Analysis on the Operational Characteristics of the Combined Generation System with Power Storage Apparatus that Apply Microcontroller

Jung-Yeol Lim, Seok-Am Yoon and In-Su Cha

Abstract - The developments of the solar and the wind power energy are necessary since the future alternative energies that have no pollution and no limitation are restricted. Currently power generation system of MW scale 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(400W) and wind power generation system(400W) was suggested. It combines wind power 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. In an experiment, when output of combined generation system gets lower than 12V(charging voltage), 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.

Keywords - hotovoltaic energy, wind power energy, combined electric power generation system, power storage

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 power energies are 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[1],[2]. Currently there has developed MW class power generation system which makes it necessary for the further research[3]-[5].

But photovoltaic and wind power 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 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 suppling power of isolated island.

2. Characteristic of wind energy and solar cell

2.1 Characteristic of wind energy

Size of wind power is 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 energy [W]

v : Wind speed [m/sec]

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A : Passing area [m²]
ρ : Air density [kg/m³]

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 the end place of rotor, Betz proved power coefficient C_p that indicates conversion efficiency. Proved C_p is 0.593[6]. But flowing of actual rotor is different from ideal state. Usually, C_p has value of 0.35~0.5 degrees[6]-[8]. Also, wind power generation system should be included efficiency η_m that transmits mechanical energy. Therefore, actually available power P_e is written by next equation.

$$P_e = C_p \eta_m \eta_g P_w = C_p \eta_m \eta_g \frac{1}{2} \rho V^3 A \quad (2)$$

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 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.

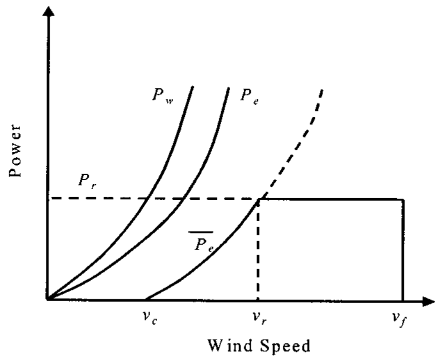


Fig. 1 Output characteristic model of wind generation system

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

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

In other words, it increases by v^3 from starting wind speed v_c to regular 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 regular wind speed v_r to final wind speed v_f as appears in Fig. 1 because value of $C_p \eta_m \eta_g v_R^3$ is kept constant regardless of wind speed.

2.2 Characteristic of solar cell

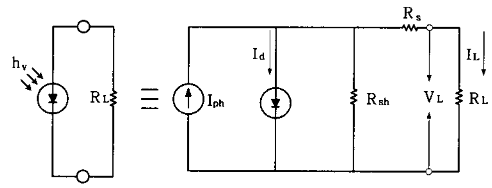


Fig. 2 Equivalent circuit of solar cell

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.

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

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.

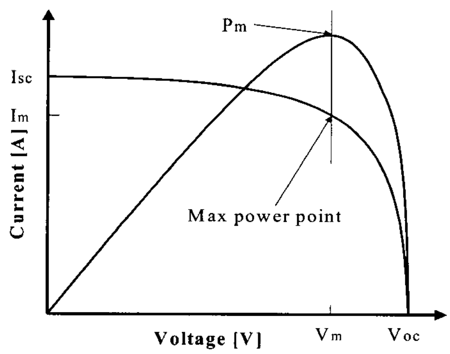


Fig. 3 Maximum output voltage and maximum power point of cell

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).

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

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).

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

where, P_{in} is the radiative photovoltaic energy.

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 was composed to generate stable output that can charge battery.

Table 1 and table 2 are the specification of wind power generation system and PV module.

Table 3 is the specification of inverter.

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 systems are 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 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.

