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Energy Storage Application into a Double DC Electric Railway

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Abstract

Electric trains use regenerative braking to improve the energy efficiency of DC electric railways. The regenerative braking power can cause overvoltage in the feeding line if it is higher than the power demand of the other trains at that instant. Braking resistors are activated to burn the excess energy to protect the network from overvoltage that originates from braking. This excess energy can be exploited by using an energy storage system (ESS). However, a stationary ESS may increase energy loss in the transmission line if its location is not optimal. This paper helps prove that the negative effect of a stationary ESS can be eliminated by optimal siting and voltage control.

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Keywords: Braking resistors; electric railways; energy storage system; regenerative power; transmission line losses;

1. Introduction

Power exchange in DC electric railways is an effective way to improve their energy efficiency. The regenerative power of a braking train is passed to other trains in power demand. However, a power mismatch or a long distance between trains reduces the transmission line's energy utilisation by wasting regenerative power as heat. Braking resistors are activated at a certain voltage threshold to dissipate regenerative power. In most DC electric railways, this regenerative power cannot be refed into the grid because of the unidirectional substations [1].

To optimise the energy efficiency of electric railways, reversible substations, onboard or stationary energy storage systems (ESSs) can be employed to reuse braking trains' regenerative energy. The high cost of using power converters to redirect the DC braking power into the AC distribution network makes it more enticing to store the regenerative energy in ESSs. Moreover, a major concern for using power converters is affecting the national grid's power quality by injecting harmonics and reactive power. On the other hand, ESSs can be implemented simply and have no impact on the power grid [2], [3].

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The position of installing ESSs in electric railways is significant because it can affect the benefits of using them. ESSs can be installed either aboard electric trains or in a stationary position alongside the tracks. An on-board ESS can store all of the regenerative energy of a certain train if the size of the ESS is large enough. On-board ESS installations result in very little regenerative power loss in the railway network's power line. However, the ESS's added weight to trains reduces energy savings. Stationary ESSs, on the other hand, are limited by the power losses in the transmission line. When trains brake far from the ESS's location, regenerative power loss in the transmission line is exacerbated. It is stated in [4], and [5] that stationary ESSs contribute to more energy loss in transmission lines than on-board ESSs. It is also stated that ESSs can reduce the power utilisation in the line by storing braking power that is supposed to be passed to running trains.

This paper investigates the energy savings in a double DC electric railway after applying a stationary ESS. It was assumed that the ESS is ideal in capturing and releasing power and has no sizing limits. The specific objective of this study was to investigate whether the negative contribution of ESSs by increasing the losses in electric railways can be avoided by optimal siting.

2. Case study

Since the proposed railway system is decoupled, it was decided to analyse the system between just two substations. The decoupling is used to isolate the sections electrically. This separation balances the load over the national grid and avoids shut-downs due to electrical faults or maintenance. The double railway track is illustrated in Fig. 1 and its parameters are displayed in Table 1. The trains receive power from the third rail and the power returns back to the substations through the fourth rail. The alphabets represent the passenger stations that are displaced by 1 km. The trains travel in two different directions and their diagrams are shown in Fig. 2. The modelling approach and the trains characteristics are discussed in detail in [6].

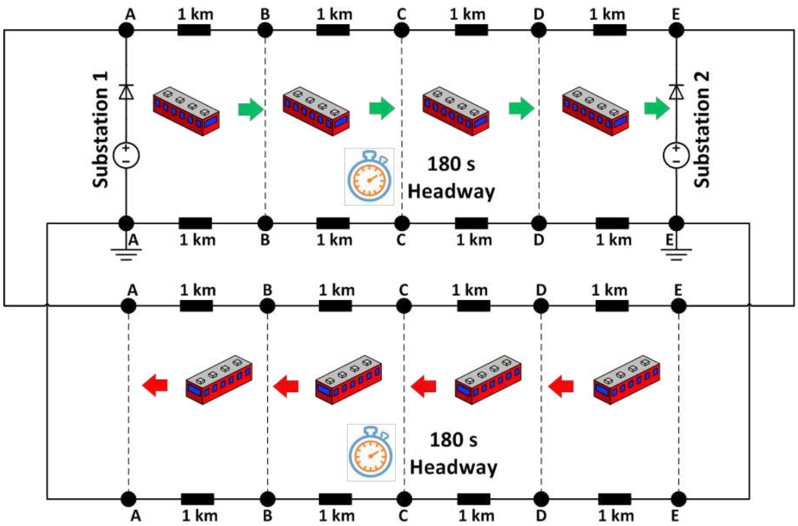

Fig. 1. Double railway track with two substations, five passenger stations, and eight running trains.

