MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE564 Project #1

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1 Inductor Design

blablabla

2 Transformer Design

With given parameters, a transformer is designed and optimized. MATLAB routine for this operation is present in the next section of the report.

Remarks and assumptions made in the optimization process are as follows:

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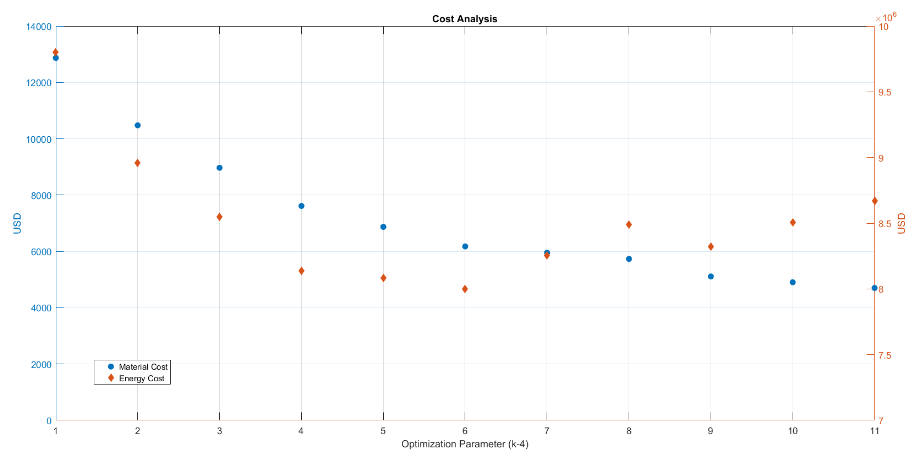

Figure 1: Cost Analysis

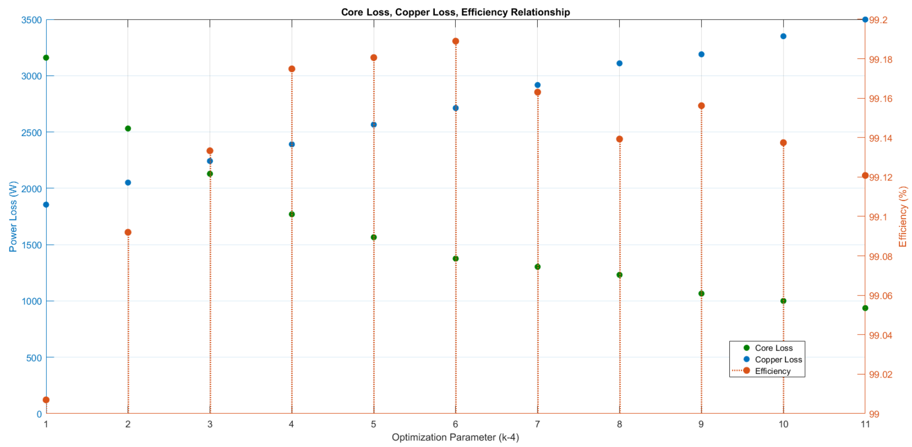

Figure 2: Relationship Between Core Loss, Copper Loss and Efficiency

10	0.1019	2.58826	5.26	0.9989	3.276392	15	2600 Hz
11	0.0907	2.30378	4.17	1.26	4.1328	12	3200 Hz
12	0.0808	2.05232	3.31	1.588	5.20864	9.3	4150 Hz

Figure 3: Cable Sizes in AWG System

Grade	THICKNESS		TYPICAL CORE LOSS AT				GUARANTEED CORE LOSS AT		TYPICAL POLARIZATION AT
powercore®	mm	inch	1.5 T 50 Hz W/kg	1.7 T 50 Hz W/kg	1.5 T 60 Hz W/lb	1.7 T 60 Hz W/lb	1.7 T 50 Hz W/kg	1.7 T 60 Hz W/lb	800 A/m typ. T
C 120-23	0.23	0.009	0.77	1.18	0.46	0.71	1.20	0.72	1.83
C 120-27	0.27	0.011	0.80	1.18	0.48	0.71	1.20	0.72	1.83
C 130-27	0.27	0.011	0.83	1.23	0.50	0.74	1.30	0.78	1.83
C 120-30	0.30	0.012	0.82	1.18	0.49	0.71	1.20	0.72	1.83
C 130-30	0.30	0.012	0.84	1.23	0.50	0.74	1.30	0.78	1.83
C 150-30	0.30	0.012	0.93	1.43	0.56	0.85	1.50	0.89	1.78
C 165-35	0.35	0.014	1.00	1.48	0.60	0.88	1.65	0.99	1.78

