INDUCTION MACHINE EXPERIMENTS

DT021A/3
Electrical Machines
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Experiment to complete

Choosing the 160KW, 400V, 50 Hz, 1487 RPM preset parameters in Simulink asynchronous squirrel-cage machine as shown in figure 1.

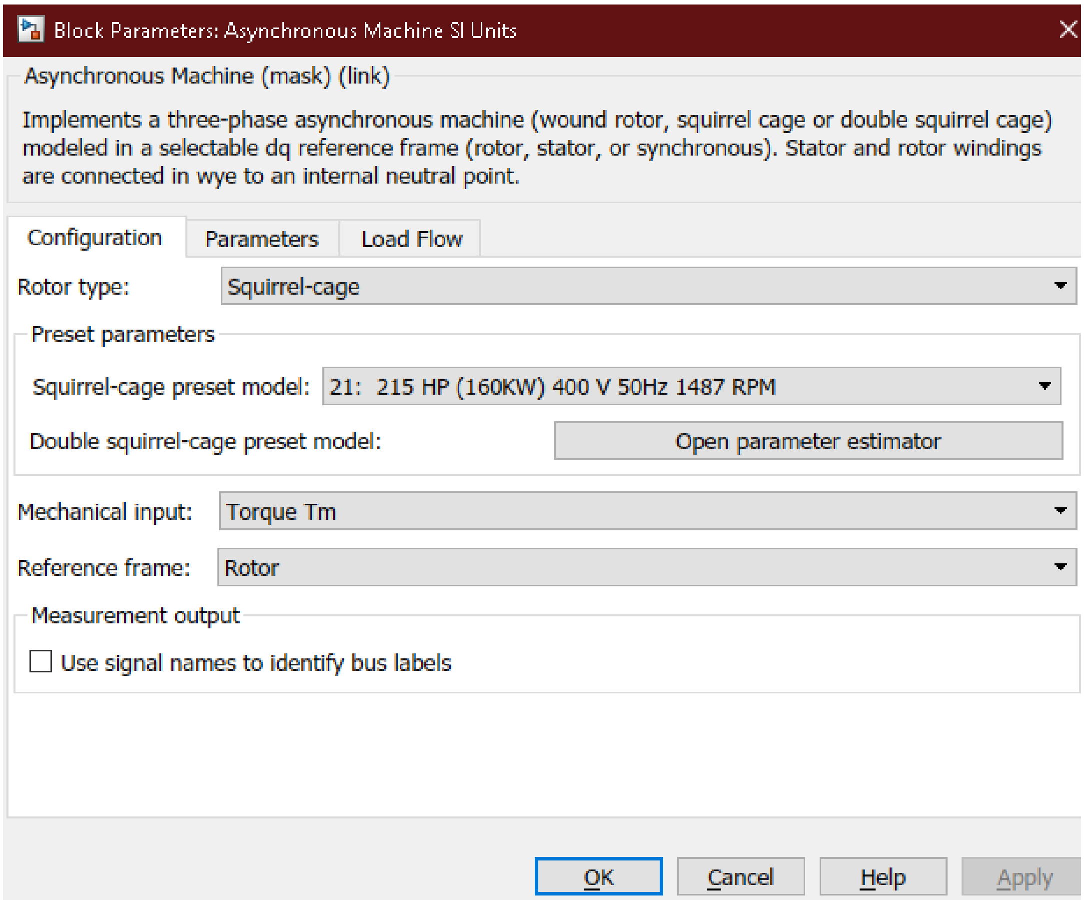


Figure 1 – Preset parameters of the asynchronous squirrel-cage machine

Balanced voltages of 400Vrms are applied to the stator terminals at the rated frequency of 50Hz. Current, voltage and power are measured at the motor input. The losses in the no-load test are caused by the core losses, winding losses, windage and friction. The Model of the squirrel is shown in figure 2.

