Transformer Lab

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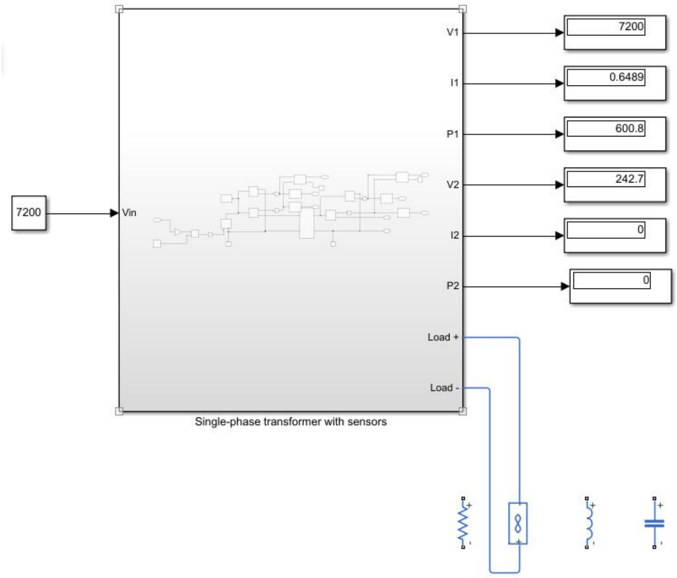
Var：4

1.2 Complete m-file with rated parameters of the transformer using nameplate information:

```
% Transformer nameplate information: 37.5 kVA, 7200/240 V, 60 Hz
% Add following parameters to m-file: rated primary voltage, rated secondary vo
% rated primary current, rated secondary current.
rpv=7200;
rsv=240;
rpc=37500/7200;
rsc=37500/240;
```

2.1 Perform open-circuit test (use rated primary voltage):

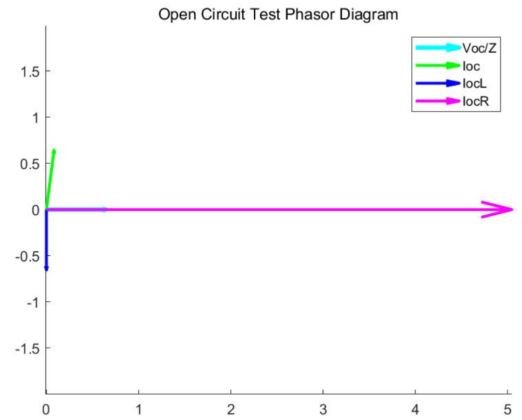


2.2 Complete m-file with data of the open-circuit test and write a script for calculation of the magnetization branch parameters (R_c , X_m):

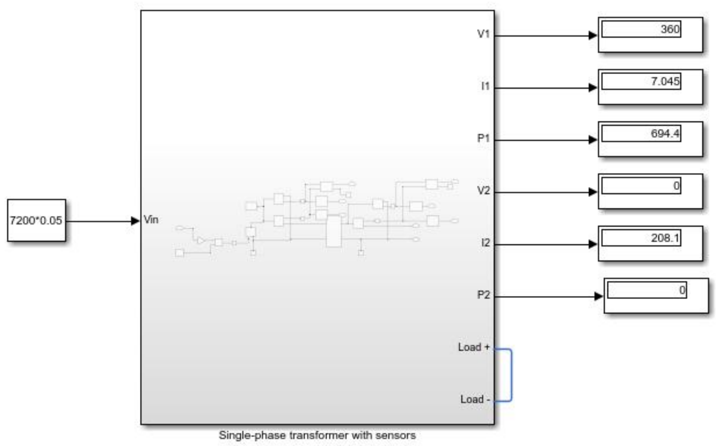
```
%% Open-circuit test
% Simulate the open-circuit test and then add following parameters to m-file: Voc, Ioc, Poc
V1oc = 7200;
V2oc = 242.7;
Ioc = 0.6489;
Poc = 600.8;

% Write script for determination of the magnetization branch parameters (Rc, Xm)
a = V1oc/V2oc; %a=30
Zoc = V1oc/Ioc; %11096
PF = Poc/(V1oc*Ioc); %0.1286
Rc = Zoc * PF; %1426.8
Xm = Zoc * sqrt(1-PF^2); %11004
theta_oc = acos(Poc/(V1oc*Ioc)); %1.4418
```

2.3 Draw phasor diagram for open-circuit test

```
%draw
vVocdZ = V1oc / sqrt(Xm^2+Rc^2) * exp(1i * 0);
vIoc = Ioc * exp(1i * theta_oc);
vIocL = V1oc / Xm * exp(1i * -pi/2);
vIocR = V1oc / Rc * exp(1i * 0);
figure;
hold on;
quiver(0, 0, real(vVocdZ), imag(vVocdZ), 0, 'cyan', 'LineWidth', 3);
quiver(0, 0, real(vIoc), imag(vIoc), 0, 'green', 'LineWidth', 2);
quiver(0, 0, real(vIocL), imag(vIocL), 0, 'blue', 'LineWidth', 2);
quiver(0, 0, real(vIocR), imag(vIocR), 0, 'magenta', 'LineWidth', 2);
hold off;
axis equal;
title("Open Circuit Test Phasor Diagram");
legend("Voc/Z", "Ioc", "IocL", "IocR");
saveas(gcf, "Open_Circuit_Test_Phasor_Diagram.png");
```



