ENGINEERING REPORT

TERTIARY WINDINGS IN TRANSFORMERS

by

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INTRODUCTION

Purpose

The purpose of this report is to explain the use of the tertiary winding in transformers connected in Y-Y; to present data resulting from simple tests; and to state the conditions under which it is desirable to use the tertiary.

In modern practice, step-up or step-down transformer banks are ordinarily connected Delta-Y, with the Delta on the low-voltage side of the transformer. However, there exist Y-Y connected banks of transformers that for many reasons cannot be conveniently changed. The tests herein described, made on a bank of three single-phase transformers connected for three-phase transformation, may be of value to those who have had trouble with the Y-Y connection. The results of the tests would be applicable as well to a three-phase shell type transformer.

Tertiary winding

The tertiary winding in a bank of Y-Y connected single phase transformers consists of three independent windings connected in Delta, one winding on the core of each transformer. These windings may be a fraction of the main winding, connected independently. (See Fig. 6).

The purpose of the tertiary may be to correct the wave form, at the same time eliminating dangerous peaks in the voltages, by providing a path for the circulating current; to limit short-circuit currents; or to supply an auxiliary load.

THEORY

If a sine wave is desired on the secondary of a transformer, the flux that induces it must change as a sine function. The permeability of transformer iron changes as the flux density changes, as may be seen from a study of the hysteretic loop of the iron; hence, the rate of variation of the flux density is different from the rate of variation of the magnetizing current causing it. Therefore, if the flux density changes as a sine function, the magnetizing current cannot be sinusoidal.

The magnetizing current must contain some harmonic or harmonics. Assuming that, due to the change in flux density, a smaller magnetizing current is required in one part of the cycle than in another part, the magnetizing-current wave will be peaked. When the flux density in the iron is low, at the first part of the half-cycle, a smaller current, comparatively, will be required than in the latter part of the half-cycle, when the flux density is high. It is evident, then, that one peak per half-cycle is required, and that the third harmonic, having a frequency of three times that of the fundamental, satisfies this condition. Owing to the fact that the halves of the cycle of the magnetizing current must be identical, no even harmonics can exist. If the magnetizing current does not contain the necessary third harmonic component, the induced voltage will not be a sine wave.

In a bank of three single-phase transformers, the peaks of the third harmonic waves occur at the same instant in all three phases, causing a triple-frequency circulating current. If no path is provided for the flow of the circulating current, the third harmonic will appear in the voltage wave from line to neutral (see Fig. 4). The resulting voltage wave may have a high peak, causing high stresses on insulations, and dangerous voltages.

Paths for the circulating third harmonic are provided in the following cases:

1. Banks with any Delta connection.

2. Y-Y connected banks when neutrals of generator and transformer primary are grounded.

3. Y-Y connected banks when the Delta-connected tertiary winding is used.

Three-phase core-type transformers are not affected because the magnetic circuits, being mutually interconnected, are supplied with magnetomotive forces necessary to produce a sine wave by an interchange of magnetomotive forces from one phase to another.

APPARATUS

General Electric Oscillograph, Type E-M, Form C, No. 181916.

Three Westinghouse 10-kv-a. Transformers, 2200-440,220,110 volts; No. 355016, No. 399488, and No. 399489.

Westinghouse Alternating-Current Generator, 30 kv-a., 2200 volts, 60 cycles, Serial No. 1616113, 1200 r.p.m.

PROCEDURE AND DISCUSSION

Each of the three transformers contained four low-tension coils which could be connected in any way desired. For this work, two of these coils, connected in parallel, formed the secondary winding; while the remaining two coils, also connected in parallel, formed the tertiary winding.

The primary and secondary of the transformer bank were both connected in Y, while the tertiary was connected in Delta. The primary was supplied with excitation from the 2200-volt, three-phase, alternating-current generator. In series with the tertiary was placed an ammeter and a switch, in order that the conditions, with and without the tertiary circuit, might be studied; and that the c irculating current, flowing in the tertiary, might be measured.

