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Energy Saving in Metropolitan Railway Substation Using Regenerative Braking

G.Ramakrishnaprabu[1], M.D.Thamilarasi [2]

Associate Professor, Dept. of EEE, VMKV Engineering College, Salem, Tamilnadu, India[1]

PG Student [PSE], Dept. of EEE, VMKV Engineering College, Salem, Tamilnadu, India[2]

ABSTRACT: Increasing attention is being paid to the energy efficiency in metro systems to reduce the operational cost and to advocate the sustainability of railway systems. Classical research has studied the energy-efficient operational strategy and the energy-efficient system design separately to reduce the traction energy consumption. This paper aims to combine the operational strategies and the system design by analyzing how the infrastructure and vehicle parameters of metro systems influence the operational traction energy consumption. Firstly, a solution approach to the optimal train control model is introduced, which is used to design the Optimal Train Control Simulator (OTCS). Then, based on the OTCS, the performance of some important energy-efficient system design strategies is investigated to reduce the trains' traction energy consumption, including reduction of the train mass, improvement of the kinetic resistance, the design of the energy-saving gradient, increasing the maximum traction and braking forces, introducing regenerative braking and timetable optimization.

KEYWORDS: Regenerative Braking System (RBS), energy storage systems (ESSs), electromagnetic clutch(EMC)
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I.INTRODUCTION

As in today's world, where there are energy crises and the resources are depleting at a higher rate, there is a need of specific technology that recovers the energy, which gets usually wasted. So, in case of automobiles one of the useful technology is the regenerative braking system. Generally in automobiles whenever the brakes are applied the vehicle comes to a halt and the kinetic energy gets wasted due to friction in the form of kinetic energy. Using regenerative braking system in automobiles enables us to recover the kinetic energy of the vehicle to some extent that is lost during the braking process. The two methods of utilizing the kinetic energy that is usually wasted by converting it into either electrical energy or into mechanical energy. Regenerative braking system can convert the kinetic energy into electrical energy with help of electric motor. And it can also convert the kinetic energy into mechanical energy, which is supplied to the vehicle whenever it is needed with the help of battery. Driving involves many braking events resulting in much higher energy losses with greater potential savings. With buses, taxis, delivery vans and so on there is even more potential for economy. Since regenerative braking results in an increase in energy output for a given energy input to a vehicle, the efficiency is improved. The amount of work done by the engine of the vehicle is reduced, in turn reducing the amount of energy required to drive the vehicle.

This technology of regenerative braking controls the speed of the vehicle by converting a portion of the vehicle's kinetic energy into another useful form of energy. The energy so produced could then be stored as electrical energy in the automobile battery, or as mechanical energy in flywheels, which can be used again by the vehicle.

Energy normally dissipated in the brakes is directed by a power transmission system to the auxiliary battery during deceleration. The energy that is stored by the vehicle is converted back into kinetic energy and used whenever the vehicle is to be accelerated. The magnitude of the portion available for energy storage varies according to the type of storage, drive train efficiency, drive cycle and inertia weigh. The effect of regenerative brakes is less at lower speeds as compared to that at higher speeds of vehicle. So the friction brakes are needed in a situation of regenerative brake failure, to stop the vehicle completely.

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II. OPTIMAL TRAIN CONTROL MODEL

The optimal train control problem applies the optimal control theory to optimize the driving strategy between successive stations, such that the mechanical traction energy is minimized.

$$minE(T)=\int T0kt(t)v(t)F(v(t))dt. \qquad (1)$$

E, T and v are the energy consumption, trip time and train speed, respectively. F denotes the available maximum traction force, and *kt* is the relative traction force, i.e., the ratio between the applied traction force and the maximum traction force. The mass-point model of the train is widely used to describe the train movement as the following equations:

$$mdv(t)dt=ktF(v(t))-kbB(v(t))-g(s)-r(v),dsdt=v, \qquad (2)$$

Where B and *kb* denote the available maximum braking force and the relative braking force. g is the gradient and curve resistance. r is the running resistance, which includes the friction and air resistance. Generally, trains will not apply the traction and braking forces at the same time. Hence,

$$kt*kb=0. \qquad (3)$$

The boundary conditions and the constraint on the speed limit are:

$$v(0)=v(T)=0,v\leq \overline{V} \qquad (4)$$

In addition, the trip distance constraint should be satisfied,

$$L=\int T0v(t)\ dt \qquad (5)$$

Additionally, the constraints on the relative traction and braking force are shown as follows.

$$kt\in[0,1],kb\in[0,1] \qquad (6)$$

The optimal train control model is concluded as Equations (1) to (6). By using the Pontryagin maximum principle, the optimal driving strategies are proven to consist of maximum acceleration, cruising with partial power, cruising with partial braking, coasting and maximum braking [3,5]. The previous works [6,] have proposed a numerical algorithm to calculate the energy-efficient driving strategy, which includes the control sequences and the corresponding switching points. The proposed algorithm will firstly present an iterative algorithm to calculate the driving strategy for one section. Then, the solution is extended to solve the driving strategy of multiple sections by distributing the energy units to sections.

