한국마린엔지니어링학회지 제31권 제5호, pp. 583~591, 2007. 7 (ISSN 1226-9549)
Journal of the Korean Society of Marine Engineering

Research into The Future Development of the Hybrid System for Buoy

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(Manuscript : Received APR 30, 2007 ; Revised JUL 20, 2007)

Abstract : This paper reports the performance of a 150W PV-wave hybrid system with battery storage in buoy. This system was originally designed to meet a new hybrid power system for buoy in Korea. In the case of lighted buoys and lighthouses, a light failure alarm system of wireless radio is attached so that light failures are immediately notified to the office. At lighthouse offshore fixed lights and light buoys where commercial electricity is not available, the power source depends on solar system and batteries. This power system has a various problems. Therefore energy derived from the sunshine, wind and waves has been used as the energy source for aids to navigation. Recently a hybrid system of combining the solar, wind and the wave generator is a favorable system for the ocean facilities like lighthouse and buoy. The hybrid system in this paper is intended for variable DC load like light, communication system in the buoy and includes a PV-wave generation system and battery. This is composed a high efficiency charging algorithm, switching converter and controller. This paper includes discussion on system reliability, power quality, and effects of hybrid system in the buoy. Simulation and experimental results show excellent performance.

Key words : PWH(PV-Wave hybrid), PV(Photovoltaic), Wave, MPPT(Maximum power point tracker), Buoy

1. Introduction

Buoy is the most inferior power condition for operation, because this is received the electric power from stand-alone power system such as solar system. Buoy is very important for preventing a marine accident of ship. There are more than 1,000 buoys on the Korean shoreline. A buoy is a floating device that can have many different purposes, which determine weather the buoy is moored to drift. The purpose of buoy can be described such as a sea mark, lifebuoy, submarine communication buoy, surface marker buoy, weather buoy,

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etc.

Output of PV power system is DC, and PV power system is linked to the DC bus. The current(I)-voltage(V) output characteristic of PV cells changes with solar irradiance and cell temperature as parameters. During a typical year, the temperature of PV cells varied from -13 ℃ to over 75 ℃, the solar irradiance varied from 0 W/m^2 to 60W/m^2, and the incident angle varied between 27 deg and 90 deg. As various PV modules respond differently to each of the parameters cited above. Maximum output of PV modules can be achieved by MPPT (Maximum Power Point Tracker) algorithm. This paper includes a discussion on the performance of PV cells, MPPT algorithm and battery characteristic.

Generally, the buoy is received the working power from PV system. PV power system for buoy has the influence of weather like solar irradiance and air temperature on the sea. Table 1 summarizes the consumption power of buoy with various equipments.

Table 1 Consumption power of buoy with various equipments

Items	Condition	Details of the calculation [W/day]	Total [W/day]
General ligh bulb type beacon light	Four-second intervals	94.37	94.37
LED type beacon light	Four-second intervals	84	84
VHF Integrated management system +LED type beacon light	Thirty-minute intervals	86.2+84	170.2
AIS Integrated management system +LED type beacon light	Thirty-minute intervals	25.8+84	109.8
	Three-minute intervals	194.4+84	278.4

The table was presented that buoy is operated with about 280 W per day, PV-wave hybrid system can be considered as viable options for future power system for buoy. The term "hybrid" usually refers to an isolated power system in which there is more than one immediate source of energy. Thus solar/wind, solar/wave, and solar/wind/wave combinations clearly fit into this category. As used in this study, the definition has been expanded to include multiple sources of energy, or multiple types of power converters, used in a regionally distant.

The power supply system for buoy may be customized to suit the application requirements and geographic location. The buoy series in Korea is for marking traffic separation zones, and for similar important locations. Each buoy is arranged for automatic operation with minimum maintenance, equipped with high power navigational aids including AIS(Automatic Identification System), and with remote monitoring and control to suit individual requirements.

In this paper, PWH(PV-Wave Hybrid) system for buoy is described with control and monitoring system. This hybrid system has to include the MPPT algorithm for PV system and the cavity resonance technique for WEC.

