INVERTER CONTROL OF MEDIUM AND HIGH SPEED LINEAR INDUCTION MOTORS

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Abstract

This paper suggests a unique configuration of certain standard inverters to give better performance from medium and high speed Linear Induction Motors (LIMs). It extends the control method suggested for low speed LIMs [1] and allows a given system parameter to be optimised.

1 Introduction

The performance characteristics of 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 extends the control method suggested for low speed LIMs [1] 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 4 and 15 m/s) and high speed (over 15 m/s). Low speed LIMs work from below mains frequency supplies, medium speed LIMs work from supplies of about mains frequency, while high speed LIMs work from supplies above mains frequency.

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.

Medium and high speed LIMs are generally used in launch and long distance transport systems where a 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. 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.

3 Typical characteristic curves

The LIM is often 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 [3] [5] [6].

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 LIM operating conditions can vary considerably in practice.

The LIM has ends; these produce end effects, entry and exit effects, winding unbalance effects and also variations in the effective number of poles. These effects are more pronounced at high speeds. The LIM performance is further complicated by the inevitable variation in the magnetic gap due to mechanical tolerances as the vehicle moves along its path. An additional factor to consider with a LIM is the attraction force between stator and rotor. This force does not cancel as it does with a circular stator but can create a force significant enough to distort or destroy the system.

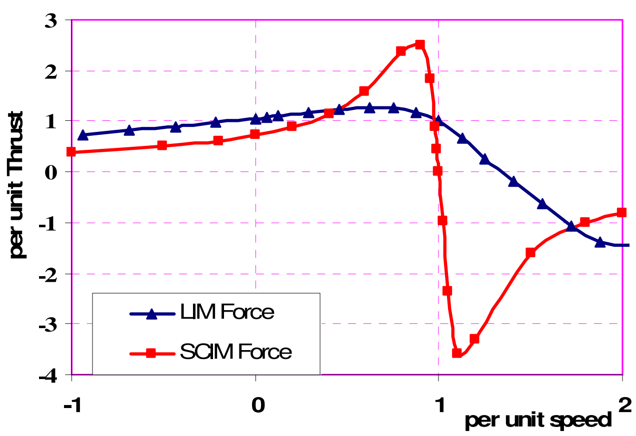

Figure 1: LIM v SCIM Thrust Characteristics

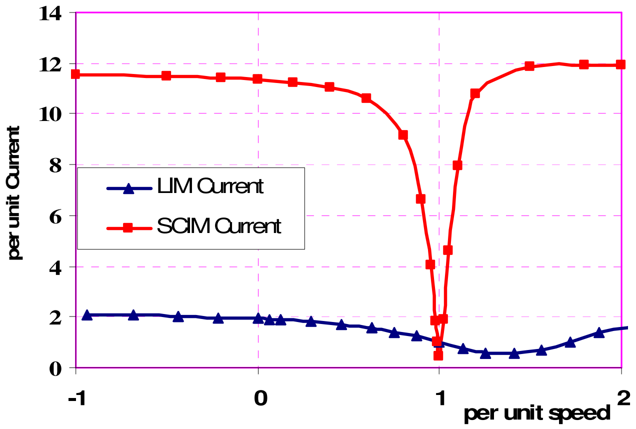

Figure 2: LIM v SCIM Current Characteristics

The combined effect of these changes produces a totally different motor characteristic, resulting in the differences shown in Figures 1&2. Note the actual value of rated current for the LIM is likely to be larger than the SCIM.

This gives a spread of characteristics for normal motor control methods [2] [4] as shown in Figures 3&4.

