BIRZEIT UNIVERSITY

Electrical and Computer Engineering Department
Electrical Machines LAB (ENEE3101)

Report on Experiment #7
Separate Winding "SW" Squirrel Cage Motor

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Abstract

In this experiment, the effect of changing number of poles SW squirrel cage induction motor on the speed, torque, power factor and power will be discussed and proven, the results will be discussed in both modes low speed mode and high-speed mode, the results expected to be seen are that the torque and speed in the low-speed mode should be less than the torque and speed in the high-speed mode for the same ratio of $\frac{T}{T_{N,net}}$, while the power factor in the low-speed mode should be smaller than the PF in the high-speed mode for the same ratio mentioned above.

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Theory

The induction motor is the most used polyphase machines, its an AC electric motor which uses the current in the rotor which is obtained by producing a uniform magnetic field B_S in the stator windings which are connected to a 3-phase power supply, the induction motor's rotor can be either wound type or squirrel-cage type.

The magnetic field B_S produced by the 3-phase power supply rotates at the synchronous speed n_S

$$n_S = \frac{120\, f_e}{P} \qquad (1)$$

Where, P is the number of poles and f_e is the electrical frequency.

To understand the results of the experiment of SW squirrel cage motor, its characteristics of Torque-Speed Curves of an Induction motor need to be discussed first, and it can be divided into 3 regions:

1. Low Slip Region:

   In this region the slip of the motor increases linearly with the load and the rotor current increases linearly with the slip, while the speed decreases linearly with the load and slip.
2. Moderate Slip Region:

   The current of the rotor increases slower than before, and the power factor starts to drop, in this region the pullout torque occurs when the increase in the rotor current is balanced by the decrease in the rotor power factor.
3. High Slip Region:

   In this region the induced torque decreases with the increasing of the slip (in other words increasing of the load), since the increase in the rotor current is covered by the decreasing of the rotor power factor.

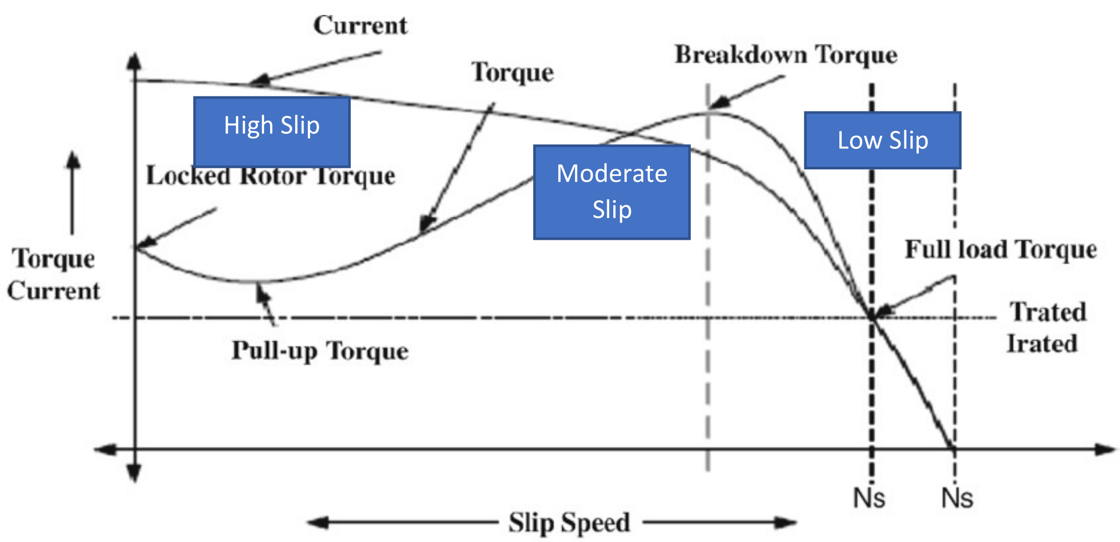

Figure 1: Torque-Speed Characteristics of an induction motor

Induction motor speed can be controlled by several ways which is:

1. Pole Changing:

   There are two main ways to change the number of poles which are:

   a. The method of Consequent Poles, this method changes the number of poles by a ratio of 2:1 using a simple switching operation.
   b. The Multiple Stator Windings method, it utilizes multiple stator windings with different number of poles, but this method comes with a disadvantage which is increasing the cost and wight of the motor.

