VERIFICATION OF POWER TRANSFORMERS VECTOR GROUP BY MEANS OF A SIMPLE AND PRECISE PROCEDURE

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ABSTRACT: *Vector group of power transformers is a key element for several operational situations involving power transformers. Parallel operation of power transformers is not possible unless all transformers connected in parallel have the same vector group, among other conditions. Differential protection of power transformers has to be adjusted to consider the phase displacement corresponding to the vector group. Although vector group is a parameter guaranteed by the manufacturer and mentioned on the transformer name plate, in practice could be necessary to verify it before the transformer is put in service. If a transformer is manufactured with a specific vector group, if used in power systems with reverse phase sequence, then the resulting vector group is different, which can have important design and operational consequences.*

KEY WORDS: Power transformer; Vector group; Electrical testing

1.INTRODUCTION

Vector group is a critical design parameter of power transformers and it specifies the phase displacement between primary and secondary windings of the transformer. Vector group notation specifies the winding configuration (star, delta or zig-zag) and the phase angle between voltage in the secondary winding (considered as reference) and primary winding [1]. The first uppercase letter designates the primary winding configuration the second lowercase letter designates the secondary winding configuration [2]. The three letters used in vector group notation are Y(y) for a star connected winding, D(d) for a delta connected winding and Z(z) for a zig-zag connected winding. In power systems where the neutral of the star-connected winding is earthed (either solidly of through other methods) the letter Y(y) is followed by N(n).

The phase shift is denoted as an integer ranging from 1 to 11, the actual displacement is obtained by multiplying the vector group number (also known as clock number) by 30°. It is important to consider the positive rotation direction.

Example: (1) Yd1 – Primary winding is star-connected (star point is isolated), secondary winding is delta-connected, the secondary voltage lags the primary voltage by 30°.
Example: (2) YNd11 - Primary winding is star-connected (star point is earthed), secondary winding is delta-connected, the secondary voltage leads the primary voltage by 30°.

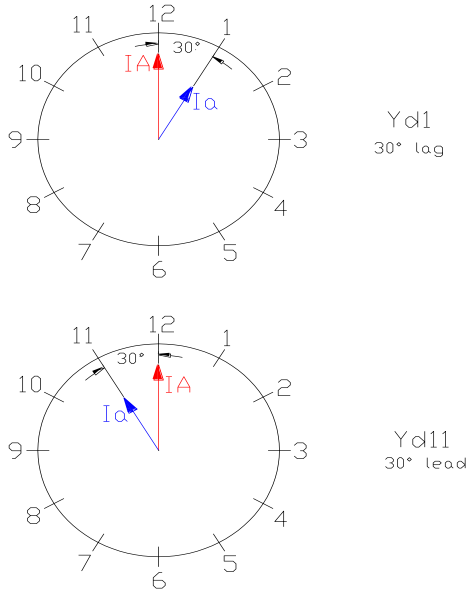

Figure 1. Phase shift for clock numbers 1 and 11 respectively for star-delta connection

.2. PHYSICAL CONNECTIONS FOR VARIOUS VECTOR GROUPS

In order to obtain a given vector group the theory of transformer can be employed. In order to obtain a given vector group the theory of transformer can be employed. In Figure 2 two basic vector groups are presented – Yy0 and Yy6. With both windings star-connected and maintaining the polarity of the windings (denoted in Figure 1 by the black dot) the Yy0 vector group can be obtained (zero phase shift between primary and secondary windings currents.

