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Operating Performances of PV Energy Generation System with MPPT

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Abstract

This paper presents the performance of PV(Photovoltaic) system, the design of MPPT and the battery characteristic. The output power of PV depends on the environmental factors such as insolation and cell temperature. It is proposed that the MPPT is based on an simple power control algorithm. Furthermore, the converter has to maintain the optimum duty ratio. A switching strategy of converter for battery may protect against excessive discharge and overcharge.

This paper includes discussion on system reliability, power quality and effects of the randomness of the wind and the solar radiation on system design.

I. Introduction

This paper describes the design of PV power system with MPPT and battery storage. The output power of a PV array is affected by environmental factors, such as insolation and temperature[1].

Generally, techniques intended to operate the system at its maximum power are employed to minimize these problems. Unlike conventional generations, the sunrays and wind can provide us a low cost and pollution-free electricity.

A PV power system is also linked to the DC bus. The bus voltage is imposed by the battery storage. Finally, a variable alternate load is fed using an inverter[2].

The current(I)-voltage(V) output characteristics of a PV panel change with solar insolation and cell temperature as parameters. It is shown that maximum power will be generated when current

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(I_m) flows in conjunction with voltage (V_m). We consider a PV array's derivative of power with respect to voltage (dp/dv) in relation to V and I. The derivative of output power with respect to output voltage of PV array is equal to zero at maximum power point.

This kind of relationship is independent on the insolation and temperature. This property may be utilized to perform maximum power tracking control in all insolation and temperature levels, the maximum power point can be obtained by regulating dp/dv toward zero.

The reference voltage is then increased or decreased such that the system is operated close to the maximum power point. This causes oscillation around the maximum power point, especially in the case of variability or slowly changing environmental conditions.

Maximum power control can be achieved by forcing the derivative (dp/dv) equal to zero under the power feedback control.

The dimension of the storage device has an important weight in the final cost of the system. So, the integration of PV and wind sources, which are generally complementary, usually reduce the site of the required storage.

This paper includes discussion on the PV system performance, the design of MPPT, the battery characteristic and the integration method of hybrid (wind+PV) system.

Ⅱ. Analysis of PV array

The output power of PV array is affected by environmental factors, such as insolation and temperature. dp/dv against V is found to be nonlinear. On the other hand, dp/dv against I is discovered to be nearly linear.

If the internal shunt and series resistances are neglected, the characteristics of a PV array can be expressed by[3],[4]:

$$I = I_{PH} - I_{sat}\left[\exp\left(\frac{q\,V}{AKT}\right) - 1\right] \qquad (1)$$

Where I and V are the output current and output voltage of PV array, respectively, I_{PH} is the light-generated current, I_{sat} is the PV array saturation current, q(1.6×10^{-19}C) is the charge of an electron, K is Boltzmann's constant, A is the ideality factor of the p-n junction and T is the PV array temperature(K).

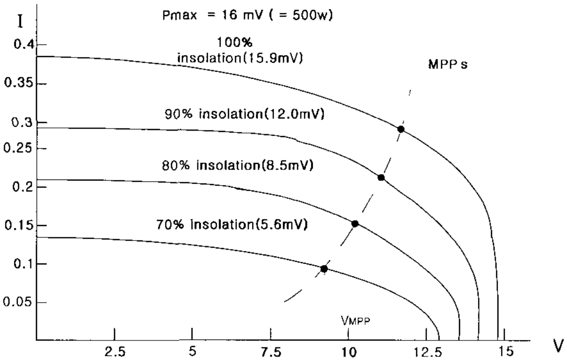


Fig. 1 Voltage-current characteristic of PV array.

