OPTIMIZING ENERGY EFFICIENCY OF A STANDALONE SOLAR SYSTEM USING PERTURB AND OBSERVE MPPT TECHNIQUE

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ABSTRACT

Solar photovoltaic system as renewable energy source has become significant due to several advantages such as the absence of fuel cost, no carbon footprints and little maintenance. The low energy conversion efficiency of the solar PV module and the power mismatch are the major obstacle here. This because they limit the implementation of PV systems by makeing it difficult for the PV array to provide optimum power enough to charge or replenish the PV system's battery bank under low irradiation adverse weather conditions. This can be partially overcome by installation of oversized PV array which results in higher capital cost and wastage of energy. This situation impedes on the anticipated return on investment as the battery banks soon die off leading to high operational cost and loss of revenue. This work confirms that maximum power can be delivered to load only when we force the PV Solar Module to operate at its maximum power point (MPP). This is accomplished by regulating the current to the right amount as that of the maximum power point using DC to DC converters and a suitable switching control algorithm. With an MPPT tracking technique, investors in Solar PV Systems now have a huge return on investment over a period of time.

KEYWORDS: MPPT, Solar, Photovoltaic, Perturb & Observe, Algorithm.

INTRODUCTION

The Perturb and Observe (P&O) algorithm is also called "hill-climbing", but both names refer to the same algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the

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DC link between the PV array and the power converter (Esram, T. and Chapman, P.L. 2007). The P&O algorithm is a relatively simple but a powerful method for MPPT. In the case of the Hill-climbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique.

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction.

Every addition to converter and MPPT algorithm adds additional cost to the entire PV system. However the cost is minimal compared to the PV panels and can usually be offset by improved efficiency. Improving efficiency is the easiest way to cut cost with a PV system. A good MPPT algorithm and a high efficiency converter are a must to improve efficiency but should not be the only changes to the standard setup. One should also employ higher output voltages to lower line losses and allow for more efficient AC conversion. The second easiest way to improve overall system cost is in the components themselves. A higher and more stable line voltage will mean smaller AC inverters with grid tie systems that will not need any boosting capabilities at all. The removal of expensive components such as current sensors also helps to keep cost at a minimum and improves the system reliability. The system needs to be robust enough that when the consumer wants to expand their energy production by adding more panels, they don't need to replace their entire system. The DC/DC converter and MPPT control algorithm proposed in this work will implement all of these improvements with the hope of creating a highly efficient, low-cost, and highly reliable solar PV system for clean renewable power generation.

LITERATURE REVIEW

In order to utilize the potential with any of these converters in a PV system, the converter needs to be controlled by a MPPT algorithm. Various MPPT algorithms (Hua,1998; Hussein, 1995; Koutroulis, 2001; Pan, 1999) have been proposed based on power measurements, including the hill-climbing (HC) method (Koutroulis, 2001), perturb and observe (P&O) method (Hua, 1998), and incremental conductance (IncCond) method (Hussein, 1995).

The HC and P&O methods achieve the same fundamental thought in different ways (Salas, 2006). These two algorithms are widely used because of their simplicity; however they can fail under rapidly changing atmospheric conditions. The incremental conductance method can track the maximum power point (MPP) more accurately than the HC and P&O algorithms can, however it is relatively complicated to implement.

Over the past decades many methods necessary to find the MPP in PV systems have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correctness of tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. A complete review of 19 different MPPT algorithms can be found in (Esram T. and Chapman P.L. 2007).

Among these techniques, the P&O and Incremental Conductance algorithms are the most common. These techniques have the advantage of an easy implementation with obvious draw back which if carefully considered can be reduced to a level it does not impact on the efficiency of the system. Other techniques based on different principles are fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one (Mohamed & Motaleb, 2010)

In normal conditions the V-P curve has only one maximum, coping with this is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves as a result of the dynamically changing weather condition. In order to relieve this problem, MPPT algorithm is implemented to cope with the fast changing weather conditions that present multiple maxima (Tat L. Nguyen and Kay-Soon Low, 2010). Some of the most popular MPPT techniques are as well.

Both P&O and Incremental Conductance algorithms are based on the "hill-climbing" principle, which consists of moving the operation point of the PV array in the direction in which power increases. Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant. The advantages of both methods are the simplicity and low computational power they need. The shortcomings include oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions.