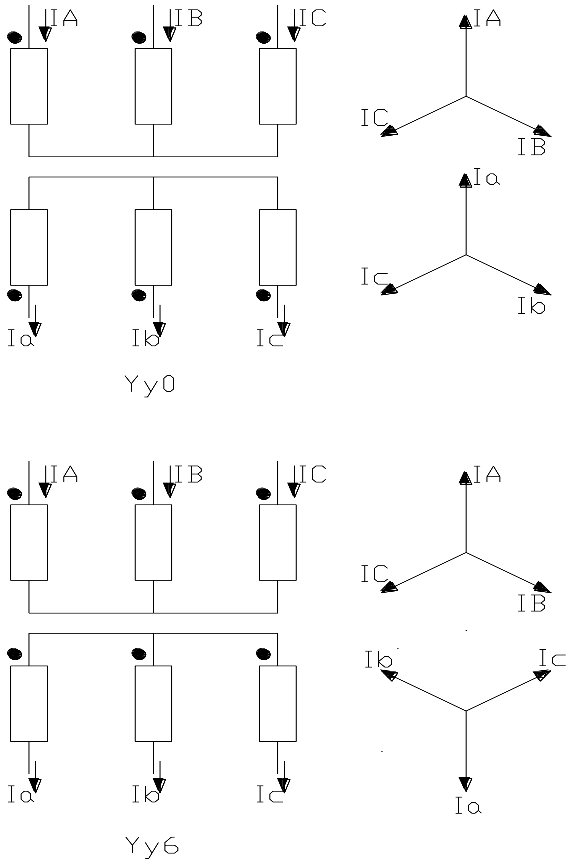

Figure 2. Vector group Yy0 and Yy6

In case of a delta-connected secondary winding the phasor diagrams are presented in Figure 3. The clock number of the Yd connection presented in Figure 3 can be obtained if the relationships between the winding currents - phasors I_x, I_y, I_z and the currents at the outputs of the transformer - phasors I_a, I_b, I_c are considered:

$$I_a = I_x - I_y \quad (1)$$
$$I_b = I_y - I_z \quad (2)$$
$$I_c = I_z - I_x \quad (3)$$

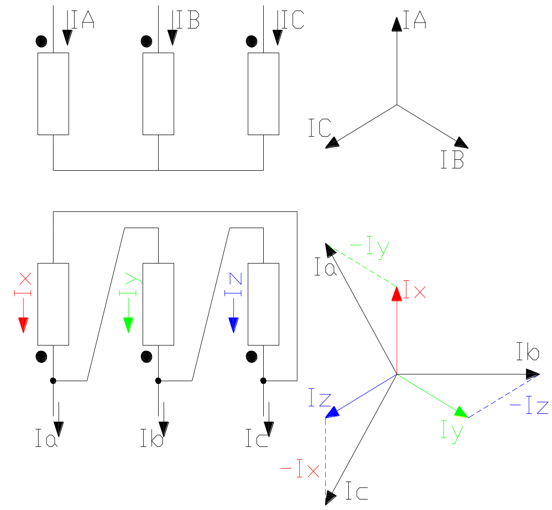

Figure 3. Phasor diagrams for Yd vector group

It can be noticed that the current in secondary winding leads the current in primary winding by 30°, which results in clock number 11. Swapping the polarity the vector group Yd7 (Figure 4) is obtained. In order to obtain the clock number 1, the following winding configuration is employed (Figure 5). In this case, the relationships between currents are as follows:

$$I_a = I_x - I_z \quad (4)$$
$$I_b = I_y - I_x \quad (5)$$
$$I_c = I_z - I_y \quad (6)$$

This results in a vector group Yd1.

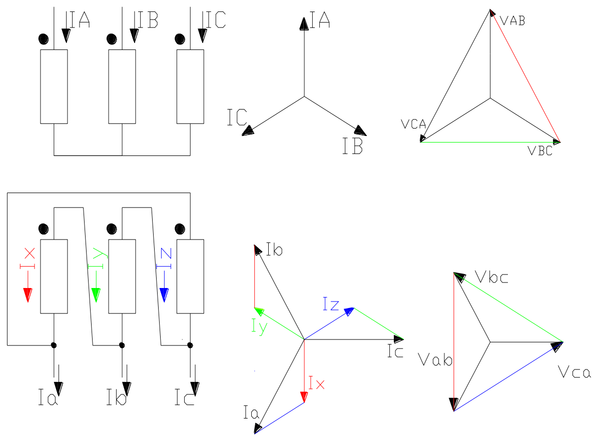

Figure 4. Yd7 vector group derived from Yd11 by swapping the LV windings polarity

