The Renewable Powered Railway: Renewable Railway Power Network Design with Optimal Energy Management

I. Introduction

Influenced by the growing daily travel demand of citizens and extension of urban land, the construction of the urban railway transit (URT) system is gradually increasing nowadays. This situation implies more electricity consumption in URT and more challenges to URT operation stability. Therefore, based on the existing traction substation, this research proposes a configuration of multi-source traction system (MSTS) for URT with a coordinated control strategy according to power profile of the system.

II. Methodology

A. Structure of multi-source traction system

The proposed multi-source traction system (MSTS) has four main parts: (1) Railway traction substation. (2) Train vehicle. (3) Energy storage system. (4) Renewable energy. The RES and ESS form a micro-grid connected to a DC busbar, and directly linked to the third rail or catenary in the traction substation, which is shown in Fig. 1.

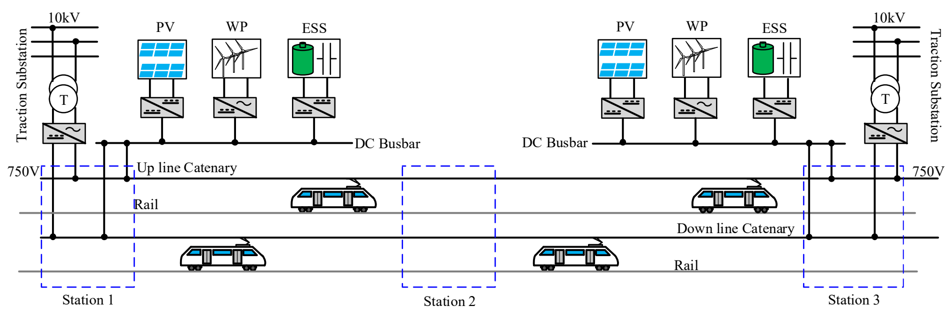

Fig. 1. Topology of the MSTS

B. Power flow analysis

To calculate the power flow of the proposed system, the nodal voltage equation method is applied here. The detailed calculation method is divided into two main parts: single-train simulator and multi-train simulator. The single-train simulator mainly obtains the train traction power demand, train regenerative braking energy, train velocity, and train location via the train movement model. In the multi-train simulator, the above results from single-train simulator will be considered together with timetable information. Then, the power and voltage of substations and catenary can be calculated via nodal voltage method in multi-train simulator.

C. Coordinated control strategy

To efficiently manage the power of each unit and reduce the energy consumption CTS, a coordinated control strategy, which considers the substation voltage, RES power, and SOC of ESS, is designed here. The proposed coordinated control strategy aims to reduce the energy consumption and peak power of substation and stabilize the voltage of substation. Meanwhile, the decrease in RES curtailment is also taken into account. To achieve a better performance of the proposed coordinated control strategy, the ESS discharging threshold need to be adjusted according to different scenarios. The charging threshold will not be optimized because the ESS SOC needs to be remained at a high level. The peak power and voltage range of substations are the main indexes of URT operation. Thus, a performance index is designed to optimize the ESS discharging.

III. Case study verification

The case study is based on three-station system (including two substations, shown in Fig. 1), considering two different departure intervals (120s for peak period and 300s for off-peak period). Firstly, the substation performance of conventional traction system (CTS) in two different departure intervals is analysed. Then, the CTS with ESS and multi-source traction system (MSTS) are compared under the proposed coordinated control strategy. At last, the MSTS is tested in long-term operation, and the system robustness is verified by extreme situation of RES.

The CTS simulation result is shown in Fig. 2 (a), and it can be obtained that both substation 1 and 2 peak power exceed 2.5 MW. The substation power keeps at a high value in peak period, while the substation power has a highest value (3.32MW) in off-peak period. The comparison between CTS with ESS and MSTS is shown in Fig. 2 (b). The peak power of substation 1 is 1.85MW MSTS, compared with 2.20 MW in CTS with ESS. The voltage drop in MSTS is also less than the one in CTS with ESS.

Long-term simulation results are shown in **Error! Reference source not found.**. It shows that the peak power of substation 1 is kept below 2.05 MW and 1.70 MW in peak and off-peak period, respectively. The voltage fluctuation is also remained from 817.9 V to 885.6 V and 826.9 V to 899.98 V in peak and off-peak period. The SOC of ESS 1 is kept above the minimum value which ensure the ESS has enough energy to provide the traction power.

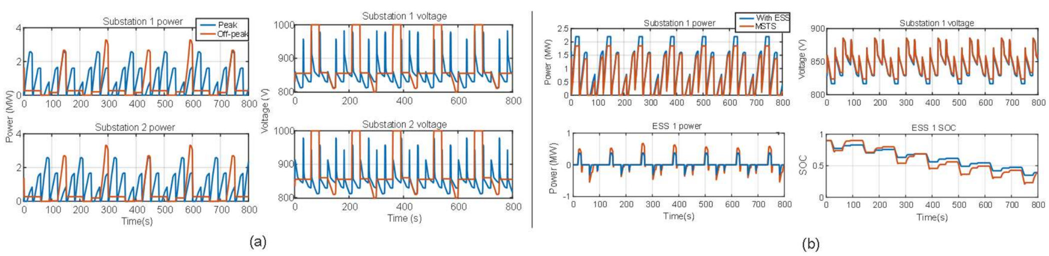

Fig. 2. Short-term simulation result: (a) CTS result (b) CTS with ESS and MSTS simlation result

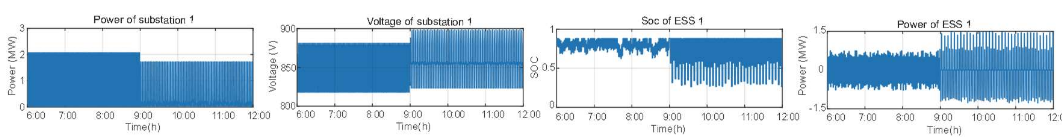

Fig. 3. Long-term simulation result (substation 1)

IV. Conclusion

The case study shows the proposed MSTS with the coordinated control strategy can reduce the peak power and voltage sag, and the substation capacity can be improved because of the decreasing peak power. In long-term simulation, the MSTS save 22.8 % energy consumption from substation compared with CTS. Besides, the robustness of the MSTS is verified by simulating extreme situations like RES fault. The proposed MSTS with coordinated control strategy can be applied in a full railway line, solving with more simulation time and nodal voltage equations. However, the proposed coordinated control strategy needs to be designed separately for scenarios with different departure intervals, and other factors like the effect of the passenger's quantity are not considered. The future research will consider a more detailed modelling method, and the real-time control strategy will be applied to cope with the uncertainty of the system. Besides, ESS will also be charged by substation to achieve an economy operation. At last, the system will be tested in a hardware-in-loop system with actual railway system data.