Lab-4: AC Squirrel-Cage Induction Motor

ELEC 342

Lab Experiment: 4

Section: D

Bench #: 7

Partners	Student ID #:	% participation	Signatures
Anshul Israni	80077357	100	AI
Deepak Roshan Thiagarajan	62802418	100	DT
Pratham Goel	90300815	100	PG

Date Performed: 24th March ‘23

Date Submitted: 31st March ‘23

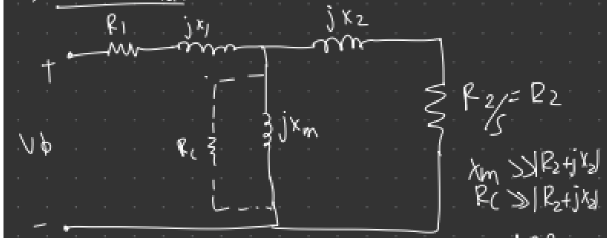
Pre-Lab:

1) Deepak Roshan Thiagarajan

Prelab 4

Deepak Roshan Thiagarajan
62802418

1) Locked Rotor Test



$s = 1$

$X_m \gg |R_2 + jX_2|$
$R_C \gg |R_2 + jX_2|$
$\therefore$ Neglect R_C & X_m

$P = \sqrt{3} V_T I_L \cos\theta$

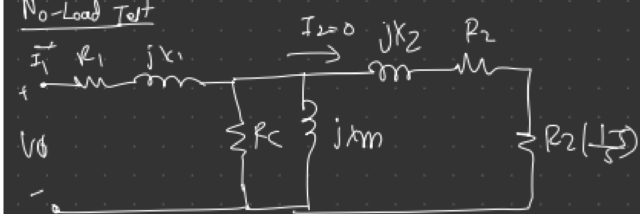
$PF = \cos\theta = \frac{P_{in}}{\sqrt{3} V_T I_L}$

$Z_{LR} = R_{LR} + jX'_{LR} = |Z_{LR}|\cos\theta + j|Z_{LR}|\sin\theta$

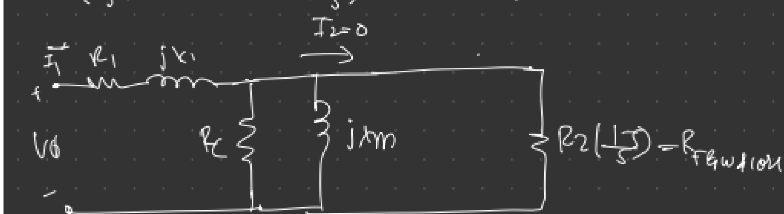
$R_{LR} = R_1 + R_2$; $X'_{LR} = x_1' + x_2'$

$X_{LR} = \frac{f_{rated}}{f_{test}} X'_{LR} = X_1 + X_2$

No-Load Test



As $R_2\left(\frac{1-s}{s}\right) \gg R_2$ && $R_2\left(\frac{1-s}{s}\right) \gg X_2$ reducing the circuit.



$P_{SCL} = 3 I_1^2 R_1$
$P_{in} = P_{SCL} + P_{core} + P_{F\&W} + P_{misc}$
$= 3 I_1^2 R_1 + P_{rot}$

$|Z_{eq}| = \frac{V_\phi}{I_{1,nl}} \approx X_1 + X_m$

where, $P_{rot} = P_{core} + P_{F\&W} + P_{misc}$

2) $$\tau_{ind} = \frac{3V_{TH}^2 R_2/s}{\omega_{synch}[R_{TH}+R_2/s]^2+[X_{TH}+X_2]^2} \qquad \left(\frac{120\times f}{P} \times \frac{2\pi}{\cancel{60}}\right)$$

$\therefore$ Subbing 60Hz

$$\Rightarrow \tau_{ind} = \frac{3V_{TH}^2 \times R_2/s}{\left(\frac{240\pi}{P}\right)\times[R_{TH}+R_2/s]^2+[X_{TH}+X_2]^2}$$ (where P are the poles)

Now for fixed voltage magnitude.

$$\tau = \frac{3\times P_{out}}{2\pi\times 60\times n_s}$$ $n_s \rightarrow$ synch speed.

3) $$\phi_M = \frac{1}{\sqrt{2}\pi N_1} \times \frac{E_1}{f}$$ where $E_1 \rightarrow$ voltage
$N_1 \rightarrow$ no of turns
$F \rightarrow$ Frequency
$\phi_m \rightarrow$ Flux

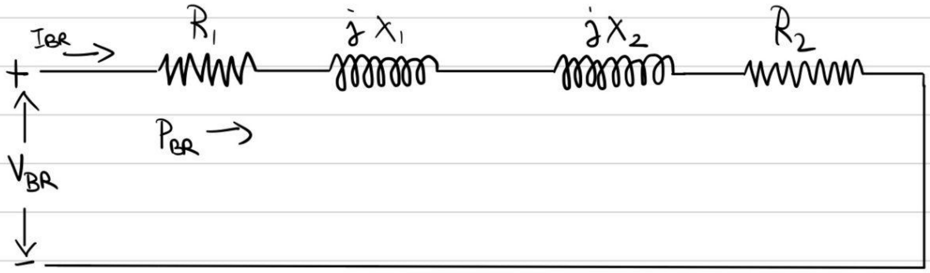
The voltage & frequency should be adjusted together in Variable Frequency Drive applications as if not the change in frequency without change in voltage would lead to the saturation of the motor. The voltage magnitude should be varied for steady torque output.

