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An Alternative to Squirrel Cage Induction Motor for Electric Traction for Indian Railways – a Theoretical Cost saving Approach

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Abstract: *Traditionally, the DC Series Motor was used for Electric Traction for reasons like high starting torque and easy speed Control. With the Advancement in control mechanism 3-ph Squirrel Cage Motor is being used currently with an AC-AC Drive. A new Cost saving approach is suggested in this paper with the use of Slip Ring Induction Motor for Indian Railways which is switching over to fully electrified routes.*
Keywords: *DC Series Motor, Squirrel Cage Motor, Slip Ring Induction Motor, Indian Railways, Cost saving.*

I. Introduction

Indian Railways one of the profit making Railway in the World and its Workhorses are the Diesel-Electric and Electric Locomotives. Both Diesel-Electric and Electric Locomotives were using DC Series Motors for driving the Axles for the reasons of high starting torque and a cheap speed control mechanism by means of series parallel control. As the onboard Alternator was introduced in the WDP Class Electromotive Diesel Locomotives, the basic Power Electronics Control Circuit became almost similar for both Diesel-Electric and Electric Locomotives with difference in the mode of feeding Power to Locomotive – Alternator in Electro Motive Diesel (EMD) [1] and Over Head Equipment (OHE) in Electric Locomotives.

Both EMD and Electric Locomotives use 3-phase Squirrel Cage Motors for driving the Axles. This is the state – of – the – art technology currently in use in the Indian Railways. The Power Converters use GTO (Gate Turn-off Thyristors) as the switching devices. A novel method of saving energy and thereby increase the profits of Railways is being studied and suggested in this paper. The ways and means of saving energy by using a Slip Ring Induction Motor will be discussed with emphasis on the starting methods, the torque developed and Braking of the Motors.

II. Construction of Stator of Induction Motors

The construction of the Stator of the Squirrel Cage and Slip Ring Induction Motors are same. The stator is formed from a stator core and stator windings. The stator core consists of thin laminations of cast iron or aluminium which are clamped together to form a hollow cylinder. Slots are provided by punching the laminations to take the windings out after completion of core assembly. Coils of insulated copper bars are then inserted into the slots. This arrangement of windings produces the number of pole pairs. The number of pole pairs and frequency of supply determine the speed of the Induction Motor [2].

2.1 Construction of the Rotor of Squirrel Cage Motor: The rotor core is fitted around the main shaft. The rotor core is made of a thin lamination of cast iron or aluminium. This is punched to the required pattern and clamped on the main shaft. The windings are then placed into the slots in the core and are all connected at each end by welding to a shorting ring or plate. They are angled in such a way that they do not lock.

2.2 Construction of Rotor of Slip Ring Motor: These Motors have Phase-Wound Rotor. The Rotor is provided with a 3-phase, double layer, distributed winding consisting of coils which are used in alternators. The rotor core is made up of steel laminations which have slots to accommodate the 3-phase windings which are placed 120' electrically apart. The rotor is wound for as many poles as in the stator and is always 3-phase. These three windings are star connected internally; the other ends are brought out and connected to insulated slip rings mounted on the shaft. The three terminal ends touch these slip rings with the help of carbon brushes which are held against the rings by a spring assembly [3].

III. Starting Methods of Induction Motors in Traction

The starting of an Induction Motor is of importance as a Squirrel Cage Induction Motor draws about 750% of its full load current during starting and thereby causes a burden on the Power system. The starting methods namely Star-Delta and Auto-Transformer Starters are not used in the Railway Traction as the Traction

Motors are fed from the Line Inverters. The only method used is inserting limiting resistors in the Stator circuit of the Induction Motors. There is lot of energy wasted in the form of heat in the starting resistance as it is very high on the Stator side. The rotor has low resistance and hence the current in the rotor is high resulting in lower starting torque in a Squirrel Cage Motor.