2. Changing the Rotor Resistance:
   Adding an external resistor to the rotor circuit would reduce the starting current, and it could increase the torque, but it will affect the efficiency badly, so, to conclude as the rotor resistance increase the speed of the rotor decreases.[1]

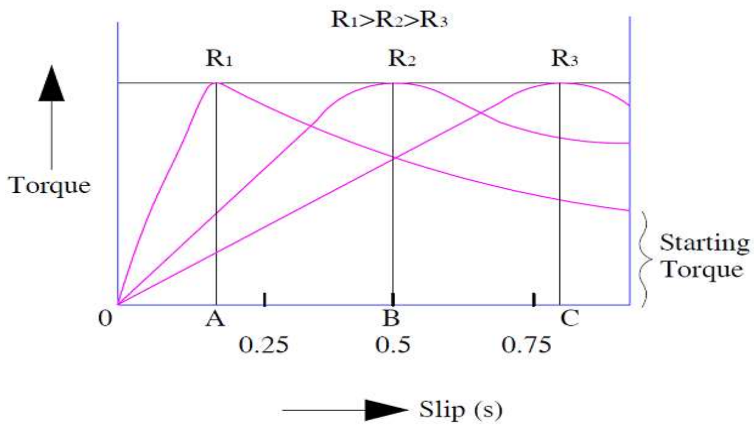

Figure 2: effect of changing the rotor resistance on the speed of an induction motor

3. Changing the line voltage:
   Decreasing the applied voltage would decrease the induced torque, and this would reduce the speed, and its disadvantage is losing of the torque when reducing voltage.

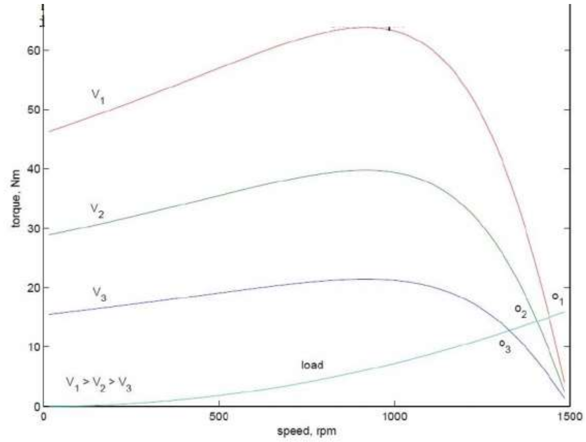

Figure 3: torque for different values of line voltage for a low-slip motor

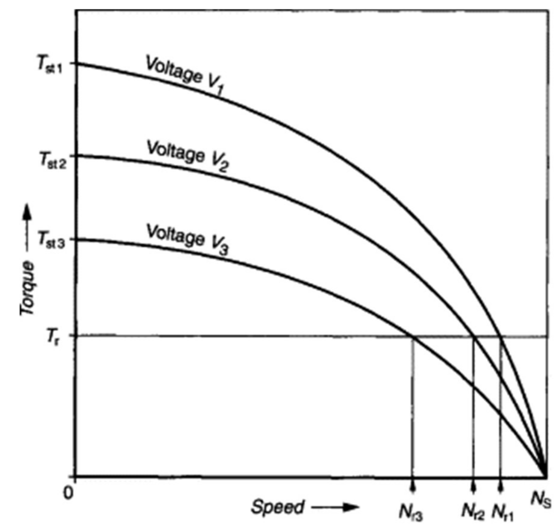

Figure 4: torque for different values of line voltage for a high-slip motor

4. Changing the line Frequency:

   Another way to control the speed of squirrel cage induction motor is changing the frequency, as it was mentioned before the relation between the speed and the frequency is given by;

$$n_S = \frac{120\ f_e}{P}$$

   Since the speed is directly proportional to the frequency, this method can't be used for large range of changing the speed.[2]

