

Selecting a Single-phase Transformer for Battery Charger Development using CAD Approach

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ABSTRACT: A single-phase transformer was needed to develop a 12V constant-voltage battery charger for a relay protection system. The transformer's power rating was estimated as 500VA for a maximum battery voltage fall of 3V. An efficiency/power-factor product of 0.81(p.u.) was stipulated. A computer software application package was developed to facilitate the designing exercise. In this paper, the author provides details of the generation of the relevant transformer operational equations in which practical considerations were duly reflected. Computer programs were written using the generated equations in the MATLAB programming language, which conduced to the production of a single-phase transformer design software application package. On test-running the package for the design specifications of the needed transformer, the following major details were obtained: The Iron-Core Details included the Diameter of Circumscribing Circle = 6.9469cm; Centre-to-Centre Distance of the Core = 8.0244cm; Total Height of the Core = 17.7310cm; Total Length of the Core = 12.6846cm; Total thickness of the Core = 4.6602cm; Magneto motive Force (mmf) = 943.1818AT; while The Winding Details included HV Winding Turns = 415; LV Winding Turns = 24; HV Standard Wire Gauge = 18; LV Standard Wire Gauge = 5; HV Phase Current = 2.2727A; LV Phase Current = 41.6667A. From the applicability check feature incorporated in the software package, a satisfactory transformer design was no doubt ascertained.

Keywords: Transformer selection, computer application, Matlab

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INTRODUCTION

Since the discovery and demonstration of electromagnetic induction principle in 1831 by Michael Faraday (Giuliani, 2021) and the consequent and subsequent invention of motors, generators and transformers, the ease and comfort of living have been witnessed in every nook and cranny of our societies. The transformer in particular, more so, the two-winding core-type transformer – which can broadly be categorized into three-phase and single-phase transformers – has helped mankind in many and sundry ways. By means of 3-phase 2-winding power transformers, bulk electric energy is economically transmitted at high voltages from city to city. By means of 3-phase 2-winding distribution transformers electric energy is safely *retailed locally* to consumers at low voltages, according to (Pansini, 1976). Single-phase 2-winding core-type transformers (such as the one proposed here) are greatly utilized in rectifiers, furnaces,

welding machines, starters, ignition systems, etc. The magnetic core and windings of a 2-winding core-type transformer is as shown in (Figure 1). No other system humanly possible can carry out the design of anything in this age much better and faster than a computer. The computer will, of course, require a design software application package. A computer-aided design software application package is a bundle of computer programs skillfully written in an adopted universal programming language codes readable and interpretable by any computer for the performance of a pre-determined objective (Enyong, 2014). Programming languages include Foxpro, C/C++, Visual Basic, Pascal, Matlab and Visual C++. Matlab which is used in this work is an acronym for Matrix Laboratory and being developed by Math Works Inc. This means that every computation thereby is performed in matrix form (Mathworks, 1996).

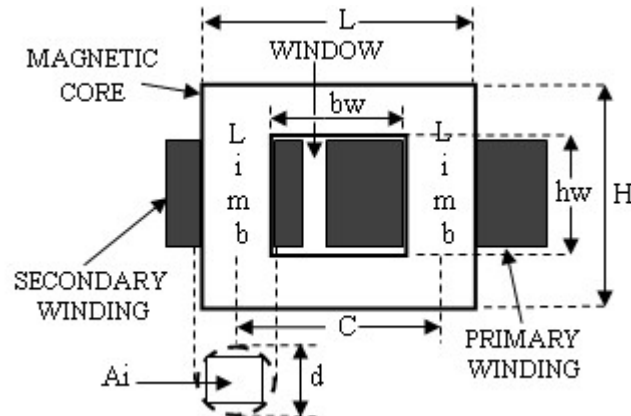


Figure 1: Two-winding Core-type Transformer, where:
 L – Overall Length of Magnetic Core; H – Overall Height of Magnetic Core;
 C – Centre-to-centre distance of limbs; A_i – Effective Magnetic core area;
 d – Diameter of the core circumscribed circle; bw – Length of window;
 hw – Height of window

