Journal of the Korean Society of Marine Engineers, Vol.28, No.2, pp.309~314, 2004(ISSN 1226-9549)

A Study on the Operation Method of Photovoltaic/Diesel Hybrid Generating System

Jae-Shik Park† · Myung-Ok So* · Heui-Han Yoo*

(Manuscript : Received DEC 15, 2003 ; Revised JAN 20, 2004)

Abstract : The exhaust gas emission from marine diesel engines is one of the major environmental issues. The authors focus the use of photovoltaic energy for the electric power system on marine ships. This paper proposes an operation method of a photovoltaic/diesel hybrid generating system for a small ship in consideration of the fluctuating photovoltaic power due to solar radiation. The aim of the proposed operation method is to minimize the fuel consumption and storage capacity of the battery. The validity of the proposed control method is shown by the numerical simulation based on the experimental data of the photovoltaic system.

Key words : Photovoltaic/diesel hybrid generating system, Environmental issue, Fuel consumption, Storage capacity of battery, Marine ship

1. Introduction

The release of gases such as CO_2, NOx and SOx not only on land but also from ships to the atmosphere is one of the major environmental issues and regulation of the exhaust gases from combustion engines has become strict in recent years[1]. Photovoltaic power generating(PV) systems are expected to be widely used because of their harmlessness to the environment[2]. It is effective to apply the PV system to marine ships as an alternative energy to fossil fuels in order to reduce the level of polluting gases in the marine environment. We have designed the electric power system composed of PV system, diesel-engine generator and battery for a small ship[3]. One of the PV systems disadvantages is the unexpected fluctuation of generated electric power caused by the unstable solar radiation[4]. It can make the output of the diesel engine fluctuate to decrease its efficiency and increase the exhaust gases. The fluctuating electric power of PV system can charge or discharge the battery when

† Corresponding Author(The Korean Society of Marine Engineers), E-mail:jsdhjpark@naver.com, Tel : 051)405-1050
* Division of Mechatronics Engineering, Korea Maritime University

the storage capacity of the battery is high enough. However, the size of the PV array and battery is desired to be as minimum as possible from the point of costs and the weight of the ship. In this paper, we propose an operation control of the electric power system with photovoltaic system for a small ship considering the fluctuating electric power of photovoltaic system due to the solar radiation. The aim of the operation method is to make the storage capacity of the battery minimum while the diesel engine keeps the constant output with high efficiency in spite of the fluctuating PV power. The numerical simulation based on experimental data of the PV system confirms the validity of the proposed operation method.

2. Photovoltaic/diesel hybrid generating system

The layout of the overall system is shown in Fig.1. The system is composed of its major components: PV array, diesel-engine generator, the battery and inverter. Here some conditions are supposed; (1) the output power of the diesel generator can be controlled, (2) the battery can be charged and discharged anytime if necessary, (3) the storage energy of the battery is known.

3. Operation of photovoltaic/diesel hybrid generating system

3.1 Objectives of the system operation

Fig.2 shows the instantaneous PV power on July 1st and 2nd 1998. It is noted that the generated PV power is not smooth but shows uneven peaks and valleys because of the fluctuation of the solar radiation caused by clouds. The fluctuating electric power of PV array can be averaged by charge into or discharge from the battery when the storage capacity of the battery is enough. However, the size of the battery is desired to be as minimum as possible from the point of view of costs and ships weight. In addition to that, the diesel-engine generator is desired to be operated under a constant output with high efficiency in order to reduce the polluting gases from the diesel engine. Consequently, photovoltaic/diesel hybrid generating system has to be addressed

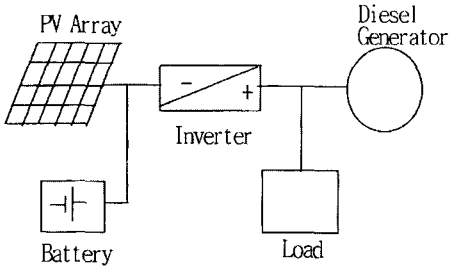

Fig. 1 Photovoltaic/diesel hybrid generating system

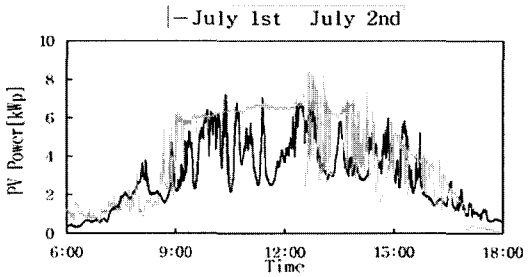

Fig. 2 10kWp PV Array Power

some conflicting objectives of system operation as follows:

(1) Keep the output of the diesel-engine generator constant with high efficiency.
(2) Minimize the fuel consumption of diesel-engine generator.
(3) Maximize utilization rate of the PV energy resource.
(4) Minimize the capacity of the battery.

