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Performance of Wind-Photovoltaic Hybrid Generation System

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Abstract : This paper reports the performance of Wind-PV(Photovoltaic) hybrid system. The output power of PV is affected by the environmental factors such as solar radiation and cell temperature. Also, the output power of wind system is generated with wind power. Integration of Wind and PV resources, which are generally complementary, usually reduce the capacity of the battery. This paper includes discussion on system reliability, power quality and effects of the randomness of the wind and the solar radiation on system design.

Key words : Hybrid system, Photovoltaic, Wind, MPPT, Switching strategy, Converter

1. Introduction

Electric power supply in areas isolated from the main grid can be provided by means of stand-alone systems based on renewable energy sources. There exist many different topologies of the electric generation hybrid system. The one under consideration in this paper is presented in the schematic diagram of Fig. 1.

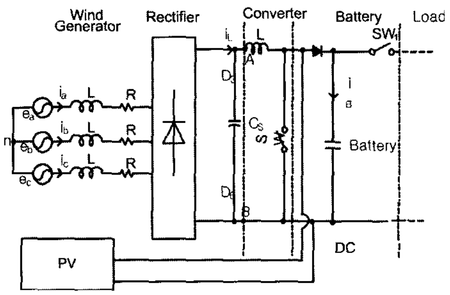

Fig. 1 Schematic diagram of the proposed system

The proposed power conversion scheme has a variety pattern of applications in the hybrid generation systems. It is function as an AC to DC converter thus transferring power from the hybrid generator to the battery while the generator supplies power to the converter. This paper describes the design of PV power system with MPPT and battery storage. PV power system is also linked to the DC bus. The bus voltage is imposed by the battery storage.

The control objective is to regulate the wind power generation to satisfy the load requirements and to charge adequately the battery. This paper includes discussion on the PV system performance, the design of MPPT and the integration method of hybrid (wind+PV) system[1],[2].

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2. PV system with MPPT

The output power of PV array is affected by environmental factors, such as solar radiation and temperature. The PV module manufacturer rating is 60W. The PV module power can be caculated by equation (1)

$$P = I_{ph} V_p - I_o V_p - \exp\left(\frac{q}{KT} V_p - I_o\right) \qquad (1)$$

Where I_{ph} is the cell photo current, V_p is the PV output voltage, I_o is the saturation current, q is the charge of electron, K is Boltzman's constant and T is the cell temperature. The relation between V_p and derivative(dP/dV_p) of output power with respect to output voltage can be expressed as

$$\frac{dP}{dV_p} = I_{ph} - I_o \exp\left(\frac{q}{KT} V_p\right)$$
$$\bullet \left[\exp(-I_o) + \frac{q}{KT} V_p\right] \qquad (2)$$

Fig. 2 shows the characteristic curves of equations (1) and (2), and their relationship.

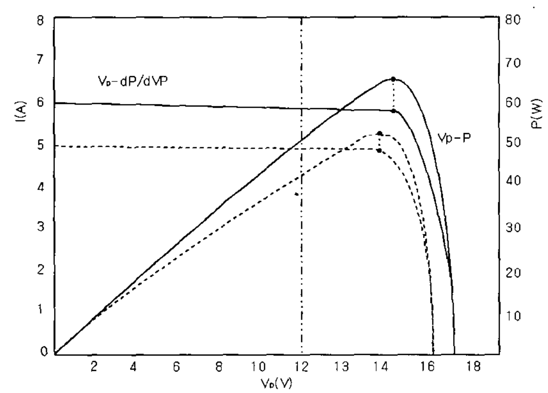


Fig. 2 Characteristic of PV module

It is shown that the MPP(Maximum Power Point) must correspond to such a point where the dp/dV_p is equal to zero. The PV module output voltage can be adjusted by this concept. In this paper, the MPPT is designed by MPC algorithm with $dP/dV_p = 0$.

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.

The array power 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.

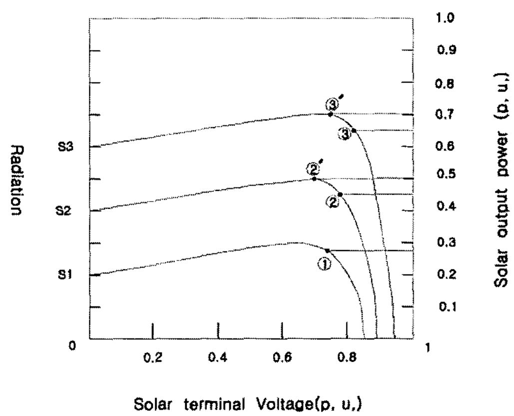


Fig. 3 MPP characteristic curves of PV array

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 of maximum power point Vm 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 algorithm for MPPT have been proposed. These algorithms assume that any variations in the solar radiation and temperature of the array are insignificant and that the constant reference voltage is an adequate approximation of the true MPP.