3.1 Make short-circuit test (you must find the primary voltage value when there are rated current in primary winding):

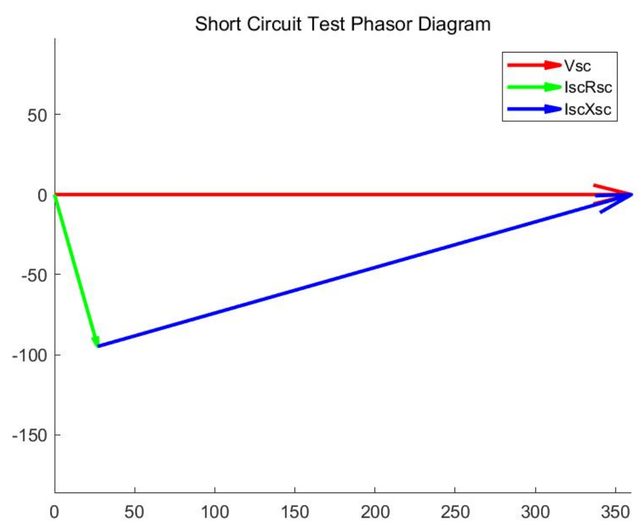


3.2 Complete m-file with data of the short circuit test and write a script for calculation of the leakage resistances (R_1, R_2) and reactances (X_{l1}, X_{l2}) :

```
%% Short - circuit test
% Simulate the short-circuit test and then add following parameters to m-file: Vsc, Isc, Psc
Vsc = 360;
Isc = 7.045;
Psc = 694.4;

% Write script for determination of the leakage resistances (R1, R2) and reactances (Xl1, Xl2)
PF_sc = Psc/(Vsc*Isc);
Z_eq = Vsc/Isc;
R_eq = Psc/Isc^2;
X_eq = sqrt(Z_eq^2-R_eq^2);
a = 7200/240;
R1 = R_eq/2;%6.9955
R2 = R_eq/(2*a^2)%0.0077
Xl1 = X_eq/2;%24.5737
Xl2 = X_eq/(2*a^2)%0.0273
```

3.3 Draw phasor diagram for short-circuit test.

```
%draw
theta_sc = acos(PF_sc);

vVsc = Vsc * exp(1i*0);
vVscR = Isc * R_eq *exp(-1i * theta_sc);
vVscX = Isc * X_eq * exp(1i * (pi/2-theta_sc));
figure;
hold on;
quiver(0, 0, real(vVsc), imag(vVsc), 0, 'r', 'LineWidth', 2);
quiver(0, 0, real(vVscR), imag(vVscR), 0, 'green', 'LineWidth', 2);
quiver(real(vVscR), imag(vVscR),real(vVscX),imag(vVscX),0, 'blue', 'LineWidth', 2);
axis equal;
title("Short Circuit Test Phasor Diagram");
legend("Vsc", "IscRsc", "IscXsc");
saveas(gcf,"Short_Circuit_Test_Phasor_Diagram.png");
```



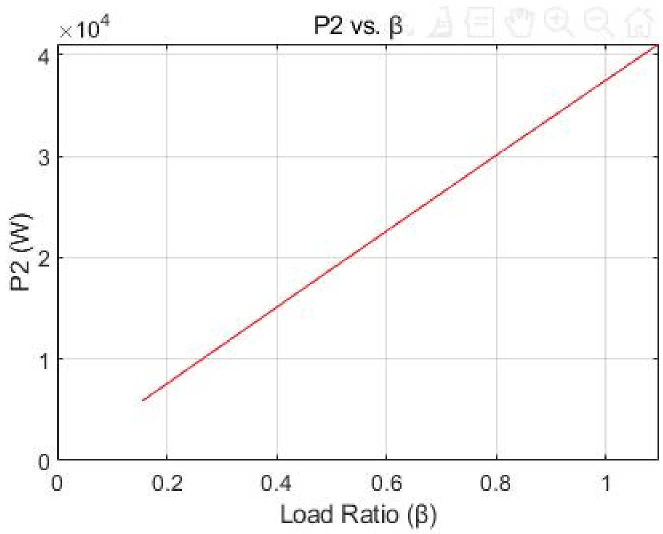
1.2 Complete m-file with data of R-load test

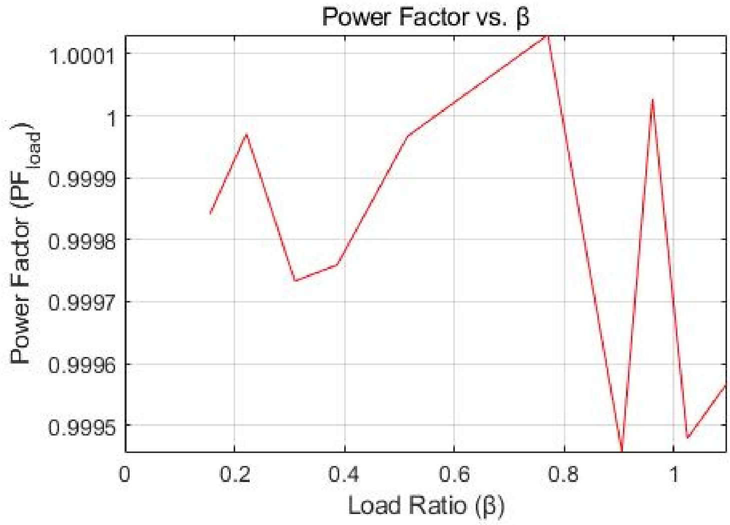
```
%% Load tests
% R-Load tests
% Values for R-Load:
R1 = [1.4 1.5 1.6 1.7 2 3 4 5 7 10]; % ohm
% Simulate the model with each value of the R-load and then add the
% following parameters to m-file for each test:
U1_R = [7200 7200 7200 7200 7200 7200 7200 7200 7200 7200];
U2_R = [239.8 240 240.1 240.3 240.7 241.4 241.7 241.9 242.1 242.3];
I1_R = [5.915 5.536 5.204 4.91 4.206 2.879 2.223 1.837 1.409 1.109];
I2_R = [171.3 160 150.1 141.4 120.3 80.45 60.42 48.38 34.59 24.23];
P1_R = [42130 39390 37000 3488029790 20120 15260 12340 8994 6480];
P2_R = [41060 38380 36040 33960 28960 19420 14600 11700 8374 5870];
```

