Jordan University
Electrical Engineering Department
2^{nd} *Exam, Second* Term
Electric Machines, 0903471

dent Name:..............................Student Number:..............................Section:..............Date:
13^{th}, 2011 ______ time allowed: $1\frac{1}{4}$ Hour

blem1 A three-phase 400 V, 50 Hz, 4-pole, Y-connected, induction motor. It has the following constants:
$= 0.6\,\Omega, X_1' = 0.6\ R_2' = 0.3\Omega, X_2' = j\,1\,\Omega;\ X_m = j\,30\Omega$. The speed-torque curve shown in Figure (1). A
tance R_{add} is added to rotor resistance R_2' to increased starting torque as shown in doted and dash-doted
. Find the two values $R_{add,1}$ and $R_{add,2}$

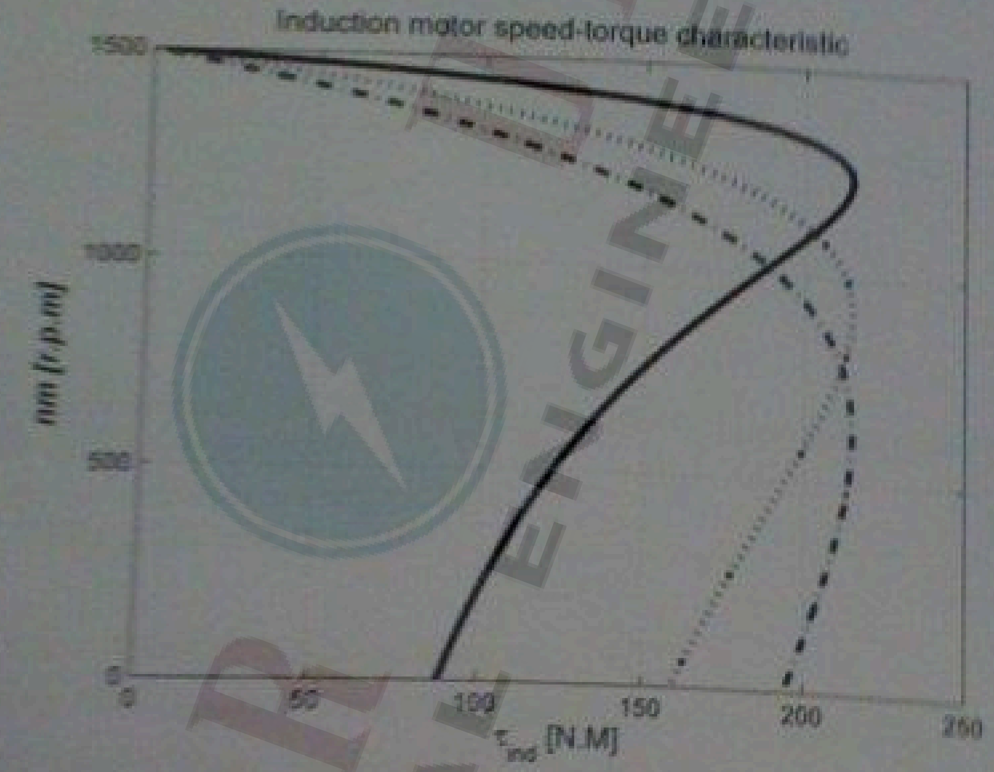


Figure 1

$$n'_{r,max} = 1230 \Longrightarrow s'_{max} = \frac{1500 - 1230}{1500} = 0.18$$

$$n''_{r,max} = 900 \Longrightarrow s''_{max} = \frac{1500 - 900}{1500} = 0.4$$

$$n'''_{r,max} = 630 \Longrightarrow s'''_{max} = \frac{1500 - 630}{1500} = 0.58$$

$$\frac{s''}{s'} = \frac{R_2' + R_{a1}}{R_2'}$$

$$R_{a1} = (\frac{s''}{s'} - 1)R_2'$$

$$R_{a1} = (2.22 - 1)R_2' = 0.366\Omega$$

$$R_{a2} = (3.22 - 1)R_2' = 0.667\Omega$$

Problem2 A 400-V 55-hp four-pole Δ-connected 50-Hz three-phase induction motor has a full-load slip of 6 percent, an efficiency of 90 percent, and a power factor of 0.85 lagging. This motor is to be started with an autotransformer to reduced voltage starter as shown in Fig.3. The rotor losses is 2270 W. Find:

(a) The rotating power losses at rated full load slip and value of R_2'?

(b) If V_T' is the reduced voltage and $x = \frac{V_T'}{V_T}$ find x to obtain the lower curve of τ versus n_m

(c) Find the ratio of $\frac{I_{st}}{I_{rat}}$ after reduction the voltage

Note: approximate the torque value up to ±10N.M and the value of current up to ±5A

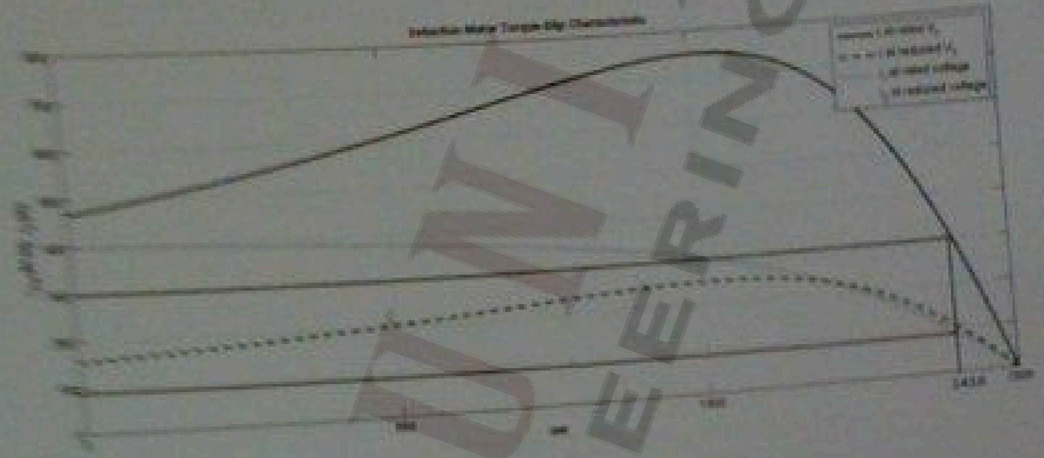


Figure 2

From the curve: The τ_{load} value opposite of 1410 r.p.m is 300 N.M, from which may find

$P_{conv} = \tau_{load} \times \omega_{sync} = \frac{300 \times 2\pi \times 1500}{60} = 47124$ W.

The converted power from electrical to mechanical is

$P_{ag} = P_{conv} + P_{RCL} = 47124 + 2270 = 49394$ W.

The rotational losses

$P_{rot} = P_{conv} - P_{out} = 47124 - 55Hp \times 746 \frac{W}{HP} = 6094$ W.

From the current curve may find $I_{L,rated} = 75$ A. This leads to find the $R_2' = \frac{P_{RCL}}{3I_2^2} = \frac{2270}{3\times75^2} = 0.13452\Omega$.

From the original curve at rated voltage may find $\tau_{started} = 468$ N.M. and $\tau'_{started} = 156$ N.M. then $\frac{156}{468} = 0.333$.

the voltage ratio is $\frac{V_T'}{V_T} = \sqrt{\frac{\tau'_{st}}{\tau_{st}}} = 0.577$

or

$\frac{\tau'_{st}}{\tau_{st}} = (\frac{V_T'}{V_T})^2$

$\frac{V_T'}{V_T} = x \Longrightarrow V_T' = 400 \times 0.577 = 231V$

$I_{st}' = \frac{V_T'}{V_T} \times I_{st} = 0.577 \times 400 = 230$ A.