1.1. No Load Test (NLT)

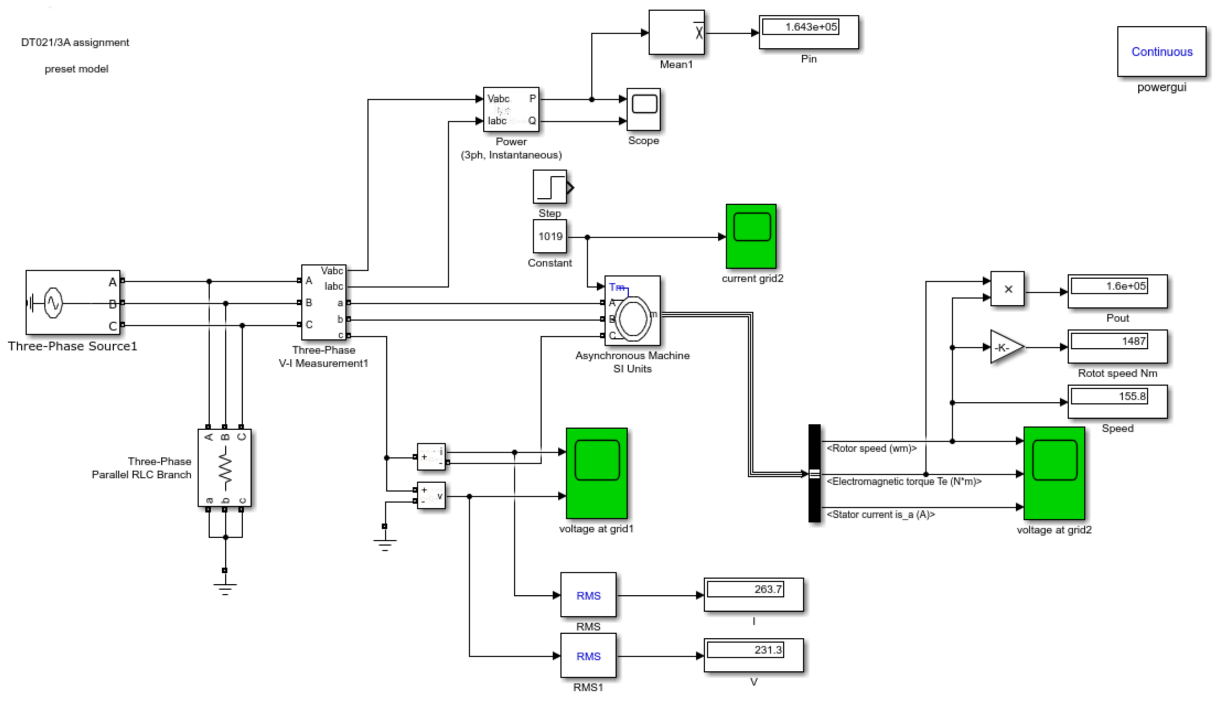


Figure 2 - Preset Model of the asynchronous squirrel-cage machine with no load

Table 1 - No-Load Test

NLT	Tm	V	I	Pin	Pout	Speed (Wm)	Rotor Speed(rpm)
	0	231.3	93.61	1748	1423	157.1	1500
	100	231.2	96.91	17470	17110	156.9	1499
	200	231.1	105.6	33250	32770	156.8	1498
	300	231.1	118.5	49060	48410	156.7	1496
	400	231.3	134.4	64930	64020	156.6	1495
	500	231.3	152.4	80840	79600	156.4	1494
	600	231.2	172	96800	95150	156.3	1493
	700	231	192.8	112800	110700	156.2	1491
	800	231.2	214.4	128900	126200	156	1490
	900	231.3	236.6	145000	141700	155.9	1489
	1000	231.3	259.3	161200	157100	155.8	1488
	1019	231.3	**263.7**	164300	**160000**	155.8	**1487**

Blocked rotor Test (BRT)

In the blocked rotor mechanical input is set to speed w where test the rotor is blocked to prevent rotation and balanced voltages are applied to the stator terminals where the rated current is achieved. The input voltage was changed to produce a current which was measured in the no-load test. The model of the blocked rotor test is shown below.