Fig. 1 shows their characteristic curves corresponding to different insolation at a constant temperature. It can be seen that the MPPs vary with the change of insolation. In order to obtain the maximum output power from the PV array at various array insolation and temperature levels, it is necessary to determine the location of MPP on the operating curves. Output power can simply be written by

$$P = I_{PH}\ V - V\,I_{sat}\left[\exp\left(\frac{q\,V}{AKT}\right) - 1\right] \qquad (2)$$

In the literature[6], instead of the I-V characteristic given by (1), the following I-V characteristic is used in many cases:

$$V= -IR_s+\frac{AKT}{q}\cdot\ln\left[\frac{I_{PH}-I+I_{sat}}{I_{sat}}\right] \qquad (3)$$

Where R_S is the intrinsic series resistance of the solar array. R_S is very small, hence it may be neglected to simplify the analysis.

From equation (1) and (3), the derivative of P with respect to Vcan be expressed as :

$$\frac{dP}{dV}=I+\frac{qV}{AKT}(I-I_{PH}-I_{sat}) \qquad (4)$$

From equation(1), the derivative of I with respect to V can be written by[3],[4],[5]:

$$\frac{dI}{dV}=\frac{q}{AKT}(I-I_{PH}-I_{sat}) \qquad (5)$$

From equation (5), dI/dV against I is a linear form. The factor "A" in equation(5) determines the cell deviation from the ideal p-n junction characteristics. From equations(4) and (5), when I is varied, dP/dV is varied proportionally.

In the process of MPPT, the PV array is always operated in the negative slope region of the characteristic curve of P against V. In this region, the voltage variation is small and can almost be considered constant.

Ⅲ. Design of control system

Fig. 2 shows PV power conditioning system. It consists of PV array, converter for MPPT, inverter and the corresponding controllers.

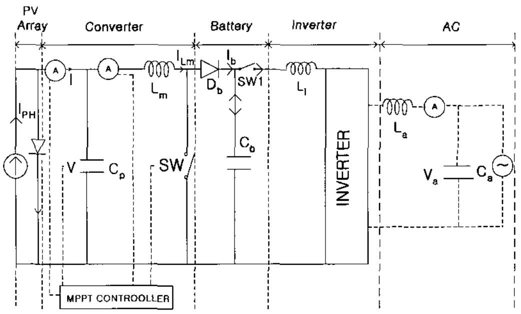


Fig. 2 Schematic diagram of a PV power *conditioning system*

Here, we arrange the converter responsible for maximum power tracking control. We suppose that the inverter has an ideal function as unity power factor output current control and constant dc voltage control in order to prevent the charged voltage of batteries from exceeding the voltage rating.

A. MPPT algorithm

MPP(Maximum Power Point) of PV array on atmospheric conditions can readily be seen in the current-voltage.

The nonlinear nature of PV systems is apparent from Fig. 1. The array current and power depend on the array terminal operating voltage. Generally, the MPPT algorithms operate by periodically perturbing the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. The way to reduce the power loss around the MPP is to decrease the perturbation cycle.

Moreover, according to atmospheric conditions, the MPPT algorithm deviates from the MPP. Fig. 3 shows the MPPs with the change in solar radiation.

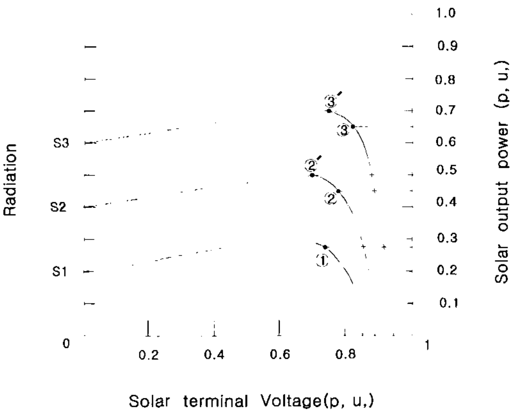


Fig. 3 MPP characteristic curves of PV array.

The array power will be measured according to the solar radiation has increased from S_1 towards S_2 and S_3 . Assume the point ① coincides with the MPP when a perturbation is moved towards point ②. In this time, the new MPP is located at ②'. The gap of ③ and ③' is a corresponding power loss.

