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OPTIMIZED MAXIMUM POWER POINT TRACKING(MPPT) OF A SOLAR PV SYSTEM WITH IMPROVED P&O METHOD

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Abstract— As the power demand increasing day by day, the power failure is also increasing. So, the renewable energy can be used to provide constant loads. To convert the basic circuit equation of solar cell into simplified form, a model is developed including the effects of changing solar irradiation and temperature. Maximum power point tracker (MPPT) control is essential to ensure the output of photovoltaic power generation system at the maximum power output as possible. Maximum power point tracking (MPPT) techniques are used in PV systems to make maximum utilization of PV array output power which depends on solar irradiation and ambient temperature. The addition of such an operating point controller will yield an estimated 60% increase in power output from the solar cells. This leads to a higher efficiency of the overall system without adding any additional photovoltaic cell surface to the existing array. There are many MPPT techniques. P&O method is simple in operation and hard ware requirement is less, but it has some power loss. IncCond method has more precise control and faster response, but it has higher hardware requirement. In order to achieve maximum efficiency of photovoltaic power generation, an efficient control method, that is (P&O) should be chosen.

Keywords— Buck Boost Converter MPPT, P&O, PV, .

I. INTRODUCTION

The generation of energy in our modern industrialized society is still mainly based on a very limited resource: petroleum. As the world's energy demands rise and new sources for petroleum become scarce, the search for alternative energy resources has become an important issue for our time. Every photovoltaic cell array has an optimum operating point, called the maximum power point (MPP), which varies depending on cell temperature and the present insolation level. The goal of this research is to find the mechanism best suited for employment in a moving vehicle to optimally track this point of maximum efficiency and adjust the operating point of the solar cell array accordingly. The solar-powered racing vehicle sol train is not yet equipped with such a maximum power point tracking (MPPT) device. There are two main groups of MPPTs: those that use analog circuitry and classical feedback control, and others that use a microprocessor to maintain control of the operating point. Analog systems have the advantage of having low cost components, but are more problematic to control. It is difficult to develop a stable system which is able to maintain its accuracy even under extreme operating conditions such as the wide temperature variations. The digitally controlled MPPT systems have the advantage that a power point tracking algorithm will not be influenced by changes in temperature and therefore will always be very reliable. This paper will introduce a novel approach to analyze, simulate, and evaluate the complete solar power supply system with a digital MPPT controller under varying operating conditions. The digitally controlled MPPT can be directly included in the simulated system, and modifications to improve the MPPT performance of conventional MPPT algorithms can be evaluated without having to build and modify an expensive prototype. To be able to properly simulate the complete solar power supply system, detailed mathematical models for all of the system's components are necessary. These components consist of the array of photovoltaic cells, an energy buffer in the form of a parallel-connected battery pack and optionally a dc-to dc converter.

II. THE PHOTOVOLTAIC POWER SYSTEM

The Photovoltaic Power supply system consists of an array of photovoltaic cells, a set of batteries as an energy buffer and optionally some kind of converter to match the voltage of the solar array with the battery voltage (Figure 1). If the conversion ratio of the converter is varied by a controller to constantly adjust the operating voltage of the solar panel to its point of maximum power (Vmp), it is being operated as a Maximum Power Point Tracker (MPPT).

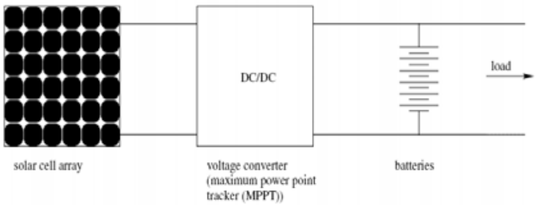

Figure 1: Power train of a solar powered system.