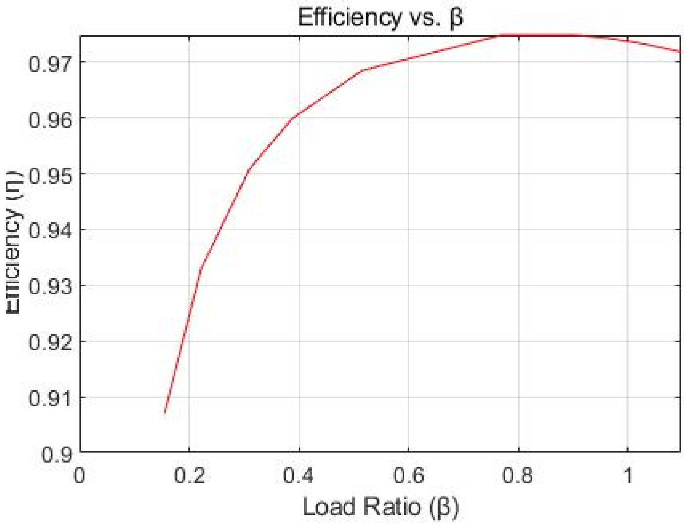
1.3 Calculate load ratio, load power factor, transformer efficiency and voltage regulation:

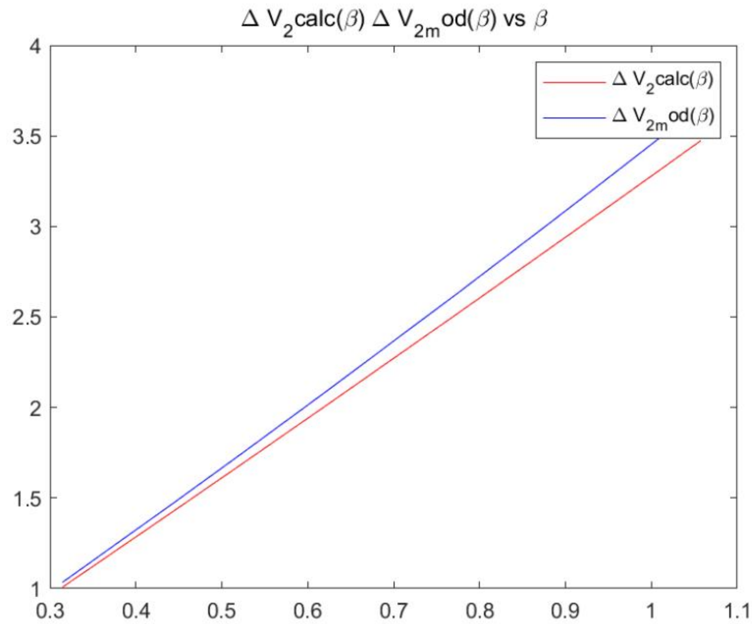
```
% Write script for determination of the load ratio, transformer efficiency, power
beta = zeros( size(R1));
power_factor = zeros(size(R1));
efficiency = zeros(size(R1));
voltage_regulation_mod = zeros(size(R1));
voltage_regulation_calc = zeros(size(R1));
theta_r = zeros(size(R1));
for k = 1:length(R1)
    beta(k) = I2_R(k)/rsc ;
    power_factor(k) = P2_R(k)/(U2_R(k)*I2_R(k));
    efficiency(k) = P2_R(k) /(P2_R(k) + beta(k)^2 *R_eq *I1_R(k)^2 + Poc);
    theta_r(k) = acos(power_factor(k)); % Calculate phase angle
    voltage_regulation_mod(k) = ((V2oc - U2_R(k))* 100 )/ U2_R(k); % Calculate measured voltage regulation rate
    voltage_regulation_calc(k)= (beta(k) *(Vsc/a) * (cos(theta_sc) * cos(theta_r(k)) + sin(theta_sc) * sin(theta_r(k)))) *100 /U2_R(k);
end
```

