JPE 2-1-2

A Study on the Characteristics of the Combined Generation System by Solar and Wind Energy with Power Storage Apparatus for the Geographical Features

Jung-Yeol Lim*, Byeong-Bok Kang, and In-Su Cha

Dept. of Electrical & Electronics Eng., Dongshin University, Korea

ABSTRACT

The development of the solar and the wind energy is necessary since the future alternative energies that have no pollution and no limitation are restricted. Currently MW Class power generation system has been developed, but it still has a few faults with the weather condition. In order to solve these existing problems, combined generation system of photovoltaic and wind power was suggested. It combines wind power energy and solar energy to have the supporting effect from each other. However, since even combined generation system cannot always generate stable output with ever-changing weather condition, power storage apparatus that uses elastic energy of spiral spring to combined generation system was also added for the present study.

Key words: Combined generation system, Photovoltaic System, Wind power energy

1. Introduction

In view of the limitation of the fossil fuel and the upward tendency of energy demand due to the raise of the living standard, the alternative energy must be developed without delay especially in Korea because of the poorness of natural resources and dependency on the thermal power generation. The development of the solar and the wind energies is necessary since the future alternative energies that have no pollution and no limitation are restricted.

Photovoltaic and wind power generation have an advantage of unlimited and unpolluted amount of energy resource. Since there is such an advantage in these energies, they are being studied and developed consistently. Currently there has developed MW Class power generation system which makes it necessary for the further research.

But photovoltaic energy and wind energy are very inconstant depending on the season, time and extremely intermittent energy sources. Because of these reasons, in view of the reliability the solar and the wind generation system have many problems (energy conversion, energy storage, load control etc.) comparing with a conventional power plant.

So, in order to solve these existing problems, combined generation system of photovoltaic and wind power, which combines wind power energy and solar energy to have effect of supporting each other, was suggested.

But, since even combined generation system cannot always generate stable output with weather condition, power storage apparatus that uses elastic energy of spiral spring to combined generation system was also added for the present study.

And it may confirm that power was continuously provided to load by storing energy obtained from generating rotary energy of spiral spring generates in

Manuscript received August 20, 2001; revised January 4, 2002.
Corresponding Author: enfdl@lycos.co.kr, Tel: +82-61-330-3209, Fax: +82-61-330-2909

small scale generator.

So, the result of this study will be piled up as the every technology for the optimal operation of the combined generation system and the essential data and technology for the development of the reliable small generation system for the supplying power of isolated island.

2. Characteristics of each energies

2.1 Characteristic of wind energy

The generating wind power is a close concerned with wind speed.

Total amount of wind energy that pass area A by wind speed v is as following.

$$P_w = \frac{1}{2}\rho v^3 A \tag{1}$$

where,

- P_w : Total amount of wind power [W]
- v : Wind speed [m/sec]
- A : Area [㎡]
- ρ : Air density [kg/㎥]

Total amount of wind energy P_w is changed to mechanical power by rotor. And when there is no change of each momentum and no flow that disturbs at end place of rotor, Betz proved power coefficient C_p that indicates conversion efficiency. Proved C_p is 0.593. But flowing of actual rotor is different from ideal state. Usually, C_p has value of 0.35~0.5 degrees. Also, wind power generation system should be included efficiency μ_m that transmits mechanical energy. Therefore, actually available power P_e is written by next equation.

$$P_e = C_p \mu_m \mu_g P_w = C_p \mu_m \mu_g \frac{1}{2}\rho v^3 A \tag{2}$$

Also, output of system starts real operation over starting wind speed V_c by mechanical inertia of system, friction and electrical loss etc. And it increases by v^3 from starting wind speed v_c to regular power P_r. Output of

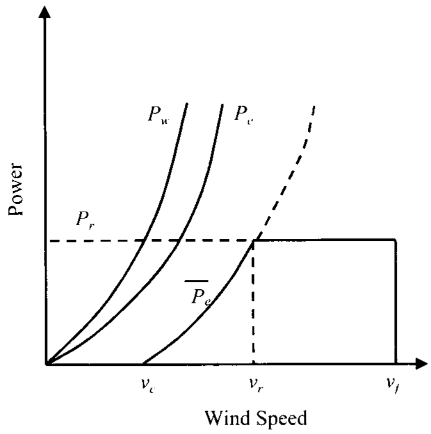


Fig. 1. Output characteristic model of wind generation system

system is kept without a change at wind speed over P_r Also, it stops output for protection of system to final win speed V_f.

