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Comparative Analysis of Windings and Vector Groups in 20/0.4 kV Distribution Transformers at CV. Centrado Prima

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Abstract— Turn ratio test is a comparison test of the number of secondary turns with the primary turns on the transformer. The turns ratio and group vector testing is one of the routine transformer tests. This test generally uses the Transformer Turns Ratio (TTR) test tool, the test equipment used sometimes experiences technical and non-technical problems so a comparative test method is needed to get a good analysis. The research method used is observational research and literature study, namely analyzing the transformer to be studied by conducting TTR testing in two ways, namely testing with test equipment and three-phase low voltage sources, aiming to obtain a very good level of accuracy. The test results were analyzed and compared with theory and calculations, with reference to the IEC 60076-1 standard. The results of the comparison of windings and group vectors using TTR 100 test equipment and a 3-phase low voltage source (TVR) show the same conclusions as the results of the analysis, where the first transformer sample is in normal condition and meets the requirements. SPLN D3.002-1:2007 or IEC Standard 60076-1. While the second sample transformer is in an abnormal condition in the W winding where the difference value is above 0.5%.

Keywords— distribution transformer, vector group, transformer turns ratio, transformer voltage ratio

I. INTRODUCTION

In an electrical energy distribution system that plays an important role is the distribution transformer. Where electrical equipment is very vital in the distribution of electrical energy to consumers or the public, for that reliability must be maintained and in good condition for the smooth distribution of electrical energy. In the transformer there will be a failure, both thermal and electrical which results in the disruption of the electric power distribution system, to prevent this it is necessary to carry out preventive, predictive or corrective maintenance, these steps are to prevent total failure [1], [2]. To keep the distribution transformer in good condition, a test is needed to determine the state or condition of the transformer, because without good maintenance it will have an impact on decreasing the performance of a transformer [3]–[5].

In carrying out the test as a basic reference, it is carried out according to SPLN D3.002-1:2007 or IEC 60076-1 by going through three kinds of tests, namely: routine testing, type testing and special testing [6]. Turning ratio testing generally uses the Transformer Turns Ratio (TTR) test equipment, the test equipment used sometimes experiences technical and non-technical problems so a comparative test method is needed to get a good analysis. From the problems above, it is necessary to understand how to analyze the test results both calculations, using TTR test equipment and using alternating low voltage sources directly.

II. METHODS

A. Transformer

A transformer is an electrical device that can convert or transfer alternating electrical energy (AC) from one voltage level to another based on the principle of electromagnetic induction (EMF Induction) that occurs between 2 (two) or more inductors (coils), but does not change the input source frequency or transformer output frequency [7]. The transformer can only work on alternating current (AC). In general, transformers are divided into 2 (two) types, namely step-up transformers and step-down transformers [8], [9].

A transformer has two or more coils that are inductive. The coils are connected magnetically. When one of the coils (primary) is connected to an alternating voltage source, a magnetic flux occurs in the laminated iron core, because the coil forms a closed network, current will flow in the primary coil resulting in flux in the coil and self-induction occurs) and induction will occur on the other side of the coil (secondary), from this induction produces a current that flows in the secondary coil when the secondary circuit is loaded, so that the overall electrical energy is channeled by magnetization.

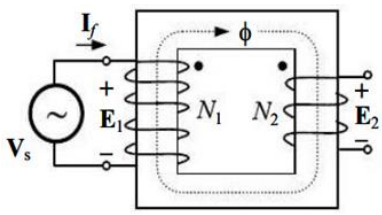

Fig. 1. Transformer In No-Load State [10]

If the magnetic $\Phi = \Phi_{max} \sin \omega t$ it will produce a flux that induces a voltage in the primary winding of:

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$$e = -N\frac{d\theta}{dt} = \Phi_{max}\cos\omega t \quad (1)$$

B. Transformer Ratio

Comparison of transformer windings there are 3 kinds of them [11]:

