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Research on Photovoltaic Maximum Power Point Tracking using Bond Graph Control Method

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***Abstract*— A new algorithm is presented to control a maximum power point tracker MPPT through a bond graph. The photovoltaic module was assumed to be connected to a generic load by means of a DC/DC converter controlled through the MPPT. Under these conditions, and for given temperature and solar radiation values, the power supplied by the module was successfully controlled by the proposed algorithm, which promptly caused the photovoltaic module to work up to the maximum power point. On other point developed in this paper is to propose a detailed comparative survey of four maximum power tracking techniques: bond graph control method, Perturb and Observe, Incremental Conductance and method using only the photovoltaic current measurement. The bond graph approach overcomes some weaknesses of the existing methods such as the P&O method as it is capable of searching for global maximum. The results of simulation show that the bond graph control algorithm significantly improves the efficiency during the tracking phase as compared to a conventional algorithm about maximum power point tracking in photovoltaic power systems. It is especially suitable for fast changing environmental conditions.**

***Keywords*— Bond Graph, Maximum Power Point Tracking (MPPT), Solar Energy, Photovoltaic Systems.**

I. INTRODUCTION

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The use of renewable energy systems as an alternative way to produce electricity has been increasing during the past years [1]. The need of a cleaner, more efficient and cheaper method for generating electric power is helping this growth.

As photovoltaic (PV) solar cells become more important in energy generation, much research and development is focused on extracting the maximum amount of power. The electrical power generated by PV is not uniform over the full operating range. There is an optimum operation point called the maximum power point (MPP) that yields maximum power generation [2]. PV electrical characteristics vary with temperature and light intensity, which changes the MPP.

In the actuality a lot of research work has been conducted to improve the use of the sun's energy. The generation of electricity using photovoltaic solar cells has been one of the most researched and studied.

PV arrays produce electric power directly from sunlight. With the advent of silicon P-N junction during the 1950s, the photoelectric current was able to produce power due to the inherent voltage drop across the junction [3]. This gives the well-known nonlinear relationship between the current and voltage of the photovoltaic cell. From this nonlinear relationship of the photovoltaic cell, it can be observed that there is a unique point, under given illumination, at which the cell produces maximum power, the so-called maximum power point (MPP). This point occurs when the rate of change of the power with respect to the voltage is equal to zero [4]. The output power of PV cell varies with depending mainly on the level of solar radiation and ambient temperature corresponding to a specific weather condition.

The MPP will change with external environment of PV cell. An important consideration in achieving high efficiency in PV power generation system is to match the PV source and load impedance properly for any weather conditions, thus obtaining maximum power generation. The technique process of maximum power point is been tracking which is called maximum power point tracking (MPPT).

Several methods have been designed and implemented to search for this operation point. They vary in complexity, convergent speed, cost and range of effectiveness [5], [6] or hardware implementation [7], [8], [9], [10]. Among those techniques, the "Perturb and Observe" (P&O) scheme [11], [13], [13] and the Incremental Conductance (INC) scheme [14], [15] are the most common due to their ease of implementation. The main drawback of these methods is that they can only track a single maximum, which is absent when the solar panels are partially shaded. Other methods that have been used to obtain the maximum power are parameters estimations [16], neural networks [17] and linear reoriented method [18].

In this paper, we present a development of a maximum power point tracker using a bond graph controller to control the duty cycle of a DC-DC converter in order to force the PV module to operate at its maximum power point, for a given temperature and irradiance, to improve the utilization of the produced energy when connected to a load.

II. Proposed Method

Figure 1 shows the proposed scheme for the MPPT.

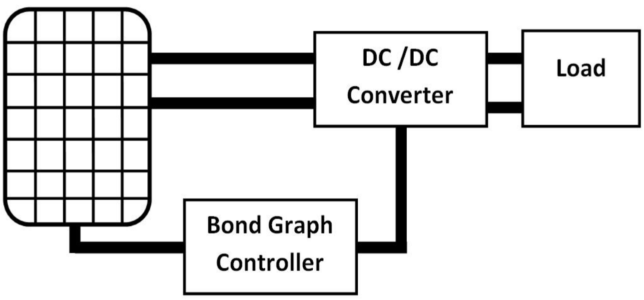

Fig. 1 General Scheme for the proposed method

This system use a PV array (s x p) composed of s in series cells and p in parallel cells. It is then connected to a DC-DC converter in order to increase or decrease the desired voltage. It is then connected directly to the load. The duty cycle of the converter is controlled by a bond graph controller. Measurement of the PV array voltage, Irradiance and Temperature on the PV array surface are taken in order to estimate the optimal voltage for the maximum power, and then a nonlinear MPPT algorithm takes this value to produce the signal for driving the switching element of the DC/DC converter.

