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

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### **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

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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

$$P_w = \frac{1}{2} \rho v^3 A \quad (1)$$

where,

$P_w$  · Total amount of wind power [W]

$v$  · Wind speed [m/sec]

$A$  · Area [ $m^2$ ]

$\rho$  · Air density [ $kg/m^3$ ]

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  $\mu_m$  that transmits mechanical energy. Therefore, actually available power  $P_e$  is written by next equation

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

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

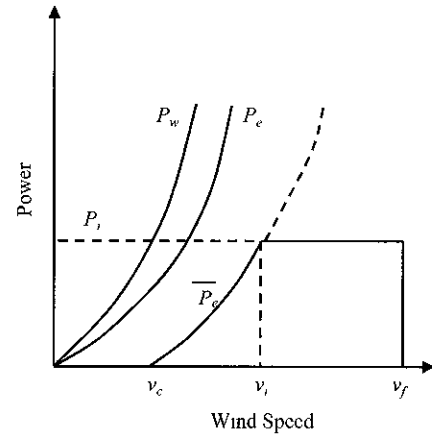


Fig 1 Output characteristic model of wind generation system

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

Fig 1 shows output characteristic model of general wind power generation system

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

$$\begin{aligned} \overline{P_e} = & \frac{1}{2} \rho A \int_{v_c}^{v_r} C_p \mu_m \mu_g v^3 P(v) dv \\ & + \frac{1}{2} \rho A C_p \mu_m \mu_g v_r^3 \int_{v_r}^{v_f} P(v) dv \end{aligned} \quad (3)$$

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

But, output energy is kept without a change from rated 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 constantly regardless of wind speed<sup>[2, 3]</sup>

### 2.2 Characteristic of solar cell

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

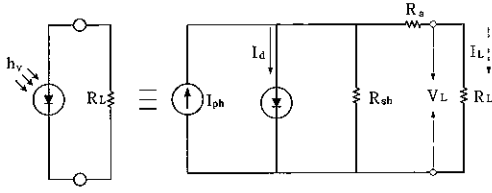


Fig 2 Equivalent circuit of solar cell

$$I = I_{ph} - I_0 \left[ \exp \left( \frac{q(V + IR_s)}{nKT} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (4)$$

But, in ideal case of  $R_s = 0$  and  $R_{sh} = \infty$ , (4) is rewritten as (5).

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

where,  $I$  output current,  $I_{ph}$ : photo current,  $I_0$  saturation current of the diode,  $n$ : diode constant,  $K$ : boltzmann constant and  $q$  electric charge

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

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

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

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

The  $FF$  is defined as (7)

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

where,  $V_m$  is the maximum output voltage and  $I_m$  is the maximum output current The energy conversion efficiency of the solar cell is defined as (8)

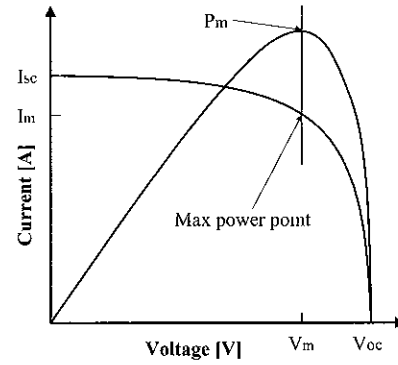


Fig 3 Maximum output voltage and maximum power point of cell

$$\eta = \frac{V_m \times I_m}{P_m} = \frac{V_{OC} \times I_{SC}}{P_m} \times FF \quad (8)$$

where,  $P_m$  is the radiative photovoltaic energy<sup>[1, 4]</sup>.

