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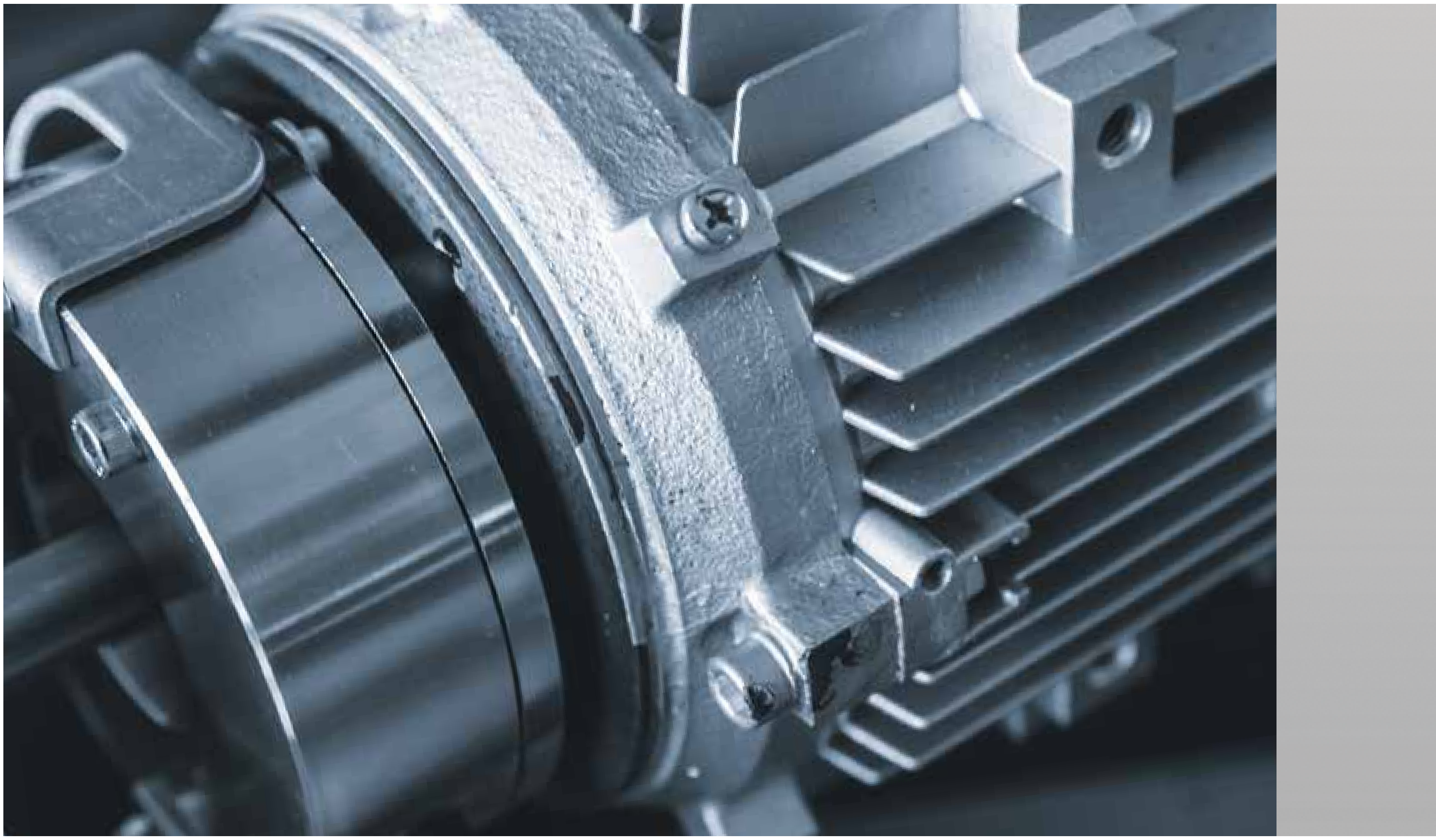


Get Your Motor Running: Reduced Voltage Starting

Rapid | Rugged | Global

Get your motor running

The starting function of motors is often misunderstood, impacting motor performance and compromising energy efficiency.

