SYNCHRONOUS MOTOR LAB

EEE3091F: Lab Report

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Lab Session #: 3A

Faculty of Engineering and the Built Environment

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AIM

To determine the operating characteristics of a synchronous machine connected to Infinite Bus bars, to measure the parameters of the equivalent circuit and to use this circuit to verify the motor performance.

DATA

Watt meter multiplication factor = X20
VAR meter multiplication factor = X30

Table 1: Effect of Field current

I_{ac} [A]	V_{ac} [V]	Power[W]	Power factor	I_f [A]	Idrive [A]	Rotor angle	VARs	VAR flow direction	Lead/Lag
5.0	228	120	0.099	8.5	0.7	88.0°	1200	+ve	Lag
2.5	229	80	0.139	6.8	0.7	87.5°	570	+ve	Lag
0.0	229	40*	0.555	5.4	0.7	89.0°	60*	Neutral	Neutral
2.5	229	100	0.173	3.6	0.7	88.0°	570	-ve	Lead
5.0	229	140	0.119	1.9	0.7	89.0°	1170	-ve	Lead

*Should be zero but there is an offset

Table 2: Effect of Mechanical Power Flow

I_{ac} [A]	V_{ac} [V]	Power[W]	Power factor	I_f [A]	Idrive [A]	Rotor angle	VARs	VAR flow direction	Lead/Lag
2.0	229	400	0.976	5.3	0.70	102°	90	-ve	Lead
1.0	229	160	0.936	5.3	0.65	96°	60	-ve	Lead
0.0	229	20	1.000	5.25	0.60	90°	0	Neutral	Neutral
1.0	229	140	0.978	5.2	0.60	86°	30	+ve	Lag
2.0	227	400	0.997	5.2	0.35	78°	30*	+ve	Lag

*There seems to be an issue as the value should have been around 90 VARs

Table 3: Exercise

I_{ac} [A]	V_{ac} [V]	Power[W]	Power factor	I_f [A]	Idrive [A]	Rotor angle	VARs	VAR flow direction	Lead/Lag
2.15	229	300	0.8	6.4	0.65	98°	225	+ve	Lag

<u>Calculations for Exercise:</u>
Pf = cos(arctan (VAR/W))

0.8 = cos(arctan (VAR/W))
tan(arccos (0.8)) = VAR/W
0.75 = VAR/W

If W = **300**:
VAR = 0.75*300 = **225**

Table 4: Effect of Field Current

I_f [A]	V_{ac} [V]	Speed [rpm]
5.22	230	3040
4	188	3040
3	139	3040
2	99	3040
0	0	3040

Table 5: Short circuit test

I_f [A]	I_{ac} [A]	Speed [rpm]
4.9	7.25	2950
4	6.20	2980
3	4.55	2995
2	2.95	3000
0	0	3000