In the case of a Slip Ring Motor, the resistances are inserted in the Rotor which results in higher resistance and low starting current thus maximising the starting torque. As the slip necessary to generate maximum torque is directly proportional to the rotor resistance, the external resistance added increases the slip. Therefore, the Slip Ring Motor takes a very low starting current of approximately 250–350% of its full load current but has about 200 – 250% of full load torque at starting. The Slip Ring Induction motor behaves as a Squirrel Cage Induction Motor once the external resistances are cut out and shorted as the Motor reaches the base speed.

The energy savings can be quite substantial for a Slip Ring IM as the starting resistances are used only on the Rotor side and hence, they will be of lower value compared to the starting resistance used on the Stator side of a Squirrel Cage IM. The schematic diagram of Rotor Resistance starting is shown in Figure 1.

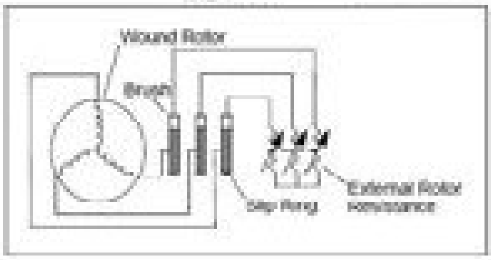

Fig. 1 Starting of Slip Ring Induction Motor

IV. Speed Control of the Traction Motors

The Speed of an IM can be controlled both from the Stator and Rotor side depending on the type of machine. In the case of a Squirrel Cage IM speed is normally controlled by varying the supply voltage or frequency of supply or the number of poles as[3], Speed is given by the formula:

$$N = \frac{120\,f}{p}(1-s) \quad \text{Eq. 1}$$

Where, s = Slip, N=speed of the motor in rpm, f = frequency in Hz and p = no. of poles.

If the speed of the Squirrel Cage motor is varied by varying the supply voltage, the Torque reduces considerably as Torque is proportional to square of the Voltage. The number of poles cannot be changed easily on board a Locomotive. The only option viable is to change the frequency of supply. This also brings about change in Torque produced as speed is inversely proportional to Torque. Hence, a constant Volt/Frequency ratio is to be maintained.

The speed of a Slip Ring IM can be varied both from stator and rotor side though speed control from the rotor side is preferred. The external resistance that is used during starting the Motor can be used to control the speed. This is possible because the slip required to generate maximum torque is directly proportional to Rotor resistance. The Motor is started with maximum resistance which is cut out on reaching the rated speed. For speed control, the same resistance is inserted into the circuit and slowly increased to bring down the speed of the Motor. The Torque-Slip relation is given by,

$$T = \frac{s}{R} \qquad \text{Eq. 2}$$

Where, s = slip and R = Rotor Resistance.

Now, when the Rotor resistance increases, torque produced decreases. But for a given trailing load, the motor, in turn the rotor has to generate the same torque. For this with the increase in Rotor resistance, the slip will also increase resulting in generation constant Torque which is nothing but reduction in speed. The disadvantage of this scheme would be wastage of energy as heat in the Resistors and also Copper losses in the Rotor.

The above mentioned disadvantage can be overcome by Slip Power Recovery Scheme. A 3-phase Rectifier – Inverter system can be connected to the Rotor of the IM and Slip Power can be harnessed thereby controlling the speed of the Motor. This scheme of speed control can be mathematically analysed as:

Power transferred from stator to rotor (or) the air-gap power P_g is given by,

$$P_g = \frac{2\,\pi\,N_s}{60} T \ \text{Watts} \quad \text{Eq. 3}$$

Where, N_s is the synchronous speed in rpm, T is Torque in Nm.

The mechanical power developed by rotor P_{mech} is given by,

$$P_{mech} = \frac{2\,\pi\,N}{60} T \quad \text{Watts} \quad \text{Eq. 4}$$

The Slip Power P_{slip} is given as,

$$P_{slip} = s\,P_g \text{ Watts} \qquad \text{Eq. 5}$$

When the speed is controlled, the slip increases which results in higher slip power. This power, in a Locomotive can be used to feed the auxiliary Blowers which are used for cooling the components. Normally the Locomotive Blowers are fed through an auxiliary winding on the secondary side of the Transformer. This can result in substantial savings as the Power from Head – On - Generation system in case of ordinary Mail/Express trains and End – On – Generation in case of Shatabdi/Rajdhani need not be used.