Finally, this paper includes discussion on the system reliability, power quality and effects of the randomness of wave and solar energy on the hybrid power system design. Also, this paper provides a summary of general and specific conclusions and recommendations concerning the hybrid power system potential for buoy.

2. PWH Configuration

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. There are several types of hybrid system such as solar and wind, solar and wave, solar and current, and etc. The hybrid system is presented in the schematic diagram of Fig. 1. The proposed power conversion schemes have a variety pattern of applications in the hybrid generation system.

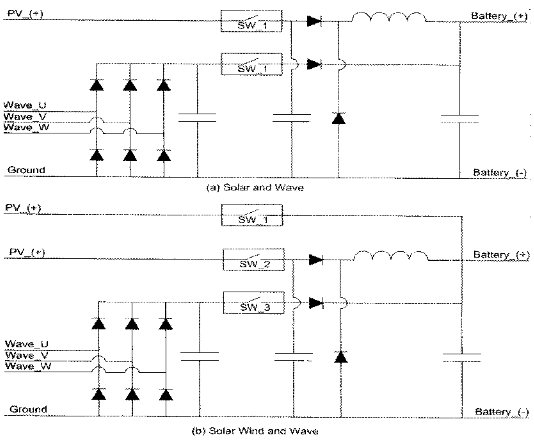

Fig. 1 Schematic diagram of hybrid system

The hybrid power generation systems are based upon the DC link converter. Generally, the wind, current and wave power generation system provide the current at a variable frequency. This current is rectified onto the DC link using a converter with switching devices. In this paper, PWH power generation system is designed, and the results of design and test with the simulator and buoy are presented. The output power of PV is affected by the environmental factors like solar irradiance, cell temperature and etc. Also, the output of WEC(Wave Energy Converter) is changed with a height and period of wave. The impacts on voltage fluctuation with the proposed hybrid power generation system can be minimized.

2.1 PV system

The hybrid power system for buoy is consisted of PV and wave systems. The power system for buoy in this paper is designed the PV-wave hybrid system. In the hybrid system, the power of PV array can be calculated by equation:

$$P= VI= VI_{sat} - VI\left[\exp\left(\frac{qV}{AKT}\right)-1\right] \qquad (1)$$

Where I and V are the output current and output voltage of the PV array, respectively, I_{ph} is the generated current under a given insolation, q is the charge of an electron, K is the Boltzmann's constant, A is the ideality factor for a p-n junction T is the cell temperature (K).

The relation between V and derivative (dP/dV) of output power with respect to output voltage can be expressed as

$$\frac{dP}{dV}= I+ V\frac{dI}{dV}= I- \frac{qVI_{sat}}{AKT}exp(\frac{qV}{AKT}) \qquad (2)$$

Where I_{sat} is the reverse saturation current.

The relation of dP/dV against I is nearly linear. Thus, when I is varied, dP/dV is varied proportionally. From equation (1) and (2), it is shown that the

MPPs(Maximum Power Points) must correspond to such a point where the dP/dV is equal to zero. The PV array output voltage can be adjusted by this concept. In this paper, the MPPT is designed by MPP algorithm with $dP/dV = 0$. 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.

MPP of PV array on atmospheric conditions can readily be seen in the current-voltage. 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 condi-tions, the MPPT algorithm deviates from the MPPs. Fig. 2 shows the MPPs with the change in solar radiation. The array power will be measured according to the solar radiation has increased from S1 towards S2 and S3.

Once solar radiation moves from S1 to S2, power point is changed from the point ①″ to ②. At this moment, it is possible to get new MPP by using MPPT algorithm. In this time, the new MPP is located at ②″. The gap of ② and ②″ is a corresponding power loss. Similarly, we can also expect the MPP at ③″ even power point moves to ③ in the change of solar radiation.

