Efficient Energy Management of a Solar PV Integrated Ship Power System

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Abstract - In this research article, a coordination method for Battery energy storage system (BESS) and ultra-capacitor is proposed for a Solar PV integrated ship power system. The key challenges in shipping industries include the fuels price rise, CO2 emission, source generators operated below their rating and power fluctuation. The ship energy storage system (ESS) has gained more interest from ship designers because it can store energy in BESS and ultra-capacitor from solar PV during off demand hours of a ship. The stored energy returns to the connected load of the ship grid when required. Here, the BESS reduces the dependency on bunker fuel and the ultra-capacitor can respond to high dynamic loads. Furthermore, integrated ship power systems were made possible due to the development of power electronics converters which as results provides better voltage and frequency regulation, fuel cost reduction, operating cost reduction, operation flexibility, superior reliability and improved ship power system stability. The simulation of the ship electrical grid connected solar PV system with ultra - capacitor and BESS is carried out using MATLAB/Simulink environment to verify that the proposed system is effective in coordinating energy management system, minimizing operating cost, and responding against dynamic load.

Keywords: BESS; ESS; Ultra capacitor; Solar PV cell; Ship power system

INTRODUCTION

Globally Renewable energy sources (RES) have attracted more in power industries due to their environment-friendly nature, vast reserve and reproducibility [1]. But the percentage share of RES in ship power system is very low and till now we have been largely depending upon bunker fuel which plays a significant role in the production of CO^2 and global warming [2]. In the shipping industries, as the emission of greenhouse gas is increased, we must find an alternative source and ESS to reduce the emission and better energy management. Faced with these issues, the shipping industries have started to increase the percentage share of RES like liquefied natural gas (LNG), wind energy, solar energy, hydrogen and tidal energy etc [3]. Today approximately 1500 ships are run by LNG, battery and hybrid mode alternatives to fossil fuel and 1100 ships are under construction. Among all RES solar energy is the most abundant source and it can be integrated with the ship power system [4-5].

Solar energy can be a cost-effective solution for ship power system operation [6]. The main advantages of solar PV cells are no need for electro-mechanical conversion, no emission, no noise, easy installation and low maintenance cost etc. [7]. As the surface temperature and solar irradiance are variable the power generation by the PV system is not stable and sporadic [8]. At the same time, shipping electrical equipment is operated in a closed environment, high temperature and humid and also connected with large number of induction motors. Several times in the ship power system the generators are operated below their rating [9]. These above factors are responsible for instantaneous power surges, voltage dips, sudden rise of PV output current and over current in ship power system. Sometimes surplus energy generation from PV system causes over voltage and below rating operation of the generator causes losses and decreases the efficiency. Hence, the ship power system requires an ESS for reliable and stable operation [10].

In this paper, simulation work is done to overcome the issues of ship power system where ultra-capacitor with BESS is the hybrid ESS. The surplus power of the ship power system stores in BESS and ultra-capacitor during low demand and it will return to the ship power system during peak hours' load demand. The power density of the ultra-capacitor is higher compared to BESS so it will able to supply power to pulse loads with 95% efficiency. Also, the response time of ultra-capacitors is very fast.

Further sections of this paper are organized as follows: Section 2 discusses the architecture of ship power system with hybrid ESS. The Simulation results and discussion are discussed in Section 3. The findings of the research work are concluded in Section 4.

