Energy Storage in Super-Capacitor with Bidirectional Power Flow Control Strategy

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Abstract: *As renewable energy sources like solar and wind become more popular, we need better ways to store extra energy. Supercapacitors are a promising option because they charge and discharge quickly and last a long time. However, to use them effectively, we need a smart system to control how they store and release energy. This research proposes a new control system for supercapacitors that uses a special converter called an MMC. This system allows supercapacitors to charge and discharge faster and respond better to changes in power demand. It's also more efficient, flexible, and reliable than traditional systems. The researchers tested the system using computer simulations and studied how different factors affect its performance. This paves the way for using supercapacitors more effectively in storing renewable energy.*

Keywords: *Cascaded, Super-Capacitor, Dual active bridge, State-of-Capacitor*

I. INTRODUCTION

The vessel-integrated power system has received extensive attention in the fields of ship propulsion, ship informatization, and DC power distribution. In the future, IPS will be one of the inevitable technical routes for renewable energy ships. In recent years, with the increasing demand for higher ship power supply reliability, equipment of pulsed loads and new high-energy weapons, energy storage systems have become an indispensable part of the second-generation IPS.

Therefore, the energy storage converter connected to the IPS medium voltage DC (MVDC) grid needs to be characterised by high voltage and large capacity, voltage conversion, electrical isolation and bidirectional conversion. To match the MVDC power grid, the converter can adopt series-parallel technology, among which the input series output parallel (ISOP) structure is the most commonly used structure, which can improve the voltage and current level of the converter.

In a power electronic transformer consisting of H-bridges cascaded by DABs is proposed to improve the power level of the train traction system. In literature, multiple standardized DC-DC converters are combined in series and parallel to improve the modularity and enhance the voltage and current level of the converter. However, most of the above topologies adopt centrally series-connected capacitors, and feature poor fault redundancy capability, so they are not suitable for occasions with high requirements on power supply reliability and continuity.

MMC is widely used in high-voltage and large-power applications because of its modular structure and fault tolerance. For high-voltage rail transit vehicles, the control strategies of super-capacitor energy storage systems based on MMC are studied. These two papers realize the balanced decoupling control of the power of super-capacitors, and put forward the corresponding energy management strategies.

In the control strategy of a modular multilevel energy storage system under two operating conditions of grid voltage symmetry and asymmetry is studied, which solves the problem of charge state balance of energy storage elements. In, a fault diagnosis method based on the combination of simple hardware detection circuit and Field Programmable Gate Array (FPGA) diagnosis algorithm for MMC super-capacitor energy storage system is proposed to improve the system's safety and reliability. Although the energy storage system based on MMC can solve the problems of MVDC grid access and fault tolerance, it can't realize the electrical isolation between MVDC bus and low voltage DC (LVDC) bus, and has high requirements for the design of power control strategy.

To realize the electrical isolation and voltage conversion, isolated bidirectional DC-DC converter needs to be used between MVDC grid and LVDC grid. DAB is a bidirectional DC-DC converter with electrical isolation capability and modular symmetrical structure. It has attracted extensive attention in the fields of electric vehicles, DC microgrids and energy storage systems. In, a solid-state transformer is proposed, which adopts the cascaded structure of half-bridge sub-module and DAB as the branch topology and ISOP as the overall structure. This topology is suitable for MV distribution network, because it is conducive to the realization of modular design and fault tolerance.

In a three port DC-DC converter composed of MMC, DAB and duplicate chopper circuits for IPS is proposed, which realizes the flexible power control among the MVDC grid, LVDC grid and distributed energy storage units. However, the above literatures study the application scenario of connecting resistive load on the LVDC bus of MMC-DAB. Their control strategy is that MMC controls the voltage of sub-module capacitors and DAB controls the voltage of the LVDC bus. If this strategy is extended to the application scenario with energy storage unit connected on the LVDC side, the DAB module usually controls the port current of the energy storage unit. To better control the port current of the energy storage unit, the filter inductor needs to be connected between the DAB converter and the energy storage unit. However, this will increase the volume and weight of the device, and the stability margin of the DAB control system is small. Especially when discharging the super-capacitor, the filter inductor and the filter capacitor at the later stage of DAB form an LC filter with large output impedance, which is easy to causes cascaded stability problems.

