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Optimal MPPT charging battery system for photovoltaic standalone applications

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***Abstract*— The photovoltaic panel produces green power, and because of its availability across the globe, it can supply isolated loads (site away of the electrical network or difficult of access). Unfortunately this energy remains very expensive. The most application of these types of power needs storage devices, the Lithium batteries are commonly used because of its powerful storage capability. Using a solar panel or an array of panels without a controller that can perform MPPT will often result in wasted power, which results in the need to install more panels for the same power requirement. For devices that have the battery connected directly to the panel, this will also result in premature battery failure or capacity loss. In this paper it is proposed a modified P&O algorithm for the MPPT which takes in account the battery's internal resistance vs temperature and stage of charging. Of course the temperature variation and irradiation of the PV panel are also introduced.**

***Keywords*— Modeling, Battery, MPPT, Charging, PV Panel**

I. Introduction

The chemical reactions at the electrode surfaces introduce electrons into the Pb electrode, and create a deficit of electrons in the PbO2 electrode. These charges change the voltages of the electrodes. The system reaches equilibrium when the energy required to deposit or remove an electron equals the energy generated by the reaction. Now the connection of an electrical load allows electrons to flow from negative to positive terminals. This reduces the charge and the voltages at the electrodes.

The chemical reactions are able to proceed, generating new electrons and generating the power that is converted to electrical form to drive the external electrical load. As the battery is discharged after use, it should be reused. So, the connection of an electrical power source (photovoltaic panel in our case) forces electrons to flow from positive to negative terminals. This increases the charge and the voltages at the electrodes. The chemical reactions are driven in the reverse direction, converting electrical energy into stored chemical energy

II. Physical Aspect of Battery Energy

As any equipment, the battery efficiency should be evaluated for an accurate operation (1). This efficiency is calculated as ratio between the require energy during charging (2) and the available energy during discharging (3).

$$\eta = E_D / E_C \tag{1}$$

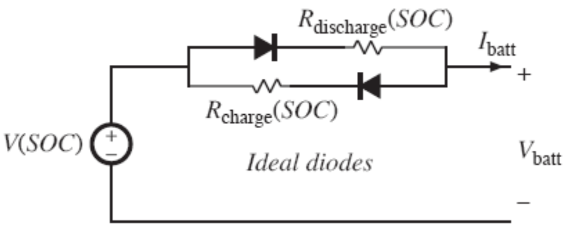
$$E_C = -\int v_{bat} i_{bat} dt \approx V_C I_C T_C \tag{2}$$

$$E_D = -\int v_{bat} i_{bat} dt \approx V_D I_D T_D \tag{3}$$

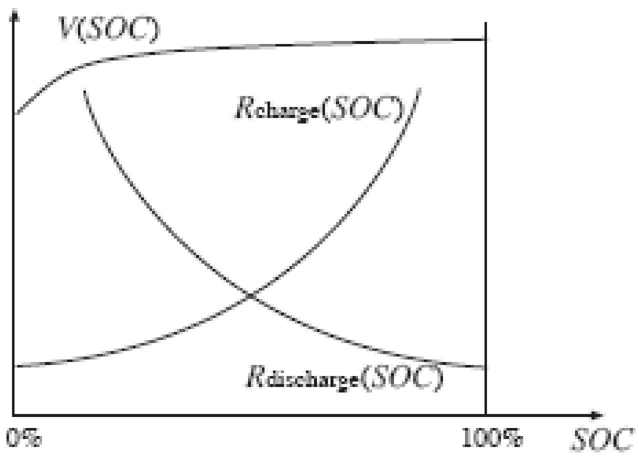
So, the replacement of these new relations the energy efficiency becomes (4)

$$\eta = \left(\frac{V_D}{V_C}\right)\left(\frac{I_D T_D}{I_C T_C}\right) \tag{4}$$