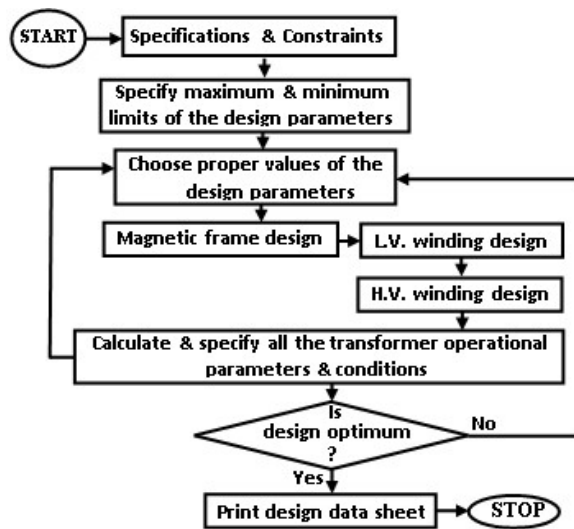


Figure 2: A Flow Chart for Computer-aided Design of Transformers

This is a software package for high performance and visualization, which combines capabilities, flexibilities, reliability and powerful graphics, hence, a premier software package for engineers and scientists. The most important feature of Matlab is its programming capability, which is relatively easy to learn and to use, and which allows user-developed functions (Okoro,2005).

Computer-aided design (CAD) of a transformer, similar to every normal engineering design, does require input data such as kVA rating, H.V./L.V. (voltage) ratio, frequency, number of phases and winding terminal connection (where applicable). For the analytical approach, which is adopted in this work due to its simplicity, the designer will select suitable values of the design parameters including maximum flux density (B_m), current density (J), window space factor (K_w), etc., based on the power rating of the transformer to be designed.

Using the earlier generated and inputted design equations, the computer calculates the complete transformer dimensions and parameters. If some or all the calculated values are not okay following the provisions of BS171, the designer will have to revise the initial assumptions regarding the design parameters. Adjustments will be carried out in this rather iterative manner, with re-calculation of the transformer parameters by the computer, until an optimum design is realized. The flow chart of the CAD of a transformer based on the analytical approach is as shown in (Figure 2).

Moreover, by way of presentation this *Introduction* obviously constitutes the 1st section of the research write-up. The 2nd section shall concern the *Generation of Transformer Equations*. Following this in the 3rd section is *Initial Design Considerations* and in the 4th section we shall have *Computer Programming*. The last but one (i.e.

the 5th) section dwells upon *Test-Running the Developed Software Application Package*. Finally, in the 6th section we shall be dealing with *Discussion, Conclusion & Recommendations*.

GENERATION OF TRANSFORMER EQUATIONS

The transformer equations in this work shall comprise the relevant magnetic circuit and electric circuit equations. The latter shall be considered first.

ELECTRIC CIRCUIT EQUATIONS

E.M.F Equations, E_1, E_2 :

For a Two-winding transformer the E.M.F equations as affecting each winding are given in (Theraja, 2002) as

$$E_1 = 4.44fB_m A_i N_1; E_2 = 4.44fB_m A_i N_2 \quad (1)$$

Where:

E_1 – Induced emf on the primary winding (in volts)
 E_2 – Induced emf on the secondary winding (in volts)
 F – Frequency of the a.c. input power (in Hz)
 N_1 – Number of turns in the primary (or No.1) winding
 N_2 – Number of turns in the secondary (or No.2) winding
 B_m – Maximum flux density in the magnetic core (in Tesla)
 A_i – Net cross-sectional area of the magnetic core (in m²)

Turns Ratio, a:

$$\frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = a \quad (2)$$

Where:

V_1 – Terminal voltage on the primary winding (in volts)
 V_2 – Terminal voltage on the secondary winding (in volts)
 I_1 – Current in the primary winding (in amps)
 I_2 – Current in the secondary winding (in amps)

Voltage Per Turn, E_t or V_t :

$$E_t = V_t = 4.44f\phi_m = 4.44fB_m A_i = K\sqrt{kVA/m} \quad (3)$$

ϕ_m – Maximum main flux; m – Number of phases;