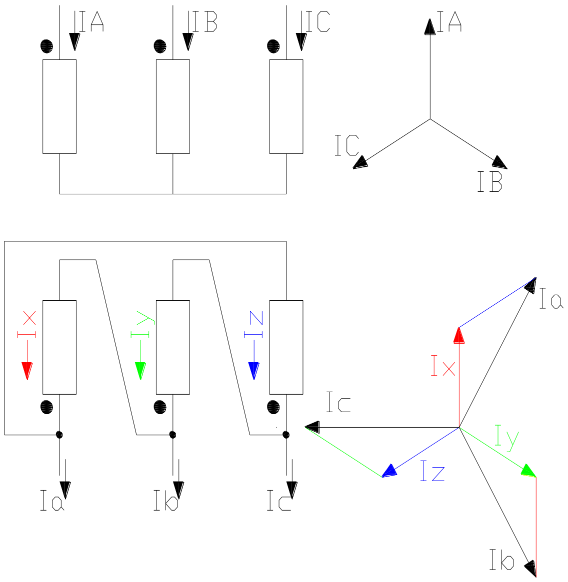

Figure 5. Vector group Yd1

Test set-up and procedure

In order to describe the procedure, a power transformer 132/33 kV is considered employing vector group Yd1 (as it is the one presented above). The transformer is supplied in the primary winding with a symmetrical voltage system 400 VAC with phase rotation L1L2L3. Then phase A of the secondary winding is connected to the star point of the primary winding. Considering the primary voltage system:

$$V_A = 400/\sqrt{3}\angle 0° \quad (7)$$

$$V_B = 400/\sqrt{3}\angle -120° \quad (8)$$

$$V_C = 400/\sqrt{3}\angle 120° \quad (9)$$

The resulting voltages in the secondary of the transformer are:

$$V_{ab} = 100\angle 0° \quad (10)$$

$$V_{bc} = 100\angle -120° \quad (11)$$

$$V_{ca} = 100\angle 120° \quad (12)$$

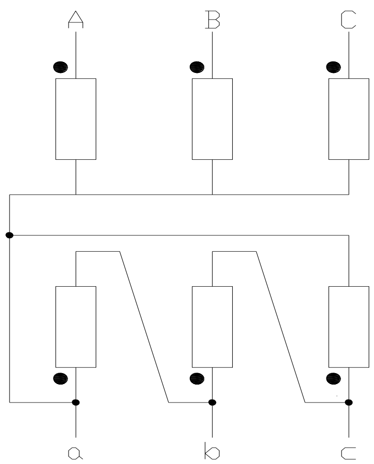

Figure 6. Connection for verifying Yd1

The connection in Figure 6 will result in an equal potential between the primary winding star point and the secondary winding phase A (denoted a). In phasor diagram, this equality is presented in Figure 7.

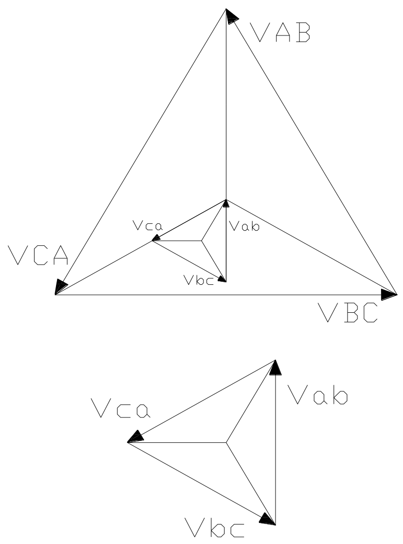

Figure 7. Phasor diagram resulting from connecting HV star point with LV phase A

Measuring the voltage between the points indicated in Table 1, these values can be then compared with the expected values. The theoretical values can be determined from the phasor diagram, presented in Figure 8.

