

Sam Harries Assignment 1 - FINAL

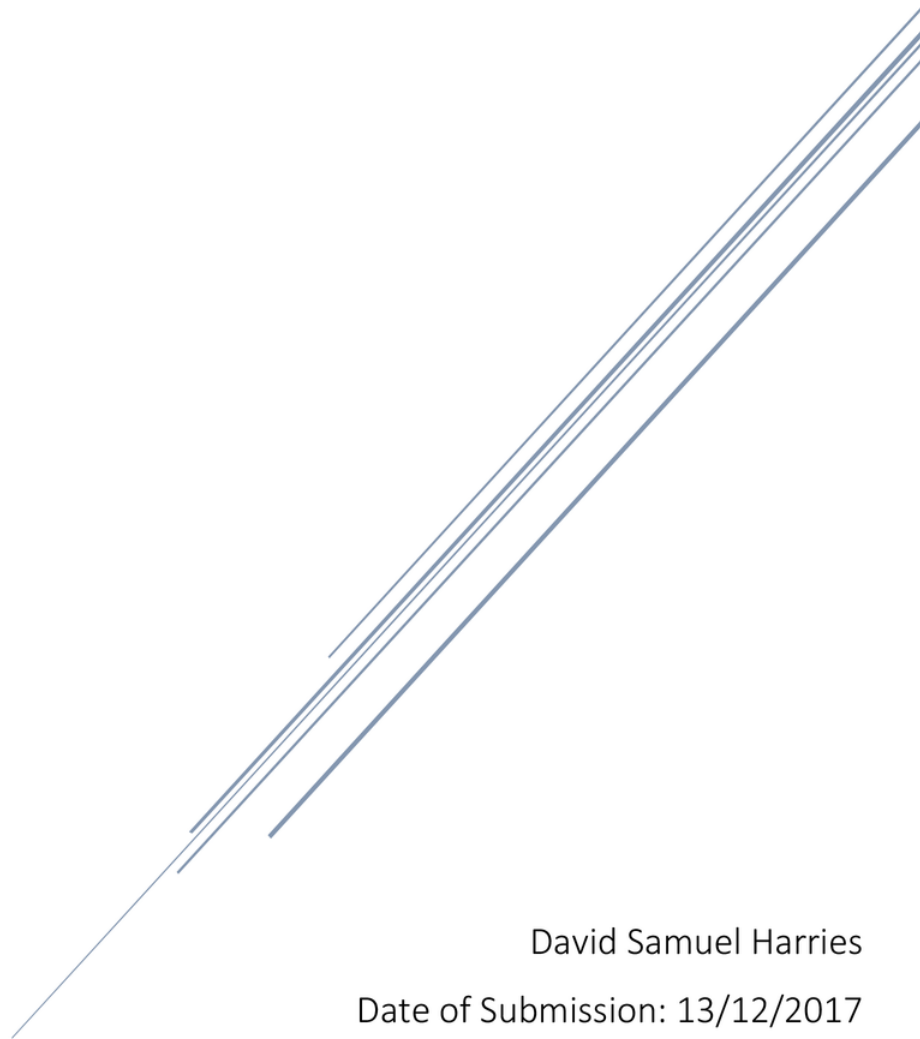
by David Harries

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HND Electrical and Electronic Engineering

PSDE5027: Power and Machines

Assignment 1: Investigation into Three Phase Induction
Motors



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1 - RESEARCH

1.1 - CONSTRUCTION AND OPERATION OF THREE-PHASE CAGE AND WOUND ROTOR INDUCTION MOTORS

The construction of Three-Phase Induction Motors consists of two main parts, the Rotor and the Stator. **Figure 1-1** shows a cut away diagram of a Three-Phase Induction Motor with each significant part numbered and labelled underneath.

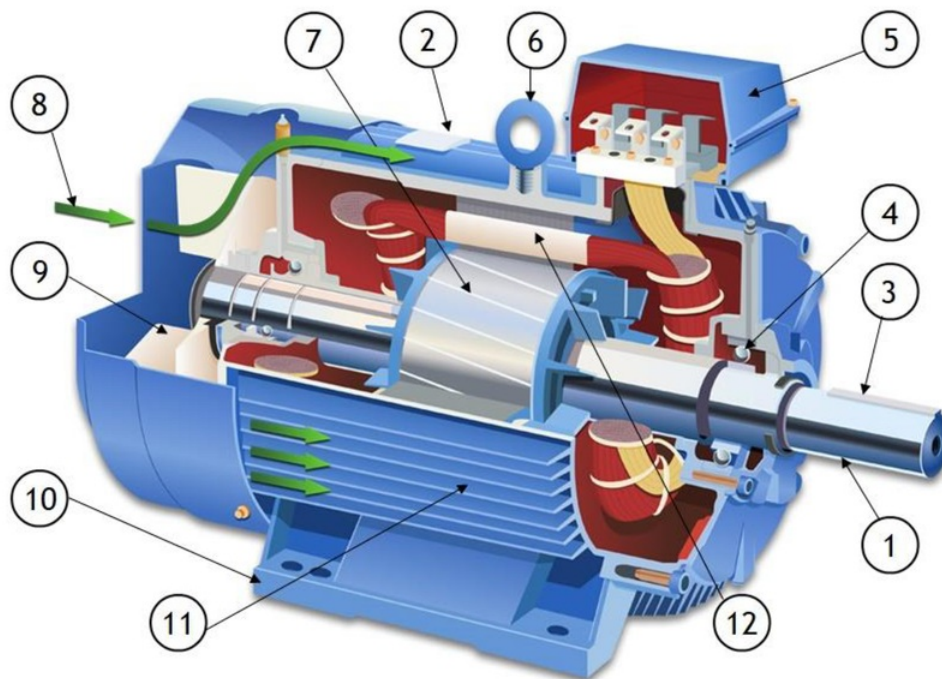


Figure 1-1

No.	Description
1	Motor Shaft
2	Name plate
3	Key and Keyway
4	Bearings
5	Terminal Box
6	Lifting eye
7	Laminated Rotor
8	Air flow intake
9	Cooling Fan
10	Mounting base
11	Cooling fins
12	Stator coils

1.1.1 – Stator Construction

The stator construction of Cage and Wound Rotor Motors is exactly the same. The stator is the stationary component of the motor as its name suggests. The stator frame is typically made using cast steel and houses the stator core. The stator core is the electrical part of the motor which consists of the stator coils which are connected around laminated low-silicon steel rings. These coils are connected in such a way that Three Single-Phase windings or “Poles” are all spaced 120° apart from each other. **Figure 1-2** shows a basic labelled diagram of how the three single phases are wound.

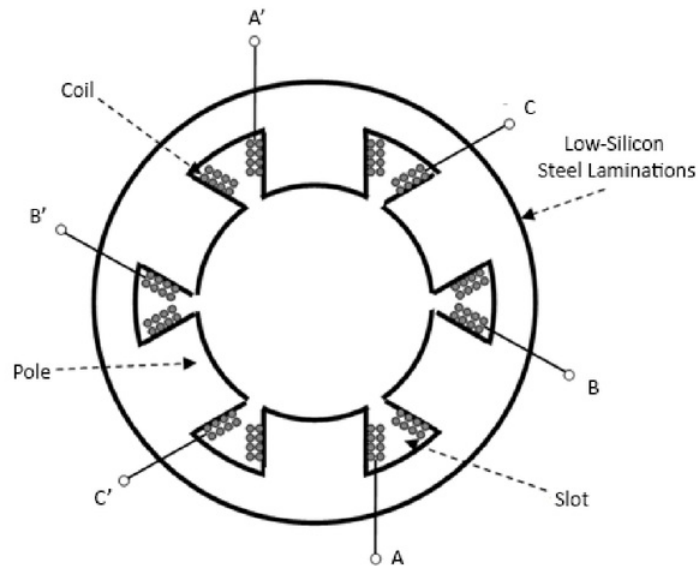


Figure 1-2

An improvement on this design can be seen in **Figure 1-3**.

