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Design Parameters of Transformer

Chinmayi Satish Thakare
Final Year B.E. Electrical Engineering
Jawaharlal Darda of Engineering and Technology, Yavatmal, Maharashtra, India
cthakare002019@gmail.com

Abstract: *Transformers are used to change ac voltage levels, as well as to provide galvanic isolation between circuits. Single and three phase transformers are extensively employed in the world's power distribution system. This chapter considers the design of single phase power transformers. It reviews the classic transformer equivalent circuit and also considers its use in steady state phase or analysis. The chapter focuses on single phase transformers. Single phase transformers are often classified as being either core type or shell type. The chapter discusses transformer performance considerations such as the calculation of transformer parameters, regulation, magnetizing current, operating point analysis, and inrush current, all in general terms. It also focuses on one specific class of transformer, develop an Magnetic Equivalent Circuit, and ultimately a design approach. Core loss is a significant contributor to overall transformer loss and dominates no load losses.*

Keywords: Road hypnosis, Driver behavior, Safety warning, Monotonous city effect.

I. INTRODUCTION

A transformer transfers electric power from one circuit to another circuit without a change in frequency. It contains primary and secondary winding. The primary winding is connected to the main supply and secondary to the required circuit. In our project circuit, we have taken the design of low power (10 KVA) single phase 50 hertz power transformer as per our requirement in the project.

The transformer is basically of three types:

- Core Type
- Shell Type
- Toroidal

In core, type windings surround a part of the core whereas in shell type core surrounds windings. In the Core type, there are two main types namely E-I type and U-T type. In this transformer design, we used E-I core type. We chose E-I core as the winding is much easier when compared to toroidal, but efficiency is very high (95%-96%). It is so because flux loss is very less in toroidal cores comparatively.

Example of core type transformer looks like :-

Fig.1: Three phase transformer(6 type core winding)

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The transformers employed in the project are

- **Series transformer:** To provide the required boost or buck voltage and
- **Control transformer:** For sensing the output voltage and for power supply.

Design Formulas:

Here we take the reference of winding data on enameled copper wire table and dimensions of transformer stampings table to select input and output windings SWG and core of the transformer for given specifications.

The design procedure is followed assuming that the following specification of a transformer are given:-

- Secondary voltage (Vs)
- Secondary current (Is)
- Turns ratio (n2/n1)

From these given details we calculate Tongue width, stack height, core type, window area as follows:-

- Secondary Volt-Amps (SVA) = secondary voltage (Vs) * secondary current(Is)
- Primary Volt-Amps (PVA) = Secondary Volt-Amps (SVA) / 0.9 (assuming efficiency of the transformer as 90%)
- Primary voltage (Vp)= Secondary voltage(Vs)/ turns ratio(n2/n1)
- Primary current (Ip) = Primary Volt-Amps(PVA)/ Primary voltage(Vp)

The require cross-sectional area of the core is given by:-

- Core area (CA) = 1.15 * sqrt (Primary Volt-amps(PVA))
- Gross core area (GCA) = Core area(CA) * 1.1

The number of turns on the winding is decided by the ratio given as:- Turns per volt (Tpv) = 1/(4.44 * 10-4 * core area* frequency * flux density)bh

Winding data on Enameled copper wire

Max. Current Capacity (Amp.)	Turns/Sq. cm	SWG
0.001	81248	50
0.0015	62134	49
0.0026	39706	48
0.0041	27546	47
0.0059	20223	46
0.0079	14392	45
0.0104	11457	44
0.0131	9337	43
0.0162	7755	42
0.0197	6543	41
0.0233	5595	40
0.0274	4838	39
0.0365	3507	38
0.0469	2800	37
0.0586	2286	36
0.0715	1902	35
0.0858	1608	34
0.1874	711	29
0.2219	609	28
0.2726	504	27
0.3284	415	26
0.4054	341	25
0.4906	286	24
0.5838	242	23
0.7945	176	22
1.0377	137	21
1.313	106	20
1.622	87.4	19
2.335	60.8	18
3.178	45.4	17
4.151	35.2	16
5.254	26.8	15
6.487	21.5	14
8.579	16.1	13

0.1013	1308	33	10.961	12.8	12
0.1182	1137	32	13.638	10.4	11
0.1364	997	31	16.6	8.7	10
0.1588	881	30			

Dimension of Transformer stampings (Core table):

Type Number	Tongue Width (cm)	Window Area (Sq. cm)	Type Number	Tongue Width (cm)	Window Area (Sq. cm)
17	1.27	1.213	9	2.223	7.865
12A	1.588	1.897	9A	2.223	7.865
74	1.748	2.284	11A	1.905	9.072
23	1.905	2.723	4A	3.335	10.284
30	2	3	2	1.905	10.891
	1.588	3.329	16	3.81	10.891
31	2.223	3.703	3	3.81	12.704
10	1.588	4.439	4AX	2.383	13.039
15	2.54	4.839	13	3.175	14.117
33	2.8	5.88	75	2.54	15.324
1	1.667	6.555	4	2.54	15.865
14	2.54	6.555	7	5.08	18.969
11	1.905	7.259	6	3.81	19.356
34	1.588	7.529	35A	3.81	39.316
3	3.175	7.562	8	5.08	49.803

For operation on mains supply, the frequency is 50HZ, while the flux density can be taken as 1Wb/sq cm. for ordinary Steel stampings and 1.3Wb/sq cm for CRGO stampings, depending on the type to be used.