Where the first part $\left(\frac{V_D}{V_C}\right)$ is defined as the voltage efficiency and the second part $\left(\frac{I_D T_D}{I_C T_C}\right)$ as the coulomb efficiency Fig.1.



a./



b./

Fig.1. Dependence of model parameters on battery state of charge (SOC)

a. *Over-discharge leads to "sulfation" and the battery is damaged*

The reaction becomes irreversible when the size of the lead-sulfate formations becomes too large. And it conduct to bulging and deformation of cases of sealed batteries

b. *Battery charge management to extend life of battery:*

- Limit depth of discharge
- When charged but not used, employ "float" mode to prevent leakage currents from discharging battery
- Pulsing to break up chunks of lead sulfate
- Trickle charging to equalize charges of series-connected cells

c. *Charge profile*

A typical good charge profile should: Bulk charging at maximum power, charging at constant voltage, the current will decrease; this reduces gassing and improves charge efficiency. Prevent discharging of battery by leakage currents. Occasional pulsing helps reverse sulfation of electrodes.
The three charging stages are:

The **bulk stage** involves about 80% of the recharge, wherein the charger current is held constant (in a constant current charger), and voltage increases.
The **absorption stage** has the charger holding the voltage at the charger's absorption, depending on charger set points) and decreasing the current until the battery is fully charged.
The **float stage** is where the charge voltage is reduced and held constant, while the current is reduced to less than 1% of battery capacity. This mode can be used to maintain a fully charged battery indefinitely.

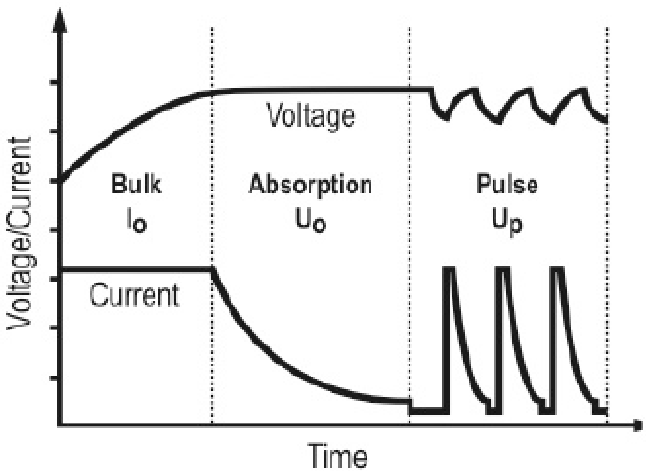


Fig.2. The three-step charge profile

Adequate chargers Fig.2 management can:
- Program charge/float voltages to needs of specific battery type
- Temperature-compensate the voltage set points
- Maintain battery in fully charged state (float mode) when in storage
- Avoid overcharging battery (charge voltage set point)
- Taper back charging current to improve charge efficiency and reduce out- gassing

For sizing a battery that should provides a reliable storage system for standalone alternate energy systems based on Photovoltaic source. One should calculate the Total Number of DC Amp Hours per Day (AHD) required to power the system (1)

$$AHD = I.H / DO \quad (4)$$

Where I is the load current; H is the hour and DO the Day of Operation

Another parameter which strongly influences the battery operation, another words the model is the temperature Fig.3

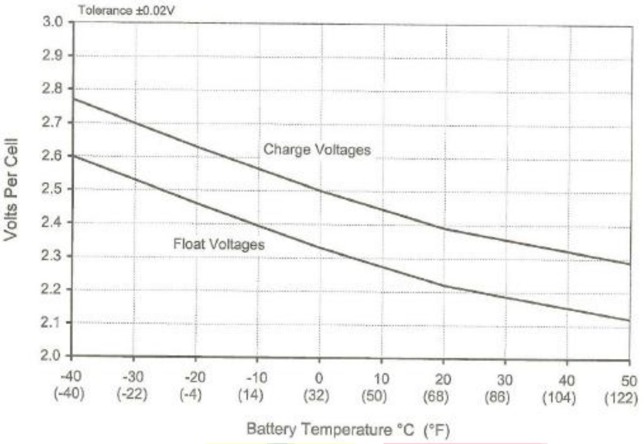


Fig.3. the effect of temperature on the charging process

The temperature of the battery can be a major factor in sizing the system. Lead acid battery capacity is reduced in cold temperatures, and its life is shortened in high temperatures.