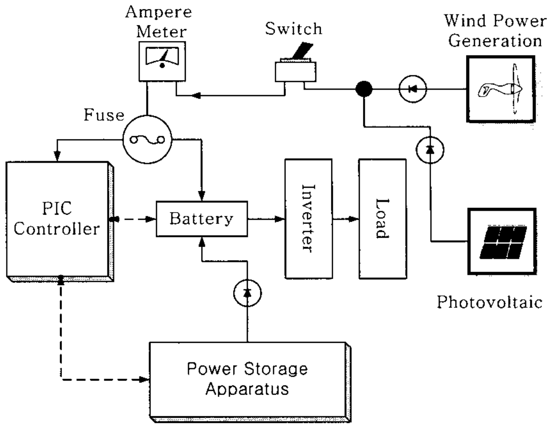


Fig. 4 Combined electric power generation system by power stroage apparatus

Table 1 Specification of wind power generation system

Division	Option
Wind Power Generation	AIR 403 (USA, Southwest Windpower, Inc.)
Type	Motive-Brushless-Permanent Margnet Type- 1Φ
Regulator's Output Power	400 [W] (12.5 [m/sec])
Output Voltage	DC 12[V]
Frequency	60 [Hz]
Rotor	Rotor Blades(3), Diameter 1.17 [m]
Blade	Wood-Epoxy
Start up Wind Speed	3 [m/sec]
Regulator Wind Speed	12.5 [m/sec]

Table 2 Specification of PV module

Model	SM-50
Maximum Power	50 [W]
Maximum Voltage	17.1 [V]
Maximum Current	2.92 [A]
Weight	6.3 [Kg]
Type	Multicystalline

Table 3 Specification of inverter

Input voltage	10.8~14.9 [V]
Output voltage	230 [V]
Output frequency	50 [Hz]
Peak power	400 [W]
Continuous power	185[W]

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.

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.

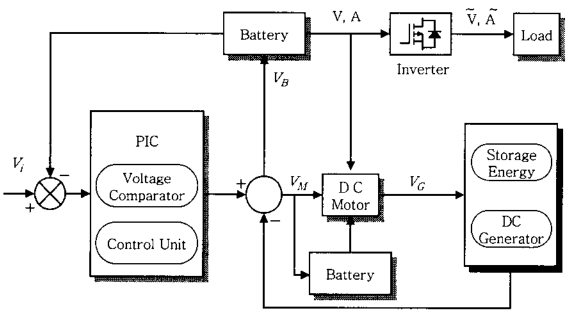


Fig. 5 Block diagram of the proposed system

Fig. 6 shows the flowchart of combined generation system.

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

When output of two kinds of power system(wind and solar) cannot supply electric power to load in case that 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 gets lower than 12[V], control unit senses this state and spiral spring system perform small scale generator.

Also, when spiral spring unties perfectly, control unit senses this state and winds spiral spring again.

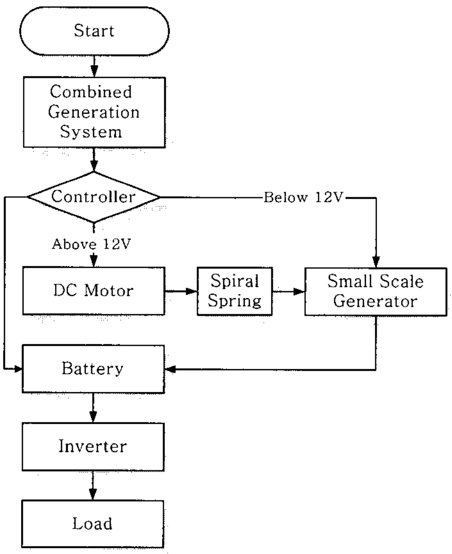
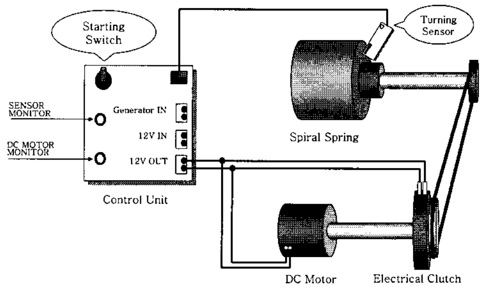


Fig. 6 Flowchart of combined electric power generation system

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 unwind spiral spring.



(a) Block diagram

(b) Photograph

Fig. 7 Power storage apparatus that uses spiral spring

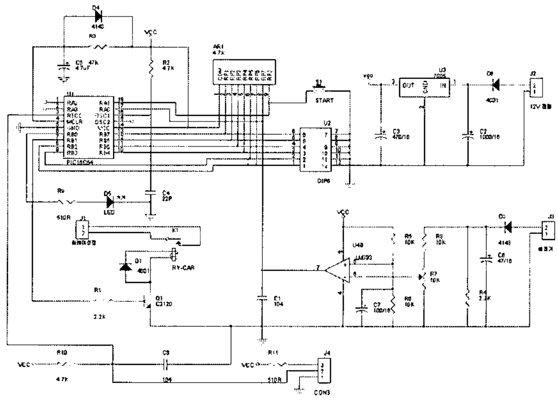


Fig. 8 Control circuit

Fig. 8 represents control circuit. Control circuit is composed 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 and use 5[V].