1. TNR (Transformer Nameplate Ratio) is the ratio data contained on the transformer name plate.

$$TNR = \frac{HV}{LV} = a \quad (2)$$

2. TVR (Transformer Voltage Ratio) is the ratio data obtained from measuring the voltage between the primary and secondary sides. Where for the group vector having a neutral terminal must be included in the measurement.

$$TVR_{(Yd)} = \frac{V_L P}{V_L S} = \frac{\sqrt{3}\, V_{ph} P}{V_{ph} S} = \sqrt{3}a \quad (3)$$

$$TVR_{(Dy)} = \frac{\mathbf{V_L P}}{\mathbf{V_L S}} = \frac{\mathbf{V_{ph} P}}{\sqrt{3}\,\mathbf{V_{ph} S}} = \frac{\boldsymbol{a}}{\sqrt{3}} \quad (4)$$

$$TVR_{(Yy/Dd)} = \frac{\mathbf{V_L P}}{\mathbf{V_L S}} = \frac{\mathbf{V_{ph} P}}{\mathbf{V_{ph} S}} = \boldsymbol{a} \quad (5)$$

Description:

V_{ph} P = Primary phase voltage (V)
V_{ph} S = Secondary phase voltage (V)
VL P = Primary voltage (L-L) (V)
VL S = Secondary voltage (L-L) (V)
a = Ratio Transformer

3. TTR (Transformer Turns Ratio) is the winding comparison data whose value is the same as the transformer voltage ratio data.

$$TTR = TVR \quad (6)$$

Deviation or difference in TTR or TVR is the allowable tolerance value in the form of %. according to IEC standard 60076-1, the maximum allowable % deviation value is ± 0.5% [12],[13].

$$Dev\,\% = \frac{a_2 - a_1}{a_1}\, x\, 100\% \quad (7)$$

Description:

Dev % = Deviation value or difference (%)
a_1 = Calculation result ratio value
a_2 = Measurement result ratio value

C. Transformer Vector Group

In the vector group transformers there are several symbols that indicate the relationship of each winding. First symbol: HV winding connection. Second symbol: LV winding connection. Third symbol: phase shift expressed as the number of hours [14].

Example: Dyn5. D is HV winding (Delta), yn is LV winding (Wye with neutral terminal), 5 is clock transformer.

In the vector groups of transformers there is the term clock number, which is the difference in the phase angle between the low-voltage coil side and the high-voltage coil. Each hour digit is multiplied by 30°. For example: 0 = 0°, 1 = 30°, 5 = 150°, 6 = 180°, 7 = 210° (-150°), 11 = 330° (-30°). Based on the value of the phase angle, the vector groups can be grouped as in table (1)

Table 1. Vector Groups Based on Lagging/Leading HV Coils against LV

o'clock	*Phase shift (deg)*	Vector Groups		
0	0	Yy0	Dd0	Dz0
1	30 lag	Yd1	Dy1	Yz1
2	60 lag		Dd2	Dz2
4	120 lag		Dd4	Dz4
5	150 lag	Yd5	Dy5	Yz5
6	180 lag	Yy6	Dd6	Dz6
7	150 lead	Yd7	Dy7	Yz7
8	120 lead		Dd8	Dz8
10	60 lead		Dd10	Dz10
11	30 lead	Yd11	Dy11	Yz11

According to IEC 60076-1, the vector group notation is HV-LV respectively. For example, a step up transformer with a delta connected secondary and a wye connected primary, is written as 'Dy1'. This indicates that the LV winding lags behind the HV by 30°. Transformer connection notation is very important to know the connection of the high voltage coil and low voltage coil in the main transformer tank (main tank) so that it can make it easier to identify the type of connection used.