1.4 Draw following diagrams: P2(β), PFload(β), η(β), ΔV%2_calc(β), ΔV%2_mod(β)

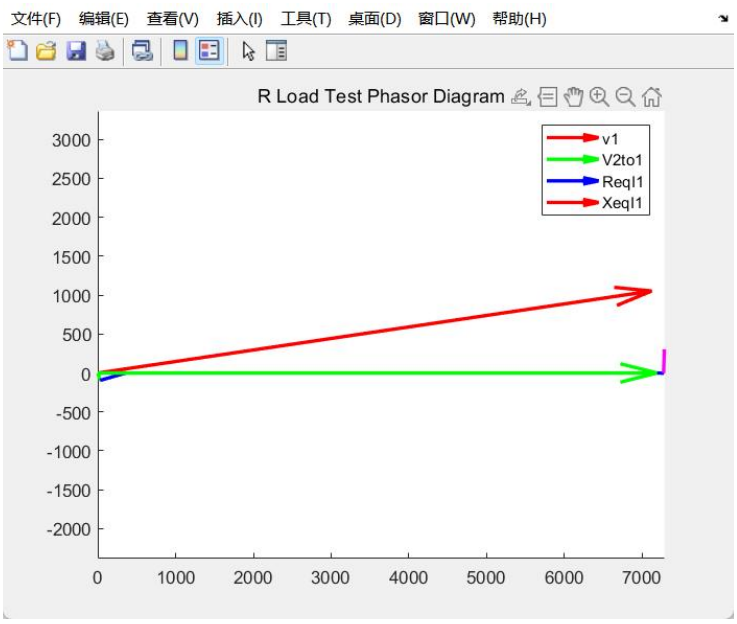



Power Factor vs. β
Power Factor (PF_{load})
1.0001
1
0.9999
0.9998
0.9997
0.9996
0.9995
0
0.2
0.4
0.6
0.8
1
Load Ratio (β)


Efficiency vs. β
Efficiency (η)
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0
0.2
0.4
0.6
0.8
1
Load Ratio (β)



1.5 Draw phasor diagram for one of the tests.



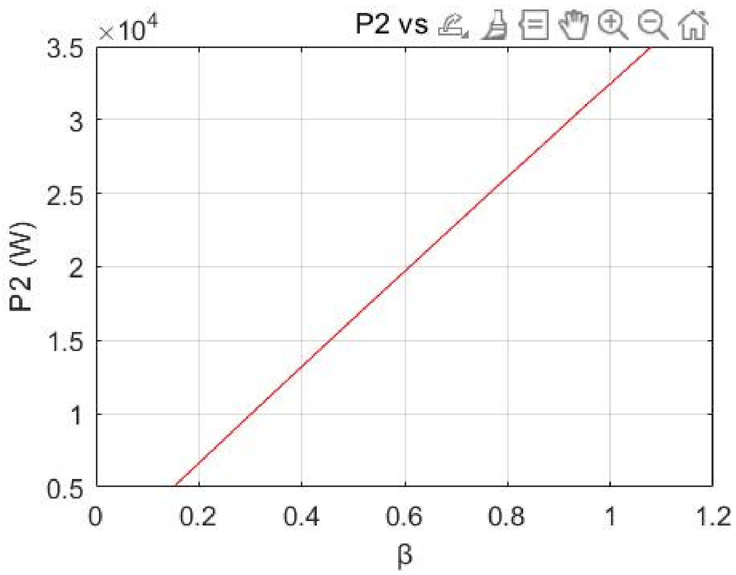
2.2 Complete m-file with data of RL-load test

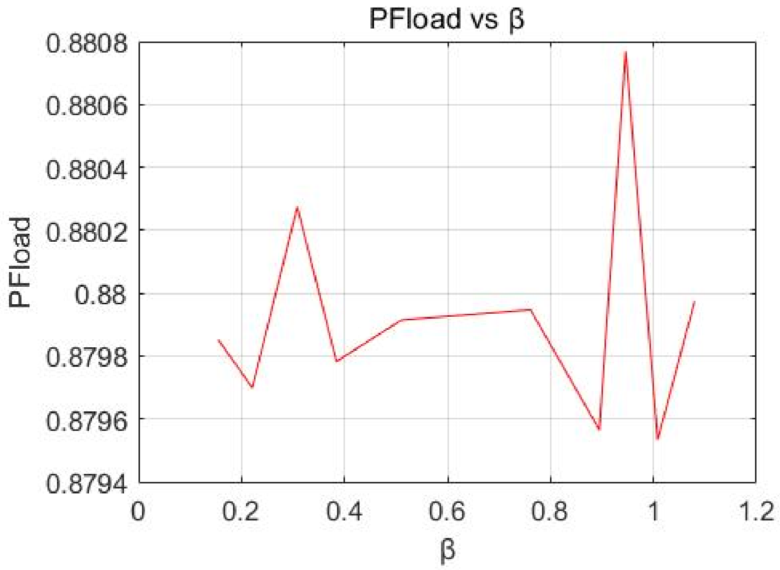
```
% RL-Load tests
% Values for R-Load:
R2 = [1.23 1.32 1.41 1.49 1.76 2.64 3.52 4.4 6.16 8.8]; % ohm
L = [1.76 1.89 2.01 2.14 2.52 3.78 5.04 6.3 8.82 12.6]; %mH
% Simulate the model with each value of the RL-load and then add the
% following parameters to m-file for each test:
U1_RL=[7200 7200 7200 7200 7200 7200 7200 7200 7200 7200];
U2_RL=[235.7 236.2 236.6 236.9 237.8 239.4 240.2 240.7 241.3 241.7];
I1_RL=[6.1 5.723 5.398 5.131 4.427 3.119 2.464 2.073 1.63 1.306];
I2_RL=[168.7 157.5 147.8 139.8 118.9 79.8 60.05 48.14 34.47 24.17];
P1_RL=[36060 33730 31760 30050 25710 17520 13360 10840 7940 5752];
P2_RL=[34990 32720 30800 29130 24880 16810 12690 10200 7317 5140];
```