Table 1. 1st characteristic set of voltages for Yd1 vector group

Measurement points	A - c	B - c
Voltage value	$V_A - V_{ca}$	$V_{ca} - V_B$

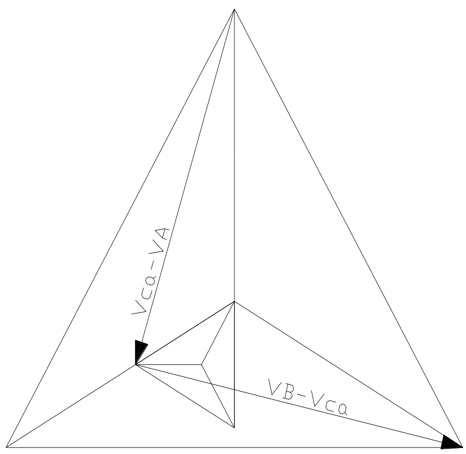

Figure 8. Phasor diagram for determining the voltages in Table 1

With primary and secondary voltage values given in Eqs 7-12, the values in Table 1 can be determined as follows:

$$V_{A-ca} = 400/\sqrt{3}\angle 0° - 100\angle 120° = 294.2\angle -17.1°$$

$$V_{ca-B} = 100\angle 120° - 400/\sqrt{3}\angle -120° = 294.2\angle 77.1°$$

The phasor sum of the voltage phasors in equations above is:

$$V_{A-ca} + V_{ca-B} = 294.2\angle -17.1° + 294.2\angle 77.1° = 400\angle 30°$$

This value is exactly V_{AB}, which can be confirmed from phasor diagram in Figure 8.
It can be noticed that the two voltages above have the same absolute value.
The same reasoning can be applied to the other voltages shown in Table 2.

Table 2. 2nd characteristic set of voltages for Yd1 vector group

Measurement points	C - b	B - b
Voltage value	$V_{ab} - V_C$	$V_{ab} - V_B$

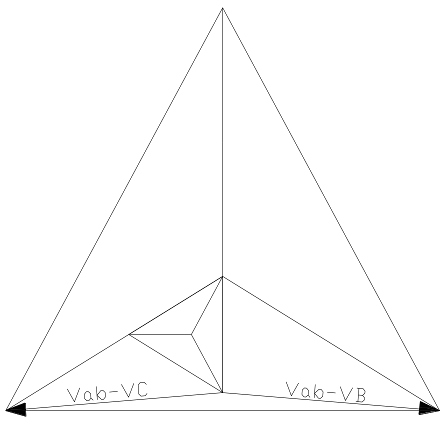

Figure 9. Phasor diagram for determining the voltages in Table 2

The characteristic voltages in Table 2 and phasor diagram in Figure 9 can be determined as follows:

$$V_{ab-C} = 100 - 400/\sqrt{3}\angle 120° = 200.8\angle 94.4°$$

$$V_{ab-B} = 100 - 400/\sqrt{3}\angle -120° = 200.8\angle -94.4°$$

One more characteristic voltage can be measured between terminals A – b will result in the following voltage:

$$V_{A-ab} = V_A + V_{ab} = 400/\sqrt{3}\angle 0° + 100\angle 0° = 331.2\angle 0°$$

The connection described here is not unique. If the star point of the transformer is not available then terminal *a* (LV, phase L1) can be connected to terminal *A* (HV, phase L1), which results in the phasor diagram shown in Figure 10.

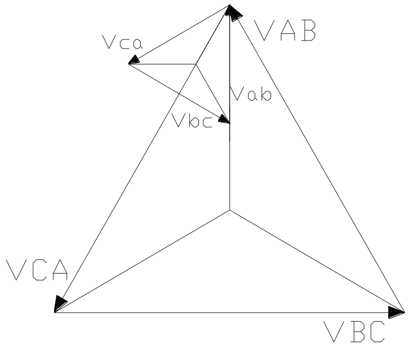

Figure 10. Phasor diagram for connection A – a (HV star point not available)

CONCLUSIONS

Vector group is a critical element not only in power systems but also in special applications, such as HVDC [3]. Power transformer vector group can be determined by means of dedicated test instruments such as TTR (Turn Ratio Testers) [2, 4, 5] or by simple and rapid method such as the voltage method, described in this paper with specific examples. Vector group employed usually in power systems are Yd11, Yd1 and Yd5. Using a delta-connected winding on the LV side ensures that zero sequence component of current occurring during earth faults does not cause a current imbalance on the HV side, as it cannot pass through a delta winding. There are other less usual vector group employed in special applications, such as HVDC.

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