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

The PV specifications are as follows : The open circuit voltage is 20V, rated circuit voltage is 16V, rated current is 5A, and rated power is 60W[3]-[5].

3. Wind generator

The wind generator is linked to the battery through the AC-DC converter. The power captured by the wind turbine may be written as the equation (3).

$$P_{wt} = 0.5\rho A C_p V^3 \tag{3}$$

where, ρ is air density (kg/㎥), A is swept area(㎡), C_p is coefficient of wind turbine, V is wind velocity(m/s).
The rotor speed can be described in the following equation :

$$\frac{d\omega_{wm}}{dt} = \frac{1}{J}\int(T_{wa} - T_{wL})dt \tag{4}$$

Where, ω_{win} is angular shaft speed, J is the inertia, T_{wa} is aerodynamic torque captured from the wind and T_{wL} is the electric torque load. The rotor speed acceleration and deceleration can be described as equation (4). The rate of rotor speed is proportional to the inverse of the inertia and difference between T_{wa} and T_{wL}. The aerodynamic torque is affected by the operating C_p. The voltage fluctuation problem is closer to a steady state problem such as load varying, which is well defined by the real and reactive power distribution.

The characteristics of wind generator are as follows : Rated power : 60W, cut in wind speed : 4m/sec, rated wind speed : 11m/sec, cut out wind speed : 20m/sec[6].

4. Converter

The converter regulates the DC output of wind generator rectifier unit and PV by switching ratio controller as shown in Fig. 4.

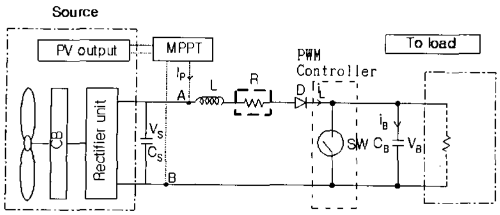
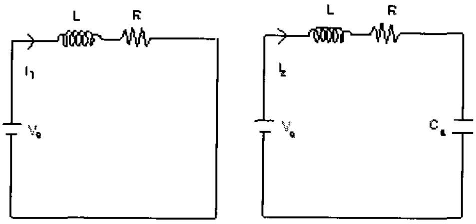


Fig. 4 Block diagram of the generator and converter



(a) on state (b) off state

Fig. 5 Equivalent circuits for the two states

We will suppose that the system switches from one state to another. Its equivalent circuits for on state and off state are given in Fig. 5.

In Fig. 5, the currents i_1 and i_2 are given by

$$i_1 = \frac{V_s}{R}[1-\exp(-t/\tau)] + I_1 \exp(-t/\tau) \tag{5}$$

$$i_2 = \frac{V_s - V_B}{R}[1-\exp(-t/\tau)] + I_2 \exp(-t/\tau) \tag{6}$$

Where $\tau = L/R$ is the time constant. R is the forward resistance of the diode and the equivalent series resistance of the inductor. V_s is the generating voltage and V_B is the battery voltage. t is the on and off state switching time.

Equation (5) and (6) are valid for $T = t_{on} + t_d$ for continuous current and $t_{on} + t_d < T$ for discontinuous current. T is the switching period and t_d is the time at which the current becomes zero. From equation (6), t_d is as follow:

$$t_d = \tau \cdot \ln[\frac{1 - A \cdot \exp(-t_{on}/\tau)}{1-A}] \tag{7}$$

Where $A = \frac{V_s}{V_b}$

This converter has a function of DC-DC boost switching regulator.

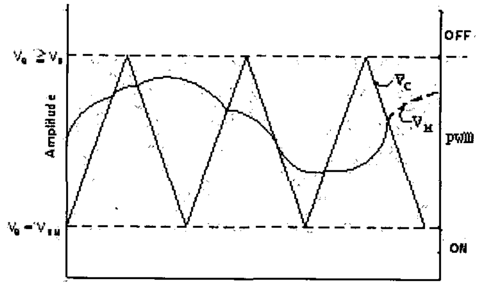


Fig. 6 Switching waveforms of converter

The converter switching strategy studied in this paper is a PWM algorithm. From Fig. 6, the PWM waveform for switching is generated by a modulating wave and a carrier wave. The generation of modulating signal V_M is generated by a difference voltage $(V_s - V_B)$ for the switching condition. The carrier signal V_s is the T periodic signal. The switching waveforms of converter are shown in Fig. 6.

The converter switches from one state to another, whenever the generating voltage V_s is boosted under the control condition $V_{BM} \le V_s \le V_B$. Where V_{BM} is a minimum battery voltage for switching condition.

The converter has the three operating condition such as OFF, PWM and ON configuration. As can be seen in Fig. 6, the operating condition of ON and OFF is fixed by V_s and V_B.

The switching condition is $V_C - V_M = 0$. The converter switches from on ($V_M > V_C$) and off ($V_M > V_C$) in the PWM area. When the inductor current becomes zero during the off state, the time is t_d ($\frac{di_L}{dt} = 0$). This converter algorithm includes the PWM strategy and the condition of t_d[7].