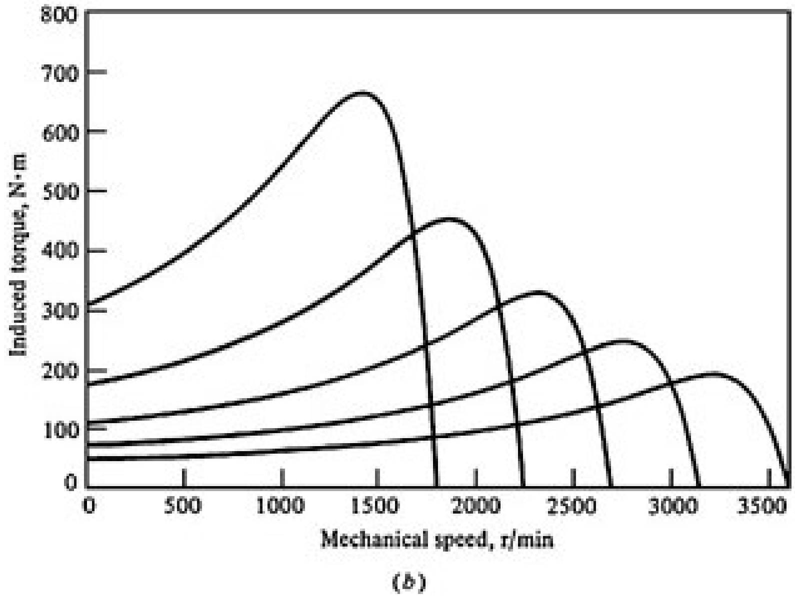

Figure 5: effect of changing the line frequency on the tprque-speed characteristics

5. Variable Voltage Variable Frequency (VVVF);

Using the variable voltage variable frequency, any combination of voltage and frequency can be used to supply the motor, it can be said that the ratio between the supply voltage and supply frequency almost equals the flux, so if this ratio was held constant the flux is almost constant too, but if the stator resistance drop is negligible & $\frac{V}{F}$ is held constant too, the slip speed for maximum torque will be independent of frequency, and the maximum torque is independent of the voltage supply.

At low frequencies, the stator supply voltage can be boosted to maintain the magnetizing voltage and hence maintain rated flux in the machine.[3]

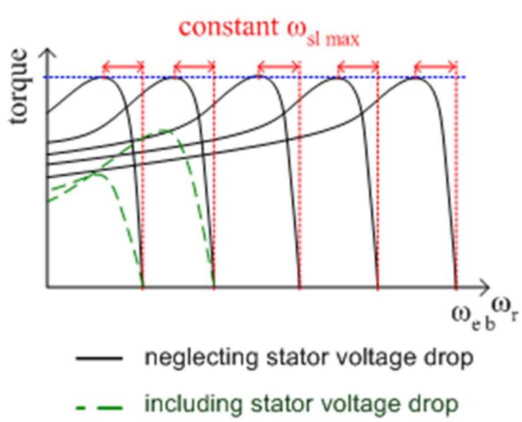

Figure 6: speed-torque characteristics

Procedure, results and discussion

A. Basic Circuit

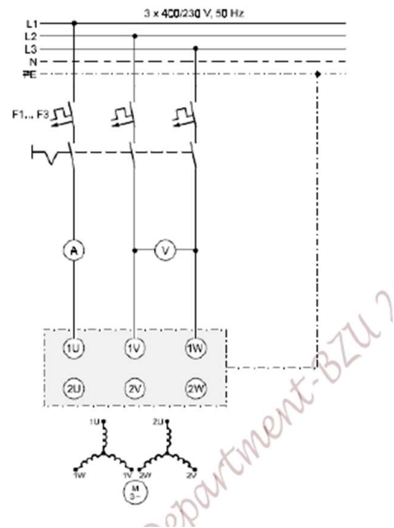

Figure 7 : SW squirrel cage induction motor - low speed mode

The connections in figure 7 were made, and the measurements were recorded,

One-phase current = 0.65 A

Line-to-line voltage = 400 V

No-load speed = 995 rpm

Direction of rotation is counterclockwise

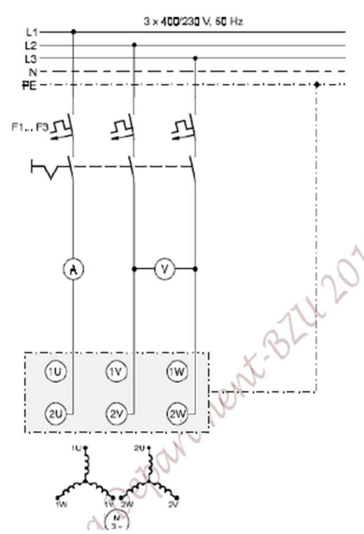

Figure 8: SW squirrel cage induction motor - high speed mode

The connections in figure 8 were made, and the measurements were recorded,

One-phase current = 0.75 A

Line-to-line voltage = 400 V

No-load speed = 1494 rpm

Direction of rotation is counterclockwise

As it can be noticed, the difference between these two connections is the current and speed, which proves that the first one is working on a low-speed mode, while the other one is functioning at a high-speed mode.

