Stability Improvement of DC Power Systems in an All-Electric Ship Using Hybrid SMES/Battery

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Abstract

As the capacity of All-Electric Ships (AES) is expected to reach hundreds of megawatts in the near future, the sudden changes in the system load may lead to serious problems, including voltage instability of the ship power grid. In order to reduce the effects of system load fluctuations on system efficiency, and to maintain the bus voltage, a hybrid SMES/battery is proposed in the AES.

Introduction

In AESs, the main sources of sudden load changes are maneuvering and pulse loads, such as electrical weapons. Electrical weapons rely on stored energy to attack targets, which need a high amount of power in a short period. The ramp-rate of the ship's generators is not high enough to maintain such loads, which makes the HESS a promising solution. A dynamic droop control is used to coordinate the charge/discharge prioritisation between the SMES and the battery. The simplified AES including HESS is modelled in Matlab/Simulink to assess the system performance.

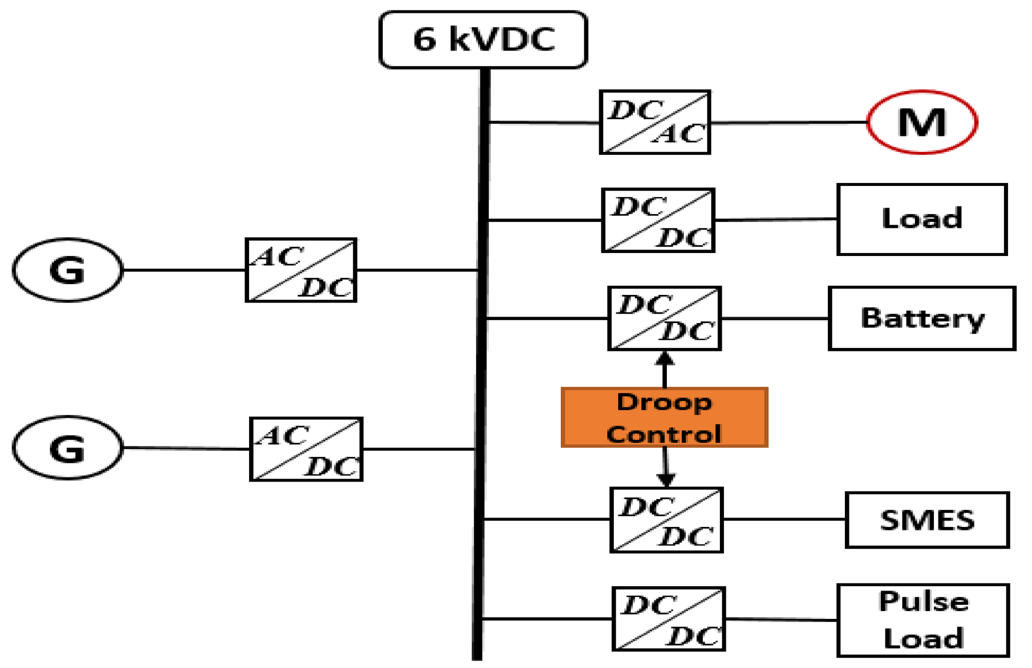

Fig.(1) Simplified all electric ship power system including SMES

Energy Storage Control Method

The stored energy in the SMES can be calculated by equation (1):

$$E = \frac{1}{2} LI^2 \qquad (1)$$

The full bridge DC/DC converter is used to control charge and discharge of SMES. SMES in this system works in three operation modes:

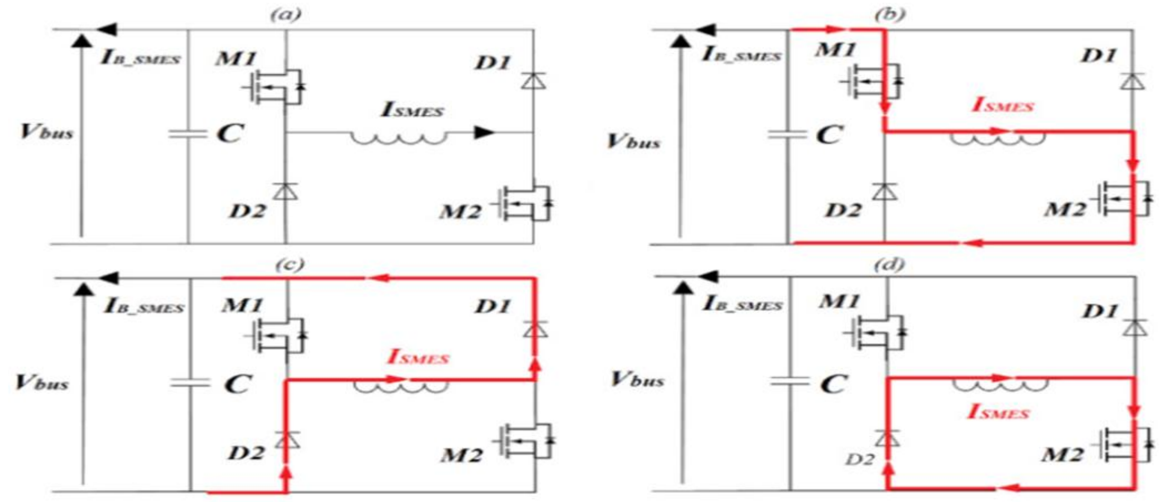

Fig.(2) DC/DC converter showing current paths in different modes: (a) circuit topology; (b) charge mode; (c) discharge mode; (d) standby

1-Vbus > Vref(max) (Charge Mode)

d1 (the duty ratio of M1) and d2 (the duty ratio of M2) are controlled by two pulses for each gate according to Fig. 3 and (2):

$$q = (k_a)\, exp(\frac{I_{smes}}{k_{smes}})^{k_b} \qquad (2)$$

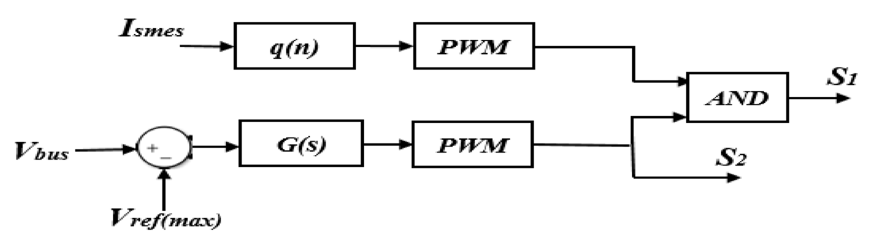

Fig.(3) Block diagram of the H-bridge DC–DC converter controller (charge mode)

2-Vbus < Vref(min) (Discharge mode)

d1 and d2 are controlled by two pulses for each gate according to Fig.4 and (3):

$$q_2 = (k_a)\, log_{10}(\frac{I_{smes}}{k_{smes}})^{k_b} \qquad (3)$$

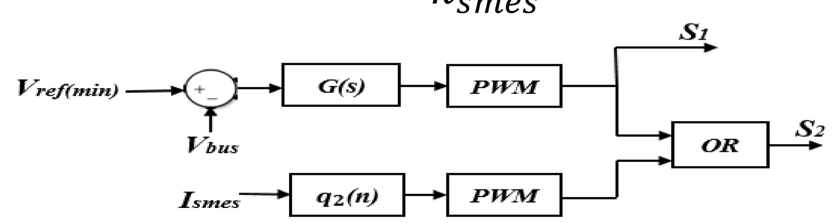

Fig.(4)Block diagram of the H-bridge DC–DC converter controller (discharge mode)

3- Vref(max) > Vbus > Vref(min) (Standby mode)

In this mode, no output current from SMES is needed. To keep the current circulating between D2 and M2, d1 is off and d2 is on.

The half bridge DC/DC bidirectional converter based on the PI controller is used to control the battery charge and discharge.

Simulation Results and Discussion

The simplified AES including the HESS is modelled in the SimPowerSystems environment. The model consists of two generators 6.6 kV, 50Hz, 7 MW, one motor 2680 hp, ship service loads 7 MW and pulse loads 5 MW. During seconds 4 to 7 and 10 to 13, 5 MW pulse loads are applied to the system. The total minimum load is 9 MW and the total maximum load is 14 MW.

