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Developed Method and Modelling of Three-phase Transformer Vector Groups Using ANSYS Maxwell

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ABSTRACT

This paper presents a developed method to connect the terminals of low voltage (LV) and high voltage (HV) windings of any given vector group connection. This method is validated by modeling different types of vector groups of three-phase transformers using three-dimensional ANSYS Maxwell. Also, it is based on drawing transformer vector group connection on clock showing phase displacement. For a given transformer vector group connection, the connection between the terminals of LV and HV windings can be deduced by using this method. Different connections of high and low voltage windings can be simulated using a three-dimensional ANSYS Maxwell based on finite elements method. The three-dimensional model of three-phase transformer indicates the winding direction, which affects transformer vector groups. The paper also describes how winding connection and phase angle between the high line voltage and Low line voltage. The paper's objective is to understand and apply this method for a given transformer vector group. And, how to model different types of transformer vector groups using three-dimensional ANSYS Maxwell to obtain comparative analysis. The transformer vector groups are very important in the transformer parallel operation.

Keywords: Three-phase transformer, Developed method, Clock showing phase displacement diagram, Connection group, ANSYS Maxwell.

1. INTRODUCTION

The three-phase transformer vector groups are very important parameters in the parallel operation of transformer and comparative analysis can be obtained by using different types of vector groups for transformers. The transformer vector groups can be selected according to the application.

A three-phase transformer is one of the important equipment's in power grid. In addition to the KVA ratings and voltage ratios one of the most important specifications is the vector group of transformers. The vector groups show the connection way of LV and HV windings and phase displacement angle between the high and low line voltage. To prevent high circulating current flow between parallel transformers, the parallel transformers must have the same vector group. Also, if vector groups can't be obtained, then input and output voltage, no-load current and iron losses can't be determined properly [1].

The LV and HV windings of three-phase transformer can be connected in different ways. The application characteristics determine the connection way of these windings.

The transformer vector groups are written on the transformer name plate according to connections between LV and HV terminals. With increasing the load demand, the parallel operation of three-phase transformer is required. In the parallel operation of three-phase transformer, the vector groups one of the main parameters must be considered [1]. The vector group is the guide for showing the connections between LV and HV windings of three -phase transformer, which is being approved by international electro technical commission (IEC). In practice, the voltage measurements on two LV and HV are used to obtain the vector group from [1, 2].

The three-phase transformer model is created on three-dimensional ANSYS Maxwell based on finite element method (FEM). FEM is used to study the magnetic effects on the characteristic performance of transformers. Also, FEM is used to determine a more detailed transformer model. The FEM theory divides the model into small elements, analyzing each element, and then adding these results [3, 4].

The paper's objective is to understand and apply the developed method for a given transformer vector group. And, how to model different types of transformer vector groups using three-dimensional ANSYS Maxwell.

2. THREE-PHASE CONNECTIONS

The connections between LV and HV windings of three-phase transformer can be done in many ways to meet the practical requirement. The LV and HV windings can be connected as star (Y), delta (D) and interconnected-star or zig-zag (Z). The voltage and current ratings depend on the connection of three-phase transformer windings. A vector group of three-phase transformers indicates the connection way of LV and HV windings and phase angle between the lowline voltage and high line voltage sides [1, 2].

The LV windings or HV windings of three-phase transformer can be connected in either Y or D respectively. Therefore, the four possible connections can be obtained [1, 2]. 1. Delta-star connection; 2. Delta-delta connection; 3. Star-star connection; 4. Star-delta connection.The delta-star transformer connection is used in the low power distribution system. The high voltage windings are connected as delta to provide a three-wire balanced load to the utility company while the low voltage windings can be connected as star to obtain the required four-wire neutral or earth connection. When the LV and HV windings have different types of winding connections, the transformer overall turns ratio becomes more complicated [1, 2].