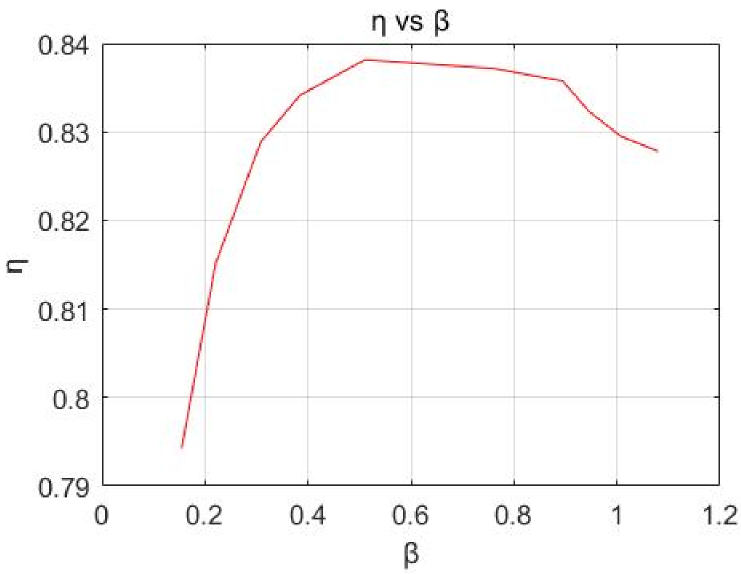
2.3 Calculate load ratio, load power factor, transformer efficiency and voltage regulation:

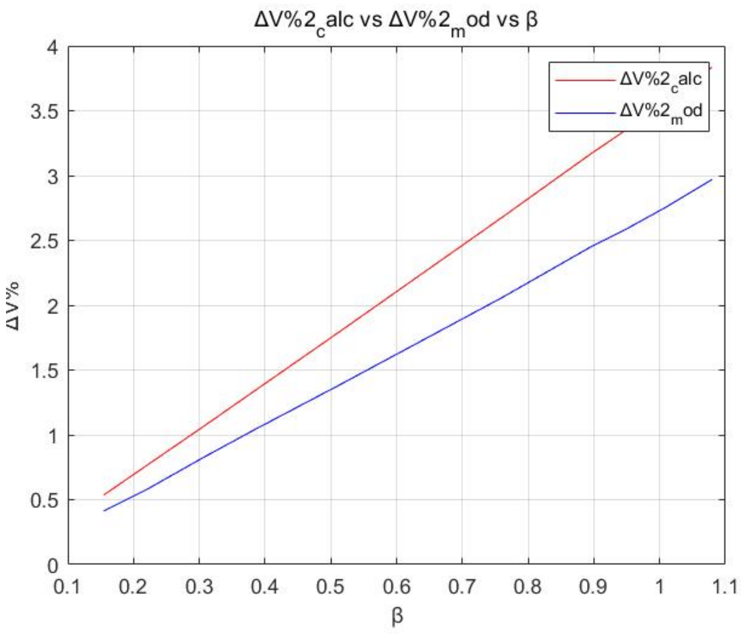
```
% Write script for determination of the load ratio, transformer efficiency, power
beta_RL = zeros( size(R2));
PF_RL = zeros(size(R2));
theta_RL = zeros(size(R2));
voltage_regulation_mod_RL = zeros(size(R2));
voltage_regulation_calc_RL = zeros(size(R2));
eta_RL = zeros(size(R2));
for k = 1:length(R2)
    beta_RL(k) = I2_RL(k)/rsc ;
    PF_RL(k) = P2_RL(k)/(U2_RL(k)*I2_RL(k));
    eta_RL(k) = P2_RL(k) /(P2_R(k) + I1_RL(k)^2 *R_eq *beta_RL(k)^2 + Poc);
    theta_RL(k) = acos(PF_RL(k)); % Calculate phase angle
    voltage_regulation_mod_RL(k) = ((V2oc - U2_RL(k))* 100 )/ U2_RL(k); % Calculate measured voltage regulation rate
    voltage_regulation_calc_RL(k)= (beta_RL(k) *(Vsc/a) * (cos(theta_sc) * cos(theta_RL(k)) + sin(theta_sc) * sin(theta_RL(k)))) *100 /U2_RL(k);
end
```

2.4 Draw following diagrams: $P_2(\beta)$, $PF_{load}(\beta)$, $\eta(\beta)$, $\Delta V\%_{2\_calc}(\beta)$, $\Delta V\%_{2\_mod}(\beta)$