Based on the above analysis, to meet the application requirements of the vessel integrated power system, this paper studies the control strategy and stability of a super-capacitor energy storage system based on MMC-DAB. The main innovations of this paper are as follows:

(1) The bidirectional power conversion of a super-capacitor energy storage system based on MMC-DAB is studied and a control strategy based on independent control of sub-module capacitor voltage is FIGURE 1. Topology of super-capacitor energy storage system based on MMC-DAB. proposed.

(2) A 1MW engineering prototype of MMC-DAB energy storage system is designed and manufactured to validate the proposed control strategy.

II. TOPOLOGY AND DAB

A dual active bridge is a bidirectional DC-DC converter with identical primary and secondary side full-bridges, a high frequency transformer, an energy transfer inductor and DC-link capacitors. Energy transfer inductance in the model refers to the leakage inductance of the transformer plus any necessary external energy transfer inductance.

The two legs of both full-bridges are driven with complimentary square-wave pulses. Power flow in the dual active bridge can be directed by phase-shifting the pulses of one bridge with respect to the other using phase shift modulation. The control directs power between the two DC buses such that the leading bridge delivers power to the lagging bridge. The applied square waves to the bridges create a voltage differential across the energy transfer inductance and direct its stored energy.

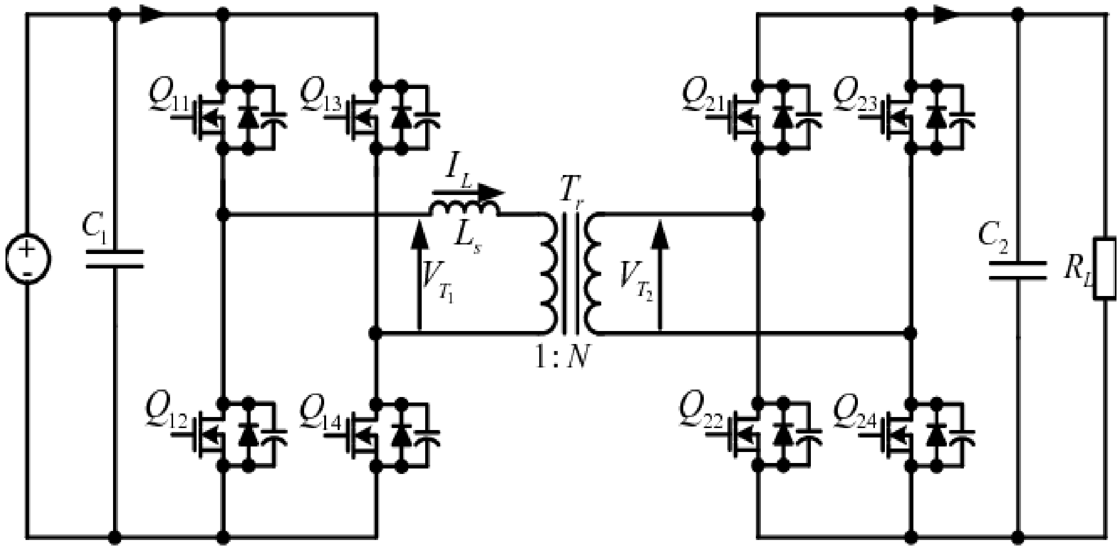


Fig.1: Schematic Diagram of Dual Active Bridge

III. SIMULATION RESULTS AND DISCUSSION

In this mode, a 60 Ω resistive load is connected to the MVDC side, and the charging and discharging experimental waveform of the 1MW modular supercapacitor energy storage system is shown in Fig. 2. In Fig. 3, the experimental waveforms of the voltage and current of the MVDC bus, sub-module capacitor voltage, supercapacitor voltage and supercapacitor current are given.