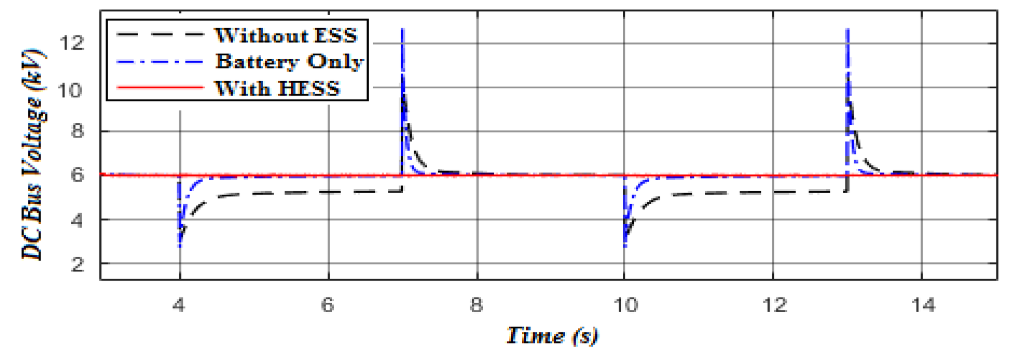

Fig.(5) The DC bus voltage without ESS, battery only system and with HESS.

Fig.6 shows the generators output power (MW). The red line shows the power output of the two generators with HESS, the output power stayed constant at 9 MW both with and without pulse loads.

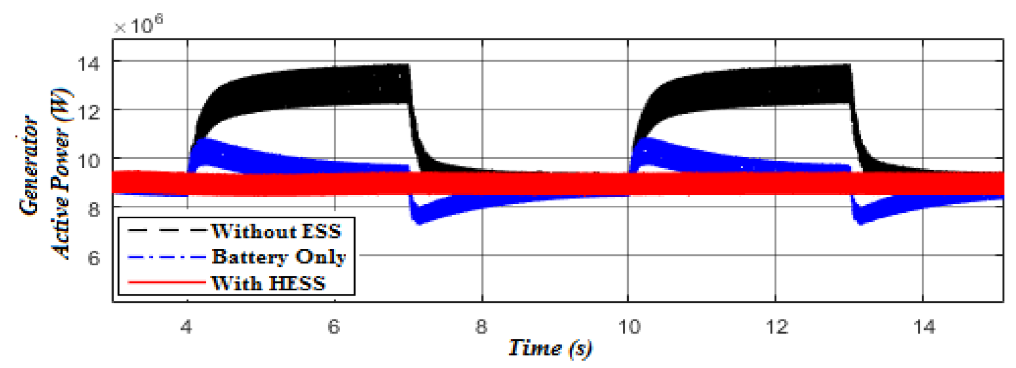

Fig.(6) The curve of the generator active power in the three different cases

The required speed of the motor in this system is 1500 RPM. Without ESS, the motor speed slows down to 1480 RPM when the pulsed load is applied, and the motor speed increases to almost 1520 RPM when the pulsed load is removed.

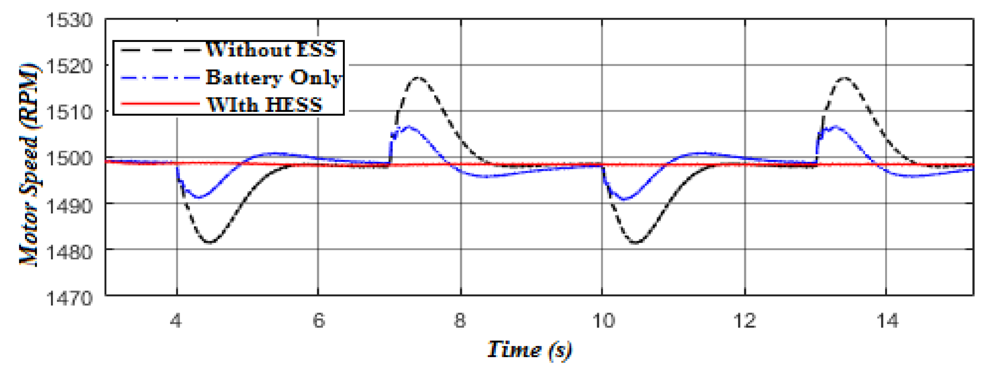

Fig.(7) The propulsion motor speed without ESS, with battery only and with HESS.

Simulation Results and Discussion

The SMES discharges when the pulse loads are applied and charges when the pulse loads are removed.