### 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 (DSA1 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

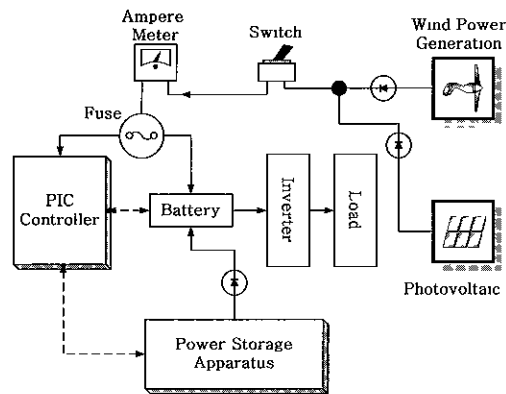


Fig. 4. Combined electric power generation system with power storage apparatus

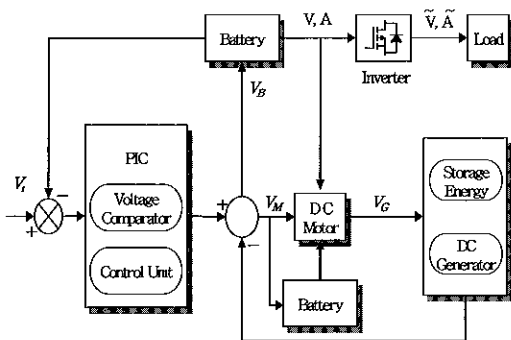


Fig 5 Block diagram of the proposed system

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.

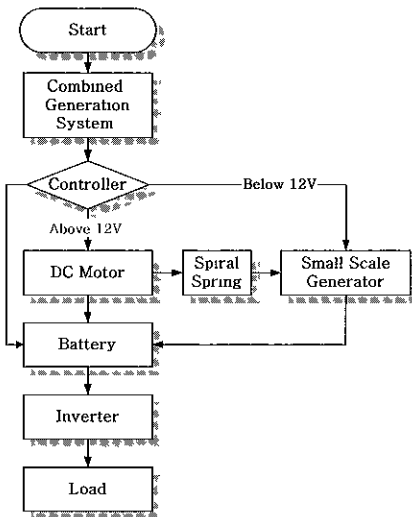


Fig 6 Flowchart of combined electric power generation system

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

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

Fig. 6 shows flowchart of combined generation system

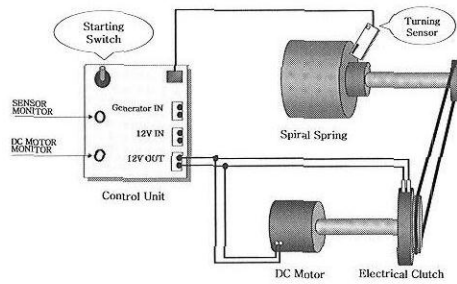
Fig. 7 shows power storage apparatus that uses elastic energy of spiral spring to combined generation system.

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

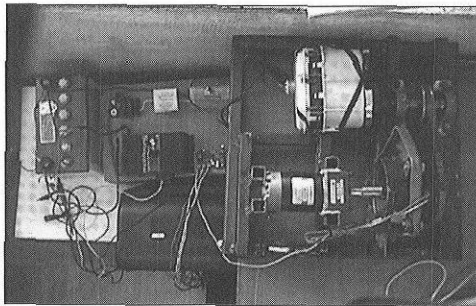
Control unit compares reference voltage by a control program and check the rotational frequency of spiral spring by sensor.

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

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



(a) Block diagram



(b) Photograph

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

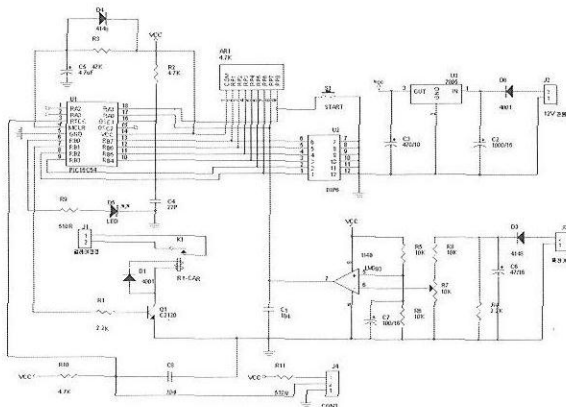


Fig. 8. Control circuit.

