International Journal of Applied Research 2015; 1(8): 412-417

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2015; 1(8): 412-417
www.allresearchjournal.com
Received: 17-05-2015
Accepted: 20-06-2015

Parantap Nandi
A/2, Building no.165 (1st floor)
Kalyani, District: Nadia, West Bengal, PIN: 741235

Correspondence:
Parantap Nandi
A/2, Building no.165 (1st floor)
Kalyani, District: Nadia, West Bengal, PIN: 741235
Email:nandiparantap@gmail.com

Methods of secondary short circuit current control in single phase transformers

Parantap Nandi

Abstract
The control of secondary current of a single phase transformer can be achieved using taps, rheostats in the secondary winding. But these lead to increase in expense as well as make the design difficult. These are effective for sensitive applications. For obtaining high current at low voltage (2-5A) at low voltage which may be used for powering small electromagnets, control of current from primary side proves to be more effective. This simply involves the principle of voltage reduction at the primary. The supply voltage is kept constant at 240V-50Hz. No intermediate transformation is required. The voltage control is achieved using

a. Resistors
b. Inductors (Choke)
c. Capacitors

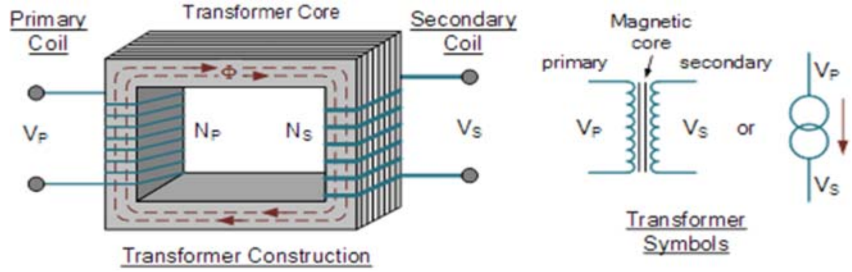
Of these capacitors prove to be most efficient. This is because capacitors can provide both reduction and magnification of transformer primary voltage. Hence, both reduction and increase of the secondary current is possible. Inductors and resistors reduce primary voltage and hence secondary short circuit current. In case of capacitors, various combinations (sometimes along with resistors and inductors) are possible. In this paper various methods of secondary current control using passive elements at the primary have been presented.

Keywords: Transformer; Resistor; Inductor; Capacitor; Electromagnet; Voltage.

1. Introduction

A transformer is a device that steps up/down voltage from primary to secondary. When it increases voltage with respect to primary, it is called a step up transformer; else it is called a step down transformer. A third condition exists in which a transformer produces the same voltage on its secondary as is applied to its primary winding. In other words, its output is identical with respect to voltage, current and power transferred. This type of transformer is called an “Impedance Transformer” and is mainly used for impedance matching or the isolation of adjoining electrical circuits.

Single phase step down transformers which provide a secondary voltage ranging from 4.5-12V are commonly available in the market. These are used for common projects. As voltage is stepped down in order to keep VA constant the current is increased. The basic diagrams & equations are given under:-



$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = \text{Turns Ratio}$$

The short circuit current at the secondary is equal to the rated value only if the primary voltage supply is exactly equal to the value supplied by the manufacturer. For e.g. if a transformer is rated 230-12V, 3A the secondary current is 3A only if the primary voltage is 230V. However, in most cases the supply voltage varies by ±20V. An increase in primary voltage increases the short circuit current drastically while a decrease in primary voltage (lower than rated value) causes a fall in the secondary short circuit current. Hence there is an essential need to control the primary voltage. Regulating the voltage of the transformer may be needed to:-

1. Supply desired voltage to the load.
2. To counter voltage drops due to loads.
3. To counter the input supply voltage changes on load.