It should be noted that the temperature of the battery itself and ambient temperature can be vastly different, especially in Sahara climate.

So an adequate sizing and management of PV panels, battery capacity and quality regulator can provide a power source many years of highly reliable energy.

III. PV PANEL MAXIMUM POWER POINT TRACKING MPPT

Many PV cell models are investigated by the researchers, and the most used is that shown in Fig.4 and detailed in the equation [1].

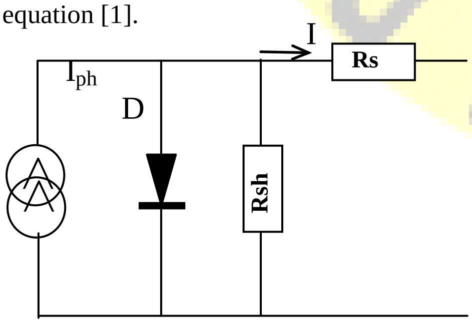


Fig.4 PV cells model

Due to its non-linear, photovoltaic cells can produce maximum power point MPP, for optimum voltage and current (3)

$$I = I_{ph} - I_o \left[e^{\frac{(V+IR_S)q}{akT_{CT}}} - 1 \right] - \frac{(V+IR_S)}{R_{Sh}} \quad (5)$$

Where

I_{sh} and I_D are the photo generated current and the dark saturation of the PV source.

R_s and R_{sh} are cell series and parallel resistances respectively

This MPP changes with the irradiation value, the I-V characteristic for P_{max} Fig.5 implies the use of a buck-boost chopper as an interface between the PV generator and the battery [2-3], because in the morning the battery imposes an important storage current, so the current should be limited, and in the end of the daylight, the storage current became weak, so the PV voltage became greater than the battery voltage which should be limited.

The chopper guaranties a maximum power delivered by the PV panel [4], this chopper has its own power consumption. The PV maximum power controller do not guaranties a maximum charging power. To transmit the maximum power to the battery [5] the chopper parameters (Rc - adjustable resistance control) must be introduced in the novel MPPT Fig.6

Resistance Rc is used to vary the output parameters of PV cells to reach the MPP. Generally the chopper is assumed as a variable resistor. Now the MPPT circuit is supplied with the PV module. This circuit provides the user with the reference values Vop and Iop. Several MPPT techniques has been proposed by researchers for the detection of this operating point, as the derivative method, artificial intelligence, the method perturb & observe, etc ... For all these techniques the principle is the same

In this work, the solar panel is used to charge a Lithium battery, which will be reused to standalone applications, as house lighting. To ensure proper control of the system, the modeling of different elements is necessary.

There are several configurations modeling the Lithium batteries [4] (e.g. distributed constant model based on the model of the power lines). The model accepted by most researchers [5] is the one shown above Fig.4

What we noticed during the association panel PV- chopper Battery, MPP shifts Fig.7. So in order to readjust to the new MPP, the next development was done in order to give the new reference values of voltage and current.

$\frac{dP_{PV}}{dt} = 0$, determines the value of I_{OP1}, therefore V_{OP1}.