E_t – Induced voltage (E.M.F) per turn; V_t – Terminal voltage per turn

$$K = \sqrt{4.44f \cdot r \cdot (10^3)}; r = \frac{\phi_m}{I_1 N_1} = \frac{\phi_m}{I_2 N_2} \quad (4a)$$

Table 1 shows values of K for various types of transformer

construction. It is to be noted in (Table 1) that, r , invariably stands for the ratio of iron area of the core, A_i , to the copper area in the window, A_c , according to (Brosan and Hayden, 1966).

$$\text{i.e. } r = \frac{A_i}{A_c}; K = \sqrt{\frac{0.008f B_m r}{J}} \quad (4b)$$

where, J – Current density (in A/mm²)

As a guide, the following values may be used for the average current density (i.e. average of L.V. and H.V. winding current densities). The values of flux density, B_m , (Tables 2 and 3) considering economy and performance are given as follows: (1) With hot-rolled, silicon-steel laminations: use 1.2 – 1.4T for power transformers, and 1.1 – 1.3T for distribution transformers. (2) With cold-rolled, grain-oriented, silicon-steel laminations: use 1.5 – 1.7T for power transformers, and 1.1 – 1.3T for distribution transformers. (3) Lower values should be used for small transformers (Mittle and Mittal, 1998).

General Turns Equation, N:

$$N = \frac{E}{E_t} = \frac{V}{V_t} \quad (5)$$

General Current Equation, I_{ph} :

$$I_{ph} = \frac{kVA \cdot 10^3}{mV_{ph}} \quad (\text{in amps}) \quad (6)$$

Conductor Cross-sectional Area, a_{x1}, a_{x2} :

$$a_{x1} = \frac{I_{ph}}{J}; a_{x2} = \frac{I_{ph}}{J} \quad \text{where } J_2 < J_{av} < J_1 \quad (7)$$

L.V. Winding Diameters, d_{i2}, d_{o2} :

(i) Inner diameter of L.V. winding, d_{i2}

$$d_{i2} = d + 2c_{i2} + 2i_{o2} \quad (8a)$$

(ii) Outer diameter of L.V. winding, d_{o2}

$$d_{o2} = d_{i2} + 2b_{r2}; b_{r2} = l_v + w_{i2} + l_v \quad (8b)$$

where, d – as earlier defined; l_v – a layer of L.V. winding; w_{i2} – winding insulating cylinder (0.1cm); c_{i2} – core insulating cylinder (0.4cm); i_{o2} – oil duct between c_{i2} and l_v (1.5cm); b_{r2} – total radial breadth of L.V. winding.

Table 1: Values of the factor K

S/No.	TRANSFORMER TYPE	FACTOR, K
1	Three-phase Core-type (Power Transformer)	0.60 to 0.65
2	Three-phase Core-type (Distribution Transformer)	0.45 to 0.50
3	Three-phase Shell-type	1.20 to 1.30
4	Single-phase Core Type	0.75 to 0.80
5	Single-phase Shell Type	1.00 to 1.10

Source: (Mittle and Mittal, 1998)

Table 2: Values of Current Density or Electric Loading, J.

S/No.	TRANSFORMER TYPE	CURRENT DENSITY
1	Distribution Transformers	2.0 to 2.5
2	Bulk Power Transformers	2.3 to 3.5
3	Large Transformers with forced oil circulation	3.0 to 4.5

Source: (Mittle and Mittal, 1998)

Table 3: Values of the factor, r.

S/No.	TRANSFORMER TYPE	FACTOR, r
1	Core-type Distribution Transformers	0.35 to 0.45
2	Core-type Bulk Power Transformers	0.55 to 0.65
3	Shell-type Bulk Power Transformers	1.00 to 1.25

Source: (Singh, 1982)

H.V. Winding Diameters, d_{i1} , d_{o1} :

(i) Inner diameter of H.V. winding:
 $d_{i1} = d_{o2} + 2w_{i1} + 2i_{o1} + 2i_{o11}$ (9a)

(ii) Outer diameter of H.V. winding: $d_{o1} = d_{i1} + 2b_{r1}$ (9b)

where, similarly, w_{i1} – winding insulating cylinder, as applicable; i_{o1} – oil duct between d_{o2} and w_{i1} (0.5cm); i_{o11} – oil duct between w_{i1} and d_{i1} (0.5cm); b_{r1} – total radial breadth of H.V. winding.