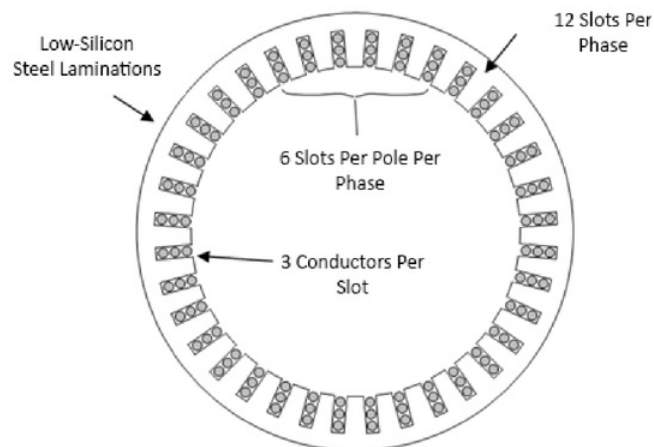


Figure 1-3

The three phases are then typically connected in either star or delta internally, which is then connected to a terminal box mounted on the stator frame for either single or dual-voltage connections. (Keljik 2009). **Figure 1-4** shows the Star and Delta connections.

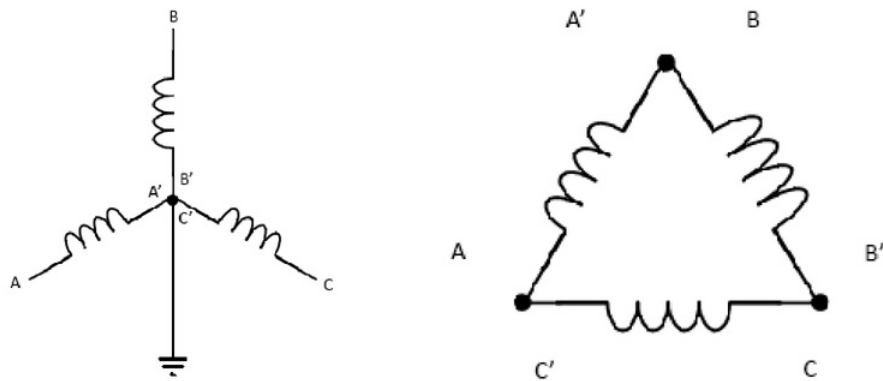


Figure 1-4

1.1.2 – Rotor Construction

The difference between a Cage Induction Motor and a Wound Rotor Induction Motor lies in the construction of the rotor. The Cage rotor is constructed using a collection of aluminium or copper conductors connected via a copper “end ring” at each end, thus creating a cage. These end rings act as a short circuit when the motor is in operation. However, the conductors are skewed to reduce noise and smooth out torque fluctuations. These fluctuations can occur due to interactions with the pole pieces of the stator. (Slemon 1966). **Figure 1-5** depicts the cage.

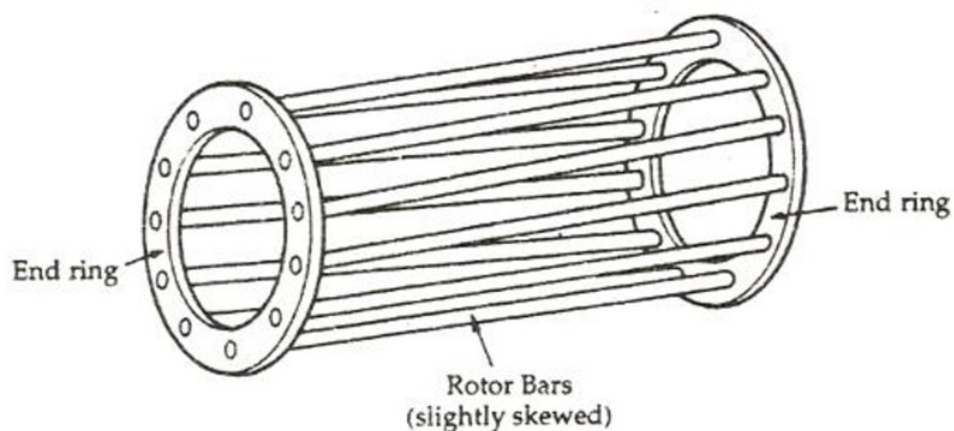


Figure 1-5

This cage acts as a skeleton for the rotor as within the cage a set of thin low-silicon steel laminations. This can be seen in **Figure 1-6**.

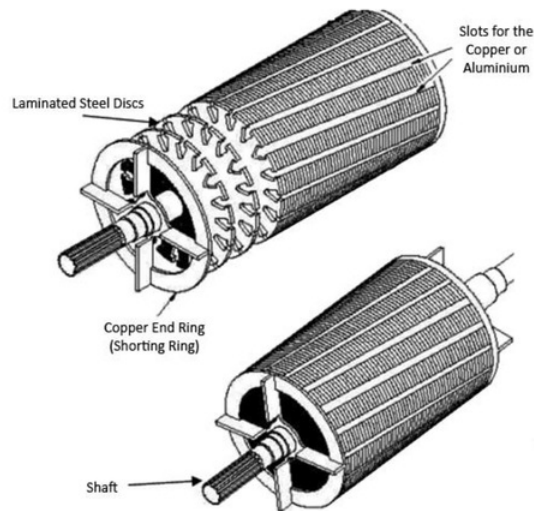


Figure 1-6

These laminations are insulated which increases their resistivity. The use of these laminations is similar to the construction of a transformer core. This is done in order to reduce the amount of energy loss from the core. The laminations reduce the eddy current within the core and lower the coercivity in order to reduce hysteresis loss. The most notable characteristic of the cage rotor is that it has no electrical connection to the stator.

The wound rotor induction rotor however, does in fact have an electrical connection to the stator. Unlike the cage rotor, the conductors are coils rather than bars. These conductors are fed through laminations within the rotor core similar to that of the cage rotor; however they are not shorted at each end of the rotor. The conductors are instead connected to slip rings. These are three separate connections located on the rotor shaft, one for each phase. The current is conducted through these slip rings via the use of spring loaded carbon brushes. This can be seen in **Figure 1-7**.

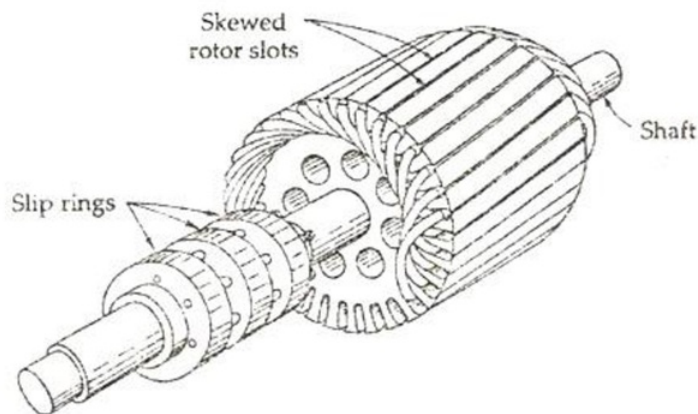


Figure 1-7

1.1.3 – Operation

The operation of an induction motor involves the principle of electromagnetic induction as the name suggests. Both the cage induction motor and the wound rotor induction motor operate by having an electric current induced within the rotor through the use of a rotating magnetic field created by the stator. The stator windings are configured so that when a three phase supply is connected, a rotating magnetic field is created by having the windings energise in a specific sequence. This is depicted in **Figure 1-8**.