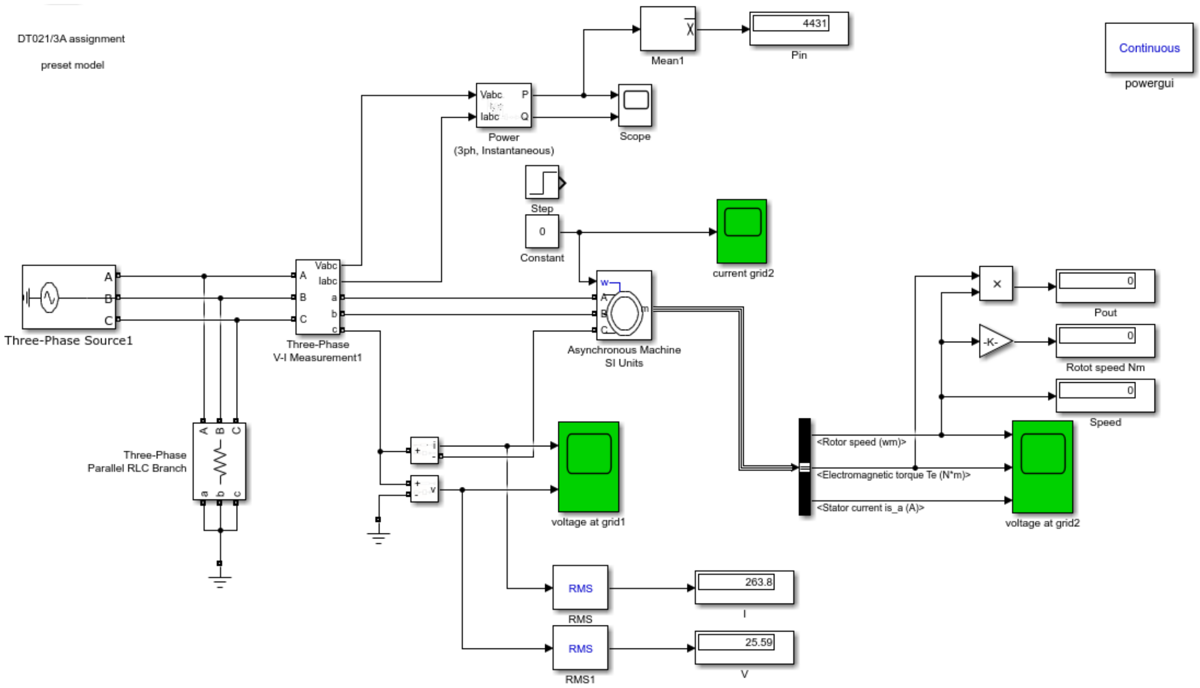


Figure 3 - Model of the Squirrel cage machine when performing a blocked rotor test (BRT)

Table 2 - Blocked rotor test (BRT)

BRT	Vrms	V	I	Pin	Pout	Speed (Wm)	Rotor Speed(rpm)
	400	231	2385	361500	0	0	0
	44.29	25.59	263.8	4431	0	0	0

Torque Speed Characteristics of the squirrel cage induction motor

The input mechanical speed was varied from 0 to 157wm (1500rpm) to show the torque and the stator current speed characteristics of the induction machine. The following values were measured to produce a torque-speed characteristics graph.

Table 3 - Characteristics results for Torque & stator current

speed (wm)	Speed (rpm)	Torque	Current
0	0	319.1	2385
10	95.49	339.5	2379
20	191	940.4	2377
30	286.5	981.2	2375
40	382	1062	2369
50	477.5	1156	2356
60	573	1270	2356
70	668.5	1404	2347
80	763.9	1571	2332
90	859.4	1781	2316
100	954.9	2050	2291
110	1050	2408	2256
120	1146	2895	2195
130	1241	3560	2078
140	1337	4331	1823
150	1432	3898	1116
157	1499	64.1	94.75