SYSTEM MODELLING

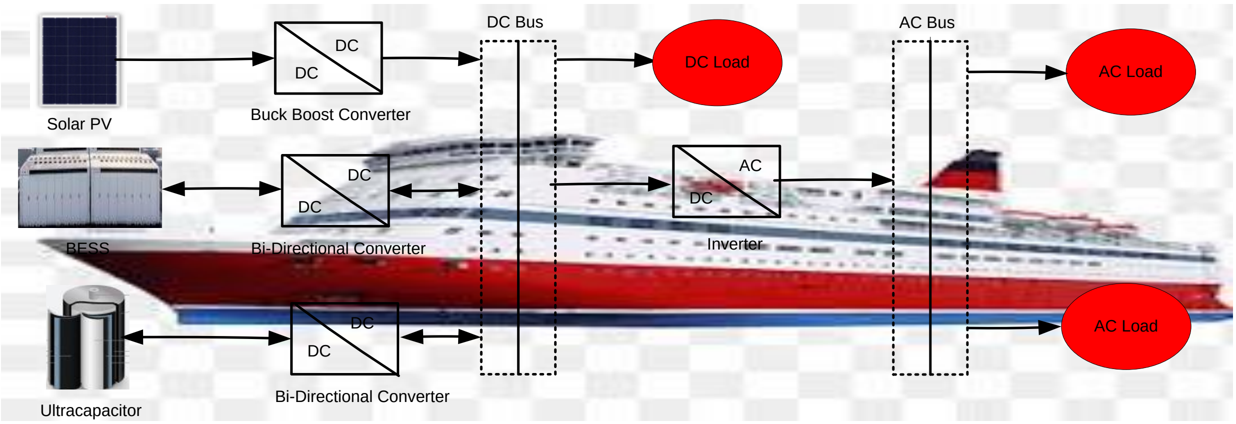

Figure .1Ship power system integrated hybrid ESS

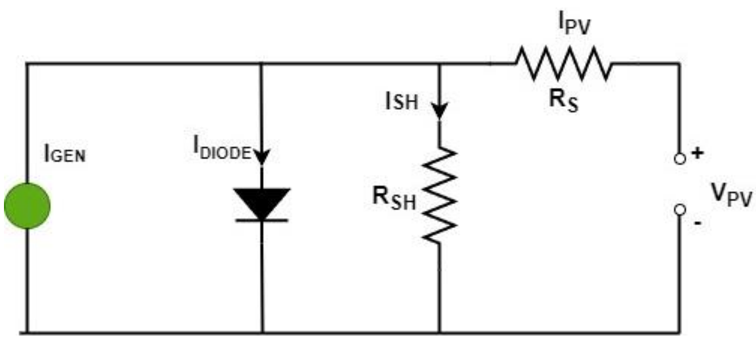

Figure .2 Solar PV Equivalent Circuit

The objective of this paper is to examine the environment-friendly and economic ship hybrid power system which is integrated with solar PV panel, ultra-capacitor, BESS, buck boost converter, bidirectional converter, bidirectional inverter, DC load and AC load. The proposed model in the MATLAB Simulink library is used in this research work is depicted in Figure 1. The energy source is assumed to consist of solar PV panel. The hybrid energy storage system consists of BESS and ultra-capacitor. Both DC and AC loads are connected to the respective AC and DC bus. The electrical equivalent circuit of solar PV is presented in Figure 2.

The mathematical electrical equivalent expression of solar PV panel is presented below;

$$I_{PV}=I_{Gen}- I_{Diode}-I_{SH} \qquad (1)$$

SIMULATION RESULTS AND DISCUSSION

In this work, the proposed ship power system is tested using MATLAB Simulink software through the design of a solar PV, BESS and ultra-capacitor. The simulation results of the system highlight the flexibility of the proposed model in energy generation using solar PV and storing the surplus energy in BESS and ultra-capacitor. The maximum power of PV is set to 0.94 kW. The simulation of the system observation for three cases is carried out as follows:

A. ***Solar panel output analysis***

The solar PV panel output voltage is 34.55 V which depends upon the configuration, irradiance of solar and temperature as depicted in Figure 3. The current output of solar PV panels is presented in Figure 4. The instantaneous and cumulative power generation of the solar PV panel is presented in Figure 5. This data indicates the voltage stability, performance of the panel, current flow within the system and generation of DC electricity. The power demand response and DC voltage are presented in Figure 6 and Figure 7 respectively. This simulation waveform indicates the energy demand, surplus energy balance and system performance. Figure 7 shows that the DC voltage is maintained at 50.5 V.

