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Research on Coordinated Control of Multiple Energy Storage Systems Considering No-load Voltage Differences

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Abstract

With the continuous expansion of the scale of urban rail transit, its energy consumption problem has become increasingly prominent. The installation of hybrid energy storage systems in traction substations enables the energy recovery device to have both high power density and high energy density. Because the no-load voltage of the substation in the urban rail distributed power supply system is different and often fluctuates. If the energy management strategy of the energy storage system is improper, and the unfavorable situation of energy circulation between the substation and the energy storage and between the multiple energy storages will occur. In this paper, each part of the traction power supply system with stationary hybrid energy storage system is modeled first, and then three operating conditions based on different no-load voltages are analyzed. By increasing the charging threshold, some operating conditions can be avoided, but at the same time, the dynamic resistance is easier to start, so a control strategy needs to be proposed to solve this problem in the future.

Keywords: Urban rail system, Hybrid energy storage, No-load voltage, Energy circulation.

1 Introduction

At present, the recovery and utilization of regenerative braking energy mainly includes three ways: train operation map optimization, energy feedback and energy storage. Compared with the onboard energy storage system, the stationary energy storage system does not increase the weight of the train, does not occupy the vehicle installation space, and has the advantages of flexible installation and low development cost.

2 Traction power supply system with hybrid energy storage system

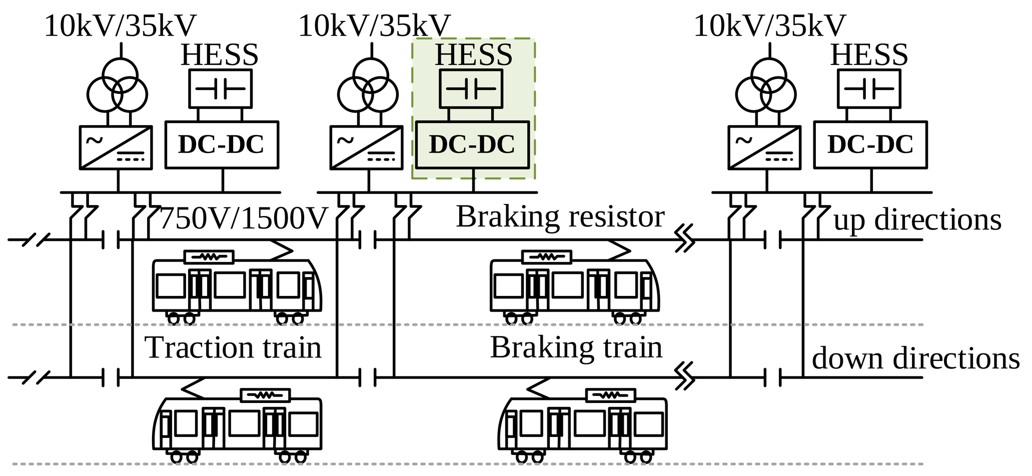

Fig. 1 Structure diagram of traction power supply system with stationary hybrid energy storage system