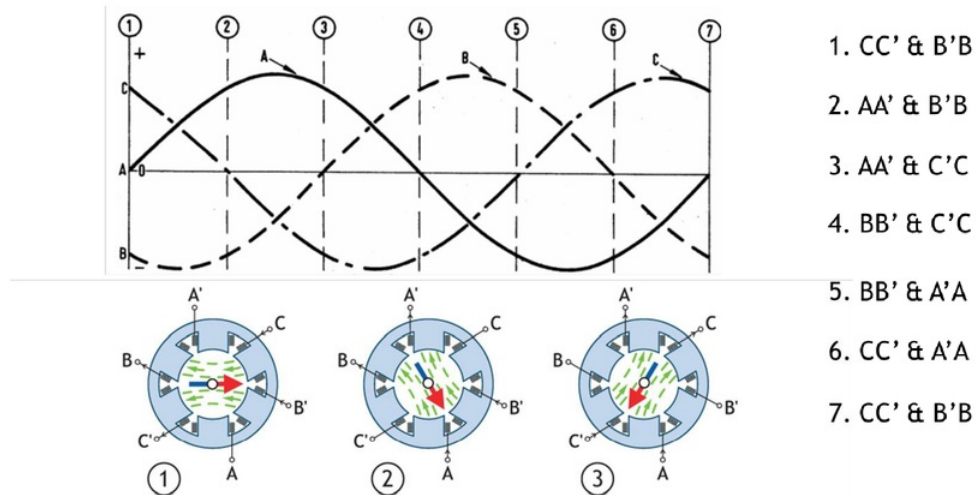


Figure 1-8

As the magnetic field rotates, it cuts through the conductors / windings within the rotor. This induces a current within the rotor which in turn creates a magnetic field surrounding the conductors / windings of the rotor. This magnetic field is then attracted to the rotating magnetic field of the stator which means the rotor starts rotating in the direction the stator field is rotating.

Due to the fact the rotor will start rotating as soon as power is applied to the stator, it can be said that induction motors are inherently self-starting.

However, because at the instant of starting, the stator field is rotating at synchronous speed and the rotor is not rotating at all, a large amount of current is induced causing very high starting current. In addition to this induction motors have low starting torque. Figure 1-9 shows the Torque – Speed and Current – Speed curves for an induction motor.

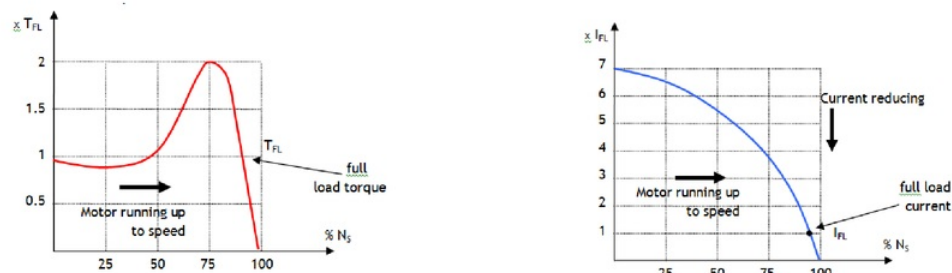


Figure 1-9

Wound rotor induction motors solve this issue using its slip rings as no power is applied to them. Instead they are used to apply external resistance in series with the rotor windings while starting to reduce the rotor current and increase starting torque. Once the motor is started the external resistance is shorted or tapered off which makes the wound rotor look like a cage rotor electrically speaking.

The benefit of using a cage rotor however is to not have to deal with the carbon brushes. So in order to fix the high starting current, different methods have been developed. These methods can also be used for the wound rotor induction motor. The first of which is through the use of a star-delta starter. This method involves starting the motor in star and switching to delta after the motor has gained speed. This method reduces the starting current by 1/3, however it also reduces the starting torque by 1/3. Figure 10 shows the Torque – Speed and Current – Speed curves for a star-delta starter.

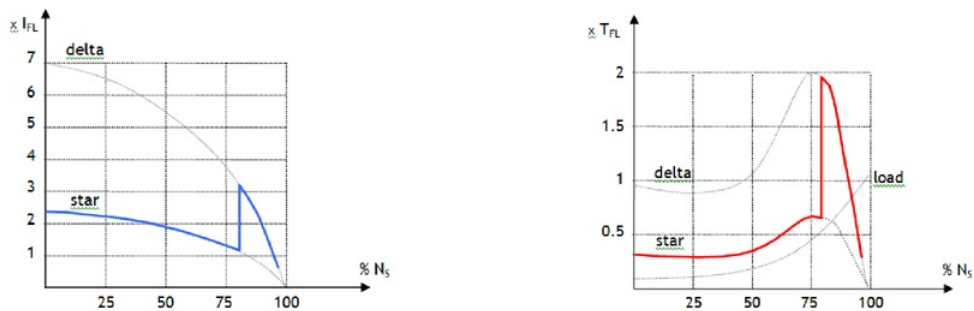


Figure 1-10

Other methods of starting a motor to counter high starting current include soft start, stator frequency ramping and for the wound rotor induction motor, the external rotor resistance method. The soft start method involves slowly increasing the voltage over time as shown in **Figure 1-11**.

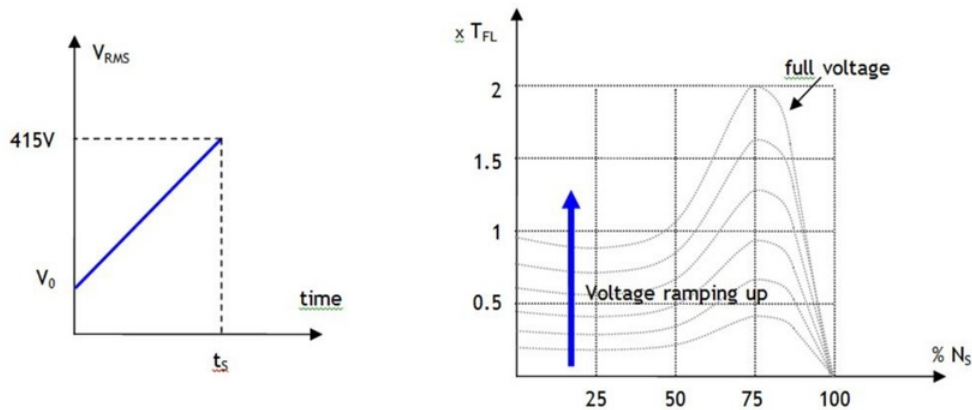


Figure 1-11

The frequency ramping method involves increasing the frequency of the stator over time from start up. This can be seen in

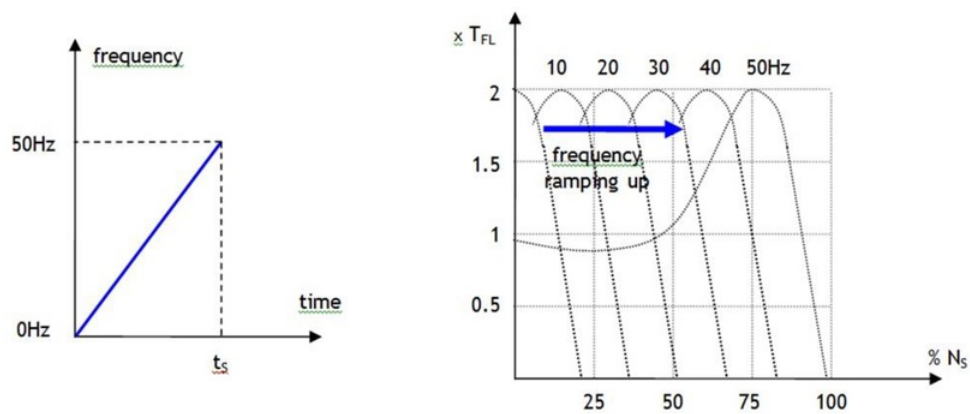


Figure 1-12

As the graph shows, the frequency is ramped up from 0 to 50. This method has high starting torque and maintains it as the frequency is increased so the motor operates close to synchronous speed.

Finally, the wound rotor induction motor has the option of using additional external resistors connected to the slip rings in order to increase rotor resistance. This lowers the starting current and after start up, can be tapered or switched off. There are two configurations that this can be done, one uses a rheostat which varies the resistance, and the other is a contactor method which uses different sets of resistors and shorts each of them off to increase the motor's speed. These can be seen in **Figure 1-13** and **Figure 1-14**.