H.V. Winding Tapping: (applicable to bulk power and distribution transformers)

Height of Winding, w.h./Axial Winding Arrangement:

Generally,

$$w.h. = h_c + 2e_{ib} + e_{rm} + sl \tag{10a}$$

$$h_c = nl_c + (n - 1)i_{sp}, \text{ for disc-type winding} \tag{10b}$$

$$h_c = nl_c, \text{ (10c) for helical or continuous cylindrical-type winding.}$$

where, h_c – total height of coil arrangement {(1) for disc-type winding there must be an insulating spacer, i_{sp} (= 0.6cm), in between every 2 adjacent coils; (2) for helical or continuous cylindrical winding there can be no spacers}; e_{ib} – top and bottom end insulation bracing (= 5cm each); e_{rm} – metallic end ring at the top (= 3.0cm); sl – slackness (= 0.8cm); n –no. of coils of disc-type winding or no. of turns of helical/continuous cylindrical winding; l_c – axial length of insulated unit coil for a disc-type winding, or that of insulated rectangular conductor or the diameter of insulated round conductor for continuous cylindrical-type winding. The value of w.h. should be about 0.7 to 0.8 h_w ; h_w – as earlier defined in

(Figure 1).

Electromagnetic output equation

The single-phase transformer output power, S_{ph} , is given by

$$S_{ph} = 2.22fB_mJ_{av}K_wA_wA_i(10^{-3}) \text{ (in kVA)} \tag{11}$$

where, A_w – Window area (in m²); K_w – Window space factor.

$$K_w = \frac{\text{TOTAL COPPER AREA IN THE WINDOW}}{\text{WINDOW AREA}} = \frac{A_c}{A_i} \tag{12}$$

The value of K_w will, of course, depend upon the following:

- i) voltage rating of the windings, mostly the highest voltage winding; and
- ii) kVA rating of the transformer.

Approximate values of K_w can be calculated using the formulae below (Mittle and Mittal,1998).

$$K_w = \frac{10}{20 + kv_1} \text{ or } K_w \cong \frac{10}{[20 + \frac{kv_1}{(1 + MV/J)}]} \tag{13}$$

where, K_w is the voltage of the H.V. winding.

MAGNETIC CIRCUIT EQUATIONS:

Diameter of the Circumscribing Circle, d:

Figure 3 below shows the relation between the diameter of the circumscribing circle, d, and the net cross-sectional area of the core, A_i .

$$d = \sqrt{A_i/K_i} \tag{15a}$$

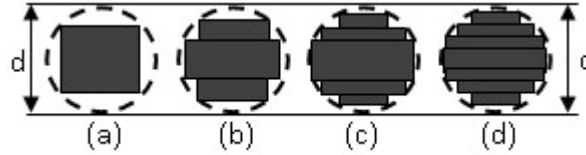


Figure 3: Relation between d and A_i (shaded area) For various Magnetic Core Cross-sections.

Table 4: Relation between d and A_i

AREA AS % OF CIRCUM- SCRIBING CIRCULAR AREA, $[A_{cc}]$	SQUARE	CRUCIFORM	3-STEPPED	4-STEPPED
Gross Area, A_g	64	79	84	87
Net Area ($A_i = K_i d^2$)	58	71	75	78
Number of packets	1	3	5	7
The Factor, K_i	0.45	0.56	0.60	0.62

Source: (Brosan and Hayden, (1966))

The ratio A_i/A_g gives the iron stacking factor, K_s , for each core configuration in (Table 4), and amounts to approximately 0.9 in each case; hence, authors often assume this value in computations, as in (Mittle and Mittal (1998)).