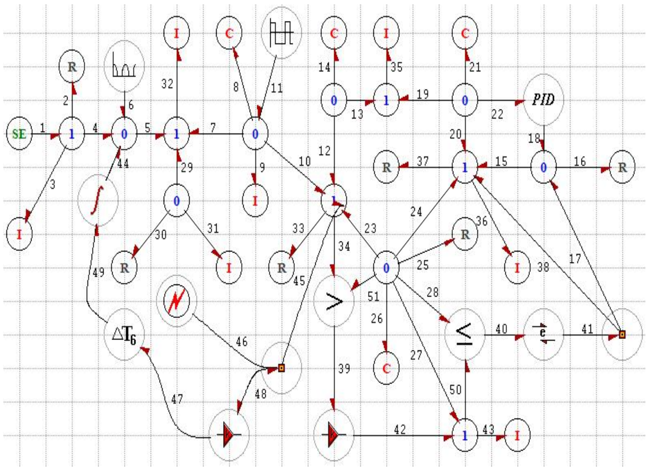

Fig. 2 Bond graph controller

III. Bond Graph Modelling

A. *PV module modelling*

The solar cell is the basic unit of photovoltaic modules which convert the sun's rays or photons directly into electrical energy. A solar cell is generally represented by a circuit diagram [19], [20] as shown in Fig.3.

The one diode model is commonly used for modelling modules of crystalline silicon technology. The equivalent electric circuit comprises a current source, two resistors, and a single-diode, as shown in Fig.3. The one-diode model contains five parameters which describe the PV module properties, The voltage current relationship that can be deduced using the equivalent circuit results in a transcendental equation [21], [22], [23], [24].

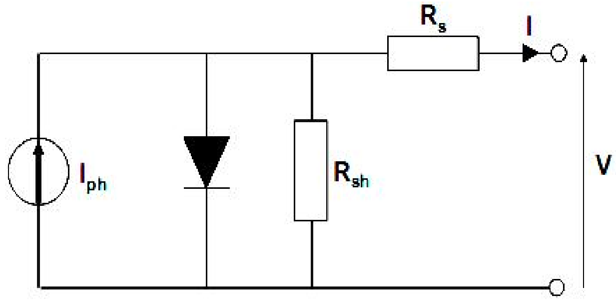

Fig. 3 Equivalent electrical circuit of photovoltaic module

The modelling of PV power supply systems is the initial stage that must precede all sizing, identification or simulation applications. PV systems' modeling however is quite complex. In literature, several models are proposed for modeling the different components of stand-alone PV systems [25], [26], [27], [28]. These are based on analytical models or numerical simulations. Other methods are based on software simulation using readymade programs like PSpice (design and simulate analog and digital circuits), Matlab-Simulink and Labview [29], [30].

Automatic data acquisition systems are currently used for both monitoring the system performance and control of its operation. The obtained information can be used to evaluate the plant efficiency during long periods and to optimize future systems in terms of performance and reliability. These systems are based on the use of micro-controller and microprocessor for PV applications [31]. Other more recent methods are based on artificial intelligence techniques used to model PV arrays, to estimate the Maximum Power Point Tracker (MPPT) point and to predict the produced energy from the system [32].

Recently, interest was given to the modeling and simulation of the whole PV system based on bond graph.

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the photovoltaic cell; they may be grouped to form panels or arrays. This model is the most classical one found in the literature and involves: a current generator for modelling the incident luminous flux, one diode for the cell polarization phenomena, and two resistors (R_s and R_{sh}) for the losses.

For the bond graph representation, the PV generator is then modelled by a flow source $S_f = I_{ph}$ in parallel with two resistors R_{diode} and R_{sh}, the whole followed by a serial resistance Rs [33]. (See figure 4).