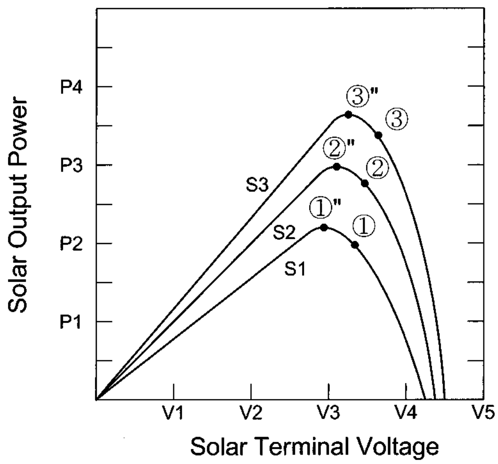

Fig. 2 Characteristic of curves of PV array

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

More important item, however, is the influence of the module temperature. The voltage Vm of maximum power point will decrease with 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 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 converter with the MPPT algorithm. The MPP can be achieved by forcing the derivative (dP/dV) equal to zero with the buck converter.

The converter for PV system must be taken to prevent excessive discharge and overcharge of batteries. Also, it has to operate a MPPT algorithm. Fig. 3 shows the buck converter, and it includes MOSFET switch for power control[1].

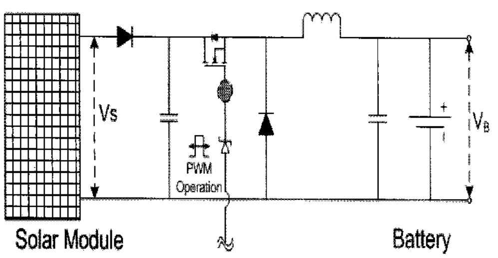

Fig. 3 Circuit of buck converter

2.2 WEC design

The economics of WEC(Wave Energy Converter) depend on three considerations such as the magnitude and dependability of the wave source, the cost of construction and maintenance of the conversion system, and the energy transmission from the site to the user.

In a random sea, a WEC is subject to waves of varying heights and periods. The increased buoyant force due to a crest is canceled by the decreased buoyancy due to the trough. A floating system will have either a natural heaving period or a natural pitching period or both if the float is unconstrained. The natural heaving frequency of a floating body is

$$f_Z = \frac{\omega_Z}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{\rho g A_{wp}}{m+m_w}} \tag{3}$$

Where ω_z is the natural circular heaving frequency, ρ is the mass density of seawater (1,030 kg/m3), A_{wp} is the water plane area of the float, m is the mass of heaving system, and $m_w (=\rho\frac{D^3}{6})$ is the added mass, that is , the mass of water excited by the heaving motion. The natural pitching frequency of a float is

$$f_\Theta = \frac{w_\Theta}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{C}{I_y+I_w}} \tag{4}$$

Where, C is the hydrostatic restoring moment coefficient,

$$C = \rho g \int_{-\frac{L}{2}}^{\frac{L}{2}} x^2 B'(x)dx = \frac{\rho g \pi D^4}{64} \tag{5}$$

I_y is the mass moment of inertia of the body about the rotational axis through the center of gravity, and $I_w (=\frac{\rho\pi D^2 d^3}{12})$ is the added mass moment of inertia.

The importance of the frequency expressions of equations (3) and (4) is that they define the conditions for motion resonance. A body with natural heaving and pitching periods described by equations (3) and (4), respectively. The amplitude of the motion will depend on the amount of damping in the system. In the design of a wave energy conversion device, therefore, our goal is to minimize the damping to obtain the maximum response.

Fig. 4 shows the proposed WEC for buoy in this paper. The air adjacent to the cap is forced through the orifice of area A_2, A_1 is the cross - sectional area of the water column, that is,

$$A_1=\frac{\pi D_1^2}{4} \tag{6}$$

Where, D_1 is the diameter of water column. Since the orifice area A_2 is much smaller than the water column area A_1, the orifice air velocity V_2 is much greater than the average vertical velocity of the air above the water column. The high-orifice velocity can be exploited by placing a double-acting turbine in the orifice to convert the Kinetic energy of the air into electrical energy. We take that the maximum power conversion occurs at a period

