IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES 2023)

Tutorial Proposal

- **Tutorial Title: Super Capacitor Energy Storage Technology for Urban Rail Transit**
- **Presenter(s):** Prof. Zhongping Yang, Beijing Jiaotong University; Prof. Fei Lin, Beijing Jiaotong University; Post-doctoral, Zhihong Zhong, Beijing Jiaotong University
- **Brief description:** No more than 600 words
- With the rapid development of urban rail transit, the problem of energy consumption has become increasingly prominent. With the aim of reducing energy consumptions of urban rail transit system, more and more energy recovery systems are put into operation on metro lines in China. It also presents new challenges to the control and energy management of regenerative energy recovery systems.
- Super capacitors(SC) have the advantages of high power density, fast charge and discharge speed, and long cycle life, which matches the features of frequent braking and high braking power of urban rail transit. This tutorial is based on more than ten years of research in our laboratory, focusing on SC energy storage technology.
- The content of this tutorial will cover the background, application, research and future prospects. It is mainly divided into the following parts.
- ① Background of super capacitor energy storage technology of urban rail transit. It includes the analysis of the current situation of regenerative braking energy utilization, the application of different forms of regenerative energy utilization in urban rail transit, and the advantages and disadvantages of different forms of regenerative energy utilization.
- ② Energy management of single energy storage system of SC. Based on the accurate modelling of the urban rail traction power supply system with SC energy storage system, the influence of multi-dimensional factors such as no-load voltage and train operation status on the utilization effect of regenerative braking energy is shown, the main problems existing in the existing strategies are analyzed. Further, to compensate for the low energy density of SC, which results in insufficient performance at certain operating conditions, the control and energy management strategies of hybrid energy storage system are analyzed.
- ③ Collaborative control strategies for multi-storage systems. In order to solve the problem of train regeneration failure and fully absorb the remaining regenerative braking energy, it is

necessary to install multiple sets of regenerative braking energy recovery systems in the Metro lines. On the other hand, in view of the existing line operation characteristics and substation space constraints, there may be multiple systems coexisting in the same line with different technical routes. Based on the energy management strategy of single energy storage system, this report builds a feasible energy management framework from the system perspective, analyzes and coordinates the energy flow among multiple sets of regenerative energy utilization systems, and proposes a feasible collaborative control strategy. In addition, considering that the on-board energy storage system is not limited by the distance of energy transmission, and has the advantages of lower line loss and faster response speed, the co-control technology of the on-board energy storage systems and the existing stationary energy storage systems will also be shown in this report.

- ④ Capacity Configuration Based on Power Flow and Energy Flow. Real-time power flow and energy flow analysis algorithms based on multidimensional matrix operations are presented, as well as two-stage capacity configuration techniques.
- ⑤ Prospect of regenerative energy recovery technology for urban rail transit. The existing problems and deficiencies in energy storage systems of urban rail transit are extracted, and suggestions for the future technological development and application direction are given.
- **Duration:** 1 hour
- **Outline:** An outline shall define topics and subtopics. No detail description (No more than 600 words)
- **1. Background of Regenerative Braking Energy Recovery for Urban Rail Transit**
- 1.1. Current status and existing problems of regenerative energy recovery in rail transit
- 1.2. Application of different forms of regenerative energy recovery technology
- 1.3. Advantages and disadvantages of different types of regenerative energy recovery technology
- **2. Energy Management Strategies for Single-Storage System of SC**
- 2.1. Definition of key indicators and analysis of multidimensional influencing factors
- 2.2. Comparative analysis of energy management strategies
- 2.3. Fuzzy control based on weak information flow
- 2.4. Reinforcement learning algorithm based on strong information flow
- **3 Hybrid Energy Storage Strategy**
- 3.1. Limitations of SC energy storage system
- 3.2. Power allocation strategies based on different energy storage characteristics
- 3.3. Analysis of online operation data of Liyuan Station on Beijing Metro Batong Line
- **4. Collaborative Control of Multi-Energy Storage Systems**

- 4.1. Energy flow analysis of multi-stationary energy storage systems
- 4.2. Collaborative control of multi-storage systems with centralized optimization and distributed decision
- 4.3. Collaborative control of on-board and stationary energy storage system based on offline optimization and rule mining
- **5. Two-stage Capacity Configuration Technology Based on Power Flow and Energy Flow**
- 4.1. Real-time power/energy tracking technology based on multidimensional matrix operations
- 4.2. Collaborative optimization of capacity configuration and system parameters
- **6. Conclusions and Prospects**
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- **Motivation and Focus:** Briefly explain why the topic is important for IESES 2023 and an overview of the learning outcome (No more than 600 words)