The voltage control can be performed by changing the turns ratio. This is done by providing taps in the winding. The volts per turn available in large transformers is quite high and hence a change of even one turn on the LV side represents a large percentage change in the voltage. Also LV currents are normally large to take out the tapping from the windings. LV winding being the inner winding in a core type transformer adds to the difficulty in taking out the taps. Hence irrespective of the end use for which the tapping is put to, taps are provided on the HV winding.

Tap changing can be effected when:-

a. The transformer is on no load (off load tap changing)
b. The load is still connected to the transformer (on load tap changing)

Off load tap changing is less expensive. The tap positions are changed when the transformer is taken out of the circuit and reconnected. On-load tap changer tries to change the taps without interruption of the load current. It costs more. A few ways of on load tap changing are:-

A. Reactor method of tap changer.
B. Parallel winding transformer method
C. Series booster method
D. Moving coil voltage regulators
E. Sliding contact regulators

The above mentioned procedures are applicable if the transformer is so manufactured. This requires more skill, cost and precise methods. Also they are more suitable for industrial applications having large ratings in the range of KVA. But for small transformers having a capacity of only a few VA these will be uneconomic.

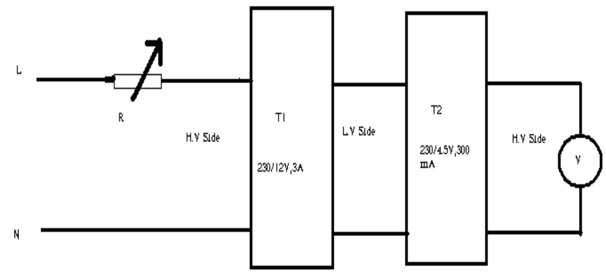
In order to overcome the odds some simple components like resistors, capacitors are connected to the transformer primary to control primary voltage as well as secondary short circuit current.

2. Materials and methods

1. Single phase transformer 230-12V,3A
2. Single phase transformer 230-4.5V, 300mA
3. Voltmeter (Analog type)
4. Ammeter (Analog type)
5. Capacitor 2.5µF-440V (used in ceiling fans)
6. Electric choke (aluminum type)
7. Incandescent lamps rated 10W, 15W, 25W &40W (each capable of working on 250V A.C)
8. Resistance type ceiling fan regulator

3. Experimental: In the experiments listed below increase of primary voltage as well as its reduction is possible.

Experiment#1



It is simple & may be accomplished by connecting a resistance of *low value* in series with the primary. The resistance of such low value (≈500Ω) may be obtained from an A.C fan regulator (resistive type). Carbon film resistors should not be used because they get burnt out quite easily and last only a few seconds. This method may be used to reduce the primary voltage to some extent (up to about 40V) and hence may reduce the secondary short circuit current. Another experiment was performed using incandescent lamps connected in series with the primary winding instead of the fan regulator. A power of incandescent lamp vs. short circuit current at the secondary terminal of T_1 was plotted.

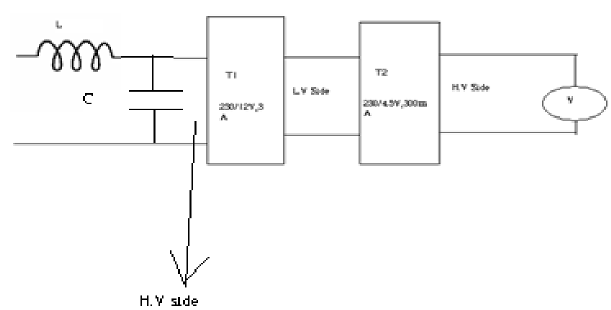
Experiment#2

An inductor replaces the series resistor in the above experiment. It is an ordinary tube light choke or the L.V side of another transformer. But it suffers from the following drawbacks:

- A series inductor makes the power factor, low and lagging.
- If L.V side of a similar transformer is used, high voltage may be induced on the H.V side which is dangerous.
- The L.V side of a transformer may not provide effective voltage control due to low reactance.