With the insertion of the Lithium battery (4) this relationship becomes incomplete. It is requested that the PV panels transfers the maximum power to the Batteries.

$$P_{PV} = dP_C + P_B \tag{6}$$

With
P_{PV} –Delivered photovoltaic panel power
dP_C – power loss at the chopper
P_B – the power transferred to the Lithium battery

Than $P_B = P_{PV} - r_C I^2$

To find the operating point ensuring maximum loading to the battery (6), $dP_B / dI = 0$, we proceed as follows.

$$P_B = IV_B = R_B I^2$$

$$P_B = R_B \left\{ I_{ph} - I_o \left[e^{\frac{(R_B + r_C + R_S) Iq}{akT_{CT}}} - 1 \right] - \frac{(R_B + r_C + R_S) I}{R_{Sh}} \right\}^2 \tag{7}$$

Due to the nonlinearity of the function (è) researchers use numerical methods [7], whose main drawback is the time required for the determination of optimal points is relatively slow. Knowing that, the position and intensity of solar radiation varies. Generally in the implementation the tracker's starting point is taken as the set rated value.

The techniques disturb and observe is the most used for its simplicity, based on the increment and decrement the reference, and then the operating point oscillates around the MPP. But it has some drawbacks that can make or diverge significantly reduce the transmit power. If the step size is large, the MPPT algorithm will respond quickly to sudden and rapid changes in operating conditions [8] but with losses. If the step width is very small losses will be reduced, but the system has a slow response to rapid changes in temperature or irradiation.

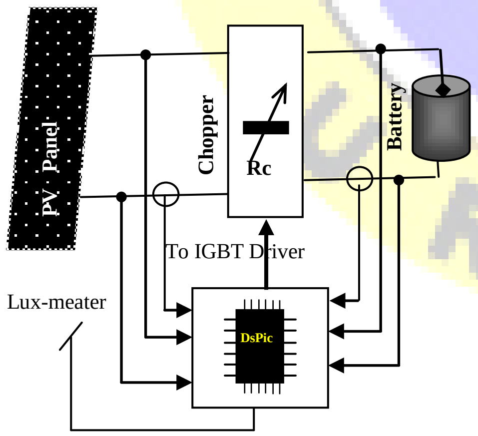


Fig. 6 lithium battery charger

The MPPT program holds in the PIC controller in addition to charging stages takes in account battery temperature that influences the internal resistance [6] value. This assumption allows to the charger controller, to operate at the true MPPT charging battery.

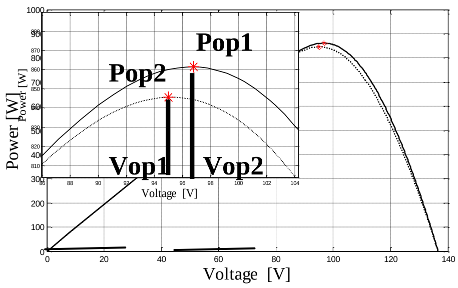


Fig.7 the Maximum Power Point shifting

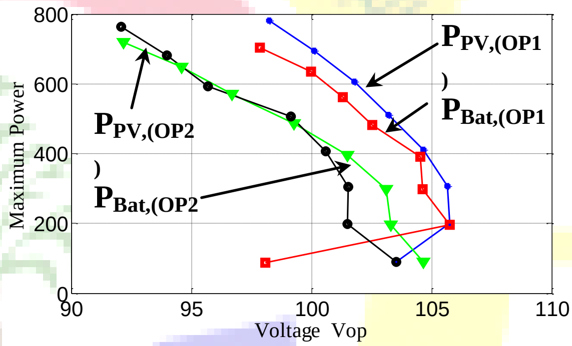


Fig.8. MPP of delivered power vs. produced power

In this figure 8 it is proved that the proposal allows an optimal extraction of the sun power and efficient charging of the battery.

IV. Conclusion

In a standalone application all the required devices should be optimized. The element that manages the different parts is the PIC controller. The modeling that takes in account the principal parameters that influences the modeling variation as ambient temperature, the battery's temperature irradiation, etc…are bring thanks to sensors connected to the controller. The proposal is very useful in order to reduce the PV panel surface. And to operates in a safe charging battery. In other words, increases the operational life of equipment.

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