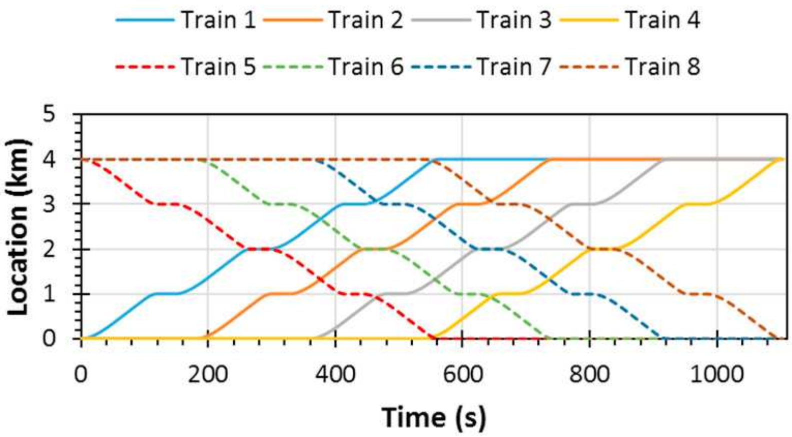

Fig. 2. Train diagrams for the double railway system.

Table 1. Parameters of the electric railway system.

Symbol	Quantity	Value
V_s	substation dc voltage	600 V
R_s	substation inner resistance	20 mΩ
R_d	rail electrical resistance	15 mΩ / km
V_{max}	voltage threshold	740 V

3. Optimal siting

The location's impact on energy storage in the proposed model is investigated in this section. An ideal ESS that has no limitations with power density and energy density was used to collect energy from braking trains and release it back to trains in power demand. It is worth mentioning that the charging voltage threshold in this study was 630 V and the discharging voltage threshold was 585 V. Changing these voltages will certainly change the presented results in this study. Before applying the ESS, the total energy loss in the railway system was 209.2 kWh. The total energy loss consists of energy lost in the internal resistors of the substations, the transmission line, and the braking resistors. After placing the ESS at different locations, it is concluded in Fig. 3 (a) that the best energy saving location is at passenger station C, which is located in the middle between the two substations. The figure also reveals that the least optimal locations for importing and exporting energy are passenger stations A and E, which is where substations 1 and 2 are located. Fig. 3 (b) displays the association between energy saving and the contribution in the losses reduction. The maximum power loss reduction in the system was found when the ESS was placed in midway between two identical substations. Therefore, to achieve optimal energy savings when using an ESS to import and export energy, it is better to place the ESS at a location where it highly reduces system energy losses.

Fig. 4 and Fig. 5 illustrate the transmission line's sensitivity to voltage control in terms of energy loss. The charging and discharging voltages were varied in small steps to study the effect of voltage variation on the transmission line's energy losses. In Fig. 4 the ESS was placed at interstation A before the charging and discharging voltages were varied in small steps. It is concluded that varying the discharging voltage threshold had no impact on line losses. This result is because the ESS was releasing power at the same location of the substation. On the other hand, charging at lower voltages increased the losses in the line. Charging at lower voltages reduced the line's receptivity by reducing the power exchange between trains which increased the line losses. In other words, the ESS imported the power that was supposed to go directly from braking trains to trains in power demand. Consequently, the substations had to feed this extra demand which required the power to travel for longer distance than before applying the ESS. Charging at higher voltages had no significant impact on increasing the line losses because the ESS was not highly involved in importing power. To summarise, substations are at the least optimal location for the ESS because the power travels for longer distance due to the ESS's negative contribution to reducing the power utilisation in the railway line.

Fig. 5 shows the voltage variation's impact on reducing the line's energy losses when the ESS was located between the two substations. The figure illustrates that exporting power in the middle reduced the line's energy losses significantly. This reduction is because the power travelled for less distance due to discharging at the furthest point from the two substations. For example, if a train is accelerating in the middle of the two substations, it will consume power from the ESS, which is very close to it instead of consuming power from the substations that are far away from it. Decreasing the discharging voltage threshold reduced the ESS's impact on reducing the transmission line's energy losses because the ESS was less involved in supporting the trains' power demand. Similar to Fig. 4, charging at lower voltages increased the transmission line's losses due to reducing the power utilisation of the line. However, charging at higher voltages reduced the losses because the ESS allowed the trains to exchange power before it got involved lately in importing the excess power.

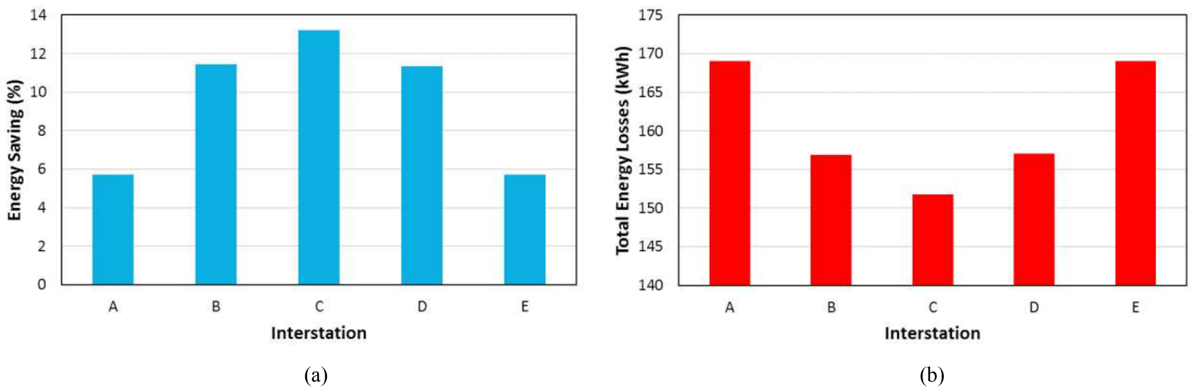

Fig. 3. (a) Energy saving after placing an ESS at different locations; (b) Total losses in the system after placing an ESS at different locations.