Then, by means of the oscillograph, the wave forms of the voltages from line to line and from line to neutral, on the secondary, with and without the tertiary, were observed and recorded by tracing. The values of the current flowing in the tertiary when the circuit was closed were also observed. All voltages from line to line and from line to neutral were measured with an ordinary alternating-current voltmeter, while the voltages from neutral to ground and from each line to ground were measured with a static voltmeter. Readings were taken with the neutrals of the transformer both grounded and floating, as shown on the data sheet.

The wave form of the tertiary circulating current was also recorded on the oscillograph. This wave, which is of triple frequency, was superimposed upon the wave of voltage from line to line by operating the synchronous motor and one element of the oscillograph from the line voltage, and a second element from the current flowing in the tertiary. The result (Fig. 3) shows very nicely the fact that the circulating current is of triple frequency, and, therefore, that it is caused, mainly, by the third harmonic component of the magnetizing current.

The reason that this triple-frequency current is attributed to the third harmonic is explained as follows:

Since identical points on the third harmonic wave occur at the same time interval as the interval between the phases, i.e., 120 degrees with respect to the fundamental frequency, it follows that the third harmonics in all three phases must combine to form a triple-frequency circulating current, whenever a path for this current is provided.

The secondary of the transformer bank was then loaded by means of an induction motor, and readings of voltages and currents taken as before. As shown by the data sheet, no change in the amount of current flowing in the tertiary was observed. This was to be expected, since the circulating current is a phenomena due to magnetizing current, which does not change with the load.

The oscillograms in Fig. 4 show the waves of voltage from line to neutral, with and without the tertiary. The distortion of this wave when the tertiary is disconnected is evident in Curve 1. The shape of the wave also indicates that the distortion is due largely to a third harmonic component. Curve 2 shows the voltage wave after the tertiary circuit has been closed. It is obvious that such distortion of the voltage wave may lead to very high peaks, which will be liable to cuase rupture of insulations.

Size of
tertiary

The size of the tertiary winding necessary to carry the third harmonic component of the magnetizing current in the transformers under test was found to be very small. With the secondary coils in parallel for 110 volts, the exciting current was 1.45 amperes (supplied to secondary), or about 1.6 per cent of the full- load current. The circulating current was .14 amperes, or about 10 per cent of the exciting current. Therefore, the tertiary need have a capacity of only .10 x 1.6, or about .16 per cent of the capacity of the transformer. However, for transformers of larger size for power work, the magnetizing current, and consequently, the tertiary current, is larger in proportion. The harmonic component of the magnetizing current is also larger, being from 20 percent to 30 per cent of the total magnetizing current. Therefore, instead of a capacity of .16 per cent, the tertiary should have a capacity of from 1 to 2 per cent of the total kv-a. capacity of the transformer.*

For grounded neutral operation, the size of the tertiary winding is fixed by the short-circuit conditions,

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*J. H. Peters, Electric Journal, Vol. XVI, No. 11, pp. 477-480.

rather than by the conditions described above. The winding must contain sufficient copper to store the I^2R loss during the interval of time between the occurrence of the short and the operation of the circuit breakers, which is generally not more than three seconds.

The amount of the short-circuit current in the tertiary, as well as in the main winding, is dependent upon the impedance between the main winding and the tertiary, and between the primary and secondary of the main winding.

If I_n is the normal full-load current, Z_t the impedance between the main winding and the tertiary, and Z_o the impedance between the primary and secondary, the short-circuit currents will be as follows:

In the case of a ground on the primary side of the transformer, the short-circuit current will have a value of $\frac{I_n}{Z_t}$, in both the tertiary and the main winding, with each of the following connections: primary and secondary neutrals grounded, supply isolated; primary and supply neutrals grounded, secondary isolated. It is evident, then, that for faults on the primary side, the short-circuit current is limited entirely by the impedance between the tertiary and main windings.

In case of a ground on the secondary side, the short-circuit current in the tertiary will have the value, $\frac{I_n}{2Z_o + Z_t}$, and in the main winding, $\frac{3I_n}{2Z_o + Z_t}$, with each of the following connections: grounded neutral on primary and secondary; and grounded neutral on seconda ry and supply. When faults on the secondary occur, the short-circuit current is limited largely by the impedance between the main winding and the tertiary.