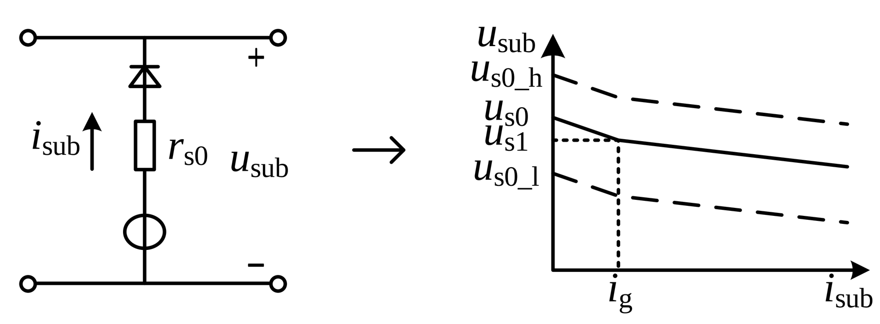

Fig. 2 Substation equivalent model and output characteristics

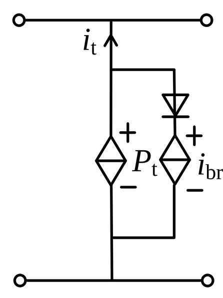

Fig. 3 Train equivalent model

An active topology in which the battery and the supercapacitor are independently controlled, that is, the battery and the supercapacitor are connected in parallel to the DC bus of the substation through bidirectional DC/DC converters, respectively. The battery module and the supercapacitor module respectively carry out the bidirectional flow of energy through the bidirectional DC/DC converter and the traction network to realize the recovery and utilization of the regenerative braking energy.

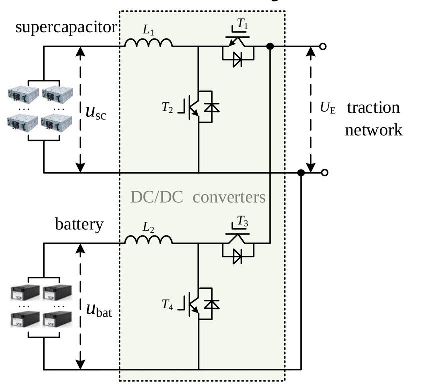

Fig. 4 Active topology of hybrid energy storage system

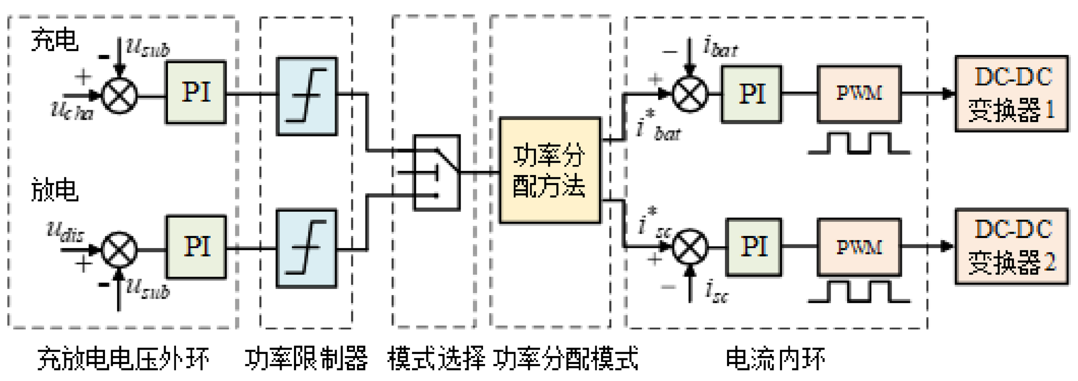

Fig. 5 Control structure diagram of hybrid energy storage system

3 The effect of different no-load voltage on configuration

This paper studies the line conditions of the certain line of Beijing Subway, which has a total of 13 stations. Among them, there are nine traction substations. From Sihuidong to Tuqiao Station, each station is equipped with energy storage devices.

TABLE I HYBRID ENERGY STORAGE CONFIGURATION

Substation	Supercapacitor (MW)	Battery (MW)
Sihui	0	0
Sihuidong	1.5	0
Gaobeidian	0	0
Communication University of China	1.5	0
Shuangqiao	0.8	0.2
Guanzhuang	1.5	0
Baliqiao	0.8	0.2
Tongzhoubeiyuan	1.5	0
Guoyuan	1.5	0
Liyuan	0.8	0.2
Tuqiao	1.5	0