2) Anshul Israni

Anshul Israni
(80077357)

Prepare a list of equations for calculating the equivalent circuit parameters using the Blocked-Rotor and No-Load Tests.

* Blocked Rotor Test →

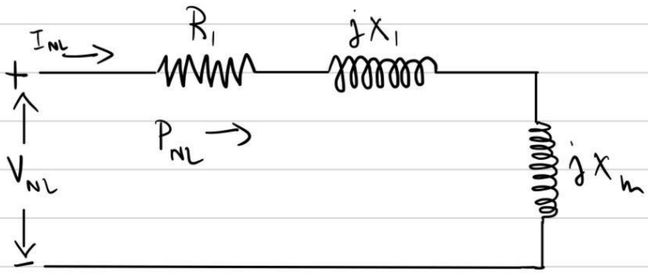


Total resistance seen by the circuit: $Z_{BR} = \frac{(V_{BR}/\sqrt{3})}{I_{BR}}$

$\therefore R_{BR} = R_1 + R_2 = \frac{P_{BR}}{I_{BR}^2}$

$\therefore X_{BR} = X_1 + X_2 = \sqrt{Z_{BR}^2 - R_{BR}^2}$

* No Load Test →



Total resistance seen by the circuit: $Z_{NL} = \frac{(V_{NL}/\sqrt{3})}{I_{NL}}$

$\therefore R_{NL} = R_1 = \frac{V_{NL}^2}{P_{NL}}$

$\therefore X_{NL} = X_1 + X_m = \sqrt{Z_{NL}^2 - R_{NL}^2}$

- Write down the expression for the torque-speed characteristic at 60 Hz fixed frequency and constant voltage magnitude.

$$\boxed{\tau = \frac{3 * P_{out}}{2\pi f_1 . n_s}}$$

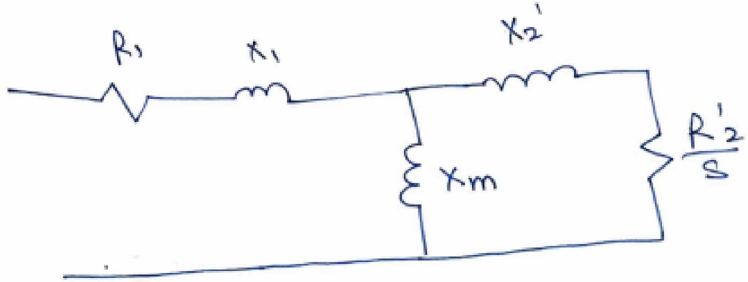
[here, P_{out} = Output power of induction motor
f_1 = Stator frequency
n_s = synchronous speed of the motor]

- Assume an inductor (a magnetizing branch of the induction machine or a transformer) under sinusoidal AC excitation. Write down an expression for the magnitude of the flux in terms of voltage and frequency. Write a sentence to rationalize why the voltage and frequency should be adjusted together for the Variable Frequency Drive applications.

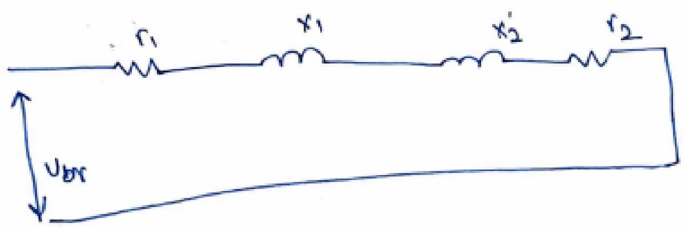
$$\phi = \left(\frac{V}{2\pi f_1}\right) . X_L$$ [here, X_m = inductive reactance]

