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Control of urban rail transit equipped with ground-based supercapacitor for energy saving and reduction of power peak demand

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ABSTRACT

An energy storage system based on Supercapacitor (SC) for metro network regenerative braking energy is investigated. The control strategy according to the various power requirements in metro line and differing characteristics of these storage devices are proposed to manage the energy and optimize the power supply system performance. In order to estimate the required energy storage system (ESS), line 5 of Beijing metro network is modeled through a novel approach, in different running interval conditions based on the real data obtained from Beijing metro office. A useful method is proposed to predict the instantaneous regenerative energy which is delivered to each substation before applying ESS and based on that the ESS configuration for each substation is determined. A simplified mathematical model of the whole metro network has been developed and the main features of the control strategy have been developed. Numerical simulations show the efficacy of suggested control and the energy saving obtained for metro trains.

Introduction

Urban rail transit has some advantages such as a large capacity, timing, safety, environmental protection and energy saving i.e. when environmental protection was advocated in the world, to prevent the greenhouse effect today, the advantages of energy-saving, environmental protection of urban rail transit more and more get the attention of people. For the city railway train, regenerative braking mode is the main way of braking. Train regenerative braking energy can supply other train traction state using the same power supply area, so as to reduce the energy consumption of train. But when the train regenerative braking reduces the reliability and security of the urban rail transit, there may be renewable failure situation. In recent years, flywheel, battery, super capacitor energy storage device, such as solution regeneration failure of the practical application of growing, how to use energy storage device to solve this problem is becoming more and more urgent.

SC energy storage compared to other energy storage method has long cycle life, high power density and no pollution to the environment, etc., has gradually been widely used. The time of charge and discharge of SC is short, the urban rail transit operation is frequent start–stop and voltage peak obvious fluctuate, and this is a very good fit SC and therefore SC is an important choice for energy storage components in the area of urban rail transit. SC is a further popularized application.

Paper [1] urban rail power supply on Pscad environment, network model, regenerative current value on each substation simulation has carried on the super capacitor capacity in accordance with the configuration and the economic evaluation; Paper [2] in the Matlab environment for urban rail traction power supply simulation, and respectively under different control strategies for vehicular and ground type SC energy storage system is analyzed in capacity configuration and energy saving. In [3] and [4], electrical trains have been considered as a useful public transportation that their efficiencies can be improved by applying the ESS; however, ESS sizing and network modeling have not been discussed in these references. In [5], different mechanical and electrical techniques have been overviewed in order to improve the energy efficiency in electrical railway systems. Some investigations have been done about the advantages of the onboard ESS in both electrical [6–11] and diesel trains [12–14]. Advantages of using different ESS for both onboard and stationary systems have been represented in [15], but the control algorithm, optimal positioning and ESS sizing have not been discussed. Quasi-static backwards looking method has been used for simulation of energy consumption of the vehicles in [16–21]. In [22–24], stationary ESS has been applied to save the regenerative energy. Stationary ESS has been proposed for voltage

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regulation of weak points in [25]. But, the metro network has not been modeled and the algorithm of ESS sizing has not been presented. Maximum regenerative energy of each station depends on the energy consumption of the auxiliary equipment, resistive forces, traffic conditions, and energy exchange between trains. Because of these difficulties, references [24–28] have considered several ESS with different capacitances and made several trial-and-error simulations to find the best configuration with the highest energy saving capability. In [22–24], the utilized power flow controller for ESSs is just based on the voltage variation of the supply line. In this paper, at first the regenerative current is analyzed, then the power flow controller is designed based on the voltage variation of the line, the current variation of electric line, and the maximum permissible charging current of the ESS. Since the current of ESS is under control, it is more reliable.

In this paper, the metro supply network and metro trains are modeled using real data obtained from Beijing line-5 metro office. The model shows the behavior of the metro line, trains, stationary ESS, and irreversible substations. The network model is simulated in the digital simulation environment of matlab software. In comparison with previous modeling methods presented in Refs. [13–16], the proposed approach presents a good physical insight into the network model. Moreover, it can be extended easily. Unlike [13–16] which use trial and error method to find the best ESS configuration with the highest energy saving, in this paper, an effective method is proposed to calculate the maximum instantaneous regenerative energy of each station analytically. Then, appropriate ESS configuration is suggested for each station.