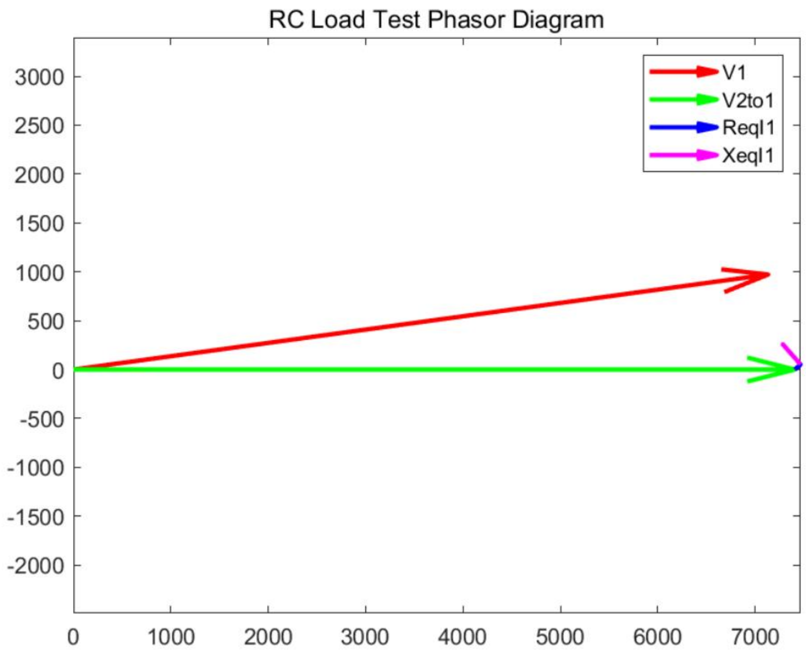



PFload vs β
0.8808
0.8806
0.8804
0.8802
0.88
0.8798
0.8796
0.8794
PFload
0
0.2
0.4
0.6
0.8
1
1.2
β


η vs β
0.84
0.83
0.82
0.81
0.8
0.79
η
0
0.2
0.4
0.6
0.8
1
1.2
β



2.5 Draw phasor diagram for one of the tests



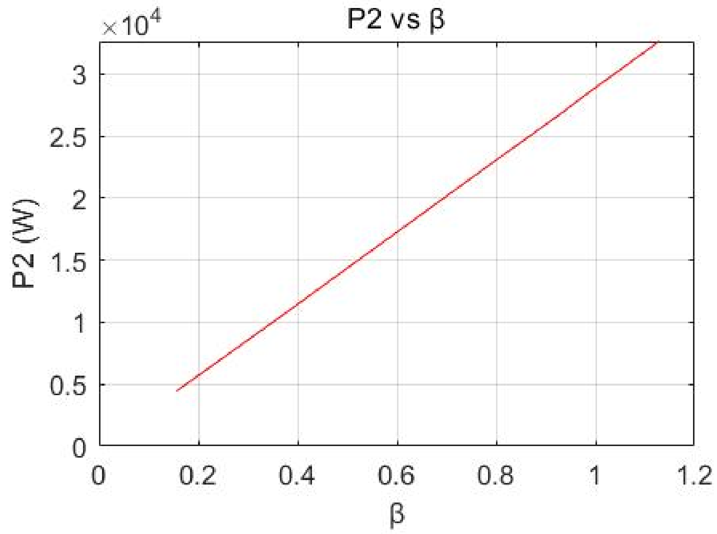
3.2 Complete m-file with data of RC-load test

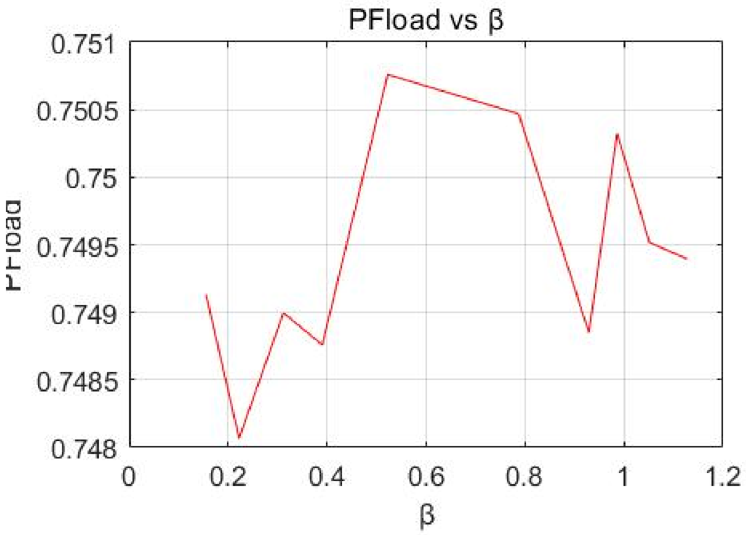
```
% RC-Load tests
% Values for RC-Load:
R3 = [1.05 1.125 1.2 1.27 1.5 2.25 3 3.75 5.25 7.5]; %ohm
C = [2.86 2.67 2.51 2.36 2.01 1.34 1 0.8 0.57 0.4]; %mF
% Simulate the model with each value of the RC-load and then add the
% following parameters to m-file for each test:
U1_RC=[7200 7200 7200 7200 7200 7200 7200 7200 7200 7200];
U2_RC = [246.9 246.7 246.4 246.2 245.7 244.7 244.2 243.9 243.6 243.3];
I1_RC= [5.626 5.224 4.881 4.58 3.836 2.46 1.783 1.394 0.9731 0.7076];
I2_RC = [176.3 164.3 154.1 145.2 123 81.65 60.98 48.73 34.72 24.3];
P1_RC= [33700 31400 29460 27690 23510 15700 11810 9535 6943 5036];
P2_RC =[32620 30380 28490 26770 22680 15000 11150 8902 6327 4429];
```

