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Boosting Energy Harvesting Using Electronics Hardware

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Abstract: This paper is focused on the digital implementation of a voltage and a current loop for a buck converter used in distributed maximum power point systems (DMPPT). It presents the importance of an additional control to improve the maximum power point tracking (MPPT) algorithm performances. The paper also proposes an original Perturb and Observe (P&O) algorithm with variable step size to search a local maximum. The calculation of the step size is independent from the slope of the solar panel's power voltage (P-V) characteristic, making the tracking performances independent of the PV module. Simulation and experimental results are finally provided to verify the performance of the system.

Keywords: *Maximum Power Point Tracking,* P*ower Electronics, Digital Control, Photovoltaic Systems.*
Collaborations: Joint Thesis with Technical University of Cluj-Napoca, Romania.

1 Introduction

Solar power is one of the renewable energy sources with the highest potential. However, despite the huge growth of the renewable industry in the last years, a lot of research work and significant investment funds are necessary before renewable energy can replace fossil fuels dominance. Photovoltaic (PV) systems are composed of PV modules placed in series and in parallel to obtain the required open circuit voltage (V_{OC}) and short circuit current (I_{SC}). The average efficiency of commercial PV arrays is close to 20% [1]. Additional losses are present in the entire system due to non ideal components. The maximization of the power extracted from the solar panel is achieved by placing a high efficiency DC-DC converter between the PV array and the load. The converter matches the impedance of the load to the impedance of the solar panel for maximum power transfer [2].

Digital control offers many advantages, in particular in power management and renewable energy systems, where there are multiple power sources, loads, power buses and converter modules. Dynamic change of system parameters and interaction between modules can lead to system instability. Storing data, for operational purposes and record keeping, together with the communication with the external world, can help system maintenance and debugging.

2 Proposed system

The efficiency of the system is influenced by the power topology and the control structure. For the last twenty years engineers have been concentrating on harvesting solar energy and improving maximum power trackers by developing complex algorithms that need a lot of computing resources and have high power consumption, thus decreasing the efficiency. The shading process is slow and the algorithm has to find the MPP between two luminosity perturbations. If this is not achieved, for some of the MPPT algorithms, the control unit gets confused and searches the MPP in the opposite direction [3].

The most popular control structure for MPPT system has only a power loop (MPPT algorithm) that controls the duty cycle of the converter, [4]. The response of the system when a luminosity step occurs depends on the working state of the converter: continuous conduction mode (CCM) or discontinuous conduction mode (DCM). When there is a sudden irradiance change, the converter working in CCM has the new MPP very close to the old optimum operating point. On the other hand, when the converter works in DCM the new MPP can be far from the old maximum power point.

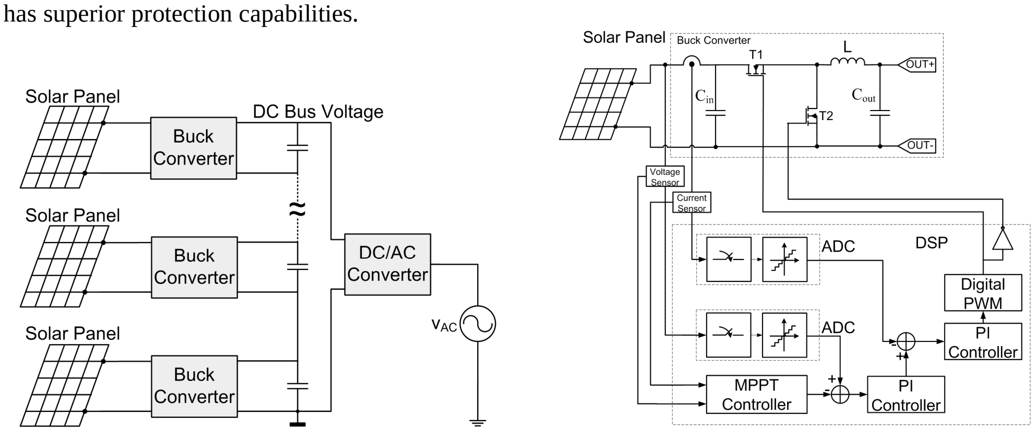
Improving the hardware and the control structure can improve the performances of the MPPT algorithm. A voltage loop is implemented in [5] in order to improve the previous control structure. When implementing a voltage loop, the MPPT algorithm computes the voltage reference for this loop. The voltage loop helps the MPPT algorithm to get closer to the new MPP after a sudden change of irradiance, independently of the operating mode of the converter (CCM or DCM). When implementing a voltage loop, it is very hard to compensate the right half plane zero present in some converters.

Another well known method of implementing a MPPT system is to use a feedback loop for the input solar panel current, [6]. This method raises problems of convergence when a luminosity step change occurs, from a high irradiance to a lower one. This is caused by the current controller that tries to maintain a higher current than the solar panel can provide, thus leading the voltage of the solar panel to drop to zero.