5. Experimental results

To verify the performance of the proposed hybrid system, the following parameters are selected for experimental implementation: The inductor L is 3mH, the capacitor C_s is 3000 μF, R is 3 Ω.

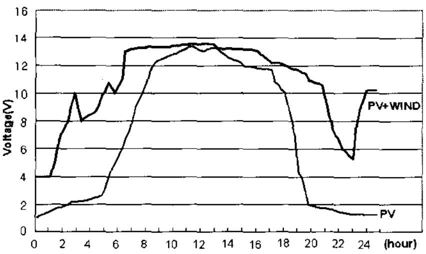
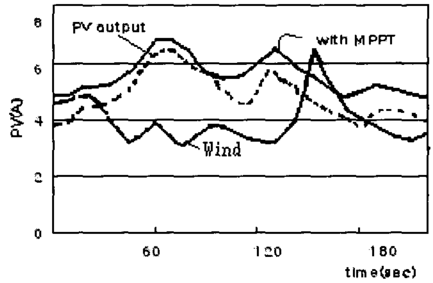


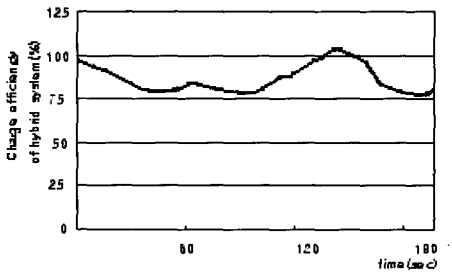
Fig. 7 Voltage characteristics of the PV and hybrid system

The PV and the wind turbine voltages follow the variability in the wind speed and in the radiation. In Fig. 7, the wind output represents randomness.

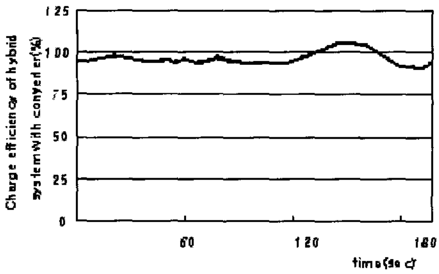
The actual situation is characterized by higher solar power availability than wind power. From Fig. 7, the wind is a more dynamic source than solar and it also provides energy during periods of little or no sunshine. So, this complementary feature is favorable to system reliability and tends to decrease the need for battery capacity.



(a) Outputs of generation system



(b) Charge efficiency of hybrid system



(c) Charge efficiency of battery

Fig. 8 Experimental results

Fig. 8 (a) displays the current supply in the converter by the PV system. It can be seen that the PV power is a more static source than wind. Fig. 8 (b) shows the charge efficiency of hybrid system.

Wind PV hybrid system forms a complementary system and this complementary feature is favorable to system reliability. The charge efficiency can be increased by converter and the charging power fluctuation has been greatly reduced.

From Fig. 8 (c), the battery voltage keeps a constant voltage with converter. Also, the DC link fluctuation can be reduced by switching strategy of converter[7].

6. Conclusion

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 hybrid system forms a complementary system. Generally, the solar is a more static source than wind, but the wind provides energy during periods of no sunshine. This hybrid system has a high efficiency and reliability.

In this paper, the wind-PV power system decrease the battery capacity for a energy system.

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

Reference

[1] Abdelali El Aroudi and Ramon Leyva Quasi periodic route to Chaos in a PWM voltage controlled DC DC boost converter. Circuits and systems I, Vol. 48, pp. 967-977, 2001.

[2] Johan H.R. Enslin, ″Integrated photovoltaic maximum power point tracking converter″, IEEE transactions on industrial electronics, Vol. 44, No. 6, pp. 769-772, 1997.

[3] T. J. Liang, Y. C. Kuo and J. F. Chen, ″Single-stage photovoltaic energy convertsion system″, IEE proc-electr. power appl., Vol. 148, No. 4, pp. 339-344, 2001.

[4] K. H. Hussein, I. Muta, T. Hoshino, M. Osakada, ″Maximum photovoltaic power tracking : an algorithm for rapidly changing atmospheric conditions″, IEEE proc.-gener. transm. distrib., Vol. 142, No. 1, pp. 59-64, 1995.

[5] Peng Wang and Roy Billinton Reliability beneft analysis of adding WTG to a distribution system. Energy Convertsion, Vol. 16, pp. 134-139, 2001.

[6] P. S. Dokopoulos, A. C. Saramourtsis, A. G. Bakirtzis Prediction and evaluation of the performance of wind diesel energy systems. Energy Convertsion, Vol. 11, pp. 385-393, 1996.

[7] Z. Chen and E. Spooner(2001). Grid power quality with variable speed wind turbines. Energy Conversion, Vol. 16, pp. 148-153, 2001

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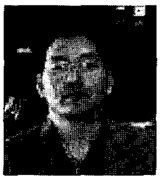

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