Hence

Primary turns (n1) = Turns per volt(Tpv) * Primary voltage(V1)

Secondary turns (n2) = Turns per volt(Tpv) * secondary voltage(V2) * 1.03 (Assume that there is 3% drop in transformer windings)

The width of the tongue of laminations is approximately given by:-

Tongue width (Tw) = Sqrt * (GCA)

Current density

It is the current carrying capacity of a wire per unit cross sectional area. It is expressed in units of Amp/ cm². The above mentioned wire table is for a continuous rating at current density of 200A/cm². For non-continuous or intermittent mode of operation of transformer one can choose a higher density up to 400A/cm² i.e., twice the normal density to economize the unit cost. It is opted as, the temperature rise for the intermittent operational cases are less for the continuous operational cases.

So depending on the current densities choosen we now calculate the values of primary and secondary currents that are to searched in wire table for selecting SWG:-

n1a = Primary current (Ip) calculated / (current density/200)

n2a = Secondary current (Is) calculated / (current density/200)

For these values of primary and secondary currents we choose the corresponding SWG and Turns per sqcm from the wire table. Then we proceed to calculate as follows:-

Primary area(pa)= Primary turns(n1) / (Primary turns per sqcm)
Secondary area(sa)= Secondary turns(n2) / (Secondary turns per sqcm)
The total window area required for the core is given by:-
Total area (TA) = Primary area (pa) + Secondary area (sa)
Extra space required for the former and insulation may be taken as 30% extra space of what is required by the actual winding area. This value is approximate and may have to be modified, depending on the actual winding method.
Window area (Wacal) = Total area (TA) * 1.3
For the above calculated value of tongue width, we choose core number and window area from the core table ensuring that the window area chosen is greater than or equal to the Gross core area. If this condition is not satisfied we go for a higher tongue width ensuring the same condition with a corresponding decrease in the stack height so as to maintain approximately constant gross core area.
Thus we get available tongue width (Twavail) and window area ((avail)(aWa)) from the core table
Stack Height = Gross core area / Tongue width ((available) (atw)).
For commercially available former size purposes, we approximate stack height to tongue width ratio to the nearest following figures of 1.25, 1.5, 1.75. At the worst case we take the ratio equal to 2. However any ratio till 2 can be taken which would call for making ones own former.
If the ratio is greater than 2 we select a higher tongue width (aTw) ensuring all the conditions as above.
Stack height(ht) / tongue width(aTw) = (some ratio)
Modified stack height = Tongue width(aTw) * Nearest value of standard ratio
Modified Gross core area = Tongue width (aTw) * Modified stack height.
Same design procedure applies for control transformer, where in we need to ensure that stack height equals Tongue width.
Thus we find core number and stack height for the given specifications.
Designing a transformer using an example:
The given details are as follows:-
Sec. voltage(Vs) = 60V
Sec current(Is) = 4.44A
Turns per ratio (n2/n1) = 0.5
Now we have to calculations as follows:-
Sec.Volt-Amps(SVA) = Vs * Is
= 60 * 4.44
=266.4VA