Reduced starting current is often required by electrical supply authorities to reduce current surges and the resulting voltage fluctuations on the supply system. Reduced voltage starting of three phase AC induction motors can be used to reduce the starting current drawn by the motor.

Reduced voltage starting of three phase induction motors

Full voltage starting (direct-on-line or DOL) creates a starting current surge equal to the locked rotor current (LRC) of the motor. The LRC typically ranges from 500% to 800% of the motor full load current (FLA). The LRC depends on the design of the motor; a value of 600% FLA is common.

The full voltage starting torque is equal to the locked rotor torque (LRT) of the motor.

Reduced voltage starting reduces the available starting torque of the motor. It cannot be used for some applications because of the load's starting torque requirements

INDUCTION MOTORS

The induction motor performs two main functions in industry:

- To convert electrical energy into mechanical energy, to accelerate the motor and load to the operating speed. This is the starting function.
- To convert electrical energy into productive work output from the machine. This is the operating or work function.

The starting characteristics and the full load characteristics are both very important in the selection and specification of motors. The starting function of the motor is poorly understood; many motors are misapplied and so exhibit very poor starting characteristics.

Full load characteristics of the operating functions are easy to specify with motor speed, torque and efficiency being the major selection criteria.

MOTOR DESIGNS

Motors consist of two major sections: the stator and the rotor.

The stator consists of magnetic poles and stator windings within the frame of the motor. The full load characteristics are determined by varying the winding configuration and the contour of the stator laminations. The motor speed is determined by the number of poles.

The rotor consists of a cylindrical short circuited winding around iron laminations. The rotor winding is often referred to as a squirrel cage.

The cage is constructed of a number of bars running parallel to the motor shaft, near the surface of the rotor. These rotor bars are short circuited by shorting rings at each end of the rotor. The shape, material and position of the bars within the rotor determine the starting characteristics of the motor. In operation, the motor performs as a transformer with current induced in the rotor by the flux from the stator. When the rotor is stationary (locked rotor conditions), the motor current is limited by the effective series impedance of the rotor and stator.

At very low speeds, the dominant impedance is the rotor. At high speeds, the stator impedance can become influential. Thus the rotor determines the starting characteristics of the motor and the stator influences the full speed characteristics.

The torque developed by the motor is a function of the rotor current, the effective rotor resistance and the rotor slip (difference between rotor speed and synchronous rotor speed). During starting, the current is limited by both the rotor resistance and the rotor leakage reactance. Motors which exhibit a high LRC tend to have a low LRT, while motors with a low LRC generally have a high LRT.

A high starting torque is generated by using a high resistance rotor, but this can result in increased slip at full load. One compromise is to use a rotor consisting of two cages: a high resistance outer cage giving a high starting torque and a high reactance inner cage giving a low slip operation.

This double cage motor can sometimes be more limited in starting capacity than single cage motors and so is not always suitable for multiple start applications. Typical full voltage starting torques (LRT) are in the range of 120% to 220% of full load torque (FLT). It is often possible to increase the LRT by over 50% by utilizing a different rotor design.

The designs of AC induction motors fall into four main categories, each exhibiting different starting and operating characteristics. The motor design should be selected by the machine manufacturer to suit the mechanical load of the machine.

- Design A motors have a shallow rotor bar design resulting in low rotor inductance and usually low rotor resistance. Design A motors exhibit a high LRC and a low LRT. They have a good operating efficiency and a high pull out torque. The full load slip of these motors is low.

  Typical LRC = 650% to 1000% FLA   Typical LRT = 100% to 140% FLT

- Design B motors have a higher rotor inductance and rotor resistance than Design A motors. Design B motors have a lower LRC and higher LRT than Design A motors. The efficiency is similar to Design A, but pull out torque can be lower and slip higher.

