Analysis of Three Phase Transformer Parallel Operation and Circulating Current

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ABSTRACT

Parallel operation of transformers is needed when the load is increased and it exceeds the capacity of the existing transformer, if multiple transformers are running in parallel and a fault occurs in one transformer, then the other parallel transformers still continue to serve the load. The reliability is increased with parallel operation than to have a single larger unit. The cost associated with maintaining the spares is less when two transformers are connected in parallel. For parallel connection of transformers, primary windings are connected source bus-bars and secondary windings are connected to the load bus-bars. The conditions of connecting transformers in parallel and loading considerations when turn ratios, impedances and MVA ratings are different. Load division or load sharing store excess electrical power during low demand periods for release as demand rises. The goal would be for the power supply system to see a load factor of 1. In this thesis, two 100MVA transformers are connected in parallel. The 230 kV to 33 kV in Substation is used as the location to study and analyze the load division and circulating current of parallel transformer operation. The parallel operation provides more reliability. So, it is used in a substation. The value of the load division and circulating current are calculated with the case of the parallel transformer in this paper.

KEYWORDS: *same voltage ratio and turn ratio, same percentage impedance and X/R ratio, circulating current*

1. INTRODUCTION

Parallel operation of transformers is needed when the load is increased and it exceeds the capacity of the existing transformer, if multiple transformers are running in parallel and a fault occurs in one transformer, then the other parallel transformers still continue to serve the load. The reliability is increased with parallel operation than to have a single larger unit. The cost associated with maintaining the spares is less when two transformers are connected in parallel. For parallel connection of transformers, primary windings are connected source bus-bars and secondary windings are connected to the load bus-bars. Various conditions that must be fulfilled the successful parallel operation of the transformer. Sometime existing transformers are parallel looking for ways of making power systems more reliable, provide better power quality, prevent voltage sags, or for additional load requirements. The conditions of connecting transformers in parallel and loading considerations when turn ratios, impedances and MVA ratings are different. Load division or load sharing store excess electrical power during low demand periods for release as demand rises. The goal would be for the power supply system to see a load factor of 1. In this paper, two 100MVA transformers are connected in parallel. The 230 kV to 33 kV in Substation is used as the location to study and analyze the load division and circulating current of parallel transformer operation. The parallel operation provides more reliability. So, it is used in a substation. The value of the load division and circulating current are calculated with the case of the parallel transformer in this paper.

2. LITERATURE REVIEW

When operating two or more transformers in parallel, their satisfactory performance requires that they have

1. Same voltage ratio and turns ratio (both primary and secondary voltage rating is the same).
2. Same percentage impedance and X/R ratio.
3. Identical position of tap changer.
4. Same MVA ratings.
5. Same phase angle shift (vector group is the same).
6. Same frequency rating.
7. Same polarity.
8. Same phase sequence.

3. MATHEMATICAL REVIEW

$$\mathbf{a} = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1} \quad (1)$$

$$E_t = k \times \sqrt{\frac{kVA}{Phase}} \quad (2)$$

$$\text{Loading on the transformer1} = \text{load} \times \frac{\frac{MVA_1}{Z_1}}{\frac{MVA_1}{Z_1} + \frac{MVA_2}{Z_2}} \quad (3)$$

$$\text{Loading on the transformer2} = \text{load} \times \frac{\frac{MVA_2}{Z_2}}{\frac{MVA_1}{Z_1} + \frac{MVA_2}{Z_2}} \quad (4)$$

$$Z_b = \frac{V_b^2}{S_b} \quad (5)$$

$$Z_1 = \%Z_1 \times Z_b \quad (6)$$

$$Z_2 = \%Z_2 \times Z_b \quad (7)$$

$$|Z| = \sqrt{R^2 + X^2} \quad (8)$$

$$\%R = \frac{\%Z_1}{\sqrt{\left[\frac{X}{R}\right]^2 + 1}} \quad (9)$$

$$\%X_1 = \%R \times \frac{X}{R} \quad (10)$$

Let %e=difference in voltage ratio expressed in percentage of normal and $k = \frac{MVA_1}{MVA_2}$ (11)

Circulating current, $\%I_c$ =

$$\%e \times \frac{100}{(\%R_1 + k \times \%R_2)^2 + (\%Z_1 + k \times \%Z_2)^2} \quad (12)$$

4. RESULTS DATA OF LOAD DIVISION AND CIRCULATING CURRENT OF PARREL TRANSFORMER OPERATION

4.1 Same voltage ratio and Turn ratio

$\frac{N_1}{N_2}$ =7

Table1. Transformer Impedance IEC 60076

MVA Rating	Percent Impedance %Z	X/R Ratio	Tolerance on %Z
<0.630	4.0	1.5	±10
0.631-1.25	5.0	3.5	±10
1.251-3.15	6.25	6.0	±10
3.151-6.3	7.15	8.5	±10
6.301-12.5	8.35	13.0	±10
12.501-25.0	10.0	20.0	±7.5
25.001-200	13.5	45.0	±7.5
>200	By agreement		

Table2.The impedance of Two Windings Distribution Transformers

MVA Rating	Percent Impedance %Z	X/R Ratio
20	10	13
57	18.2	34
74	8.9	25
80	18.9	35
120	22.5	63
125	13.1	52
180	22.2	38
255	14.8	43