Prim.Volt-Amps(PVA) = SVA / 0.9
= 296.00VA

Prim.Voltage (Vp) = V2 / (n2/n1)
= 60/0.5
= 120V

Prim.current (Ip) = PVA/Vp
= 296.0/ 120
= 2.467A

Core Area(CA) = 1.15 * sqrt(PVA)
= 1.15 * sqrt(296)
= 19.785 cm²

Gross core area(GCA) = CA * 1.1
= 19.785 * 1.1
= 21.76 cm^2
Turns per volt(Tpv) = 1 / (4.44 * 10-4 * CA *frequency * Flux density)
= 1 / (4.44 * 10-4 * 19.785 * 50 *1)
= 2.272 turns per volt
Prim.Turns(N1) = Tpv * Vp
= 2.276 * 120
= 272.73 turns
Sec.Turns(N2) = Tpv * Vs * 1.03
= 2.276 * 60 * 1.03
= 140.46 turns
Tongue width(TW) = Sqrt*(GCA)
= 4.690 cm
We are choosing the current density as 300A/cm^2, but the current density in the wire table is given for 200A/cm^2, then
Primary current search value = Ip / (current density/200)
= 2.467 / (300/200)
= 1.644A
Secondary current search value = Is / (current density/200)
= 4.44 / (300/200)
= 2.96A
For these values of primary and secondary currents we choose the corresponding SWG and Turns per sqcm from the wire table.
SWG1=19
SWG2=18
Turn per sqcm of primary = 87.4 cm^2 turns per sqcm of secondary =60.8 cm^2
Primary area(pa) = n1 / turns per sqcm(primary)
= 272.73 / 87.4
= 3.120 cm^2
Secondary area(sa) = n2 / turns per sqcm(secondary)
= 140.46 / 60.8
= 2.310 cm^2
Total area(at) = pa + sa
= 3.120 + 2.310
= 5.430 cm^2
Window area (Wa) = total area * 1.3
= 5.430 * 1.3
= 7.059 cm^2
For the above calculated value of tongue width, we choose core number and window area from the core table ensuring that the window area chosen is greater than or equal to the Gross core area. If this condition is not satisfied we go for a higher tongue width ensuring the same condition with a corresponding decrease in the stack height so as to maintain approximately constant gross core area.
Thus we get available tongue width (Twavail) and window area ((avail)(aWa)) from the core table:
So tongue width available (atw) = 3.81cm
Window area available (awa) = 10.891 cm^2
Core number = 16
Stack Height = gca / atw
= 21.99 / 3.810
= 5.774cm

For performance reasons, we approximate stack height to tongue width (aTw) ratio to the nearest following figures of 1.25, 1.5, and 1.75. At the worst case we take the ratio equal to 2.

If the ratio is greater than 2 we select a higher tongue width ensuring all the conditions as above.

Stack height(ht) / tongue width(aTw) = 5.774 / 3.81 = 1.516

Modified stack height = Tongue width(aTw) * Nearest value of standard ratio
= 3.810 * 1.516 = 5.715cm

Modified Gross core area = Tongue width (aTw) * Modified stack height
= 3.810 * 5.715
= 21.774 cm^2

Thus we find core number and stack height for the given specifications.

Design of a small control transformer with example:

The given details are as follows:-

Sec. voltage(Vs) = 18V

Sec current(Is) = 0.3A

Turns per ratio (n2/n1) = 1

Now we have to calculations as follows:-

Sec.Volt-Amps(SVA) = Vs * Is
= 18 * 0.3
= 5.4VA

Prim.Volt-Amps(PVA) = SVA / 0.9
= 5.4 / 0.9
= 6VA

Prim. Voltage (Vp) = V2 / (n2/n1)
= 18/1
= 18V

Prim. current (Ip) = PVA/Vp
= 6 / 18
= 0.333A

Core Area(CA) = 1.15 * sqrt(PVA)
= 1.15 * sqrt(6)
= 2.822 cm^2

Cross core area(GCA) = CA * 1.1
= 2.822 * 1.1
= 3.132 cm^2

Turns per volt(Tpv) = 1 / (4.44 * 10-4 * CA *frequency * Flux density)
= 1 / (4.44 * 10-4 * 2.822 * 50 *1)
= 15.963 turns per volt

Prim. Turns(N1) = Tpv * Vp
= 15.963 * 18
= 287.337 turns

Sec.Turns(N2) = Tpv * Vs * 1.03
= 15.963 * 60 * 1.03
= 295.957 turns

Tongue width(TW) = Sqrt*(GCA)
= sqrt * (3.132)
= 1.770 cm

We are choosing the current density as 200A/cm^2, but the current density in the wire table is given for 200A/cm^2, then

Primary current search value = Ip / (current density/200)
= 0.333 / (200/200) = 0.333A

Secondary current search value = Is / (current density/200)
= 0.3 / (200/200)
= 0.3A

For these values of primary and secondary currents we choose the corresponding SWG and Turns per Sq. cm from the wire table.

SWG1=26
SWG2=27
Turn per Sq. cm of primary = 415 turns
Turns per Sq. cm of secondary = 504 turns
Primary area(pa) = n1 / turns per sqcm(primary)
= 287.337 / 415
= 0.692 cm²
Secondary area(sa) = n2 / turns per sqcm(secondary)
= 295.957 / 504
= 0.587 cm²
Total area(at) = pa + sa
= 0.692 + 0.587
= 1.280 cm²
Window area (Wa) = total area * 1.3
= 1.280 * 1.3
= 1.663 cm²

For the above calculated value of tongue width, we choose core number and window area from the core table ensuring that the window area chosen is greater than or equal to the Gross core area. If this condition is not satisfied we go for a higher tongue width ensuring the same condition with a corresponding decrease in the stack height so as to maintain approximately constant gross core area.

Thus we get available tongue width (Twavail) and window area ((avail)(aWa)) from the core table

So tongue width available (atw) = 1.905cm
Window area available (awa) = 18.969 cm²
Core number = 23
Stack Height = gca / atw
= 3.132 / 1.905
= 1.905cm

Hence the control transformer is designed.

II. CONCLUSION

A procedure for the optimal transformer. A transformer is a passive electrical device that can change the voltage in an alternating current (AC) electric circuit. Transformers are used to increase or decrease the operating voltage levels between circuits.

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