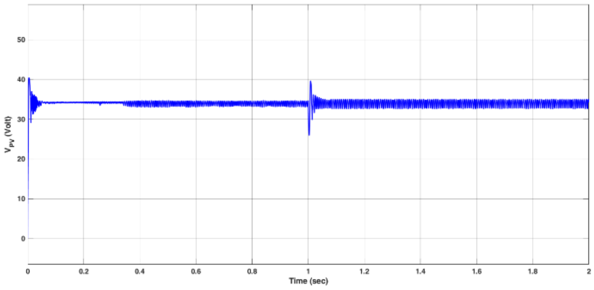

Figure. .3 Solar PV panel output voltage

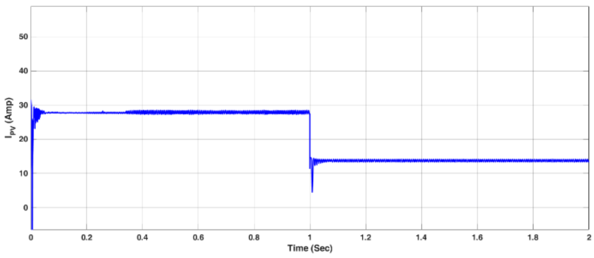

Figure. 4 Solar PV panel output current

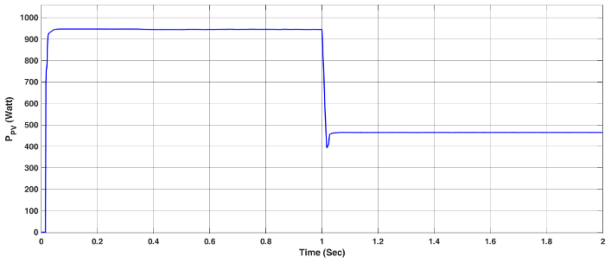

Figure. .5 Solar PV panel output power

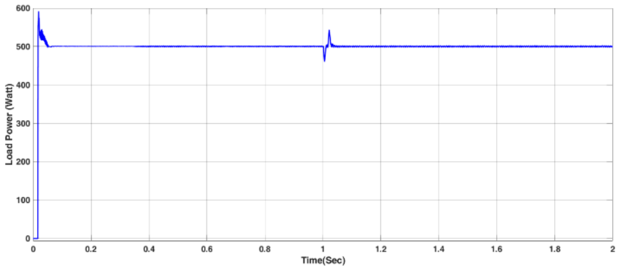

Figure .6 Power demand response

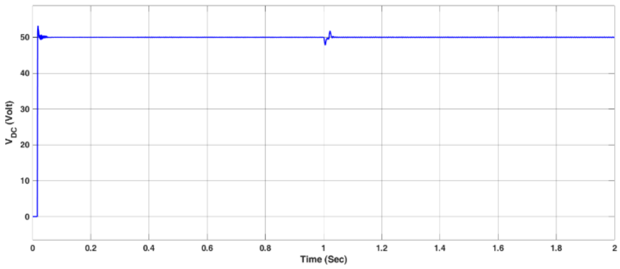

Figure. 7 Voltage response (DC)

B. ***Battery output analysis***

The simulation waveforms from Figure 8 to Figure 11 show the battery state of charge (SOC), voltage, current and power respectively.