  Typical LRC = 550% to 650% FLA   Typical LRT = 140% to 240% FLT

- Design C motors are often known as double cage motors because of two windings on the rotor. One winding is low resistance as found in Design B motors and the outer winding has a high resistance. The low resistance inner winding is designed to have a high reactance. Double cage motors have a low LRC and high LRT, typically greater than 200%.
- Design D motors have a high reactance squirrel cage winding. They exhibit a high LRT (up to 300%) and a low LRC. The high resistance rotor results in a high full load slip and low efficiency.

Increasing the motor size or rating will not always increase the starting torque. When it is difficult to start a machine, the motor is often incorrectly replaced with a higher rated motor. In fact an equivalent rated motor of a different design is often more effective and costs less.

Application Examples

EXAMPLE 1

A 75 hp motor with 180% LRT has a higher start torque than a 100 hp motor with 120% LRT. The starting current for the 75 hp motor is generally less than the 100 hp motor.

Incorrect motor selection may use an oversized motor to achieve the required starting torque, with associated increased motor and starter cost, and a higher starting current.

With reduced voltage starting, the torque is reduced by the square of the current or voltage reduction. High current motors tend to have low starting torque, so any reduction in the start voltage results in a greater difference in starting torque between the high and low starting torque motors.

In many applications the starting current is required to be less than 300% FLA. Reduction from 600% FLA to 300% FLA is a 2:1 reduction, resulting in a torque reduction of 4:1. Reduction from 900% FLA to 300% FLA is a 3:1 reduction in current, resulting in a 9:1 reduction in starting torque.

EXAMPLE 2

Motor A has LRT 180% and LRC 600%, so at 300% FLA the motor produces 45% starting torque. Motor B has LRT 120% and LRC 900%, so at 300% FLA produces 13% starting torque. This is a torque differential of over 3 times for two motors which appear to be very similar and would be sold in direct competition.

The higher torque motor may be a little more expensive, but this is insignificant compared to the torque available. The increase in torque means some machines can be successfully started at 300% FLA with Motor A but not with Motor B. To develop 45% FLT, Motor B requires 520% FLA. This would result in much more expensive starting equipment and in many cases the start current would be unacceptable.

Motor A: LRT = 180%, LRC = 600%

At 300% FLA the torque is: 180 x (300 / 600) × (300 / 600) = 45%

Motor B: LRT = 120%, LRC = 900%

At 300% FLA the torque is: 120 x (300 / 900) × (300 / 900) = 13%

In many situations it is best to use a high starting torque motor which has a low LRC. This may result in a higher motor cost, but the cost of the motor and starter combination will often be reduced.

EXAMPLE 3

Table 1 shows that for motors of similar rating, the usable torque can cover a wide range under reduced voltage (or reduced current) starting conditions.

For the nine motors surveyed, the initial start torque at 300% FLA ranges from 66% to 24%, a span of greater than 2:1 at the same current. The motors have very different starting efficiencies, despite the very similar full load characteristics.

The initial start torque: $TST = LRT \times (I_{ST} / LRC) \times (I_{ST} / LRC)$

						Torque % FLT	
Motor	Speed RPM	FLA A	LRC % FLA	LRT % FLT	FL eff %	@ 300% FLA	@ 400% FLA
1	1470	191	600	260	93	65	116
2	1475	184	600	190	94	48	84
3	1475	191	570	150	92	42	74
4	1480	187	660	190	95	39	70
5	1470	185	550	120	92	36	64
6	1470	191	670	150	93	30	54
7	1480	190	780	200	94	30	53
8	1475	182	850	220	94	27	49
9	1480	190	670	120	94	24	43

Table 1: A selection of 110 kW four pole motors and their characteristics

EXAMPLE 4

Table 2 shows that with an initial start torque of 50% FLT, a standard duty starter can be used with Motor 1, but with Motor 9, a more expensive heavy duty starter is needed. The lower starting efficiency motors also suffer a high level of heating during start and so the number of starts per hour must be lower.

