

# INDUCTION MOTOR CHARACTERISTICS AND APPLICATIONS FOR DC ELECTRIFIED RAILWAY SYSTEMS

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*Key words: Induction motor, electrified railway, dynamic behavior, regenerative braking*

## ABSTRACT

Induction motor structures in DC electrified railways with their dynamic performance are studied. Characteristics of the current, voltage, electrical and mechanical torque and active and reactive power in accelerating, normal and regenerative braking are investigated. The characteristics of the induction motors used for Tabriz urban railway are simulated with PSCAD/EMTDC software proving the investigated characteristics.

## I. INTRODUCTION

With utilization of voltage source type inverters, AC traction motors are presently common in electric railway traction applications. Several AC motors such as switched reluctance, permanent magnet synchronous and asynchronous motors are being used widely in electrified traction applications. Meanwhile, serial excitation DC motors and induction AC motors are used mostly for DC electrified traction systems [1,2]. Every electric railway traction wagon manufacturing company uses one of the mentioned motor structures for traction force generation which is needed to run the train sets.

DC electrified railways mostly used as urban or suburban transportation means are feed with 750, 1500 or 3000 V DC through several bulk substations which the 20 or 63 kV power supply is stepped down and rectified in several traction substations along the route. The traction substations mostly use 12 or 24 pulse converters for reducing the harmonics in the DC bus which is going to feed the electrical motors and also the AC network feeding the traction system [3].

In this paper, urban railway of Tabriz is studied as a practical application. Tabriz urban railway is a 750 V DC system which feeds the train sets through overhead contact system [4]. The train sets are 5-car sets which the end cars do not have any electrical drives and there are four induction motors on each of the three middle ones used for generating the sufficient traction force for the train sets. The induction motors are fed through inverters which supply the 0.4 kV, 3 ph, 50 Hz power demand of the induction motors. The connections of the induction motors can be changed from series to parallel modes

which enables higher electric torque at starting and braking times for achieving the required acceleration and deceleration ratings by connecting them in series mode and having higher speed at normal conditions by connecting them in parallel. The schematic diagram of the induction motors on every car is shown in Fig. 1.

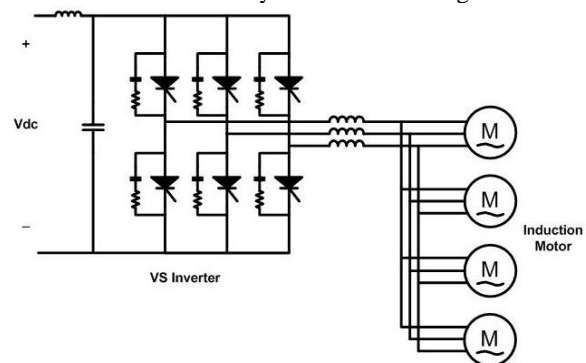


Fig. 1. Schematic diagram of the induction motors on every car of the train sets.

## II. INDUCTION MOTOR CHARACTERISTICS FOR TRACTION SYSTEMS

Traction loads require a high torque at starting to meet the train resistance and acceleration effort which lasts 2-4 minutes for urban or suburban trains. Also because of irregular interruptions on the pantograph structure of the trains, the interruptions should not cause distress to the traction motor by way of current rush and its associated ill-effects. The induction motor should also be capable of dynamic braking- rheostatic or regenerative which enables the possibility of running the motor as generator that can impart considerable advantages to electric traction by way of saving energy saving as the regenerated power in most situations can be consumed within the system. All traction motors are subjected to vibration and impacts arising out of the movement of the train set on the rails which has a significant effect on the brush gear and commutation of the traction motors.

The robustness of induction motors of squirrel cage type and its reduced maintenance and operation cost has already attracted the traction railway applications. The development of power electronics such as GTO or IGBT has led to application of induction motors for traction purposes through invention and accurate control of PWM controlled variable voltage variable frequency (VVVF) inverters which give a VVVF output from a DC input. Therefore, the need for an in-built series characteristic for self-regulation becomes redundant if an induction motor is fed with VVVF supply because it eliminates the main drawbacks of an induction motor such as switchings in speed and torque control methods [5,6].