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 decreases 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.

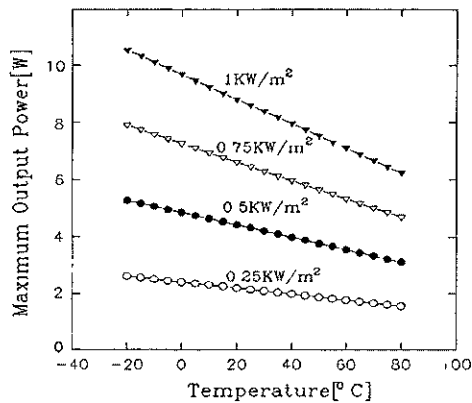


Fig 9 The characteristics of maximum output power according to the irradiation.

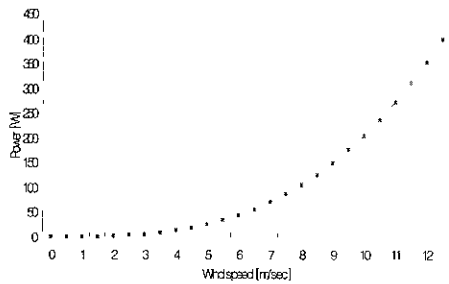


Fig 10 The power characteristic of wind power system according to the wind speed

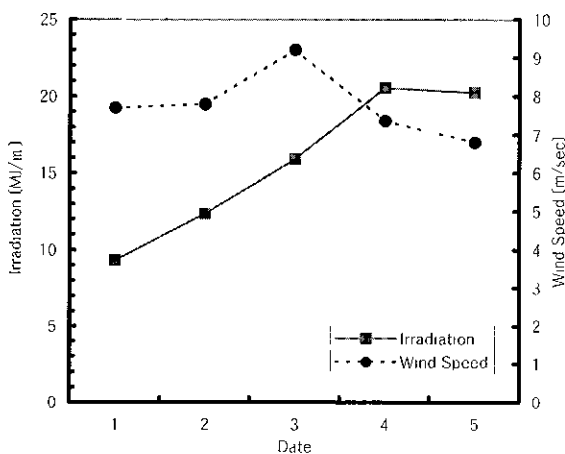


Fig 11 Maximum instantaneous wind speed and irradiation in months in Jeon-nam, Naju(2001.1-2001.5)

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.

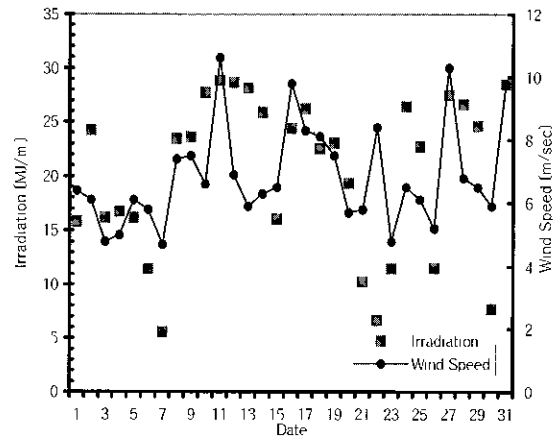


Fig 12 Maximum instantaneous wind speed and irradiation in the month of May in Jeon-nam, Naju (2001.5.1-2001.5.31)