3) Pratham Goel

Pre-lab #4



Blocked Rotor

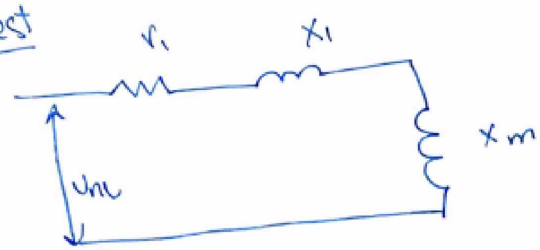


$$Z_{br} = \frac{(V_{br}/\sqrt{3})}{I_{br}}$$

$$r_{br} = \frac{P_{br}}{I_{br}^2} = r_1 + r_2'$$

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

No-load test



$$Z_{nl} = \frac{(V_{nl}/\sqrt{3})}{I_{nl}}$$

$$r_{nl} = \frac{P_{nl}}{I_{nl}^2}$$

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

2) $\cancel{T = \frac{(3V^2 R_2 \times s)}{\sqrt{(sR_2)^2 + (X_2)^2}}}$

$$T = \frac{(3 \cdot V^2 \cdot R_2 \cdot s)}{((sR_2)^2 + (X_2)^2)}$$

where $s = \frac{1800 - N}{1800}$ at $\underline{\underline{60\,Hz}}$

3) $$|\Phi| = \frac{V}{2\pi f X_e}$$

Table 1: Motor Nameplate Information and Nominal Characteristics

Info/Parameter	Nominal/Rated Value	Comments
NEMA Class	B	
Horse Power	0.25	
Speed	1750	
Number of Poles	4	(120*60) / 1750 ≅ 4
Line Current	6.6	Assuming the motor windings are connected in parallel
Line Voltage	34	Assuming the motor windings are connected in parallel
Calculations corresponding to full load		
Efficiency	67.74501%	
Power Factor	0.78486	

How can you explain the voltage and current information? Briefly explain why the motor has two sets of values.

The nameplate of the motor provides two values for current and voltage because the stator windings can be connected in either series or parallel inside the machine. The lower value on the nameplate indicates a parallel connection, while the higher value indicates a series connection.

Table 2: Nominal/rated phase voltage and current assuming Y-connected winding

$V_1(rms), V$	$I_1(rms), A$
19.62	3.81

Table 3: Stator winding DC resistance measurement (Do not exceed 5 A dc current!)

	Measurements (line-to-line)		**Calculation**
Using DC Source	V_{dc}, V	I_{dc}, A	$R_{1,dc} = 0.5V_{dc}/I_{dc}, \Omega$
	1.8	4.63	0.19438
Using Multimeter	R_{total}, Ω		$R_{1,dc} = 0.5R_{total}, \Omega$
	0.34 - 004 = 0.3		0.15

Table 4: No-load measurement (motor is free spinning)

Average phase voltage $V_{nl}(rms), V$	Average phase current $I_{nl}(rms), A$	Average phase power-factor angle $\varphi_{nl}(\deg)$	Total real power P_{nl}, W	**Calculate** rotational losses P_{rot}, W
19.52	6.06	-81	55	33.585

Table 5: Blocked-rotor measurement (motor is not spinning)

Average phase voltage $V_{br}(rms), V$	Average phase current $I_{br}(rms), A$	Average phase power-factor angle $\varphi_{br}(\deg)$	Total real power P_{br}, W	Stall Torque T_{br}, Nm
4.57	6.85	-53.8	55.4	0.05

Table 6: Load test measurement: (under nominal voltage, 20 – 23V)

Measurement #	1	2	3	4	5	6	7
$V_{ph}(ave, rms), V$ keep it constant	19.26	19.24	19.28	19.25	19.27	19.27	19.26
$I_{ph}(ave, rms), A$	6.0	6.37	6.69	6.98	7.33	7.74	7.97
$\varphi_{pf}(ave, \deg)$	-74.6	-69.6	-64.6	-60.3	-56.6	-53.3	-51.6
$P_{in}(total), W$	93.3	128.2	164.1	201.2	233.9	267.3	285
n, rpm	1763	1757	1750	1743	1736	1728	1726
T_m, Nm	0.24	0.42	0.60	0.76	0.93	1.08	1.16
Calculation							
P_m, W	44.32	77.31	110	138.78	169.14	195.51	209.75
Slip s	0.0205	0.0239	0.0278	0.0316	0.0356	0.04	0.0411
Using last measurement, calculate SR $SR = \left(n_1 - n_{7,load}\right) / n_{7,load}$	0.0214368482						

Using last measurement, calculate efficiency of the Motor, % P_m/P_{in}	73.596491228 %

Table 7: Motor speed control by varying voltage (Motor may stall at low voltages)

Measurement #	1	2	3	4	5	6
$V_{ph}(ave, rms), V$	19.37	16.38	13.37	10.20	-	-
$I_{ph}(ave, rms), A$	7.89	7.87	8.67	11.57	-	-
$\varphi_{pf}(ave, \deg)$	-52.2	-44.8	-38.5	-37.5	-	-
$P_{in}(total), W$	281.1	273.9	272.8	279.5	-	-
n, rpm	1726	1704	1654	1461	-	-
T_m, Nm	1.15	1.13	1.10	1.00	-	-
Calculation						
P_m, W	207.942	201.721	190.6038	153.057	-	-
Slip s	0.041111	0.05333	0.081111	0.188333	-	-
Using last measurement, calculate SR $SR = \left(n_1 - n_{last,load}\right) / n_{last,load}$	0.181					

Table 8: Load test measurement: (under low voltage, 12 – 14V)

Measurement #	1	2	3	4	5	6	7
$V_{ph}(ave, rms), V$ keep it constant	13.47	13.50	13.48	13.47	13.46	13.46	13.46
$I_{ph}(ave, rms), A$	4..44	4.96	5.61	6.37	7.18	8.05	8.49
$\varphi_{pf}(ave, \deg)$	-67.7	-58.3	-51.1	-45.9	-42.4	-39.7	-38.8
$P_{in}(total), W$	68.5	105.3	142.1	178.5	213.9	250.3	267.1
T_m, Nm	0.22	0.40	0.56	0.72	0.87	1.02	1.08

n, rpm	1754	1738	1723	1705	1687	1668	1657
Calculation							
P_m, W	40.43	72.83	101.082	128.60	153.76	178.23	187.47
Slip s	0.025	0.034	0.043	0.052	0.063	0.073	0.0794