Three-phase transformer is divided into four main groups according to the phase displacement between the low and high line voltage. Phase displacement is the delay angle of low line voltage to high line voltage, and it is measured in units of 30° in clockwise direction. The four groups are shown in Table 1. The simulation of different groups of the three- transformer can be done using maxwell external circuit. In maxwell external circuit, the transformer terminals can be changed to simulate any transformer connection.

Table 1. Group No. of Various Winding Designs

Group No.	Phase Displacement	Connection
1	0^o	Yy0, Dd0, Dz0
2	180°	Yy6, Dd6, Dz6
3	-30°	Yd1, Dy1, Yz1
4	30°	Yd11, Dy11, Yz11

3. PHASE DISPLACEMENT

According to IEC coding technique, the vector groups can be represented by using letters and numbers for HV and LV windings. The first capital letter is used for the HV winding while the second small letter is used for LV winding. And the third letter is represented to the neutral connection in the case of distribution transformers. Finally, the number represents the value of phase angle between the high and low line voltage [2].

The high line voltage vector is a stationary at 12 clock and is taken as reference. While low line voltage phasor is rotating with respect to high line voltage vector, to represent phase angle between the high and low line voltage. The rotation direction of the low line voltage phasor will determine the phase angle sign. For anti-clockwise rotation, the phase angle is positive (low line voltage leads high line voltage), and the phase angle is negative (low line voltage lags high line voltage) for clockwise rotation. Each hour is represented to 30^0, therefore 1st hour= 30^o, 2nd hour= 60^o and so on. Hence, the phase angle varies in steps of 30 degrees. as shown in Fig.1 and Fig.2 [1]. When the LV phasor moves clockwise, the phase angle is changed. Each hour is represented to 30^0 so the phase angle is increased by $30\,^o$ for each hour are shown in Table 2.

Table 2. Phase displacement of various LV phasor positions

LV phasor position	Phase Displacement
12 - clock	0^o
1 - clock	-30^o
2- clock	-60^o
3- clock	-90^o
4 - clock	-120^o
5 - clock	-150^o
6 - clock	-180^o or 180^o
7 - clock	-210^o
8 - clock	-240^o
9 - clock	-270^o or 90^o
10 - clock	-300^o or 60^o
11 - clock	-330^o or 30^o

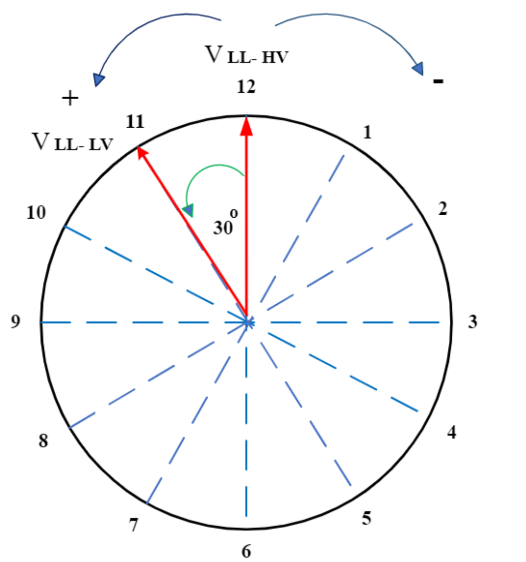

Figure 1: Clock showing phase displacement: The $V_{LL\text{-}LV}$ leads $V_{LL\text{-}HV}$ by 30^o.

According to transformer connections, the phase angle varies from 0^o to 330^o in steps of 30^o. The phase angle is written in the fourth position of vector group by using the corresponding clock position. For example, For Dyn11 the clock hour is 11. The clock hour determines the angle between low line voltage and high line voltage. And according to the rotation direction of the low line voltage phasor, the low line voltage leads (anti-clockwise or +) or lags (clockwise or -) the high line voltage. In the connection of Dyn11, the low line voltage leads the high line voltage vector by 30^o, or the high line voltage lags the low line voltage by 30^o.

