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Operation of DC Chopper Coupled with Photovoltatic Power System

تشغيل مقطع جهد مستمر موصل مع نظام قوى فوتوفولتى

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الغرض من هذا البحث هو معرفة الأداء الكهربي لنظام قوى فوتوفولتى موصل مع مقطع جهد مستمر تم تصميمه في معمل الطاقة الشمسية سابقا. وقد تمت هذه الدراسة عمليا بالمعمل وتم معرفة الأداء الكهربى للنظام عمليا. ثم بعد ذلك تم عمل نموذج رياضي هام يوضح أداء النظام. ولقد تم عمليا معرفة الحد الأقصى لقيمة تردد التقطيع. حيث وجد عمليا أنه إذا زاد هذا التردد عن القيمة القصوى فان خرج النظام لا يتأثر بتشغيل المقطع. هذا وقد تم معرفة تأثير تغير الحمل وكذلك أيضا مستوى الإشعاع الشمسي على أداء النظام ككل.

Abstract

The aim of this paper is the determination of electrical performance of photovoltatic power system connected with a predesigned Dc chopper (DCC), which is built in the solar energy laboratory of our electrical department. Mathematical model is built up to define the system operation. Optimum limits of chopping frequency are determined. The effect of load and insolation level change upon the performance of solar cells array (SCA) are investigated.

Introduction

In the practical PV (photovoltaic) system, it is required to use maximum power point tracking (MPPT) control scheme to track the maximum output power operating point irrespective of operating conditions of insolations and temperature of the PV array. Although a lot of papers on MPPT control have been reported so far, including the application of fuzzy logic and or neural network, most of them are essentially based on the principle so called "mountain climbing method" [1-3].

Reference [4] proposes a new simple MPPT (maximum power point tracking) control scheme for PV array based on a principle of power equilibrium at dc link. In contrast to the typical conventional MPPT scheme based on so called mountain climbing

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method, the proposed scheme needs no detection or tables expect for several numbers of operational amplifiers. Reference [5] addresses the problem of load matching to the PV array. The quality of load matching is defined by two factors: the insolation-utilization efficiency, and the time–utilization efficiency, both are defined by the ratio of load input power to the maximum available power of the PV array for a given insolation level and time. Optimum matching of loads to the photovoltatic generator is most desirable for more accurate sizing higher system performance and maximum utilization of cost solar array generator. The quality of load matching depends on the PV array characteristic, the load characteristic and the insolation profile. Matching factor is defined as the ratio of load energy to the array maximum energy over one day period. Optimum matching is achieved by determining the optimal array parameters with respect to the load parameters. Optimization is carried out by using direct search techniques as shown in reference [6].

In this paper the Dc chopper plays an important role of matching the load with solar cells array (SCA). The DCC regulating the SCA terminal voltage and tracks it at maximum power points. The technique of changing frequency is used to achieve the previous aim [7].

Experimental System under Test and the results

For obtaining the electrical characteristic of solar cells array, the experimental system shown in Fig.1 is built up. This system contains one module of SCA (with specifications 75 watt maximum output power, 21.7 volt open circuit voltage), DC chopper (DCC), which is designed in our laboratory, and variable static resistive load. The design procedures of the chopper are shown in reference [7]. The aim for obtaining the previous characteristics is the determination of the optimum frequencies required to operate the load continuously at maximum power point at different insolation levels. To achieve the later goal, the electrical characteristics of SCA directly connected with the load are recorded at different insolation levels. Then, the locus of maximum power points curve is obtained. Fig.2 illustrates these characteristics and the locus of the maximum power points of the module under test. On the other hand, the electrical characteristics of SCA under test connected with the same load through DCC are also recorded at different insolation levels and chopping frequencies. Fig.3 shows the sample of these measurements. In this figure the I-V characteristic of SCA without connection of DCC is known as the extreme characteristic. The optimum load (load at maximum power point) for the extreme characteristic is also shown in the figure by the extreme load line (L_0). Other arbitrary loads are also shown in the figure. These loads don't operate at maximum power point of the extreme characteristic. The problem is how to operate these loads at voltage of maximum power point (to regulate the load voltage) of the extreme characteristic. At this instant the role of DCC becomes very important. The DCC is employed to operate these arbitrary loads at voltage of maximum power point of the extreme characteristic by changing its chopping frequency. The figure shows also that the electrical characteristics of SCA at different chopping frequencies (the insolation level is constant) (C.F) go down the extreme characteristic and the arbitrary loads become the optimum ones for these characteristics. Fig.3 represents that the voltages at maximum power point for all characteristics become fixed. Various behaviors of SCA are obtained from the previous figure. The relationship between the voltage deviation (V_D) and chopping frequency at different insolation levels is illustrated in Fig. 4. The voltage deviation V_D is formed as,