Width of the Window, b_w :

$$b_w \cong C - 0.9d \quad (16)$$

Area of Window, A_w :

$$A_w = h_y b_w \quad (17)$$

Overall Length of Magnetic Core, L :

$$L \cong C + 0.9d \quad (\text{for single-phase, all stepped core}) \quad (18)$$

Overall Height of Magnetic Core, H :

$$H \cong h_y + 2(0.9d) \quad (\text{for all stepped core}) \quad (19)$$

Cross-sectional area of yoke, A_y :

$$A_y = 1.1A_i \text{ to } 1.15A_i \quad (20)$$

Such values of A_y help to reduce B_m in the yoke, hence making for the reduction of iron losses in the yoke, according to (Mittle and Mittal, (1998)).

Width of the yoke, w_y :

$$\left. \begin{aligned} w_y &= 0.9d \quad (\text{for 3-stepped core}) \\ &= 0.85d \quad (\text{for cruciform core}) \\ &= 0.7d \quad (\text{for square core}) \end{aligned} \right\} \quad (21a)$$

Similarly, for all design purposes, one can apply

$$w_y \cong 0.9d \quad (\text{for all stepped cores}) \quad (21b)$$

Height of the Yoke, h_y :

$$h_y = \frac{A_y}{w_y} \quad (22)$$

However, for this work it shall be taken that

$$A_y = A_i \text{ and } w_y = d \quad (23)$$

This is, of course, satisfactory in all practical considerations.

Weight of Copper, W_{tc} :

A rough calculation is advisable as follows according to (Singh B. (1982)):

- i) Allot $\frac{1}{2}$ the window space to the coils of each limb, i.e. $b_w/2$.
- ii) Calculate the mean diameter of the coils of each limb, i.e. roughly

$$d_m = \left\{ d + \left(\frac{b_w}{2} \right) \right\} \text{ in cm} \quad (24)$$

- iii) Calculate the mean length of turns for the coils of each limb, i.e.

$$l_{mt} = \pi d_m = \pi \left\{ d + \left(\frac{b_w}{2} \right) \right\} \text{ in cm}$$

- iv) Calculate the volume of copper per limb of transformer, i.e.

$$V_{cl} = K_w \cdot \left\{ l_{mt} \cdot \left[\left(\frac{b_w}{2} \right) \cdot h_y \right] \right\} \text{ in cm}^3 \quad (25)$$

v) Now calculate the weight of copper per limb of transformer, i.e.

$$Wt_{c1} = 0.0089V_{c1} \text{ in Kg} \quad (26)$$

vi) Total weight of copper in transformer, i.e.

$$Wt_{c1} = 2(0.0089V_{c1}), \text{ for single-phase core-type} \quad (27)$$

where, density of copper is given as 0.0089 Kg/cm^3 or 8.9 Kg/dm^3 as in [10].

INITIAL DESIGN CONSIDERATIONS

To enable proper selection of transformer for the charger, the battery loading effect will first be estimated. In this regard, it is important to consider a maximum voltage fall to the tune of 3V for a given battery when discharged. The internal equivalent series resistance (ESR) of a rechargeable battery shall be taken typically as 0.1Ω (at 40°C) according to (Wikipedia, the free encyclopedia (2016). Thus, the maximum charging current expected shall be $3/0.1 = 30\text{A}$. And for a high enough efficiency and power factor of 0.9p.u. in both cases (Mittle and Mittal, 1998), we have an efficiency/power-factor product, $epp = 0.9^2 = 0.8$ p.u. The transformer rated apparent power shall therefore be, $S_{rated} = VI/epp. = (30*12)/0.81 = 444.4\text{VA}$, so we take the preferred value of 500VA.

COMPUTER PROGRAMMING

The computer programs written in MATLAB and duly arranged to execute both fresh design of two-winding core-type transformers as well as the redesign of broken-down same type transformers for rewinding purposes are as presented below. In order to really appreciate the program writing, which is of the analytical approach as earlier indicated, it will be expected of the reader to have had a good idea of the MATLAB high level computer language.

PROGRAMS FOR DESIGN OF A SINGLE-PHASE TRANSFORMER:

Presented below are three programs which constitute a software package and meant for fresh design of a core-type 2-winding single-phase transformer.