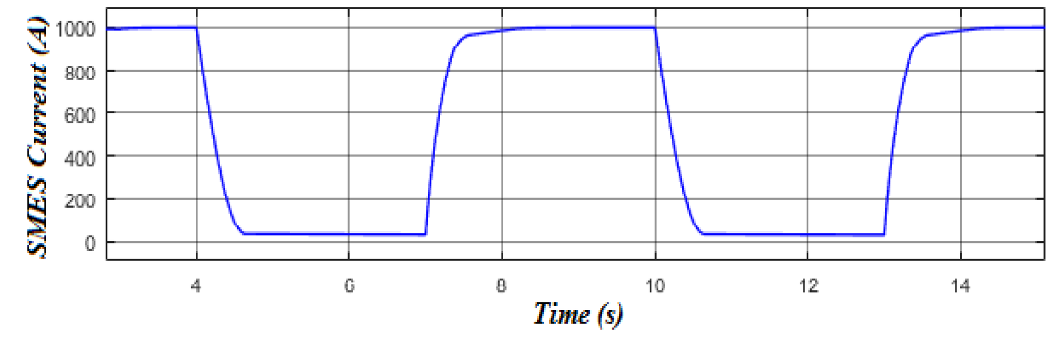

Fig.(8) SMES current

The SMES energy capacity to maintain the voltage at the required range is 500 kJ. The battery capacity was calculated at 13.88 kWh to cover the requirements of the pulse loads demand and to maintain the battery SOC constraints.

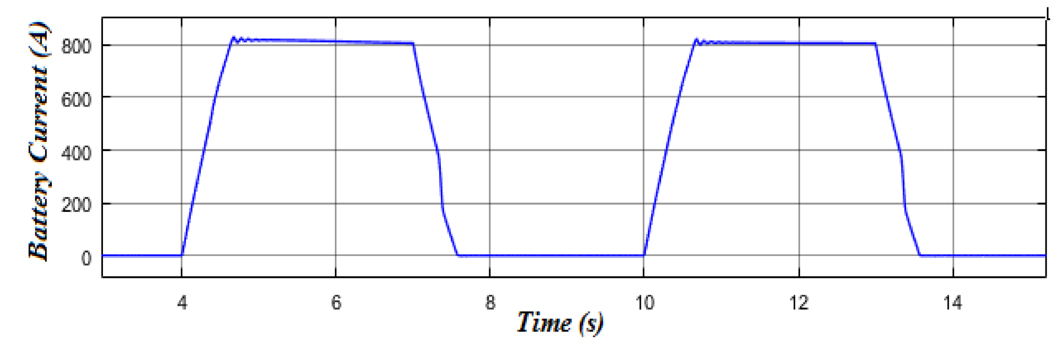

Fig.(9) Battery output current.

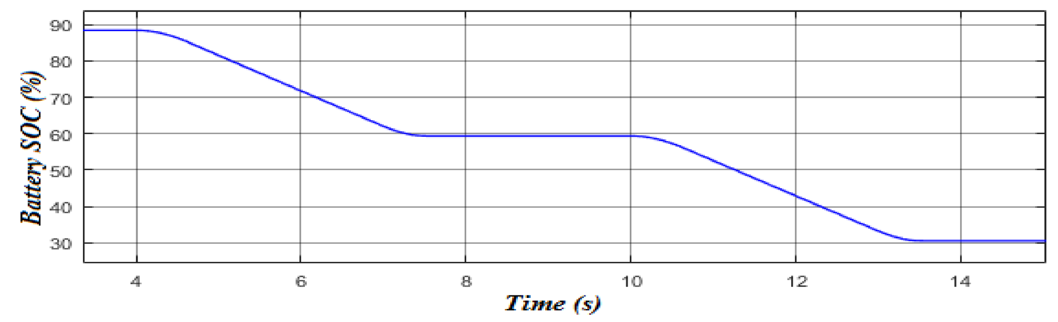

Fig.(10) Battery State of Charge

Conclusion

- The simplified AES including HESS has been modelled successfully in Matlab/Simulimk platform to test the effectiveness of the HESS on the ship power.
- The hybrid SMES/Battery demonstrated good performance during the sudden load changes by:
  - ✓ Maintaining the main DC bus at the targeted range.
  - ✓ Keeping the motor at the required speed.
  - ✓ Maintaining constant generation output power both with and without pulse loads.