Fig. 1 shows output characteristic model of gener wind power generation system.

Actual average output energy $\overline{P_e}$ of wind system is a following by Fig. 1.

$$\overline{P_e} = \frac{1}{2}\rho A \int_{v_c}^{v_R} C_p \mu_m \mu_g v^3 P(v) dv + \frac{1}{2}\rho A C_p \mu_m \mu_g v_R{}^3 \int_{v_R}^{v_F} P(v) dv \tag{3}$$

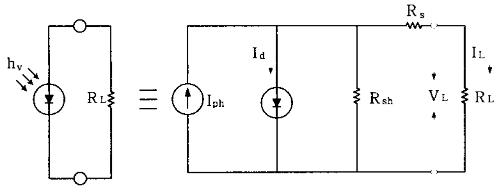
In other words, it increases by v^3 from starting win speed v_c to rated wind speed v_r. And value of powe coefficient and each efficiency is decided by wind spee v and the rotational frequency of rotor.

But, output energy is kept without a change from rate wind speed v_r to final wind speed v_f as appears in Fig. 1.

Because value of $C_p \mu_m \mu_g v_R{}^3$ is kept constantl regardless of wind speed[2, 3].

2.2 Characteristic of solar cell

Fig. 2 shows the equivalent circuit of solar cell usin photovoltaic effect. In actual case, the series resistor an the parallel resistor are added. And the characteristic c voltage-current is as following at solar radiation.



ig. 2. Equivalent circuit of solar cell.

$$I = I_{Ph} - I_0\left[\exp\left(\frac{q(V+IR_S)}{nKT}\right) - 1\right] - \frac{V+IR_S}{R_{Sh}} \tag{4}$$

But, in ideal case of $R_S = 0$ and $R_{Sh} = \infty$, (4) is ewritten as (5).

$$I = I_{Ph} - I_0\left[\exp\left(\frac{qV}{nKT}\right) - 1\right] \tag{5}$$

vhere, I : output current, I_{Ph} : photo current, I_0 : aturation current of the diode, n : diode constant, K : oltzmann constant and q : electric charge.

Fig. 3 shows the characteristic of maximum output oltage and maximum power point for solar cell at onstant temperature and irradiation.

The three variables V_{OC}, I_{SC}, and FF (Fill Factor) of ig. 2 are the parameters connected with the conversion fficiency for energy.

On condition of $I = 0$, (5) is rewritten as (6). And on ondition of $V = 0$, I_{SC} is same with I_{Ph}.

$$V_{OC} = \frac{nKT}{q}\ln\left(\frac{I_{Ph}}{I_0} + 1\right) \tag{6}$$

he FF is defined as (7).

$$FF = (V_m \times I_m)/(V_{OC} \times I_{SC}) \tag{7}$$

vhere, V_m is the maximum output voltage and I_m is he maximum output current. The energy conversion fficiency of the solar cell is defined as (8).

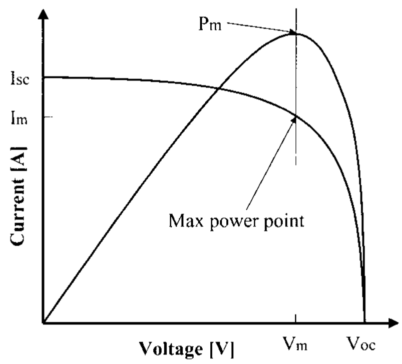


Fig. 3. Maximum output voltage and maximum power point of cell.

$$\eta = \frac{V_m \times I_m}{P_{in}} = \frac{V_{OC} \times I_{SC}}{P_{in}} \times FF \tag{8}$$

where, P_{in} is the radiative photovoltaic energy[1, 4].

