

A Review about Vector Group Connections In Transformers

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Abstract

Transformer is the most important unit in an electrical distribution network. All transformers are subjected to various tests at the manufacturer's test laboratory before despatch to the destination of erection. Measurement of turn's ratio is one of the routine tests which each transformer has to undergo. In the case of an ordinary winding resistance meter, we can measure the winding resistance and the contact resistance together. It is not possible to measure the contact resistance separately by this meter. Now contact resistance meter is available, it is designed to measure the contact resistances of various Test Objects such as Transformers, Circuit Breakers, Isolators, Bus-bar joints, Welded joints etc. Advanced winding resistance ohmmeter with Dynamic resistance measurement for OLTC is available now with an International trademark. The dynamic resistance measurement detects carbonized spots and weak contacts in the mechanism of a tap changer. In this paper, I wish to discuss the practical differences created in the turn ratio measurement because of the tap switch contact resistance.

Keywords: *Transformer, circuit breakers, contact resistance, tap changer*

1. Introduction

The three distinct ways by which a three phase windings can be connected are Star connection, Delta connection and Inter-star connection. Delta and star connections are most commonly used. Inter-star connection finds occasional applications, mostly in specialized constructions like earthing transformer and transformers for multiple pulse circuits. As an example, in a two winding transformer, the primary winding can be connected either in star, or in delta or in inter-star; similarly, the secondary winding can be collected in star or in delta or in inter-star. It is common practice to denote high voltage connections in delta by D, in star connection by Y and in inter-star connection by Z. The lower Case letters are applicable for the lower voltage connections (d, y and z). Based on this, it is theoretically possible to connect any pair of windings in a 3 phase transformer in the following pairs of combinations: Dd, Dy, Dz, Yd, Yy, Yz, Zd, Zy and Zz; of this, the first six, are the most commonly encountered ones in practice. As is well known, there is a phase angle difference between primary and secondary voltages. This phase difference varies in steps of 30 degrees (the movement achieved in terms of degrees on a clock when you move from one specified hour position to next). Hence 12'0 clock position represents zero degrees. As we move clockwise, each subsequent hour position adds 30 degrees to the previous position. As examples

- 1'0 clock position signifies 30 degrees (phase shift of 30 degrees to right)

- 6'O clock position signifies 180 degrees
- 11'O clock position corresponds to 330 degrees (phase shift of 30 degrees to left)

Depending upon the individual connections, this phase shift (from 0 to 330 degrees in steps of 30 degrees) needs to be mentioned along with connection combination. This is practically done using the corresponding clock position. The clock position indicates the angle by which secondary vector leads or lags the primary vector. In case of Dyn11, the secondary vector leads the primary vector by 30 degrees, where as in Dy1 connection, secondary vector lags the primary vector by 30 degrees.

2. What is polarity?

When the pairs of coils have the same winding direction, then the voltages of induction in both the coils are in the same direction, from one end to the other. But when the two coils are having opposite winding directions, the voltages of induction are in opposite directions. We are applying an alternating voltage to the equipment. Hence there is nothing like a positive or negative polarity. But for connections, we need to consider the instantaneous direction of voltages (polarity) of the selected ends. This basically depends on the directions of the windings and the ends selected for connection. The direction of winding for the coils and the method of interconnection are specified by design department. Winding directions change depending upon the direction of rotation of machine, the direction of copper feeding and the starting (and finishing) ends. It can also change because of manufacturing inconveniences. The verification of polarity for interconnections and of turns ratio is carried out by means of a single phase fed ratiometer . The polarity has to be verified immediately after assembly of coils on the core with top yoke in position, prior to starting any connection activities.

2.1 Instantaneous Polarity

The ratiometer establishes the instantaneous polarities of the pairs of windings on a particular limb. It is also necessary that the coil sets on each of the three limbs of a given transformer are all identical in their winding directions.

Let us mark the two windings of high voltage winding as H1 and H2 (it does not matter which one is which). Similarly, let us mark the two ends of low voltage winding as L1 and L2. To establish relative polarities between two windings on a give phase, connect one end of high voltage winding (say H2) to one end of low voltage winding (say L2) on this phase. Apply 230 volts to H1-H2. For this example let us take a ratio of turns to 1. This means that the transformed voltage on LV side is also 230 volts. Measure the voltage between H1 and L1. One of the two following scenarios can arise either additive or subtractive polarity.

