Inverter control of low speed Linear Induction Motors

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1. Introduction

The performance characteristics of low speed Linear Induction Motors (LIMs) are considerably different to the characteristics of Squirrel Cage Induction Motors (SCIMs). When LIMs are fed from standard inverters that are configured to optimally drive SCIMs, these differences result in non optimal performance of LIM driven systems.

This paper presents ways of configuring standard inverters to give better system performance when driving LIMs. The methods presented here can also be extended to give better performance from medium and high speed LIMs.

2. General

The performance characteristics of a LIM depend on its design. The operation of LIMs can be divided into several speed ranges: low speed (up to about 4 m/s), medium speed (between about 4 and 15 m/s) and high speed (over 15 m/s). The optimum method of controlling a LIM depends on its designed running speed. This paper describes the simpler operation of a low speed LIM.

A large number of models of inverter are now available, although they all drive SCIMs using various control algorithms, the implementation of these 'standard' control methods differ in detail and configurability. Not all models of inverter allow the user to adjust its configuration to suit the different requirements of a LIM driven system.

Low speed LIMs are generally used in localised transport systems where a loaded vehicle is required to smoothly accelerate to its running speed, travel at this speed until it nears its destination, where it must smoothly decelerate to a low speed and then stop at its destination. After being unloaded the vehicle must return to its start point while empty. The required accuracy of the speeds, smoothness of the motion and accuracy of the stopping position are dependent on the application.

The inverter is required to perform these actions with a minimum of external components and should provide smooth acceleration, deceleration and good speed holding independent of vehicle loading. It should also drive the LIM in such a way as to minimise the stresses on the LIM (both mechanical and thermal) and provide suitable protection to both the LIM and the complete system.

A system driven by a LIM does not have the advantage of a speed reduction gearbox. To drive a load at a low speed, the LIM must produce its usable force at this low speed. Because of this, low speed LIMs are normally designed to operate from a supply frequency less than the mains. Medium speed LIMs work from supplies of about mains frequency while high speed LIMs work from supplies above mains frequency.

3. Typical characteristic curves

The LIM is required to both drive and brake the load. To understand how this differs from the operation of a SCIM, the driving and braking characteristics of both types of motor need to be considered together.

The LIM is normally considered to be a squirrel cage induction motor cut down its axis and opened out. From this description the characteristics of the two types of motor should be comparable. This is not the case as the specific details of the motors operating conditions are varied considerably when it is used.

This can be seen by considering the effect of the changes to the values in the standard induction motor equivalent circuit shown in Fig 1 Note this circuit shows Rm and Xm in their correct locations as the simplifying assumptions do not apply to LIMs.

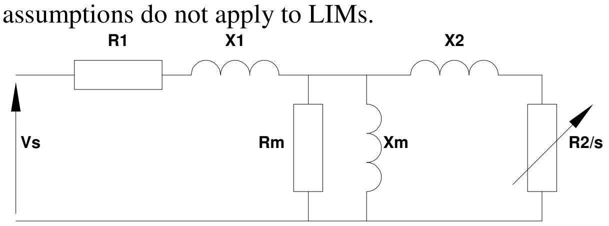

Figure 1 Equivalent circuit of an Induction motor

The first significant change made to the operating conditions of a LIM is that the squirrel cage is transformed into a continuous conducting plate and placed in the gap between rotor and stator laminations. This has several consequences, the main ones being the increase in the magnetic gap, the increase in the rotor resistance (caused by less conductor material being used to limit the increase in magnetic gap) [1] [2].

This change affects the following circuit elements:-

X1 is increased as the increase in magnetic gap increases the leakage.

Xm is reduced to push flux across the larger magnetic gap.

X2 is generally reduced as the secondary circuit is not constrained to bars in slots.

R2 is increased as less rotor conductor is present.

The next significant change is caused by further opening up the magnetic gap to give mechanical running clearance.

This change affects the following circuit elements:-

X1 is further increased as the increase in magnetic gap increases the leakage.

Xm is further reduced to push flux across the larger magnetic gap.