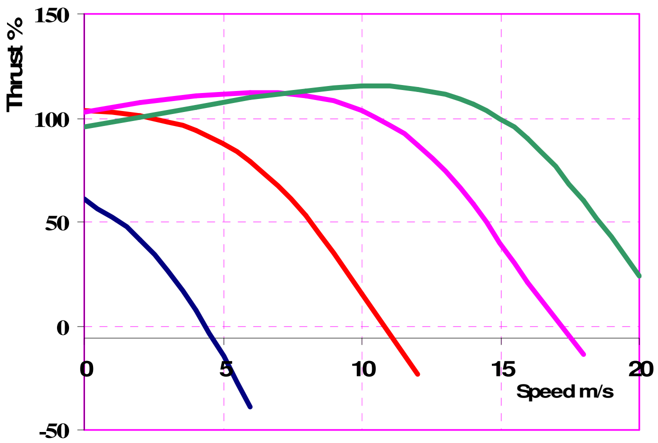

Figure 3: Constant V/f LIM Thrust / Speed Characteristics

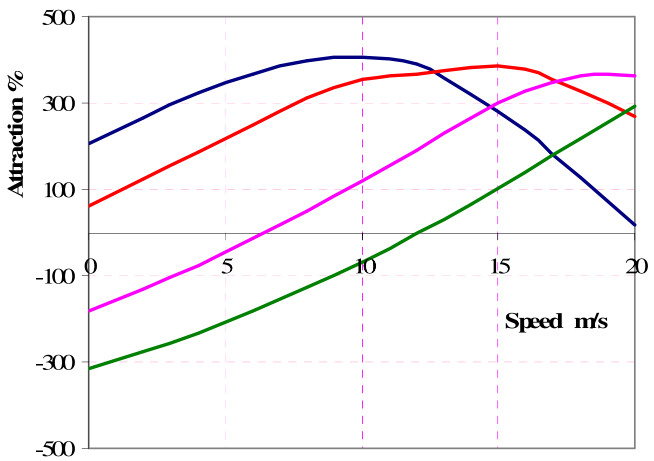

Figure 4: Constant V/f LIM Attraction / Speed Characteristics

4 Control methods

It can be clearly seen from the characteristic curves that normal control methods do not give the best performance from the LIM as the speed has a considerable variation with load, the current does not change sufficiently to give good compensation, and the available low speed thrust is significantly restricted.

Because of these different characteristics, the operating regions of a LIM are different to the SCIM. The LIM does not provide useful regen braking until the synchronous speed is much lower than the running speed. This results in very poor braking at low speeds, requiring a different braking strategy at low speeds. Plug braking is used as shown in Figure 5.

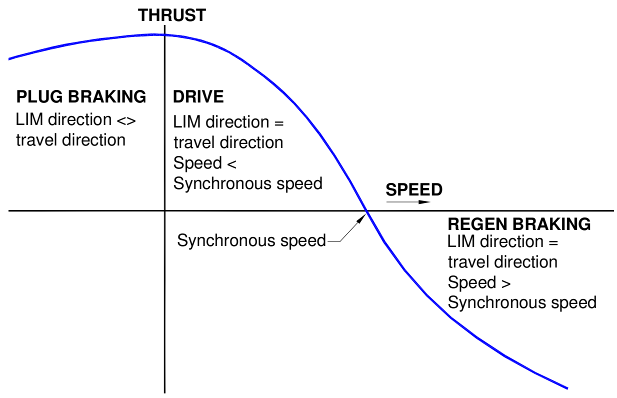

Figure 5: Operating regions of a LIM

4.1 Closed loop fixed frequency control

This is the suggested method of control for low speed LIMs [1]. 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 speed and the actual measured velocity. 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 method of control has limitations when applied to medium and high speed LIMs:-

a) The available starting thrust can be much less than the running thrust.

b) During running up to rated speed the slip is very high, resulting in significant reaction plate heating.

c) Running at lower than rated speed is inefficient due to the increased losses.

d) Plug braking at high speeds requires a larger than rated current. This can be significantly larger than the rated value and require the fitting of a larger inverter.

e) Plug braking at high speeds produces very large slip losses in the reaction plate.

4.2 Closed loop variable frequency control

To reduce the effects listed above, the frequency and voltage are modified differently. The drive and braking sections are treated separately.

4.2.1 Closed loop variable frequency control in drive

To reduce the effects (a), (b), and (c) detailed above, the frequency is allowed to vary as the speed increases. This is not the conventional setting of the frequency to approximate the synchronous value at the required speed, but setting a value related to the actual speed.

The actual frequency used is set to a value to give a required response: either to give maximum efficiency, minimum reaction plate heating, minimum stator heating, minimum attraction force, or some best compromise.

The applied voltage at this frequency is set to give the required drive thrust from the LIM (as determined by the closed loop feedback system). A maximum voltage is set for each operating point to prevent undesirable effects such as saturation.

4.2.2 Closed loop variable frequency control in braking

Braking from high speeds with a LIM creates some unexpected challenges. Using the standard re-gen braking system has limited success due to the large slip required, the large attraction force, and the large series impedance of typical LIMs.