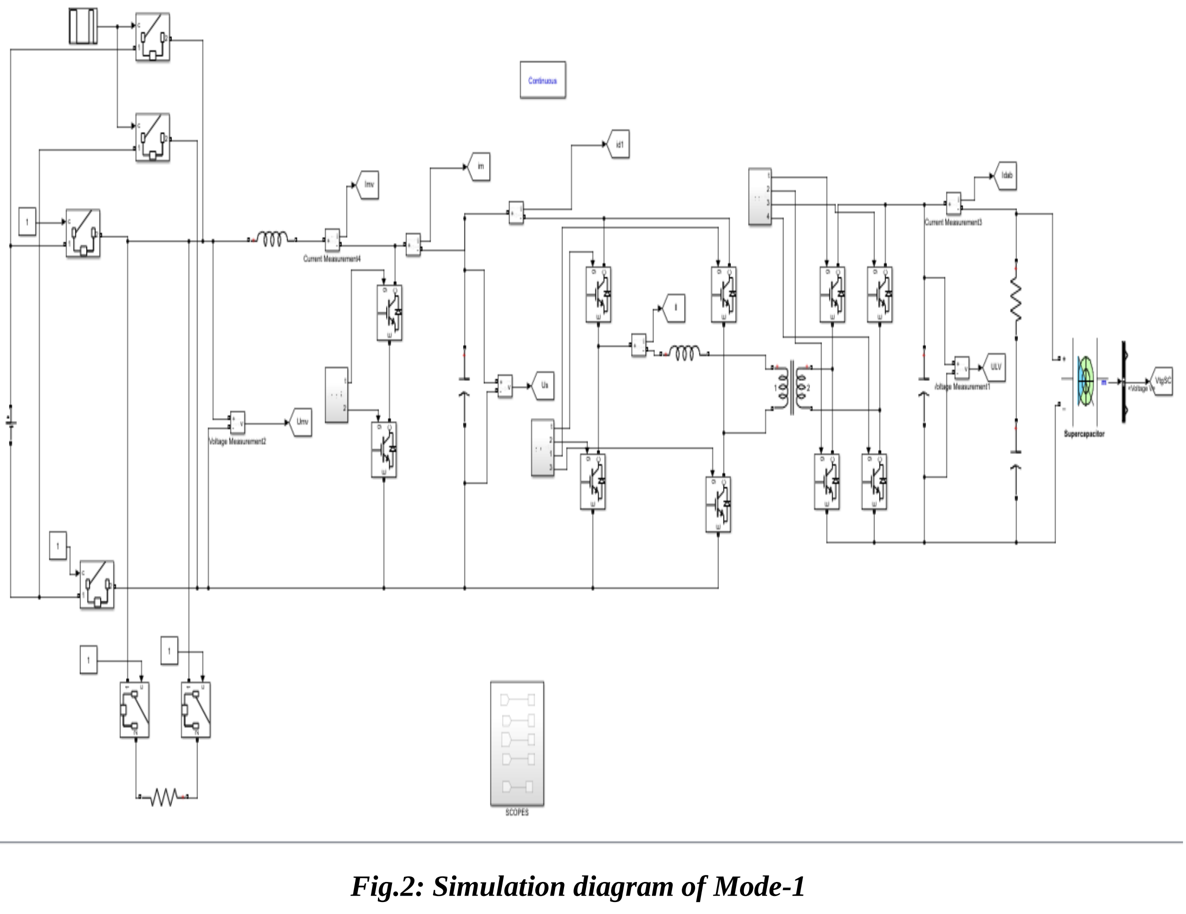
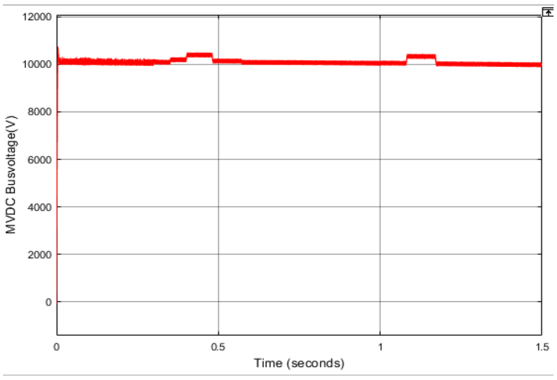
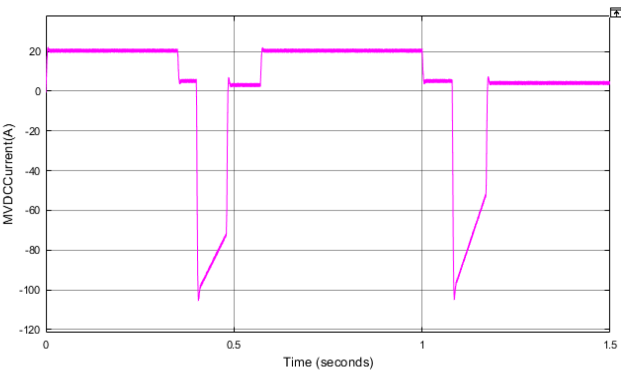