Table3. Transformer Tap Position

Number of Tap	Voltage
1	260360
2	256565
3	252770
4	248957
5	245180
6	241385
7	237590
8	233795
9	Normal tap
10	226205
11	222410
12	218615
13	214820
14	221025
15	207230
16	203435
17	199640

Table4. Actual Data of Loading in Substation

Time Interval	Loading of Transformer
6 PM to 11 PM	126 MVA
11 PM to 8 AM	50 MVA
8 AM to 6 PM	92 MVA

4.2. Same Percentage Impedance and X/R Ratio

Case 1: Equal Impedance, Ratio and Same MVA
Capacity of Transformer 1 =100MVA
Capacity of Transformer 2 =100MVA
% impedance, Z_1 =13.5%
% impedance, Z_2 =13.5%
Voltage ratio the same, Total load =200MVA
Loading on the transformer 1 =100 MVA
Loading on the transformer 2 =100 MVA
Tap of transformer 1 = 0 (Normal tap)
Tap of transformer 2 = 0 (Normal tap)
Different voltage ratio = % e = 0
Circulating current, % I_c=0

Case 2: Equal Impedance, Ratios and different MVA
Capacity of Transformer 1 =80MVA
Capacity of Transformer 2 =57MVA
% impedance, Z1 =18.9 %
% impedance, Z2 =18.9 %
Total load =137 MVA
Total load =137 MVA
Loading on the transformer 1=80MVA
Loading on the transformer 2=57MVA
Circulating current, % I_c =0

Case 3: Unequal Impedance but Same Ratio and MVA
Capacity of Transformer 1 =100MVA
Capacity of Transformer 2 =100MVA
% impedance, Z1 =13.5 %
% impedance, Z2 =22 %
Voltage ratio the same,
Total load =200 MVA
Loading on the transformer 1=124 MVA
Loading on the transformer2 = 76 MVA
To calculate circulating current, , % I_c=0

Case 4: Unequal Impedance and MVA but Same Ratio
Capacity of transformer1, (MVA1) =100 MVA
Capacity of transformer2, (MVA2) =80 MVA
% Impedance, Z1 = 13.5 %
% Impedance, Z = 18.9 %
Voltage ratio the same,
Total load = 180 MVA
Loading on the transformer 1 = 115MVA
Loading on the transformer 2 = 65MVA
Circulating current, % I_c =0

Case 5: Equal Impedance and MVA but Unequal Ratio
Capacity of transformer1, (MVA1) =100 MVA
Capacity of transformer 2, (MVA2) =100 MVA
% Impedance, Z1 =13.5%
% Impedance, Z2 =13.5%
Total load =200 MVA
Loading on the transformer 1=100 MVA
Loading on the transformer 1=100 MVA
Circulating current, % I_c =6.1%

Table5. Resulting of Circulating Current

Tap	Different voltage ratio	Circulating current
1	1.65	6.1
2	3.3	12.2
3	4.95	`18.3
4	6.6	24.4
5	8.25	30.5
6	9.9	36.7
7	11.6	42.8
8	13.2	48.9
9	-	-
10	1.65	6.1
11	3.3	12.2
12	4.95	18.3
13	6.6	24.4
14	8.25	30.5
15	9.9	36.7
16	11.6	42.8
17	13.2	48.9

Case 6: Unequal Impedance, MVA Ratings and Different Ratios
Capacity of transformer1, (MVA1) =100 MVA
Capacity of transformer2, (MVA2) =80 MVA
% Impedance, Z1 = 13.5 %
% Impedance, Z2 =18.9 %
Total load =180 MVA
Loading on the transformer 1 = 115MVA
Loading on the transformer 2 65MVA
Circulating current, % I_c =4.4%

Table5. Resulting of Circulating Current

Tap	Different voltage ratio	Circulating current
1	1.65	4.44
2	3.3	8.89
3	4.95	13.33
4	6.6	17.77
5	8.25	22.22
6	9.9	26.66
7	11.6	31.25
8	13.2	35.54
9	-	-
10	1.65	4.44
11	3.3	8.89
12	4.95	13.33
13	6.6	17.77
14	8.25	22.22
15	9.9	26.66
16	11.6	31.24
17	13.2	35.54

Table4.7. Resulting Table of Six Cases

Percent Impedance,		Loading on Transformer1	Loadingon Transformer2	Circulating Current, I_c (%)
% Z_1	% Z_2			
13.5%	13.5%	100 MVA	100 MVA	0
18.9%	18.9%	80 MVA	57 MVA	0
13.5%	22%	124 MVA	76 MVA	0
13.5%	18.9%	115 MVA	65 MVA	0
13.5%	13.5%	100 MVA	100 MVA	6.1 to 48.9 (According to Tap Ratio)
13.5%	18.9%	115 MVA	65 MVA	4.44 to 35.54 (According to Tap Ratio)

5. CONCLUSION

Loading considerations for paralleling transformers are simple unless MVA, percent impedances or ratios are different. When parallel transformer turn ratios and percent impedances are the same, equal load division will exist on each transformer. When paralleled transformer MVA ratings are the same but the percent impedances are different, then unequal load division will occur. The same is true for unequal percent impedances and unequal MVA. Circulation currents only exist if the turn ratios do not match on each transformer. The magnitude of the circulating currents will also depend on the X/R ratios of the transformers. Delta-delta to delta-wye transformer paralleling should not be attempted.

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