III. REGENERATIVE BRAKING

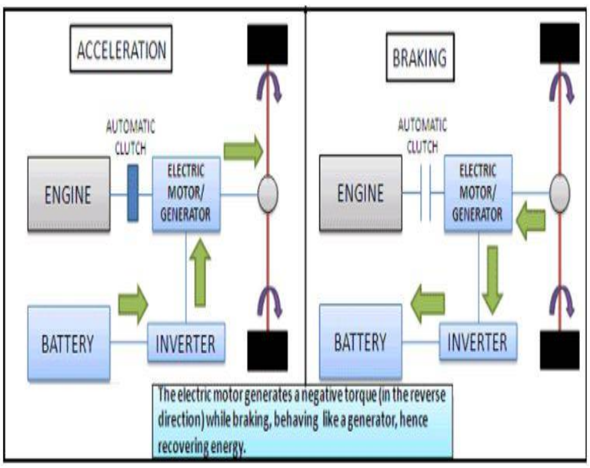

Fig.1Regenaerative Braking

Many modern metro vehicles are capable of converting kinetic energy into electrical energy when trains apply electrical braking, which is known as regenerative braking. According to [1], approximately 30% of the traction energy from the braking train can be recovered and then reused in the systems. More importantly, the characteristic of the train operations in metro systems is that the maximum acceleration and electrical braking regimes frequently happen, which

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provides a good opportunity for trains to utilize the regenerative energy. Efficient utilization of the regenerative energy could make a great difference in reducing the energy consumption of metro systems. The recovered regenerative energy can be firstly used by the on-board systems, such as lights, carborne signaling systems and air conditioning. The rest of energy will be fed back to the power network, such that it can be used by the other accelerating trains. The energy could also be stored in the energy storage systems (ESSs) and then be reused by trains. Hence, the utilization of regenerative braking energy can be classified into two ways, i.e., immediate energy exchange between trains and energy exchange between trains through ESSs.
For the storage of the regenerative energy, ESSs (such as super-capacitor, batteries, flywheels and superconducting magnetic energy storage) should be installed.

IV. PNEUMATIC ARRANGEMENT OF RBS

The pneumatic arrangement consists of one plate, for applying the braking system in the vehicle. When applying the brake, the pressure will generate the power from the dynamo. Here the motor is used to run the vehicle wheel shaft using the belt and pulley arrangement in the shaft we are fixing another drive to EMC system which is coupled dynamo arrangement. Whenever we apply the brake pressure sensor is sense the value of pressure and it give the signal to the amplifier and it passed through the control unit, the control unit will activate the MOSFET drive to control the motor drive then the EMC is rotate the dynamo to generate the electric power. The power from the dynamo is AC the control unit converts into DC and stored to the battery. Using this equipment we can easily generate the power supply. The all above process are controlled by the control unit it is nothing but the small chip called microcontroller it's already programmed and feed in the chip for working. This equipment is mainly used in all types of four wheeler vehicles in automobile.

The chain is used to drive to couple the wheel with the electromagnetic clutch. The electromagnetic clutch is also coupled with a dynamo, by which electrical power generation is possible.

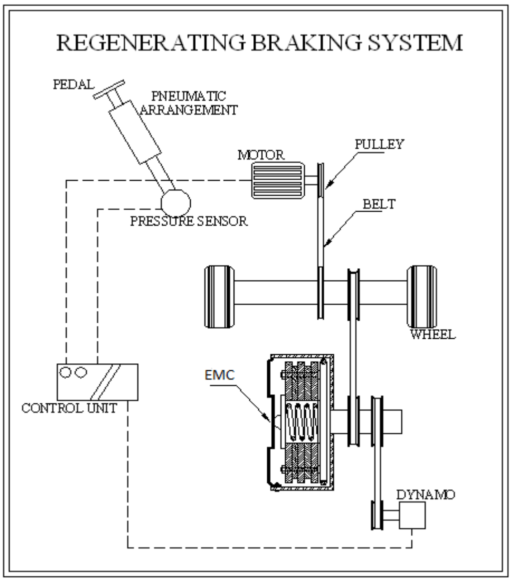

Fig.2 Pneumatic Arrangement

The wheel is mounted on a shaft. The motor coupled with the wheel just rotates at a certain speed. A POT is arranged such that the speed of the motor can be controlled. When we apply the brake, it presses the limit switch and supply to the motor is stopped and it is provided to the clutch. The POT is arranged with the accelerator pedal .When the clutch starts to work the electric power supply is generated

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Since the dynamo is coupled with the electromagnetic clutch (EMC). The generated electric power can be stored in the battery and it can be used to run the motor.

V. RESULT AND DISCUSSION

In the Fig 3 shows the installation position and Energy exchange between trains through ESS Systems, during the operation ESSs can be divided into two types, i.e., ESSs on the trains or ESSs along the track side.