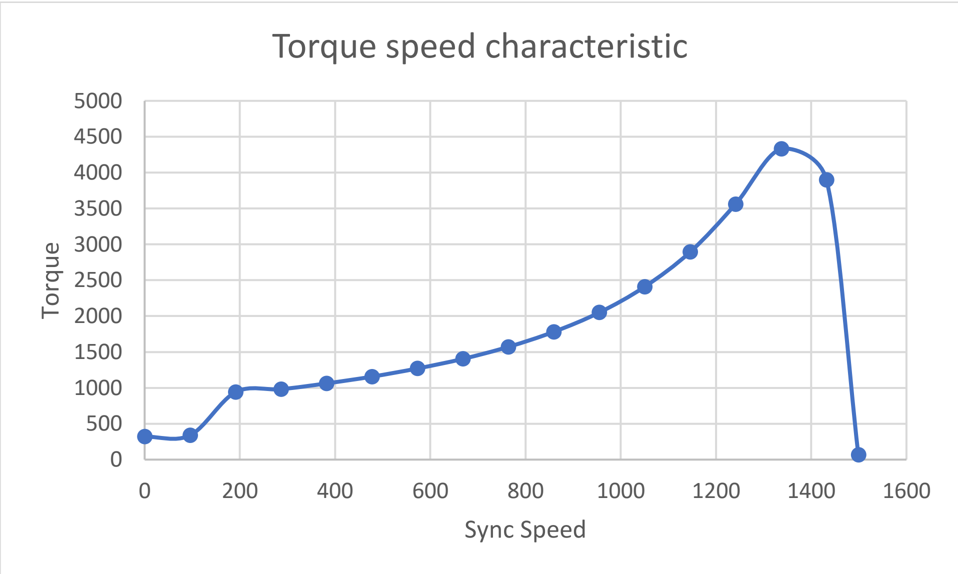
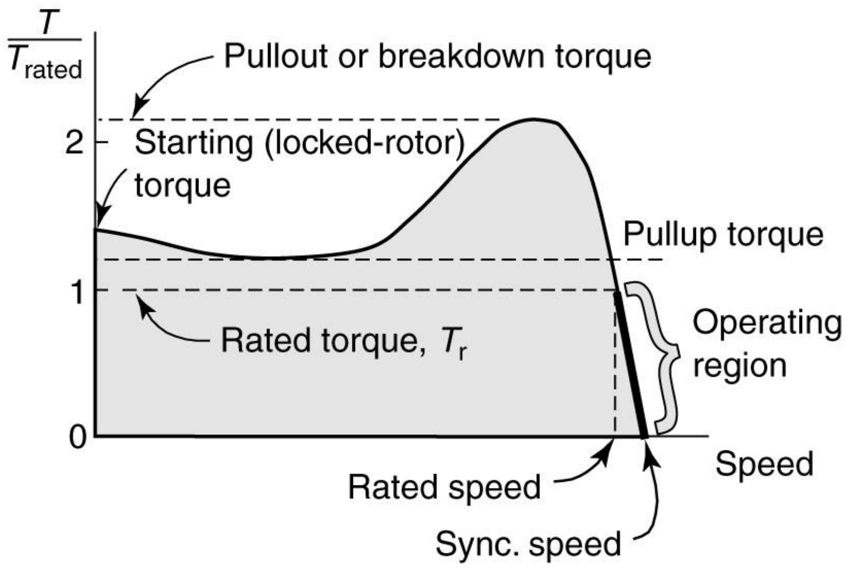


Figure 4 - Graph of the Torque speed characteristic



The torque-speed graph typically consists of the following characteristics:

- Starting (locked rotor) is the minimum torque that the motor develops at rest for all angular positions of the rotor at the rated voltage and frequency.
- Pull up torque is the accelerating torque, when the motor accelerates, the torque develops slightly decreases. Pull-up torque is the minimum torque developed by the motor in as starting process.
- Breakdown torque is the maximum torque that the motor develops at rated voltage and frequency, without an abrupt drop in speed.
- Full-load torque is the torque required to produce the rated power at the rated speed.