3. Hybrid system

Combined generation system of photovoltaic and wind power, which has effect of supporting each other, is added power storage apparatus that uses elastic energy of spiral spring. So, even if weather condition changes, combined generation system were composed to generate stable output that can charge battery.

Fig. 4 shows schematic diagram of combined generation system with power storage apparatus in addition.

The output terminals of two different system are hooked each through diode (DSAI 17-18A, VRRM = 800-1800 [V], IF(RMS)= 40 [A], IF(AV)M = 25 [A]). Therefore, if one output is bigger than the other power system, only bigger system is supplied source.

Power storage apparatus that uses elastic energy of spiral spring is consisted of DC motor and small scale generator. Power is continuously provided to load through the inverter by charging battery obtained from generating rotary energy of spiral spring generates in this small scale generator.

Spiral spring that is used to power storage apparatus is the quality of STC-5(KS: Korean Industrial Standard). STC-5 is kind of Carbon Tool Steels. On annealing condition, ST-5 has characteristic that processing is easiest

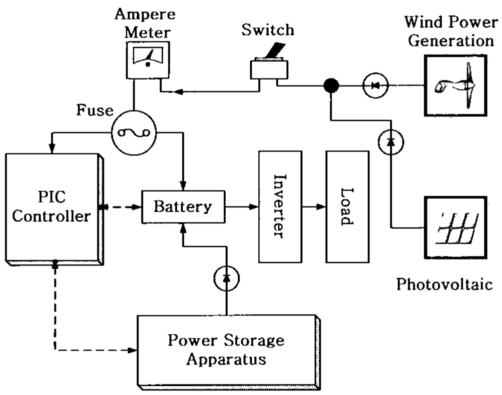


Fig. 4. . Combined electric power generation system with power storage apparatus.

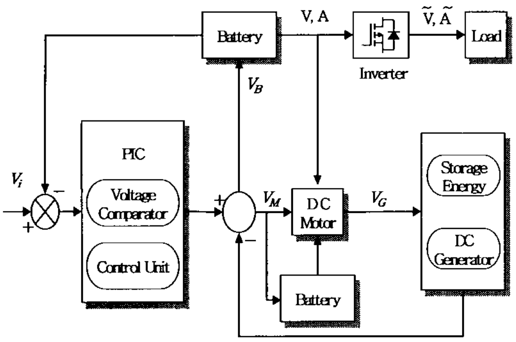


Fig. 5. Block diagram of the proposed system.

among Tools Steels. And it has the highest internal impact. External form has size of diameter 10 [cm], inside diameter 2 [cm] and height 5 [cm].

Spiral spring winds in 2 minutes and winds down in 30 minutes.

When output of combined generation system gets over 12[V], DC motor in power storage apparatus operates and winds spiral that is connected to small scale generator.

Also output of combined generation system charges battery and output of battery is supplied to load through the inverter.

And, when output of combined generation system gets lower than 12[V], power was continuously supplied to load through the inverter by charging energy obtained from generating rotary energy of spiral spring operates in small scale generator.

Fig. 5 shows block diagram of combined generation compensation system with power storage apparatus.

When input voltage V_i gets, control unit that uses microprocessor (PIC1654) compares reference voltage.

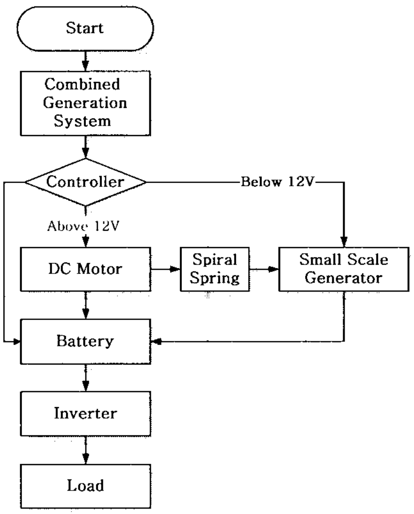


Fig. 6. Flowchart of combined electric power generation systen

When input voltage V_i gets over 12[V], batte charges V_B . At the same time, V_M operates DC mot and winds spiral spring.