$$V_D = V_{Loc} - V_{mpe} \quad (1)$$

Where;

V_{mpe} is the voltage at maximum power point of the extreme characteristic at specific insolation level and V_{Loc} is the voltage corresponding to the intersection of load line with chopping characteristic (the characteristic of SCA connected with DCC at the same insolation level of the extreme characteristics). This figure represents that for all insolation levels V_D decreases as the frequency increases. But, the rate of change of V_D is very low in the frequency range of $60<F_{ch}<400$HZ. Conversely, the previous change becomes very high during the range of $400<F_{ch}<1000$ HZ. This is due the fact that the first range of the chopping frequency (C.F) provides suitable frequencies for high loads. On the other hand, the second range represents suitable chopping frequencies for low loads near to the maximum power point of the extreme characteristic. The dc chopper frequency range suitable for the module under test is $60<F_{ch}<1000$HZ. The high level of C.F (1000 HZ) is the extreme frequency above which the DCC loses its role of operation with SCA and doesn't operate. The low level of C.F (60Hz) represents the minimum value of C.F corresponding to a very high load level. At this load the SCA must not operate, because the extracted power of SCA becomes very small. The relationship between the ratio of the load at maximum power points of chopping characteristics and that of the extreme characteristic which is called as load ratio (L_r) against frequency is illustrated in Fig.5.

$$L_r = \frac{L_n}{L_0} \tag{2}$$

Where,

L_n is the arbitrary load in ohm, L_0 is the optimum load located at maximum power point (MPP) of the extreme characteristic. The figure represents the inverse relation between L_r and C.F. The effect of insolation level upon the tested module is also illustrated in this figure. At high insolation level, large values of load ratios are obtained. Conversely, small values of L_r are achieved at low insolation level. This means that, the chopper loses its role at low levels of insolations. In essence, there are two limits control the DCC operation. The first one is C.F and the other becomes insolation level. Fig.5. is modeled mathematically for giving required C.F at any level of insolation and any load ratio. This relation is modeled as;

$$f_{ch} = \frac{Ln(L_r)}{8*10^{-5}*I_h} \quad \text{[Hz]} \tag{3}$$

Where, I_h is insolation level ,W/m^2.

Fig.6. shows the relation between specific load terminal voltage and insolation level at different C.F. (the load is fixed constant during the measurements). The figure represents that, the linear part of the characteristics are obtained at C.F range of $0<F_{ch}\leq 400$ HZ. But at the range $400<F_{ch}<800$ HZ the load terminal voltage becomes constant at values rather than that at maximum power points.

Conclusions

In this paper the technique of varying the solar cells array terminal voltage by using a predesigned Dc chopper, which is built up at solar energy laboratory of electrical engineering department, is used for fixing the array terminal voltage at specific value and tracking the point of maximum power of SCA. The best value of voltage at which the array terminal voltage must be fixed is the voltage at maximum power point of the SCA characteristies without using DCC. The DCC employs for fixing the array terminal voltage at pervious specific value. The electrical performance of the photovoltaic system operates with and without Dc chopper is investigated. The results show that, there exist lower and upper levels of chopping frequencies between them the best operation of the system which contains Dc chopper is obtained. The frequency range of operation depends upon the number of modules used. An important mathematical model is built up for determining the optimum chopping frequency at which the DC chopper operates at specific load and insolation level. The results show that the insolation levels and load ratios having significant effect upon the PV system operates with DCC.