The start current for an initial start torque can be calculated as follows:

$I_{ST} = LRC \times \sqrt{(T_{ST} / LRT)}$

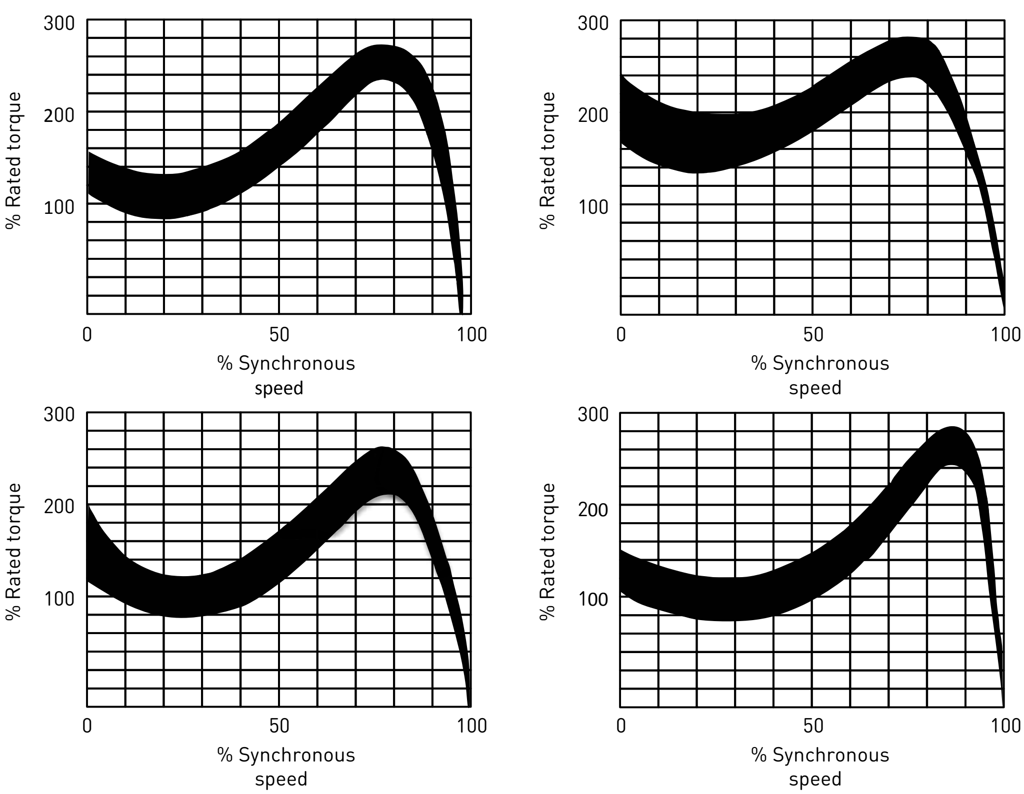
Motor	10% FLT	20% FLT	50% FLT	100% FLT
1	120% FLA	170% FLA	260% FLA	370% FLA
2	140% FLA	190% FLA	310% FLA	440% FLA
3	150% FLA	210% FLA	330% FLA	470% FLA
4	150% FLA	220% FLA	340% FLA	480% FLA
5	160% FLA	230% FLA	360% FLA	500% FLA
6	170% FLA	250% FLA	390% FLA	550% FLA
7	180% FLA	250% FLA	390% FLA	550% FLA
8	180% FLA	260% FLA	410% FLA	570% FLA
9	200% FLA	280% FLA	430% FLA	610% FLA

Table 2: Start currents for a specified initial start torque

SPEED/TORQUE CURVES

The speed/torque curves are unique to each motor design type. When engineering a motor and starter for an application, the speed/torque curve for the motor and starter should be plotted against the machine speed/torque curve. Some motor manufacturers show the curve as a single line, while others illustrate the curve as a shaded band. The speed/torque characteristics are not smooth, but have many peaks and troughs. The manufacturers' curves are averages only.

To ensure the motor will start satisfactorily, there should be a good differential between the motor torque and the machine torque requirement at all speeds. If the start torque is marginal, the motor will noticeably change in acceleration as it increases in speed. The flat spots are usually very audible. Particularly severe torque flat spots occur for motors which have a rotor that is 'off round' causing an uneven air gap between the rotor and stator.



Examples of speed/torque curves.

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