D. Research Methodology and Data Collection Technique

The research methodology used is the Observational Research and Literature study, which is observing the transformer to be studied by testing TTR and group vectors in two ways, namely using test equipment (TTR) and using a 3-phase low voltage source, the test results are compared with the calculated data (theoretical). The analysis is based on the standard IEC 60076-1 or SPLN D3.00:2007 where the maximum deviation is ± 0.5% and reads the group vector based on the high voltage winding against the voltage winding with the angle difference indicated by the clock. The following is a flow chart of the research used.

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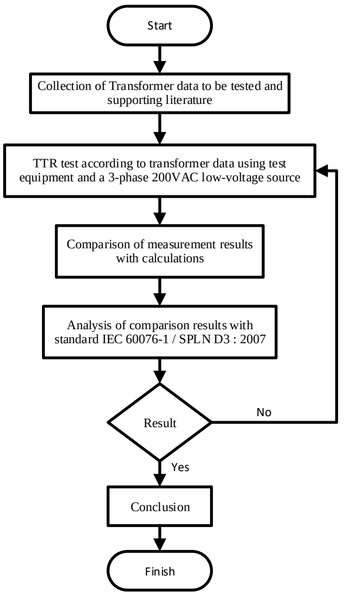

Fig. 2. Research Flowchart

Data retrieval is done by observing the transformer name plate, the data as reference data for analysis. Further data collection by testing using test equipment using either TTR 100 or manual testing, namely using a low-voltage AC source directly by performing two different tests, namely the ratio test and the vector group test. This data retrieval is carried out as a comparison between reference data and primary data which includes test or measurement data.

In testing the vector group using a 3-phase 200 VAC low voltage source, it is done by connecting 2 (two) terminals with the same letter (marking), between the high voltage terminal side and the low voltage terminal side, then on the high-voltage terminal, it is connected to a low-voltage source of 200 VAC, while the low-voltage terminal is open (Figure 3). The condition in this experiment is that the 1U terminal on the high voltage side and 2u on the low voltage side is connected using an additional cable, then voltage measurements are made on the other terminals (1V,1W,2v and 2w).

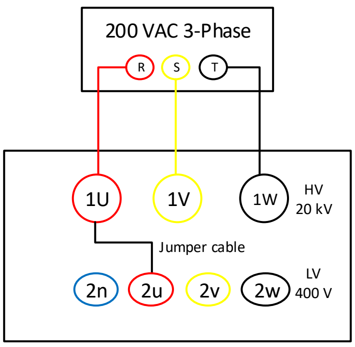

Fig. 3. Vector groups manual test connection

Vector group testing using an AC low voltage source needs to pay attention to several points that must be met, namely: The transformer has a good (balanced) winding ratio for all phases (normal transformer) and the low voltage source used must be good (balanced) and stable.

In testing the Dyn5 vector group using a low voltage source of 200 VAC 3 phase, assuming the interphase voltage on the high voltage side is E, and the interphase voltage on the low voltage side is e, then using the law of triangle science, for clock transformer 5, then we get the equation:

$$1V - 2v = E + 0{,}87e\ (V) \quad (8)$$

$$1V - 2w = E + 0{,}87e\ (V) \quad (9)$$

$$1W - 2v = E\ (V) \quad (10)$$

$$1W - 2w = E + 0{,}87e\ (V) \quad (11)$$

If the measurement results do not match the calculation results. So that the measurement results are matched with table (2) to find out the transformer hours obtained:

Table 2. Transformer Clock Measurement Results [15]

O'clock	Voltage measurement results based on the clock
0	1V-2v = 1W-2w > 1V-2w = 1W-2v
5	1V-2v = 1W-2w = 1V-2w > 1W-2v
6	1V-2v = 1W-2w < 1V-2w = 1W-2v
11	1V-2v = 1W-2w = 1V-2w < 1W-2v

III. Results and Discussion

In this research, the samples used were 2 units of distribution transformer 20 kV/400 V, vector group Dyn5 with a capacity of 400 kVA (sample 1) and 630 kVA (sample 2). The standard used is the international standard IEC 60076-1 and the national standard SPLN D3:2007. For writing or reading vector groups starting from a higher voltage to a lower voltage and the clock number according to the phase angle shift between the primary and secondary coils, the test data uses the "Megger" TTR100 test tool and a low voltage source of 200 VAC as follows.