Table 9: VFD: Motor speed control by the varying frequency at Vdc =45 V

Measurement #	1	2	3	4	5	6
f_{ac}, Hz	10	20	40	60	80	95
Inverter input DC current $I_{inv,dc}, A$	0.79	1.41	2.53	3.76	4.83	6.47
$V_{ph}(ave, rms), V$	1.26	7.38	14.49	19.15	19.95	19.84
$I_{ph}(ave, rms), A$	0	6.96	7.13	6.31	6.07	6.54
$\varphi_{pf}(ave, \deg)$	-18.6	-67.3	-71.5	-65.2	-50.7	-44.6
$P_{in-ac}(total), W$	31.6	52.4	101.7	146	210.6	275.9
n, rpm	280	578	1140	1732	2347	2706
T_m, Nm	0.20	0.32	0.48	0.64	0.71	0.82
Calculate Slip s	0.844	0.678	0.366	0.03778	-0.304	-0.503

Calculate these values corresponding to different frequencies	Inverter input power P_{in-dc}, W	Input power at the Induction Motor terminals P_{in-ac}, W	Output mechanical power P_m, W	Efficiency of the Inverter, % P_{in-ac}/P_{in-dc}	Efficiency of the Motor, % P_m/P_{in-ac}
$f_{ac} = 10Hz$	35.55	31.6	5.877	88.89 %	18.60 %
$f_{ac} = 60Hz$	169.20	146	116.12	86.29 %	79.53 %
$f_{ac} = 95Hz$	291.15	275.9	232.458	94.76 %	84.25 %

Task 5: Calculations and Analysis

Task 5A: Determining Motor Parameters

1)

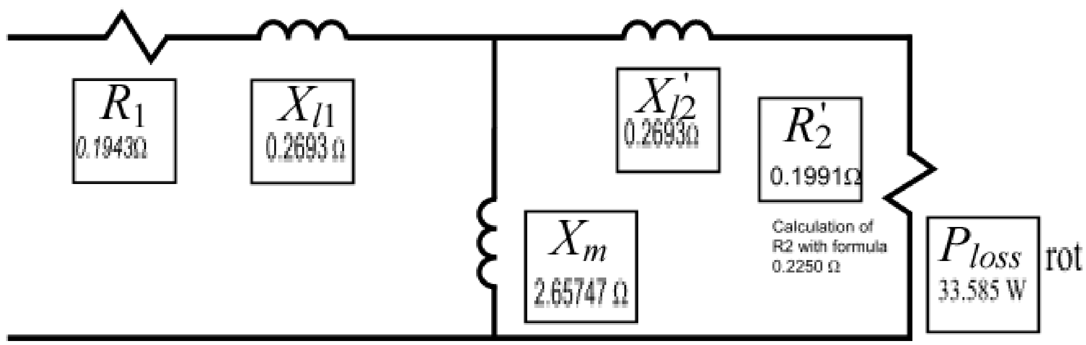


Fig. A. Induction Machine Equivalent Circuit. Fill in the corresponding boxes with machine parameters. Make sure to include the units.

2) Using

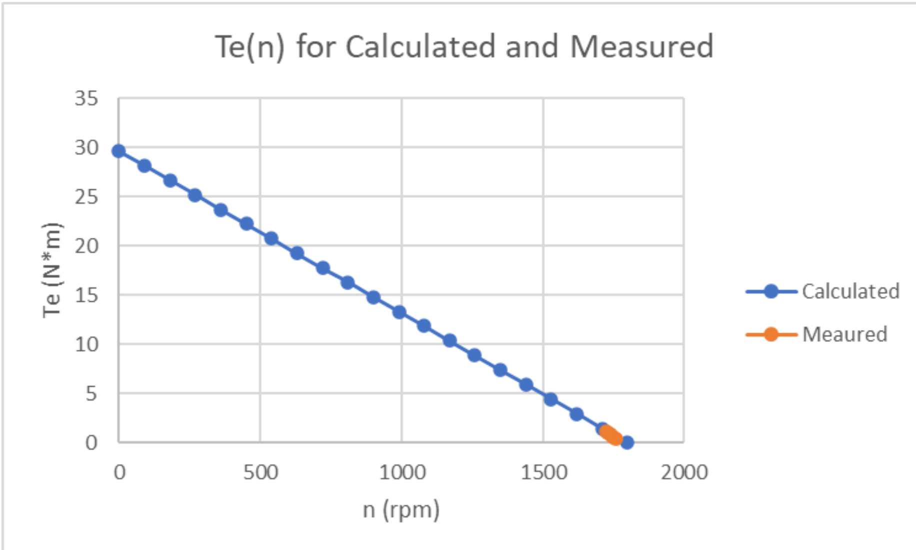
$$T_e = T_m = \frac{3V_1^{\,2} * (R_2'/s)}{\omega_{syn}(R_2'/s)^2} = \frac{3V_1^{\,2} * (s)}{\omega_{syn}(R_2')}$$