Increasing the poles, leads to a decrease of the synchronous speed and the mechanical speed, so the first circuit has a smaller number of poles compared to the second circuit which is functioning on the high-speed mode.

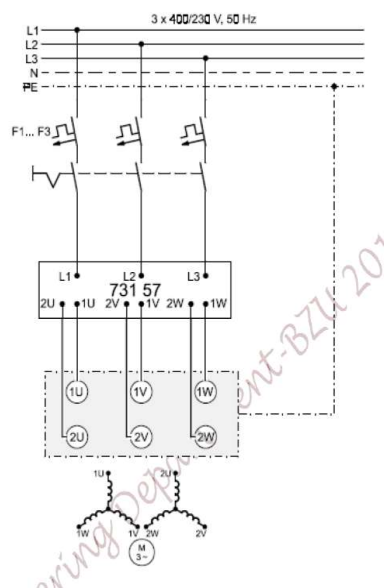

Figure 9: SW sqirrel cage induction motor - pole changer

In this circuit both modes of motor were connected, using a pole change switch, this switch have three modes, the first 1 is 0 where the motor isn't functioning, when the switch position changes from 0 to 1 the low mode squirrel cage induction motor is connected and the measurements are similar to the same from circuit in figure 7.

One-phase current = 0.64 A

Line-to-line voltage = 400 V

No-load speed = 995 rpm

Direction of rotation is clockwise

When the position of the switch is turned from 1 to 2, the high-mode of the SW squirrel cage induction motor is connected and functioning, and the measurement is similar almost identical to the values from the high mode motor in figure 8.

One-phase current = 0.75 A

Line-to-line voltage = 400 V

No-load speed = 1494 rpm

Direction of rotation is clockwise

B. Characteristics in Motor Operation

a. Efficiency Calculations

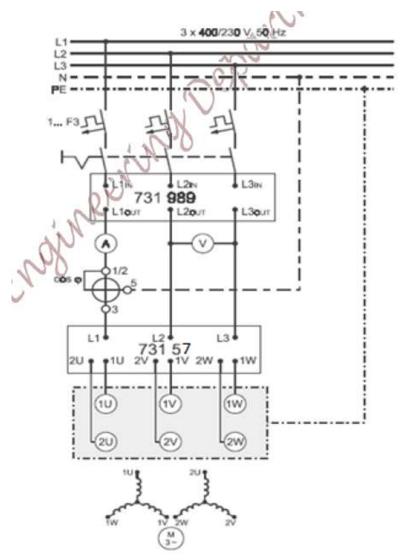

Figure 10: SW squirrel cage induction motor

Table 1: Nominal values for the motor

Nominal Voltage V_N	400
Nominal Current I_N (low speed)	0.6
Nominal Current I_N (high speed)	0.7
Nominal Power Factor, $Cos(\vartheta_N)$ (low speed)	0.71
Nominal Power Factor, $Cos(\vartheta_N)$ (high speed)	0.72
Nominal Speed n_N (low speed)	880
Nominal Speed n_N (high speed)	1390
Nominal Power P_N (low speed)	0.11 k
Nominal Power P_N (high speed)	0.2 k

Low-Speed Mode:

Since the nominal values in the table above are given, the Nominal Torque τ_N can be calculated,

$$P_N = \tau_N \ \omega_N \tag{2}$$

$$\tau_N = \frac{60}{2\pi} . \frac{P_N}{\omega_N}$$

$$\tau_N = 1.19 \text{ Nm}$$

The input Power can be calculated by

$$P_{in} = \sqrt{3} \ V_L \ I_L \cos \psi \tag{3}$$

$$P_{in} = \sqrt{3} \text{ x } 400 \text{ x } 0.6 \text{ x } 0.71$$

$$P_{in} = 295.14 \text{ watt}$$

The theoretical efficiency,

$$\eta_{eff} = \frac{P_{out}}{P_{in}} \ x \ 100\% \tag{4}$$

$$\eta_{eff} = \frac{0.11k}{295.14} \ x \ 100\%$$

$$\eta_{eff} = \ 37.27\%$$

High-Speed Mode:

Since the nominal values in the table above are given, the Nominal Torque τ_N can be calculated,

$$P_N = \tau_N \ \omega_N$$

$$\tau_N = \frac{60}{2\pi} . \frac{P_N}{\omega_N}$$

$$\tau_N = 1.37 \text{ Nm}$$

The input Power can be calculated by

$$P_{in} = \sqrt{3} \ V_L \ I_L \cos \psi$$

$$P_{in} = \sqrt{3} \text{ x } 400 \text{ x } 0.6 \text{ x } 0.72$$

$$P_{in} = 299.29 \text{ watt}$$

The theoretical efficiency,

$$\eta_{eff} = \frac{P_{out}}{P_{in}} \ x \ 100\%$$

$$\eta_{eff} = \frac{0.2k}{299.29} \ x \ 100\%$$

$$\eta_{eff} = \ 66.82\%$$

b. Load Characteristics

After the circuit in figure 10 was implemented, the pole change switch was set to low mode (position 1), and the line-to-line voltage $V_{L\text{-}L}$, the one phase current, the power factor, the speed and the torque were plotted as seen in figures down below.

Table 2: Characteristic for the SW squirrel cage in low speed mode

$T/T_{N,act}$	0	0.2	0.4	0.6	0.8	1	1.2
T/[Nm]	0	0.238	0.476	0.714	0.952	1.19	1.428
n/[rpm]	985	988	976	964	948	932	909
I/[A]	0.65	0.64	0.65	0.65	0.65	0.66	0.67
cos(ϑ)	0.4	0.45	0.5	0.55	0.6	0.65	0.7
n/Nn	1.119318	1.122727	1.109091	1.095455	1.077273	1.059091	1.032955
$I/I_{N,act}$	1.083333	1.066667	1.083333	1.083333	1.083333	1.1	1.116667
P1/[W]	180.1333	199.5323	225.1666	247.6833	270.1999	297.2199	324.9327
p1/p1N	1.637575	1.81393	2.046969	2.251666	2.456363	2.701999	2.953934
P2/[W]	0	24.62422	48.65028	72.07819	94.50916	116.1426	135.9317
p2/p2N	0	0.223857	0.442275	0.655256	0.859174	1.055842	1.235743
eff	0	12.34097	21.60635	29.10095	34.97749	39.07631	41.83379

After reading measurements for the several values of torque, the pole change switch was set to high mode (position 2), and the same measurements were taken again.

Table 3: Characteristic for the SW squirrel cage in high speed mode

$T/T_{N,act}$	0	0.2	0.4	0.6	0.8	1	1.2
T/[Nm]	0	0.274	0.548	0.822	1.096	1.37	1.644
n/[rpm]	1496	1489	1477	1464	1449	1433	1416
I/[A]	0.73	0.74	0.72	0.72	0.73	0.76	0.8
cos(ϑ)	0.3	0.35	0.4	0.5	0.55	0.65	0.7
n/Nn	1.076259	1.071223	1.06259	1.053237	1.042446	1.030935	1.018705
$I/I_{N,act}$	1.042857	1.057143	1.028571	1.028571	1.042857	1.085714	1.142857
P1/[W]	151.7277	179.4405	199.5323	249.4153	278.1674	342.2532	387.9794
p1/p1N	0.758638	0.897202	0.997661	1.247077	1.390837	1.711266	1.939897
P2/[W]	0	42.72419	84.75975	126.0206	166.3059	205.5869	243.7775
p2/p2N	0	0.213621	0.423799	0.630103	0.831529	1.027934	1.218888
eff	0	23.80968	42.47922	50.5264	59.78626	60.06864	62.8326

Where the calculation when $\frac{T}{T_{N,act}} = 0.2$ in the high-speed mode:

Where the calculation when T = 0.274 Nm,

Normalized Speed	$\frac{n}{n_N} = \frac{1489}{1390} = 1.0712$	(5)
Normalized Current	$\frac{I}{I_N} = \frac{0.74}{0.7} = 1.057$	(6)
Input Power	$P_1 = \sqrt{3}\ V_L\ I_L \cos\psi$ $= \sqrt{3} * 400 * 0.74 * 0.35$ $= 179.4\ W$	(7)
Output Power	$P_2 = \tau\ \omega = 0.274 * \frac{2\pi}{60} * 1489 = 42.72\ W$	(8)