A. Test results using the TTR 100 test tool "Megger"

Table 3. TTR test results 400 kVA 20 kV/ 400 V Dyn5

Tap	U	V	W	CAL	$\bar{X}$ Dev (%)
1	91,219	91,245	91,238	90,933	0,33
Dev (%)	0,32	0,34	0,34		
2	89,037	89,038	89,048	88,768	0,31
Dev (%)	0,30	0,30	0,32		
3	86,875	86,875	86,875	86,603	0,31
Dev (%)	0,31	0,31	0,31		
4	84,677	84,690	84,662	84,437	0,28
Dev (%)	0,28	0,30	0,27		
5	82,522	82,511	82,507	82,272	0,29
Dev (%)	0,30	0,29	0,28		

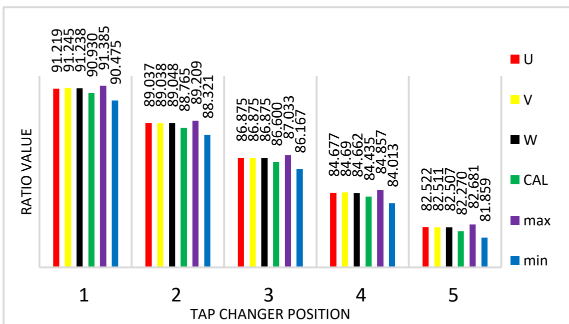

Fig. 4. Graph TTR test results 400 kVA

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Table 4. TTR test results 630 kVA 20 kV/ 400 V Dyn5.

Tap	U	V	W	CAL	$\bar{X}$ Dev (%)
1	91,147	91,127	216,25	90,933	46,15
Dev (%)	0,24	0,21	138		
2	88,951	88,955	211,49	88,768	46,14
Dev (%)	0,21	0,21	138		
3	86,770	86,804	210,56	86,603	47,8
Dev (%)	0,19	0,23	143		
4	84,664	84,614	207,51	84,437	48,83
Dev (%)	0,27	0,21	146		
5	82,509	82,454	195,71	82,272	46,17
Dev (%)	0,29	0,22	138		

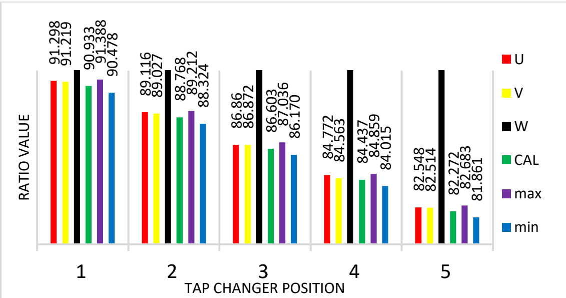

Fig. 5. Graph TTR test results 630 kVA

B. Test results using TVR using 200 VAC 3 Phase.

Table 5. TVR Test Results 400 kVA 20 kV / 400 V Dyn5

No	1U-1V (V)	1V-1W (V)	1W-1U (V)	2u-2n (V)	2v-2n (V)	2w-2n (V)
1	200,2	200,3	200,2	2,195	2,197	2,195
2	200,3	200,2	200,2	2,253	2,251	2,250
3	200,3	200,3	200,2	2,305	2,307	2,305
4	200,1	200,2	200,1	2,363	2,368	2,363
5	200,3	200,2	200,3	2,427	2,425	2,427