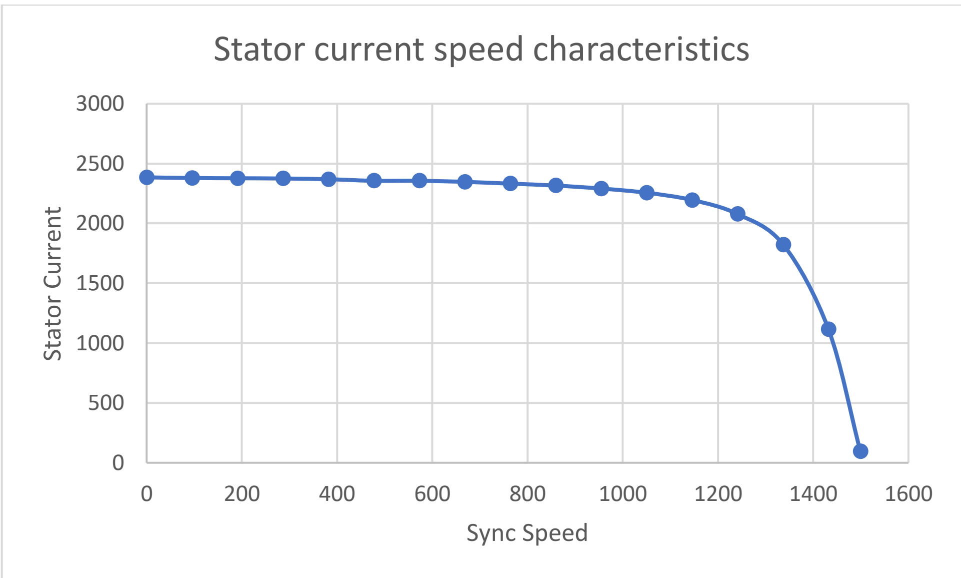
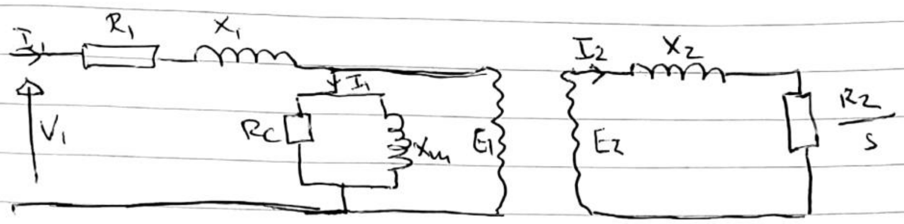


Figure 5 - Graph of the Stator current speed characteristic

The stator current speed characteristic graph is shown above in figure 5 where the starting current is 2385A when the rotor speed is at 0 RPM. The stator current reduces when the speed is increased.

Equivalent Circuit

Equivalant Circuit

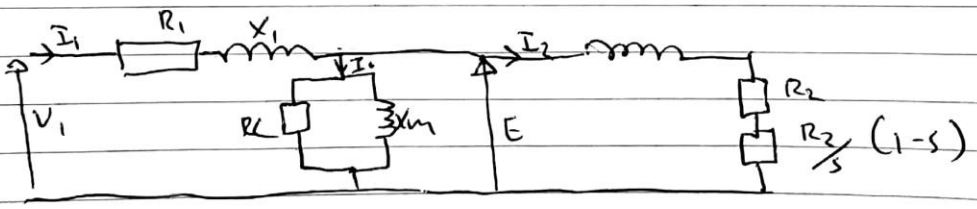


$$I_2 = \frac{sE_2}{R_2 + jsX_2} \qquad I_2 = \frac{E_2}{\frac{R_2}{s} + jX_2}$$

$$\frac{R_2}{s} = \frac{R_2}{s} - R_2 + R_2$$

$$= R_2\left(\tfrac{1}{s} - 1\right) + R_2 \quad = R_2 + R_2\left(\tfrac{1}{s} - 1\right)$$

$$\Rightarrow \frac{R_2}{s} = R_2 + \frac{R_2}{s}(1-s)$$



where :

V_1 = Terminal Voltage

R_1 = Stator winding resistance

jX_m = Magnetising reactance

jX_1 = Stator leakage loss

R_C = Core loss resistance

E_1 = Induced voltage in the rotor winding

jX_2 = Rotor leakage reactance

R_2 = Rotor winding resistance

Equivalent Circuit Calculations

$\rightarrow \quad I_{rc} = \frac{P_{nl}}{V_{nl}}$

$I_{rc} = \frac{1423}{231.3}$

$\underline{I_{rc} = 6.15\ A}$

$\rightarrow \quad R_c = \frac{V_{nl}}{I_{rc}}$

$RC = \frac{231.3}{6.15}$

$\underline{RC = 37.6\ \Omega}$

$\rightarrow \quad I_{xm} = \sqrt{I_{nl}^2 - I_{rc}^2}$

$I_{xm} = \sqrt{(94.75)^2 - (6.15)^2}$

$\underline{I_{xm} = 94.5\ A}$

$\rightarrow \quad X_m = \frac{V_{nl}}{I_{xm}}$

$X_m = \frac{231.3}{94.5}$

$\underline{X_m = 2.447}$

$\rightarrow \quad P_{br} = I_{br}^2 \times R_{eq}$

$\frac{P_{br}}{I_{br}^2} = R_{eq}$

$R_{eq} = \frac{4431}{263.8}$

$\underline{R_{eq} = 16.797\ \Omega}$

$\rightarrow$ $Z_{eq} = \frac{V_{bn}}{I_{bn}}$

$Z_{eq} = \frac{44.29}{263.8}$

$Z_{eq} = 0.1679$

$\rightarrow$ $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$

$X_{eq} = \sqrt{(0.1679)^2 - (16.797)^2}$

$X_{eq} = 16.79$

A numerical Problem

Problem

3 Phase 460 V, 60 Hz, 4 Pole star connected

$R_s = 0.42\,\Omega$, $R_r = 0.23\,\Omega$, $X_s = X_r = 0.82\,\Omega$

$X_m = 22\,\Omega$.