Design mode selection program:

%Opening program for transformer CAD beginning with mode selection.

```
disp('DESIGN OF A CORE-TYPE SINGLE-PHASE TRANSFORMER.');
```

```
disp('Fresh Design Mode=11; Re-design Mode=12')
```

```
ModNo=input('Please, select your design mode number, ModNo=')
if ModNo==11
run('enyo1phXformFD')
elseif ModNo==12
run('enyo1phXformRD')
end
```

Main Design Computational and Logic Program:

```
%This Program handles fresh design computations of the
core dimensions
%and winding requirements of a core-type square-core 1-
phase transformer.
disp('THE FRESH TRANSFORMER DESIGN MODE
HAS BEEN SELECTED');
disp(' AND ');
disp(' THE SINGLE-PHASE 50Hz TRANSFORMER
DESIGN PROGRAM');
disp(' IS NOW SET TO RUN PROPER ');
disp(' ');
kVA=input('Please, enter the input power in kva, kVA=')
kV1=input('Enter H.V. winding phase voltage in kv, kV1=')
kV2=input('Enter L.V. winding phase voltage in kv, kV2=')
Ki=input('Enter iron-core stepping factor, Ki=')
K=input('Enter the volt-per-turn K factor, K=')
Bm=input('Enter the flux density in Tesla, Bm=')
Jav=input('Enter the current density in A/mm^2, Jav=')
m=1; f=50; %no. of phases and power frequency (in Hz)
Kw=10/(30+kV2); %window factor
Vt=K*sqrt(kVA/m); %voltage per turn in volts
Ai=Vt/(4.44*f*Bm); %net (or effective) core area in m^2
bc=sqrt(Ai); tc=bc; %breadth and thickness of core area
in m, respectively.
Aw=kVA*10^3/(2.22*f*Bm*(Jav*10^6)*Kw*Ai); %window
area in m^2 for
%1-phase transformers
d=sqrt(Ai/Ki); %diameter of circumscribing circle in m
bw=sqrt(Aw/2.5); %window breadth in m
hw=Aw/bw; %window height in m
C=bw+bc; %centre-to-centre limb distance in m
L=C+bc; %total horizontal length of magnetic circuit in m
H=hw+(2*tc); %total vertical length of magnetic circuit in
m
disp('MAGNETIC CIRCUIT DETAILS');
Diameter_of_Circumscribing_Circle_in_cm=d*10^2
Height_of_Window_in_cm=hw*10^2
Breadth_of_Window_in_cm=bw*10^2
Area_of_Window_in_sqcm=Aw*10^4
Core_Net_Square_Xsectional_Areas_in_sqcm=Ai*10^4
Centre_to_Centre_Distance_of_Limbs_in_cm=C*10^2
Total_Height_of_Core_in_cm=H*10^2
Total_Length_of_Core_in_cm=L*10^2
Breadth_or_Thickness_of_Core_in_cm=bc*10^2
N1=round(kV1*10^3/Vt); %no. of HV winding turns per
phase
I1=kVA/(m*kV1); %HV winding phase current in amps
```

```

ax1=l1/Jav; %xsectional area of bare HV winding
conductor in mm^2
dx1=sqrt(4*ax1/pi); %diameter of bare HV winding
conductor in mm
N2p=round(N1*kV2/kV1); % possible no. of LV winding
turns per phase
Ts=round(N2p/2); %number of turns of LV tap sections
N2=2*Ts; %actual number of LV winding turns per phase
I2=kVA/(m*kV2); %phase current of LV winding
ax2=I2/Jav; %xsectional area of bare HV winding
conductor in mm^2
dx2=sqrt(4*ax2/pi); %diameter of bare HV winding
conductor in mm
mmf=I1*N1; %transformer magnetomotive force (mmf in
AT)
Magnetomotive_Force_in_AT=mmf
SWG3=[3 4 5 6 7 8 9 10 11 12 13 14]; %round copper
SWG
Area3=[32.2 27.3 22.8 18.7 15.7 13.0 10.5 8.30 6.82 5.48
4.29 3.24];
%cross-sectional areas of round copper conductor
SWG4=[15 16 17 18 19 20 21 22 23 24 25 26 27];
%round copper SWG
Area4=[2.63 2.07 1.59 1.17 0.81 0.66 0.52 0.40 0.29 0.25
0.20 0.16 0.14];
%cross-sectional areas of round copper conductor
if ax1>=3.0 & ax1<=32.2
    SWG1=interp1(Area3,SWG3,ax1,'nearest'); %HV
winding conductor SWG
elseif ax1>=0.14 & ax1<=2.63
    SWG1=interp1(Area4,SWG4,ax1,'nearest'); %HV
winding conductor SWG
end
if ax2>=3.0 & ax2<=32.2
    SWG2=interp1(Area3,SWG3,ax2,'nearest'); %LV
winding conductor SWG
elseif ax2>=0.14 & ax2<=2.63
    SWG2=interp1(Area4,SWG4,ax2,'nearest'); %LV
winding conductor SWG
end
s_w_g=[1 5 8 10 12 13 15 19 21 23];
ena=[0.14 0.13 0.12 0.11 0.10 0.08 0.07 0.06 0.055
0.04];
ena2=interp1(s_w_g,ena,SWG2,'nearest'); %light enamel
covering for round
%conductors of the LV winding in mm
ena1=interp1(s_w_g,ena,SWG1,'nearest'); %light enamel
covering for round
%conductors of the HV winding in mm
dx1i=dx1+ena1; %diameter of enamel insulated HV
winding conductor in mm
dx2i=dx2+ena2; %diameter of enamel insulated LV
winding conductor in mm
disp('MAJOR ELECTRIC CIRCUIT PARAMETERS');
Voltage_per_Turn_in_Volts=Vt
HV_Number_of_Turns=N1
HV_Phase_Current_in_amps=I1