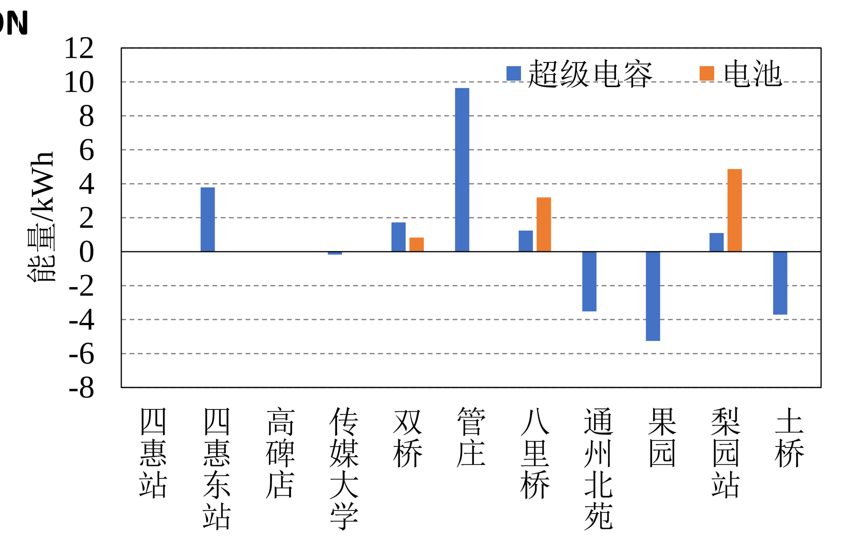

Fig. 6 Difference of energy storage charging energy

According to the current configuration of the subway line, analyze the four groups of simulations without energy storage, with energy storage, the same no-load voltage, and different no-load voltages at the 300s departure interval, calculate the change of the energy-saving rate, and analyze the difference in the no-load voltage for the configuration of the influences.

TABLE II ENERGY CONSUMPTION OF EACH PART OF THE SYSTEM

Energy/kWh	Without ESS		With ESS	
	same no-load voltage	different no-load voltage	same no-load voltage	different no-load voltage
System energy consumption	317.46	320.78	265.95	272.30
Braking resistance loss	50.24	53.84	3.61	8.69
Line loss	28.62	28.12	24.01	25.10
Energy saving rate	-	-	16.22%	15.11%

The table II compares the energy consumption of each part of the system and the change of the energy saving rate when the no-load voltage is the same or different. Compared with the same no-load voltage setting, the energy consumption of the system and the loss of the braking resistor have increased, and the line loss after installing the energy storage has also increased. The energy saving rate dropped from 16.22% to 15.11%.

4 The effect of different no-load voltage on the control strategy

TABLE III ENERGY CONSUMPTION OF EACH PART OF THE SYSTEM

Energy	Value/V
Sihui output energy	0.1066
Sihuidong output energy	0.0518
Gaobeidian output energy	0.9316
Energy storage charge	8.905
Energy storage discharge	0
Train input braking energy	8.988
Braking resistor loss	0.473
Train regenerative braking energy recovered from energy storage	8.515
Energy from substation charging to storage	0.39