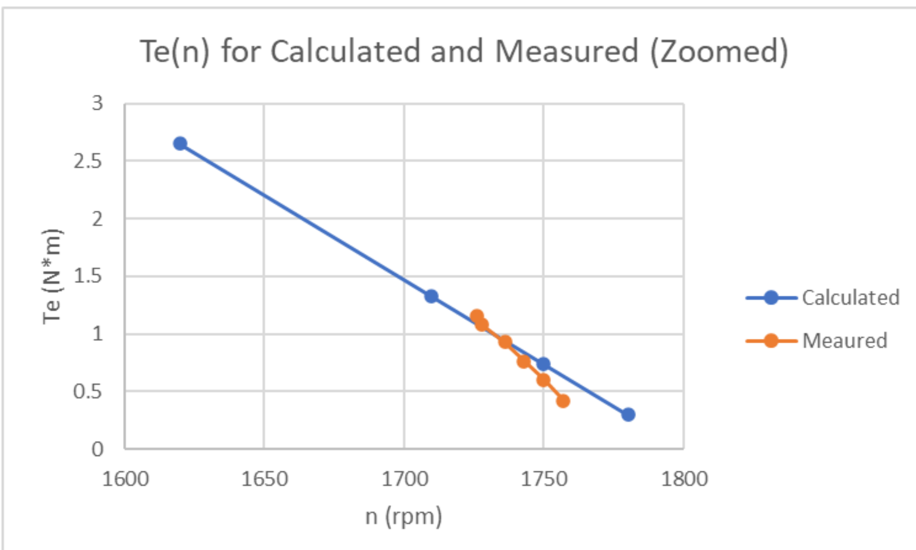
We use the above formula to calculate R_2 which we get average as 0.2250 Ω for the 7 values we measured in Table 6.

The resistance value obtained from the blocked rotor test is heavily influenced by the AC effective resistance, which is caused by the higher frequency of the machine running at 60 Hz, 1800 rpm. This means that the resistance value we determined may not be very accurate since the AC effective resistance is usually higher than the DC resistance. To obtain a more precise figure, we can use the formula and calculate the resistance value based on the DC resistance. Therefore, we will use R2' = 0.225 for our computations.

Task 5 B: Equivalent Circuit vs. Measured Comparison

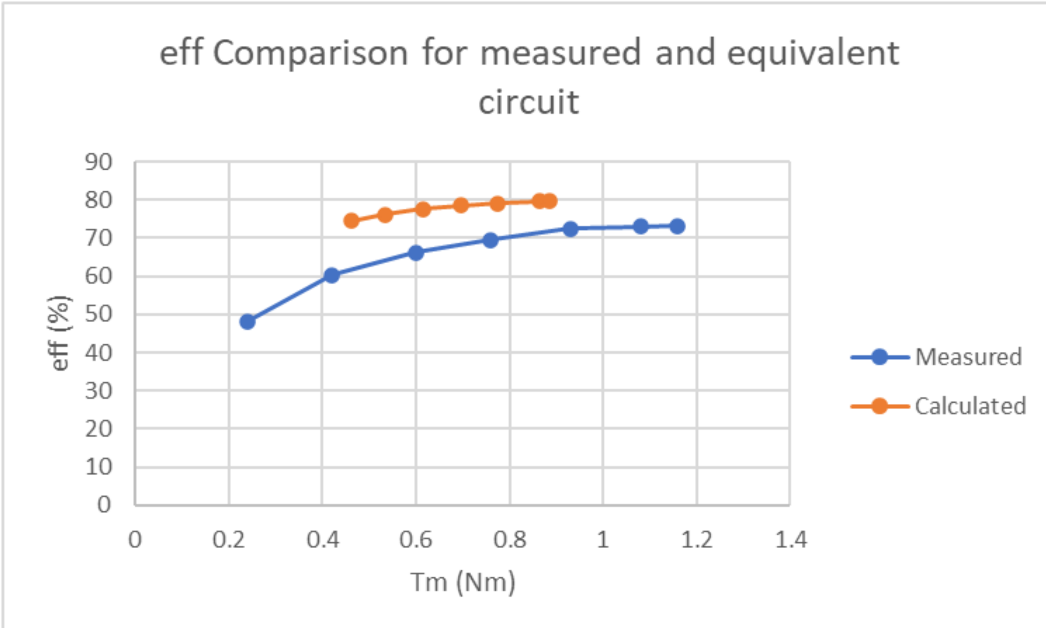
1)