METHODOLOGY

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. On the left of the MPP increasing the voltage increases the power whereas on the right decreasing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented (Esram T. and Chapman, P.L. 2007). The process is repeated until the MPP is reached. There are multiple ways to try to optimize the P&O algorithm. The first and most important is to choose the constants within the system carefully. The first constant: - $r_C, \left\{1 - \left(\frac{P_K}{P_{K-1}}\right) <= r_C\right\}$ that tells the algorithm whether or not the MPP has changed, needs to be sized just right. It needs to be big enough to stop the oscillation effect once the MPP has been found but small enough to ensure that the algorithm will move to the correct point when the MPP changes even slightly.

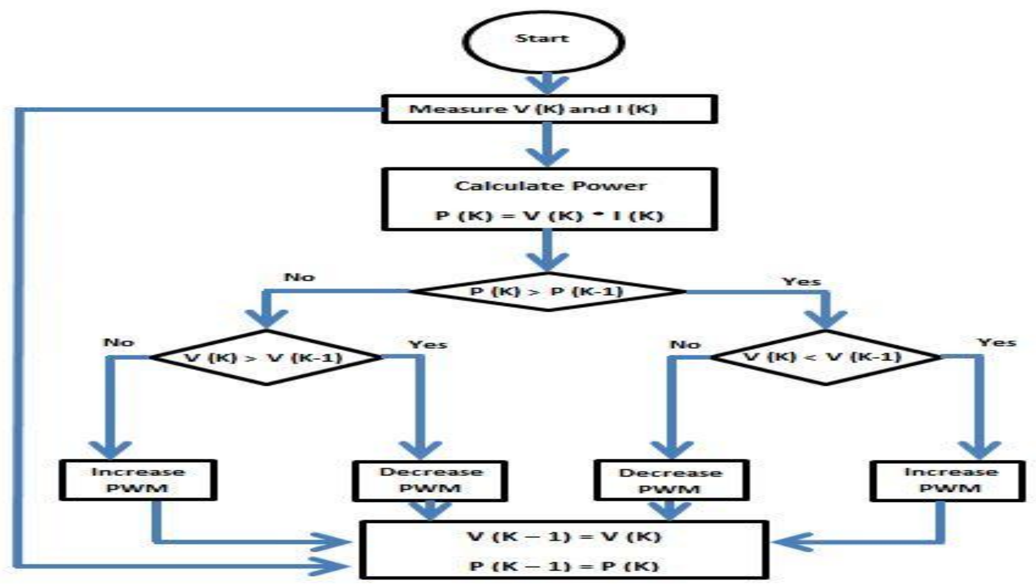

Fig 1: Perturb and Observe MPPT Algorithm

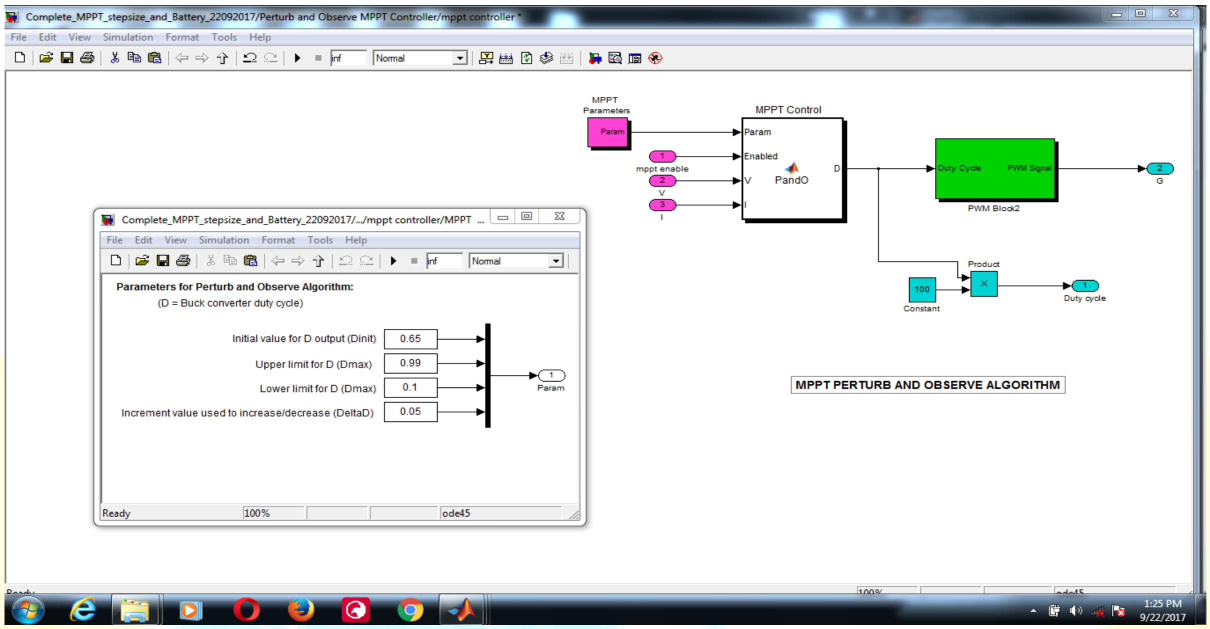

Fig 2: MPPT Perturb and Observe Algorithm Function Block

Another important constant to optimize is the amount the duty cycle changes (Δd) with each perturbation. This needs to be small enough to allow for a sufficient number of steps within the full duty cycle range. It is also important to make this number small enough that when the MPP is reached one change won't be enough to throw it over the MPP causing the same oscillations that were avoided by sizing $\left\{1 - \left(\frac{P_K}{P_{K-1}}\right) <= r_C\right\}$ correctly. This also means that the amount of change in the duty cycle should be correlated with the first constant as well.

This all makes it sound as though it would be best to have Δd as small as possible, but this would also cause problems. The system needs to be able to respond to rapid changes in the environment, such as cloud cover. If a cloud suddenly shades part of the panel the algorithm should be able to quickly account for the change in MPP and move the operating point to the new MPP. Having the amount of change in the duty cycle per iteration very small would mean that it would take a great number of iterations to reach the new MPP. Every iteration where the panel is not operating at the MPP can be considered a loss in power. Therefore it is important to have Δd be large enough to allow the algorithm to converge to a new MPP quickly. This shows that there is a large trade-off between speed and efficiency with this algorithm. The algorithm in use here increases or decreases the duty cycle by 0.125% per iteration.