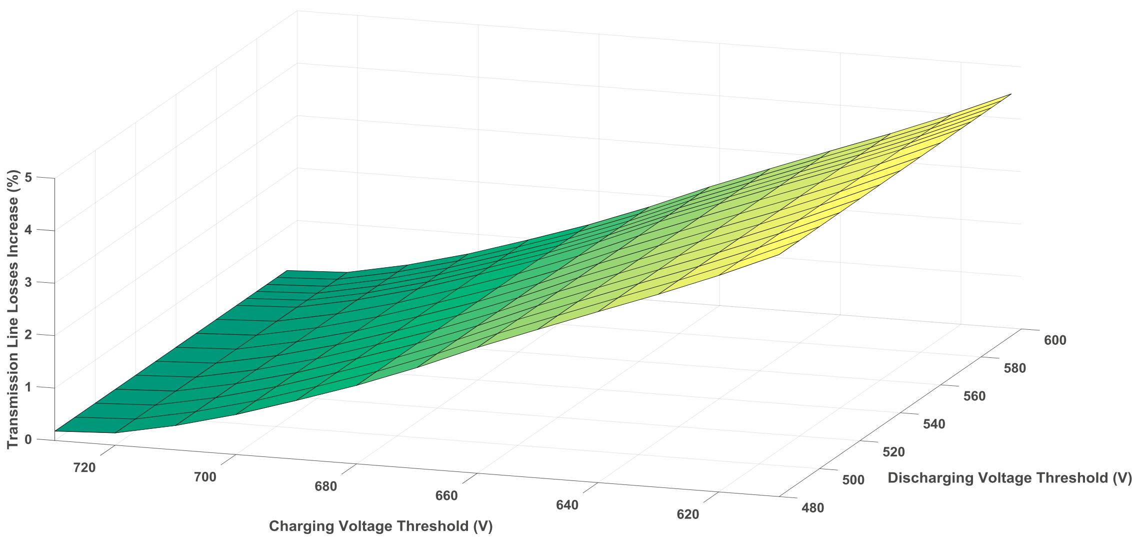

Fig. 4. Transmission line losses increase when placing an ESS at interstation A.

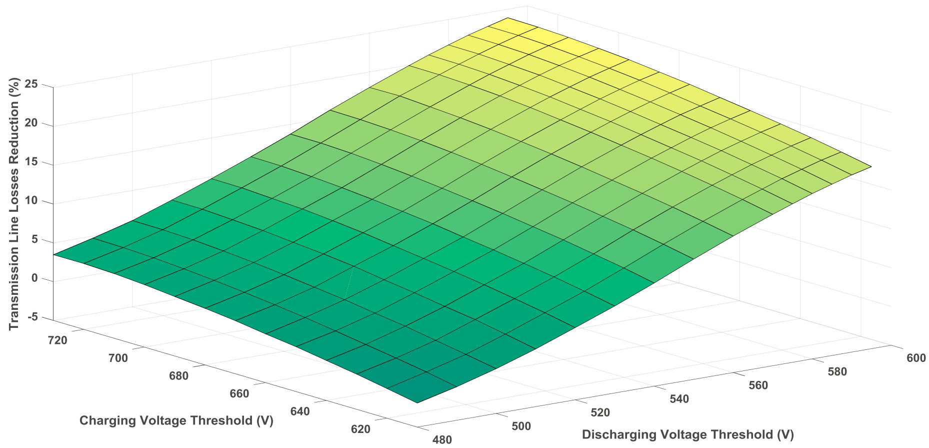

Fig. 5. Transmission line losses increase when placing an ESS at interstation C.

4. Conclusion

The work has presented a case study of eight trains running on a four km double railway. The feeding network voltage reaches high values during braking. To protect the network from overvoltage, braking resistors are connected in parallel with the trains to burn the excess energy. Therefore, an ideal ESS was used to exploit the excess energy instead of burning it in the onboard braking resistors. The optimal siting of ESS and voltage sensitivity analysis has been discussed in detail. It has been concluded that installing an ESS at the substations' locations contributes negatively, notably when importing power at lower voltages. This negative impact occurs due to reducing the railway line's receptivity. On the other hand, installing an ESS at the furthest point between two substations increases the energy efficiency of electric railways significantly due to the high reduction of energy loss.

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