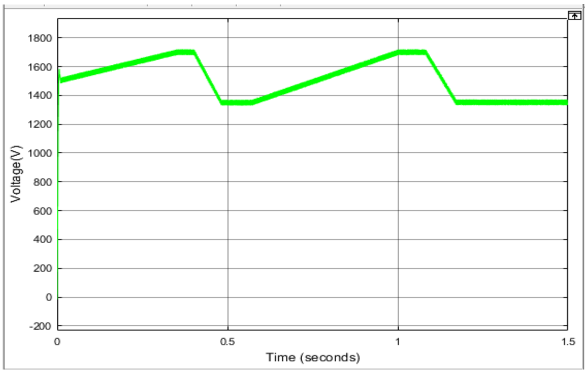
Fig.2: Simulation diagram of Mode-1



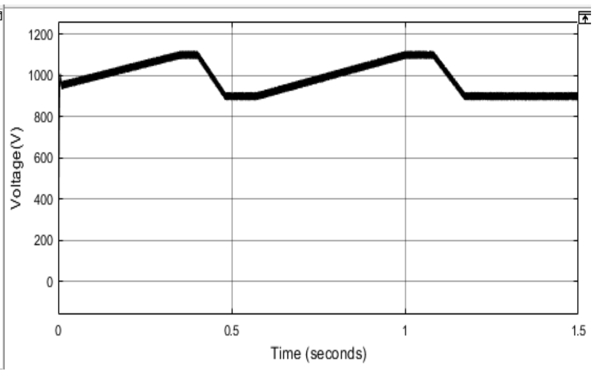
(a) Voltage (V)



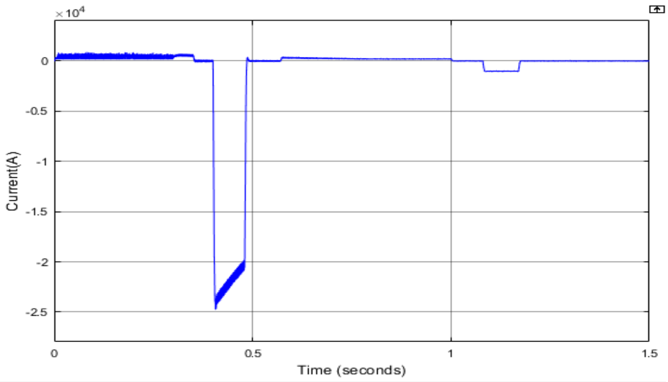
(b) Bus current of MVDC



(c) Sub module capacitor Voltage



(d) Super capacitor voltage



(e) Bus current of LVDC

Fig.3: Output wave forms of proposed system from mode-1 operation

Under the charging state, the 10kV DC power source supplies power to the supercapacitor energy storage unit through the converter. The reference value of the single branch current command of the DAB module is 20A. At this time, the charging current of the supercapacitor is 160A, the charging power reaches 160kW, and the supercapacitor voltage rises evenly from 860V to 1080V.

Besides, since the voltage at both ends of the DAB is controlled by voltage voltage-matching strategy, the sub-module capacitor voltage increases from 1376V to 1728V with the change of the supercapacitor voltage value.