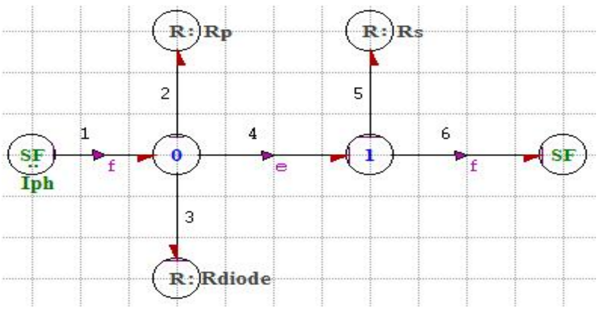

Fig. 4 Bond graph model of PV

B. Boost Converter Model

The power produced by the solar panel depends on two factors which are irradiation and temperature. As irradiation and temperature change through time, the produced voltage fluctuates and becomes unstable. A converter is therefore inserted to produce a constant voltage and ensure the transfer of the maximum power from the solar panel to the load.

The boost converter, or set-up converter, we have used consists of an inductor, a switch, a diode, and tow capacitors as shown in Figure (5).

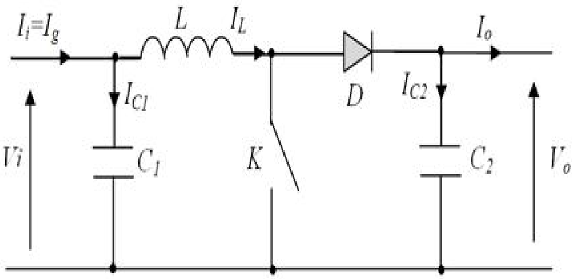

Fig.5 Electrical circuit of a boost converter

The bond graph model of the chopper is thus given by the figure (6).

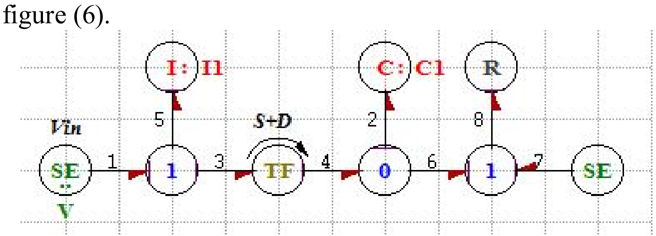

Fig. 6 Bond graph model of boost converter

IV. Algorithm Validation

The proposed algorithm was validated by means of simulations performed with the Symbols code in two different situations, the former assuming the presence of the proposed control system and the latter its absence. In both cases the module output power was evaluated in order to perform a subsequent comparison. During the tests, the PV module was submitted to constant temperature and solar radiation conditions.

In the former test the DC/DC converter was connected between the module and the load without controller; in this case the PV module was connected to generic impedance. Under these conditions, the output power is always less than 20 W, as can be seen in Fig. 7.

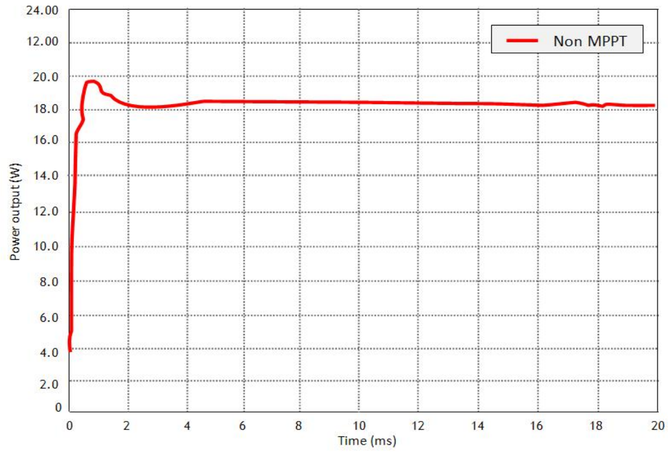

Fig. 7 Output power without MPPT

In the latter test the same conditions were maintained, but the MPPT control was properly inserted. In this case the output power is always greater than 20 W, as can be seen in Fig. 8.