$I_{rat} = \frac{P_{out}/\eta}{\sqrt{3}V_T PF} = $ [illegible] $= 77.4$ A. $\frac{I_{st}}{I_{rat}} = \frac{400}{77.4} = 5.16$ reduced to $\frac{I'_{st}}{I_{rat}} = \frac{231}{77.4} = 2.98$

SOLUTION This problem is best solved with MATLAB, since it involves calculating the torque-speed values at many points. A MATLAB program to calculate and display both torque-speed characteristics is shown below. Note that this program shows the torque-speed curve for both positive and negative directions of rotation. Also, note that we had to avoid calculating the slip at exactly 0 or 2, since those numbers would produce divide-by-zero errors in Z_F and Z_B respectively.

```
% M-file: torque_speed_curve3.m
% M-file create a plot of the torque-speed curve of the
%   single-phase induction motor of Problem 10-4.

% First, initialize the values needed in this program.
r1 = 1.80;                          % Stator resistance
x1 = 2.40;                          % Stator reactance
r2 = 2.50;                          % Rotor resistance
x2 = 2.40;                          % Rotor reactance
xm = 60;                            % Magnetization branch reactance
v = 120;                            % Single-Phase voltage
n_sync = 1800;                      % Synchronous speed (r/min)
w_sync = 188.5;                     % Synchronous speed (rad/s)

% Specify slip ranges to plot
s = 0:0.01:2.0;

% Offset slips at 0 and 2 slightly to avoid divide by zero errors
s(1)   = 0.0001;
s(201) = 1.9999;

% Get the corresponding speeds in rpm
nm = ( 1 - s) * n_sync;

% Caclulate Zf and Zb as a function of slip
zf = (r2 ./ s + j*x2) .* (j*xm) ./ (r2 ./ s + j*x2 + j*xm);
zb = (r2 ./(2-s) + j*x2) .* (j*xm) ./ (r2 ./(2-s) + j*x2 + j*xm);

% Calculate the current flowing at each slip
i1 = v ./ ( r1 + j*x1 + zf + zb);

% Calculate the air-gap power
p_ag_f = abs(i1).^2 .* 0.5 .* real(zf);
p_ag_b = abs(i1).^2 .* 0.5 .* real(zb);
p_ag = p_ag_f - p_ag_b;

% Calculate torque in N-m.
t_ind = p_ag ./ w_sync;

% Plot the torque-speed curve
figure(1)
plot(nm,t_ind,'Color','b','LineWidth',2.0);
xlabel('\itn_{m} \rm(r/min)');
ylabel('\tau_{ind} \rm(N-m)');
title ('Single Phase Induction motor torque-speed
characteristic','FontSize',12);
grid on;
hold off;
```

Problem3 A three-phase 400 V, 50 Hz, 4-pole, Y-connected, induction motor. The torque speed curve is given in Figure (3). Neglect rotational, core, friction and windage losses **except** the load losses (stator and rotor). It has the following constants: $R_1 = 0.25\,\Omega$, $R_2' = 0.4\,\Omega$, $X_2' = j\,1\,\Omega$; $X_m = j\,50\,\Omega$. If the motor operates at $\tau_d = 221.2\ N.M$ find X_1