On the contrary, when input voltage V_i gets low than 12[V] or voltage of battery is dropped, power w supplied to load through the inverter by charging volta V_G obtained from spiral spring operates in small sca generator in power storage apparatus.

Fig. 6 shows flowchart of combined generation system

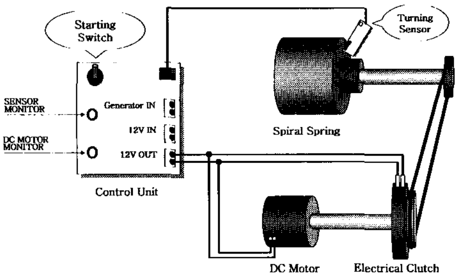
Fig. 7 shows power storage apparatus that uses elast energy of spiral spring to combined generation system.

DC Motor (TD8025G-12, 12[V], 2.5[A], 25[W 300[rpm]) and Gear Motor (S8KA60B, 50[rpm]) wind ar wind down spiral spring.

Control unit compares reference voltage by a contr program and check the rotational frequency of spir spring by sensor.

When output of two different power system (win solar) cannot supply electric power to load becau weather condition is unbalanced, combined generatic system with power storage apparatus can supply power load through the inverter.

When output of combined generation system photovoltaic and wind power gets over 12V, DC motor power storage apparatus operates but output of small sca generator is stop. At this time, DC motor is winds spiral spring as only unwound degree.



(a) Block diagram

(b) Photograph

Fig. 7. Power storage apparatus that uses spiral spring.

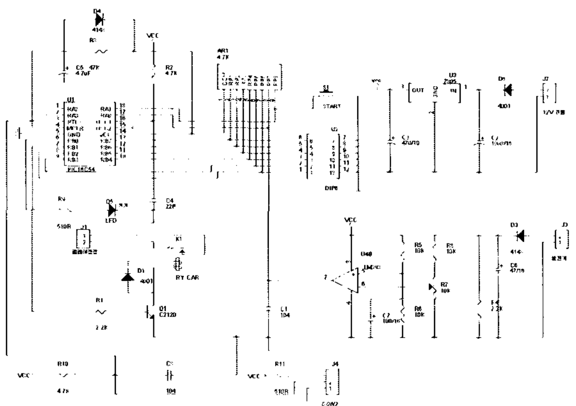


Fig. 8. Control circuit.

If output of combined generation system gets lower than 12V, it was confirmed that power was continuously provided to load through the inverter by storing energy obtained from generating rotary energy of spiral spring generates in small scale generator.

Fig. 8 represents control circuit. Control circuit is composing of microprocessor (PIC16C54), power supply, output terminal of combined generation system, comparator (LM393), relay that can run DC motor and sensor to sense rotational frequency. Power supply part uses output of battery. So, power of microprocessor and comparator (LM393) connects regulator 7805 and use 5[V]. The following is a part of a control program.

```
MAIN_START    CLRWDT
              BSF      LED
              BCF      OUT
              BTFSC    START
              GOTO     MAIN_START; NO
MAIN_LP1      MOVLW    .70
              CALL     DLY1
              BTFSC    START
              GOTO     MAIN_START
              MOVLW    B'10100000'   ; TIMER0 INT
              MOVWF    INTCON        ; Interrupt Enable
              DECF     DIP_DATA
MAIN_START1   BTFSS    MY_STATUS, 0
              GOTO     MAIN_START1
              BCF      LED           ; LED ON
              MOVLW    .20
              CALL     DLY1
              BSF      LED           ; LED OFF
              BCF      MY_STATUS, 0
              GOTO     MAIN_START1
              END
```

4. Experiment and discussion

Fig. 9 shows characteristics of maximum output power with simulation waveform according to irradiation. When temperature increases, the maximum output power deceases linearly. And when value of irradiation increases, slope has steep characteristic.

Fig. 10 represents power characteristic of wind power generation system with simulation waveform according to the wind speed. When wind speed increases, the power increases linearly.

Fig. 11 shows maximum instantaneous wind speed and irradiation for five months in Jeon-nam, Naju(2001.1-2001.5).

Fig. 12 shows maximum instantaneous wind speed and irradiation in the month of May in Jeon-nam, Naju (2001.5.1-2001.5.31).