A. *Physical Structure of a Photovoltaic Cell*

A solar cell is a semiconducting device that absorbs light and converts it into electrical energy. Today's most common cell is a mass manufactured single p-n junction Silicon (Si) cell with efficiency up to about 17%. It consists of a moderately p-doped base substrate and a thin heavily n-doped top layer. Thin metal contacts on the surface and a plain metal layer on the back connect this photovoltaic element to the load. If exposed to radiation, electron-hole pairs are created by photons with an energy greater than the band-gap energy of the semiconductor (hv > Eg). This is called the photovoltaic effect. The newly created charge symmetries in the depletion region are separated by the existing electric field. This leads to a forward bias of the p-n junction and builds up a voltage potential called the photo-voltage. As soon as a load is connected to the cell, this voltage will cause a current (called the photo-current) to flow through the load. In addition the forward bias of the p-n junction also leads to a small diode current Id in the opposing direction of the photo-current. The p-n junction properties and the discussed reaction of the semiconductor to radiation lead to the simplified and idealized equivalent circuit diagram of a photovoltaic cell as shown in Figure 2.

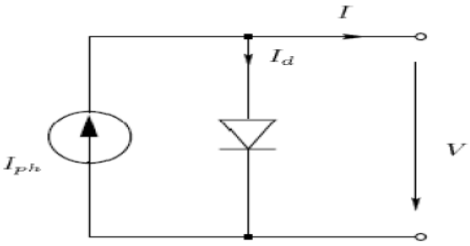

Figure 2: Simple equivalent circuit diagram for a PV cell.

Application of Kirchhoff’s law and the exponential diode equation (1) leads to a simple mathematical model for a photovoltaic cell.

$$I_d = I_s\left[e^{\frac{qV}{2kT}} - 1\right] \qquad (1)$$

$$I = I_{ph} - I_s\left[e^{\frac{qV}{2kT}} - 1\right]$$

(2)

I and V are the output current and voltage of the cell. Iph is the generated photocurrent and Is is the reverse saturation current of the diode. Furthermore, the characteristics are influenced by the temperature T and by the constant for the elementary charge and Boltzmann's constant k.

B. *Equivalent Circuit and Mathematical Model*

Actual measurements on real cells under diverse operating conditions, however, show the need for a more sophisticated model. In particular the internal resistance of the device has to be taken into consideration. This leads to the widely used “two-diode model" as shown in Figure 3.

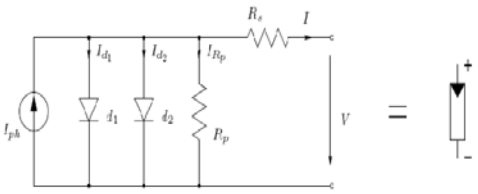

Figure 3: Equivalent two-diode circuit model of a photovoltaic cell and its circuit symbol.

Figure 3 is a representation of the mathematical model for the current-voltage characteristic which is given as :

$$I = I_{ph} \quad I_{s1}\left[e^{\frac{q(V+IR_s)}{n_1kT}} \quad 1\right] \quad I_{s2}\left[e^{\frac{q(V+IR_s)}{n_2kT}} \quad 1\right] \quad V \mid \frac{IR_s}{R_p}$$

(3)

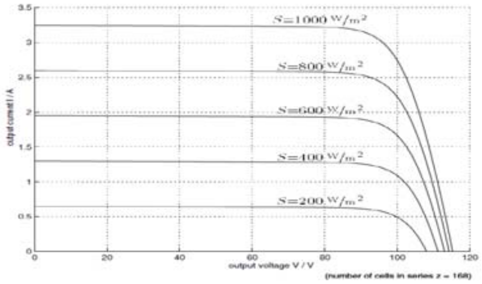

Figure 4: I-V characteristics of a photovoltaic cell array for various values of irradiance S at a temperature of 25 degC.

It can also be seen that the output power of a solar panel not only depends on temperature and insolation, but also very strongly on its operating voltage V. The point of maximum power indicated as MPP (Maximum Power Point) is the desired operating point for a photovoltaic array to obtain maximum efficiency.