Table 6. TVR Test Results 630 kVA 20 kV / 400 V Dyn5

No	1U-1V (V)	1V-1W (V)	1W-1U (V)	2u-2n (V)	2v-2n (V)	2w-2n (V)
1	200,2	200,3	200,2	2,195	2,197	2,195
2	200,3	200,2	200,2	2,253	2,251	2,250
3	200,3	200,3	200,2	2,305	2,307	2,305
4	200,1	200,2	200,1	2,363	2,368	2,363
5	200,3	200,2	200,3	2,427	2,425	2,427

From the results of the TVR test measurements (Table 5) and (Table 6), to get the value of the voltage comparison, a calculation is carried out using equation (4) because the vector group of the sample transformer is Dyn5. And to find out the deviation or difference in the ratio of the results of the TVR test using equation (6), the value of the ratio and deviation of each transformer is in accordance with tables (7) and (8).

Table 7. TVR Calculation Results (Sample 1)

Tap	U	V	W	CAL	$\bar{X}$ Dev (%)
1	91,255	91,271	91,225	90,933	0,34
Dev (%)	0,32	0,37	0,32		
2	88,885	88,955	88,978	88,768	0,2
Dev (%)	0,14	0,21	0,24		
3	86,904	86,817	86,860	86,603	0,3
Dev (%)	0,35	0,25	0,30		
4	84,695	84,696	84,695	84,437	0,31
Dev (%)	0,31	0,31	0,31		
5	82,541	82,539	82,521	82,272	0,32
Dev (%)	0,33	0,33	0,31		

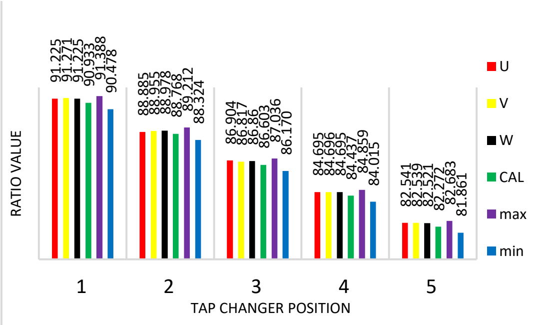

Fig. 6. Graph TVR test results 400 kVA

Table 8. TVR Calculation Results (Sample 2)

Tap	U	V	W	CAL	$\bar{X}$ Dev (%)
1	91,298	91,219	164,180	90,933	27,1
Dev (%)	0,41	0,32	80,56		
2	89,116	89,027	160,48	88,768	27,16
Dev (%)	0,40	0,30	80,78		
3	86,860	86,872	178,839	86,603	35,7
Dev (%)	0,30	0,31	106,5		
4	84,772	84,563	152,901	84,437	27,21
Dev (%)	0,40	0,15	81,09		
5	82,548	82,514	151,165	82,272	28,13
Dev (%)	0,34	0,30	83,74		

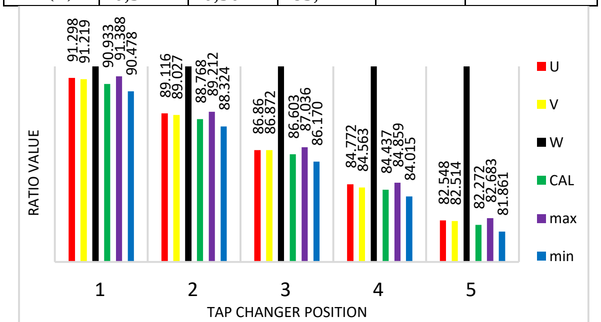

Fig. 7. Graph TVR test results 630 kVA

C. Vector Group Test Results Using 200 VAC 3 Phase.

Table 9. Transformer vector group test results (400 kVA)

Terminal	Measurement results (V)	Terminal	Measurement results (V)
1U-1V	202	1V-2v	205,8
1V-1W	202	1V-2w	205,8
1U-1W	202	1W-2w	205,8
2u-2v	4,03	1W-2v	202
2v-2w	4,03		
2w-2u	4,03		