Normally, the MPP is the maximum of the power curve. So, the power is increasing with the voltage on the left region of MPP and it is decreasing on the right region of MPP. In this region, the voltage variation is small and can almost be considered constant.

More important, however, is the influence of the module temperature.

The voltage V_m of maximum power point will decrease with an increasing module temperature. The MPPT has to include basic functions such as keeping the module operating in its maximum power point.

Many control algorithms for MPPT have been proposed. These algorithms[7] assume that any variations in the insolation and temperature of the array are insignificant and that the constant reference voltage is an adequate approximation of the true MPP.

The most useful algorithms are a VFC (Voltage Feedback Control). This control method is simple, however, it has the drawbacks such as a negligible environment factors and a limitative application for battery storage system. Therefore, this algorithm is only suitable for use under the constant insolation condition.

In this paper, we consider a MPC(Maximum Power Control) in the MPPT algorithm. The MPC can be achieved by forcing the derivative (dP / dV) equal to zero under the power feedback control.

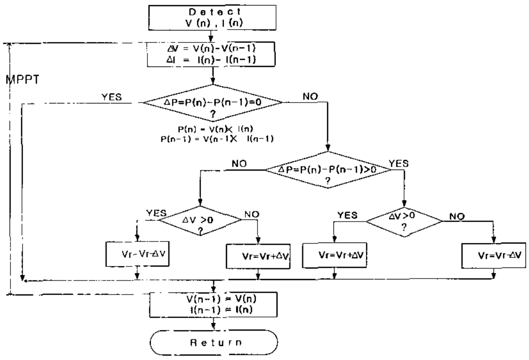


Fig. 4 Flowchart of proposed MPPT strategy.

The flowchart of MPC strategy is shown in Fig. 4. Where, V(n), I(n) and P(n) are the momentary voltage, current and power of PV array, and V(n-1), I(n-1) and P(n-1) are the previous voltage, current and power, respectively.

The ΔP [$P(n) - P(n-1)$] term can be replaced by

$$\Delta P = \Delta V \left(I + \frac{\Delta I \cdot V}{\Delta V} \right) \qquad (6)$$

The MPPT algorithm is performed by calculation ΔP . At $\Delta P = 0$, no control action is needed, therefore the adjustment stage will be passed and the algorithm will update the stored parameters at the end of the cycle. At the $\Delta P \neq 0$, control action for reference voltage Vr is needed. The MPPT algorithm is used in the converter for power conditioning system.

B. Converter

Fig. 5 shows the equivalent circuit model for converter. Assuming SW is an ideal switch, T is the control period $(T = T_{on} + T_{off})$and the duty ratio $\frac{T_{on}}{T}$ is $0 \leq \frac{T_{on}}{T} \leq 1$.

The converter performs the switching function for MPPT, and has two operating state, on and off.

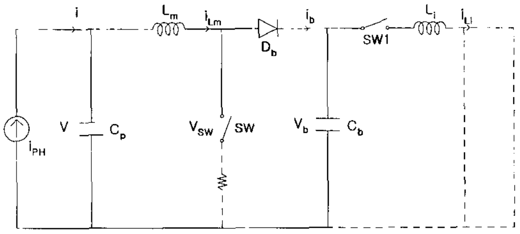


Fig. 5 Equivalent circuit for converter.