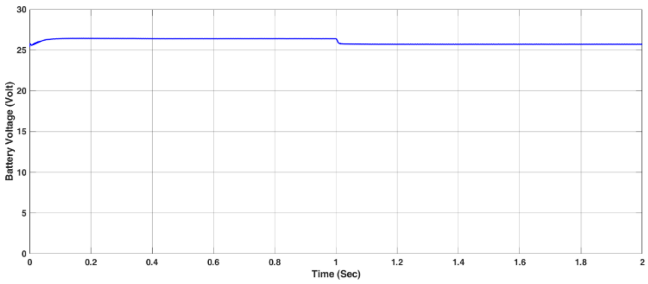

Figure. 8 BESS output voltage

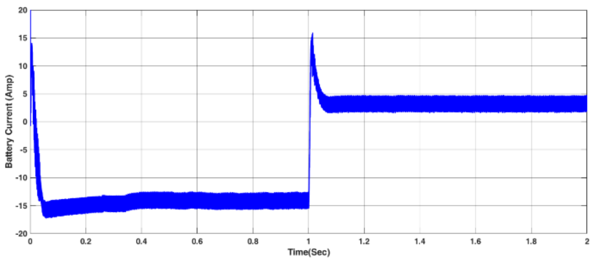

Figure. 9 BESS output current

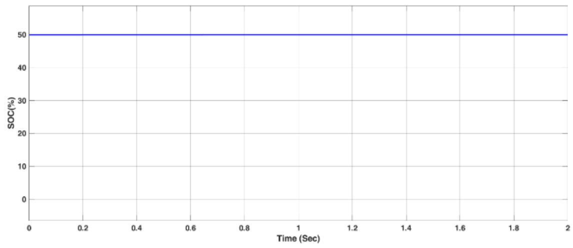

Figure. 10 BESS SOC response

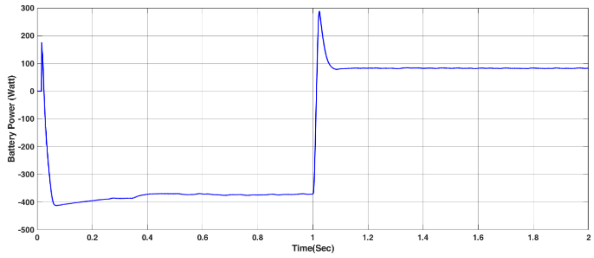

Figure. 11 BESS output Power

These waveforms illustrate the charging of the battery during surplus energy available and discharge during demand.

C. Ultra capacitor output analysis

The simulation waveforms from Figure 12 to Figure 15 show ultra-capacitor output voltage, current, SOC and power response. The ultra-capacitor supplies power during peak power and pulsed power demand. The approximate output voltage of the ultra-capacitor is 33 V.

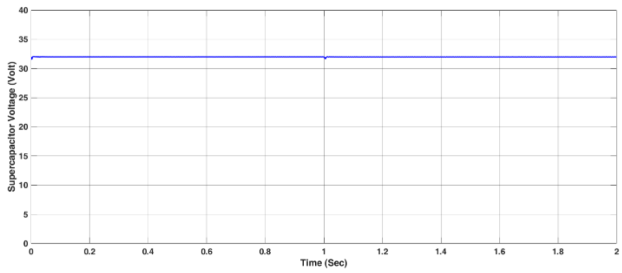

Figure. 12 Ultra-capacitor output voltage

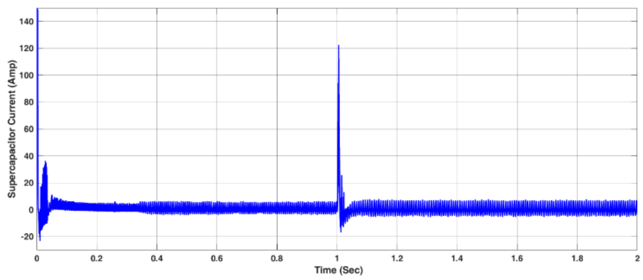

Figure. 13 Ultra-capacitor output current

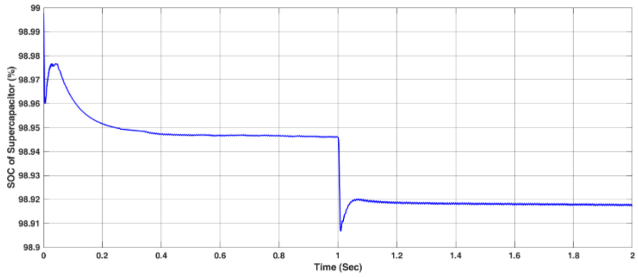

Figure. 14 Ultra-capacitor SOC

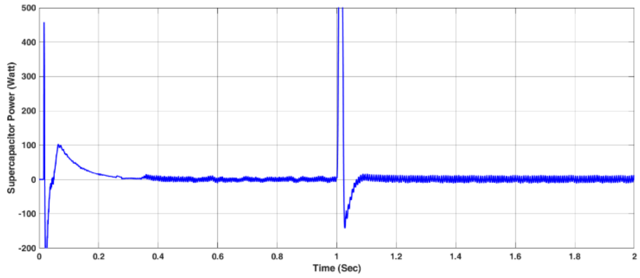

Figure. 15 Ultra-capacitor output Power

CONCLUSION

In this article, a ship power system with an efficient hybrid ESS model is investigated for application in off-shore ships. The simulation results highlight the superiority and efficiency of the model. The energy produced from solar PV panel and the energy stored in BESS and ultra-capacitor are determined via MATLAB. Different three responses of solar PV, BESS and ultra-capacitor voltage, current and power are analysed. The responses show that the integration of the ship power system with the hybrid energy storage system stores and utilises the excess solar energy which reduces the dependence on bunker fuel. Also, the proposed model saves fuel consumption, decreases its cost and reduces carbon emission which proves its superiority and efficiency. In the future, this work may focus on experimental validation which will support off-shore ships to reduce bunker fuel costs and greenhouse gases.

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