Rheostat

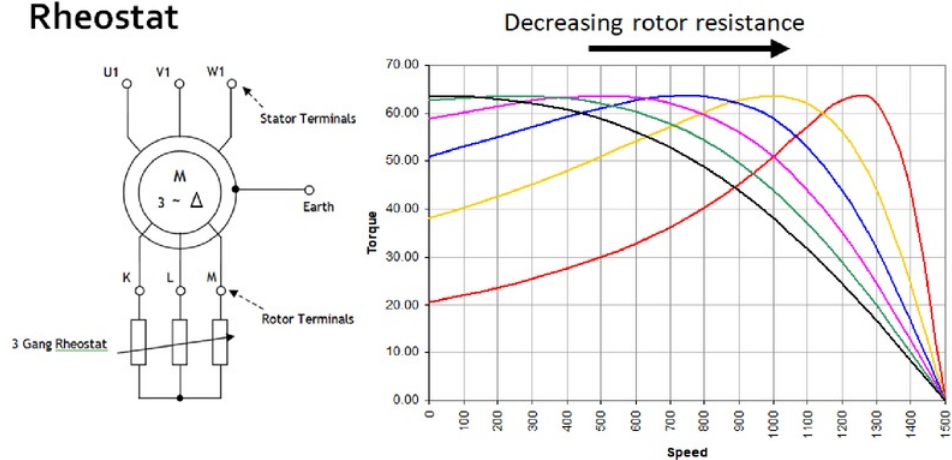


Figure 1-13

Contactor method

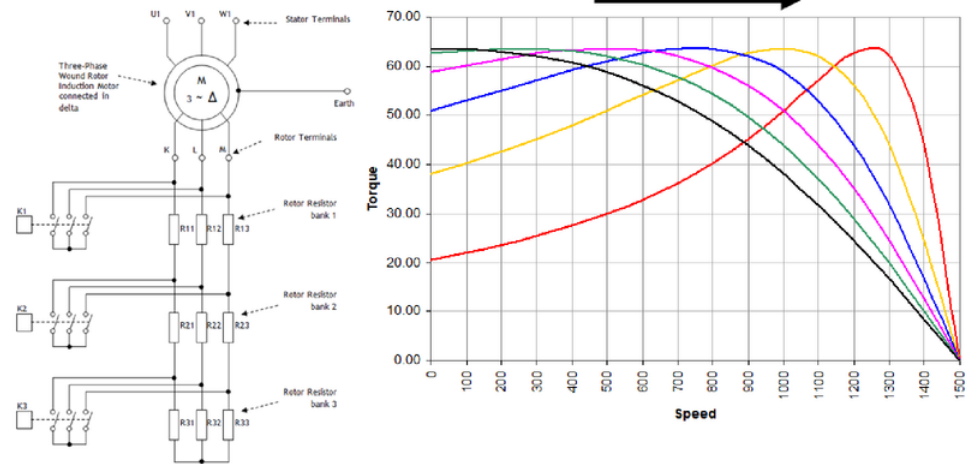


Figure 1-14

1.2 - EQUIVALENT CIRCUIT FOR A THREE-PHASE WOUND ROTOR INDUCTION MOTOR

As previously stated, the construction of an induction motor is similar to that of a transformer. In the case of a motor, the stator can be considered the primary windings and the rotor can be considered the secondary since a current is induced in it. Using this knowledge a circuit diagram can be drawn. This can be seen in **Figure 1-15**.

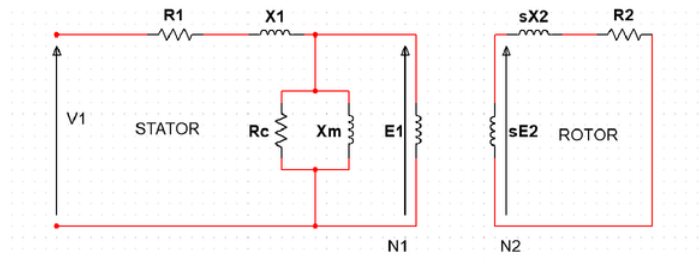


Figure 1-15

This circuit diagram shows the various parameters of the induction motor such as the losses from each component. The parameters in **Figure 1-15** represent the following;

R_1 = Stator Winding Resistance

X_1 = Stator Winding Inductance

X_m = Magnetizing Reactance of the Winding

R_c = Stator Core Losses

R_2 = Rotor Resistance (Includes External Resistance for Wound Rotor)

X_2 = Rotor Leakage Reactance

$V_1 = \text{Stator Phase Voltage}$

$E_1 = \text{Stator Induced EMF At Standstill}$

$E_2 = \text{Rotor Induced EMF At Standstill}$

$\frac{N_1}{N_2} = \text{Stator : Rotor Winding Ratio}$

Using these parameters the following can be deduced:

$$\text{At Standstill: } E_2 = \left(\frac{N_2}{N_1}\right) \times E_1$$

Furthermore, the frequency of the rotor current is dependent on the relative speed between the rotor and the stator field. Therefore:

$$f_R = S f_s$$

If the rotor was looked at at standstill, slip (S) is equal to 1. Therefore:

$$f_R = f_s$$

However, as the rotor starts moving its speed increases. As its speed increases the value of S decreases meaning f_R also decreases. The parameters X_2 and E_2 depend on this frequency. Because the frequency of the rotor current changes with S, so will these parameters. Therefore they become:

$$X_2 \rightarrow S X_2$$

$$E_2 \rightarrow S E_2$$

The equivalent circuit shown in **Figure 1-15** can be redrawn with currents added with the ideal transformer voltage ratio. This is shown in **Figure 1-16**.

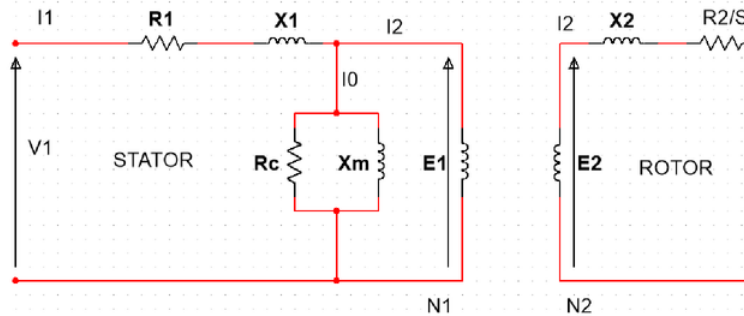


Figure 1-16

As **Figure 1-16** shows, I_2 is the balancing current supplying the rotor from the stator. The equivalent circuit diagram can be simplified further by neglecting the stator winding impedance and the core. This can be seen in **Figure 1-17**.

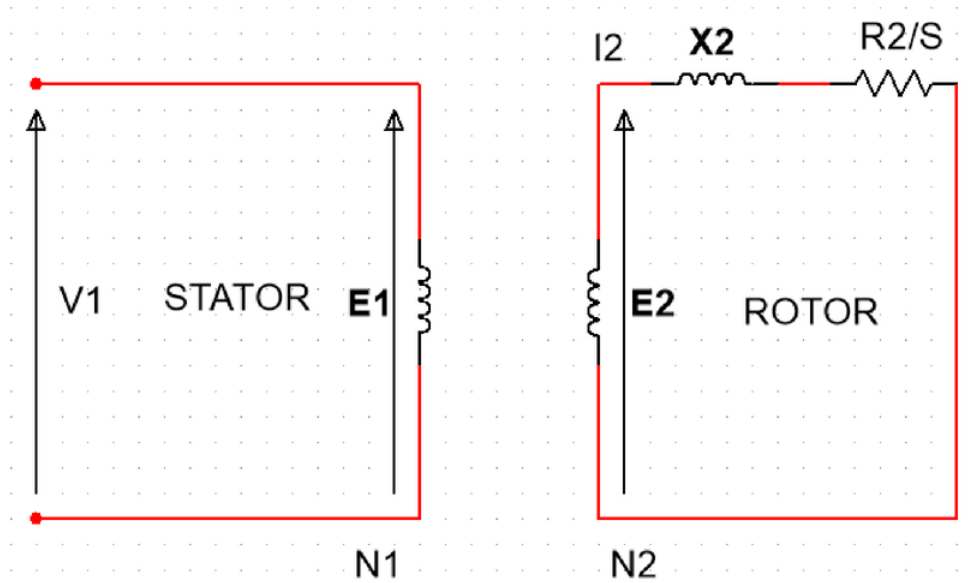


Figure 1-17

Using this final approximate equivalent circuit, the rotor impedance, the rotor current and the power lost in the rotor can be calculated.