V. Braking in Locomotive

Rheostatic Braking and Regenerative Braking are the most commonly used Braking mechanism in Railways. In Rheostatic Braking, the stator winding of the Squirrel Cage Motor is disconnected from AC supply and excited from a DC source to produce a stationary DC field. The stator winding now acts as DC field and the rotor acts as the armature. The rotor windings now form the load in which heat energy gets dissipated. Hence, the size of the motor has to be increased to dissipate the heat generated. In case of a Slip Ring Motor, the Resistances that were used at starting can be inserted to employ Rheostatic Braking. The advantage is that heat is dissipated in the external resistances and hence the rotor does not get heated up much. The main advantage that can be observed in braking of a Slip Ring IM is that, the Pull – Out Torque remains maximum up to zero speeds.

In Regenerative Braking method, the Induction Motor works as a Generator when it runs above synchronous speed and feeds power to the supply. The disadvantage lies in the fact that the generated voltage must be higher than the supply voltage; it should match the supply frequency and should also be devoid of harmonics. Hence, Regenerative Braking requires complex Power Electronics to eliminate the harmonics and match the frequencies. Regenerative Braking is ideally employed when there are trains available on both Up and Down Lines in a rail network at the given instant as the generated voltage of one Locomotive will be absorbed by the other without feeding the Transmission lines.

In the Slip Ring Motors, the slip power recovered during speed control can be employed to run the auxiliaries like the charging of batteries, running blower fans, operating lights etc. instead of feeding back to the supply mains. This would serve the purpose of braking of the Traction Motors and also save the energy tapped from the mains to drive the Locomotive auxiliaries which are of lower voltage and current ratings.

VI. Adhesion

Adhesion is the friction between the rail and the wheel of the Locomotive. The Tractive Effort at the Driving Wheels can be increased by increasing the torque exerted by the Motor. After a certain limit, the increase in torque exerted by the Motor does not increase the Tractive Effort but causes the Driving Wheels to slip. The maximum value of Tractive Effort at which Driving Wheels will not slip depends on the dead weight over the Driving Axle.

$$\therefore \quad F \propto W$$

$$\text{Or,} \quad F = \mu_a W \qquad \text{Eq. 6}$$

If F is expressed in Newton and W in Tonnes, the above Equation becomes,

$$F = 9.81 \times 1000\,\mu_a\,W \qquad \text{Eq. 7}$$

The constant of proportionality μ_a is called the coefficient of Adhesion. In order to increase the Tractive Effort of a Locomotive, it is not enough to increase the Horse Power of the Locomotive alone but also increase the weight on the Driving Wheels. The adhesive weight can only be increased by increasing the number of Driving Axles. Adhesion is also very important for Braking. A braking effort more than the adhesive weight of the vehicle, will result in skidding. Maximum braking effort is possible only under maximum adhesion conditions.

In a DC Locomotive, since the torque-speed curve is flat (Fig. 2), consequent to the occurrence of initial slip, there will not be as much reduction in tractive effort developed as in an AC Locomotive. This tractive effort produced is much above the adhesion limit. The chances of restoration of grip on the rail are low and therefore the probability of re-absorption of wheel slip is low. Also, the Motor Control is by Series-Parallel control. If there are two pairs of DC Motors then, at starting both pairs of motors are in series and resistance is inserted in series which is cut out gradually. By means of series parallel control, these two pairs of motors are then connected in parallel. Before slip takes place since speed of two motors in series is same, their back electro motive forces are equal and therefore applied voltage across each motor is same. As soon as slip takes place due to any of the above mentioned reasons, speed of the motor of the slipping axle will rise. This will increase the back electro motive force of the motor of the slipping axle. As a result proportion of the applied voltage across slipping motor will increase and that across non slipping motors will reduce. The result of this situation is that the speed of the slipping motor will go on increasing and that of non-slipping motor will go in decreasing. This reduces the adhesion. The adhesion is reduced in a DC Motor as it does not have a smooth start because of the Rheostatic starting method.