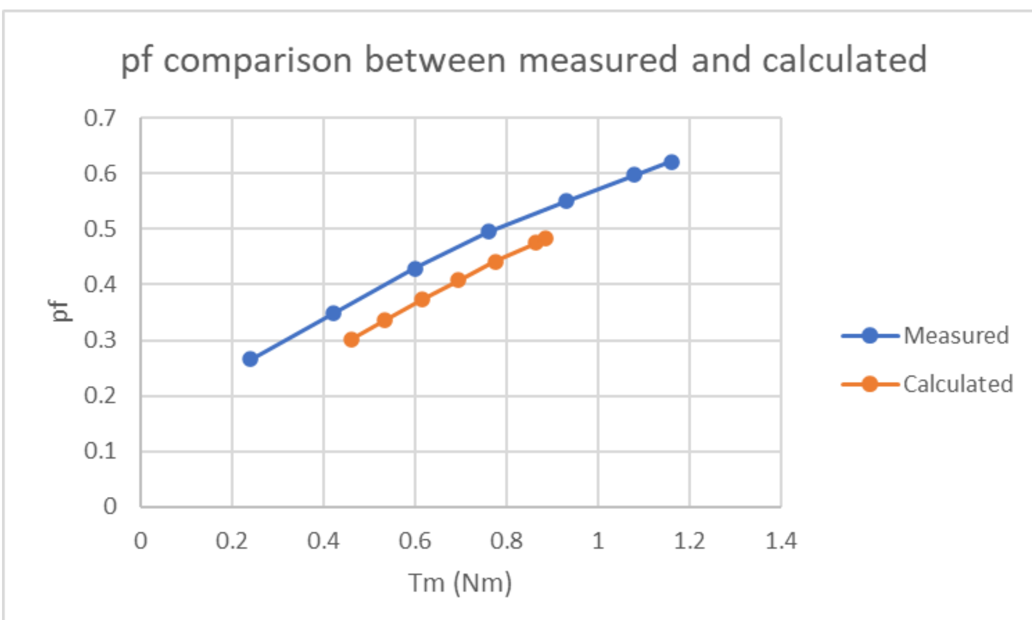
We observe that both our calculated and measured values provide very similar graphs with few lines converging on the downward-sloping straight lines. This proves that using the $T_e = \frac{3V_1^{2} * (s)}{\omega_{syn}(R_2^{'})}$ formula given in the lab manual provides results with negligible error margins.

2)



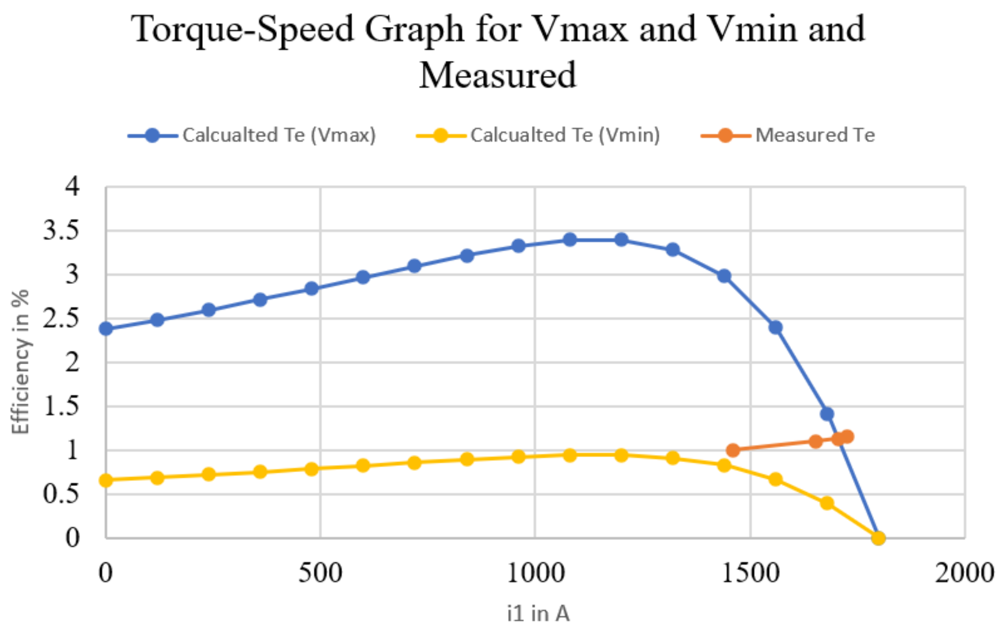
From the above graph, we can see that a smaller value of resistance was calculated for the equivalent circuit in comparison to the values measured in Table 6. This leads to smaller losses due to the resistance, hence the efficiency is lower as well.

3)



When comparing the results of Table 6 and the Equivalent Circuit models, it is evident that they have similar power factor values for corresponding Tm points, with very minimal differences. This implies that the Equivalent Circuit model is effective in accurately calculating the power factor.