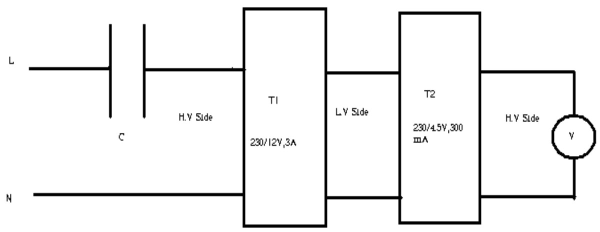
This method also reduces the primary voltage and hence the secondary short circuit current.

Experiment#3



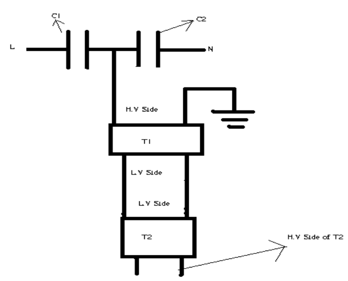
As seen from the figure a series LC circuit is used for voltage control. The voltage across the capacitor is fed to the main transformer. The striking feature of this method is that input voltage to the transformer primary can be made greater than the voltage available at the supply terminals. This depends on the capacitance of the capacitor used. For large value of capacitance the primary voltage is high. The capacitance was varied as 5, 7.5 & 10µF and the corresponding voltages were tabulated. A resistor was inserted in series to allow the voltage to be increased in steps. Increase in primary voltage as well as its reduction is possible.

Experiment#4

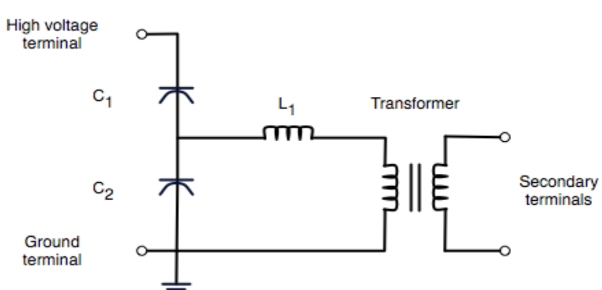


This may be referred to as the *'series capacitor method'*. A suitable capacitor is connected in series with the primary winding. The voltage on the primary side solely depends on the capacitance of the capacitor. Hence the choice of the capacitor is highly critical. As the supply frequency is very low i.e. 50Hz the capacitive reactance may be too large and it may reduce the primary voltage to a great extent. It is somewhat similar to LC voltage control mentioned earlier. Here the choke is not used. The transformer primary performs the function of the choke. The resistance of the choke is avoided in the circuit and hence this leads to higher efficiency.

Experiment#5



The circuit resembles a capacitive transformer circuit. A short description is necessary.

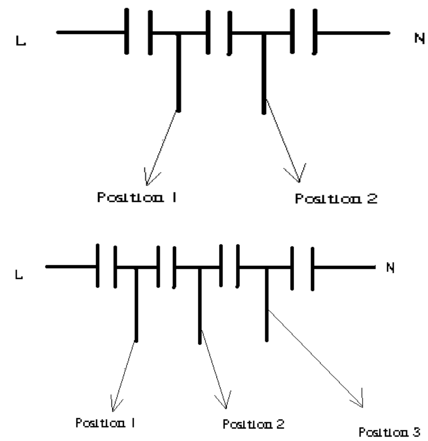


A capacitor voltage transformer (CVT or CCVT), is a transformer used in power systems to step down extra high voltage signals and provide a low voltage signal, for metering or operating a protective relay.

The difference is evident from the diagram. In a CVT the transformer is connected in parallel with the capacitor. But in the above the mid-point of the series combination is connected to the first terminal while the other terminal is grounded. Thus the primary voltage of the transformer is a reduced one. Voltage to the primary may be further reduced by connecting a capacitor or a resistor in parallel with the transformer primary. But connection of a capacitor is better because a resistor leads to power loss. If a capacitor is connected in series with the primary, the primary voltage and hence the secondary short circuit current may be increased. Thus an effective variation of input voltage may be obtained.