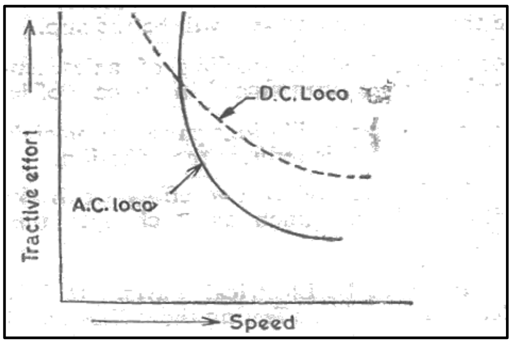

Fig. 2 Tractive Effort – Speed Curve [4]

In an AC Locomotive, on occurrence of slight wheel slip, torque developed reduces by large amount because of the steepness of the curve. This reduction in torque is so much that the new tractive effort is lower than the adhesion limit and this registers grip on the track. This means that the wheels will be re-attached to the rail before rail slip becomes perceptible. Therefore, possibility of wheel slip being re-absorbed is more in an AC Locomotive [4]. As all motors are connected in parallel and independently fed, slipping of any one of the Motors has no effect on the variation of applied voltage on other motors. Therefore adhesion is not impaired. The AC Locomotives have smooth starting by means of Rectifier-Inverter and hence the adhesion is enhanced. As Wheel Slip is observed normally during the starting of the Locomotive, the Motor at the slipping axle has to regain its speed and produce the required torque immediately after regaining grip on the track. This kind of adjustment of speed and production of torque is better in a Slip Ring IM as the Torque produced is proportional to the slip of the Motor. As the Rotor Resistance is varied, the starting torque will be higher.

VII. Energy and Cost Saving

The use of a Slip Ring IM in place of Squirrel Cage IM is being widely researched in applications like Mills. Though the initial cost of Slip Ring IM is seen as a disadvantage, the Slip Ring IM is more efficient in utilisation of energy. It has been proved in the case of Mills which make use of Induction Motors of the ratings of 1MW and above that, use of Slip Power Recovery scheme has considerable savings in the long run and also has the lowest energy losses [5]. In Traction application, a Slip Ring IM can produce higher starting torque with minimal starting current which in turn saves the energy dissipated as the starting resistance is on the Rotor side which is of lesser value as compared to the resistance used on the Stator side. The heat energy dissipated during braking is also on the Rotor side and hence the size of the stator is reduced in case of Slip Ring IM where as in a Squirrel Cage IM the stator has to be bigger to allow ventilation as the heat is dissipated in the stator. Hence, the savings effected by Slip Power Recovery Scheme would over ride the high initial cost of the Slip Ring Induction Motor and can be used for future Traction Applications.

VIII. Conclusion

As the Railways make use of many Diesel-Electric and Electric Locomotives, the savings in energy and hence the reduction in cost of operations will reflect in the profits made. Any substantial savings can be re-invested in other aspects like maintenance of rolling stock, improving the technology of signalling etc. The use of Slip Power Recovery scheme would result in substantial saving for the Railways and hence research work and field trials can be done on a pilot basis in future as it has been proved that the performance Slip Ring Induction Motor is far more superior to a Squirrel Cage Induction Motor in Mills. As the size of the Slip Ring Motor is also considerably reduced for the same ratings, the weight on the Axle is also brought down. Overall performance in starting, running, braking and adhesion would be better in a Slip Ring Induction Motor as compared to a Squirrel Cage Induction Motor.

References

[1]. Mihai Huzau, Eva Dulf and Clement Festila. About Quasi Direct Feed Possibility of the Induction Traction Motors from Diesel Electric Locomotives. IEEE Transactions 2006
[2]. Toby J Nicholson DC and AC Traction Motors. IET Professional Development Course in Traction Systems 3-7 Nov 2008, Manchester Pages34-44.
[3]. J. B. Gupta A Text Book of Electrical Machines
[4]. H. Partab Modern Electric Traction. Pritam Surat & Bros, Agra.
[5]. Paul Blaiklock, William Horvath Saving Energy TMEIC GE, USA – Motor Technology September-2009
[6]. B. K. Bose Power Electronics and AC Drives. Prentice Hall Inc., New Jersey