2.2 Additive Polarity

As shown in Fig 1., the voltage is 460 volts. This means that, in the voltmeter circuit, the two voltages are, additive. Alternately, the voltage in winding is in direction H2 to H1

and in low voltage winding it is from L1 to L2. This means that the points we have interconnected are not of same polarity. At the give instant, these voltages add. Hence corresponding-terminals of like polarity are H2 and L1 (or H1 and L2)

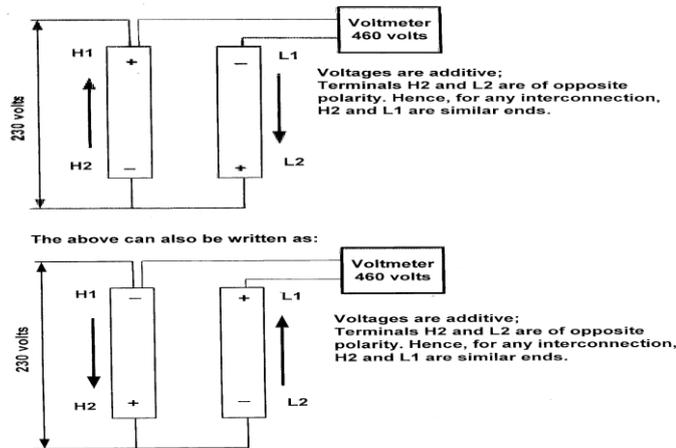


Fig.1: Additive Polarity

2.3. Subtractive Polarity

As shown in Fig 2., the voltage is zero. This means that in the voltmeter circuit, the two voltages are subtractive. Alternately, the voltage in winding is in direction H2 to H1 and in low voltage winding it is from L2 to L1. This means that the points we have interconnected are of same polarity. At the given instant these voltages subtract. Hence corresponding terminals of like polarity are H1 and L1 (or H2 and L2).

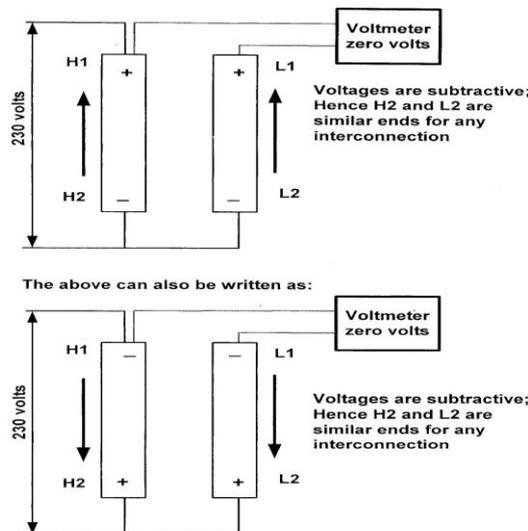


Fig.2: Subtractive Polarity

3. Verification of Vector group



Fig.3: Ratiometer

The ratiometer does precisely this by establishing the correct polarities for the two windings. Once we get the correct ratio with right polarity, then the terminals to which plus terminal of ratiometer HV side and LV side are connected are the like terminals of same polarity for any interconnection. Similarly, the terminals to which the minus terminal of ratiometer HV side and LV side are connected are the like terminals of same polarity (but opposite to that of the first pair) for any interconnection. It is very important to understand the above concept. Once this is clear, the rest is very easy. As an example, assume the three HV terminals to be U, V and W. Let the corresponding LV terminals be u, v, w and n. Then for vector connection Dyn 11, the following is the correspondence between HV and LV side.

- ‘UV’ should correspond to ‘un’ (with U and u being of one polarity; V and n form the second pair of terminals with opposite polarity).
- Similarly, ‘VW’ corresponds to ‘vn’ and ‘WU’ corresponds to ‘wn’.

Both the following ratiometer connections are correct for vector connection Dyn11, except that whatever mode of connection is chosen, it must be cyclically repeated for all three phases.

Table 1: Ratiometer connections

Ratiometer HV side to Transformer HV side		Ratiometer LV side to Transformer LV side	
U is +ve	V is -ve	u is +ve	n is -ve
U is -ve	V is +ve	u is -ve	n is +ve

3.1 Conditions for Vector Check

The vector connection forms one of the most important parameters from user's perspective, Hence it is very essential to verify that the inter-winding connections are indeed as per customers' requirements. The ratio meter used for measuring no-load voltage ratio, functions only when primary and secondary winding polarities are identical for the connection made. Hence establishment of the polarity of individual windings is a

comparatively easy task. For multi-winding transformers, two definite reference points are physically connected so that it is suitable to apply a 3 phase voltage. A low magnitude (normally about 400 volts) 3 phase AC voltage is applied on the high voltage winding and all the possible voltages are measured.