The last main way to optimize this algorithm is to change the time between when one iteration ends and the next one begins. There needs to be enough time between the iterations to be sure that the converter or panel has reached a steady state after a variation in duty cycle. If there is not enough time the power calculation may be made from fluctuating voltage and currents. The fluctuations would cause the calculated power to be wrong, which could make the rest of the algorithm change the duty cycle in the wrong direction.

Here again careful decisions need to be made because if the time between iterations is too long then there will be convergence issues with the system under rapidly changing conditions.

RESULTS AND CONCULSIONS

The PV model simulation results show that the effects of increase in solar irradiation on the voltage and current of the PV module or array is positive i.e. both voltage and current were observed to increase when solar irradiance was increased. Similarly, the power is equally positive as an increase in irradiation brings about an increase in PV module or array power. With the above establish, the effects of shading or low solar irradiance on PV Solar module/array was equally observed and analyzed for MPPT and PWM charge controllers to show that shading effects is more pronounced in PWM charge controllers since the PV module output voltage (Vpv) is closely matched with the battery bank voltage.

Further comparison was done to compare the power output of an MPPT charge controller and that of a PWM charge controller to justify the claim the an MPPT charge controller with above 95% efficiency is far better than the PWM charge controller which is only about 45 – 50% efficient. The basic premise behind Perturb and Observe is that the algorithm is constantly comparing the array’s output power after a small, deliberate perturbation in the array’s operating voltage applied. If the output power is increased after the perturbation, then the array’s operating point is now closer to the MPP, and the algorithm continues to “climb the hill” towards the MPP. If the power is decreased, then the operating point is further from the MPP, and the algorithm reverses the algebraic sign of the perturbation in order to “climb the hill.”