$$|E_2| = \frac{N_2}{N_1} \times |E_1|$$

$$\text{Since } E_1 = V_1$$

$$|E_2| = \frac{N_2}{N_1} \times |V_1|$$

$$\text{The rotor impedance: } |Z_2| = \sqrt{\left(\frac{R_2^2}{S}\right) + X_2^2}$$

$$\text{The rotor current: } |I_2| = \frac{|E_2|}{|Z_2|} = \frac{|E_2|}{\sqrt{\frac{R_2^2}{S^2} + X_2^2}} = \frac{S|E_2|}{\sqrt{\frac{R_2^2}{S^2} + S^2 X_2^2}} = \frac{|E_2|}{\frac{1}{S}\sqrt{R_2^2 + S^2 X_2^2}} = \frac{S|E_2|}{\sqrt{R_2^2 + S^2 X_2^2}}$$

$$\text{Power Lost: } P_{Loss} = |E_2|^2 \times R_2 = \frac{S^2 |E_2|^2 R_2}{(R_2^2 + S^2 X_2^2)}$$

From this a Torque equation can be derived. Rotor Power and Stator Power can be written as: (Since $\omega = 2\pi n$)

$$P_R = T\omega_R = 2\pi n_R T$$

$$P_S = T\omega_S = 2\pi n_S T$$

By substituting the equation $n_R = (1 - S)n_S$ into the equation above for rotor power:

$$P_R = 2\pi(1 - S)n_S T$$

$$P_R = 2\pi n_S T - 2\pi S n_S T$$

$$P_R = P_S - SP_S$$

The above equation shows that the term SP_S which equals $(2\pi sn_s T)$ represents the energy lost in the rotor. This energy is lost in the form of heat from the windings which are commonly called "Copper Losses". Therefore:

$$P_{Loss} = 2\pi sn_s T$$

Finally, a formula for Torque can be derived using the two Power Loss formula derived above.

$$2\pi sn_s T = \frac{S^2 |E_2|^2 R_2}{(R_2^2 + S^2 X_2^2)}$$

$$\therefore T = \frac{1}{2\pi n_s} \times \frac{S |E_2|^2 R_2}{(R_2^2 + S^2 X_2^2)}$$

This equation combines mechanical and electrical parameters which enables the prediction of performance for the motor. The graph shown in **Figure 1-18** can be derived by plotting Torque against Slip.

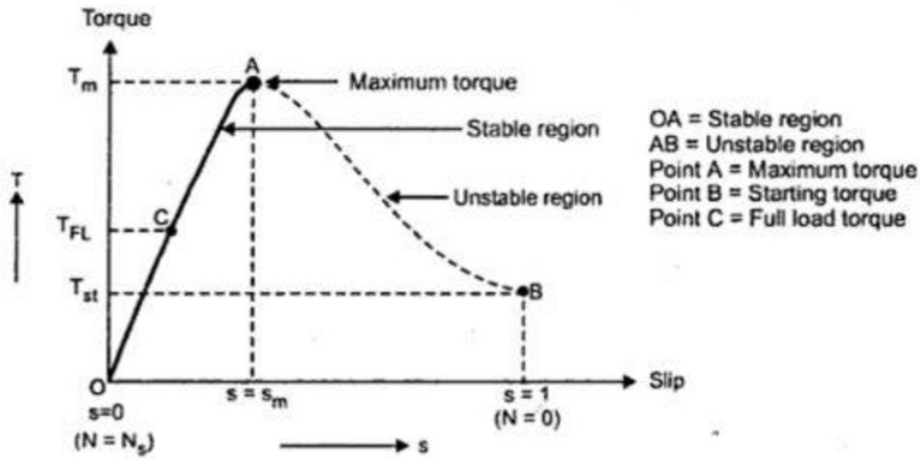


Figure 1-18

The region from the origin to maximum torque shows that when the motor is in the low slip / stable region, torque and slip are proportional. This changes just before the Torque reaches its maximum. The maximum torque can be figured out by differentiating the torque equation that was derived previously and equating to 0 as at maximum torque, the gradient of the graph is 0.

$$\therefore T_{Max} = \frac{|E_2|^2}{4\pi n_s X_2}$$

1.3 – METHODS OF SPEED CONTROL AND BRAKING

1.3.1 – Speed Control

The speed of a motor can be controlled from the stator side, or from the rotor side. To see how the speed can be controlled from the stator side the motor can be looked at like a transformer. The following two equations can be used to deduce some methods of speed control.

$$N_s = \frac{f_s}{p} \text{ and } 4.44fN\Phi_{max}$$

The first equation shows that the synchronous speed can be changed by the frequency of the stator field. It can also be changed by the number of pole pairs.

The second equation can be used to compare an induction motor to a transformer. It can be seen that if the frequency changes, so does the synchronous speed. However, so does the electromagnetic flux. A decrease in frequency will cause an increase in flux which will saturate both rotor and stator cores. Therefore, the flux must be maintained. To do this the voltage must be changed. For example, if the frequency is decreased, the voltage must also be decreased in order to reduce the flux as well. Thus, a frequency : voltage ratio is maintained. This method of speed control is commonly called the v/f method. For this method to function, an inverter must be used alongside a variable supply.

To see how the speed can be controlled by controlling the supply voltage, the Torque equation from the previous section can be used. From that equation it can be deduced that controlling the supply voltage gives control over the speed of the motor. In the low slip region of the Torque / Speed graph $s^2X_2^2$ can be considered negligible. The equation can be reduced to:

$$T \propto \frac{sE_2^2}{R_2}$$

Since the rotor resistance is a constant, the equation can once again be rewritten as:

$$T \propto sE_2^2$$

From the equivalent circuit earlier it is deduced that the emf induced in the rotor is proportional to V_1 . $\therefore T \propto sV^2$ Which means as the supply voltage increases or decreases, the torque will also increase or decrease. However, when the motor is loaded the torque must remain the same. Therefore, changing speed using voltage is only possible if the slip is increased or decreased. This method of speed control isn't commonly used as it requires a very big change on voltage for a small change in speed. This can result in a large current being drawn by the motor which can cause overheating.

Another method of speed control from the stator side is to have multiple stator windings. This method only works with squirrel cage induction motors, is costly and doesn't have smooth speed control. This method involves having multiple sets of windings within the stator that are electrically isolated from each other. Each set of windings has a different number of poles allowing for them to be switched for different speeds. However, due to the fact that the speed is determined by the number of poles which are predetermined by the construction of the motor, there is no smooth transition between speeds. It only works with squirrel cage induction motors and is much more costly than the other methods as extra windings are required.

The next method of speed control from the stator side is to use Pole Amplitude Modulation, commonly called PAM. This method involves superimposing a magnetomotive (mmf) sinewave with a different number of poles over the motor's original magnetomotive sinewave. This can be seen in the following formula:

$f_1(\theta)$ = The original mmf

$f_2(\theta)$ = The modulation mmf

P_1 = number of poles of the induction motor

P_2 = number of poles of the modulator wave

$$f_1(\theta) = F_1 \sin \frac{P_1 \theta}{2}$$

$$f_2(\theta) = F_2 \sin \frac{P_2 \theta}{2}$$

Post modulation the resultant mmf wave can be shown as:

$$F_r(\theta) = F_1 F_2 \sin \frac{P_1 \theta}{2} \sin \frac{P_2 \theta}{2}$$

By using the trigonometric function:

$$2 \sin A \sin B = \cos \frac{A - B}{2} - \cos \frac{A + B}{2}$$

The final resultant mmf wave is shown as:

$$F_r(\theta) = F_1 F_2 \frac{\cos \frac{(P_1 - P_2)\theta}{2} - \cos \frac{(P_1 + P_2)\theta}{2}}{2}$$

From this it can be seen that the resultant mmf wave has two different numbers of poles.

$$P_{1.1} = P_1 - P_2 \text{ and } P_{1.2} = P_1 + P_2$$

The final method of speed control from the stator side of the motor is by using variable resistance. This works exactly the same as the voltage control method discussed previously, however the voltage is lowered by increasing resistance across a rheostat rather than using a variable supply.