In such a condition, the hard characteristics of induction motors which exhibits a sharp drop in torque with slight increase in speed becomes an advantage for realizing maximum out of the available adhesion. And when a wheel slips on the track, the torque would drop sharp to a low value which in turn would restrict the slipping speed and prevent a run-away circumstance.

Squirrel cage type induction motor is ideal for traction applications because of several reasons such as low initial manufacturing cost, reducing maintenance costs to negligible percentage of total train set costs, possibility of regenerative braking, increasing speed, reducing motor weight, etc.

Induction motors are capable of higher rotational speed and power output; hence their weight is much lower for the same output of a DC series one. An induction motor is also capable of producing more tractive effort than the same motor volume of a DC series one. This is due to the absence of commutator which allows more space for torque producing electromagnetics. In addition, induction motors have higher thermal limit than DC motors because the only winding having insulation is static and the stator has a larger surface area for heat transfer.

The characteristics of induction motors for LRT systems of the cities in Iran, including force-accelerating, force-decelerating, speed and current waveforms are shown in appendix [7].

### III. DYNAMIC PERFORMANCE OF INDUCTION MOTORS

For studying the load flow analysis of the traction power distribution systems, the power consumption of the train operation is necessary to be investigated and the dynamical behaviour of the traction system loads along the route to be studied [8,9]. Fig. 2 shows the typical speed profile of a train set between two stations. When the train starts from the station, it operates in constant acceleration mode as shown in region I. As the speed reaches 22 km/hour, the operation mode is changed to constant power in region II. When the speed is above 37 km/hour, the train set is operated in constant slip mode where the traction effort is inversely proportional to the square of the train speed, as shown in region III. After the speed reaches the cruising speed, the train operates with coasting mode without applying any input propulsion

power, shown in region IV. When the train approaches the next station, the electric regeneration braking is applied by operating the induction motors as induction generators so that the kinetic energy of the train set can be converted into electricity to achieve the energy conservation as shown in region V. For each operation mode, the power demand of the train set can be solved based on the acceleration and various types of train resistance. Therefore, the power demand of a train set from the first station to the last one along the route resembles Fig. 3.

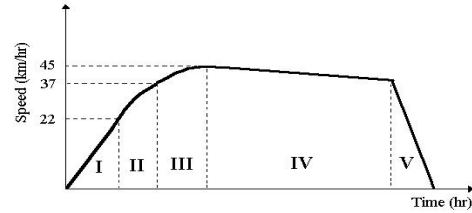


Fig. 2. Speed characteristics of the train sets with time and place variation.

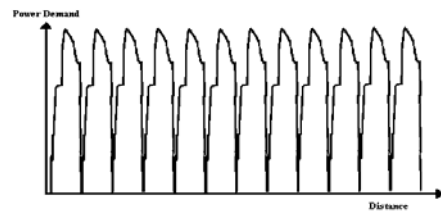


Fig. 3. Power demand characteristic of a train set from the first station to the last one, along the route.

### IV. SIMULATION RESULTS

In this paper, two train sets of Tabriz urban railway are simulated with PSCAD/EMTDC software which use induction motors as their tractive force production with regenerative braking ability. The first train set starts running while the other train is standstill, after a period the second train starts moving and after some time, the first train uses regenerative braking for stopping at the next station which the regenerated active power is consumed in the second train and after a period, the second train starts braking which because of no need for the regenerated power, it would be consumed in the resistor banks. The schematic diagram of the study case is shown in Fig. 4.

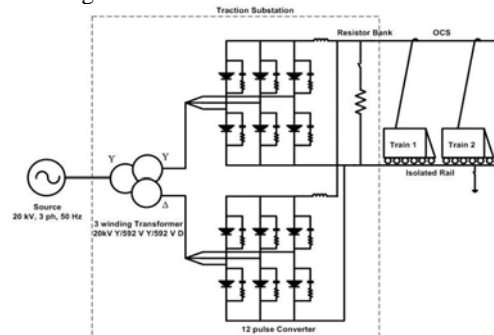


Fig. 4. Schematic diagram of the simulated study case with PSCAD/EMTDC.

The induction motors are fed through SPWM controlled inverters and the induction motors are controlled in V/F constant mode. The DC voltage is feeding the voltage source inverter through a LC filter. The capacitor of this filter is used for reducing the ripples of the DC voltage caused by the converters in the traction substations and the reactance for reducing the ripples of the current passing through the inverter. The three phase output of the inverter again passes through low value reactances for minimizing the THD of the AC current feeding the induction motors. The 750 V DC input of the VSI is inverted to 0.4 kV three phase as shown in Fig. 5 with the RMS value shown in Fig. 6.

