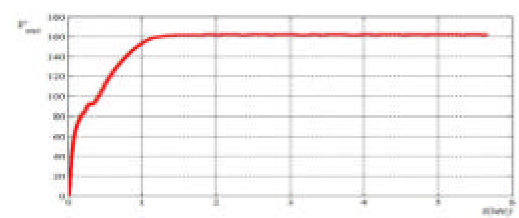

Fig. 16: Fly-back forward dc/dc converter output voltage with incremental conductance algorithm of dynamic deviations size

deviations size, the value of pulse width is fixed at 0.43; hence the solar cell output voltage reaches to 165 V.

Fly-back forward dc/dc converter output voltage with incremental conductance algorithm of dynamic deviations size: According to Fig. 16, after tracking the solar cell maximum power point via incremental conductance algorithm of dynamic deviations size, the value of pulse width is fixed at 0.43; hence the solar cell output voltage reaches to 165 V.

CONCLUSION

Global energy crisis, ending of fossil fuels and harmful environmental impacts of using these fuels have led to the significant development of using solar energy particularly in the form of photovoltaic systems. It mainly is because of the important and vital role of these sources for reducing dependence to fossil fuels and decreasing greenhouse gas emissions. Now a days, photovoltaic systems are used in three ways: standalone systems, grid connected systems and hybrid systems. Electricity grid independent systems in order to provide electrical energy needed for out of grid areas and prevent over extension of electricity grids use photovoltaic systems. A grid independent solar system has been designed in present thesis. According to the results it could be said that.

A dc/dc converter used at a solar system must be compatible with features and specifications of photovoltaic sources; that is, it must have high input current and low input voltage as well limited input current ripple. Current Fed Converters (CFC) such as interleaved fly-back forward converters because of some innate features like capability of high voltage increase and low width have drawn lots of attention (Hiyama *et al*., 1995).

Interleaved fly-back forward converter analysis suggests that it is capable to increase voltage by many times, though, its pulse width is rather small and at the same time voltage tension on power switches is more less than output voltage. This implies that it is very suitable for photovoltaic applications.

Simulated results show that incremental conductance algorithm of dynamic deviations size tracks maximum power point at a short time. This implies that its speed is more than incremental conductance algorithm of constant deviations size. Simulation results provide an evidence for the efficiency of incremental conductance algorithm of variable deviations size.

According to the results, maximum power point tracking speed by incremental conductance of variable deviations size compared to incremental conductance of constant deviations size has been double.

SUGGESTIONS

The structure of proposed solar system is made of a solar cell, dc/dc converter and load. To proceed it is suggested that a battery to be used at the mentioned system structure in order that the load to be supplied by the battery when required.

Control system to be designed in a way that system reliability to be maintained desirable if the solar cell productivity is higher than the load power.

In this study a resistive load of one simple phase has been used at dc/dc output converter. To proceed it is suggested that operation accuracy of the RL three-phase load to be examined. In this case, using an inverter at dc/dc converter output is necessary.

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