Scheme Design of Green Power Barge for Ships to be released at the Anchorage of Three Gorges

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Abstract. In order to realize the shore power access for the ships to be released at the Three Gorges anchorage and mitigate the discharge of vessels in the Three Gorges anchorage, and based on the analysis of the electricity demand of the ships to be released at the Three Gorges anchorage, a set of photovoltaic-shore power complementary power supply system built on the platform of pontoon catamaran has proved the social benefits of the design, providing the basis for the design and application of solar energy in the field of marine shore power.

1. Introduction
Ships to be released at the anchorage of the Three Gorges reservoir are multitudinous. During the waiting period of the ship, electric power is required to maintain the normal operation of the electrical equipment and auxiliary machinery on board. At present, most ships to be released apply their own diesel generator as the power source for berthing. The diesel generators mostly operate at idle speed, whose efficiency is significantly lower than that of diesel generators under normal operation, resulting in a huge energy waste and a large amount of NOx, SOx and other noxious gases. The application of clean energy such as wind energy and solar energy as external power sources to power ships to be released will greatly reduce energy consumption and emission of hazardous substances, and the cost of electricity will be significantly reduced.

The Three Gorges reservoir has the characteristics of large height of water during one year period. Taking barges as berthing docks and equipping shore power connecting devices on barges will effectively overcome the water level problem. At present, some barges have been installed with solar photovoltaic systems. However, at present, solar photovoltaic systems installed on barges have a small capacity and are mainly intended to meet the electricity demand of barges and cannot meet the onshore electricity demand of berthing vessels. Therefore, this paper presents a design scheme based on pontoon catamaran platform and solar photovoltaic power generation system. It takes full advantage of the solar photovoltaic system installed on the barge and the complementary power supply of shore-based power grid to effectively meet the all-weather electricity demand of ships to be released at the anchorage.

2. Overall program of new energy shore power supply system

2.1 Application method
The water level in the Three Gorges reservoir varies greatly. There are many technical problems in adopting the method of direct shore power supply to ships to be released. The traditional barge
floating dock being largely with single-hull, there are defects of a small area and the difficulty to large-scale deployment of photovoltaic power generation equipment. At the same time, the existing barges are largely docked by ships in parallel, making it difficult to establish a direct connection between the dock and all berthing vessels.

Therefore, this design intends to apply a floating platform based on the pontoon catamaran design, and to arrange a large number of photovoltaic power generation devices on the power supply platform by taking advantages of the platform of pontoon catamaran. In the meantime, combined with the sound hydrological conditions and small flow velocity in the Three Gorges reservoir, the berthing method of berthing vessels was changed from parallel docking to vertical docking. Besides making effective use of the resources of the surrounding waters of the platform, all vessels can establish direct connection with the power supply platform. Table 1 shows the main indicators of floating platform.

Table 1 Main dimensions of power barge

| names             | symbols | units | values |
|-------------------|---------|-------|--------|
| total length      | L_{OA}  | m     | 70.00  |
| waterline length  | L_{WL}  | m     | 68.00  |
| molded breadth    | B       | m     | 40.00  |
| body molded breadth | b   | m     | 10.00  |
| Molded depth      | D       | m     | 3.00   |
| Design Draught    | d       | m     | 1.40   |

Notes: The computation of main sizes of the hull applies L_{WL}, b and D parameters.

2.2 Principles of Systems

According to the classification of photovoltaic systems and their application in ships, the photovoltaic systems can be divided into three types: off-grid photovoltaic system, grid-connected photovoltaic system and hybrid photovoltaic system\(^1\).

Solar photovoltaic power generation system bears the feature of great change in power generation characteristics during a day, and the marine load does not change significantly with the passage of time. Therefore, the contradiction between generated power and load of the solar photovoltaic system must be solved. One way is to apply the off-grid PV system to store the remaining energy of the PV system when the power of the PV system is in surplus and to supplement the energy of the PV system when the output power of the PV system is insufficient. This approach makes better use of electricity generated by solar photovoltaic system, but storage battery of several times the capacity of solar photovoltaic systems must be equipped, with high cost, difficult maintenance and large covering area. The other way is to apply grid-connected PV system. It will send excess power back to the shore-based grid when the PV system output power is greater than the load power, while the shore-based grid will supplement it when the output power of the PV system is insufficient\(^2\). Considering that the capacity of the barge photovoltaic system is limited and it is difficult to fully meet the all-weather
electricity demand of the barge itself and the berthing vessel to be released, it is proposed to adopt a grid-connected photovoltaic system. The specific system architecture is shown in Figure 2.