No load loss = 60 W, Rotor speed 1750 rpm.

a) Synchronous speed

$$N_s = \frac{120 \times f}{P} = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

b) Slip s

$$s = \frac{N_s - N_r}{P} = \frac{1800 - 1750}{1800} = 0.0277$$

c) Input current I_1

$$\boxed{I_1 = \frac{V_{ph}}{Z_{in}}} \Rightarrow V_{ph} = \frac{460}{\sqrt{3}} = 265.5811$$

$$\Rightarrow Z_{in} = X_m \,||\, \left(R_s + X_s + X_r + \frac{R_r}{s}\right)$$

$$22j \,||\, \left(0.42 + 0.82j + 0.82j + \frac{0.23}{0.02771}\right)$$

$$j22 \,||\, 8.7023 + 1.64j$$

$$Z_{in} = \frac{22j \times (8.7023 + 1.64j)}{22j + (8.7023 + 1.64j)} = 7.73378 \angle 30.8$$

$$I_1 = \frac{V_{ph}}{Z_{in}} = \frac{265.58}{7.734 \angle 30.8} = 34.3 \angle 30.88$$

$$I_1 = 34.3 A$$

e) Input power factor of the supply

$$P_i = 3 \times V_{ph} \times I_1 \times \cos(30.822)$$

$$P_i = 3 \times \frac{460}{\sqrt{3}} \times 34.34 \times \cos(30.8221) =$$

$$P_i = 23.5 KW$$

f) air Gap power

$$\boxed{P_g = 3 \times I_r^2 \times \frac{R_r}{s}}$$

$$I_r^2 = \frac{V_{ph}}{\sqrt{(R_s + \frac{R_r}{s})^2 + (X_s + X_r)^2}}$$

$$I_r^2 = \frac{460/\sqrt{3}}{\sqrt{(0.42 + 0.23/0.02771)^2 + (0.82 + 0.82)^2}} =$$

$$I_r^2 = 30A$$

$$P_g = 3 \times 30^2 \times \frac{0.23}{0.02771} = 22.36 kW$$

g) Rotor copper loss

$$P_{copper} = 3 \times I_r^2 \times R_r$$

$$P_{copper} = 3 \times 30^2 \times 0.23 = 620.59 W$$

H) Develope torque

$$T_e = \frac{P_g}{W_s} \rightarrow W_s = \frac{2\pi N_s}{60}$$

$$W_s = \frac{2\pi \times 1800}{60} = 188.5 r/s$$

$$T_e = \frac{22347.35}{188.5}$$

$$T_e = 118.556 \text{ Nm}$$

I) Efficiency

$$\mathcal{E} = \frac{Out}{In} = \frac{P_{out}}{P_{in}} = \frac{P_g - P_{copper} - P_{nl}}{P_{in}} \times 100$$

$$\mathcal{E} = \frac{22347.35 - 620.5 - 60}{23553.44} \times 100 = 92\%$$

j) Slip for maximum torque

$$S_{max} = \frac{R_r}{\sqrt{R_s^2 + (X_s + X_r)^2}} = \frac{0.23}{\sqrt{0.42^2 + (0.82 + 0.82)^2}}$$

$$Slipe_{max} = 0.13586$$

K) Maximum develpet torque

$$T_{max} = \frac{1}{2 w_s} \times \frac{3 \times V_{ph}^2}{R_s + \sqrt{R_s^2 + (X_s + X_r)^2}}$$

$$T_{max} = \frac{1}{2 \times 188.5} \times \frac{3 \times \frac{460^2}{\sqrt{3}}}{0.42 + \sqrt{0.42^2 + (0.82 + 0.82)^2}}$$

$$T_{max} = 265.645 \text{ Nm}$$