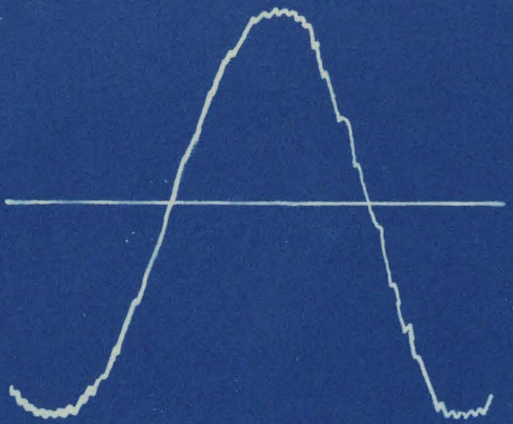
The impedance between the tertiary and the main winding should, preferably, be made large, in order that the short-circuit current, and, consequently, the capacity of the tertiary, may be small.*

*J. H. Peters, Electric Journal, loc. cit.

CONCLUSIONS

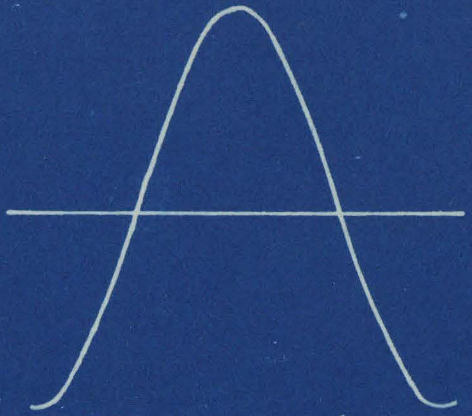
As a result of these investigations, it is evident that, where conditions necessitate the use of the Y-Y connection, the tertiary winding should be employed to take care of the third harmonic component of the magnetizing current, which, if not provided for, may cause dangerous peaks in the voltage from line to neutral, and hence to ground. Furthermore, since the Y-Y connection nearly always makes grounded neutral operation desirable, if not necessary, the tertiary should be used to limit the short-circuit currents in case of accidental grounding of any of the lines.

In some installations, it might be advisable to use the tertiary to carry an auxiliary load, so as to eliminate the necessity of having idle copper, such as would ex ist where the tertiary is designed to carry a large short-circuit current for a short period.



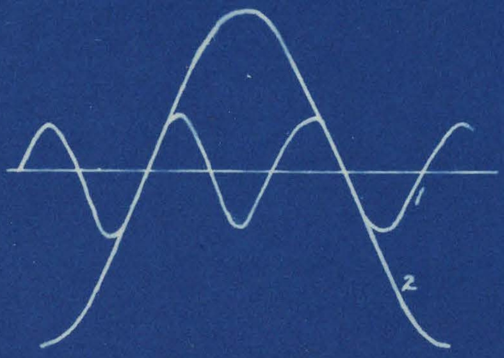
EMF line-line of Alternator

FIG. 1



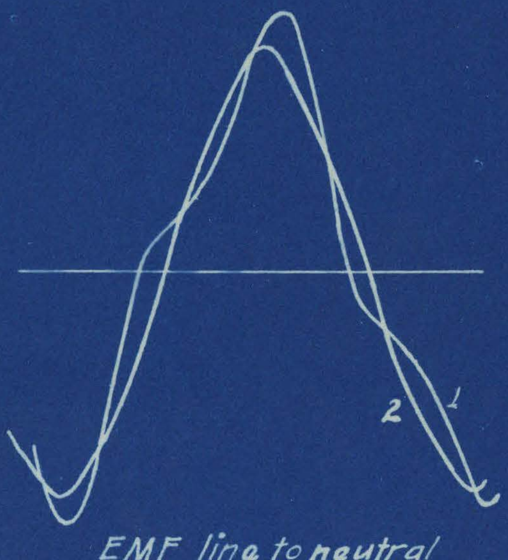
EMF line to line (L.T.)
H.T. neutral grounded

FIG. 2



1 Current in Tertiary
2 Current in line (L.T.)
L.T. & H.T. neutrals floating

FIG. 3



EMF line to neutral
1 without Tertiary
2 with Tertiary
(H.T. neutral grounded
or floating)

FIG. 4