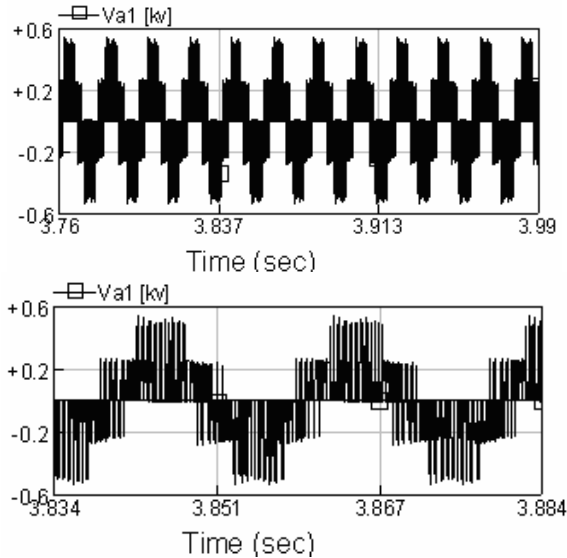


Fig. 5. The output voltage of the PWM controlled inverter feeding the induction motors.

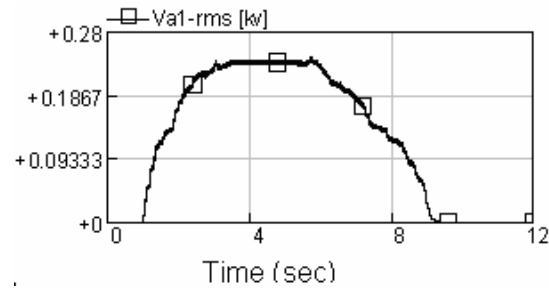


Fig. 6. RMS of the output voltage of the PWM controlled inverter feeding the induction motors.

The DC current feeding the VSI of the first and second train sets as  $i_1$  and  $i_2$  is shown in Fig. 7. It is shown that during the accelerating time, the amplitude of  $i_1$  and  $i_2$  increases, it is almost constant in the constant speed mode and during regenerating braking mode, it will decrease and flow back from the inverter to the DC bus. If the conventional braking is happened instead of the regenerative, the current values decreases to constant

value of zero. Therefore, the DC current of the overhead contact system as the sum of  $i_1$  and  $i_2$  is shown in Fig. 8.

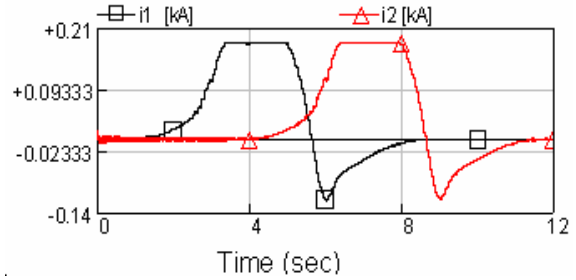


Fig. 7. DC current feeding the inverters of the first and second train sets.

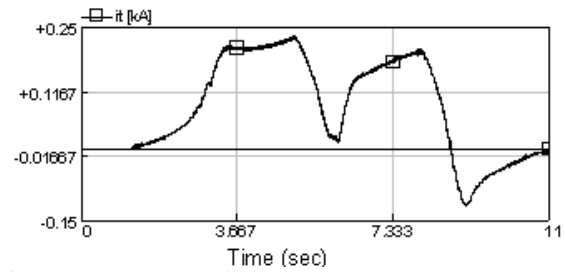


Fig. 8. DC bus current in the overhead contact system.

The RMS output current of the inverters of the first and second train set are shown in Fig. 9. It can be understood that at the accelerating time, the current increases but it reaches to its steady state value very fast and when regenerative braking happens, there is an overshoot in the decreasing waveform of the current because of the reactive part of the current because the induction machine consumes reactive power in generator mode. Providing conventional braking instead of regenerative, the current waveform would decrease to constant value of zero without a sudden overshoot.