Photovoltaic system and wind power generation system have effect of supporting each other in environmental side.

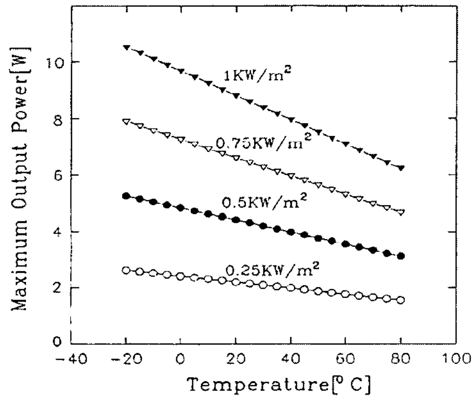


Fig. 9. The characteristics of maximum output power according to the irradiation.

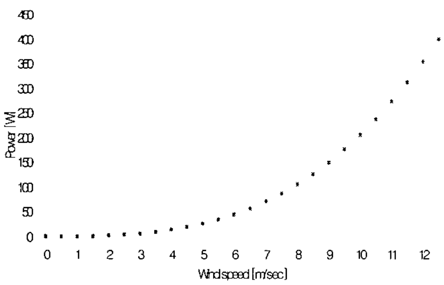


Fig. 10. The power characteristic of wind power system according to the wind speed.

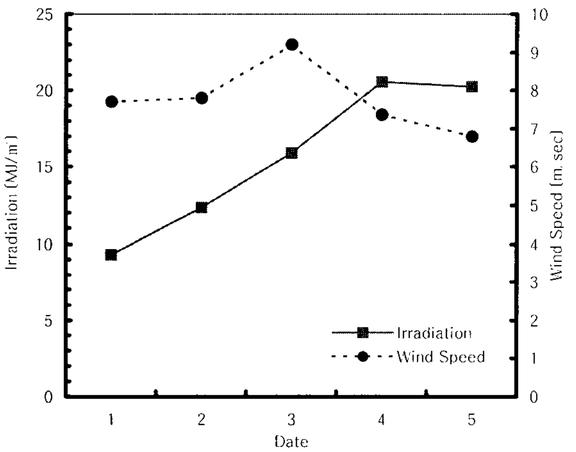


Fig. 11. Maximum instantaneous wind speed and irradiation in months in Jeon-nam, Naju(2001.1-2001.5).

Fig. 13 represents output waveform of wind generator according to change of wind speed. We can know that voltage and current are greatly changed according to wind speed and wind direction.

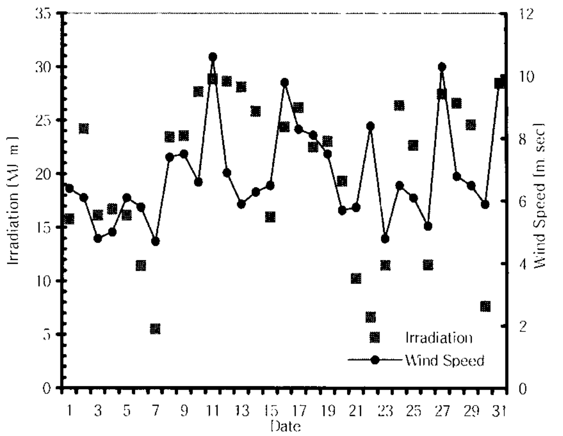


Fig. 12. Maximum instantaneous wind speed and irradiation i the month of May in Jeon-nam, Naju (2001.5.1-2001.5.31).

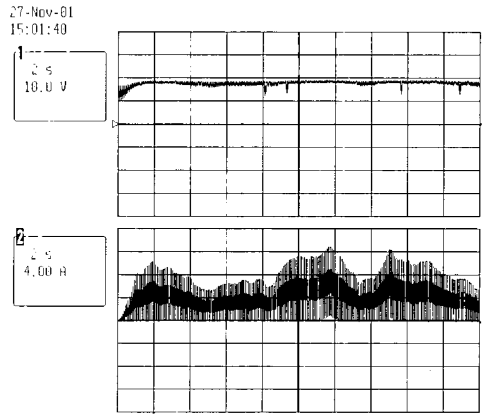


Fig. 13. Output voltage and current of wind power generator.