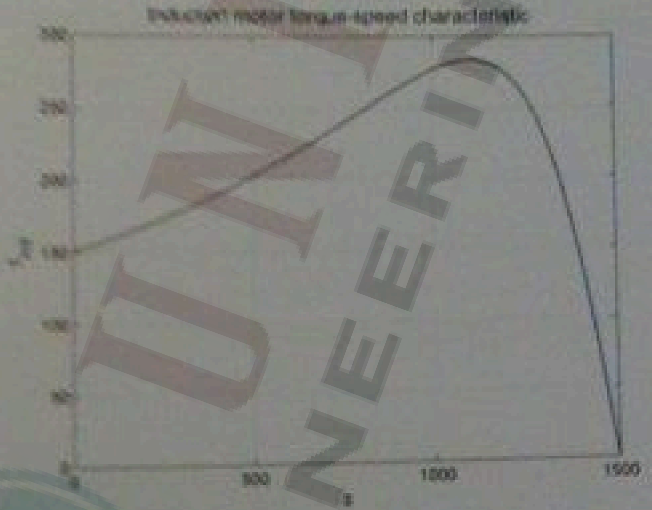


Figure 3

$R_2' = 0.4;\ X_2' = j1; X_m = j50,\ R_1 = 0.25;\ s = 0.12\ V_\phi = 400/\sqrt(3)$

$Z_F = \frac{jX_m \times (R_2'/s + X_2')}{(jX_m + R_2'/s + X_2')} = 3.19 + j1.19$

From curve $\tau_{ind} = 221.2\ N.m$ and The $P_{ag} = \tau \times \omega_{sys} = 34728\ W$ then

$I_A = \sqrt{\frac{P_{ag}}{3 \times R_F}} = 60.24\ A$

$Z_{eq} = \frac{V_\phi}{I_A} = \frac{400/\sqrt{3}}{60.24} = 3.834$

$Z_{eq} = Z_1 + Z_F = \sqrt{(R_1 + R_F)^2 + (X_1 + X_F)^2}$

$(X_1 + X_F) = \sqrt{Z_{eq}^2 - (R_1 + R_F)^2} = \sqrt{3.834^2 - (0.25 + 1.19)^2} = 3.553$

$X_1 = 3.553 - 1.19 = 2.36$

$I_2 = I_A \times \frac{jX_m}{j(X_m + X_2) + R_2} = 40.94\ A$

$Z_{F,st} = \frac{jX_m \times (R_2'/1 + X_2')}{(X_m + R_2'/1 + X_2')} = 0.2316 + j1.3491 =$