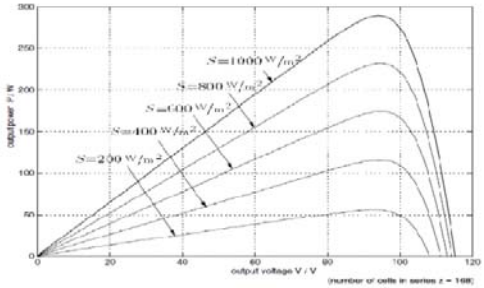

Figure 5: P-V characteristics of a photovoltaic cell array for various values of irradiance S at a temperature of 25 deg C

III. DC-DC CONVERTERS

In this section the principles of switching power conversion are introduced and details of different DC-DC converter circuits are discussed.

A switching converter consists of capacitors, inductors, and switches. All these devices ideally do not consume any power, which is the reason for the high efficiencies of switching converters. The switch is realized with a switched mode semiconductor device, usually a MOSFET. If the semiconductor device is in the off-state, its current is zero and hence its power dissipation is zero. If the device is in the on-state (i. e. saturated), the voltage drop across it will be close to zero and hence the dissipated power will be very small.

During the operation of the converter, the switch will be switched at a constant frequency fs with an on-time of DTs, and an off-time of (1-D)Ts, where Ts is the switching period 1/fs and D is the duty ratio of the switch.

A. *The Buck-Boost Converter*

The buck-boost converter combines the properties of the buck and boost configurations. It can be used to ideally transform any dc input voltage into any desired dc output voltage. In practical usage the ideality is of course limited by component losses.

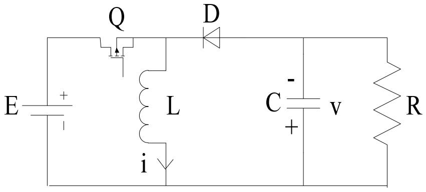

Figure 5: Ideal buck-boost converter circuit

The dc conversion ratio M(D) of the ideal buck-boost converter

$$M(D) = \frac{V_o}{V_s} = -\frac{D}{D'} = -\frac{D}{1-D} \quad (4)$$

Figure 6 illustrates the conversion ratio of a buck-boost converter as a plot over the duty ratio D. Determination of voltage and current ripple A linear ripple approximation is done, like previously discussed converter types, to determine equations which make it easier to design a converter which will meet desired maximum switching ripple specifications. It is assumed that the slope of the ripple during either of the two time intervals in a switching period Ts is a linear function of time.

The non-ideal converter model One important issue when designing a high efficiency switching converter is to determine the dependency of the conversion ratio on the losses occurring in the real, non-ideal components. As in the buck converter example, only the dependency on the inductor losses is analyzed.

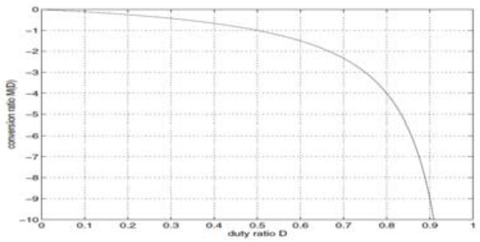

Figure 6 : Conversion ratio M(D) vs. duty ratio D for an ideal buck-boost converter

IV. MAXIMUM POWER POINT TRACKING

A. *The voltage-feedback method*

A dc-to-dc converter can be used to convert the voltage level at a photovoltaic cell array to another voltage level at the load. Feedback of the panel voltage and comparison with a constant reference voltage can be used to continuously adjust the duty ratio of the converter to operate the solar panel at a predefined operating point close to the MPP. This method makes it possible to operate a solar array under unknown or changing load conditions and still be able to choose a desirable operating point for the panel.

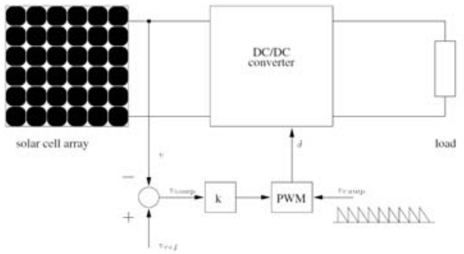

Figure 7: Voltage-feedback with pulse width modulation (PWM) on a dc-dc converter