Example:

We consider the case of a Dyn 11 transformer.

The polarity references phase by phase are:

UV - un ; VW - vn ; WU - wn.

We connect "U" phase of high voltage winding to "u" phase of low voltage winding. We apply - 400 volts, 3 phase voltage at 50 Hz (our supply frequency) to the high voltage delta side. We measure the all possible voltages.

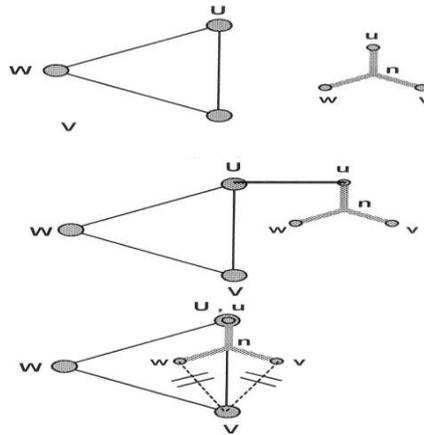


Fig. 4: Vector Group Connections

For connection Dyn 11 ,the following conditions must be satisfied:

$$V_v = V_w$$

$$W_v > W_w$$

$$U_n + V_n = UV$$

$$W_n > V_n$$

Such a superposition is possible for all types of connections. A voltmeter with a high input impedance has to be used for such measurements (Eg., digital meters)

4. Winding Directions

The standards define various vector connections. They assume same winding direction in both the windings and indicate corresponding pairs of terminals that gives the required vector group.

4.1 Same Winding Directions

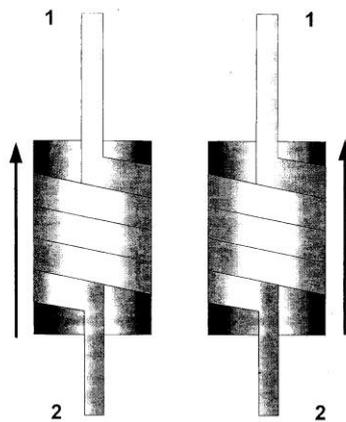


Fig. 3: Same Winding Direction

The hypothetical helix is in the same direction in both the coils viewed from either end. Hence induced voltages in the energised coil and the other coil are in the same direction; In other words, the terminals 1 and 1 have the same polarity; the terminals 2 and 2 have the same polarity, but the polarity is opposite to that of the pair 1 and 1.

4.1 Opposite Winding Directions

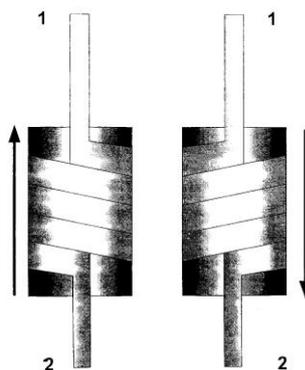


Fig.4: Opposite Winding Direction

The hypothetical helix has opposite directions in the coils viewed from either end. Hence induced voltages in the energised coil and the other coil are in opposite direction; In other words, the terminals 1 and 1 have opposite polarity; similarly the terminals 2 and 2 have opposite polarity. In transformers with foil winding, the neutral is formed with the outside

bus-bars from foil winding. Hence, it is the L V side neutral that should be fixed in all measurements, since based on the sequence of connections, this cannot change.

5. Procedure for Interconnection

- Establish the polarities using the above method.
- Interchange polarity based on required connection (so that neutral in foil connected transformers has the required polarity).
- Refer the guidelines given in the Standards for interconnection.

6. Conclusions

The instantaneous polarity is something we assign. We can assign either positive or negative polarity for a given pair of terminals. The other pair of terminals automatically has the opposite polarity to this pair. The verification of polarity for interconnections and of turns ratio is carried out by means of a single phase ratiometer. It is seen when the windings are of same direction or subtractive polarity the vector group connections are perfect. Theoretically, very low DC voltage pulse can be used for establishing polarity. But in practice, in view of severe effects of inductance in windings and residual magnetism in core, this is never used for transformers. This method is resorted to only for current transformers. This paper did evolve with my practical and theoretical experiences gained during my days in Transformer manufacturing, MNC companies

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