$P_{scl} = 3I_A^2 R_1 = 602\ W$

$P_{in} = P_{ag} + P_{scl} = 25870\ W$

$P_{rcl} = 3I_2^2 R_2' = 1259\ W$

$P_{out} = P_{ag} - P_{rcl} = 23919\ W$

$\eta = \frac{P_{out}}{P_{in}} = 0.925$

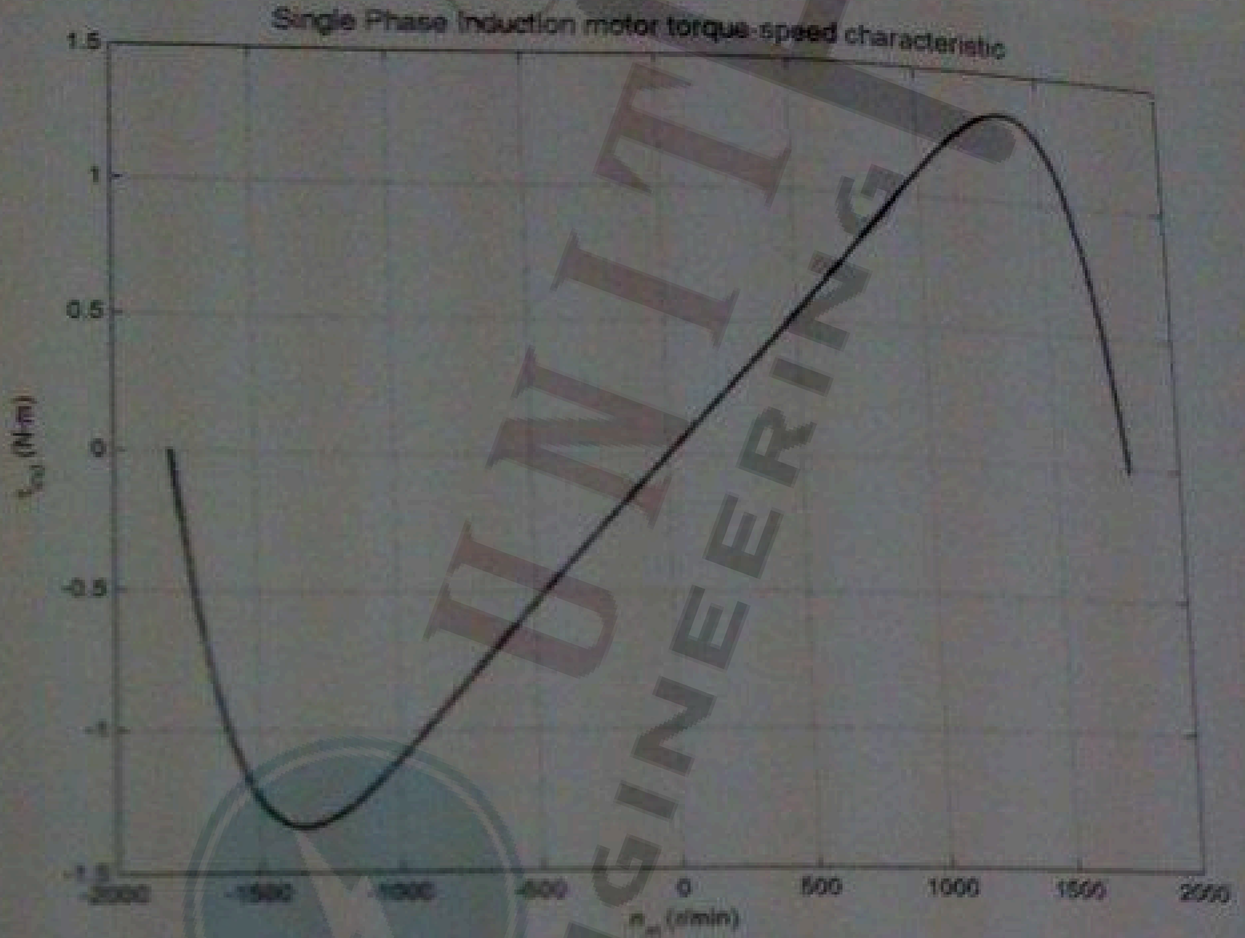
$\tau = 160\ N.m$

$I_{st}/I_{fl} = \sqrt{\frac{\tau_{st}}{[illegible]}} = \sqrt{\frac{54}{160 \times [illegible]}} = 2.6$

$\tau_{st} = 53\ N.m; P_{st} = \tau_{st} \times \omega_{sys} = 8340\ W$

$I_{A,st} = \sqrt{\frac{P_{st}}{3 \times R_F}} = 110\ A$

The resulting torque-speed characteristic is shown below:



0-5. A 220-V, 1.5-hp 50-Hz, two-pole, capacitor-start induction motor has the following main-w impedances:

$R_1 = 1.40\ \Omega$ $\quad X_1 = 2.01\ \Omega$ $\quad X_M = 105\ \Omega$

$R_2 = 1.50\ \Omega$ $\quad X_2 = 2.01\ \Omega$

At a slip of 0.05, the motor's rotational losses are 291 W. The rotational losses may be assumed over the normal operating range of the motor. Find the following quantities for this motor at 5 per

(a) Stator current
(b) Stator power factor
(c) Input power
(d) P_{AG}
(e) P_{conv}
(f) P_{out}
(g) τ_{ind}
(h) τ_{load}
(i) Efficiency

SOLUTION The equivalent circuit of the motor is shown below

The Fig. shows the V-curve of a 3ϕ, 400-HP, 480 V, 50 Hz, 2-pole Y-connected synchronous motor has a reactance of 1.1 Ω. Neglect friction, windage, and core losses for this problem.