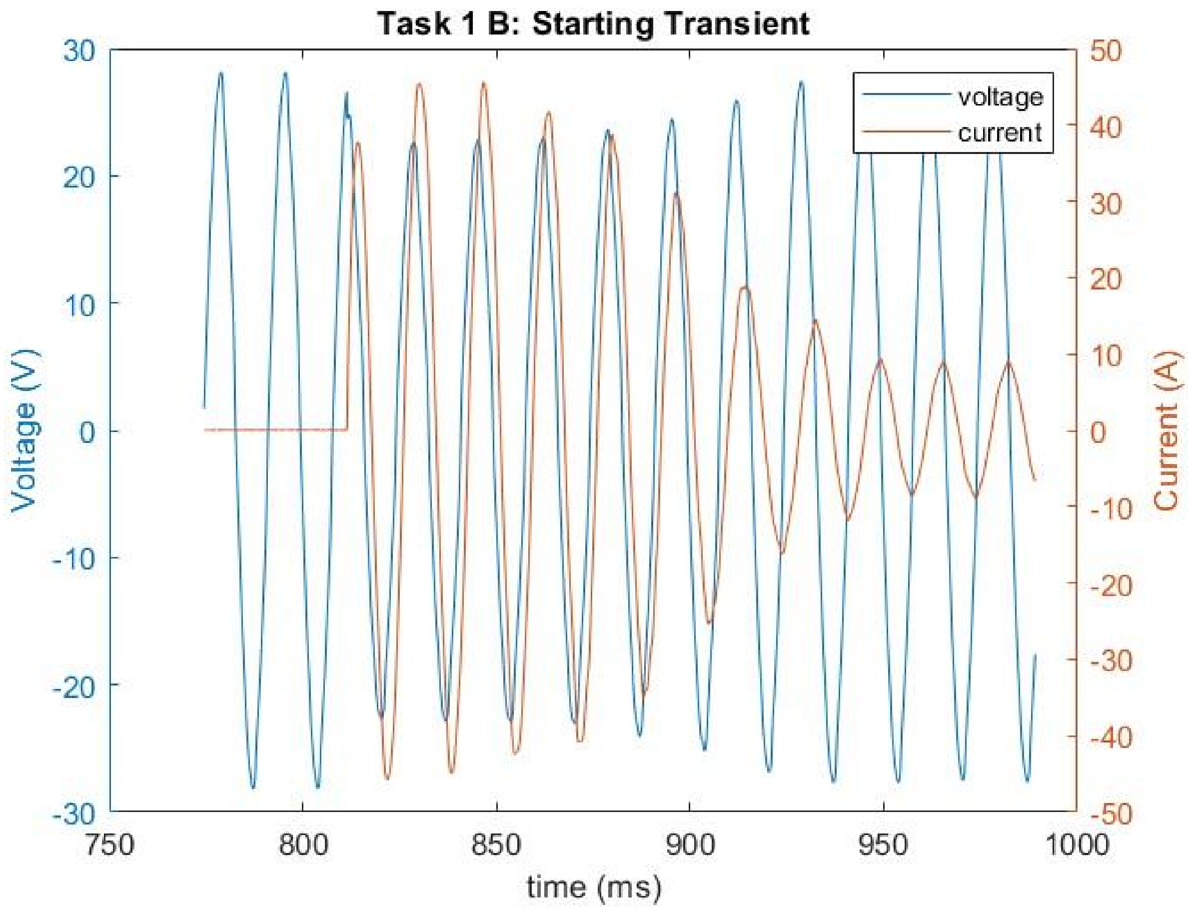
4)



We use table 7 for the measured values and get calculated values of Te using Vmax-19.37 V and Vmin-10.20 V. We can observe that the Speed Regulation is directly proportional to the Input Voltage.