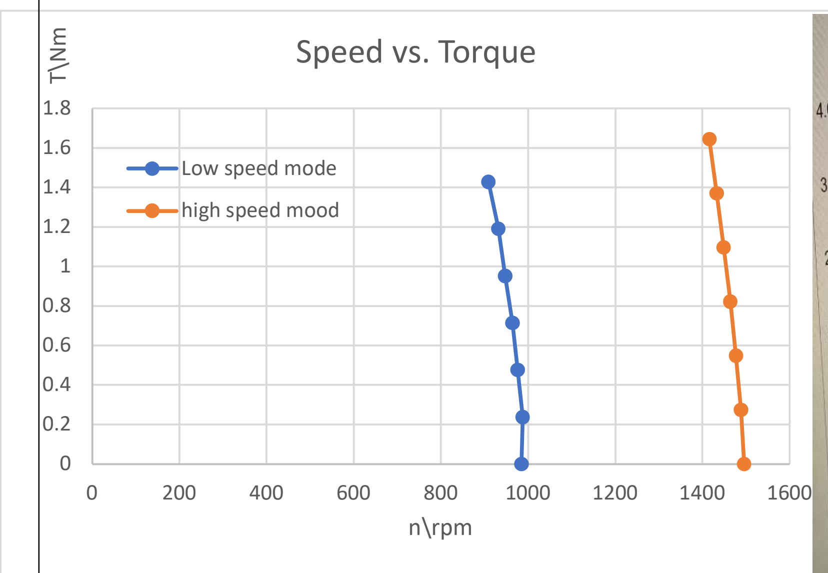

Figure 11: speed vs torque (calculated values)

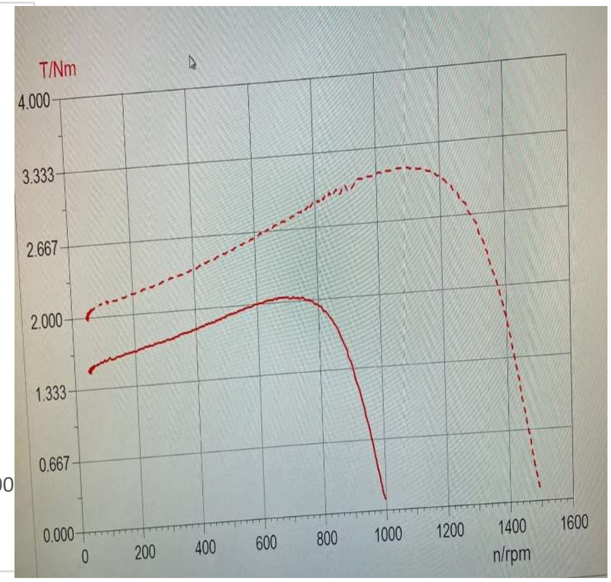

Figure 12: speed vs torque (measured values using CPM 10 software)

The plot from the calculated values only represents small range of speed between 900 – 1000 for the low mode, and 1400 – 1500 for the high-speed mode, but if we compared these ranges with the plot on the right in figure 12, it can be noticed that both starts the same with almost the same values.

Also, the high-speed mode obviously has the higher speed for the same value of torque compared with the low-speed mode in both figures.

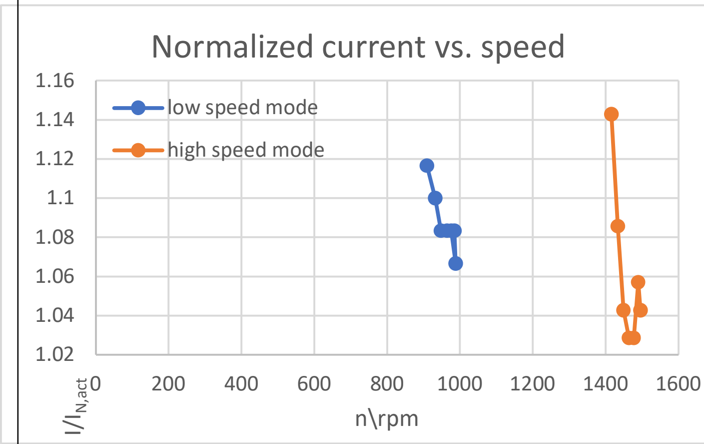

Figure 13: Normalized current vs. speed (calculated values)