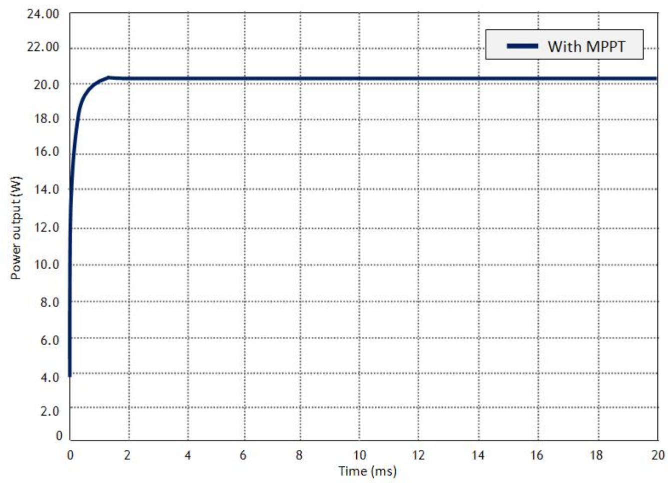

Fig. 8 Output power with MPPT

V. BOND GRAPH METHOD

The response time of the maximum PV power tracking due to a step irradiance input reflects the tracking speed of the MPPT method.

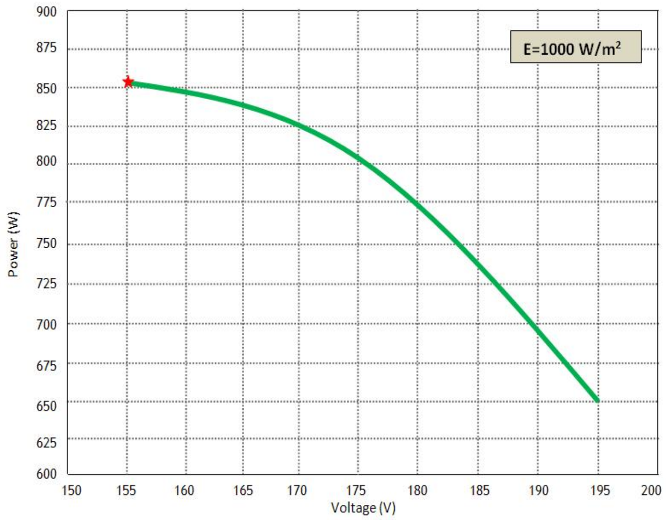

Fig. 9 Variation of power according to the tension

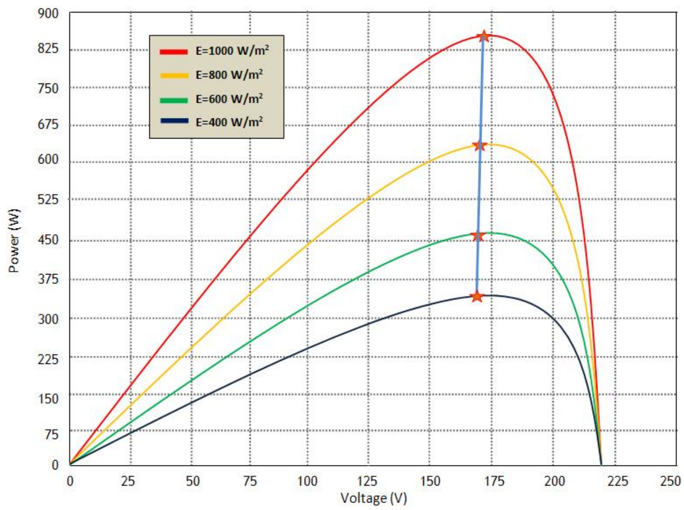

Fig. 10 PV power of MPPT method under step changing irradiance

VI. INCREMENTAL CONDUCTANCE METHOD

It was said previously that this method uses the incrementing of the conductance seen by the source. The voltage and currents of the panel are read by sensors, in such a way that the controller can calculate the conductance and the incremental conductance, and decides on the direction of the incrementing, until their equality.