The speed can also be controlled from the rotor side. The first method is by increasing rotor resistance. This can be seen by looking at the torque equation again. In the low slip region of the Torque / Speed graph $S^2 X_2^2$ can be considered negligible, and the emf in the rotor is constant. Therefore the torque equation can be simplified down to:

$$T \propto \frac{S}{R_2}$$

This proves that the speed can be controlled by changing the rotor resistance. This method of speed control has a few problems however. Firstly, external resistance can only be added to a wound rotor induction motor, not a squirrel cage. Secondly the speed cannot go above its normal value. Thirdly, if resistance is added, more energy is lost through heat. And finally, large speed changes require very large resistance values to be added to the circuit, which hurts efficiency.

The next method of speed control from the rotor side is by injecting emf into the rotor. By injecting an emf into the rotor, the speed can be increased or decreased whether the injected emf complements or opposes the rotor's original emf. If it opposes the emf, the rotor resistance increases which slows the motor's speed, and vice versa if it complements. This method of speed control is good because it allows a wide range of speed control without causing massive inefficiency.

1.3.2 – Braking

There are three main methods of braking induction motors. The first is DC injection which involves injecting DC into the stator. In doing this it causes the rotating magnetic field to slow down and eventually stop. The rotor continues rotating faster than the stator field. In an induction motor, when the rotor is moving faster than the stator field (when slip is less than 0) the motor essentially becomes a generator. This causes a negative torque in the positive direction.

The second method of braking is frequency reduction. This method works on the same principle that the DC injection method uses. The stator field slows down, however the torque reduces more steadily than in DC injection. The torque becomes negative in the positive direction, slip is also negative, and the motor becomes a generator until the rotor eventually stops.

The final method of braking is Plug Breaking. This method is dangerous and can harm the motor as two of the phases in the stator are switch which causes the rotating magnetic field to rotate in the opposite direction. At the point of the phase switching, up to four times the amount of kinetic energy is transferred into the motor's windings which creates a lot of heat which can be fatal for the motor. A speed sensing relay must be used in order to cut power off to the stator field when the rotor reaches close to 0 rpm or the rotor will start rotating in the same direction the stator field is moving.

2 - SIMULATION

This section will detail a simulation of a Three-Phase Wound Rotor Induction Motor. The simulation will use the parameters provided by the brief:

- Open circuit EMF between slip-rings = 161.6V.
- Rotor resistance = 4.8Ω.
- Locked rotor reactance = 39.6Ω.
- Supply frequency = 50Hz.
- Motor poles = 2.
- Fractional slip ranging from -1 to 2 in increments of 0.1.

The simulation is carried out using excel and the formula discussed in section 1.3. The formula used can be seen below.

$$T = \frac{1}{2\pi n_s} \times \frac{s|E_2|^2 R_2}{(R_2^2 + s^2 X_2^2)}$$

$$|I_2| = \frac{s|E_2|}{\sqrt{R_2^2 + s^2 X_2^2}}$$

The results can be seen in **Figure 2-1**.

	Rotor Speed	Torque	Rotor Current
-1.00	6000	-0.75	-4.05
-0.90	5700	-0.83	-4.04
-0.80	5400	-0.93	-4.03
-0.70	5100	-1.06	-4.02
-0.60	4800	-1.22	-4.00
-0.50	4500	-1.44	-3.97
-0.40	4200	-1.75	-3.91
-0.30	3900	-2.19	-3.78
-0.20	3600	-2.79	-3.49
-0.10	3300	-3.09	-2.60
0.00	3000	0.00	0.00
0.10	2700	3.09	2.60
0.20	2400	2.79	3.49
0.30	2100	2.19	3.78
0.40	1800	1.75	3.91
0.50	1500	1.44	3.97
0.60	1200	1.22	4.00
0.70	900	1.06	4.02
0.80	600	0.93	4.03
0.90	300	0.83	4.04
1.00	0	0.75	4.05
1.10	-300	0.69	4.06
1.20	-600	0.63	4.06
1.30	-900	0.58	4.06
1.40	-1200	0.54	4.07
1.50	-1500	0.51	4.07
1.60	-1800	0.47	4.07
1.70	-2100	0.45	4.07
1.80	-2400	0.42	4.07
1.90	-2700	0.40	4.07
2.00	-3000	0.38	4.07

Table 2-1

A graph was produced from the results to show the change in torque and rotor current as fractional slip is increased. This can be seen in **Figure 2-1**.

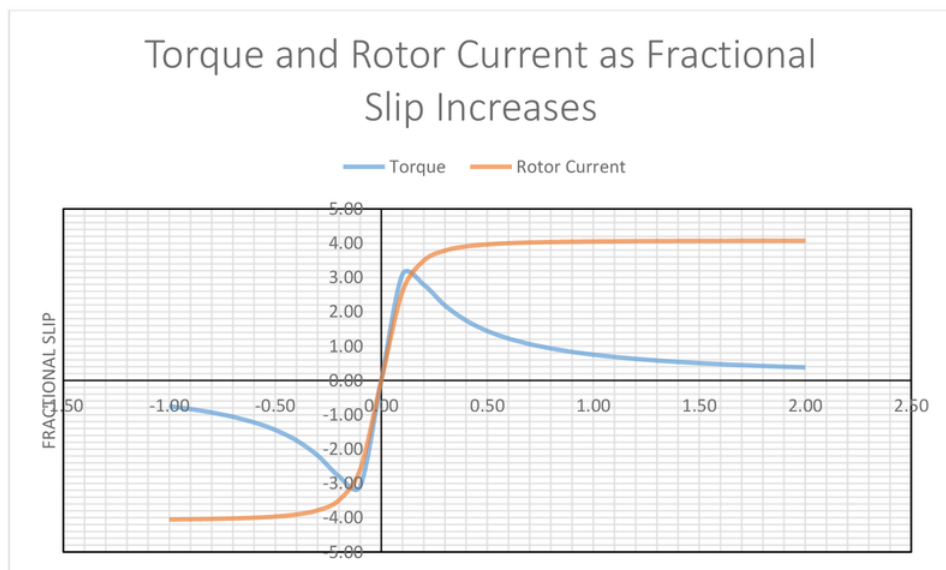


Figure 2-1

A second graph was also produced that shows the relationship between rotor speed and torque. This can be seen in **Figure 2-2**.

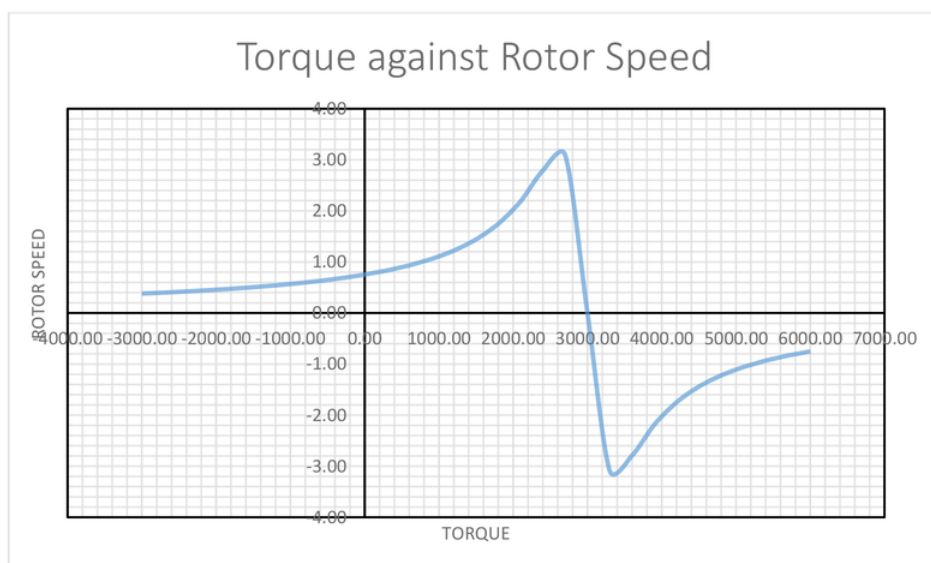


Figure 2-2

Figure 2-2 shows that there are three main areas of operation for the motor as the rotor speed is changed. The motoring is the first in which positive torque is produced since the rotor

speed is slower than the stator field speed. This region begins where $n_R = 0$, and ends where the torque line crosses the X-axis, at which point $n_R = n_S$. Additionally, when the motor is operating in this region the fractional slip ranges between 1 and 0. A fractional slip of 0 means that the rotor is moving as fast as the stator field. When this happens the motor is no longer in the motoring region and has entered the generating region.