All the disadvantages of the existing MPPT systems are eliminated by implementing an average current mode control on the solar panel current. In order to charge a battery, the converter has to act like a current source. The current loop transforms the system into a current source at the input of the battery. The system is presented in Fig. 1a) and the proposed control structure is in Fig. 1b)

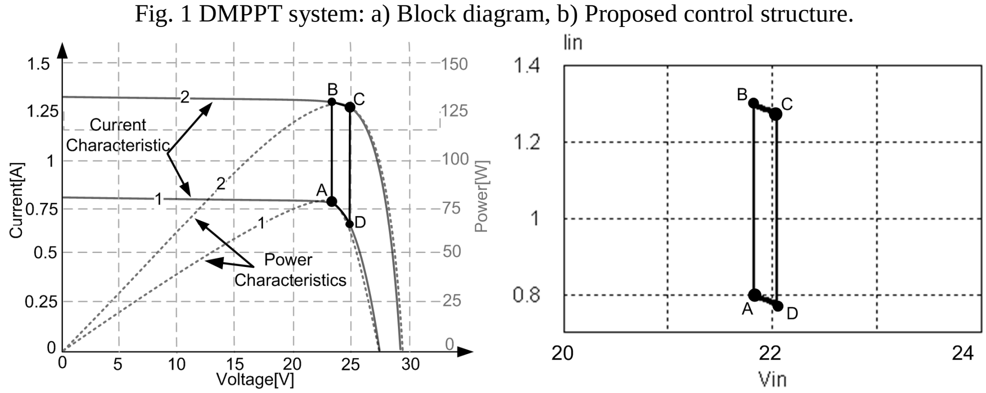
Another advantage is the possibility of paralleling multiple converters. It is much easier to connect current sources in parallel than to connect voltage sources. The current loop also offers short circuit protection in case of a malfunction in the system or an overloading. From the point of view of stability, the system is reduced by an order when implementing a current loop, because the inductor is transformed into a current source [7].

The response to a luminosity step is the same as in the case of a system with a voltage loop. The operating mode of the converter (CCM or DCM) does not influence the response of the system in case of an irradiance change. Even though the systems with control loops have the same luminosity response, the proposed control topology has superior protection capabilities.



a) b)

Fig. 1 DMPPT system: a) Block diagram, b) Proposed control structure.



a) b)

Fig. 2 Proposed control topology luminosity step response: a) I-V characteristic response, b) simulation result

3 Proposed MPPT algorithm

The most popular algorithm found in many MPPT controllers on the market is the P&O algorithm. An improved version of the P&O algorithm, with variable step size, is proposed.

3.1 Perturb and Observe with fixed step size

This algorithm perturbs the control signal (reference voltage that tracks the input voltage, duty cycle), and measures the variation of the input power. If this variation is positive, then the direction of perturbation is maintained. Otherwise, it means that the operating point has moved further apart from the MPP and the direction of the perturbation is changed. The decision time of the MPPT algorithm and the step size of the perturbation influence the power consumption and the efficiency of the system. A system with a small decision time for the MPPT algorithm will consume a lot of energy, even if the MPP is found very fast, and on the other side, if the decision time is large, the MPPT algorithm can get confused if the irradiance changes between samplings. The decision time represents the time between two consecutive changes of the operating point.

3.2 Proposed Perturb and Observe with variable step size

The principle of this algorithm is based on the P&O with fixed step size and three weights method. This algorithm uses a novel method to calculate the step size. This method does not involve complex calculation to compute the slope of the P-V curve (dP/dV), like in [8]. The proposed algorithm has a fixed number of step sizes, step1-step8, where step1 is the smallest and step8 is the largest. When the system is far from the MPP, the step size is high and gets smaller as it gets closer to the MPP.

The algorithm is detailed in Fig. 3 ’x1’-‘x8’ represent the points through which the operating point passes when finding the MPP. Let us suppose that the initial start up of the operating point is in ‘x1’ and the perturbation step size is step4. The step size increases when the operating point changes in the same direction twice in a row. Between ’x1’-‘x7’ the perturbation step size increases to step6. The algorithm sees that ‘x7’ is getting further apart from the MPP and changes the direction. Now the search is locked between points ’x6’ and ’x7’. When there is a change of direction in the command signal, the algorithm has locked the MPP between two previous operating points. The algorithm detects that step6 is too large, so the step size is decreased. The step size is decreased when the current operating point does not change or when the operating point oscillates between two states. After the MPP is locked, the step begins to decrease because the above statements occur.

The proposed algorithm computes the step size independently of the dP/dV value, thus making the algorithm suited for any PV module, without the need of modifying the gain of the current and voltage sensors and threshold levels.