4. Experiment and discussion

Fig. 9 represents simulation results of the characteristics of maximum output power. When temperature is increasing, the maximum output power deceased linearly and the large value of insolation has steep slope characteristic.

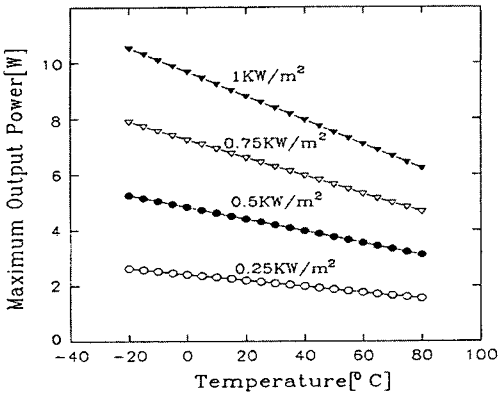


Fig. 9 The characteristics of maximum output power according to the solar insolation

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 non-linearly.

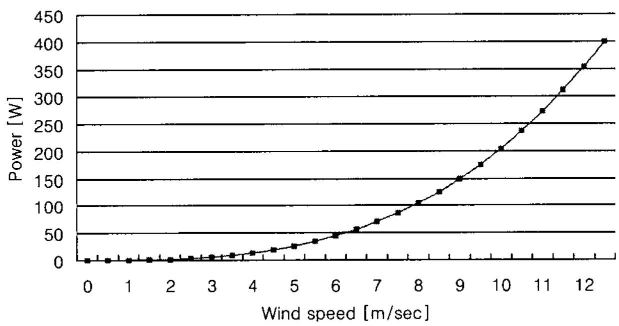


Fig. 10 The power characteristic of wind power system according to the wind speed.

Fig. 11 represents output waveform of combined generator according to change of wind speed and irradiation. We can know that voltage and current are greatly changed according to wind speed and wind direction.

Fig. 12 shows output voltage waveform 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.

Fig. 13 shows actual and ideal driving characteristic of power storage apparatus. When it compares actual and ideal driving characteristic, actual compensation has 11%