As n_R is increased further and surpasses n_S the fractional slip becomes negative. In order for $n_R > n_S$, a prime mover or load must be used to drive the motor. **Figure 2-1** shows that S goes into the negative region of the graph when the motor is generating. This can be proven by:

$$n_R = 2n_S$$

$$S = \frac{n_S - 2n_S}{n_S} = \frac{-n_S}{n_S} = -1$$

In addition to this, the torque is also negative. This is proven as torque is a function of fractional slip, so when the slip is negative so is the torque with respect to the direction the rotor is moving. Since the torque is operating in the opposite direction to the rotor, a braking effect is imposed on the prime mover or load.

The final area is the braking region. This region details what happens when the motor is driven in the opposite direction to the stator field. It starts in the region where $2 > \text{slip} > 1$. As the speed of the motor reduces, the slip increases. This can be seen in **Figure 2-1**. It can also be proven by:

$$n_R = -n_S$$

$$S = \frac{n_S - (-n_S)}{n_S} = \frac{2n_S}{n_S} = 2$$

The motor torque in this region is positive in a negative direction which acts as a brake since the rotor is moving in the opposite direction to the stator field.

3 - PRACTICAL INVESTIGATION

This section will detail the practical experiment detailed in the assignment brief. After setting everything up according to the brief, the two tests were taken and the readings were documented in an excel spreadsheet. These can be seen in **Figure 3-1**.

Torque [Nm]	Speed [RPM]	Line Current [A]	Line Voltage [V]	Power Factor	% Slip	Apparent Input Power [VA]	Real Input Power [VA_r]	Angular Velocity [rad/s]	Output Power [W]
0	2950	0.57	214	0.53	0.02	209.00	177.00	308.92	110.00
0.05	2900	0.62	213	0.64	0.03	230.00	175.00	303.69	148.00
0.1	2850	0.64	213	0.67	0.05	233.00	174.00	298.45	152.00
0.2	2800	0.71	213	0.75	0.07	259.00	172.00	293.22	195.00
0.4	2750	0.78	213	0.81	0.08	289.00	170.00	287.98	230.00
0.5	2700	0.88	213	0.85	0.10	326.00	171.00	282.74	278.00
0.7	2650	0.99	213	0.87	0.12	359.00	174.00	277.51	314.00
0.8	2600	1.04	213	0.88	0.13	364.00	175.00	272.27	325.00
0.9	2550	1.13	213	0.9	0.15	425.00	183.00	267.04	371.00
1	2500	1.23	213	0.91	0.17	451	189	261.80	407
No Load	3000	0.536	213	0.2	0.00	200.00	196	314.16	40.6
No Load	3050	0.577	213	-0.21	-0.02	218.00	-213	319.40	42.1
No Load	3100	0.657	213	-0.36	-0.03	248.00	-231	324.63	91.2
No Load	3150	0.732	213	-0.47	-0.05	275.00	-244	329.87	128
No Load	3200	0.885	213	-0.6	-0.07	334.00	-268	335.10	200
No Load	3250	0.998	213	-0.65	-0.08	379.00	-286	340.34	248
No Load	3300	1.12	213	-0.67	-0.10	423.00	-306	345.58	294

Figure 3-1

The first test was to see the effect increasing the load had on the motor in increments of 0.2Nm and taking measurements for the speed, input power, line current, power factor and line voltage. The slip also had to be calculated and documented.

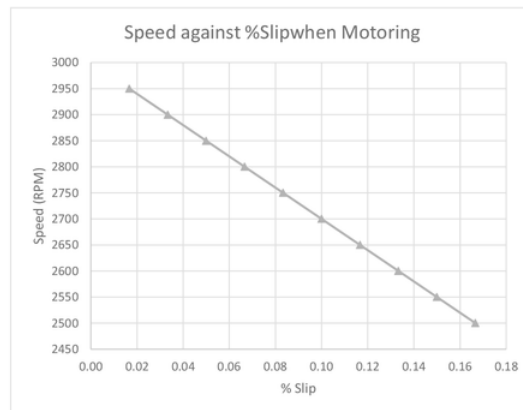


Figure 3-2

As **Figure 3-2** shows, the speed starts off at nearly synchronous speed with no load. As the load increases, the % slip also increases which is an expected result. Therefore the speed and % slip have a linear relationship. The slip is also between 0 and 1 which is the motoring region of operation. This is an expected result.

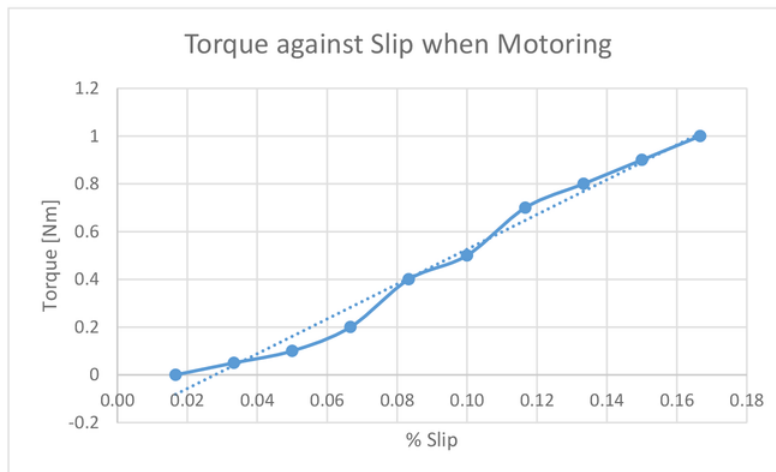


Figure 3-3

Figure 3-3 shows that as the load increases, the % slip also increases. The readings were slightly inaccurate; however there is a positive correlation between the two parameters and the line of best fit shows a linear relationship between the two. This is again an expected result.

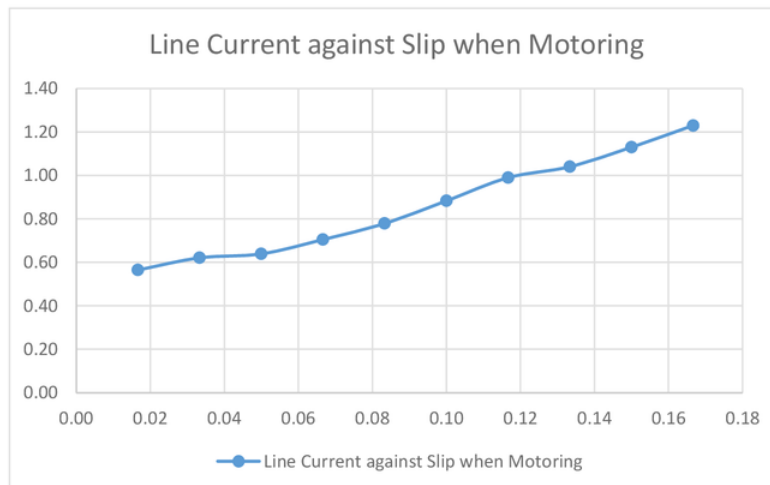


Figure 3-4

Figure 3-4 shows that as the slip increases, the line current also increases in a linear fashion. This is because the torque is increasing in a linear fashion to the slip, which causes the motor to draw in more current. The power vs % slip graph also shows a linear increase. This can be seen in **Figure 3-5**.