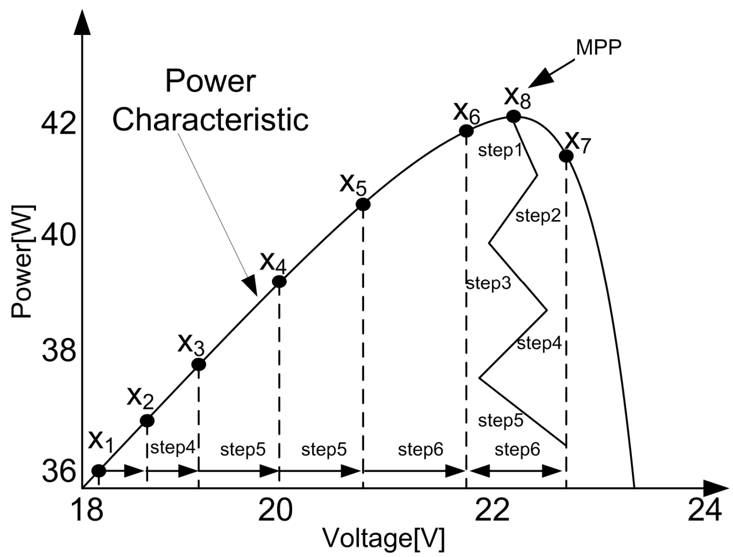
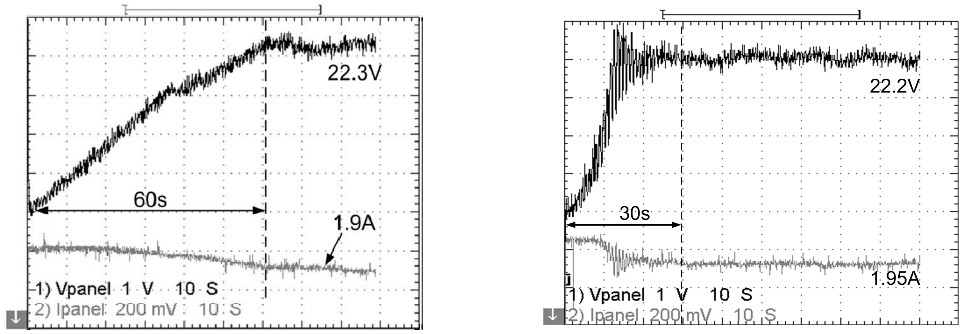


Fig. 3 Proposed algorithm.

4 Experimental results

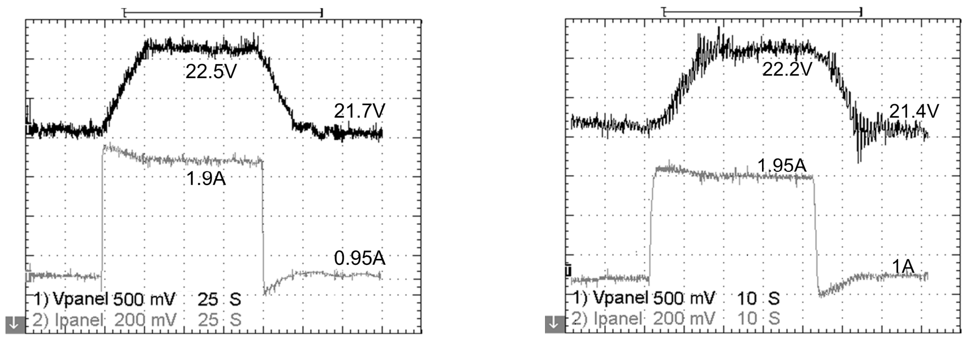
The experimental results obtained with the novel configuration and the proposed algorithm, are discussed in this section. A current source with diodes is used to build the model for the solar panel. This method allows the simulation of step luminosity change by varying the short circuit current to known and repetitive values and enables the comparison between the two algorithms, under the same conditions. A TMS320F2808 digital controller from Texas Instruments was used. The solar panel gives a V_{oc} of 25.5V and I_{sc} of 2A, the load of the converter is a 12V lead acid battery, 45Ah and the components of the converter are L=23uH, C_{in}=1mF, C_f=100nF, R_f=10kΩ and F_{sw}=100kHz.

The experimental results for the P&O algorithm with fixed step converging to the MPP presents a time response of 60s Fig. 4a) and, for the variable step, presents a time response of 30s Fig. 4b). It can be seen that the proposed algorithm has increased performance demonstrated through a faster convergence to the MPP than the fixed step P&O. Furthermore, the experimental results for a luminosity step response for the P&O with fixed step takes 25s Fig. 5a) and 15s Fig. 5b) for the proposed algorithm. It can be seen that the proposed algorithm has increased performance, demonstrated through faster transient response when a luminosity step variation occurs. The short circuit current is varied from 1A to 2A.



a) b)

Fig. 4 Experimental results for convergence to the MPP of the P&O algorithm : a) fixed step, b) proposed algorithm.



a) b)

Fig. 5 Experimental results for luminosity step response of the P&O algorithm: a) fixed step, b) proposed algorithm.

5 Conclusion

The new system presented in this paper resolves the problems of the existing maximum power point controllers. It improves the shading response and step load changes by making both the stability of the system and the MPPT algorithm independent of the solar panel. A MPPT configuration was developed, with its small signal model, and an improved P&O algorithm, unique through its feature of step size change, proved with simulation and experimental results. Digital control adds the flexibility to design a control structure for which there is no specialized IC for implementation. For future research MPPT algorithms are developed for searching the optimum operating point for systems affected by partial shading. Such a system will be combined with an inverter, thus having a complete system dedicated to energy harvesting.

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