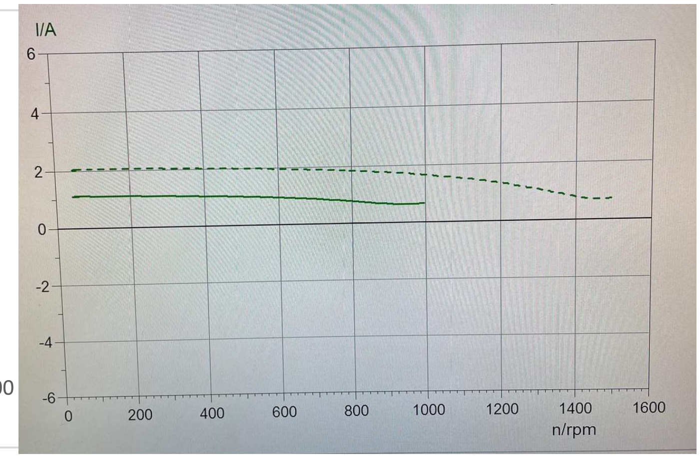

Figure 14: Current vs. speed (measured values)

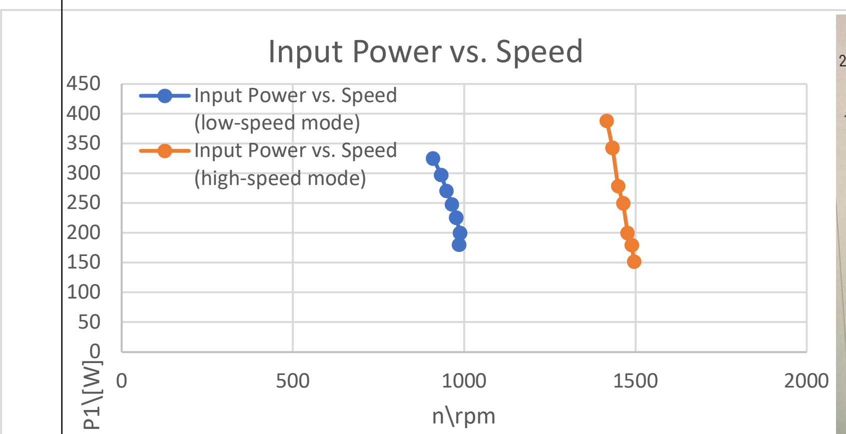

Figure 16: Input Power vs. speed (calculated values)

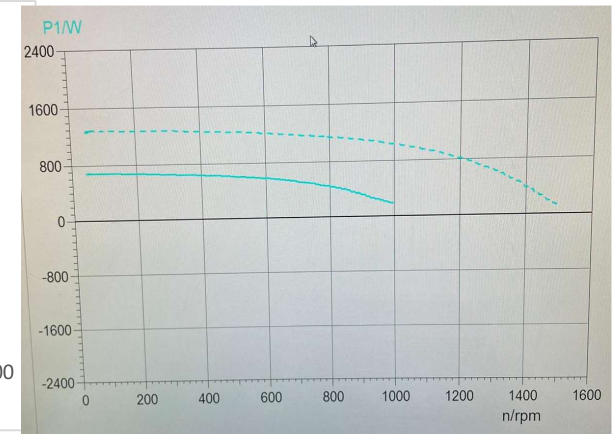

Figure 15:Input Power vs. speed (measured values)

In general the power in the high-speed mode is higher than it in the low-speed mode since the current in the high-speed mode is higher than the other mode as mentioned before, snd the same applies for the output power of the motor as shown down below in figures 17 and 18

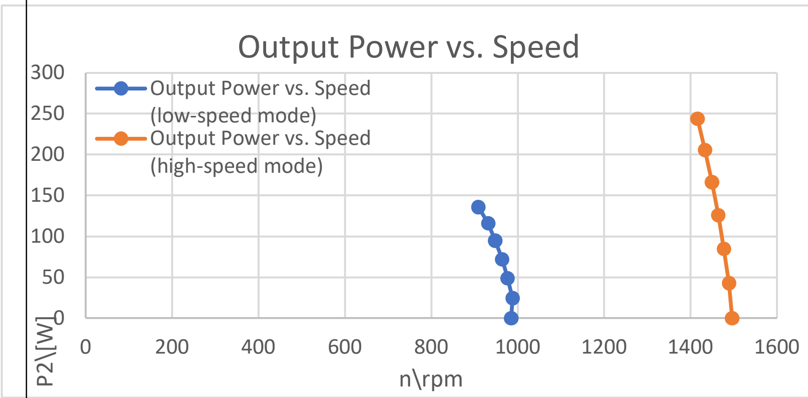

Figure 18: Output Power vs. Speed (calculated values)