(a) Find the torque angle δ and the power factor if the motor operates at points P and K.

(b) Explain your answer by drawing exact phasor diagram.

~~Pout = 400 × 746 = 298400~~

$V_\phi = \frac{480}{\sqrt{3}} = 277.13$

$X_s = 1.1$

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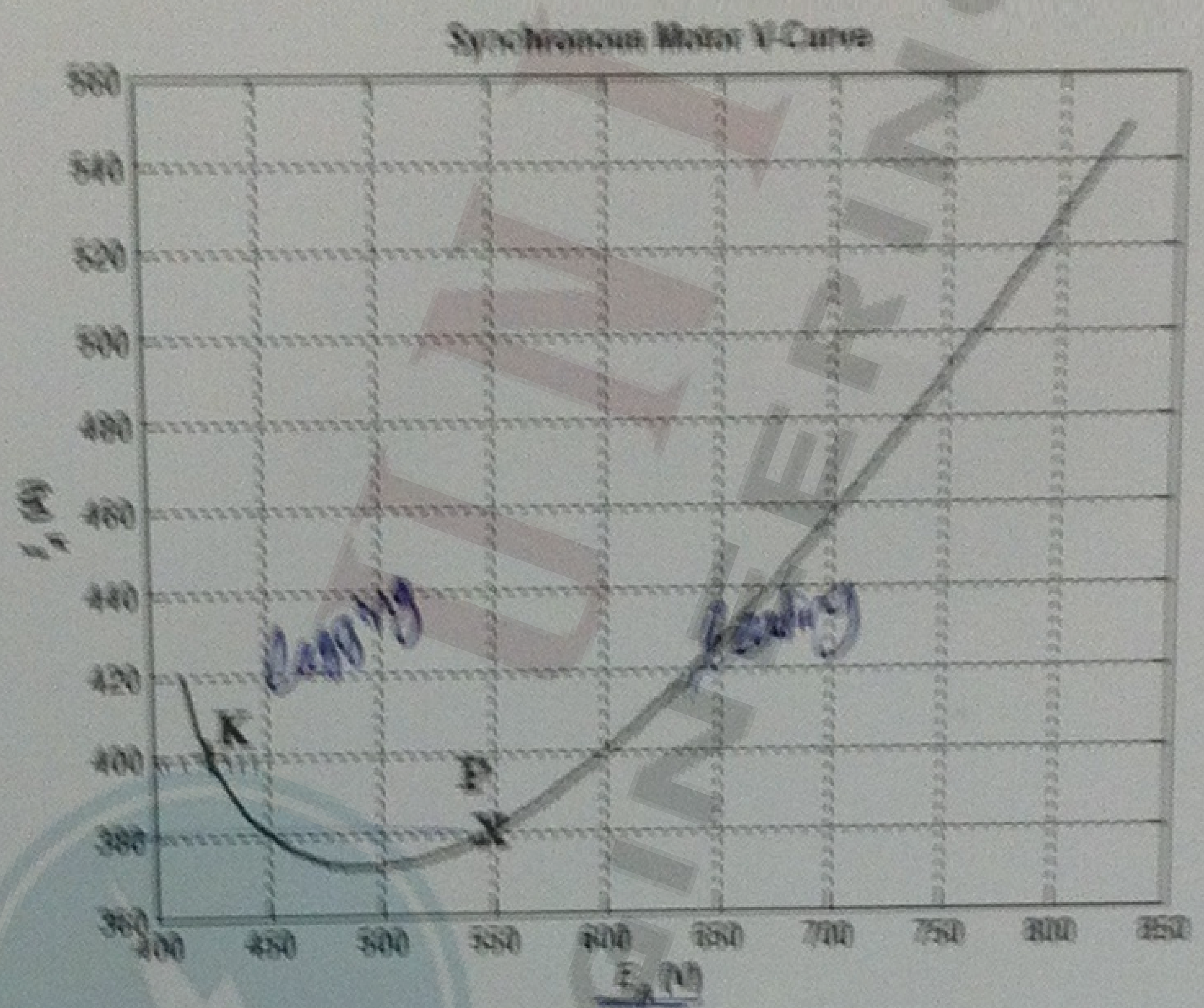
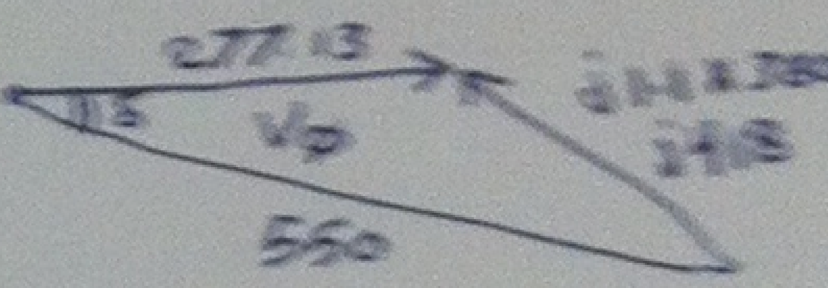
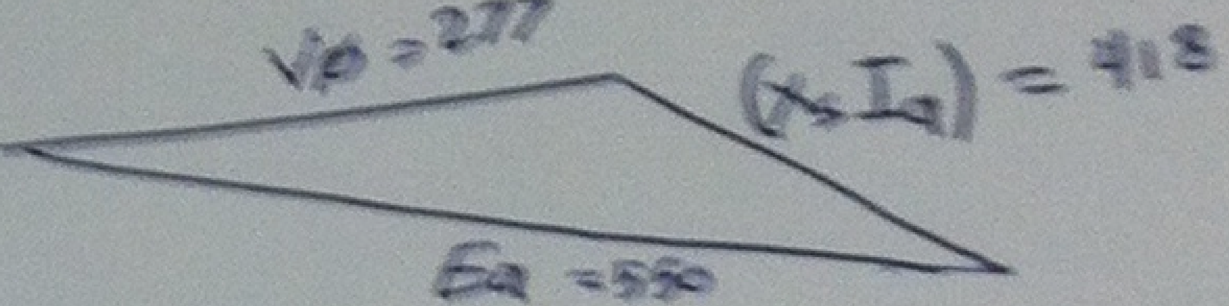