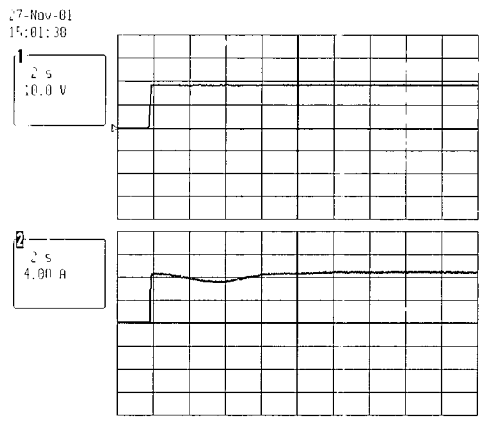


Fig. 14. Output voltage and current of photovoltaic system.

Fig. 14 shows the output voltage and current o photovoltaic system under a good weather condition.

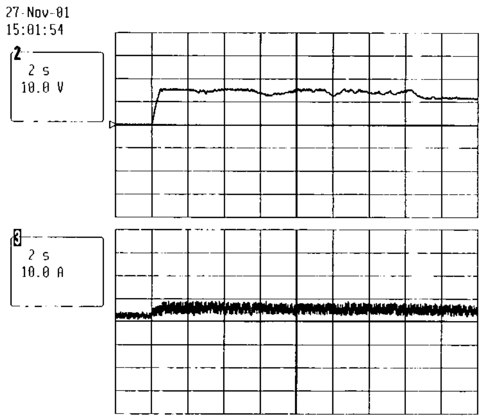


Fig. 15. Output voltage of small scale generator.

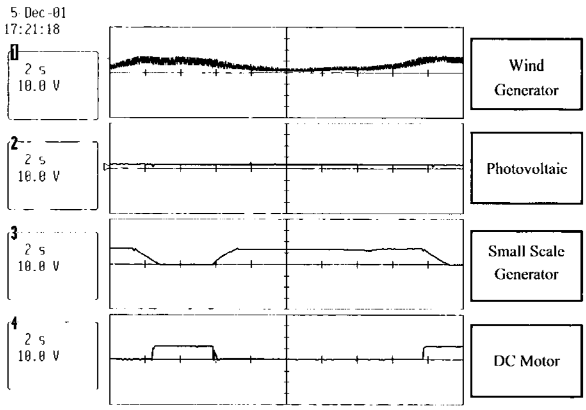


Fig. 16. Driving characteristics of DC motor that is connected to small scale generator.

Fig. 15 shows output voltage of small scale generator in power storage apparatus.

In view of the results so far achieved, it was obviously that output voltage and current of small scale generator in power storage apparatus are enough to charge battery.

Figs. 16 and 17 represents driving characteristics of hybrid system and small scale generator in power storage apparatus that operates. When output voltage of combined generation system gets less than 12 [V], it can know that small scale generator is running.

If output voltage of two different system (solar, wind) drops below 12 [V], control unit senses this state and spiral spring system operates small scale generator at the same time.

When output of photovoltaic and wind power gets over 12V, DC motor in power storage apparatus operates and only winds spiral spring that is connected to small scale generator. But, generation of small scale generator is stop.

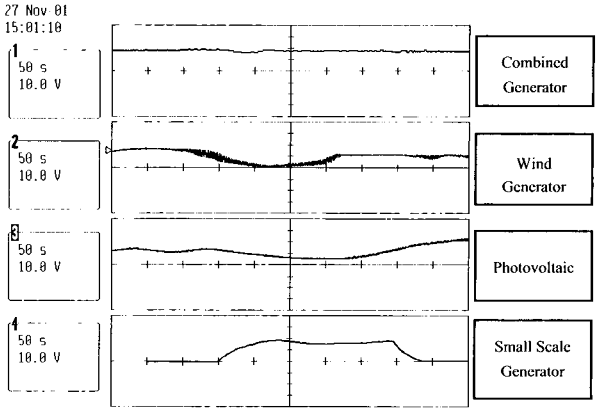


Fig. 17. Waveform of output voltage from conventional syster and small scale generator.