X2 is increased as the magnetic gap increases the leakage.

This effect is further complicated by the inevitable variation in the magnetic gap as the vehicle moves along its path.

The last significant change is caused by the inclusion of the ends of the stator. This adds end effects, entry and exit effects, winding unbalance effects and variation in the effective number of poles. This change does not directly affect any of the normal equivalent circuit parameters, but does add additional elements that have an effect on the performance of the LIM. The number of effective poles will change during a cycle as the ends are weakly energised for part of the time.

The combined effect of these changes produces a totally different motor characteristic [1] [2], resulting in the differences shown in Fig 5 and Fig 6. Note the actual value of current for the LIM is likely to be larger than the SCIM.

This gives a spread of characteristics for normal motor control methods as shown in Fig 2.

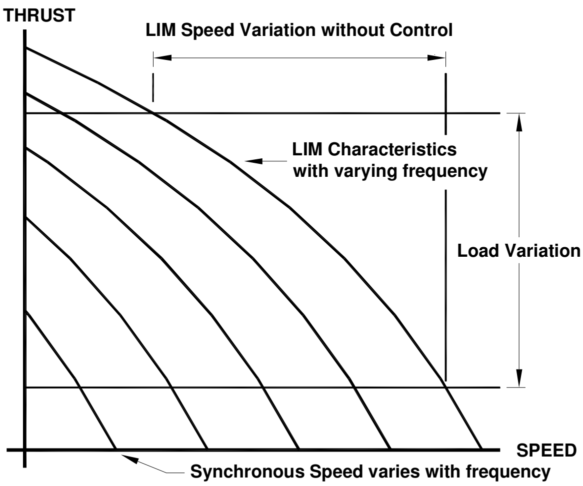

Figure 2 LIM characteristics v/f constant

An additional factor to consider with a LIM is the attraction force. This force does not balance as it does with a circular stator but can distort or destroy the system.

Because these characteristics are different, the LIM can operate in regions not normally used by SCIMs. These operating regions are defined in Fig 3.

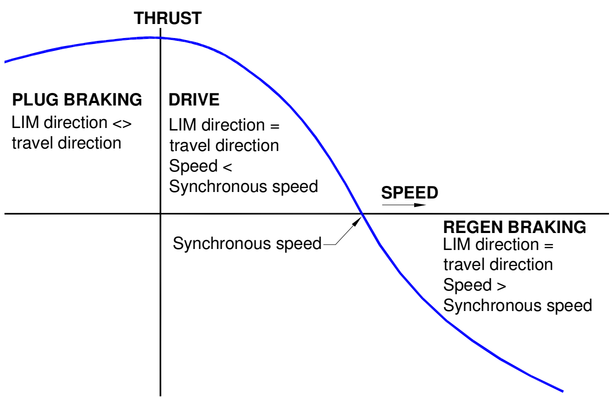

Figure 3 Operating regions of a LIM

From the characteristics in Fig 2, Fig 5 and Fig 6 the following points are readily apparent:-

a) For a given rated speed, the synchronous speed of the LIM is much higher than that of the SCIM.
b) Small changes in load give much larger changes in speed with a LIM.
c) A LIM driven system at no load could run at a much higher speed than desired.
d) Regenerative braking is not as effective in LIMs and a very large reduction in frequency is required before any effective braking force is produced.
e) The LIM can produce significant braking force in the plugging region.
f) The variation of supply current with speed is much less pronounced in LIMs.
g) At the lower supply frequency, the LIMs output is significantly reduced.

4. Possible Control methods

4.1 Open loop scalar control

This is the control method initially used when SCIMs were first driven by inverters.

The frequency is set to the required speed and the voltage is set to keep the ratio of voltage / frequency constant [3].

Two improvements were added to later inverters:

1) Increasing the voltage at lower frequencies to compensate for the motors stator resistance.
2) Slightly increasing the frequency (and voltage) when the motor current increases to compensate for the loss in speed due to an increase in the load.

Even with all the above improvements, when this method of control is applied to a LIM, the LIM does not respond well. This is a direct result of the differences in characteristics as noted above.