3.2 Control method

Fg.3 shows an operation control pattern for the photovoltaic/diesel hybrid generating system[5]. The abscissa shows the storage energy of the battery and the ordinate means the PV power output. The diesel-engine generator and the battery are controlled by each operating mode (Ⅰ~Ⅵ) according to the PV power output and the storage energy of the battery as shown in the Fig. 3 and Table 1. That is, the diesel-engine generator stops and the surplus power charges the battery when the PV power is greater than the total load(Mode Ⅰ). The dieselengine generator keeps the power output constant in the most efficient condition when the storage energy of the battery is less than B_{CM}(ModeⅡor Ⅴ according to the PV power). When the energy of the battery increases above B_{CH}, the diesel-engine generator stops and the PV power and the discharge from the battery supplies the power of the load(Mode Ⅲ). In the case where both the PV power and the energy of the battery are small(below Yp and B_{CL}, respectively), the dieselengine generator works at the maximum output(Mode Ⅳ). Mode Ⅵ indicates that the battery cannot be charged anymore and the surplus power is lost.

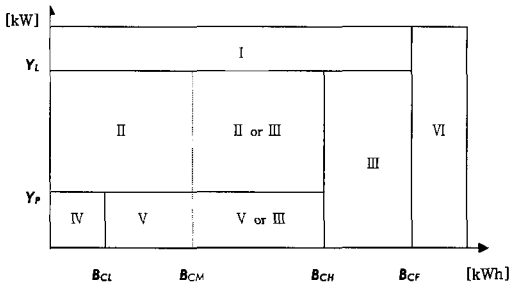

Fig. 3 Operation control pattern: B_{CL} is the minimum storage energy of the battery, B_{CM} is the point to start the diesel generator; B_{CH} is the point to stop the diesel generator; B_{CF} is the storage capacity of the battery, Y_L is the total demand load and Y_P is the diesel constant output

Table 1 Operating modes

Mode	Diesel generator	Battery
Ⅰ	Stop	Charge
Ⅱ	Constant output	Charge
Ⅲ	Stop	Discharge
Ⅳ	Constant output	Discharge
Ⅴ	Maximum output	Charge
Ⅵ	Stop	No charge

4. Simulation

4.1 Simulation method

An actual ship is chosen as a model for our study. It is a small commuter boat that cruises for 6 hours(from 10 to 16 O'clock) every other day in Osaka bay[3]. The states of the diesel-engine generator and the battery are calculated by means of the actual data of the Kobe University of Mercantile Marine during July 1998[8]. The load of the electric power system is supposed to be constant at 5kW. The

maximum and constant output of the capacity of the diesel-engine generator are 5 and 3.5kW, respectively. The B_{CL}, B_{CM}, B_{CH} are 30, 40 and 70% of the capacity of the battery, respectively. The simulation is conducted under the condition that the PV array sizes are from 3 to 6kWp and the capacities of the battery are from 10 to 30kWh.

4.2 Simulation results

Fig. 4 shows an example of simulation results. First, the battery has the maximum storage energy of 20kWh. Then, the boat starts to cruise at 10 O'clock and the PV power and the discharge from the battery supplies the load(Mode Ⅲ). The diesel-engine generator starts to work at 13:15 because the storage energy of the battery decreased 7.5kWh(B_{CM}). The diesel-engine generator keeps the output power 3.5kW and the battery is charged or discharged according to the PV power(Mode Ⅱor Ⅳ). The boat stops at 16 Oclock and the PV power charges the battery after that(Mode Ⅰ). The battery is also charged by PV power on the next day when the boat does not cruise.

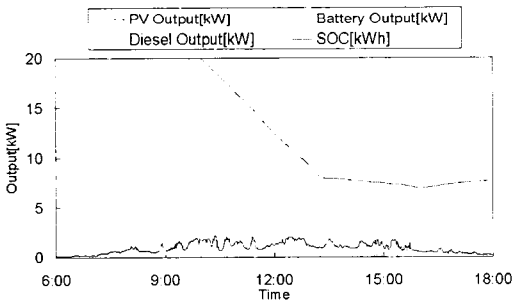

Fig. 4 Output of the photovoltaic/diesel hybrid generating system (PV array of 3kWp, battery of 20kWh)

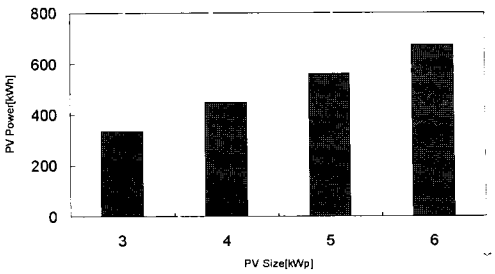

Fig. 5 Total PV energy during the month

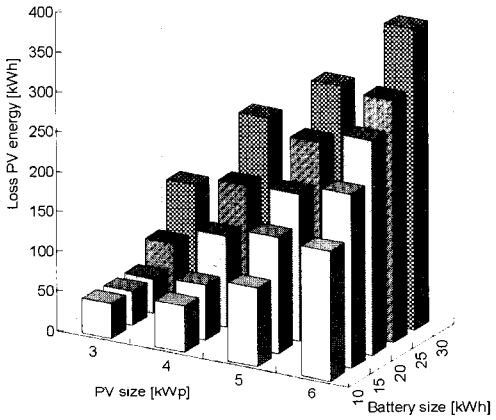

Fig. 6 PV energy loss

Fig.5 shows the maximum energy generated by the PV array during the month. The PV array of 3kWp can generate electric energy of 337kWh, that of 6kWp can generate 674kWh. Because the total amount of the load is about 450kWh, the PV array over 4kWp can basically supply all the necessary load. However, the hybrid system with the small battery cannot use all the PV energy as shown in Fig.6. It shows the amount of the PV energy during the month that could not charge the battery and was lost because the battery was full. The utilization rate of the PV energy is shown in Fig.7.