3. System performance indicators

3.1 Principles of Systems

According to the statistics of 2014, the annual light radiation intensity statistics of Yichang are listed in Table 2:

| months | Daily average solar radiation on the horizon each month (kW·h/m²/day) | Average monthly temperature (°C) | Daily average solar radiation on the PV array horizon |
|--------|-------------------------------------------------|-------------------------------|----------------------------------|
| Jan.   | 2.32                                            | 2.80                          | 3.17                             |
| Feb.   | 2.53                                            | 5.20                          | 4.02                             |
| Mar.   | 3.00                                            | 9.30                          | 4.96                             |
| Apr.   | 3.72                                            | 15.90                         | 5.61                             |
| May    | 4.01                                            | 20.50                         | 6.07                             |
| Jun.   | 4.31                                            | 24.10                         | 6.50                             |
| Jul.   | 4.52                                            | 26.10                         | 6.44                             |
| Aug.   | 4.35                                            | 25.20                         | 6.34                             |
| Sep.   | 3.66                                            | 21.80                         | 5.91                             |
| Oct.   | 2.92                                            | 16.50                         | 5.34                             |
| Nov.   | 2.57                                            | 10.70                         | 4.22                             |
| Dec.   | 2.31                                            | 4.70                          | 3.38                             |

According to the data of solar energy resources in Yichang in Table 2 and the annual average intensity of light emission in Yichang is 5.16 kW·h / m² / day. The light resources from March to November fall far behind that from December to February. Based on the purpose of maximizing the application of new energy power generation, solar photovoltaic power generation of the future system should be able to meet the basic needs of the best lighting resources from March to November, in order to achieve the best cost performance.

3.2 Load calculation of power supply system

1) Electricity demand of barge platform

According to the electricity consumption survey, Table 3 shows that the power demand of a typical anchoring barge power supply system is no fewer than 39.92 kW·h[3] in terms of daily generation capacity.

| device names             | Service hours (h/day) | Power consumption (Wh/day) | Operating current (A) |
|--------------------------|-----------------------|---------------------------|-----------------------|
| kitchen fittings         | 1                     | 1 320                     | 13.5                  |
| hanging air-conditioner  | 12 (2sets in total)   | 24 000                    | 18                    |
| refrigerator             | 24                    | 1 000                     | 1                     |
| daily illumination       | 36                    | 1 440                     | 0.2                   |
| very high frequency (VHF)| 24                    | 200                       | 0.4                   |
| floodlight               | 1 (2sets in total)    | 600                       | 2.7                   |
| TV                       | 14                    | 2 100                     | 0.68                  |
| washing machine          | 1                     | 400                       | 1.8                   |
| computer                 | 4 (2sets in total)    | 3 200                     | 1.8                   |
| sum                      |                       | 39 920                    |                       |
2) Electricity demand of berthing ship to be released
   According to the survey, typical ships in the Three Gorges area have a load power of about 10 kW.h under berthing conditions, and some ships (such as container ships, passenger ships, etc.) have large load power. Considering the berthing objects in barge anchorage are mostly bulk carriers, tankers and other ships with relatively small loads, daily electricity consumption of berthing vessels is about 1920 kW.h, with single power barges powering for eight berthing vessels as an example.

4. System design

4.1 Overall design of the system

According to the characteristics of the solar photovoltaic system and the load of the berthing ship to be released, the grid-connected photovoltaic system may be set up with three working modes as shown in Figure 3, corresponding to different operating conditions of the solar photovoltaic system at different time frames of the day.