Since the 21st century, urban rail transit has entered a rapid development stage. With China as an example, by the end of 2021, the running mileage of urban rail transit in China has reached 9207km, of which 7210km is the Metro mileage. With the increase of running mileage, power consumption is also increasing year by year. The annual power consumption of Metro is 21.31 billion degrees, of which traction power accounts for about 53% of the total power consumption. The energy consumption of urban rail transit system has the characteristics of huge value, complex composition and numerous influencing factors. Research and application of regenerative braking energy utilization equipment to effectively reduce energy consumption of urban rail transit system, especially traction energy consumption, is of great significance to promote green sustainable development of urban rail transit in China. In addition to direct energy-saving benefits, additional benefits such as reduced brake pad wear, reduced rail potential and reduced peak power of substation also play an important role in energy saving and consumption reduction of urban rail transit.

This report mainly includes the following outcomes.

1. Overview of related research and application at home and abroad
2. Analysis of the multidimensional factors on the energy utilization effect
3. Energy management strategies based on different information flows
4. Demonstrative application and effect analysis of power-type and energy-type hybrid systems
5. Collaborative control of multi-storage systems with centralized optimization and distributed decision-making
6. Collaborative control of on-board and stationary energy storage systems based on offline optimization and rule mining
7. Real-time power/energy tracking technology

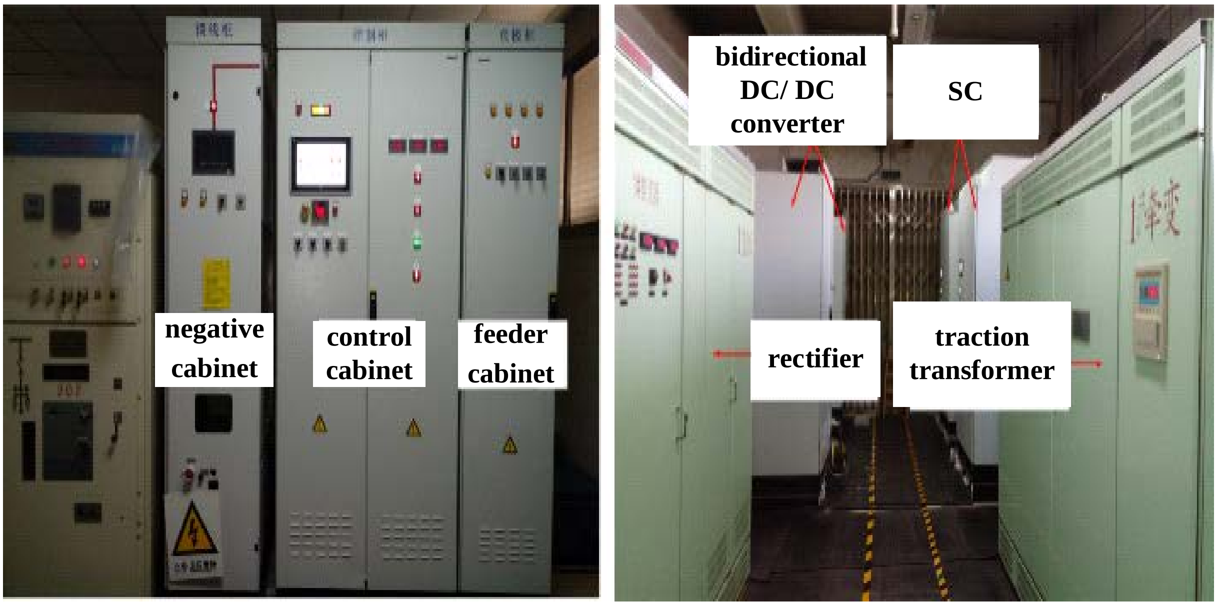

Fig.1 Application of power-type and energy-type hybrid systems

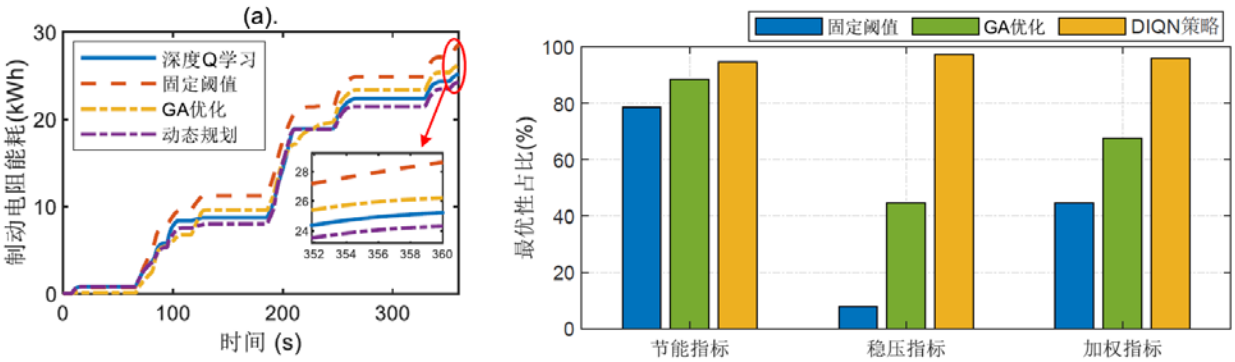

Fig.2 The effet of reinforcement learning algorithm based on strong information flow