B. *The perturbation and observation method (P&O)*

The P&O method is a widely used approach to MPPT. It employs a microprocessor with the values for panel voltage V and panel current I as its input values and the desired operating voltage Vref as its output value. The notation used for the desired operating voltage Vref alludes to the fact that this system can then be inserted in the already discussed voltage-feedback controller to supply Vref. Another possible configuration is to have the microprocessor directly controlling the dc-to-dc converter's PWM input variable d. This makes the extra voltage control feedback loop dispensable. As the name of the P&O method states, this process works by perturbing the system by increasing or decreasing the array operating voltage and observing its impact on the array output power. Figure 3.3 shows a flow chart diagram of the P&O algorithm as it is implemented in the controlling microprocessor. As can be seen in Figure 3.3, V and I are measured to calculate the current array output power P(k). This value for P(k) is compared to the value obtained from the last measurement P(k+1). If the output power has increased since the last measurement, the perturbation of the output voltage will continue in the same direction as in the last cycle. If the output power has decreased since the last measurement, the perturbation of the output voltage will be reversed to the opposite direction of the last cycle. With this algorithm the operating voltage V is perturbed with every MPPT cycle. As soon as the MPP is reached, V will oscillate around the ideal operating voltage Vmp. This causes a power loss which depends on the step width of a single perturbation. If the step width is large, the MPPT algorithm will be responding quickly to sudden changes in operating conditions with the tradeoff of increased losses under stable or slowly changing conditions. If the step width is very small the losses under stable or slowly changing conditions will be reduced, but the system will be only able to respond very slowly to rapid changes in temperature or insulation. The value for the ideal step width is system dependent and needs to be determined experimentally.

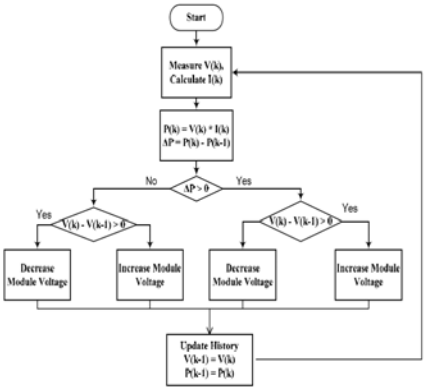

Figure 8: Flow chart of the P&O MPPT algorithm

In the case of a sudden increase in insolation S, the P&O algorithm reacts as if the increase occurred as a result of the previous perturbation of the array operating voltage. The next perturbation, therefore, will be in the same direction as the previous one. Assuming that the system has been oscillating around the MPP, it can be seen in Figure 8 that a continuous perturbation in one direction will lead to an operating point far away from the actual MPP. This process continues until the increase in insolation slows down or ends.

V. SIMULATION AND EVALUATION

Simulations are a powerful tool for evaluating the theoretical performance of different systems. The device under test can be operated under easily controllable conditions and its performance can be precisely monitored. The process of simulation links the two major parts of a system design: the theoretical outline and the realization of a prototype. Finally, since changes in the design can be made easily in a simulated system, it is possible to experiment with a wide set of variations in order to find the optimum solution. Since digital MPPT methods provide better control than analog techniques and are essentially independent of environmental influences on performance, they are best suited for operation in the rough conditions of an outdoor system. The challenging aspect of the design of a digital controller for MPPT applications is the inclusion of a discrete-time device into a continuous-time environment. This makes it impossible to obtain a closed-form transfer-function for conventional analysis of the system's stability and dynamic performance. The MathWorks' software package Matlab includes the simulation tool Simulink . It provides the possibility to simulate mixed continuous and discrete system. This makes it well suited to implement, test, and evaluate digital MPPT systems introduced in section III, Simulink allows for the division of a simulated system into a number of subsystems. These subsystems can be modeled and tested individually and then interconnected later. This makes it possible to build the physical subsystems such as the solar panel, the batteries, the dc-to-dc converter, and the MPPT as independent units and verify their proper functionality. Finally these subsystems can be combined to form a complete MPPT-controlled photovoltaic power system as shown in Figure 7. MPPT techniques and converter types can be combined and their operation can be simulated on solar panels and battery pack of any desired size under an unlimited variety of operating conditions. The MPPT-controlled photovoltaic power system is simulated as a combination of subsystems as shown in Figure 7. Individual subsystem blocks represent the actual physical parts of the power supply system.