This converter is step-up converter, in this case the output voltage is always larger than or equal to the input voltage. The corresponding relation is as follow :

$$\frac{V_b}{V} = \frac{1}{1-\frac{T_{on}}{T}} = \frac{T}{T_{off}} \tag{7}$$

In Fig. 5, when SW is turned on (T_{on}), the energy from the PV array is stored in the inductor L_m, and when the SW is turned off (T_{off}), the energy is delivered to the DC link batteries C_b. The on (T_{on}) state of the SW can be expressed as

$$\frac{dV}{dt} = \frac{1}{C_p}(i - i_{L_m}) \tag{8}$$

$$\frac{d}{dt} i_{L_m} = \frac{1}{L_m} V = \frac{1}{L_m} \cdot V_b \cdot \frac{T_{off}}{T} \tag{9}$$

The off (T_{off}) state can be written by

$$L_m \frac{d}{dt} i_{L_m} = V - V_b \tag{10}$$

If it neglects the losses in the diode, the switching transister and the inductor, this converter's relation can be expressed as

$$V \cdot i \fallingdotseq V_b \cdot i_b \tag{11}$$

From equation (7), (8), (9) and (10), it is seen that V is controlled by on and off time of SW. The $\frac{T_{on}}{T}$ ratio of the switch is controlled by a system that measures input voltage or output voltage. The system situation is changed continuously to maintain the optimum $\frac{T_{on}}{T}$ value.

Ⅳ. Battery characteristic

PV applications require energy storage due to time shifts between the energy supply and demand. For this purpose the PV application systems use the storage batteries. In principle, the leads to a certain mismatch between the battery voltage and the optimum PV voltage therefor cause energy losses[6].

If the components are chosen appropriately as shown in Fig. 6, the energy losses are in the range of a few percent when using direct coupling via shunt controller as Fig. 2 compared to ideal matching by converter[7].

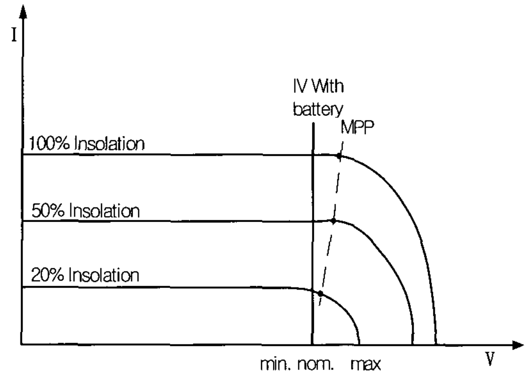


Fig. 6 I-V curve of an ideal battery (vertical line)

In Fig. 6, the I-V curve of an ideal battery (a vertical line) varies within a given voltage range depending on the state of charge (from 11V to 14.4V for a 12V lead-acid battery). Also, the PV array is operated close to the MPP without any additional control if the nominal voltage of the PV array is chosen appropriately.

In this paper, the research purpose of battery characteristic is to match battery voltage and PV array voltage and to extend battery life time. Furthermore, the charge controller can control a charging process for battery.

A controller as shown in Fig. 5 can be operated in short circuit mode for any time without damage while charging, the current flows through the diode D_b into battery. The D_b prevents reverse current flowing from the battery into the switch. Furthermore, it suppresses discharging currents into PV array during the night.

When the EOC(End of Cut) voltage is reached for the first time, the battery is not yet fully charged. As soon as the battery voltage reaches the EOC voltage, the charging current is dropped to zero by closing the SW.

Fig. 7 shows that the operation of MPPT based on converter is not relevant in the region of Z_1. In the region of Z_2, the MPPT is operated in accordance with the condition of battery and load. The operation of MPPT is relevant in the region of Z_3. The strategy of charge controller make use of first threshold for the EOC voltage. To achieve maximum life time of battery, deep discharge region B should be prevented by SW1 in Fig. 5.

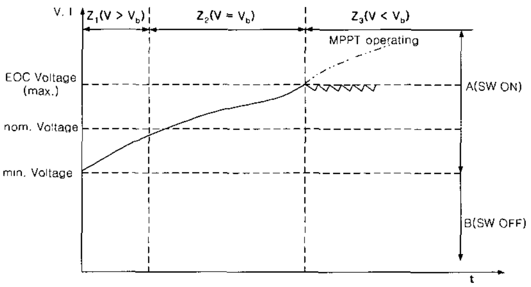


Fig. 7 Battery voltage and current.