Experiment#6

The above circuit was constructed for operating electromagnets producing magnetic field in the range of 200-300AT. The electromagnet was constructed by winding 100 turns of fine copper wire on a GI core or a simple iron nail or rod. A current ranging from 2-4A can be obtained by proper design which may drive the electromagnet e.g. sounder of a telegraph set. Separate experiments were conducted using a 3 capacitor set and a 4 capacitor set. (Diagram given under).



This method is highly useful and one of the best methods for controlling primary voltage and secondary short circuit current in its conjunction. The transformer primary is connected between with either of the 2 positions (1/2) and ground). But *a huge primary voltage does not mean a very large short circuit current at the secondary*. Also the voltage across each capacitor varies as the 'tap' position is varied. On shorting the primary voltage of the transformer drastically falls. This is undesirable under normal conditions but under special conditions as is seen in the situation of operating an electromagnet the drastic fall in voltage proves highly useful.

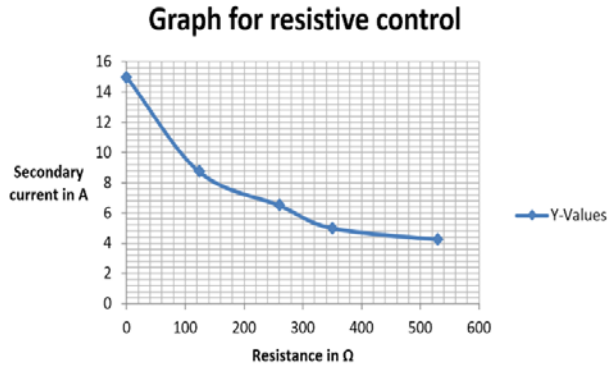
4. Observations

For resistive control both a table was tabulated and also a graph was plotted. The table was made keeping at par the circuit shown in experiment#1 while the graph was plotted by disconnecting T_2 and short circuiting the L.V terminals of T_1 with an ammeter.

Table 1: (for resistive voltage control)

Resistor value in Ω	Voltage across resistor	Primary voltage	Voltage at secondary of the other transformer at no load
530	15V	200V	170V
350	10V	210V	180V
260	5V	220V	182V
123	Negligible in the range of mV	230V	190V
0	do	240V	195V

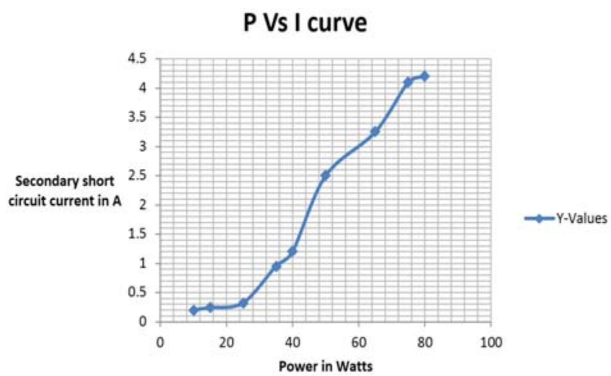
It is seen from the table that the voltage drop across the resistor is not very high and hence power loss will be within tolerable limits. But if resistor has a high value (>600Ω) this will not be the case and hence power loss will have to be taken in to account.



Graph 1

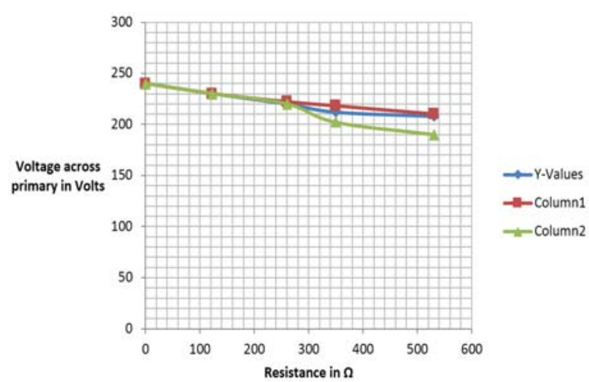
It is seen from the graph that in the absence of any resistance, the short circuit current is very high i.e.15Awhich is 5times the rated current of 3A. Hence, under this condition the winding is sure to burn out. On the other hand on inserting a resistance of 550-600Ω**, a safe amount of current i.e. 2.5A (average value may be obtained).