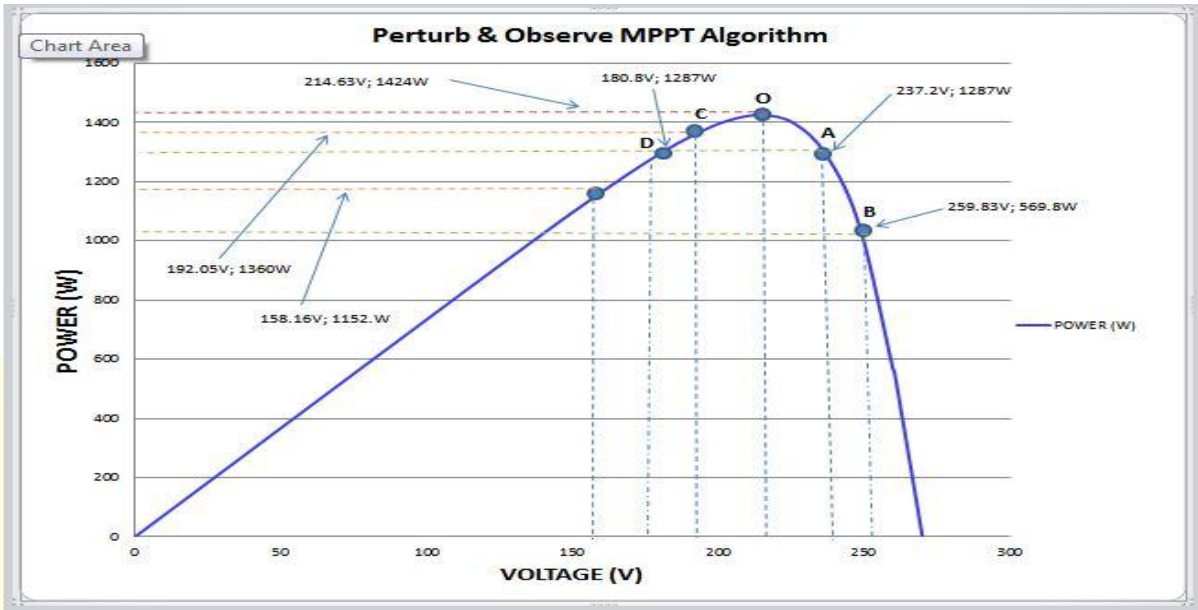

Fig 3: Graphical illustration of Perturb and Observe MPPT Technique using the Solar P – V curve

V(K) = Present Voltage measurement; V(K-1) = Previous Voltage measurement

P(K) = Present value of Power; P(K-1) = Previous value of Power

Sometimes, the levels of operation of the simulation of the Charge controller using P&O MPPT algorithm with reference voltage perturbation when the system could be started and run at 850-W/m^2 solar irradiance and 25^{o}C cell temperature with a low perturbation frequency of 100 Hz and a high step size of 13.5 V which represents an increment of duty cycle by 0.05 (5%). But here system operation is better explained with reference to the array power-voltage curve at the same irradiance and cell temperature levels.

The array power was measured to be around 1287W with the system operating at the initial reference voltage of 237Vdc as is represented by point “A”. The initial perturbation direction is to increase the reference voltage, so the reference voltage is increased in steps of 13.5 V (the step size) to 259.83V thereby moving the operating point to point B. Similarly, the Array power at B is measured after a perturbation period of 1 s has passed. As a result of the decrease in power at point B from 1287W to 569.8W, the P&O algorithm reverses the perturbation direction, decreasing the reference voltage to 237V and moving the operating point back to point A.

Due to the power increase as a result of moving from point B to point A, the algorithm continues in this direction to decrease the reference voltage to 214V (i.e. point O). The power is also measured and since the power at O which is 1424W is more than the power at point A (1287W) perturbation continues in the same direction to decrease the reference voltage by the step size to get to point C. At point C, the reference voltage is 192Vdc and the power is measured and observed to be lower than the power at A.

As a result, the direction of perturbation reverses from point C to the direction of point O. The perturbation continues changing direction with the sole aim of tracking the maximum power point as the solar irradiance continues to change due to the dynamic nature of the weather.

Moreover, the effects of increase in solar irradiation on the voltage and current of the PV module or array is positive i.e. both voltage and current were observed to increase when solar irradiance was increased. Similarly, the power is equally positive as an increase in irradiation brings about an increase in PV module or array power.

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