```

```

HV_Bare_Conductor_Xsection_in_sqmm=ax1
HV_Winding_Standard_Wire_Gauge=SWG1
LV_Number_of_Turns=N2
Number_of_Turns_of_LV_Tap_Sections=Ts
LV_Phase_Current_in_amps=I2
LV_Bare_Conductor_Xsection_in_sqmm=ax2
LV_Winding_Standard_Wire_Gauge=SWG2
L1=L; %overall length of yoke
wh=0.7*hw; %height of windings on the limbs (in m)
ips=0.3; %core-to-winding insulating paper separation
thickness (in mm)
icb=0.4; %insulating cotton binding tape thickness (in
mm)
acs=10.0; %air cooling space (in mm)
p=0.02; %specific resistance value at 75degC in (ohm-
mm^2/m)
br1=dx1i*(round(dx1i*N1/(wh*10^3))); %actual radial
breadth of HV wdg (mm)
br2=dx2i*(round(dx2i*N2/(wh*10^3))); %actual radial
breadth of LV wdg (mm)
lin=(bc*10^3)+(2*ips); %inner length of both LV and HV
windings (mm)
lo1=lin+(2*br1)+(2*icb); %outer length of HV winding
(mm)
lo2=lin+(2*br2)+(2*icb); %outer length of LV winding
(mm)
lm1=(lin+lo1)/2; lm2=(lin+lo2)/2; %mean lengths of HV &
LV windings,
%respectively (mm)
lmt1=4*lm1; lmt2=4*lm2; %mean length of HV & LV
winding turns, resp. (mm)
r1=(p*(lmt1/10^3)*N1)/ax1; %resistance of HV winding
conductor (ohms)
r2=(p*(lmt2/10^3)*N2)/ax2; %resistance of LV winding
conductor (ohms)
dosh=(lo1+lo2)/2; %half the sum of HV & LV windings
outer lengths (mm)
Mean_Length_of_HV_Square_Winding_in_cm=lm1/10
Mean_Length_of_LV_Square_Winding_in_cm=lm2/10
Mean_Length_of_HV_Winding_Turn_in_cm=lmt1/10
Mean_Length_of_LV_Winding_Turn_in_cm=lmt2/10
Resistance_per_phase_of_HV_Winding_in_ohm=r1
Resistance_per_phase_of_LV_Winding_in_ohm=r2
run('enyo1phXformConf');