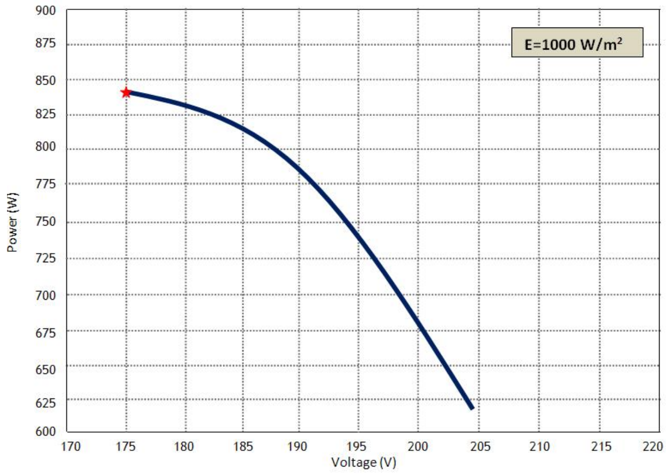

Fig. 11 Variation of power according to the tension

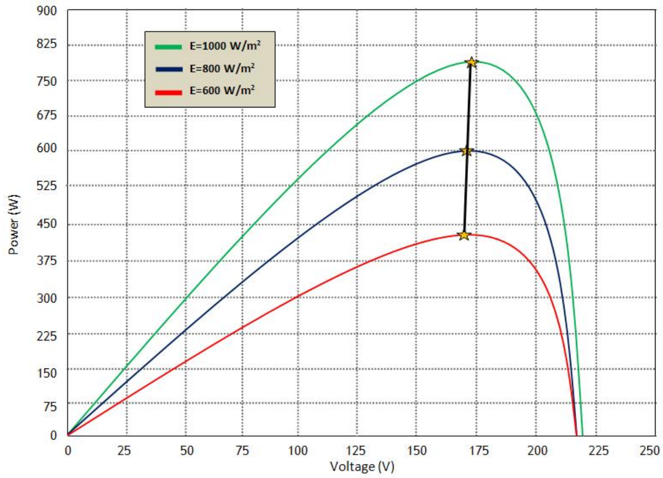

Fig. 12 PV power of MPPT method under step changing irradiance

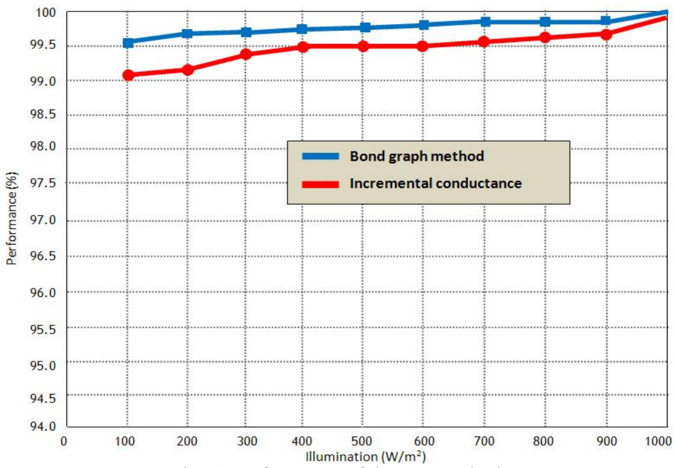

Fig.13 Performance of the two methods

From the previous figure the bond graph method is most effective against other methods. The second method is slower (speed point of view), given the number of iterations required to reach the MPP (180 iterations) and for slow changes in illumination, but with power losses due to the oscillation around the MPP, these losses may be even more important when weather conditions fluctuate rapidly (as a day cloud).

Such weather conditions are a problem for the search of MPP whatever the algorithm used, in fact, so that it can be effective, it is necessary that the static converter operates in steady state before new disturbances are made like bond graph method. In terms of speed the latter technique is faster, given the number of iterations required to reach the MPP (152 iterations).

VII. Conclusion

The PV array output power delivered to the load can be maximized using MPPT control method. In this paper, a new algorithm is introduced for an MPPT controller developed by means of the bond graph approach. The use of an MPPT control plays the important role of significantly increasing the efficiency of a photovoltaic generating system. Also this paper has demonstrated that the tracking speed of the proposed method is significantly improved compared to the other method. A grid-connected PV system using three MPPT controls is simulated and compared. Simulation results have verified the tracking accuracy and speed of proposed MPPT control.

The bond graph tool in multi-field matter seems the best tool adapted to this spot; in addition to its use for the structural analysis and simulation. The found results proved to be interesting because they found curves reveal a similarity between the found results and the results expected (real) in the specifications.

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