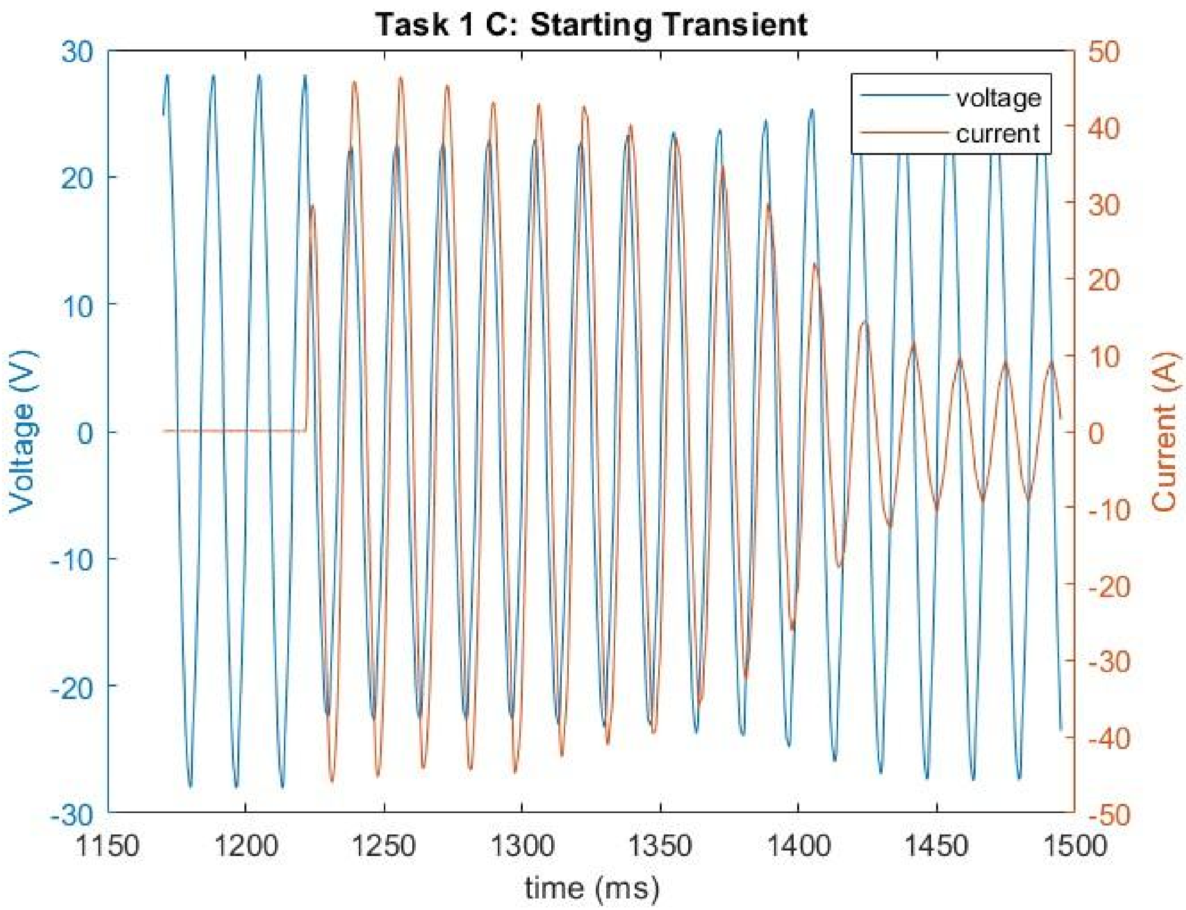
5) We can say that the accuracy for our equivalent circuit is approximately equal to the values we have measured.

Task 5 C: Starting Transients



The transient in task 1B lasted for

$$949.509 - 811.336 = 138.173\, ms$$



Similarly for task 1c, it lasted for

$$1458.17 - 1221.73 = 236.44$$

The initial surge of power when starting an induction machine can create an issue for the rest of the power network because it causes a temporary decrease in voltage. This voltage drop means that other devices connected to the same line as the induction machine will receive less voltage when the machine is turned on. If the voltage drops below the operating level for those devices, they will temporarily stop functioning until the voltage returns to its previous level after the initial surge. In the case of large induction motors used in industrial settings, it's important to stagger their start-up times to prevent all the machines from turning on at the same time. Otherwise, other critical equipment on the site could be affected by the voltage drop in the network output. One possible solution to this problem is to reduce the line impedances in the network, which would result in less voltage being lost over the line when a high current is drawn. However, this may not always be feasible for larger and more complex networks.

c) Observing the voltage and current levels during the initial power surge of an AC device can provide us with a rough idea of the impedance of the AC power supply. In this case, we can see that the voltage peak during the startup transient is around 35.811 V, and the peak current draw is approximately 45.82 A. By dividing the voltage peak by the peak current draw, we can calculate the total resistance to be 0.781 Ω. To determine the AC impedance, we need to subtract the total equivalent impedance of the circuit from the total resistance measured during the startup transient.

Task 5D: Variable Speed Operation

1) In Task 3B we controlled the speed of the induction motor by adjusting the input voltage.

The method of adjusting voltage is an economical way of regulating the speed of an induction motor. It does not require any additional drivers, which is why it is commonly used in small and medium-sized motors. It allows for a steady and uninterrupted alteration of motor speed, without abrupt movements or fluctuations.

The disadvantage is that when the voltage is reduced to control the speed of the motor, the torque output is also reduced. This may not be suitable for applications where high torque is required at low speeds and can result in stalling of the motor. Additionally, varying input voltage can result in increased wear and tear on the motor, thus reducing its reliability over time.

2) In Task 4 we controlled the induction motor's speed using Variable Frequency Drive (VFD).

The advantage of using the method of variable frequency drive (VFD) is that it can enable a gradual start and stop of the motor, resulting in lower mechanical stresses and an increased lifespan of the motor. Also, it allows to vary the frequency (hence voltage) smoothly without any significant change in the current.

However, the cost of the VFD is relatively high compared to other speed control methods, making it less appealing for small and medium-sized motor applications. Additionally, the VFD requires additional drivers, which can make the system demand regular maintenance.

3) Efficiency calculations in Table 9 show that the motor has significantly lower efficiency than the inverter, indicating that most of the energy is lost in the motor. The most efficient frequency was found to be 95 Hz, with some drop in efficiency at 60 Hz and a significant drop at 10 Hz.

Summary

In this lab, we gained knowledge and skills related to configuring, operating, and testing induction motors. We learned how to interpret motor nameplates, perform tests to evaluate motor performance, and adjust the motor speed using various methods. Additionally, we learned about different equations and constants related to induction motors and the effects of transient current and voltage. Overall, this lab provided us with valuable insights into the behavior of induction motors, which will be useful when selecting motors for future projects and research.