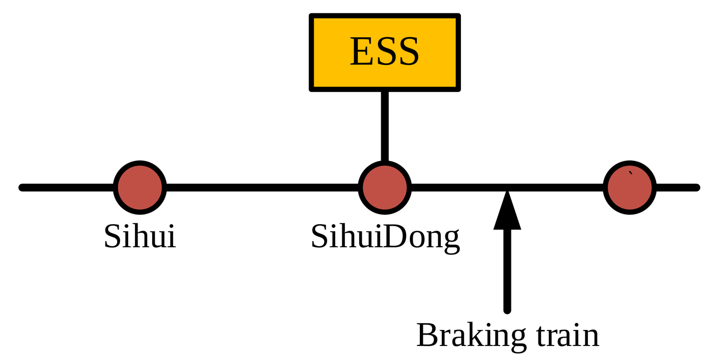

Fig. 7 Case 1: Substation charging energy storage

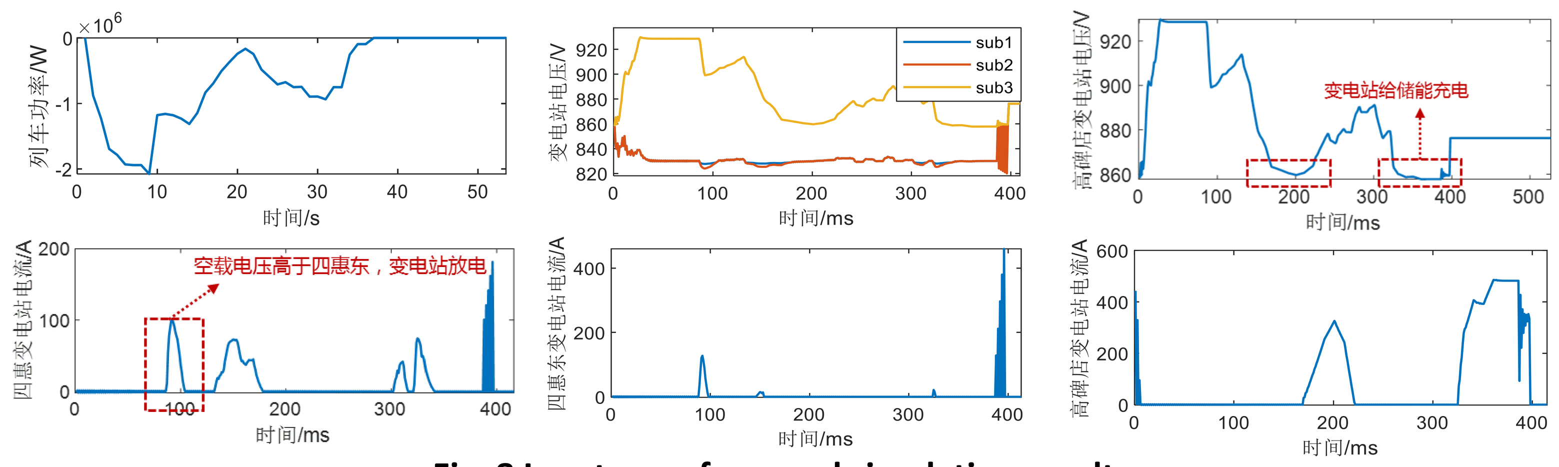

Fig. 8 Input waveform and simulation results

TABLE III ENERGY CONSUMPTION OF EACH PART OF THE SYSTEM

Energy	Value/V
Sihui output energy	0.0241
Sihuidong output energy	0.0355
Gaobeidian output energy	9.1984
Sihuidong energy storage charging energy	4.625
Gaobeidian energy storage and discharge energy	4.485
Train input traction energy	8.988
Braking resistor loss	0