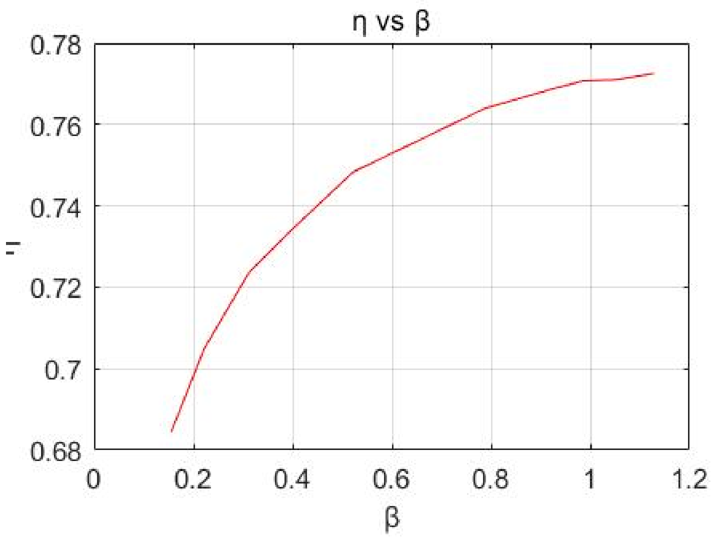
3.3 Calculate load ratio, load power factor, transformer efficiency and voltage regulation:

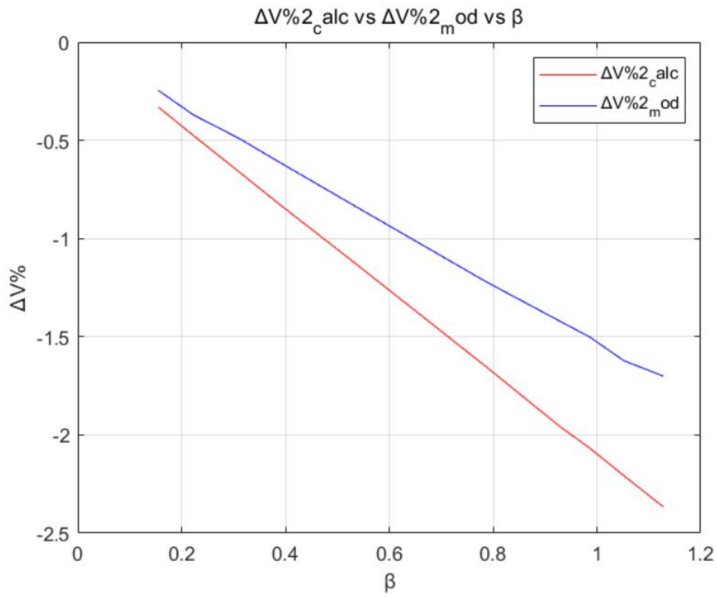
```
% Write script for determination of the load ratio, transformer efficiency, power
beta_RC = zeros( size(R3));
PF_RC = zeros(size(R3));
theta_RC = zeros(size(R3));
voltage_regulation_mod_RC = zeros(size(R3));
voltage_regulation_calc_RC = zeros(size(R3));
eta_RC = zeros(size(R3));
for k = 1:length(R3)
    beta_RC(k) = I2_RC(k)/rsc ;
    PF_RC(k) = P2_RC(k)/(U2_RC(k)*I2_RC(k));
    eta_RC(k) = P2_RC(k) /(P2_R(k) + I1_RC(k)^2 *R_eq *beta_RC(k)^2 + Poc);
    theta_RC(k) = acos(PF_RC(k)); % Calculate phase angle
    voltage_regulation_mod_RC(k) = ((V2oc - U2_RC(k))* 100 )/ U2_RC(k); % Calculate measured voltage regulation rate
    voltage_regulation_calc_RC(k)= (beta_RC(k) *(Vsc/a) * (cos(theta_sc) * cos(theta_RC(k)) - sin(theta_sc) * sin(theta_RC(k)))) *100 /U2_RC(k);

end
```

3.4 Draw following diagrams: $P_2(\beta)$, $PF_{load}(\beta)$, $\eta(\beta)$, $\Delta V\%_{2\_calc}(\beta)$, $\Delta V\%_{2\_mod}(\beta)$