The low speed method of plug braking suffers from the effects (d) and (e) as noted above.

The solution is to reduce the speed using a form of re-gen braking and then switch to plug braking when the speed has been sufficiently reduced and the attraction force is still within acceptable limits.

4.2.3 Complete closed loop variable frequency control

Combining drive and braking segments give the performance curves as shown in Figure 6. This control method can only be generated by an inverter that is capable of independently setting the output frequency and direction from an input value, the output voltage from a derived PID error amplifier value, and will allow fast direction switching.

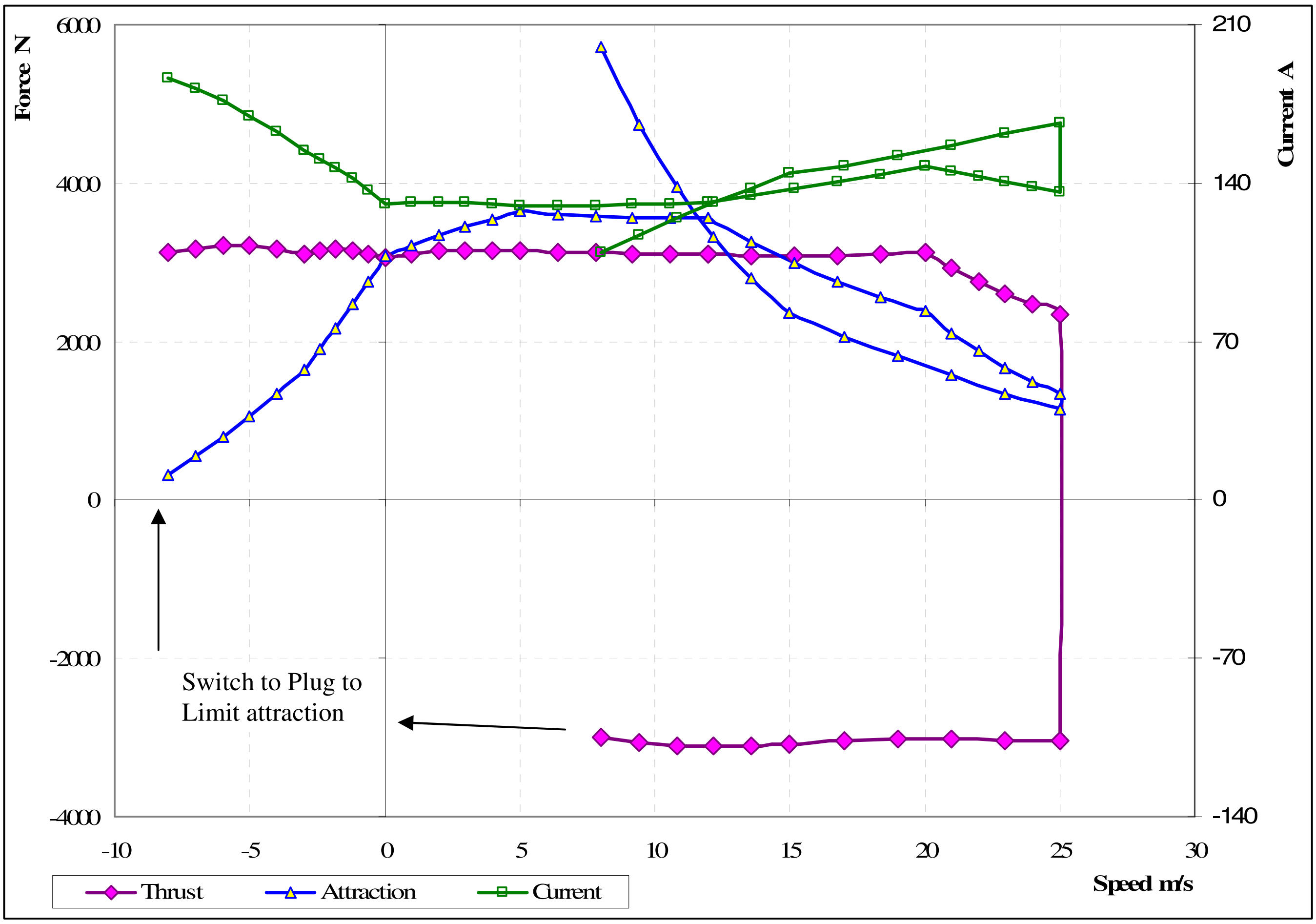

Figure 6: Performance envelope limits for a controlled LIM

5 Typical LIM Controller

The typical LIM controller is the same closed loop speed controller that was described for a low speed LIM [1]. The only difference is in the internal operation of the "LIM Characteristic" block which has been significantly altered

This controller has 5 main control blocks and some limiting and monitoring blocks as shown in Figure 7.