**This will vary according to the rating of the transformer.



Graph 2

Primary voltage can be further reduced by connecting a capacitor in parallel with the primary and connecting a resistance in series with the combination. This experiment was designed by maintaining a secondary load of 118Ω. A corresponding graph for various capacitances was plotted.



The blue line corresponds to no capacitance, red line 2.5µF and green line 5µF inn parallel with the primary.

In inductive voltage control (experiment#2) an aluminum choke used in fluorescent tubes was connected is series with the primary winding. The following table depicts the recordings:

Table 2: (for voltage control with choke)

D.C resistance of choke	Voltage across choke	Voltage across primary of T1	Voltage output from T2	Short circuit current on removal of T2
60Ω	5V	200V	170V	3.5A

This reveals that the short circuit current is brought to a reasonable range by connecting a choke in series with the primary winding. The voltage drop across the choke is very small owing to the low reactance compared to the reactance of the transformer.

In case of series LC circuit used to control the primary voltage an aluminum choke was connected is series with a capacitor and the capacitance was varied as 5, 7.5 & 10µF. This was accomplished by parallel combination of 2.5µF capacitors. The tables are given under:-

Table 3: (for LC control with 5µF)

Resistor value in Ω	Voltage across choke	Primary voltage	Voltage at secondary of the other transformer at no load
530	40V	220V	190V
350	30V	240V	200V
260	20V	250V	205V
123	20V	260V	210V
0	20V	265V	215V

The 5 resistances were connected one at a time and were obtained from a ceiling fan regulator.

Table 4: (for LC control with 7.5µF)

Resistor value in Ω	Voltage across choke	Primary voltage	Voltage at secondary of the other transformer at no load
530	145V	160V	120V
350	165V	220V	180V
260	160V	255V	210V
123	140V	275V	215V
0	140V	285V	215V

Table 5: (for LC control with 10µF)

Resistor value in Ω	Voltage across choke	Primary voltage	Voltage at secondary of the other transformer at no load
530	150V	80V	20V
350	190V	160V	110V
260	212V	220V	170V
123	210V	285V	220V
0	210V	300V	230V

It is seen that more the value of capacitance, more the voltage across the choke for a given resistance. Also, if the capacitance is large the transformer primary voltage follows a wider range. This is due to the fact that larger the capacitance smaller is the capacitive reactance for a fixed frequency. Thus for a large value of control resistance the primary voltage is less when capacitance is more. As the value of resistance is decreased the capacitive reactance becomes dominating and hence the

primary voltage increases.
The following table was prepared when transformer primary was connected to series capacitors of various values:-

Table 6: (for capacitive voltage control)

Capacitance(μF)	Voltage across capacitor	Primary voltage	Voltage at secondary of the other transformer at no load
.625	250V	140V	125V
.83	300V	170V	160V
1.25	320V	210V	190V
2.5	350V	260V	210V
5	400V	310V	230V

As the capacitance in series is increased both the voltage across the capacitor as well as that across the transformer primary increases. The current obviously is not in phase with the voltage. On shorting the primary of transformer T_1, the primary voltage falls drastically while a secondary current of about 6A is obtained.

Table 7: (for a 3 capacitor system)

Tap position	V_{C1}	V_{C2}	V_{C3}	Voltage across transformer primary	Secondary short circuit current
1	400V	140V	150V	290V	2A
2	16V	18V	32V	40	.5A

Table 8: (for a 4 capacitor system)

Tap position	V_{C1}	V_{C2}	V_{C3}	V_{C4}	Primary voltage	Secondary short circuit current
1	410V	40V	40V	40V	285V	3.5A
2	230V	230V	230V	110V	260V	2.6A
3	10V	10V	10V	10V	15V	.2A

As the position of the tap is taken further from the live conductor the voltage across the primary and hence the secondary current decreases. The position nearest to the live conductor (but not the live itself) is the source of greatest voltage.