V. Experimental results

The proposed PV system is implemented using a system controller based on MPPT algorithm and battery characteristic.

Fig. 8 shows the flowchart of the proposed system control. The system consists of a PV system, a dc/dc converter, a battery, a switch, and a controller.

Experimental data of the PV arrays was recorded under different atmospheric conditions and results were analysed for three cases as follows:

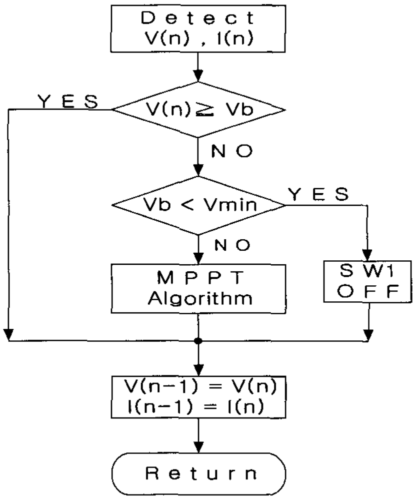
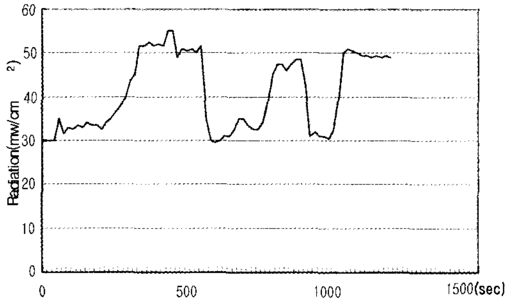
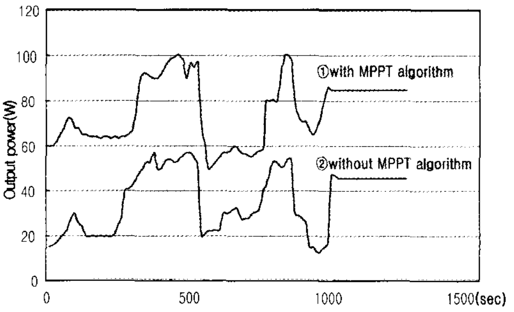


Fig. 8 System control flowchart.



(a) Solar radiation



(b) Output power

Fig. 9 Experimental results of PV system

a) Without MPPT algorithm
b) With MPPT algorithm of power control
c) With MPPT algorithm of power control and wind operating[8]

From Fig. 9, we note the significant power loss when the load was directly connected to the PV array without MPPT. The output power of PV system is increased by MPPT.

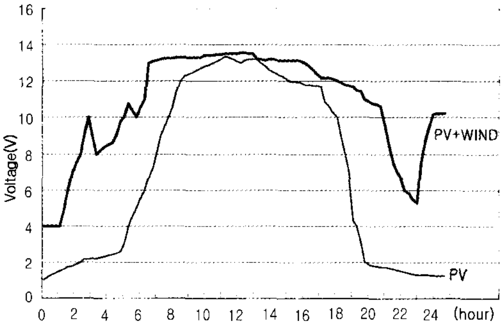


Fig. 10 Voltage characteristics of the PV and wind turbine

The PV and the wind turbine voltages follow the variability in the wind speed and in the radiation. In Fig. 10, the wind output is random.

The actual situation is characterized by higher solar power availability than wind power. From Fig. 10, the wind is a more dynamic source than solar and it also provides energy during periods of little or no sunshine. So, this complementary feature is favorable to system reliability and tends to decrease the need for battery capacity.

Ⅵ. Conclusion

The proposed MPPT has several advantages as compared with previous MPPT's. In this paper, the MPPT algorithm is easier to implement and provides a complementary system. The output power of PV is increased by MPPT and an additional advantage is the fluctuating reduction of converter output with the MPPT and wind system. The wind-PV power system decreases the battery capacity for a energy system.

Further work includes an optimization of system size such as converter and battery.

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