5. Conclusion

Existing wind power generation system cannot generat power without extra power generation when wind spee gets reduced, because blade rotates at slow speed.

Therefore, it can only be operated at limited conditio of wind speed, and has problem of very low efficiency o wind power, due to the characteristics of wind speed. I the same manner, photovoltaic system also react sensitively to the weather of low changing efficiency irradiation or temperature. And, its characteristics ar different according to manufacturer of solar cell.

In order to solve these existing problems, combine generation system of photovoltaic and wind power, whic combines wind power energy and solar energy to hav effect of supporting each other, was suggested. Bu since even combined generation system cannot alway generate stable output according to weather condition, i this study, power storage apparatus that uses elastic energ of spiral spring to combined generation system o photovoltaic and wind power, which has effect o supporting each other, was also added.

When output of combined generation system gets abov or below 12V, power of small scale generator was stoppe or continuously provided to load. Because of workin time required for DC motor is about 2 minutes and smal scale generator operates during about 30 minutes. It wa found that energy efficiency obtained by operating smal scale generator as spiral got unwound was more tha energy needed to operate DC motor. It has means o compensation for a weakness of system.

In fact, it is very difficult to find the way to optimize the combined generation system. If weather information can be collected for a long period of time and optimize variable analysis through standardizing operation and maintenance, it will be possible to create small scale power storage combined generation system that has characteristics of continuous operation without any concerns of changing weather and geological problem, highly efficient energy conversion. Then, it will be very helpful to use the clean energy efficiently by distributing to normal houses and small sized power demanding islands.

References

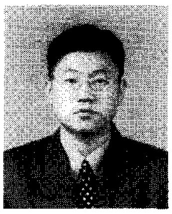
[1] L. A. Schienbein and D. J. Malcolm, "Design performance and economics of 50kW vertical axis wind turbine", *J. of Solar Energy Engineering*, Vol. 105, No. 11, pp. 418~423, 1983.

[2] Z. Salameh, D. Taylor, "Step-Up Maximum Power Point Tracker for Photovoltaic Arrays", *Solar Energy*, Vol. 44, No. 1, pp. 57~61, 1990.

[3] Victorio Arcidiacono, Sando Corsi, Luciano Lambri, "Maximum Power Point Tracker for Photovoltaic Power Plants", *IEEE*, pp. 507~512, 1982.

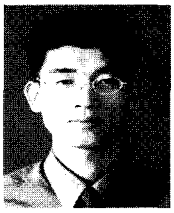
[4] Randall C. Maydew and Paul C. Kimas. "Aerodynamic performance of vertical and horizontal axis turbine", *J. of Energy (USA)*, Vol. 5, No. 3, pp. 189~190, 1981.

[5] De Vries, "Fluid Dynamic Aspect of Wind Energy Conversion, Advisory Group for Aerospace Research & Development", AGARD-AG-243, 1979.



Jung-Yeol Lim was born in Gwang-Ju Korea, on 1969. He received the B.S. and M.S. degrees in Electronic Engineering from the Dongshin University, Jeon-nam, Korea in 1996 and 1998, respectively.

He is currently Ph. D candidate in the same university. His interest field Photovoltaic System design.



Byong-Bok Gang was born in Gwang-Ju Korea, on 1972. He received the B.S. and M.S. degrees in Electronic Engineering from the Dongshin University, Jeon-nam, Korea in 1995 and 1997, respectively.

He is currently Ph. D candidate in the same university. His interest field: Wind power energy by regional special quality.

In-Su Cha was born in Sun-Chon, Jeon-Nam on 1959. He received the B.S. degrees in Electrical Engineering from Chosun University in 1982 and M.S. degrees from Chungang University in 1984, and Ph. D degrees from Chosun University in 1989.

From 1997.9 to 1997.11, he is visiting scholar in electricity & electrical laboratory, Germany Darmstadt University. He has been with the Dept. Electrical & Electronics Eng., Dongshin University since 1990, where he is now a professor. His primary research interests are in the field of Power Electronics, combined generation system and its optimization.