Regenerative Braking in Metro Rolling Stock

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Keywords: CI–Converter Inverter, TIMS – Train Integrated Management System DT Car–Driving Trailer Car, M Car–Motor Car, VVVF–Variable Voltage Variable Frequency, IGBT–Insulated Gate Bipolar Transistor, THD–Total Harmonic Distortion

Synopsis: Traction accounts for about 60-80% of total energy consumption in a Metro system. The quantity of energy consumed by trains is influenced by a wide range of factors, design of train being one of them. Hence, optimization of overall system design in order to control consumption of electricity becomes essential. The modern design of Metro Rolling Stock incorporating three phase induction motors and Converter Inverter enables recovery of a major portion of consumed electricity by way of using regenerative braking. Metro railways worldwide have reported an average of about 20% saving in traction energy on account of regeneration. It also helps to reduce heat load inside tunnel and thus reduce Air Conditioning load. With increased awareness and commitment for environment metros have also taken it as Green House Gas reduction initiative. Regenerated energy is mostly used by other trains powering in the network. The quality of regenerated power is important since the injected harmonics effect signaling, communication system and other loads connected on the grid.

1. INTRODUCTION

With smaller inter-station distances, Metro operation is essentially of start/stop nature. Due to frequent acceleration & de-acceleration requirements, energy demand is very high. Traction accounts for about 60-80% of total energy consumption in a Metro system. The quantity of energy consumed by trains is influenced by a wide range of factors, which can be grouped as (i) Design of network, (ii) Design of trains & (iii) Service planning operation. Hence, optimization of overall system design in order to control consumption of electricity becomes essential. The scope of this paper is limited to one of design aspect of trains i.e. regenerative braking. The modern design of Metro Rolling Stock incorporating three phase induction motors and Converter Inverter enables recovery of a major portion of consumed electricity by way of using regenerative braking. Metro railways worldwide have reported an average of about 20% saving on account of regeneration. By using intelligent blending of regenerative and pneumatic braking, optimization of energy recovery as well as accurate control of train movement can be achieved. In addition to saving of electricity, regenerative braking provides additional benefits in form of lesser wear of wheel and brake pads.
In Metro applications, there is likelihood of having a considerable area of underground operation. An efficiently employed regenerative braking system helps to reduce heat load inside tunnel and thus reduce Air Conditioning load. Needless to mention that regenerative braking helps in mitigating Global Warming by way of reducing carbon emissions due to reduced electricity requirements from grid.

2. **Energy Saving Initiative**

Energy cost accounts for 5% to 15% of operating cost in most of metros. 60% to 80% of this energy is used in Traction while auxiliary loads in station area i.e. lighting, air-conditioning, lifts, escalators etc. accounts for 20% to 40%. In DMRC energy cost is almost 30% of operating cost and auxiliary loads accounts for 50% of this due to adverse ratio of underground stations. Metros have taken several energy saving initiatives like regenerative braking, rationalization of trains during off peak hours, building energy management etc. It is found that saving due to regenerative braking amounts to an average of about 20% of traction energy and is the most important energy saving initiative and obviously almost all metros have implemented regenerative braking in various degrees depending on age & technology of stock in use. Quantum of energy regenerated varies from 5% in Hong Kong KCRC to 30% in Lisbon Metro and 34% in Delhi Metro.

3. **Technology options vis-à-vis Energy Recovery**

   (i) **Traction Motor**

   Both dc and ac traction motors are used in metro applications. Technically, it is possible to recover energy in dc motors also using dc-dc chopper configuration. Battery operated vehicles do it often. However, due to maintenance-intensiveness dc traction motors have been edged out, hence, this aspect is not being dealt further.

   (ii) **Type of Catenary Supply (dc, ac)**

   Technically, it is possible to recover energy in dc catenary system also. As long as energy is consumed within the railway operators’ network, there is no issue, else additional dc-ac converter is required at substation before it can be fed back to power utility. It was attempted on Central Railway long back without much success. It will result in overvoltage, if not used by other trains. Option of ac traction with state of art VVVF drive gives seamless recovery of energy during braking.

4. **Utilisation of Energy Regenerated**

Regenerated energy is mostly used by other trains powering in the network. Some metros have used this for feeding station loads and even stored in flywheels. The
return of power to utility is rarely done and is limited on account of financial arrangement with power utility as well as quality of power.

5. **Consideration for Regenerated Power**

The harmonic injection into source during powering and regeneration is an important aspect. The limits provided by power utilities are to be complied. The harmonics injected into grid affect other users as well as communication system. It also has impact on signalling systems within railway operator’s network.

(i) Harmonic Pollution level in grid is measured in items of voltage and current THD (Total Harmonic Distortion). Voltage THD is what influences other loads on the grid. DMRC has set a limit of 2% for voltage THD, though power utility has not set any such limit so far.

(ii) Harmonic pollution w.r.t. Communication system is measured in terms of phsophometric current.

(iii) The impact of harmonics generated on signalling system is specific to the frequency band used by signalling contractor and is defined in terms of Signal to Noise ratio and Total earth leakage current.

6. **DMRC Rolling Stock**

Delhi Metro Rail Corporation (DMRC) rolling stock uses 25 kV ac traction with ac propulsion system capable of regeneration on its network. A typical rake used by DMRC consists of two units, each comprising a Driving Trailer (DT) and a Motor (M) Car.