5. Results and Discussions

A single phase A.C transformer when fed from a single phase A.C supply gives a very large quantity of secondary short circuit current due to fluctuations in the supply which may provide a voltage greater than the rated primary voltage. Such high currents may damage the insulation and burn the secondary winding. Hence a control on this phenomenon is necessary.
The control over primary voltage and secondary short circuit current is achieved by connecting passive elements like resistors, chokes and capacitors with the primary winding. The important results have been summarized under:-

1. A resistance when connected in series with the primary winding may provide a voltage drop across itself and reduce the primary voltage and thereby secondary short circuit current. The value of resistor must lie between 400-600Ω for ratings around 3A and it will vary according to the transformer rating. Small amount of power is wasted in the resistor, but it need not be taken in to account. This method is cheap and can only provide a reduction in primary voltage.
2. An inductor e.g. a choke can also reduce the primary voltage to some extent but the circuit will become bulky while the power factor will become low lagging.
3. A combination of inductor and capacitor can increase primary voltage as well as decrease it. As the transformer primary is connected in parallel with the capacitor improvement in power factor can be observed. Low value capacitance gives voltage lower than rated one and vice versa.
4. Capacitors when connected in series with the primary winding of the transformer may increase the primary voltage to a high value and hence the secondary short circuit current. But the high value of voltage at the primary is not in phase with the primary current due to the basic property of a circuit consisting of an inductor and capacitor (the transformer behaves as an inductor). The high voltage saturates the core and secondary voltage is not increased considerably. Noise in the transformer becomes high and core losses increase. The eddy currents cause rapid heating. Primary voltage increases for large capacitances (>1μF) while it decreases for small capacitances (in the range of pF).
5. A series combination of capacitors connected between live and neutral can act as a source of reduced voltage when the voltage is taken between a mid-point and earth. Generally the point nearest to the live conductor gives greatest voltage. The point nearest to the neutral gives lowest voltage.

6. Conclusion

The primary voltage control is normally done using taps. The commonly used method is on load tap changing (discussed earlier). But for this the transformer has to be designed such that the taps may be taken out. This is advantageous for large transformers for industrial applications e.t.c. For small transformers used in applications like making toy electromagnets this method may prove uneconomical.
In such cases the primary winding design need not be altered. As such passive elements like resistors, capacitors or chokes may be connected 'externally' with the primary winding and secondary current may be controlled. Capacitors when used for control can decrease primary voltage, increase primary voltage on proper connection. Also, capacitors can improve power factor. Resistors are cheap and can decrease primary voltage and secondary short circuit current. But carbon resistors are unsuitable because they burn out. Resistors result in small loss of power but the circuit can be easily and cheaply constructed. The circuit may prove useful for powering small electromagnets or telegraph sets. Chokes make the circuit bulky and reduce the power factor. So use of chokes should be avoided.

7. Acknowledgements

I'd like to express my sincerest gratitude to Mr. P.B Nandi (D.A.O-1) and Mrs. K Nandi for financing and encouraging this work and making it successful.

8. References

1. Transformer and Inductor Design [1] Handbook, Fourth Edition (Electrical and Computer Engineering) Hardcover – 4 May by Colonel Wm. T. McLyman (Author), 2011.

2. Transformer Engineering: Design, Technology, and Diagnostics [2], Second Edition Hardcover – Import, 10 Oct 2012 by S.V. Kulkarni and S.A. Khaparde
3. The J & P Transformer Book: A Practical Technology of the Power Transformer by A. C. Franklin, D. P. Franklin
4. Design of transformers [3] by Indrajit Dasgupta
5. Electrical Transformers and Power Equipment by Anthony J. Pansini