$$T_c=2\pi\sqrt{\frac{L_1+L_1'}{g}} \tag{7}$$

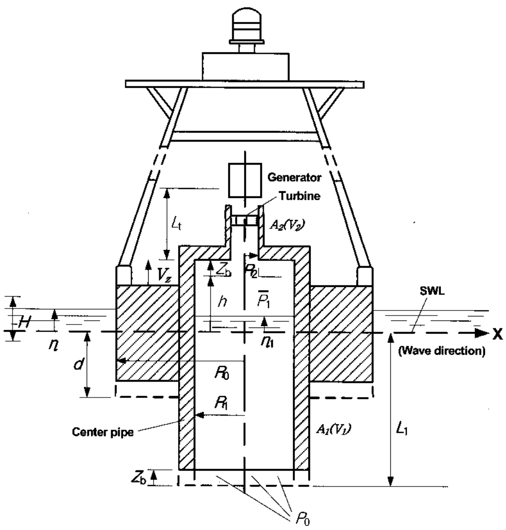

Fig. 4 Proposed WEC for buoy

Referring to Fig. 4, the air velocity in the orifice v_2 can be expected to have two relative maxima, one at the cavity resonance frequency and the other at the heaving resonance frequency. The relationship between the air and body velocities are as follows:

$$v_2=\frac{(v_1-v_z)A_1}{A_2} \tag{8}$$

Where, v_1 is the velocity of water column.

By using these resonance conditions, we can now see that the design condition is $\omega_c \doteq \omega_z$. Using the results of equation (3):

$$\frac{g}{L_1+L_1'}=\rho\frac{gA_{wp}}{m+m_w} \tag{9}$$

Where, for an axis symmetric float with an outer diameter D_0 and an inner diameter D_1, the water plane area is

$$A_g=\frac{\pi}{4}(D_0^2-D_1^2) \tag{10}$$

To optimize the design of this buoy system, use the design condition given in equation (9). This equation describes the condition whereby $T_c=T_z$. Since the higher-period wave has the higher power, we choose T_c to be the design period. We keep the dimensions in equation (9) the same as originally used and simply change the mass 'm' of the system by adding ballast. The added mass m_w is a function of geometry and will slightly change with the additional draft d. We can be derived the design mass m value from equation (9).

3. System Analysis and Results

The proposed hybrid power system for buoy is consisted of the PV and wave system. Fig. 5 shows the block diagram of the proposed hybrid power generation system.

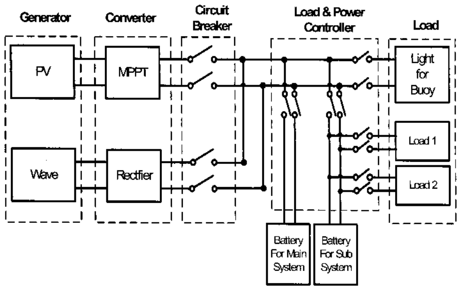

Fig. 5 Block diagram of hybrid power generation system

The impacts on voltage fluctuation with the proposed hybrid power generation system can be minimized and furthermore, the network voltage control may also be improved by the proposed converter algorithm. For part of the day, the power production and load is changed[2].

Fig. 6 shows the output power of PV system with MPPT, or not.

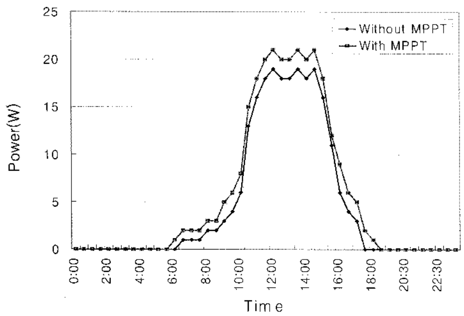

Fig. 6 Experimental results of PV system

The output power is increased with MPPT algorithm, the MPPT provides significantly improved tracking. The data of the typical time period is used to assess resource availability of this particular time period. The basic properties of the buoy simulator are illustrated in table 2. The simulator can be controlled the wave frequency by the motor rpm and water column length. The motor rpm is controlled from 0 to 110 with inverter, and this simulator is adjusted the stroke from 20 to 80 cm for testing of wave height influence. And the generating power is changed from 0 to 100 W[3].