When the reference value of the single branch current command of the DAB module is 0A, there is no power flow, the current of the LVDC bus is 0, and the supercapacitor voltage is unchanged. Under the discharging state, the reference value of the single branch current command of the DAB module is 125A.

At this time, the discharging current of the LVDC bus is 1000A, and the supercapacitor voltage decreases evenly from 1080V to 860V. The sub-module capacitor voltage command changes with the supercapacitor voltage value from 1728V to 1376V, and the discharge power of the system reaches 1MW.

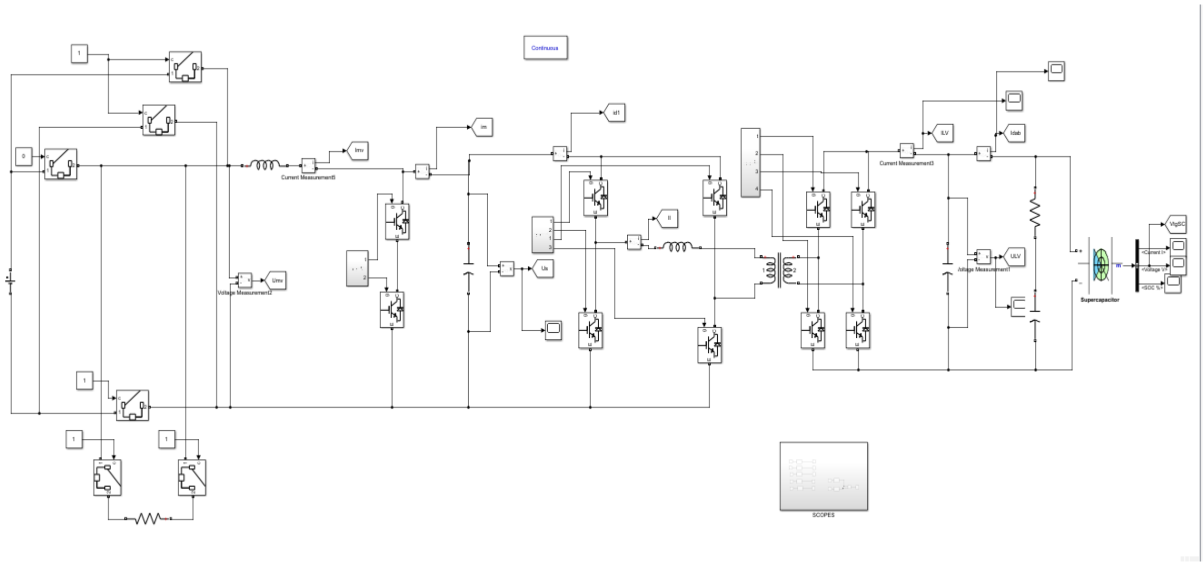
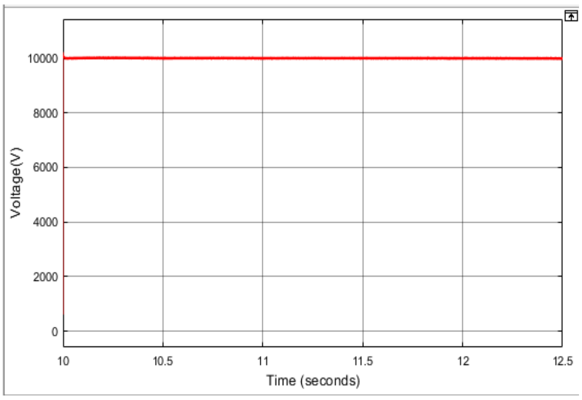
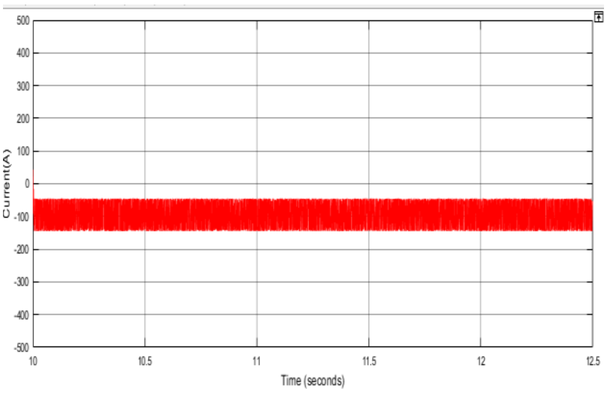