4. DEVELOPED METHOD TO CONNECT THE TERMINALS OF HV AND LV WINDINGS IN VECTOR GROUP CONNECTION

By using this method, any transformer vector group connection can be drawn on clock showing phase displacement. After that, the connections between terminals for LV and HV windings can be deduced from this drawing.

The direction winding of LV and HV windings for each transformer limb is the same. Therefore, the polarity of induced voltages in the LV and HV windings are in the same direction. The induced voltages in the LV and HV windings are increased or decreased simultaneously for the same polarity ends of the windings. The same polarity ends can be represented using dot convention as shown in Fig. 3.

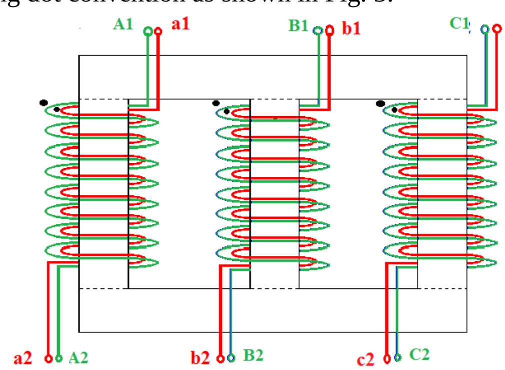

Figure 2: terminals for HV and LV windings.

If the HV and LV winding terminals are known, the winding polarity (winding direction) can be determined according to [5].

Once the polarities for the LV and HV windings are determined, the vector group connection can be drawn on clock showing phase displacement diagram. For drawing the vector connection Dyn 1, assume the capital letters (A, B, and C) for the three HV terminals. And the small letters (a, b, c and n) correspond to LV terminals. **The method has three steps as following:**

The first step: drawing the LV sides as following an, bn and cn, where the terminal a at 1 0' clock and the phase shift between them equals to 120^o.

The second step: from HV and LV winding polarities, the HV coils parallel to LV coils can be obtained. Therefore, the HV sides CA, AB and BC are drawing parallel to LV sides an, bn and cn respectively. Each two coils (one from HV and LV windings) on each transformer limb are parallel.

The third step: the dot polarity can be added at HV and LV terminals as shown in Fig. 4.

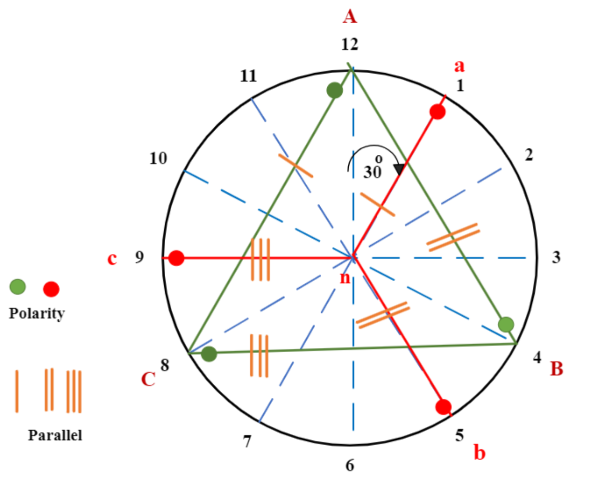

Figure 3: Clock showing phase displacement diagram of Dyn1.

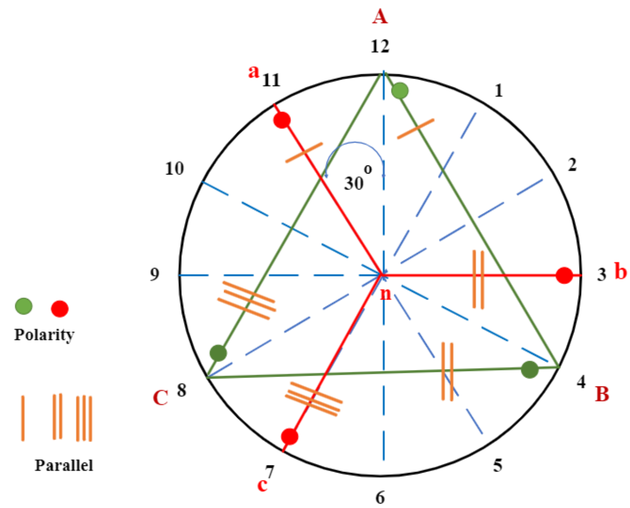

Figure 5: Clock showing phase displacement diagram of Dyn11.