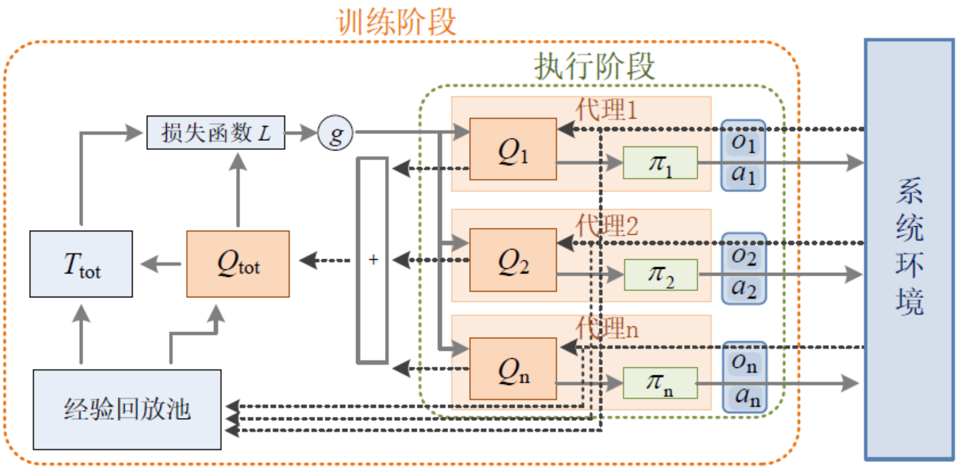

Fig.3 Collaborative control of multi-storage systems with centralized optimization and distributed decision-making

Prospects for future technologies

- **Brief CV:** Photo, name, email, and short resume (relevant to the proposal).

Zhongping Yang (M'14) received the M.Eng. degree and Ph.D. degree from the University of Tokyo, Tokyo, Japan in 1999 and 2002 respectively. He is currently a Professor of Beijing Jiaotong University, Beijing, China. His research interests include high-speed rail integration technology, traction & regenerative braking technology. E-mail: zhpyang@bjtu.edu.cn.

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- **Relevant publications:** Up to 5 publications including edited books

- 1. Zhu F, Yang Z, Xia H, et al. Hierarchical Control and Full-range Dynamic Performance Optimization of Supercapacitor Energy Storage System in Urban Railway[J]. IEEE Transactions on Industrial Electronics, PP(99):1-1.
- 2. Q. Qin, T. Guo, F. Lin and Z. Yang, "Energy Transfer Strategy for Urban Rail Transit Battery Energy Storage System to Reduce Peak Power of Traction Substation," in *IEEE Transactions on Vehicular Technology*.
- 3. Zhong, Z. Yang, X. Fang, F. Lin and Z. Tian, "Hierarchical Optimization of an On-Board Supercapacitor Energy Storage System Considering Train Electric Braking Characteristics and System Loss," in *IEEE Transactions on Vehicular Technology*, vol. 69, no. 3, pp. 2576-2587, March 2020, doi: 10.1109/TVT.2020.2967467.
- 4. F. Zhu, Z. Yang, Z. Zhao and F. Lin, "Two-Stage Synthetic Optimization of Supercapacitor-Based Energy Storage Systems, Traction Power Parameters and Train Operation in Urban Rail Transit," in IEEE Transactions on Vehicular Technology, vol. 70, no. 9, pp. 8590-8605, Sept. 2021, doi: 10.1109/TVT.2021.3100412.
- 5. Liu Yuyan, Yang Zhongping, Wu Xiaobo, at al. Adaptive Threshold Adjustment Strategy Based on Fuzzy Logic Control for Ground Energy Storage System in Urban Rail Transit[J]. IEEE Transactions on Vehicular Technology , 2021, 70(10): 9945-9956.

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Deadlines:

Full paper submission:	Feb. 5, 2023
Paper acceptance notification:	Apr. 15, 2023
Camera-ready paper submission:	May 15, 2023

Please send this completed document to:
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