a)

@ point P $E_a = 550$, $I_a = 380$, $V_\phi = 277.13$



$c^2 = a^2 + b^2 - 2ab\cos\delta$ — cosine law



$\Rightarrow (X_s I_a)^2 = (V_\phi)^2 + (E_a)^2 - 2 E_a V_\phi \cos\delta$

$(418)^2 = (277)^2 + (550)^2 - 2\times550\times(277.13)\cos\delta$

$\Rightarrow \cos\delta = \frac{-204505}{-2\times550\times277.13} = 0.671 \Rightarrow \delta_P = 47.848$ leading

@ point K $E_a = 425$, $I_a = 400$, $V_\phi = 277.13 \Rightarrow X_s I_a = 440$

$(X_s I_a)^2 = (V_\phi)^2 + E_a^2 - 2E_a V_\phi \cos\delta$

$\Rightarrow \cos\delta = \frac{440^2 - 425^2 - 277.13}{-2\times425\times277.13} = 0.27$

$\delta = \cos^{-1} 0.27 = 79.33°$ lagging

Changes

if you want to assume $V_\phi = 480 \Rightarrow \delta_K = 57.79$ pf = 0.5329

" " " " " $E_{a\,\text{line to N}} = \frac{425}{\sqrt{3}} \Rightarrow \delta_K = 65.68$ pf = 0.41

if " " " " " $= \frac{550}{\sqrt{3}} \Rightarrow \delta_P = 89$ pf = 0.96

" " " " " $V_\phi = 480 \Rightarrow$