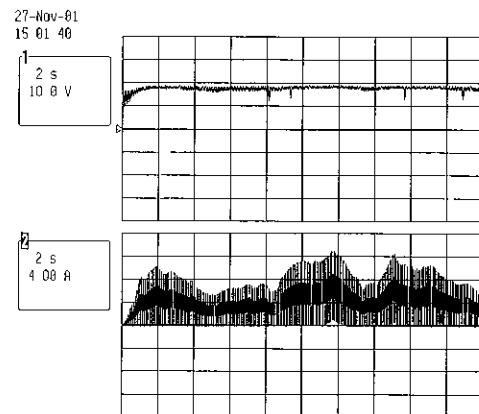


Fig 13 Output voltage and current of wind power generator

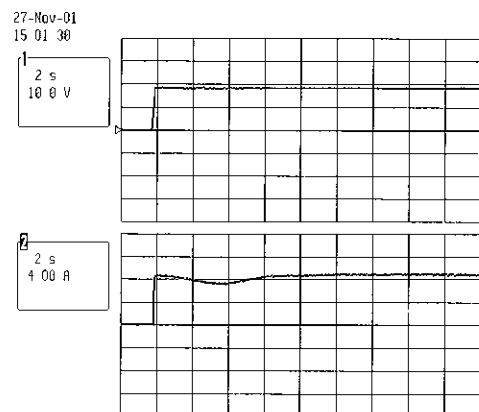


Fig 14 Output voltage and current of photovoltaic system

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

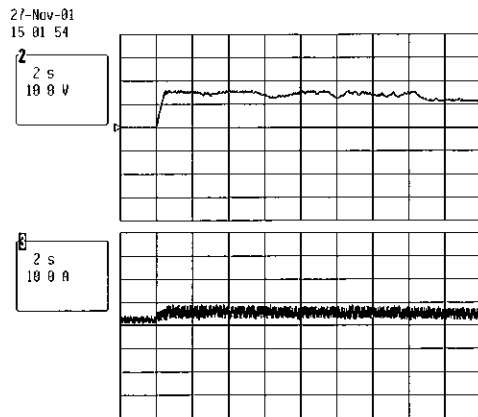


Fig 15 Output voltage of small scale generator

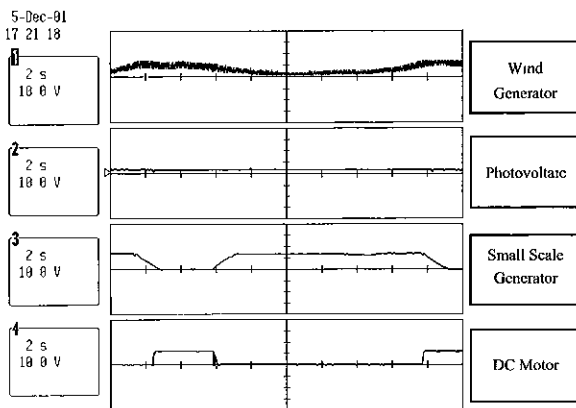


Fig 16 Driving characteristics of DC motor that is connected to small scale generator

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.

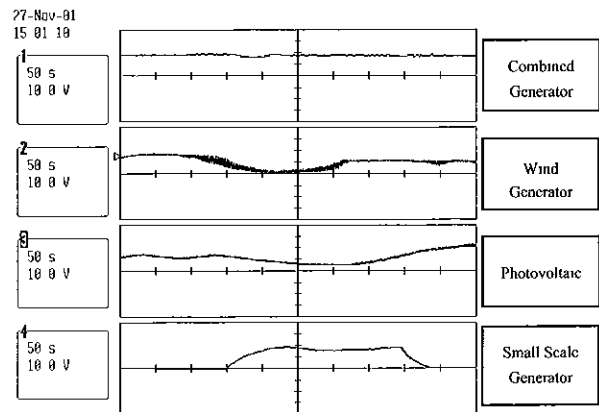


Fig 17 Waveform of output voltage from conventional system and small scale generator

## 5. Conclusion

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

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

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 according to weather condition, in this study, power storage apparatus that uses elastic energy of spiral spring to combined generation system of photovoltaic and wind power, which has effect of supporting each other, was also added.

When output of combined generation system gets above or below 12V, power of small scale generator was stopped or continuously provided to load. Because of working time required for DC motor is about 2 minutes and small scale generator operates during about 30 minutes It was found that energy efficiency obtained by operating small scale generator as spiral got unwound was more than energy needed to operate DC motor. It has means of 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.

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