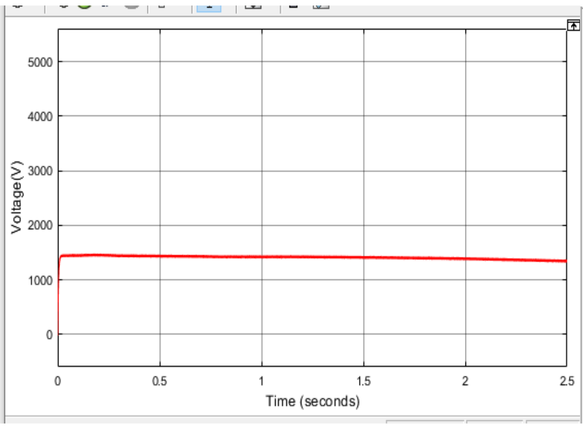
Fig.4: Simulation diagram of Mode-2

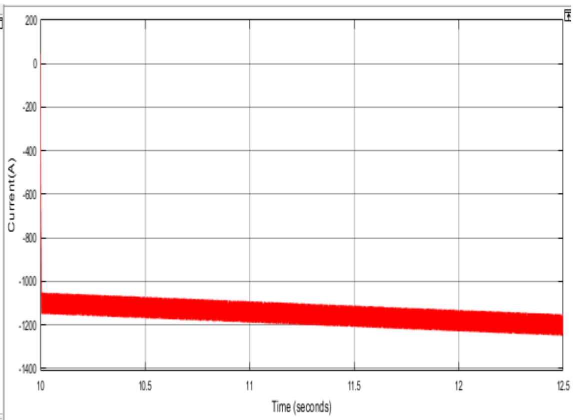
In Fig. 4, during the switching of charging and discharging current commands, the load at both ends of the MVDC grid fluctuates, and the internal resistance current Ir decreases, which causes the voltage waveform of the MVDC bus to fluctuate. But the voltage fluctuation is 1%, which is within the acceptable range.



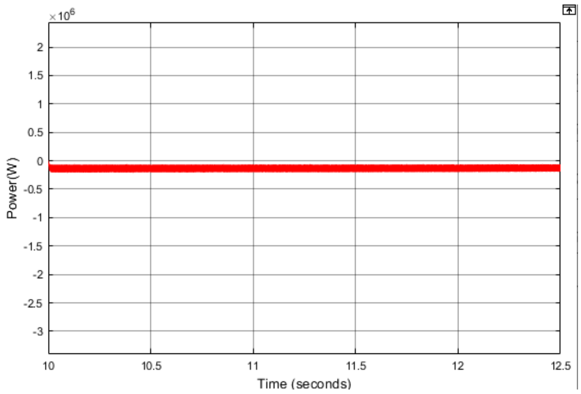


(a) Bus voltage of MVDC ***(b) Bus current of MVDC***





(c) Sub module capacitor voltage ***(d) Bus current of LVDC***



(e) Power(w)

Fig.5: Output wave forms of proposed system from mode-2 operation

Therefore, the supercapacitor energy storage unit can maintain the short-term support of the power grid energy at the MVDC side as shown in Fig.5, ensuring the reliability and sustainability of the power supply of the MVDC bus, making the energy flow more flexible.

IV. CONCLUSION

This research explores a new way to store energy on ships using supercapacitors. By connecting them to a specific part of the power system (LVDC bus) and utilizing a clever control strategy, the system can both regulate energy flow more reliably and provide short bursts of power for onboard needs. The study compares existing methods with the proposed approach, finding the new system to be significantly more stable. To prove its effectiveness, the researchers even built and tested a 1 megawatt version of this system successfully.

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