4.2 Closed loop scalar control

The performance of the open loop scalar control is improved by using actual measured speed to correct the reduction in speed due to load [3].

In general the feedback system is only capable of fine tuning the output frequency over a small adjustment band. This scheme also results in a bad response from the LIM.

4.3 Open loop flux vector control

Open loop flux vector control is an improvement on the open loop scalar control. The inverter is first tuned to the motor by obtaining motor parameter data by running tests with the shaft mechanically disconnected from the load. The effect of load on the motor can then be more accurately estimated and compensated for by taking more detailed current measurements [3].

Some inverters use the effects caused by the variation of rotor reactance as it rotates to also monitor the rotor speed.

When this technique is applied to the control of a LIM, the results are dependent on the particular algorithms used in the inverters firmware.

A LIM can never be run totally unloaded, as the reaction plate forms part of the vehicle. Thus the motor always sees a base load. Running a LIM for a length of time at various settings to tune the inverter can also be difficult, the vehicle runs on a track of fixed length, this can be shorter than the length of run required to tune the inverter.

The parameter values obtained from testing a LIM using inverter auto-tune, or by calculation, are often outside the range of acceptable values set by the inverter manufacture.

The LIM does not have rotor bars, so trying to detect the changes generated by the passage of the rotor bars will not work.

Due to the large slip of the LIM and low variation of current with load, using this method does not usually provide good control.

4.4 Closed loop flux vector control

The performance of the open loop flux vector control is improved by using actual measured speed [3].

The setting up of the inverter for this control method normally requires the inverter to run its auto-tune algorithm, with the same problems as stated for the open loop flux vector control mode.

The parameter values obtained from testing a LIM using inverter auto-tune, or by calculation, are often outside the range of acceptable values set by the inverter manufacture.

Control by this method normally results in more audible noise, greater mechanical stress and higher than optimum LIM current.

4.5 Closed loop fixed frequency control

This method of control is not normally available from an inverter. It is suited to the control of low speed LIMs and other motors with a high resistance rotor such as wound rotor motors that were often used on crane hoists.

This method of control only works with a closed loop system using an actual velocity signal, the measuring of the motor current or setting of motor parameters are not required as the feedback signal compensates for all these variations.

The motor is always driven at its rated frequency. The output power is adjusted by varying the voltage in response to the error between the required and actual velocities. If the speed is too high, braking force is required. The braking force is provided by reversing the phase sequence and using the plugging characteristic of the LIM. During plug braking, the frequency remains at its rated value. This results in a control scheme that only draws current from the supply when an output force is required from the drive. This results in a reduction in input power, reaction plate and LIM heating over the previous LIM control schemes.

To achieve reasonable control from this type of system, it requires the fast changing of the LIMs voltage without changing the frequency. It also requires the inverter to be able to very quickly reverse the phase rotation of the frequency.

This system of control requires an inverter that can be re-configured into this mode, with parameters that can accept the range of values required to drive the LIM.

The characteristics of a LIM driven by this control method are shown in Fig 4.

5. Typical LIM Controller

The typical LIM controller as shown in Fig 7 is different to a normal inverter in several ways:

1) The PWM driver is controlled by independent voltage and frequency inputs.
2) The set speed, ramps and PID blocks do not control the frequency.
3) There is a new block called “LIM Characteristic”.
4) Actual speed feedback is required.
5) Additional trip conditions have been added.

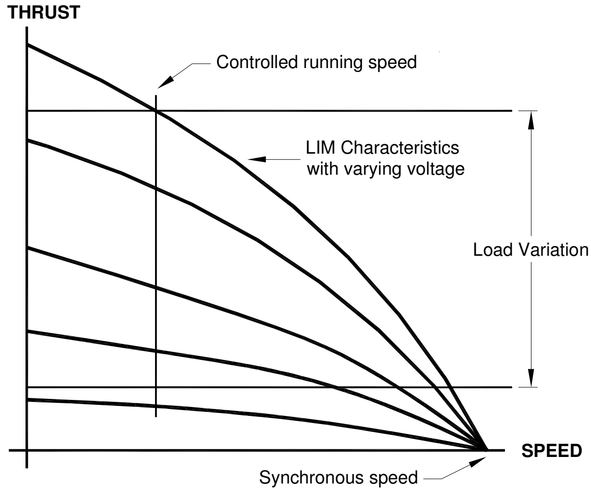

Figure 4 LIM with fixed frequency & variable voltage control

5.1 LIM Characteristic block

This block determines the frequency, direction and maximum voltage to apply to the LIM at any given instant. The exact particulars of this block depend on the rated operating point and application of the particular LIM it is driving.