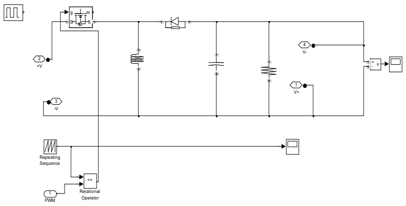

Figure 9: Simulation of the P&O MPPT method in combination with a buck-boost converter under stable environmental conditions

Further simulations have been done for a solar power supply system with P&O MPPT employing a boost converter. At a sampling rate of 100Hz it shows the P&O-characteristic low amplitude oscillations around the MPP under stable environmental conditions. The top curve shows that the dynamic response of the system to a step of the control input is not as well behaved as it was for the system employing the buck converter. However, the digital feedback control has a stabilizing effect on the system which prevents instability.

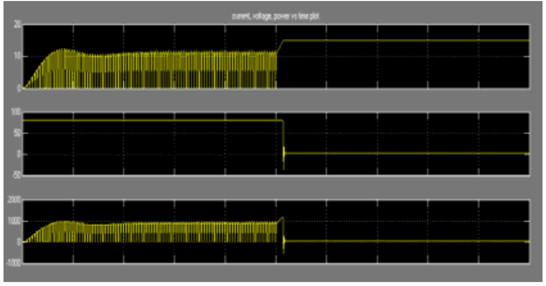

Figure 10: Solar PV Output current, voltage V and power P in a system with P&O MPPT on a buck-boost converter

Finally, the buck-boost converter has the great advantage of having a continuous operating range between step-down and step-up operation. It is therefore possible to choose its output voltage to be lower, equal, or even higher that its input voltage. The output voltage is negative, which means the battery and any other load on its bus must be connected accordingly.

The final simulation model of MPPT using improved P & O is shown below:

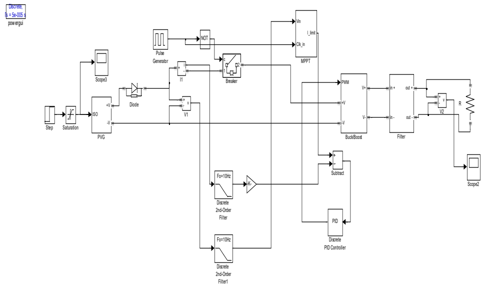

Figure 11: Simulation Model of MPPT using P & O in combination with the buck/boost converter

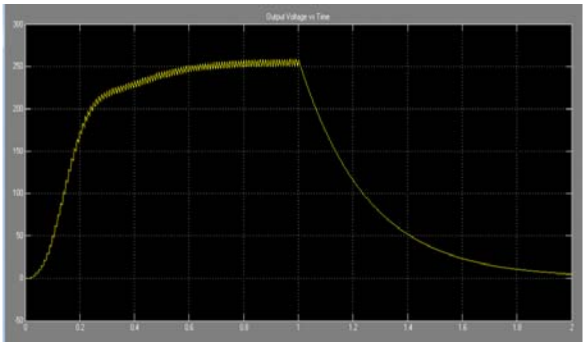

Figure 12: Plot of waveform showing Output voltage vs Time of a PV system with P&O MPPT on a buck/boost converter

VI. CONCLUSION

A detailed analysis of the individual components of the photovoltaic power system was undertaken to evaluate their performance in the complete system under operating conditions characteristic for a moving system. The simulations were concentrated on the analysis and evaluation of microprocessor controlled MPPT methods which provide superior controllability and have the ability to handle very complex tracking conditions. Operation under slowly increasing power levels, caused by moderately rising insolation levels or by decreasing cell temperature, revealed a slight lag behind the other simulated techniques and an associated power loss. This was more than overcome by this technique's extraordinary performance under rapidly increasing insolation levels. The deviation from the MPP, as observed with other simulated MPPT methods, did not occur. This made the improved P&O algorithm superior to all evaluated models and led to a significantly higher average power output under randomly and rapidly changing environmental conditions as they occur in a moving system.

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