The fourth step: From clock showing phase displacement diagram, can be deduced the connections between terminals for HV and LV windings steps as shown in Fig. 5. Starting at dot terminal of any phase and moving through coil of this phase to the dot terminal of another phase and so on to obtain the connection. The output terminals can be taken at circle peripheral.

For Dyn1, to form LV winding wye (y), the connections can be easily deduced. The un- dot terminals are connected to neutral, the dot terminals represent the output terminal of y. For HV winding delta (D), starting at dot terminal of A and moving through coil A to the dot terminal of C. Then, from dot terminal of C and moving through coil C to the dot terminal of B. finally, from dot terminal of B and moving through coil B to the dot terminal of A. The output terminals can be taken at dots.

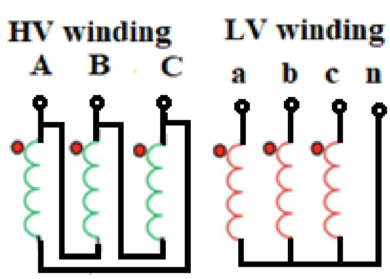

Figure 4: Connections between terminals for HV and LV windings for Dyn1.

Another example, for drawing the vector connection Dyn11. It can be drawn using the pervious steps as shown in Fig.6. But in the first step, the terminal a at 11 0' clock.

Also, connections between terminals for HV and LV windings for Dyn11 can be deduced using the fourth step: as shown in Fig. 7.

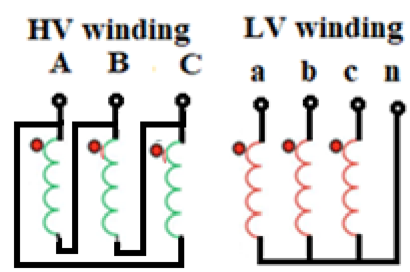

Figure6: Connections between terminals for HV and LV windings for Dyn11.

Therefore, by using this method can be deduced the connection between the LV and HV winding terminals to form any vector group connection. This technique can be repeated for any transformer vector group connection and can be validated using maxwell ANSYS model of transformer vector group connection.

5. THREE-DIMENSIONAL MAXWELL ANSYS OF TRANSFORMER AND EXCITATION CIRCUIT

A three-phase transformer is simulated using three-dimensional maxwell ANSYS as shown in Fig. 8. The transient solution is used for the computation of results.

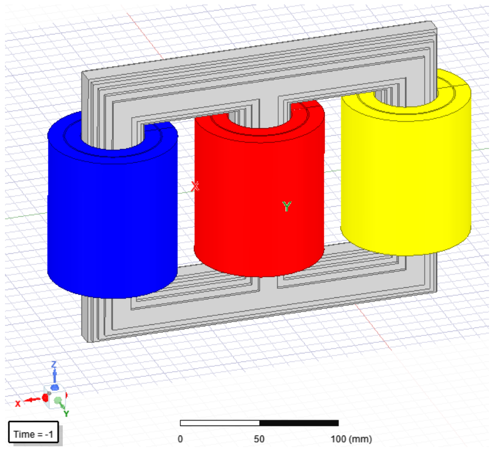

Figure 7: Three-dimensional maxwell ANSYS model of three-phase transformer

By setting the excitation of the transformer winding using external maxwell circuit design. Therefore, the LV and HV winding of three-phase transformer will appear in maxwell circuit as shown in Fig.9.