Figure 3 functional block diagram of power supply mode
4.2 Photovoltaic array design of barges

In order to determine the installation number and location of solar photovoltaic panels, the total power of the required solar photovoltaic panels shall first be determined according to the electricity usage of the barges and their berthing vessels. Second, the installable area of the barge panels shall be measured and then the effective installation area of solar photovoltaic panels shall be calculated according to the installation angle of the panels. Then, the installation number and location of solar photovoltaic panels shall be determined on the basis of a comprehensive comparison of various panel sizes and generation capacity[4].

Since the top of the power supply platform is large in area and has a sound lighting effect, solar panel is installed at the top of the power supply platform. Considering the large number of berthing ships to be released by the Three Gorges and high power consumption, the design enhances the photovoltaic power generation effect from two aspects. On the one hand, given the large size of the power supply platform, it is possible to make the utmost of the top area to lay out the photovoltaic power generation equipment. Taking into account the necessity to reserve a channel as a PV panel array access channel, so the layout of photovoltaic power generation equipment is shown in Figure 4. The estimated area of photovoltaic panels can be about 2 000 m². On the other hand, considering the actual installation of photovoltaic array on the power supply platform and its applying environment, the design proposes to adopt a single-axis solar tracking technology based on the tracking of the sun, which enjoys the advantages of mature technology, simple design, and easy installation. Photovoltaic single-axis tracking mechanism is shown in Figure 5.

Because of the large installation area of the photovoltaic panels used in this design, it is more suitable for the design of inclined solar panels to improve the photovoltaic power generation efficiency by setting the optimal inclination angle.

The latitude and longitude of Yichang City is 111.3° longitude and 30.7° north latitude. By consulting the relevant literature, we know that the best inclination of PV panels in Yichang is 20°.

4.3 Photovoltaic system power generation calculation

According to the data in Table 2, the daily average total solar radiation \( G_t = 5.16 \text{ kW.h/m}^2/\text{day} \); according to Figure 4, the design layout of the photovoltaic panels is about 2000 m²; the effective lighting time is about 4h in Yichang. Substituting into the photovoltaic power generation system, the formula is as follows:

\[
Q = N \times P \times T \times \eta_1 \times \eta_2
\]

Notes:
W - Daily effective power generation (unit: kW.h);
Gτ - the monthly average amount of radiation, kW h / m2 (calculated by 30 days per month)
η - total efficiency of grid-connected PV system;
A - the total area of photovoltaic panels;
T - effective light time (unit: h);
Total efficiency of grid-connected PV power generation system:
Notes: \( \eta_1 = 85\% \) PV array efficiency; \( \eta_2 = 95\% \) inverter conversion efficiency.
Through calculation: daily generating capacity of photovoltaic power generation system \( W = 111.12 \) kW.h.

5. Efficiency analysis and calculation
Under the traditional power supply mode, the ship relies solely on the diesel generator to provide the electricity required for daily production and life during the waiting period. According to the survey, load power of typical ships in the Three Gorges area is about 10 kW.h under berthing conditions. Take eight berthing ships consuming electricity as an example, the daily consumption of diesel for power is \( 1920 \times 245 = 470400 \) g.

The photovoltaic system of a single-powered barge generates approximately \( 1111.12 \) kW.h per day and it is designed to supply power to 8 ships simultaneously. The daily electricity required for shore power supply is about:

\[
240 \times 8 + 50 - 1111.12 = 858.88 \text{ kW.h}
\]

According to Table 4, a powered barge and its berthing electrical vessels will generate 690.5 kg CO\(_2\) emissions, 188.4 kg carbon emissions, 20.8 kg SO\(_2\) emissions and 10.4 kg NO\(_x\) emissions, while also significantly reducing emissions of solid particulate matter. It enjoys significant emission reduction benefits compared with ship with generators for power supply.

6. Conclusion
The power supply platform in the Three Gorges anchorage based on wind, light and shore power hybrid power supply studied in this paper enjoys the advantages of strong environmental adaptability and obvious energy-conserving effect. Compared with the current diesel engine power supply applied in ships to be released, the design effectively solves the key technical problems of shore power supply in the Three Gorges, providing a new feasible scheme to enhance the modernization of inland river shipping and reduce the discharge in the Three Gorges reservoir area.

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