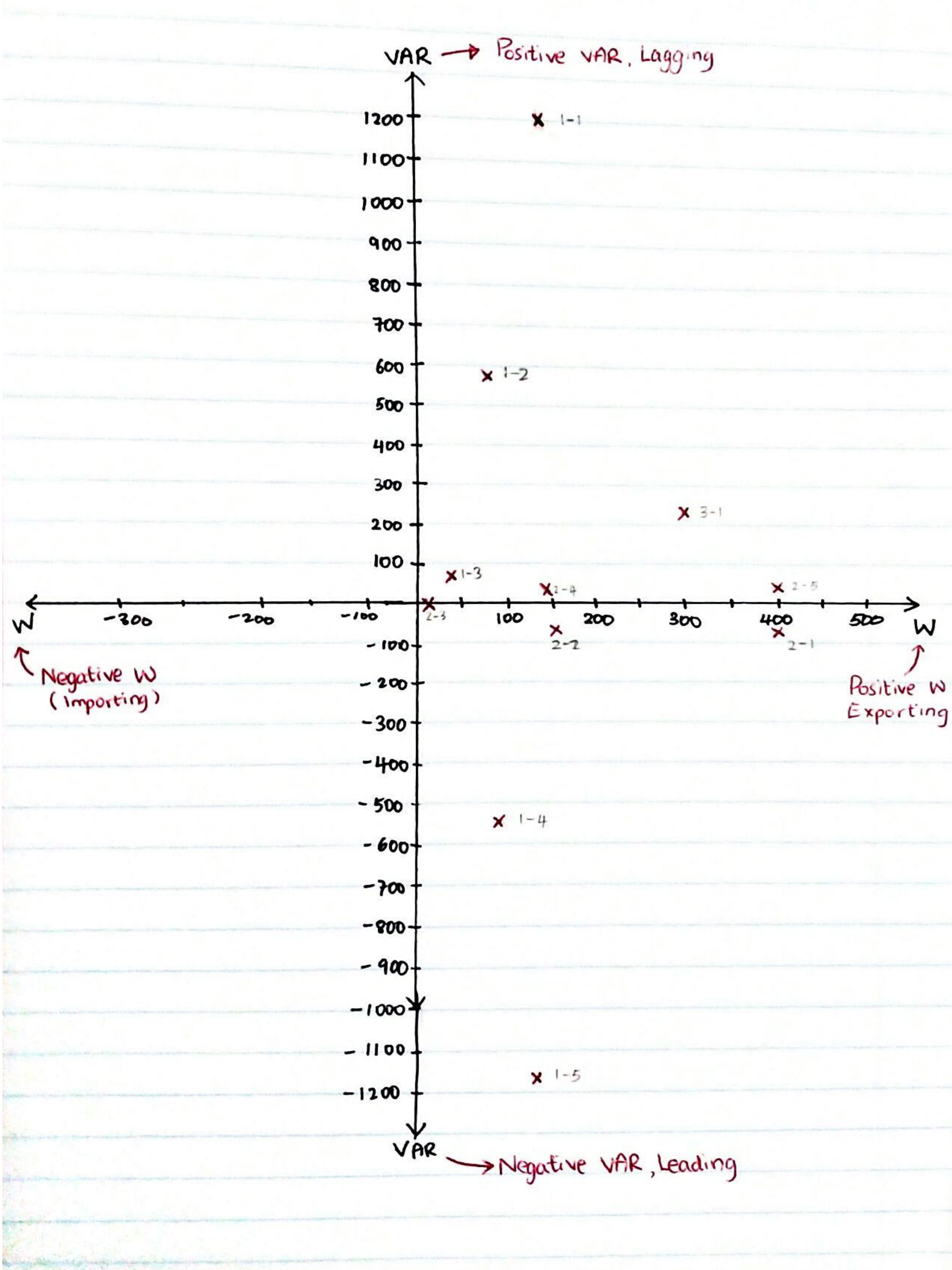
Stator Resistance:

A = 0.828 Ω
B = 0.937 Ω
C = 0.870 Ω
Average = 0.878 Ω

Hence, Stator resistance, **R = 0.878 Ω**

RESULTS

Question 1:



Question 2:

Given that the supply has a frequency of 50Hz and the machine is 2-pole, the theoretical synchronous speed is:

Ns = (120*f) /p = (120*50) / 2 = 3000rpm

From tables 4 and 5, we see that the maximum speed is 3040rpm.

Then maximum error = $\frac{3040-3000}{3000}$ * 100% = 1.33%

This agrees well within the accuracy of the tachogenerator which is ±1.5%

Question 3:

By adjusting I_f, it is possible to get more than one identical value for I_{ac}. This is possible because the machine can supply reactive power (act as an inductor) or absorb reactive power (act as a capacitor). As a result, we get similar I_{ac} values for different I_f values since the direction of VARs get changed. This can be seen in tables 1 and 2.

Question 4:

This machine is known as a synchronous condenser and is operated in a borderline condition between a motor and a generator with no mechanical load to fulfill this condition. It can compensate either a lagging or a leading power factor by absorbing or supplying reactive power to the line. This enhances power-line voltage regulation.

Question 5:

When the machine was supplying VARs to the system, the rotor angle was lagging.

Question 6:

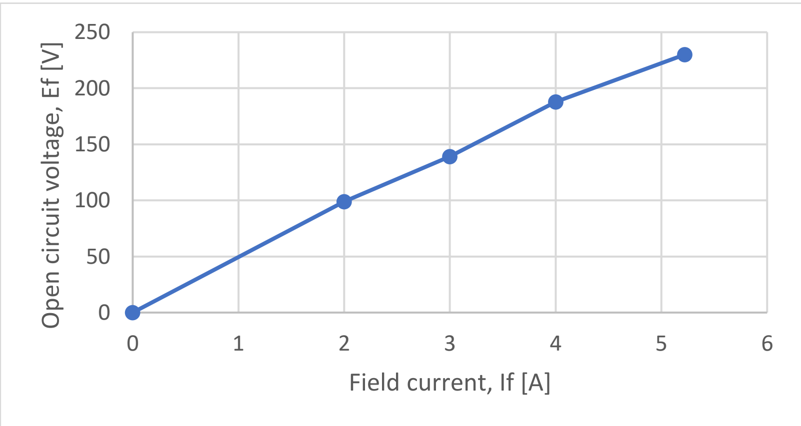


Figure 1: Open circuit voltage vs. Field current

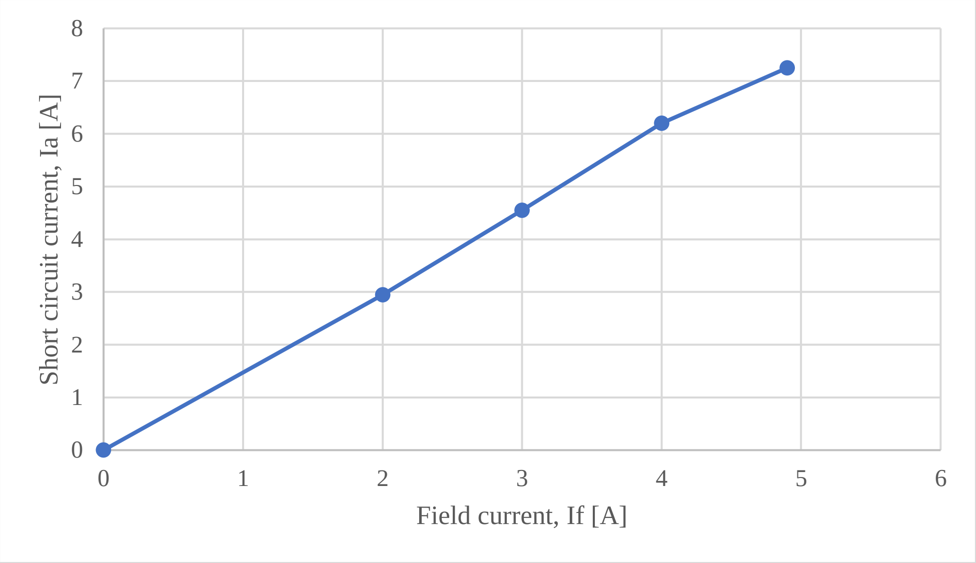


Figure 2: Short circuit current vs. Field current

Using $E_f = I_a * \sqrt{Xs^2 + R^2}$, where R = 0.878Ω

E_f [V]	I_a [A]	$(Xs)^2$ [Ω^2]	Xs [Ω]	I_f [A]
230	7.25	1005.65	31.71199	5
188	6.2	918.688	30.30987	4
139	4.55	932.498	30.53683	3
99	2.95	1125.457	33.54783	2
0	0	0	0	0

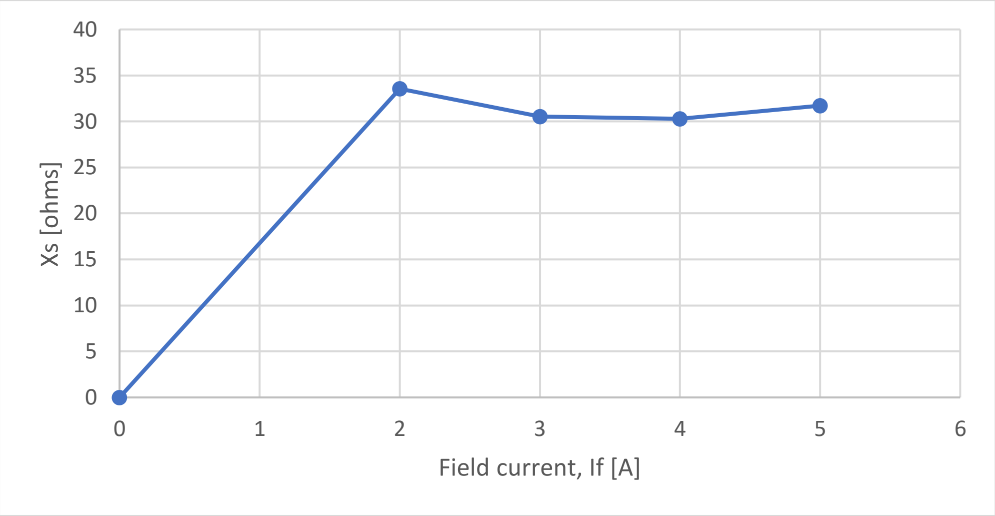


Figure 3: Xs vs. Field current

- Xs departs from a linear curve because the machine is driven into saturation.