Table 10. Transformer vector group test results (630 kVA)

Terminal	Measurement results (V)	Terminal	Measurement results (V)
1U-1V	200	1V-2v	203,9
1V-1W	200	1V-2w	201,1
1U-1W	200	1W-2w	201,8
2u-2v	4	1W-2v	202,8
2v-2w	3,57		
2w-2u	2,58		

By using equation (8), (9), (10) and (11) for testing the transformer clock is 5 then:

1. Transformer 400 kVA:

$$1V - 2v = 205{,}8\ V = 202 + 3{,}8 \approx E + 0{,}87\ e$$
$$1V - 2w = 205{,}8\ V = 202 + 3{,}8 \approx E + 0{,}87\ e$$
$$1W - 2v = 202\ V \approx E$$
$$1W - 2w = 205{,}8\ V = 202 + 3{,}8 \approx E + 0{,}87\ e$$

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From the above calculation, we get: 1V-2v = 1W-2w = 1V-2w > 1W-2v.

2. Transformer 630 kVA:

$1V - 2v = 203{,}9\ V = 200 + 3{,}9 \approx E + 0{,}87\ e$

$1V - 2w = 201{,}1\ V = 200 + 1{,}1 \neq E + 0{,}87\ e$

$1W - 2v = 201{,}8\ V \neq E$

$1W - 2w = 201{,}8\ V = 200 + 1{,}8 \neq E + 0{,}87\ e$

From the above calculation, we get: 1V-2v > 1W-2w = 1V-2w = 1W-2v

Based on tables (9) and (10) as well as the calculations above, for a 400 kVA transformer the clock transformer is 5 (five), while for a 630 kVA transformer it does not match the transformer clock equation based on table (1) because of the abnormal W phase winding.

D. TTR, TVR and vector group analysis

Based on the test using "Megger" TTR100 and a low voltage source of 200 VAC, for transformer sample 1 (400 kVA) as shown in table (3) and table (7) the deviation obtained is below 0.5%. With a total average deviation of 0.3% for each tap, and for transformer sample 2 (630 kVA) as listed in tables (4) and (8), the deviation obtained for the U and V phases has a normal ratio value, but for the W phase is not normal, which is above the permissible tolerance, with a total average deviation of each Tap by 47%.

Based on vector group testing using a low voltage source of 200 VAC as shown in tables (9) and (10) transformer sample 1 (400 kVA) shows the transformer clock value is 5. While for transformer sample 2 (630 kVA) it does not match any clock transformer based on table (2) due to winding abnormal W phase.

IV. Conclusion

Based on the test results obtained several conclusions, among others:

A. Test the turns ratio and vector group using the TTR 100 “Megger” test kit:
   1. Transformer sample 1 (400 kVA) from all tested Taps obtained a deviation value below 0.5%, and for the average deviation of each Tap it was 0.3%. The vector group is Dyn5, so this transformer is in normal condition.
   2. Transformer sample 2 (630 kVA) from all tested Taps found abnormalities in the W phase winding with a deviation of more than 0.5% and for a total average deviation of 47%.

B. Tests using a low voltage source 3 Phase 200 VAC obtained the same results as testing using the TTR 100 test equipment, namely:
   1. Transformer sample 1 (400 kVA) under normal conditions with a deviation value below 0.5% with an average deviation of 0.29% and for group vector testing by connecting terminals 1U and 2u the results are 1V-2v = 1W-2w = 1V-2w > 1W-2v, which indicates the clock transformer is 5, so the group vector is the same as the data on the installed nameplate, namely Dyn5.
   2. Transformer sample 2 (630 kVA) has an abnormality in the W phase winding with a deviation of above 0.5% with an average deviation of 23.86%, for group vector testing by connecting the 1U and 2u terminals, the results are 1V-2v = 1W-2w = 1V-2w > 1W-2v which does not show the transformer clock = 5, because there is a winding damage in the W phase.

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