![Schematic Diagram of DMRC Rolling Stock Propulsion system](image)

**Figure: Schematic Diagram of DMRC Rolling Stock Propulsion system**

Propulsion system consists of Transformer, Converter Inverter and ac three phase traction motors. Converter Inverter is the key equipment, which extracts the kinetic energy from vehicle during braking and reconverts into electricity. Initially, three phase power at variable frequency at traction motor-converter inverter interface, it is converted to single phase by CI at power frequency synchronized to the grid and
within permissible harmonics level. Then, it is fed back to internal grid of DMRC. Regenerated electricity is used by Auxiliary System of the train regenerating as well as other Rolling Stocks operating at that time in powering mode on the network.

Traction motors on DMRC trains are VVVF vector control, 220 KW, 1450V, 3 phase Squirrel cage Induction Motors. A typical performance curve of DMRC traction motor in braking mode is depicted below. It can be seen that maximum regenerative braking effort can be achieved between train speeds of 5-48 Kmph, above which it exponentially reduces.

![Performance Curve of DMRC Traction Motor](attachment:performance_curve.png)

Traction Transformer used is with high impedance secondary winding, since it will require to be shorted during PWM control of converter-inverter.

7. **Operational practices on DMRC and benefits accrued due to regenerative braking**

DMRC on its various lines have employed Automatic Train Protection System (ATP). Over and above ATP System, DMRC has employed Automatic Train Operation (ATO) System on its Line-2, where trains automatically flip flops between powering and braking. In line-3 operation, DMRC has employed automatic control of train braking by way of using a Train Interface Computer (TIC) Control, whereby braking requirements of train are automatically controlled. On its line-1 operation, DMRC employed a system where train operators are trained to effect optimal performance of train on regenerative braking front.
Line wise performance of DMRC trains on regenerative braking, with existing network is reproduced below:

<table>
<thead>
<tr>
<th>SN</th>
<th>Line</th>
<th>Inter-station distance (Km)</th>
<th>Cumulative Energy consumption (KWHr/Train/Km)</th>
<th>Regenerated Energy KwHr/Train/Km</th>
<th>Percentage of Regeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Line 1</td>
<td>1.19 (25.09/21)</td>
<td>14.5</td>
<td>4.9</td>
<td>33.7%</td>
</tr>
<tr>
<td>2</td>
<td>Line 2</td>
<td>1.10 (11/10)</td>
<td>16</td>
<td>4.6</td>
<td>28.8%</td>
</tr>
<tr>
<td>3</td>
<td>Line 3</td>
<td>1.06 (33/31)</td>
<td>16.2</td>
<td>5.5</td>
<td>34%</td>
</tr>
</tbody>
</table>

8. **Other Indirect Benefits**

M Car uses dynamic braking predominantly while DT Car uses only pneumatic brakes. Hence, the wheel wear in DT Car is more, almost double. The saving in wheel wear of M Car results in savings of approx. Rs. 1.3 lakh/annum/train.

Saving in brake block consumptions – Reduced consumption of brake blocks in M Car helps DMRC save approx. Rs. 53,000/annum/train.

Besides the saving in terms of reduced down time and manpower required for wheel turning/brake block replacement are also significant.

9. **DMRC Project on Carbon Credits**

The regenerative braking technology employed in DMRC is different from Calcutta Metro and several other metros worldwide, which employ conventional rheostatic braking system, where kinetic energy of the de-accelerating Rolling Stock is dissipated into heat energy. The energy recovered not only remains unutilised but contribute additionally to the heat load, which has to be extracted by air-conditioning, resulting into additional expenditure. The choice made by DMRC for using regenerative braking technology displays the environmental consciousness of its Management.

Encouraged by the agreed international agreement, DMRC initiated a project activity for registration of its Clean Development Mechanism (CDM) Project, where DMRC is expected to earn carbon credit for effecting reduction in Green House Gases (GHG) reduction. DMRC Project was registered at UNFCCC on 27th December 2007. DMRC has projected a conservative estimate of 51250 MWhrs of annual energy saving on account of regenerative barking on all trains of its existing network. This saving of electrical energy translates into 41000 Certified Emission Reductions (CERs) or in other words saving of 41000 tones of CO₂ from being injected into atmosphere.

10. **Improvements in Phase-II Rolling Stock**

DMRC has further implemented the major design changes in its Phase-II Rolling Stock. Control of train braking has been made at bogie level. In existing System
Brake Electronic Control Unit (BECU) is controlling Braking (Pneumatic + Dynamic) at car level and failure of BECU in M Car unit would lead to complete shut down of pneumatic and regenerative braking on the M car. In modified System being implemented on phase-II Rolling Stock, Converter Inverter directly communicates with TIMS and decides regenerative braking effort. Hence failure of 1 BECU shall not impact the performance of train on braking front. Regenerative braking will be decided by CI and pneumatic brake by the second BECU, which overtakes the functions of failed BECU. With the modified design, availability of regenerated electricity will further improve.

11. **Change in operational practice to optimize energy consumption**

   There is possibility of optimizing energy consumption by changes is operating practices. Hong Kong KCRC saves up to 6.5% of traction energy by optimizing ATO settings, while Hong Kong MTRC reduces energy consumption in off peak hours by balancing reduced station dwell time with increased inter station timings.

12. **Conclusion**

   Energy cost is 5 to 15% of operating cost in Metros and traction power consumption accounts for 60-80% of this energy cost. Saving achieved through regenerative braking is an average of about 20% and hence this is acknowledged as most significant step for energy saving. Besides energy saving, regenerative braking has indirect benefits in terms of reduction in maintenance, increase in train availability and reduced heat load generation in underground corridors.