System arrangement

This study is applied to the line-5 of Beijing metro network. The total length of the line is about 42 km. It connects the south west of Beijing to the north east of it with 24 stations.

Characteristics of network and control strategy

Fig. 1 shows the constitute of railway vehicle with power supply, including ESS, power mains, discharge and charge. From this figure, we know the flow direction of current with charge and discharger, and know the character of SC control curve. Motor control states can be divided into three modes. When powering, the traction motor absorbs energy from the feeder line, leading to the voltage drop; when braking, the motor as generator feeds energy to the feeder, leading to the voltage rise. The voltage fluctuation significantly affects the characteristic of the train running [20]. In this paper, the data used for the study are based on the real measurements of Beijing metro line 5 and are demonstrated in Fig. 2. The figure shows the details of driving cycle between two stations. Fig. 3 shows the running character of the whole line. The maximum speed is 80 km/h during acceleration and the maximum acceleration is 1 m/s^2.

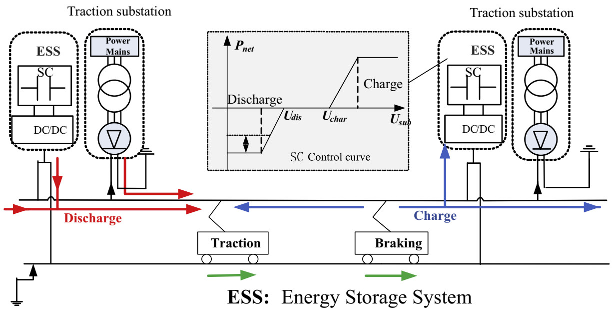

Fig. 1. Vehicle network traction characteristic.

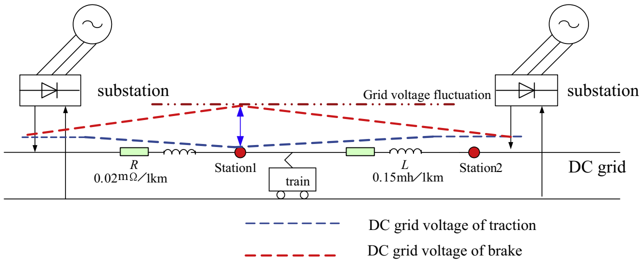

Fig. 2. Voltage fluctuation of DC system.

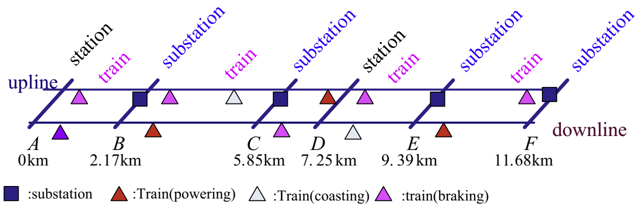

Fig. 3. Sketch of a domestic metro line.

The railway transit network model includes trains, unidirectional substations, ESS, and connecting lines, as shown in Fig. 4. Substations are modeled as ideal DC voltage sources. The connecting lines are modeled as electric resistances. Since the trains are moving between these stations, the resistance among the train, the starting station and the next station is time variant. Therefore, for each time point, these values were calculated as

$$R' = k * x(t)/1000 \quad (1)$$

$$R'' = k * (d - x(t))/1000 \quad (2)$$

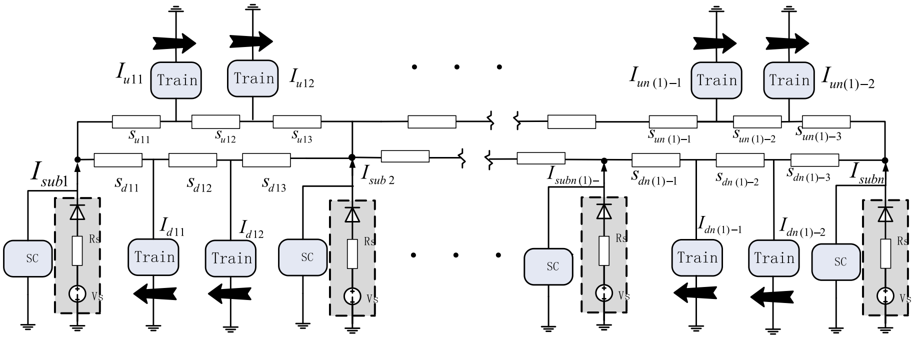

Fig. 4. Modeling of the metro network.