5.1 "S" Ramp required speed generation block

This block keeps the required speed within acceleration and deceleration limits that are achievable by the LIM. This helps keep the PID amplifier within its working range

5.2 Speed feedback block

This block converts the measured speed signals into an actual speed value including the direction of travel.

The actual speed is required to form a closed loop speed controller and to select the LIMs voltage and frequency points.

5.3 PID amplifier block

This block determines the drive level required to maintain the set speed. This is a standard PID controller working on the error between the required speed and the actual speed.

5.4 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.

When controlling medium and high speed LIMs this block's outputs are a complex function of actual speed and desired drive or braking mode.

By adjusting the specific behaviour of this block the system can be optimised to produce the desired optimum performance (system efficiency, inverter current rating, LIM rating, reaction plate heating, attraction force etc).

5.5 Output power stage

This block takes the required output frequency, direction, and voltage as determined by the LIM characteristic block and drives the high power stage to produce this signal at the LIM terminals.

6 Conclusions

A medium or high 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.

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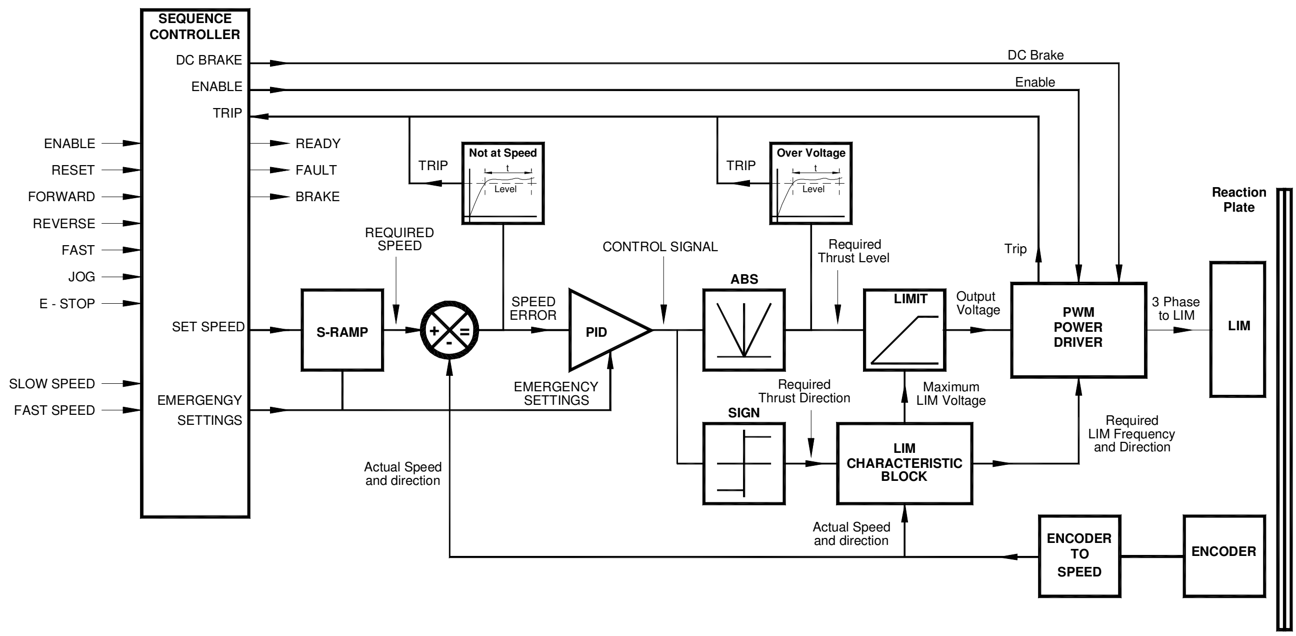

Figure 7: Typical LIM controller Block Diagram