Figure 4: Properties of Steel Laminations

3 Code for Transformer Design and Optimization

EE564 Project#1 Q2 by G. Hande Bayazit

Contents

Parameters

```
B_op=1.5; %T
mu=1.83/800;
f=50; %Hz
P1= 500e3; %W
V1=34500; %V
V2=25000; %V
I1=P1/V1; %A
J=4; %A/mm^2
a_cable=I1/J; %mm^2
fprintf('Cable area should be around %d mm^2.\n',a_cable);

% This value is close to AWG11 size.

a_cable=4.1684; %mm^2
dia_cable=2.30378; %mm
res_cable=4.1328; %Ohms/km
```

```
Cable area should be around 3.623188e+00 mm^2.
```

Sizing

```
% Recalling the equation: V_ind=2*pi/sqrt(2)*f*B*A*N
% A*N is constant and they are dependent on each other. Optimum values of
% them will be found with an optimization parameter "k".

ff=0.5; %fill factor
dens_steel=7650; %kg/m^3
dens_copper=8940; %kg/m^3
core_loss_dens=0.77; %W/kg
price_steel=3; %$/kg
price_copper=7; %$/kg

i=1;
for k=5:15
```

```
    N1(:,i)=69*k;
    N2(:,i)=50*k;
    A(:,i)=V2*sqrt(2)/(2*pi*f*B_op*N1(:,i)); %m^2

    % Window area

    x1(:,i)=dia_cable*23/ff/1000; %m
    x2(:,i)=dia_cable*3*k/ff/1000; %m
    x3(:,i)=ceil(sqrt(A(:,i)*10000))/100; %m

    w1(:,i)=x1(:,i);
    w2(:,i)=2*x2(:,i)+0.03;

%     fprintf('Window area is %d m^2.\n',w1(:,i)*w2(:,i));

    % Overall dimensions

    e1(:,i)=w1(:,i)+2*x3(:,i);
    e2(:,i)=w2(:,i)+2*x3(:,i);

%     fprintf('Dimensions of the transformer is %d x %d x %d m.\n',e1(:,i),e2(:,i),x3(:,

    vol(:,i)=(e1(:,i)*e2(:,i)-w1(:,i)*w2(:,i))*x3(:,i);

    m_steel(:,i)=dens_steel*vol(:,i);

%     fprintf('Steel mass is %d kg.\n',m_steel(:,i));

    core_loss(:,i)=core_loss_dens*m_steel(:,i);

%     fprintf('Core loss is %d Watts.\n',core_loss(:,i));

    % Cable length

    mean_length(:,i)=2*(x2(:,i)/2+x3(:,i))+pi*x3(:,i)*sqrt(2); %m
    l1(:,i)=mean_length(:,i)*N1(:,i);
    l2(:,i)=mean_length(:,i)*N2(:,i);

    r1(:,i)=l1(:,i)*res_cable/1000; %Ohms
    r2(:,i)=r1(:,i)*(N2(:,i)/N1(:,i))^2; %Ohms
```

```
    vol_copper(:,i)=2*l1(:,i)*a_cable/1000000; %m^3
    m_copper(:,i)=vol_copper(:,i)*dens_copper; %kg

%     fprintf('Copper mass is %d kg.\n',m_copper(:,i));

    copper_loss(:,i)=I1^2*r1(:,i)*2; %W

%     fprintf('Copper loss is %d Watts.\n',copper_loss(:,i));

    % Inductances

    % Assuming L1 and L2 are 0.02 pu;

    ind1=V1^2/(P1*2*pi*f)*0.02; %H
    ind2=ind1*(N2/N1)^2; %H

    Leff(:,i)=2*(w1(:,i)+w2(:,i)+2*x3(:,i)); %m

    ind_m(:,i)=N1(:,i).^2*mu*A(:,i)/Leff(:,i); %H

    % Efficiency

    eff(:,i)=P1/(P1+core_loss(:,i)+copper_loss(:,i))*100; %percent

    % Cost

    cost(:,i)=price_copper*m_copper(:,i)+price_steel*m_steel(:,i); %$

    %Unit price of electricity: 0.4482 TL = 0.1125 USD

    lost_power(:,i)=P1*(100-eff(:,i))/1000; %kW

    lost_energy(:,i)=lost_power(:,i)*24*365*20*0.1125; %$

    cost_actual(:,i)=cost(:,i)+lost_energy(:,i); %$


    i=i+1;
end
```