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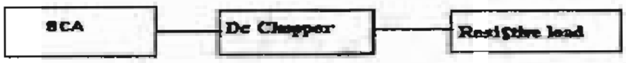

Fig.1Block Diagram of the Experimental system

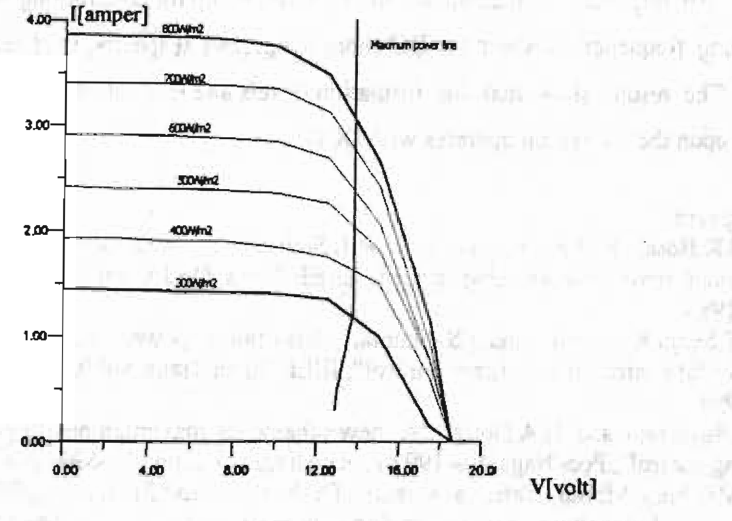

Fig.2 I-V characteristics of SCA under test and the locus of maximum power point at Different Insolation levels without coupling with DCC.

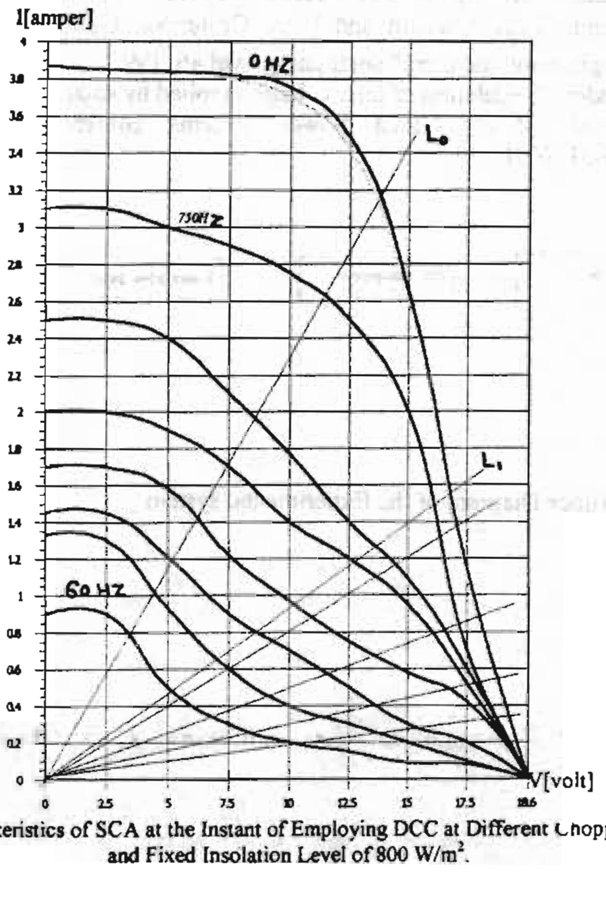

Fig.3 I-V Characteristics of SCA at the Instant of Employing DCC at Different Chopping Frequencies and Fixed Insolation Level of 800 W/m².