This block is its simplest when controlling a low speed LIM as the outputs are fixed as follows:-

Maximum LIM voltage	=	LIM rated voltage.
LIM frequency	=	LIM rated frequency.
Phase rotation	=	Sign of required thrust (+ve thrust = forwards).

When controlling medium and high speed LIMs this block becomes much more involved.

5.2 Emergency settings link

During an emergency stop, the normal speed ramps should be removed, and the fastest deceleration possible should be used. This needs an automatic change to the ramp block and may require an alternative set of PID gain settings.

6. Conclusions

A low speed LIM can be driven from a correctly configured inverter. The standard inverter control modes do not produce the best control of the LIM. Not all makes of inverter are capable of the best LIM control.

7. References

[1] S.J.O. Proverbs “The design and performance of linear induction machines” M. Phil thesis 1993

[2] S. Nasar, I. Boldea “Linear electric motors” Prentice hall 1987

[3] Control Techniques “Drives and controls handbook” Institution of Electrical Engineers 2001

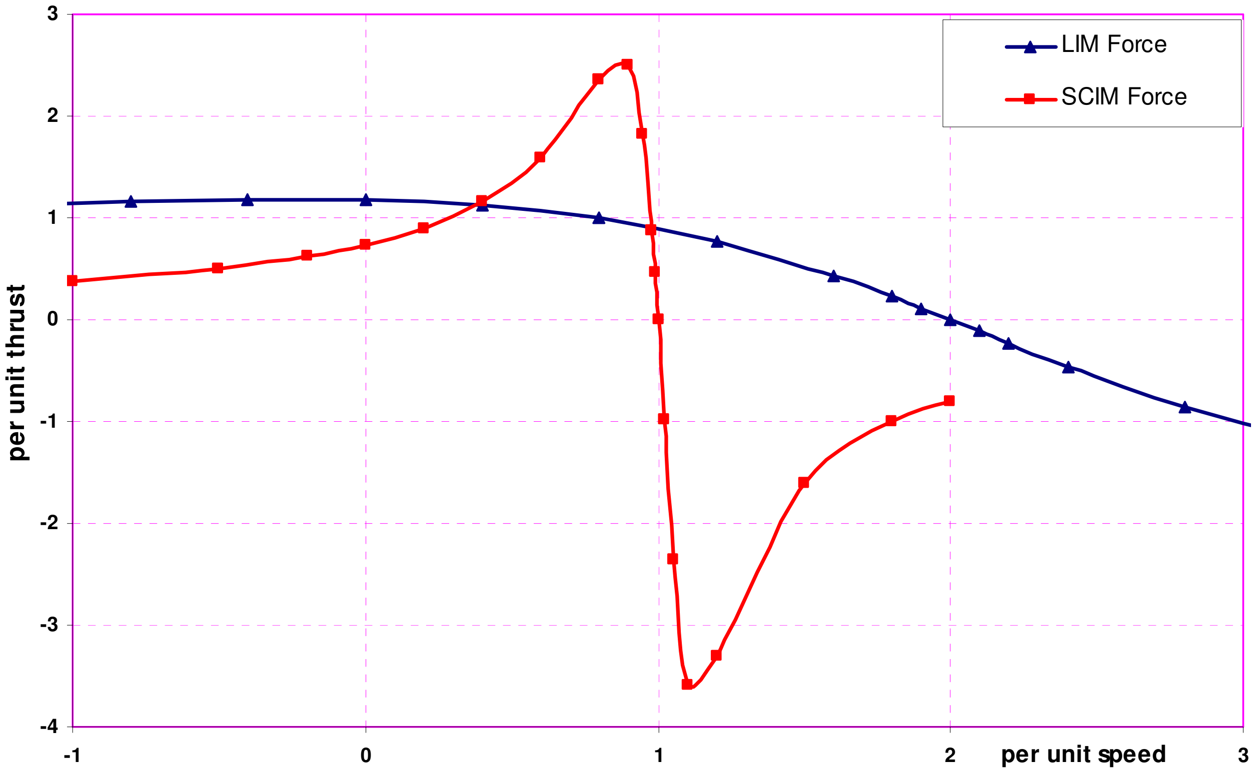

Figure 5 Comparison of typical low speed LIM & SCIM @ rated voltage & frequency

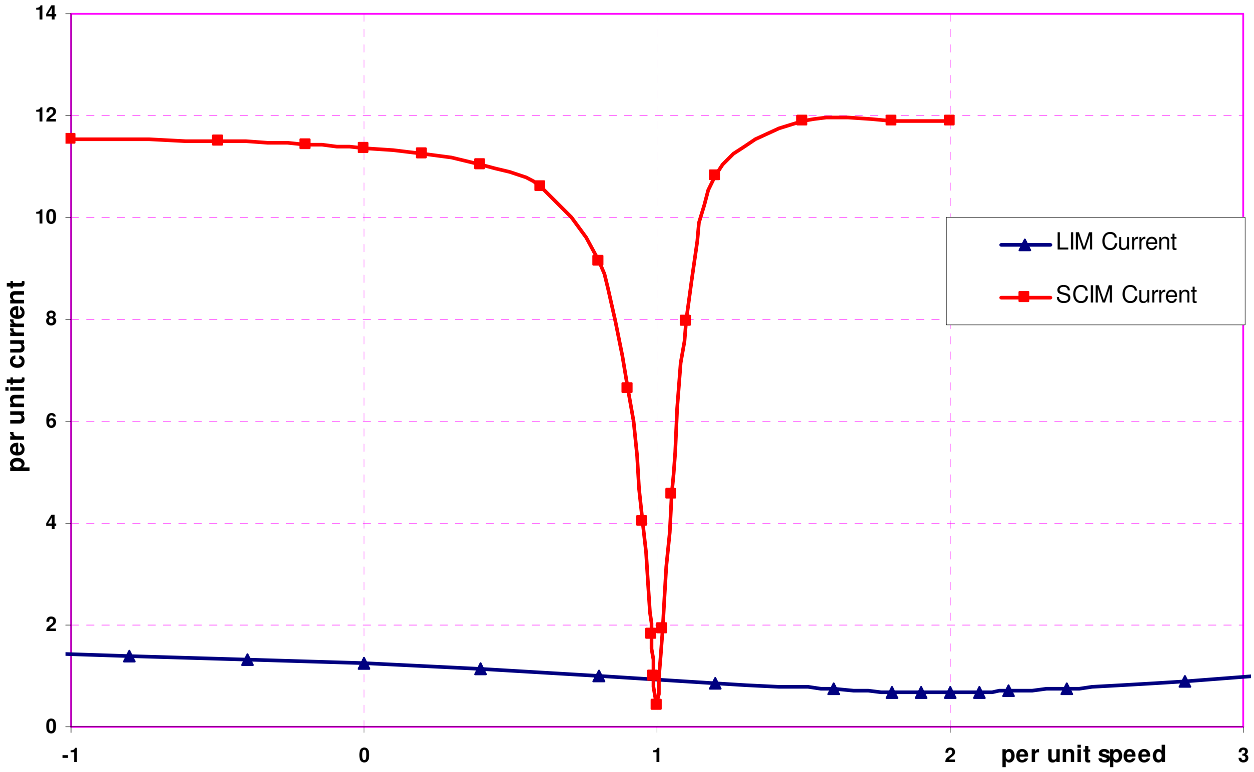

Figure 6 Comparison of typical low speed LIM & SCIM @ rated voltage & frequency

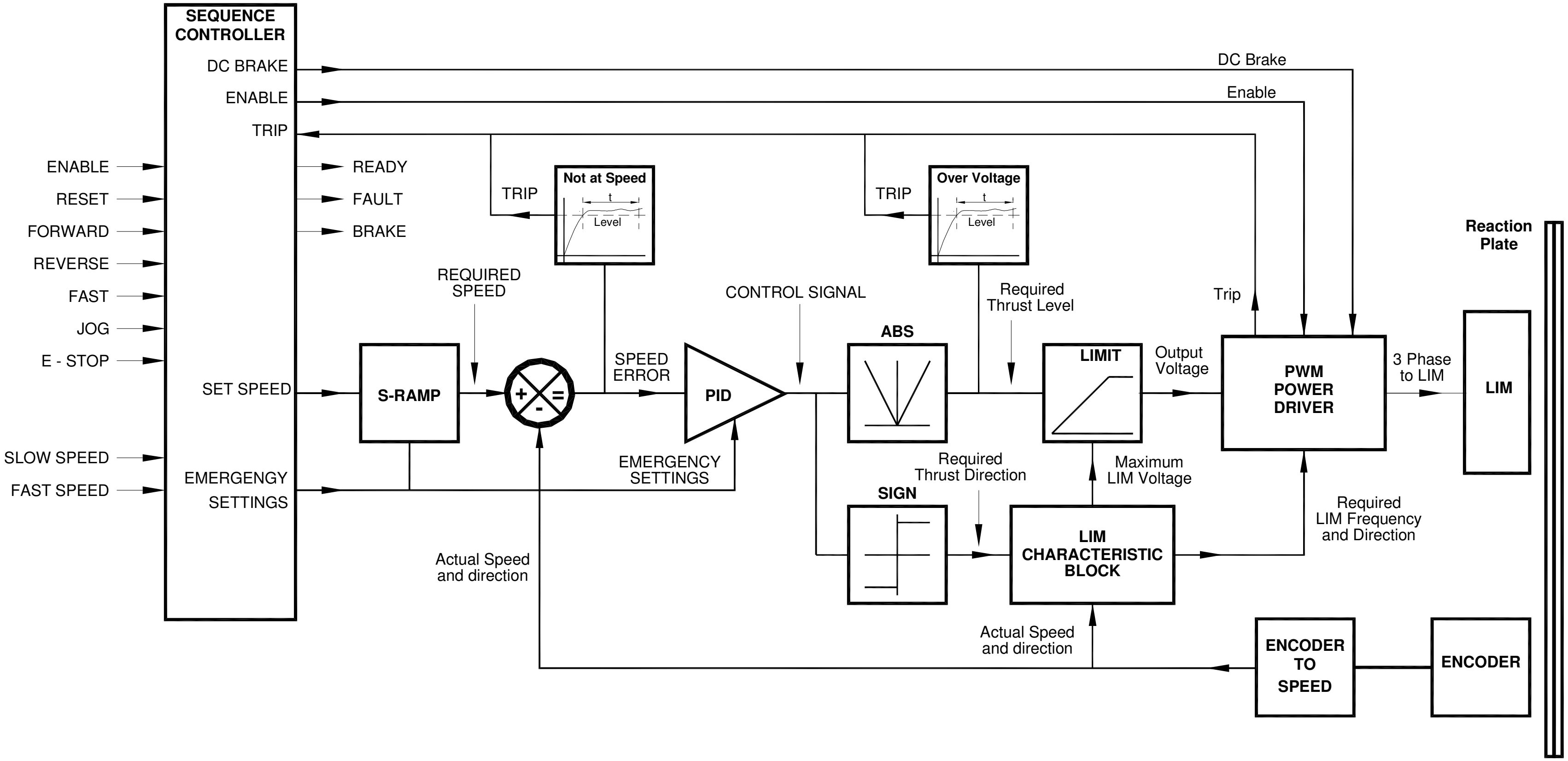

Figure 7 Typical block diagram of a LIM speed controller