```

Satisfactory Design Check Program:

```

%This is the Terminal Program that takes care of the
check to confirm
%the accomplishment of a satisfactory design or
otherwise
D=(dosh+acs)/10^3; %confirmatory factor for adequate
centre-to-centre
%distance of core or limbs (in m)
if D<=C
disp('MAGNETIC CIRCUIT DIMENSIONS OKAY!');
disp(' ');

```

```

disp('PRINT OUT OR STORE YOUR RESULT');
disp(' ');
disp('DONE');
else
disp('Magnetic Circuit Window Cannot Accommodate');
disp('Windings Properly. Pls Decrease K and/or Jav');
run('enyo1phXformFD');
end

```

Running the developed software application package

The result of test-running the developed software application package was as given in the presentation that follows

Design of a core-type single-phase transformer.
 Fresh Design Mode=11; Re-design Mode=12
 Please, select your design mode number, ModNo=11

The fresh transformer design mode has been selected and the single-phase 50hz transformer design program is now set to run proper

Please, enter the input power in kva, kVA=0.5
 Enter H.V. winding phase voltage in kv, kV1=0.22
 Enter L.V. winding phase voltage in kv, kV2=0.012
 Enter iron-core stepping factor, Ki=0.45
 Enter the volt-per-turn K factor, K=0.75
 Enter the flux density in Tesla, Bm=1.1
 Enter the current density in A/mm², Jav=2.0

MAGNETIC CIRCUIT DETAILS

```

Diameter_of_Circumscribing_Circle_in_cm = 6.9469
Height_of_Window_in_cm = 8.4106
Breadth_of_Window_in_cm = 3.3643
Area_of_Window_in_sqcm = 28.2956
Core_Net_Square_Xsectional_Areas_in_sqcm = 21.7170
Centre_to_Centre_Distance_of_Limbs_in_cm = 8.0244
Total_Height_of_Core_in_cm = 17.7310
Total_Length_of_Core_in_cm = 12.6846
Breadth_or_Thickness_of_Core_in_cm = 4.6602
Magnetomotive_Force_in_AT = 943.1818

```

ELECTRIC CIRCUIT DETAILS

```

Voltage_per_Turn_in_Volts = 0.5303
HV_Number_of_Turns = 415
HV_Phase_Current_in_amps = 2.2727
HV_Bare_Conductor_Xsection_in_sqmm = 1.1364
HV_Winding_Standard_Wire_Gauge = 18
LV_Number_of_Turns = 24
Number_of_Turns_of_LV_Tap_Sections = 12
LV_Phase_Current_in_amps = 41.6667
LV_Bare_Conductor_Xsection_in_sqmm = 20.8333
LV_Winding_Standard_Wire_Gauge = 5
Mean_Length_of_HV_Square_Winding_in_cm = 5.8967

```

```

Mean_Length_of_LV_Square_Winding_in_cm = 5.8162
Mean_Length_of_HV_Winding_Turn_in_cm = 23.5869
Mean_Length_of_LV_Winding_Turn_in_cm = 23.2649
Resistance_per_phase_of_HV_Winding_in_ohm=1.7228
Resistance_per_phase_of_LV_Winding_in_ohm = 0.0054

```

Magnetic circuit dimensions okay!
 print out or store your result

DONE

>>

Conclusion

Developing a software application package for computer-aided design of electrical equipment is highly fascinating. MATLAB simplifies the process of creating such a package once the essential working equations are established. This package includes an inbuilt check feature to ensure proper winding accommodation within the transformer window, preventing unrealistic miniature single-phase transformer designs and saving time. The package employs an iterative and manual approach to optimal design, with the K factor and the average current density (Jav) being the primary adjustable parameters. The satisfactory and practical results presented above were obtained using this method. The author strongly recommends incorporating a synthesis approach in future packages for its automatic and time-saving benefits. However, the current iterative analysis method is highly valuable for academic purposes.

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