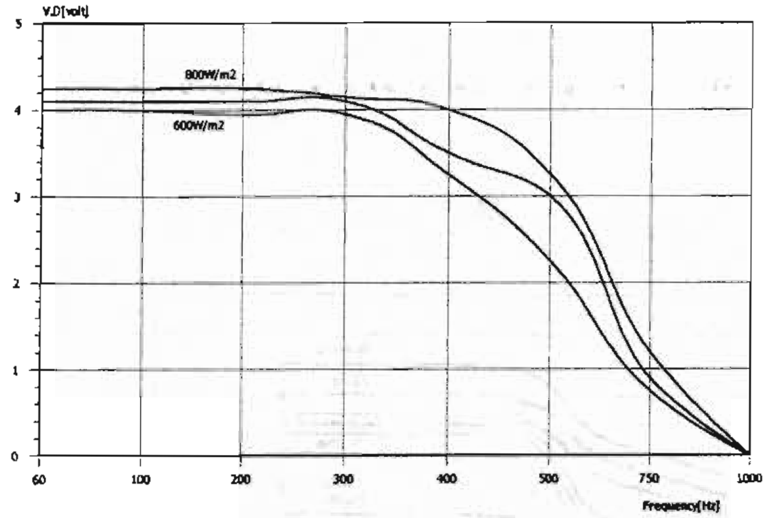

Fig.4 Relationships between Voltage Deviation V_D and chopping frequencies at Different Insolation levels.

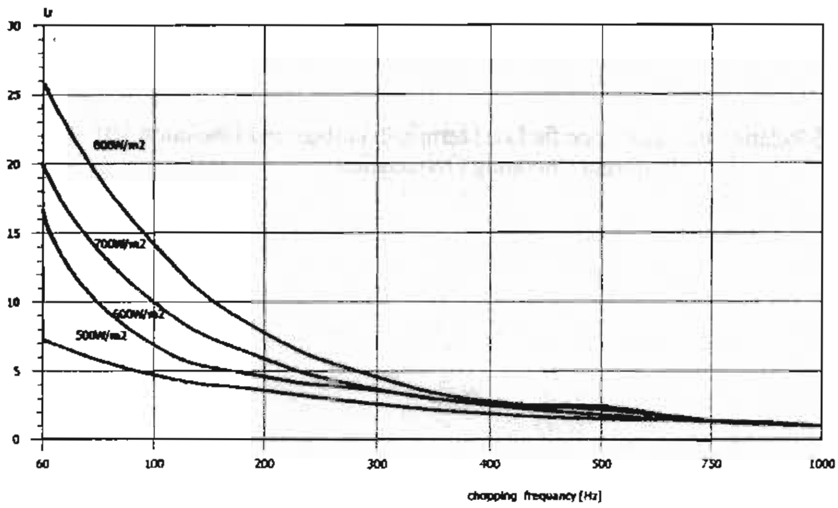

Fig.5 The Load ratio L_r against Chopping Frequency at Different Levels of Insolation.

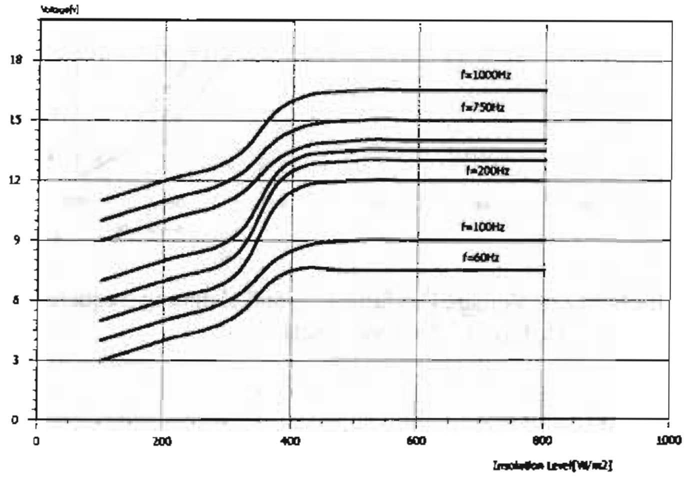

Fig.6 Relation between Specific Load terminal Voltage and Insolation level at Different Chopping Frequencies.