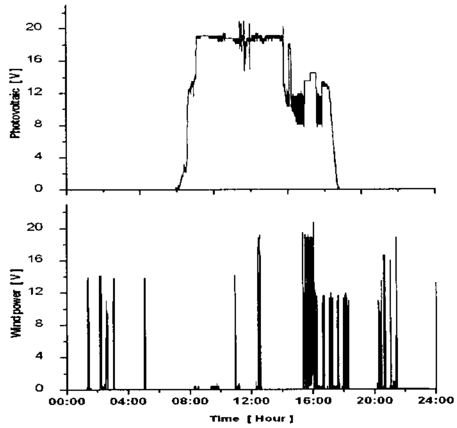


Fig. 11 Output voltage waveform of wind power and photovoltaic

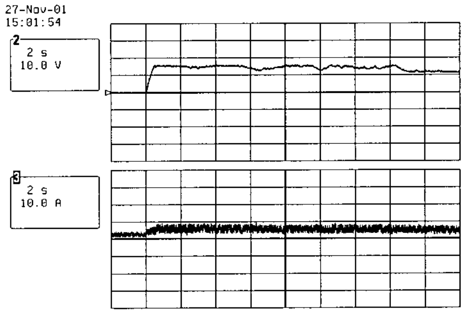
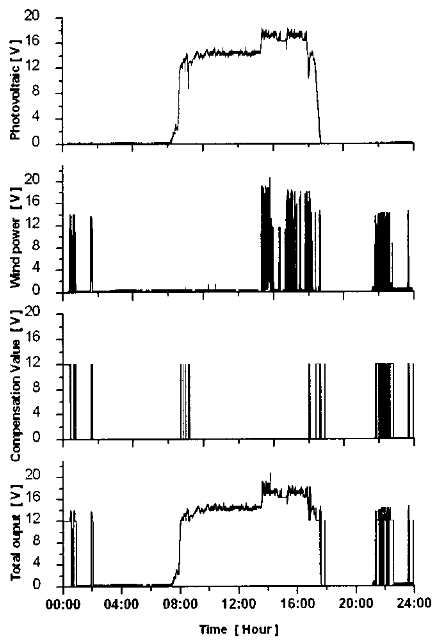
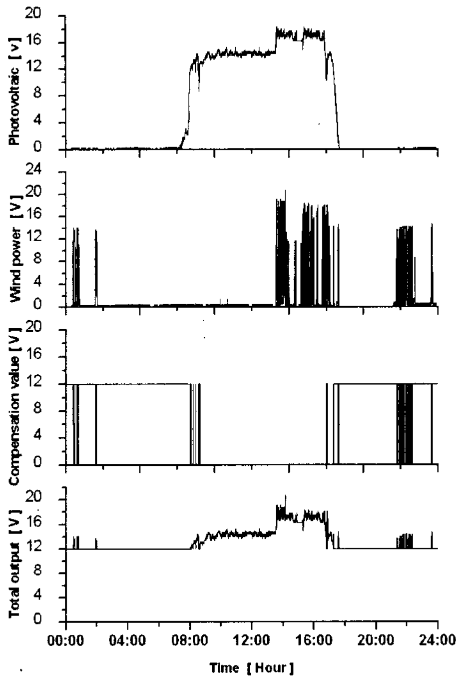


Fig. 12 Output voltage waveform of small scale generator

efficiency. But ideal compensation needs about 61% efficiency to compensate output of combined generator perfectly. This data decides the most suitable capacity of spiral spring.



(a) Real



(b) Ideal

Fig. 13 Output waveform for a load of inverter

Fig. 14 shows voltage, current waveform of inverter on load state. Here, inverter input is 12 [V], and load is 220 [V], 200 [W].

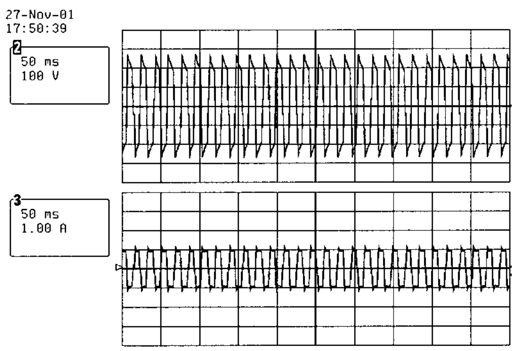


Fig. 14 Output waveform for a load of inverter

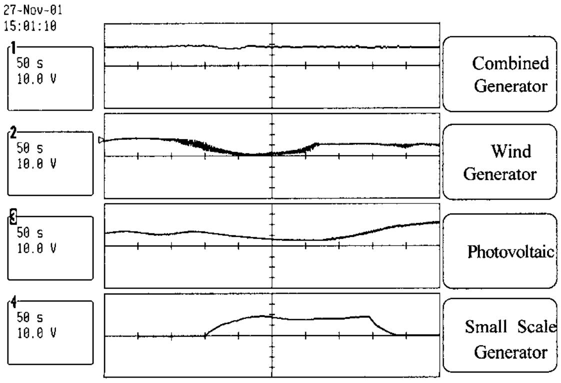


Fig. 15 Waveform of output voltage from conventional system and small scale generator

Fig. 15 represents driving characteristic 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], we can know that small scale generator is running.

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

When spiral spring unties perfectly or starts good generation in two different system, control unit senses this state and winds spiral spring again.

5. Conclusion

Combined generation system of photovoltaic(400W) and wind power(400W), 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 of photovoltaic and wind power gets over 12V, DC motor in power storage apparatus operates and winds spiral that is connected to small scale generator. And, when output of 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. Because battery thar uses in an experiment is charged more than 12V, reference voltage is 12V.

At this point, working time required for DC motor is about 30 minutes. It was found that energy efficiency obtained by operating small scale generator as spiral spring got unwound was more than energy needed to operate DC motor. It has means of compensation for a weakness of system.

When it compares actual and ideal driving characteristic of power storage apparatus, actual compensation has 11% efficiency. But ideal compensation needs about 61% efficiency to compensate output of combined generator perfectly. This data decides the most suitable capacity of spiral spring.

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. That is, it is going to solve interval problem that photovoltaic and wind power energy have.

Finally, 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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