Future energy efficient rail

Applying eco-driving and appropriate traffic regulation can help with reduction of energy consumption in railways

Energy usage in electrical railway systems is being analysed in order to find technologies, developments and procedures for increasing energy efficiency. It is a global concern as it is an environmental problem, and also due to the associated economical cost.

Factors such as the low friction wheel-rail that allows coasting for long distances, electric traction, a high transport capacity and the possibility of adapting the number of coaches to demand make railways an efficient mode of transport. Not only the metropolitan, commuter or traditional long distances lines, but also high speed services are efficient taking into account that reducing the travel time, the consumption of auxiliary services, and the number of stops as well as having regular speed limits allow reduction of energy consumption.

A more efficient railway system is possible and new strategies to reduce energy consumption are being studied, focusing on infrastructure, vehicle design and traffic operation.

OPERATION STRATEGIES

Both infrastructure and vehicle strategies are long-medium term decisions and involve important investments, but strategies focused on rail traffic operation can be applied in the short term or even in real time. Given the current infrastructure, and the vehicles in service, rail traffic operation can optimise energy efficiency with only low levels of investments.

Traffic operation strategies can be divided into three types: planning, eco-driving design and real time traffic control.

During traffic planning, the adjustment of the service offered to passengers to the actual demand is fundamental to achieving desired levels of train occupancy. Of course, a compromise must be found due to the fact that a railway is frequently considered to be a basic service offered to passengers and there is a need for minimum rail services, even if these are not justified by demand. This is particularly the case for commuter trains and metro lines, more than high speed lines.

In addition, the efficient design of timetables may also reduce energy consumption. When timetables are designed, the minimum running time, obtained by the flat out speed profile, is increased by a time margin that makes it possible to make up time in the event of delays. This time is needed if the rail system is to comply with punctuality requirements and, when the train is not delayed, it can also be used to reduce energy consumption. The way the time margin is distributed during the trip should take into account not only punctuality criterion according to the probability distribution of delays along the line, but also energy optimisation.

The relationship between travel time and the consumption depending on the type of driving can be analysed graphically, showing that different trips with different energy consumptions can provide the same running time depending on the driving style.

When the timetable is designed, the running time for the trip is chosen, and energy savings can be obtained using the time margin of the timetable when the train is not delayed. Then, the driving must be designed to obtain the minimum consumption associated with that running time, that is, the eco-driving.

Eco-driving consists of a sequence of efficient driving commands. There are three types of these commands: coast, speed regulation, and speed regulation without braking. The eco-driving is then designed, and the slot assigned to the service must be respected. That is, the driving of a train should not affect the following train on the same line.

TRAFFIC CONTROL

These off-line efficient design procedures should be followed by efficient real-time traffic control. Traffic control allows real time planning and driving update when the train is delayed. Thus, to adapt the driving to real-time changing conditions, a new eco-driving is put into practice with a different travel time.

Three levels can be distinguished in rail traffic control: a single train regulation, calculation of a new schedule, and a global traffic control system. In single train regulation, on-board train control is necessary if the schedule is to be complied with. However, when delays are significant, with nonplanned speed reductions or other incidences, the schedule has to be recalculated to adapt the driving in real time. The centralised regulation system allows global traffic optimisation, and the minimising of delays and of energy consumption.

The optimal solution is automatic traffic regulation and execution of commands, supervised by the onboard signalling system. On metro lines with global traffic control and equipped with Automatic Train Operation (ATO) systems that execute efficient commands, important energy savings and improvement in regularity can be achieved.

On high speed trains, it is necessary that the eco-driving can be modified on-line according to the changing conditions, such as temporary speed limits or delays, by means of onboard advice systems or efficient ATO systems.

METRO LINES

Metro trains with ATO equipment receive the parameters needed to be executed between two stations. These parameters correspond to one of a pre-programmed set of alternative ATO speed profiles per inter-station. The centralised regulation system selects in real time the appropriated speed profile to be sent at the beginning of each trip and executed by the train. As a result, traffic control system performance and total energy consumption strongly depend on the off-line design of the ATO speed profiles.

The ATO speed profile is selected on-line by the centralised regulation system according to the required running time. When a train must be held up, from the passenger's point of view a longer running time is preferred rather than a longer station waiting time. In addition, this control strategy involves energy savings because slower speed profiles result in less traction consumption. However, these ATO speed profiles have usually been designed according to running time and comfort criteria, but not to energy consumption criteria.

When the centralised traffic regulation system was implemented in Madrid Underground the quality of service increased by 50 per cent. In addition, energy consumption was reduced by 18 per cent even considering that speed profiles were not optimised.

Then, the set of speed profiles had to be redesigned to minimise the energy consumption given the target running time. For that purpose the railways systems research group at the Universidad Pontificia Comillas has developed a specific design procedure.

The proposed method is based on the accurate simulation of all the possible combinations of ATO speed commands for each inter-station. The simulation model has been modularised and each module represents the different subsystems of a real train.