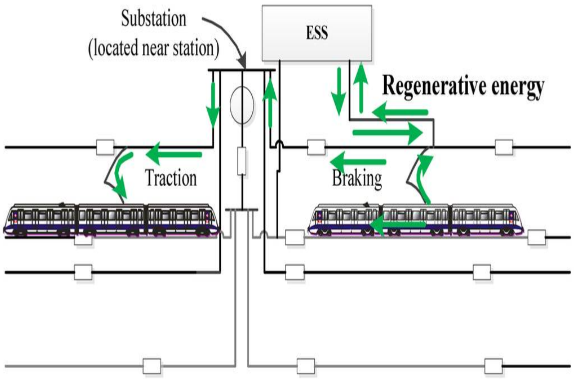

Fig 3 Energy Exchange between Trains through Energy Storage Systems (Esss)

The on-board ESSs, e.g., super-capacitor and batteries, are installed on trains, and the stored regenerative energy can only be used by the train itself. The advantage is that the efficiency of the reused regenerative energy is high, since this energy can be duratively and effectively utilized with less line losses. However, the installation of the on-board ESSs will greatly increase the train mass and will require a large space, so it is seldom used in practice nowadays. The wayside ESSs can store the generated regenerated energy when nearby trains are applying regenerative braking. Then, the stored energy can be reused by the passing trains when they need it. The application of the wayside ESSs requires an electrical controller to distinguish the driving strategy of the nearby trains by detecting the voltage of the power line. Trains in rail and rapid transit systems are usually braking near stations, and thus, the ESSs are normally installed near stations to increase the recovery efficiency. Compared to the on-board ESSs, one of the advantages for the application of the wayside ESSs is that they can recover regenerative energy from multiple braking trains at the same time, and their installation has little influence the operation and maintenance. However, waysides ESSs are usually less efficient due to the transmission losses on the power line. According to experimental results, the rate of energy reduction with ESSs ranges from 12%–20% for different lines.

In the fig 4, the immediate energy exchange between trains could achieve good utilization of the regenerative energy without installing other equipment.

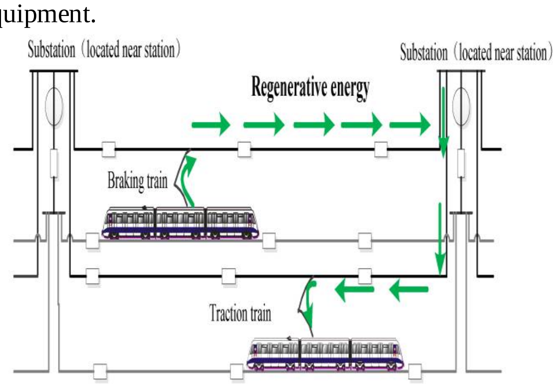

Fig 4 Immediate Energy Exchange Between Trains By Regenerative Braking.

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However, the immediate energy exchange between trains needs cooperative operation between the braking and traction trains. Firstly, if there are no other traction trains when trains are braking, the regenerative energy will increase the voltage of the grid to a high level until the tolerative voltage limit is reached. Then, the following regenerative energy will be wasted at the braking resistance to protect the power network. Secondly, the distance between the traction and braking trains should be short to achieve a high efficiency. Furthermore, the driving strategy of the cooperative trains should be applying traction and braking at the same time. In conclusion, the traction and braking trains should be matched in the time, space and driving strategy. The trip distance of metro systems is short, and the traction and braking processes usually happen near stations. As a result, a good cooperation between trains can be achieved near stations by optimizing the train timetable.

In our previous work a cooperative train control model has been studied, in which the regenerative energy is used better by adjusting the departure time. The simulation results show that the net energy consumption can be reduced by 11.34% for peak hours with combining the energy-efficient driving strategy and utilization of the regenerative energy.

In the fig 5, the energy saved by using the different vehicles shown and the better fuel economy is shown

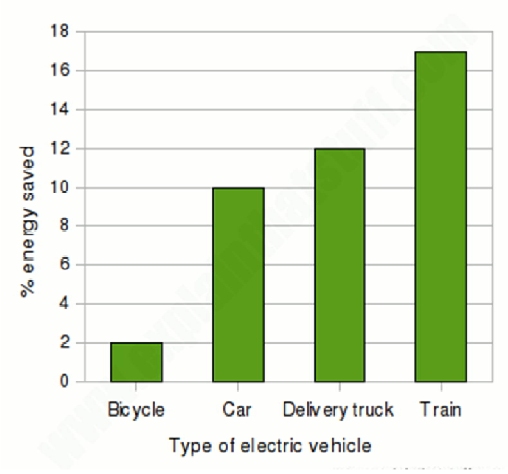

Fig 5 Energy Saved

When compare to other vehicles like bicycle, car and delivery truck while implementing in Metro trains which saves approximately 30% fuel consumption shows better fuel economy

VI.CONCLUSION

The regenerative braking system used in the vehicles satisfies the purpose of saving a part of the energy lost during braking also it can be operated at high temperature range and are efficient as compared to conventional braking system. The results from some of the test conducted show that around 30% of the energy delivered can be recovered by the system. Regenerative braking system has a wide scope for further development and the energy savings. The use of more efficient systems could lead to huge savings in the economy of any country. The braking arrangement can be installed in Metro Trains from this the net energy consumption at substations will be reduced.

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