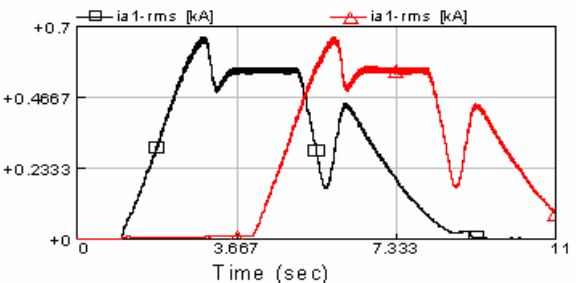


Fig. 9. RMS output current of the inverters of the first and second train sets.

The active and reactive power consumption of the first and second train sets are shown in figures 10 and 11 respectively. The regenerated active power of the first train set is consumed by the second train but regenerated active power of the second train set is wasted in the resistor banks in the traction substation because of no active power demand in the system as shown in Fig. 12.

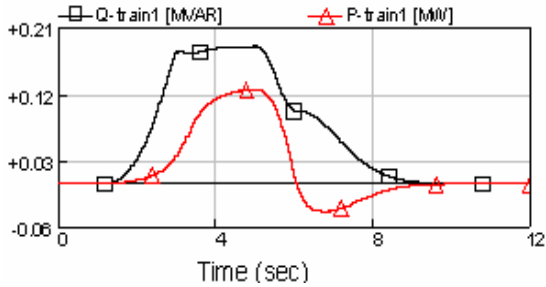


Fig. 10. Active and reactive power consumption of the induction motors on the first train set.

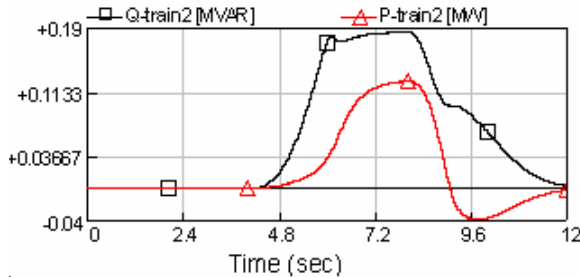


Fig. 11. Active and reactive power consumption of the induction motors on the second train set.

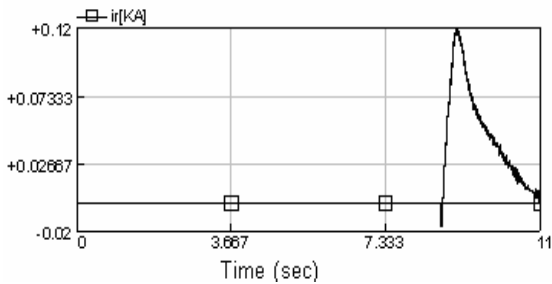


Fig. 12. DC current in the resistor bank in the traction substation.

The electrical and mechanical torques of both of the train sets are also shown in Figures 13 and 14 respectively. Because of the losses, the values of the mechanical torque are a little bit smaller than the electrical torque values.

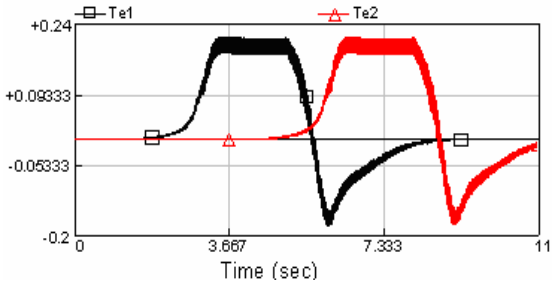


Fig. 13. Electrical torque of the first and second train sets.

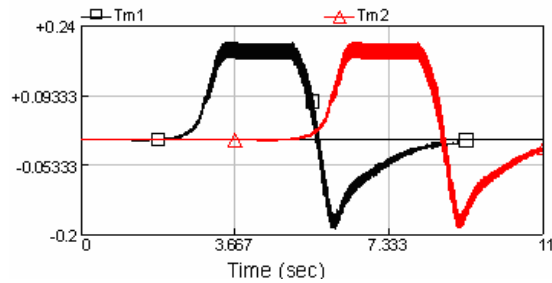


Fig. 14. Mechanical torque of the first and second train sets.

Rotor angle of the induction motors of the train sets are also shown in Figures 15 and 16, respectively.