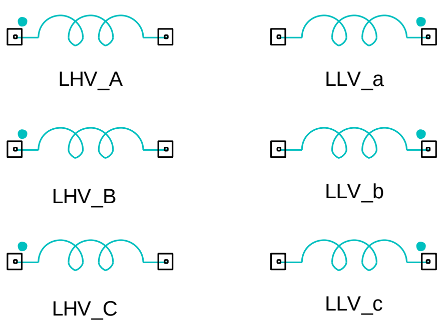

Figure 8: HV and LV winding of three-phase transformer in the maxwell circuit.

The LV and HV winding of three-phase transformer can be connected in many methods (delta-delta, delta-star, star-star, star-delta, and so on). Based on the LV and HV winding connections, the vector group of the transformer is determined. Using maxwell external circuit, the transformer terminals can be excited and changed for each case of transformer connection. Fig. 10, Fig. 11, Fig. 12, Fig. 13 show the different external excitation circuits of the different transformer vector group.

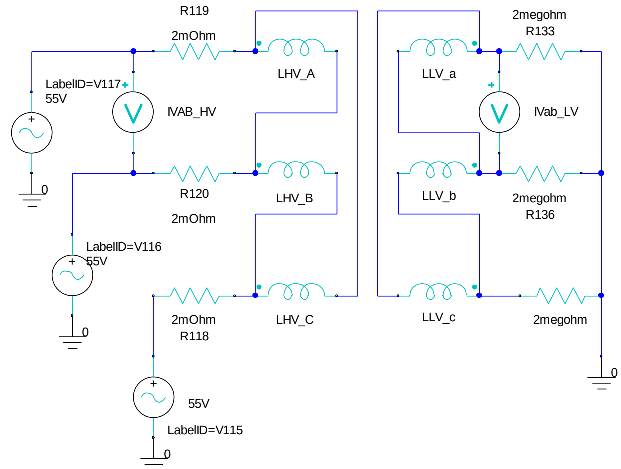

Figure 9: External excitation circuit of three-phase transformer star-star connection (Dd0).

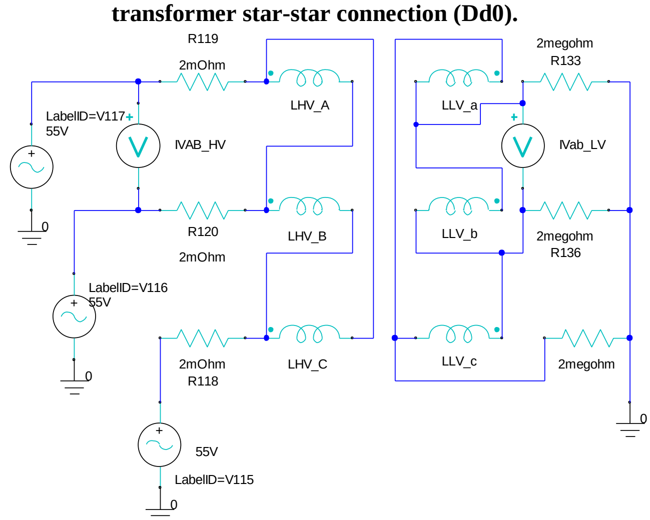

Figure 10: External excitation circuit of three-phase transformer star-star connection (Dd6).