Xs (rated) = $\sqrt{(\frac{Ef\ airgap}{Iac})^2 - R^2}$

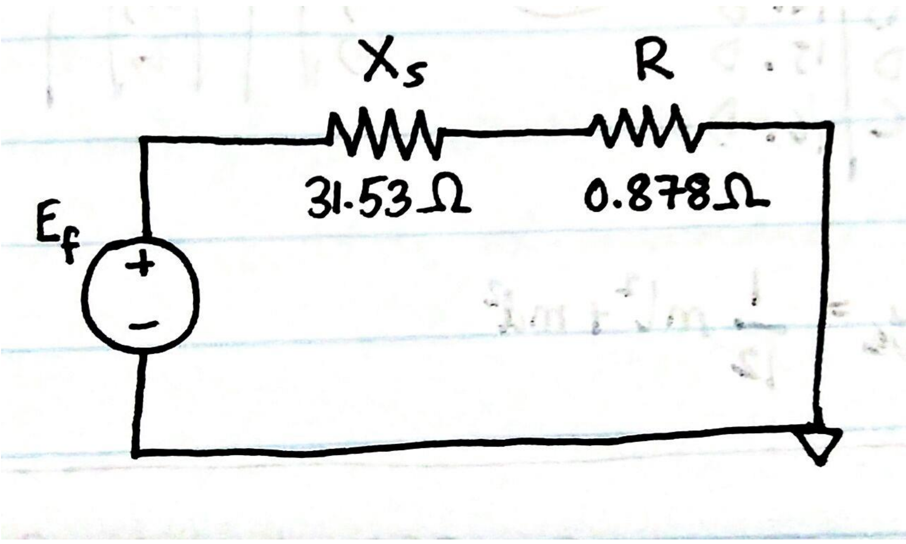
Xs (rated) = $\sqrt{(\frac{270}{7.7})^2 - 0.878^2}$ = 35.05 Ω

- Xs (rated) = 35.05Ω
- Average Xs from graph = 31.53 Ω

Xs as a percentage of the rated basis = $\left(\frac{31.53}{35.05}\right) * 100\%$ = **89.96%**

Stator resistance as a percentage = 0.878*100% = **87.8%**

Equivalent Circuit Diagram:



Question 7:

$$\vec{E}_f = \vec{I}_a R_a + j\vec{I}_a X_s + \vec{V}_t$$

$$|\vec{E}_f| = \sqrt{(I_a R_a)^2 + (I_a X_s)^2 + (V_t)^2}$$

where:

$I_a = 2.15A$, $R_a = 0.878\Omega$, $X_s = 31.53\Omega$, $V_t = 229V$

$$\therefore |\vec{E}_f| = 238.83$$

$$I_a^* = \frac{|E_f|\angle(\theta_s-\delta) - |V_t|\angle\theta_s}{|Z_s|}$$

$$|I_a^* Z_s| = E_f\cos(\theta_s-\delta) + E_f\sin(\theta_s-\delta) - V_t$$

$$(2.15)\left(\sqrt{(31.53)^2+(0.878)^2}\right) = \cancel{E_f}\ 238.83\left[\cos(\theta_s-\delta)+\sin(\theta_s-\delta)\right] - 229$$

$$\cos(\theta_s-\delta) + \sin(\theta_s-\delta) = 1.243$$

let $\alpha = \theta_s - \delta$

$\cancel{\cos(\theta_s-\delta)}$

$$\cos\alpha + \sin\alpha = 1.243$$

$$\sqrt{(1-\sin^2\alpha)} + \sin\alpha = 1.243$$

$$2\sin^2\alpha - 2.486\sin\alpha + 0.545 = 0$$

$\sin\alpha = 0.2842$ or $\cancel{\sin\alpha = 0.9558}$

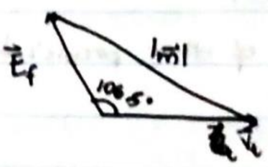
$$\alpha = 16.51°$$

but $\alpha = \theta_s - \delta$

conjugate

$$\delta = \theta_s - \alpha = 90 - (-16.51)$$

Rotor Angle $\rightarrow \delta = 106.51°$



$$|\vec{m}|^2 = (E_f)^2 + (V_t)^2 - 2(E_f)(V_t)\cos 106.51°$$

$$|\vec{m}| = 374.89$$

$$|\vec{m}|\cos\beta = V_t$$

$$V_t = 374.89\cos\beta = 229$$

$$\beta = 52.35°$$

$$\theta = 90 - \beta = 90 - 52.35°$$

$$\theta = 37.65$$

$$\boxed{PF = \cos\theta = 0.79}$$

Thus, the measured power factor and rotor angle agree with the calculated value expressed as a percentage of the measured value in the following way:

Active Power = s*cosθ = 380*cos(37.65) = **300.9W**
Reactive Power = s*sinθ = 380*sin(37.65) = **232.1 VAR**

- % error in Rotor angle = $\frac{106.5-98}{98}$ * 100% = 8.67%
- % error in PF = $\frac{0.8-0.79}{0.8}$ * 100% = 1.25%
- % error in Reactive Power = $\frac{232.1-225}{225}$ * 100% = 3.16%
- % error in Active Power = $\frac{300.9-300}{300}$ * 100% = 0.3%

Hence:

Power factor = **0.79 ± 1.25%**

Reactive Power = **(232.10 ± 3.16%) VARs**

Real Power = **(300.9 ± 0.3%) Watts**