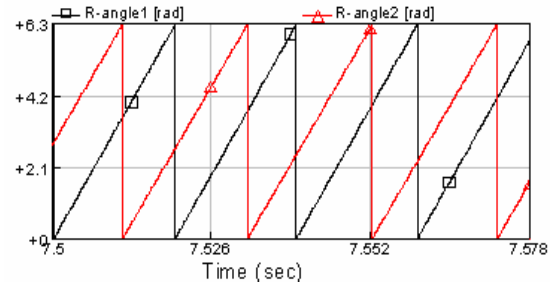


Fig. 15. Rotor angle of the induction motors of the first and second train sets.

## V. CONCLUSION

Induction motors are used widely for DC electrified urban railway traction systems because of lower manufacturing and maintenance costs and weight, better electrical current and torque characteristics and regenerative braking possibility. In this paper, different characteristics of induction motors used for railway traction applications were investigated and proved through the simulation results for a practical usage on Tabriz urban railway system done with PSCAD/EMTDC software. The input current, active and reactive power and electrical and mechanical torque waveforms of the inverter fed induction motor in accelerating, constant speed and regenerative braking modes were studied.

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## APPENDIX

The characteristics of induction motors for LRT systems in the cities of *Tabriz*, *Esfahan* and *Shiraz* in Iran recommended by *Alstom Transportation* such as accelerating, decelerating and speed characteristics are shown in Fig. 17.

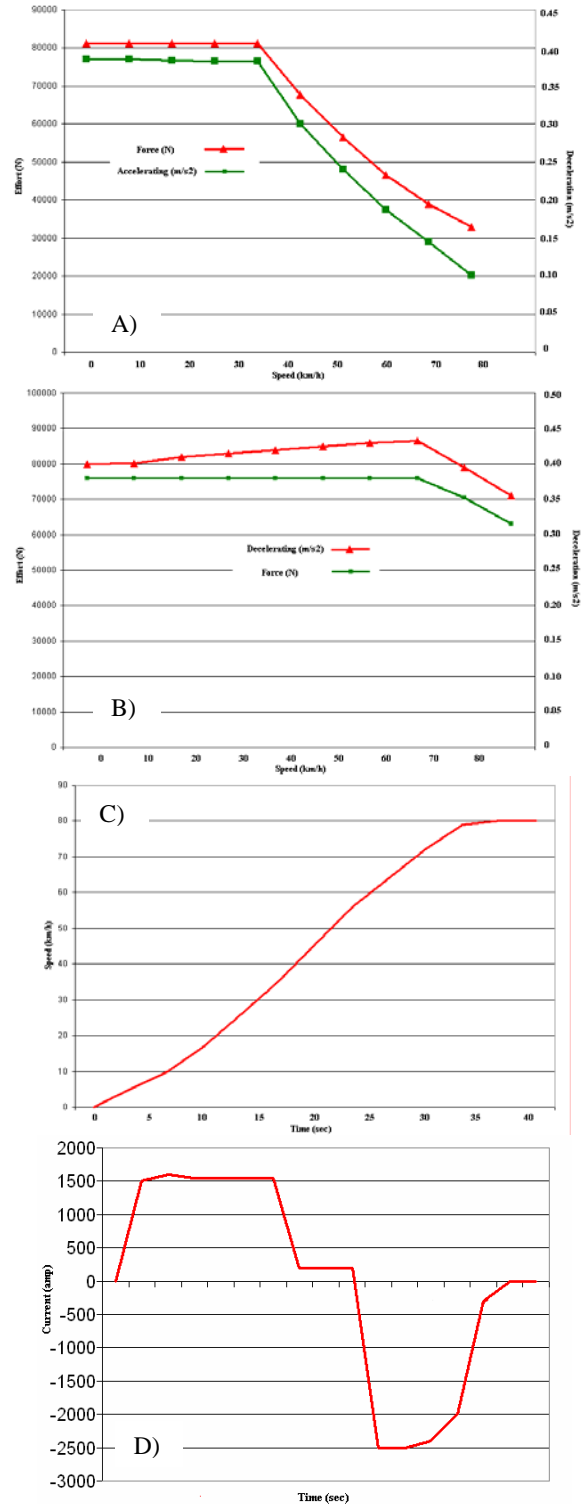


Fig. 17. characteristics of induction motors for LRT systems of the cities in Iran, a) force-accelerating, b) force-decelerating, c) speed d)current.