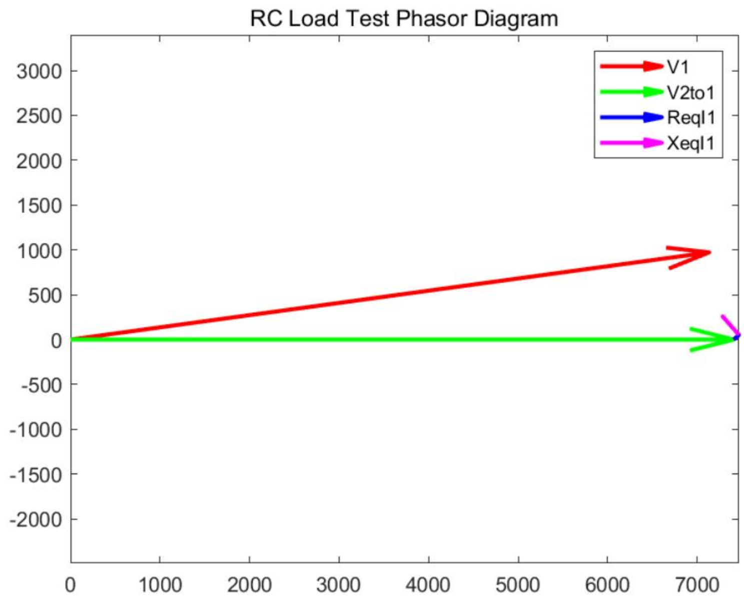

P2 vs β
×10^4
P2 (W)
β


PFload vs β
PFload
β


η vs β
η
β



3.5 Draw phasor diagram for one of the tests.



a	30
beta	[1.0963,1.0240...
beta_RC	[1.1283,1.0515...
beta_RL	[1.0797,1.0080...
C	[2.8600,2.6700...
efficiency	[0.9719,0.9734...
eta_RC	[0.7725,0.7710...
eta_RL	[0.8278,0.8295...
I1_R	[5.9150,5.5360...
I1_RC	[5.6260,5.2240...
I1_RL	[6.1000,5.7230...
I2_R	[171.3000,160,...
I2_RC	[176.3000,164....
I2_RL	[168.7000,157....
Ioc	0.6489
Isc	7.0450
k	10
L	[1.7600,1.8900...
P1_R	[42130,39390,...
P1_RC	[33700,31400,...
P1_RL	[36060,33730,...
P2_R	[41060,38380,...
P2_RC	[32620,30380,...
P2_RL	[34990,32720,...
PF	0.1286
PF_1_r	0.9892
PF_1_rL	0.8210
PF_RC	[0.7494,0.7495...
PF_RL	[0.8800,0.8795...
PF_sc	0.2738
Poc	600.8000
power_factor	[0.9996,0.9995...
Psc	694.4000
R1	[1.4000,1.5000...
R2	[1.2300,1.3200...
R3	[1.0500,1.1250...
R_eq	13.9910
Rc	1.4268e+03
rpc	5.2083
rpv	7200
rsc	156.2500
rsv	240
S_1_r	42588
S_1_rL	43920
theta_oc	1.4418
theta_prime_r	0.1468
theta_prime...	0.6076
theta_r	[0.0294 + 0.00...
theta_RC	[0.7236,0.7235...
theta_RL	[0.4950,0.4959...
theta_sc	1.2935
U1_R	[7200,7200,72...
U1_RC	[7200,7200,72...
U1_RL	[7200,7200,72...
U2_R	[239.8000,240,...
U2_RC	[246.9000,246....
U2_RL	[235.7000,236....
V1oc	7200
V2oc	242.7000
vIoc	0.0834 + 0.6435i
vIocL	0.0000 - 0.6543i
vIocR	5.0461
voltage_reg...	[1.6565 + 0.00...
voltage_reg...	[-2.3671,-2.206...
voltage_reg...	[3.8358,3.5769...
voltage_reg...	[1.2093,1.1250...
voltage_reg...	[-1.7011,-1.621...
voltage_reg...	[2.9699,2.7519...
vReqI1R	82.7300 - 2.43...
vReqI1RL	75.1085 - 40.5...
Vsc	360
vV1R	7.1226e+03 + ...
vV1RL	3.6035e+03 + ...
vV2R	239.8000
vV2RL	235.7000
vV2to1R	7194
vV2to1RL	7071
vVocdZ	0.6489
vVsc	360
vVscR	26.9870 - 94.7...
vVscX	3.3301e+02 + ...
vXeqI1R	8.5427e+00 + ...
vXeqI1RL	2.1664e-05 + 2...
X11	24.5737
X12	0.0273
X_eq	49.1474
Xm	1.1004e+04
Z_eq	51.1001
Zoc	1.1096e+04

Conclusion:

This laboratory exercise focused on investigating the impact of different load types on transformer performance, specifically voltage regulation. We conducted tests with resistive (R-load), resistive-inductive (RL-load), and resistive-capacitive (RC-load) loads and compared the results with theoretical calculations and Simulink models.

The experiments demonstrated a strong correlation between theoretical and modeled values, validating the accuracy of our approach. However, some discrepancies were observed, particularly in the case of RC-loads, which could be attributed to potential errors in model parameters or assumptions.

Load Type Impact: Different load types significantly affect transformer performance:

R-loads (Resistive): Most efficient with a power factor of 1, resulting in minimal voltage drops and stable operation.

RL-loads (Resistive-Inductive): Lagging power factor due to inductive component leads to increased voltage drops and reduced efficiency.

RC-loads (Resistive-Capacitive): Leading power factor due to capacitive component can cause voltage rise and impact transformer efficiency.

Waveform Characteristics:

RL-loads: Current lags behind voltage due to inductive component, leading to distorted waveforms and increased losses.

RC-loads: Current leads the voltage due to capacitive component, causing similar waveform distortions and increased losses.

Efficiency and Voltage Regulation:

R-loads: Efficiency increases initially with load ratio and then decreases due to increased copper losses.

RL-loads: Similar trend as R-loads but with a slightly lower peak efficiency.

RC-loads: Efficiency increases initially but experiences a sharp drop due to the leading power factor.

Voltage Regulation:

R- and RL-loads: Positive and increase proportionally with load ratio.

RC-loads: Negative and decrease with load ratio, with some discrepancies observed between calculated and modeled values.