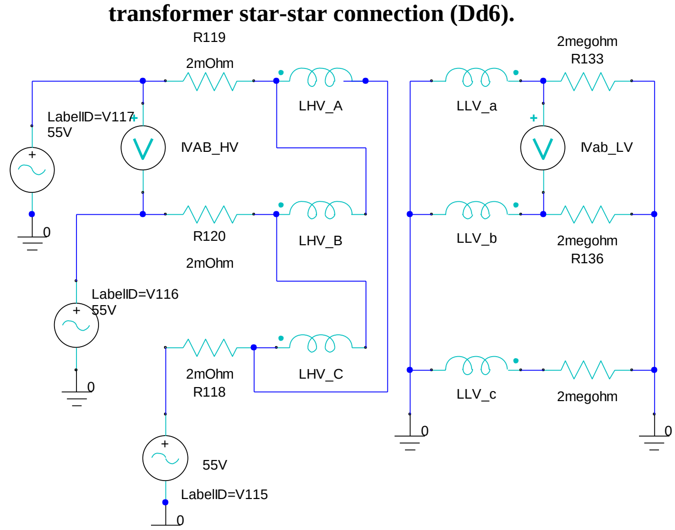

Figure 11: External excitation circuit of three-phase transformer star-star connection (Dyn1).

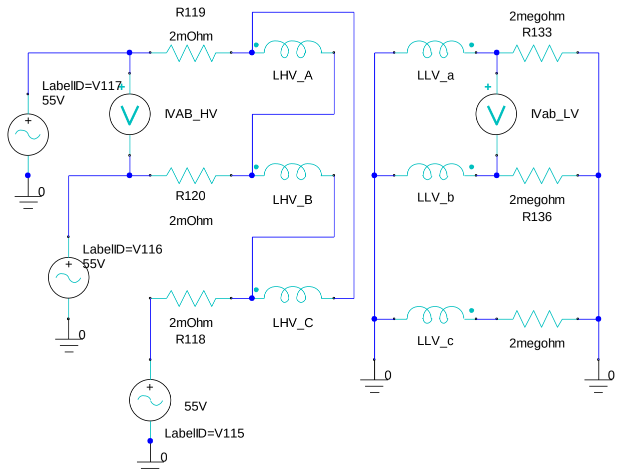

Figure 12: External excitation circuit of three-phase transformer star-star connection (Dyn11).

6. MAXWELL ANSYS RESULTS

The simulation results of four groups (Dd0, Dd6, Dyn1 and Dyn11) are shown in table 3, table 4, table 5 and table 6. The high line voltage ($V_{AB\text{-}HV}$) is taken as reference, and it is angle equals to 0^o. It is noticed that the angle of low line voltage ($V_{ab\text{-}LV}$) varies according to the transformer connection.

Table 3. Connection Dd0 simulation result

Freq [Hz]	Ang_deg (Node Voltage (V_{AB_HV}) [deg]	Ang_deg (Node Voltage (V_{ab_LV}) [deg]
50	0	0

Table 4. Connection Dd6 simulation result

Freq [Hz]	Ang_deg (Node Voltage (V_{AB_HV}) [deg]	Ang_deg (Node Voltage (V_{ab_LV}) [deg]
50	0	180^o

Table 5. Connection Dyn1 simulation result

Freq [Hz]	Ang_deg (Node Voltage (V_{AB_HV}) [deg]	Ang_deg (Node Voltage (V_{ab_LV}) [deg]
50	0	- 30^o

Table 6. Connection Dyn11 simulation result

Freq [Hz]	Ang_deg (Node Voltage (V_{AB_HV}) [deg]	Ang_deg (Node Voltage (V_{ab_LV}) [deg]
50	0	30^o

In Dd0, the phase displacement is equals to 0^o. The phase displacement of Dd6 is 180^o (30*6=180^o). For Dyn1, the phase displacement is -30^o (The $V_{ab\text{-}LV}$ lags $V_{AB\text{-}HV}$ by 30^o). The simulation results are as data given in table.1. Therefore, the simulation results are very accurate.

7. CONCLUSION

From the simulation maxwell results, the calculation of phase displacement value between the transformer windings is accurate. Therefore, based on these results the winding direction and connection of winding terminals are determined if the transformer is still in the design stage. Also, the transformer maxwell model can be used to check the group connection on transformer nameplate. The transformer vector groups using ANSYS Maxwell saves time and reduces the cost.

8. REFERENCES

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