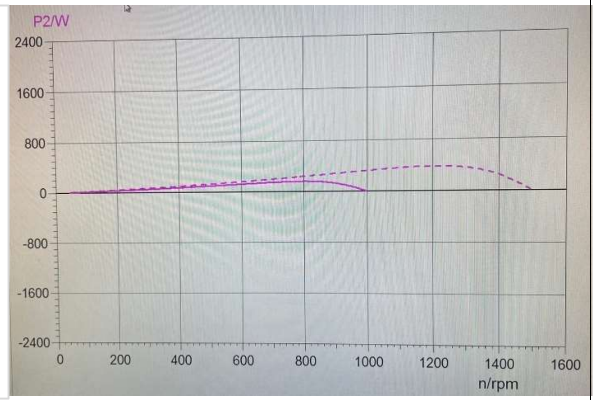

Figure 17: Output Power vs. Speed (measured values)

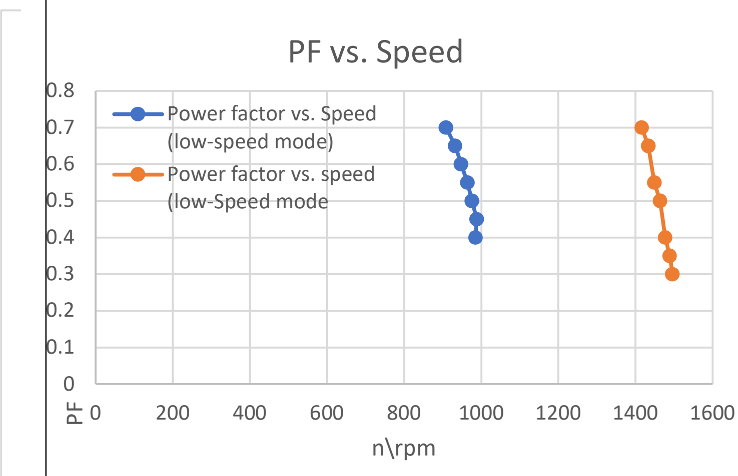

Figure 19: Power Factor vs. Speed (calculated values)

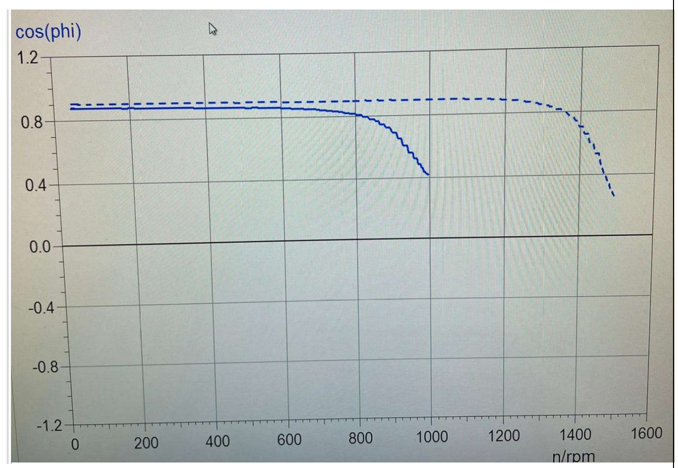

Figure 20: Output Power vs. Speed (measured values)

Power factor also increases with the decrease of the speed, till it hits a specific point and it gets almost constant.

Conclusion

To sum up, increasing the number of poles will lead to a decrease in the speed, so it can be concluded that the low-speed mode has a higher number of poles compared to the high-speed mode, and since increasing the number of poles affect the speed by decreasing it, it affects the torque, current and power too, if the two modes were compared it can be noticed that each characteristic is higher in the high-speed mode than the low-speed mode for the same value of speed.

It worth mentioning that although this method is expensive but it’s very effective way to control the speed of the squirrel cage induction rotor, as it can be noticed in figure 12 and as it was mentioned before in the conclusion, the pull-out torque was increased with the second winding of the motor.

References

[1] https://electricalbaba.com/rotor-resistance-control-induction-motor/

Accessed on 1/11/2021 on 9:30 pm

[2] https://electricityshock.com/how-do-you-control-the-speed-of-a-squirrel-cage-induction-motor/

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[3] http://people.ucalgary.ca/~aknigh/vsd/ssim/sine/vvvf.html

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[4] ENEE2408 Electrical Machines

[5] ENEE3101 Electrical Machines Laboratory