Table 2 Simulator properties for WEC

ITEMS	SPECIFICATIONS
MAIN BASE	L3,345 x B800 x H1,050mm / SS SQUARE BAR
AIR DUCT	ID754 x L1000mm / PP PLATE
AIR CORN	ID754 x ID230 x L408mm / PP PLATE
AIR PISTON	OD752mm / PP PLATE with CRANK MECHANISM
CONTROL SYSTEM	PERIOD CONTROL : 0~110RPM WAVE HEIGHT CONTROL : 200~800mm DRIVING UNIT : GEARED MOTOR
TURBINE DUCT	ID230 x L600 x 10T / TRANSPARENCY ACRYL
AIR TURBINE	TYPE : WELLS TURBINE BLADE SECTION : NACA0020 /6-BLADES MATERIAL : AL & ABS RESIN
GENERATOR	12VDC, 100W
RPM METER	MAX. 20,000RPM
BATTERY	2V 400Ah × 3

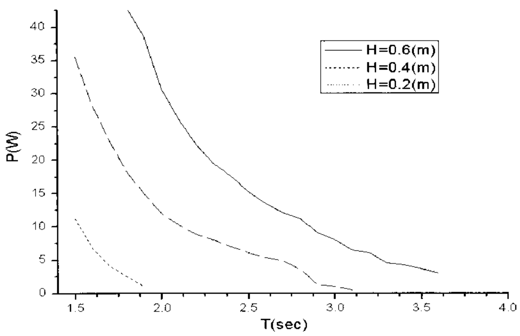

Fig. 7 Generating power with the water column period variation

Fig. 7 is shown the results for the effect of water column with the period T. The generating power as predicted by the theory is seen to increase with increasing values of water column height and decrease with increasing values of oscillating water column period T.

The design optimization of hybrid system for buoy is conditionally upon the resource availability of the site. In the case of buoy, the size and capacity of PV system has to reduce for installation and reliability[4].

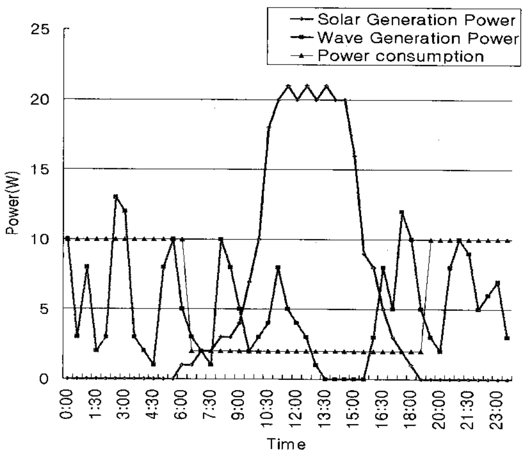

Fig. 8 The power production and load for the day

Fig. 8 shows typical profiles of the load of buoy and the PWH energy production for each operation condition.

These diagrams display also the important role of the battery storage. In most cases, between 10:00 AM and 3:00 PM, the system is able to produce more power than required by load.

4. Conclusion

This paper has discussed the simulation and experience with the PV and wave power system with storage during two weeks of operation. The conclusions drawn from the analysis are the following:

1) PV- wave hybrid power generation with battery storage forms a complementary system.
2) The wave is a more dynamic source than solar, but it also provides energy during periods of little or no sunshine. This complementary feature is favorable to system reliability.
3) This hybrid system decreases the battery capacity for buoy system, and it has many benefits such as a installation, cost, efficiency and reliability in the buoy.

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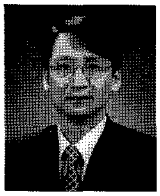

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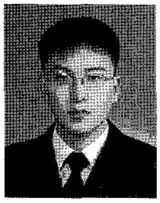

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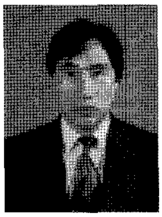

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