Conclusion

% Considering the optimizaton results, optimum case for the design seems to

```
% be i=6, k=10. Transformer parameters are as follows:

k=10;
i=6;

    N1(:,i)=69*k;
    N2(:,i)=50*k;
    A(:,i)=V2*sqrt(2)/(2*pi*f*B_op*N1(:,i)); %m^2



    % Window area

    x1(:,i)=dia_cable*23/ff/1000; %m
    x2(:,i)=dia_cable*3*k/ff/1000; %m
    x3(:,i)=ceil(sqrt(A(:,i)*10000))/100; %m

    w1(:,i)=x1(:,i);
    w2(:,i)=2*x2(:,i)+0.03;


    % Overall dimensions

    e1(:,i)=w1(:,i)+2*x3(:,i);
    e2(:,i)=w2(:,i)+2*x3(:,i);

    vol(:,i)=(e1(:,i)*e2(:,i)-w1(:,i)*w2(:,i))*x3(:,i);

    m_steel(:,i)=dens_steel*vol(:,i);

    core_loss(:,i)=core_loss_dens*m_steel(:,i);

    % Cable length

    mean_length(:,i)=2*(x2(:,i)/2+x3(:,i))+pi*x3(:,i)*sqrt(2); %m
    l1(:,i)=mean_length(:,i)*N1(:,i);
    l2(:,i)=mean_length(:,i)*N2(:,i);

    r1(:,i)=l1(:,i)*res_cable/1000; %Ohms
    r2(:,i)=r1(:,i)*(N2(:,i)/N1(:,i))^2; %Ohms

    vol_copper(:,i)=2*l1(:,i)*a_cable/1000000; %m^3
```

```
m_copper(:,i)=vol_copper(:,i)*dens_copper; %kg

copper_loss(:,i)=I1^2*r1(:,i)*2; %W

% Inductances

% Assuming L1 and L2 are 0.02 pu;

ind1=V1^2/(P1*2*pi*f)*0.02; %H
ind2=ind1*(N2/N1)^2; %H

Leff(:,i)=2*(w1(:,i)+w2(:,i)+2*x3(:,i)); %m

ind_m(:,i)=N1(:,i).^2*mu*A(:,i)/Leff(:,i); %H

% Efficiency

eff(:,i)=P1/(P1+core_loss(:,i)+copper_loss(:,i))*100; %percent

% Cost

cost(:,i)=price_copper*m_copper(:,i)+price_steel*m_steel(:,i); %$


%Unit price of electricity: 0.4482 TL = 0.1125 USD

lost_power(:,i)=P1*(100-eff(:,i))/1000; %kW

lost_energy(:,i)=lost_power(:,i)*24*365*20*0.1125; %$

cost_actual(:,i)=cost(:,i)+lost_energy(:,i); %$

fprintf('Turns ratio is %d : %d. \n',N1(:,i),N2(:,i));

fprintf('Window area is %d m^2.\n',w1(:,i)*w2(:,i));

fprintf('Dimensions of the transformer is %d x %d x %d m.\n',e1(:,i),e2(:,i),x3(:,i)

fprintf('Steel mass is %d kg.\n',m_steel(:,i));

fprintf('Core loss is %d Watts.\n',core_loss(:,i));
```

```
fprintf('R1= %d Ohms, R2= %d Ohms. \n',r1(:,i),r2(:,i));

fprintf('Copper mass is %d kg.\n',m_copper(:,i));

fprintf('Copper loss is %d Watts.\n',copper_loss(:,i));

fprintf('L1= %d H, L2= %d H, Lm= %d H. \n',ind1,ind2,ind_m(:,i));

fprintf('Efficiency is %d percent. \n',eff(:,i));

fprintf('Material cost is %d USD. Lost money in 20 years is %d USD. \n',cost(:,i),co
```

```
Turns ratio is 690 : 500.
Window area is 3.247608e-02 m^2.
Dimensions of the transformer is 7.659739e-01 x 9.664536e-01 x 3.300000e-01 m.
Steel mass is 1.786846e+03 kg.
Core loss is 1.375872e+03 Watts.
R1= 6.457173e+00 Ohms, R2= 3.390660e+00 Ohms.
Copper mass is 1.164488e+02 kg.
Copper loss is 2.712528e+03 Watts.
L1= 1.515473e-01 H, L2= 7.957747e-02 H, Lm= 5.521107e+01 H.
Efficiency is 9.918895e+01 percent.
Material cost is 6.175681e+03 USD. Lost money in 20 years is 7.999056e+06 USD.
```