The ATO model represents the control logic of the driving, with the same behavior as the ATO equipment in service. At each simulation step, the position and speed of the train is inputted. Then, a percentage of traction set value is calculated depending on the state of the train: motoring, braking to target speed, braking to stop, etc. The motor module calculates the force needed and a jerk limitation checks there are no abrupt changes in force in transitions like traction-braking or braking-traction in order to assure the comfort of passengers. Subsequently, the new acceleration, speed and position of the train must be calculated. For that purpose the resistance to train movement is needed. The track gradient resistance is calculated from a list with the initial and final points of downhill and uphill sections, their values, and the slope transition curves. Curves are treated as equivalent slopes added to the actual ones. At each simulation step, an average of the gradient where the train is situated is calculated.

> A more efficient railway system is possible and new strategies to reduce energy consumption are being studied, focusing on infrastructure, vehicle design and traffic operation

Finally, the energy consumption is calculated according to the time increment and the current at each simulation step. A model including the variation of the efficiency depending on the ratio between the required and the maximum force is needed to obtain realistic results.

This modular architecture allows the validation of each module separately and an easy adjustment for specific features of a particular ATO equipment. To this end, the simulator input interfaces are designed to enable the definition of track layout, train characteristics, and ATO system configuration.

ON-BOARD COMMUNICATION

In order to record real data of trains in Madrid Underground, the recording equipment was connected onboard to the communication bus of the traction control system during several trips. A comparison of complete simulations and measured data of running times and energy consumption was carried out in order to validate the high accuracy of the simulator.

In the proposed method, the simulator is used for the design of the speed profiles. It combines all the possible commands that the ATO system provides obtaining all the possible speed profiles for each inter-station. The solution space is plotted in a time-consumption graph with every profile characterised by its running time and consumption. Moreover the simulator indicates which profiles are not suitable to be implemented due to comfort or operational restrictions.

The procedure was applied to redesign the speed profiles on Madrid Underground lines, minimising the energy consumption. After the new profiles were put in service, 12 per cent of additional energy savings were measured.

ENERGY TRANSFER

New models were also developed to design timetables that improve the energy transfer between trains. When trains are in a braking process, the electrical brake regenerates energy that is put on catenary if another train is demanding energy at the same moment. If not, the regenerated energy is wasted on resistors.

The objective of this model is to maximise the synchronisation between speed-up processes and brake down in order to maximise the energy transfer, thus reducing the net energy consumption measured on substations. Timetables were calculated for the off-peak hour in Madrid Underground and the correlation between the synchronised time and the reduction of net energy consumption was shown.

New possibilities are to be explored associated to the latest signalling technology of metro lines, CBTC. This continuous bidirectional communication system allows the increase in capacity on metro lines, and the continuous control of the train. Thus, the new traffic regulation system can make use of these characteristics to improve the quality of service as well as to reduce the energy consumption in operation by means of on-line intelligent management of railways traffic.

Renfe and Comillas University have been collaborating in different projects to design high speed eco-driving for the following cases: high speed train (HST) class 102 in high speed line (HSL) Madrid-Barcelona (Madrid-Zaragoza section), HST class 120 in HSL Madrid-Barcelona (Madrid-Plasencia de Jalón section), HST class 103 in HSL Madrid-Barcelona, HST class 102 in HSL Madrid-Málaga, and HST class100 in HSL Madrid-Sevilla.

HIGH SPEED LINES

High speed lines have specific characteristics that must be considered, thus a new simulation tool had to be developed and validated to include also the manual driving restrictions. Preliminary night-time tests as well as tests on commercial services were carried out for model adjustment and confirmation. Once the simulator had been verified, different trips on the same section of track were simulated by executing different efficient driving command sequences that result in different running times and associated consumption. The eco-driving was designed for the selected line, train and commercial service, and finally, the designed eco-drivings were tested.

Eco-driving was guided according to the optimal design in commercial services and onboard measurements were recorded to compare them with non-guided driving measured in the same trip conditions (comparing only non-delayed trains). 19 tests with HST in commercial services and 12 specific tests were carried out and average savings measured were 21 per cent.

Thus, it has been shown that in Madrid Underground 18 per cent of savings were measured with the implementation of the regulation system and 12 per cent of savings were measured with the optimised ATO speed profiles. On Spanish high speed lines 21 per cent of savings were measured executing the designed eco-drivings. All these figures demonstrate the impact that strategies focused on traffic operation can have on the reduction of energy consumption, particularly if the possibility of its application in the short term and with a low effort and investment cost, is taken into account.

We can conclude that energy efficiency on railways is also a matter of short term, low-investment traffic operation measures. These strategies, which optimise driving, the design of timetables and the on-line traffic regulation, can have an important impact on the efficiency of rail systems as demonstrated on metro lines and high speed lines.

This article was written by A. Paloma Cucala García and Antonio Fernández Cardador from the IIT, Universidad Pontificia Comillas, Spain

FOR MORE INFORMATION

Web: www.iit.upcomillas.es
E-mail: info@iit.upcomillas.es