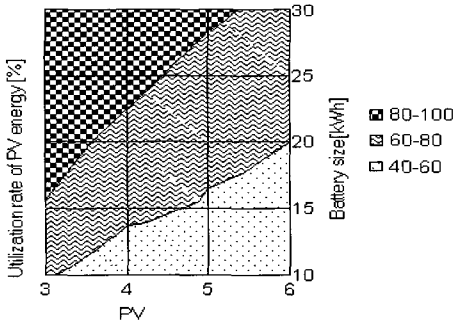

Fig. 7 Utlization rate of PV energy resource

The values are the rate of the available PV energy to the maximum PV energy in Fig.5. The system with a large PV array and a small battery tends to be worse in the utilization rate of PV energy resource. The system with a PV array of 6kWp and a battery of 10kWp has a rate of 38%, but the system with a PV array of 3kWp and a battery of 30kWh has a rate of 87%. The simulation results show that it is recommended to use a PV array of 3kWp with a battery of 20kWh, a PV array of 4kWp with a battery of 25kWh, and a PV array of 5kWp with battery size of 30kWh in view of cost performance.

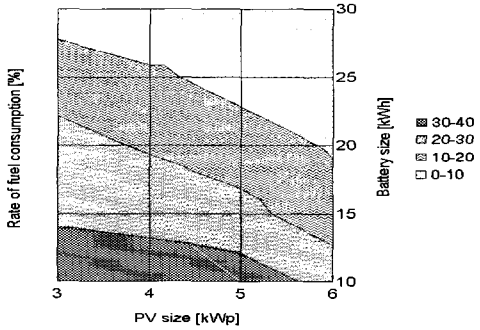

Fig. 8 Rate of fuel consumption

Fig. 8 shows the rate of the fuel consumption of the proposed system to that of the diesel-engine generating system without PV array during the month of July. The system with a small PV array tends to be worse in the fuel consumption. The hybrid system with a PV array of 3kWp and a battery of 10kWh consumes 38% of the fuel that is consumed by the diesel-engine generating system without PV array. However, the system with a PV array of 5kWp and a battery of 30 kWh and the system with a PV array of 6kWp and a battery of 25 kWh consume no fuel.

5. Conclusions

This paper proposed an operation control method of the photovoltaic/diesel hybrid generating system for a small ship in consideration of the fluctuating electric power of PV system due to the solar radiation. The aim of the operation control is to make the storage capacity of the battery minimum while the diesel-engine generator keeps the output constant with high efficiency in spite of the fluctuating PV power. It was verified that the proposed operation control was effective through the simulation using the experimental data of the actual PV system during the month of July 1998. The simulation results also suggested the utilization rate of PV energy resource and the fuel consumption for the various PV array sizes and storage capacities of the battery. The method to decide the optimal PV array size and the capacity of the battery in terms of costs, environmental effects and limitations for ships can be made based on the proposed operation control and simulation result.

References

[1] IMO, MEPC, Prevention of Air Pollutants from Ships Including Fuel Quality, Dec., 1997

[2] R. Ramakumar and J.E.Bigger, "Photovoltaic System", Proceedings of IEEE, Vol.81, No.3, March, 1993

[3] David E. Hasti, "Photvoltaic Power System Application", IEEE Power Engineering Review, April 18-19,1994

[4] T.Katagi, J.S. Park and T.Hashimoto, "Basic Design of Electric Power System with Photovoltaic System for ships", Transactions of IEE Japan, Vol.118-B, No.9, pp.976-982, 1998

[5] J.S. Park : "Basic Study on Photovoltaic/ Diesel Hybrid Generating System Considering Radiation of Solar Radiation", ISCIE Proceedings 42th, No.6054, 1998

[6] M.Tsukamoto, "Optimization of Equipments Size of Photovoltaic Power System with Diesel Generator, JERS,Vol.10,No.4, pp.372-378, 1989

[7] Y. Kemmolu, "Adaptive Fuzzy Control for Fuel Reduction of Photovoltaic/ Wind/ Diesel Power Generating System", Transactions of IEE Japan, Vol.118-B, No.11, pp.1284-1291, 1998

[8] T.Katagi, "Construction of Photovoltaic/ Diesel Hybrid Generating Experimental System", SCIE Proceedings 41th, pp.627-628, 1997