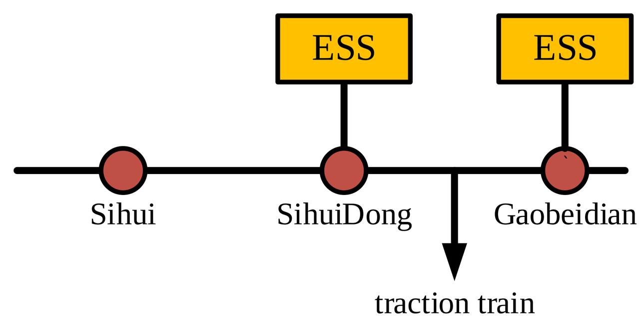

Fig. 9 Case2: Mutual charging between energy storage

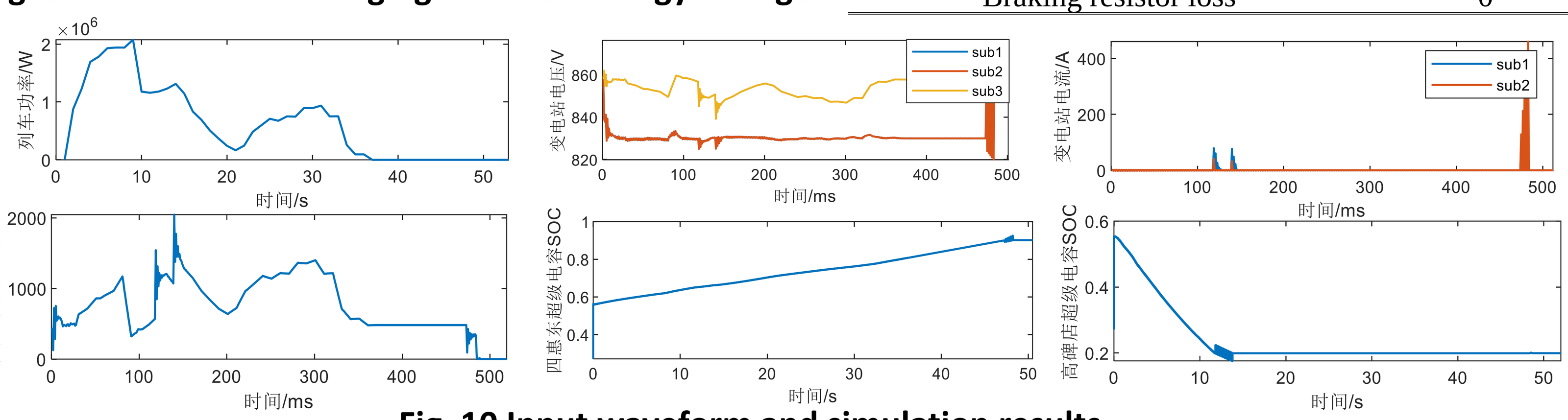

Fig. 10 Input waveform and simulation results

TABLE IV ENERGY CONSUMPTION OF EACH PART OF THE SYSTEM

Energy	Value/V
Substation output total energy (Gaobeidian)	0.535
Energy storage charge	8.669
Energy storage discharge	0
Train input braking energy	8.988
Braking resistor loss	0.676

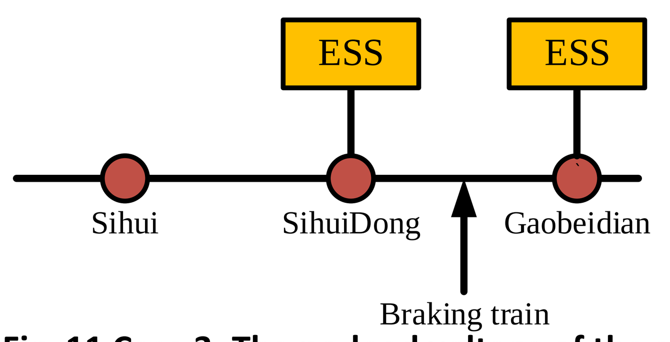

Fig. 11 Case 3: The no-load voltage of the substation is close to the starting voltage of the braking resistor

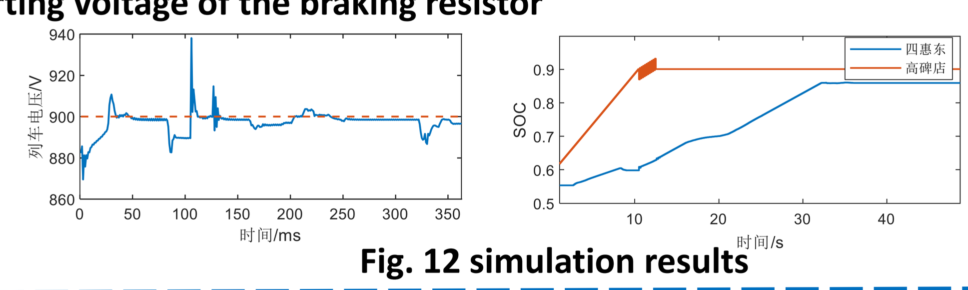

Fig. 12 simulation results

5 Summary

This paper mainly analyzes the charging and discharging control strategy problem of multi-energy storage system under the condition that the no-load voltage of the substation is different and fluctuates with time in the urban rail distributed power supply system. Firstly, the model of each part of the traction power supply system with stationary hybrid energy storage system is modeled, and then three kinds of work based on the energy circulation between substations and energy storage with different no-load voltages and between multiple energy storages are analyzed. Some working conditions can be avoided by increasing the charging threshold, but at the same time, the braking resistor is easier to start. Therefore, a control strategy needs to be proposed to balance the problem of energy circulation and braking resistor starting.