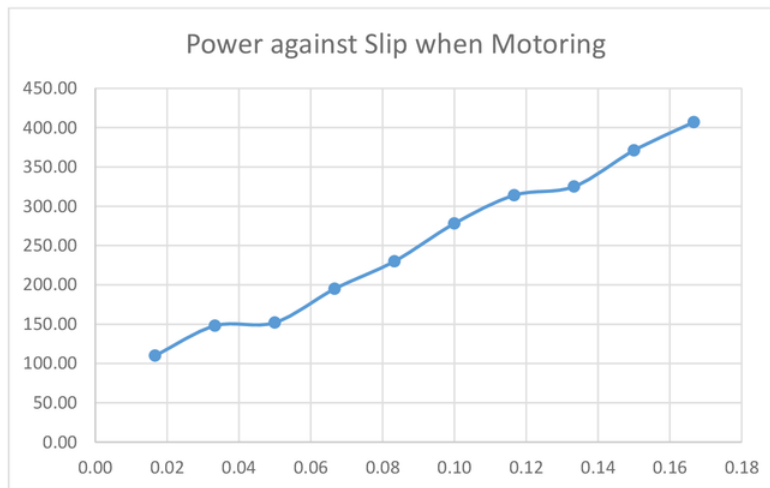


Figure 3-5

The power factor graph vs % slip graph can be seen in **Figure 3-6**.

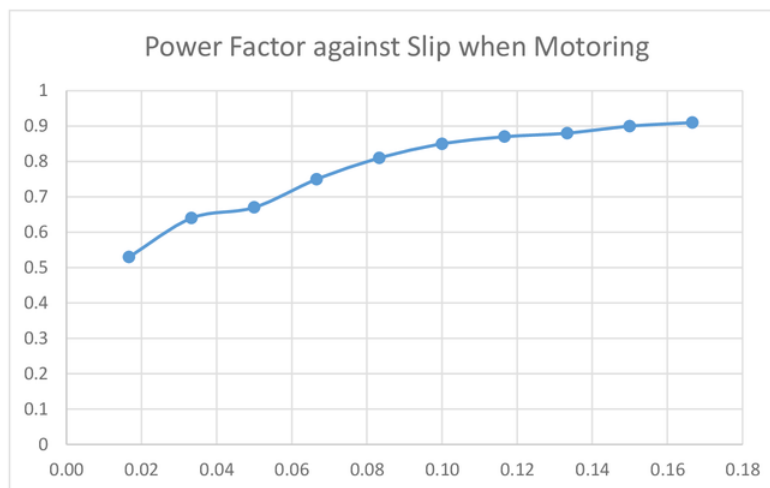


Figure 3-6

Figure 3-6 shows the power factor increase as the slip is increased. However the gradient of the curve decreases as the % slip gets higher. This is expected as the % slip is proportional to the torque and the power factor increases towards full load. However, in a real experiment such as this it will never reach 1. The power factor of this experiment enters steady state at roughly 0.9.

The second part of the experiment was to test the motor under no load conditions at synchronous speed, then increase the motor's speed by driving it with a variable-frequency drive. The results are shown in **Figure 3-1**.

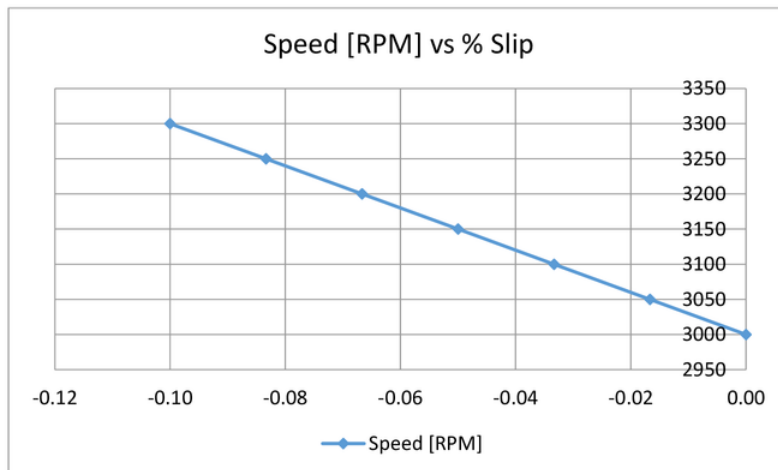


Figure 3-7

Figure 3-7 shows the speed vs % slip when the motor speed was being increased by the VFD. The first thing to note is that the slip is now negative. As stated back in section 2, when rotor is moving faster than the stator field, the motor is operating as a generator. When a motor operates as a generator its % slip becomes negative. This is an expected result. Once again the % slip has a linear relationship with the speed. If these results were to be plotted on the same graph as **Figure 3-2** it would create a straight line.

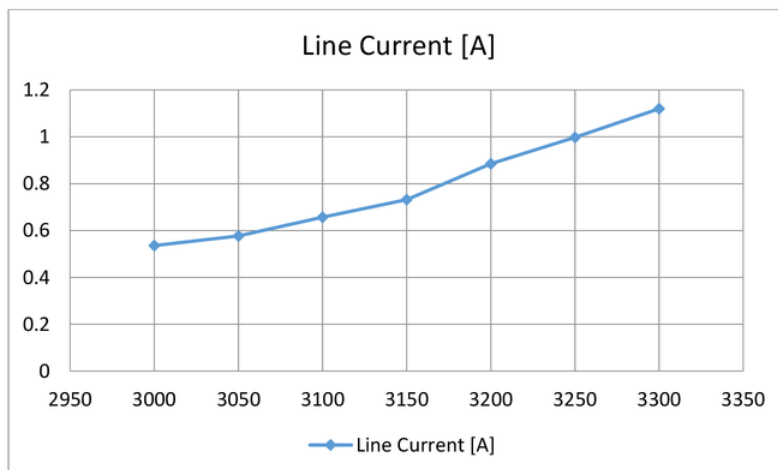


Figure 3-8

Figure 3-8 shows the line current against the speed. It shows that as the speed of the motor increases the line current also increases. This is because the motor is now generating current.

For all of the measurement intervals the line voltage stayed at 213V since the supply voltage was from the mains. The only variance was at 214 in the first reading which could be due to mains voltage fluctuations.

4 - CONCLUSION

In conclusion, induction motors are very powerful machines that are very versatile when it comes to the speed control and braking. The squirrel cage and wound rotor induction motors share very similar operations yet have very distinct differences about them, such as the wound rotor having slip rings which enables the ability to increase the rotor resistance to lower starting current.

The simulation showed that induction motors have three regions of operation, motoring, braking and generating. Each of these regions has their own characteristics and are all determined by the % slip which is derived from the synchronous speed and the rotor speed.

In comparison the practical experiment went equally well as all of the readings confirmed what was deduced from the simulation about the three operating regions. In order to get better results however, more time should have been allocated in order to collect more results which would provide more detailed graphs. The sample size was rather small to really show some of the characteristics of the induction motor. Another, change would be to test the three types of braking on the motor to collect data on how each braking method effects torque, the speed, braking time and line current.

5 - CITATION LIST

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6 - APPENDICES

Sam Harries Assignment 1 - FINAL

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

66/100

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GRADING FORM: CSG-RUBIC

DAVID HARRIES**66****RESEARCH-INFORMED LITERATURE**

There is good evidence of background reading and research covering many aspects of induction machines. (19/25) A good list is provided but few sources have been cited in the text of the report. Some diagrams need referencing also. (2/5)

21**KNOWLEDGE AND UNDERSTANDING**

Brief explanation given with equations provided from theory. (6/10) A brief description is given but further marks were available for a schematic diagram and photo of the experimental setup. (5/10)

11**ANALYSIS**

Section 2: Analysis of simulation - Good analysis presented. Further marks were available for a

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discussion on the optimum regions of operation.
(6/10) Section 3: Analysis of practical experimental results - Some analysis presented but further marks were available for comparisons with research and simulation. There are some errors in the table.
(5/10) Section 4: Overall conclusions and recommendations - Brief conclusions offered with a few recommendations. (5/10)

PRACTICAL APPLICATION AND DEP.



Section 2: Presentation of simulation results - Results are well presented in table and graphic format. (5/5) Results are well presented in table and graphic format but some graphs are unnecessary as speed will always be linear to fractional slip. (4/5)

9

SKILLS FOR PROFESSIONAL PRAC.



Report has a very good structure with clear figures listed and labelled correctly and generally well written. (9/10)

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