Parallel Operation of Two Single-phase Transformers

Aim

- To understand prerequisites for operation of transformers in parallel
- To study power-sharing between two single-phase transformers operated in parallel

Theory

A power transformer is one of the most vital and an equally expensive components in a power system. It may so happen that, over time, due to load growth in its service area, an existing transformer may not be able to withstand the demand during peak-hours without exceeding its long-term MVA rating. Operating a transformer in such a fashion would cause overheating and degrade its expected life. In most cases, instead of commissioning an entirely new higher capacity unit, a more viable alternative exists in adding a smaller unit in parallel to complement the existing one. In other words, a new smaller capacity transformer can now be connected in parallel to the existing one such that the two share a large peak load in a specific proportion and the one operating near limits is relieved of the burden. Also, during light load conditions, the additive capacity can be kept offline, if desired. To successfully operate the transformers in parallel, while commissioning, certain rules must be followed. We state them below, as applied to the single-phase transformers used in the experiment.

Requirements for Parallel Operation of Two Single-phase Transformers

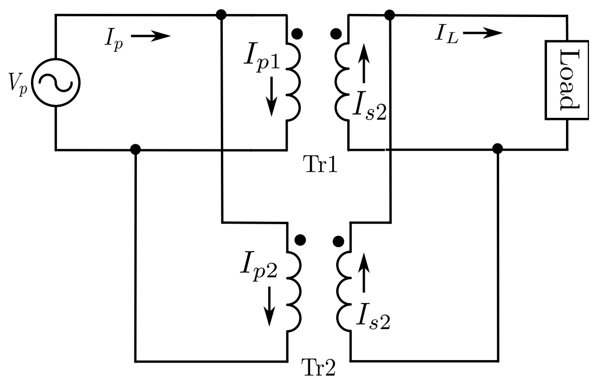

Figure 1: Conceptual Diagram of Two single-phase Transformers in Parallel

Refering to Fig.1, if the transformers getting connected in parallel are excited using same rated primary voltage source, then the following prerequisites must be met

- *The polarities of corresponding primary and secondary terminals of the two transformers must be same*

  Referring to Fig.1, if the said condition is not satisfied and the back emfs at the secondary windings have opposite polarities at the dots, the windings form a closed electric circuit with two voltage sources of equal magnitude connected in series additively. This results in a very high circulating current limited only by the winding resistance which is very small. Hence it is imperative to conduct a polarity test on the two transformers to establish identical winding polarities.

- *The no-load primary and secondary voltages of the two transformers should match closely in magnitude as well as in phase*

  On similar lines with the previous condition, if the no-load transformer voltages are not equal in magnitude and phase, a closed electric circuit with a voltage source equal to the difference of instantaneous secondary voltages is formed and circulating currents are established even before loads are connected. The circulating currents get reflected on the primary side as well. The more the phasor difference, more is the circulating current. Hence it is advisable to conduct a test to verify the no-load rated voltages of the two transformers.

- *The per unit impedances of two transformers on their respective Zbases must be equal if the transformers have to share the load in proportion to their ratings*

  Under parallel operation, the two transformers would share the total load current as indicated in

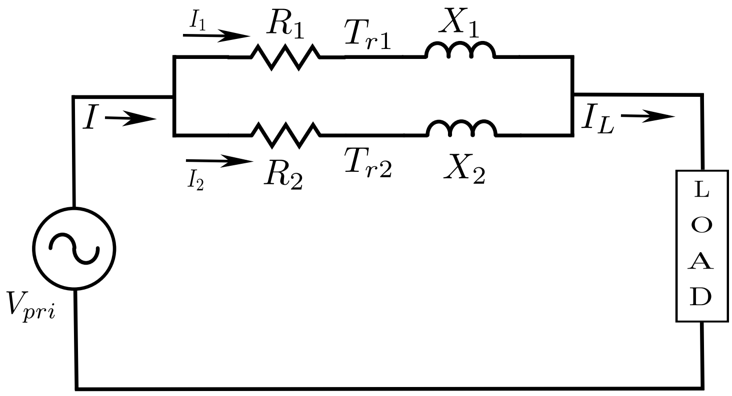

Figure 2: Equivalent Circuit of Two Single-phase Transformers in Parallel

Fig.2. In this figure, the equivalent circuit of transformer is shown with all quantities referred to the primary side. Also note that all quantities are in complex numbers unless specified otherwise.

$$I_L = I_1 + I_2 \tag{1}$$

$$I_1 = \frac{Z_2}{Z_1 + Z_2} I_L \tag{2}$$

$$I_2 = \frac{Z_1}{Z_1 + Z_2} I_L \qquad \text{where,} \quad Z = R + jX$$

Following this further, if the phase angles of Z_1 and Z_2 are exactly matched, the magnitudes of transformer currents are in inverse proportion to the respective transformer equivalent leakage impedances.

$$\frac{|I_1|}{|I_2|} = \frac{|Z_2|}{|Z_1|} \tag{3}$$

This can be further extended to determine the power sharing between transformers.

Consider two transformers of different MVA ratings connected in parallel with the same voltage ratings. It is desirable that they share the load in proportion of their MVA ratings. Hence we have in absolute scale (not in per unit),

$$\frac{S_1^*}{S_2^*} = \frac{V_1^* I_1}{V_2^* I_2} \tag{4}$$

Dividing both sides by respective transformer MVA ratings and considering that voltage ratings are equal, we have in per unit scale,

$$\frac{|S_1|}{|S_2|} = \frac{|I_1|}{|I_2|} = 1 = \frac{|Z_2|}{|Z_1|} \tag{5}$$

Note that, after dividing the proposed power sharing by respective ratings of the transformers, the share ratio becomes unity. Now, using (4) and (6), we conclude that, the per unit impedances of the two units must be equal for this type of power sharing.

Procedure

For each of the transformers, note down the name plate ratings and determine the rated currents for both the windings. The two units must have identical voltage ratings or the same transformation ratio. Also, It is assumed that we have the leakage impedance parameters determined for each unit through short-circuit tests already performed.

A. First, perform the polarity test on each of the units and label or note down terminals with the same polarity

B. Also, confirm that no-load secondary voltages of both transformers match in magnitude. If possible, also check the respective instantaneous phase angles.

   Note: It is important to perform both these tests before attempting the parallel operation.

C. Perform the SC test to find out leakage impedance parameters of the two transformers. Attempt to calculate the power sharing analytically using equivalent circuit of transformer.

D. With the primaries in unenergized state, connect a common load across the transformer secondaries, with the load kVA rating not exceeding the total kVA rating of the two units.

E. Slowly increase the autotransformer voltage until rated voltage appears across the primaries of each transformer.

Record

- Note down the following quantities
  - Primary currents of both transformers
  - Secondary currents of both transformers
  - Load current
  - Load voltage
- Calculate real, reactive and apparent powers delivered to the load by each unit analytically.
- Determine the power sharing between the two transformers and compare share of each against their corresponding leakage impedances.
- Compare the experimental and analytical results

Follow-up Questions

1. Why do we need to operate transformers in parallel?
2. Calculate the circulating current in two paralleled single-phase transformers with leakage impedance 5% each and no-load voltage difference of 1%. Express in percentage of full load current.

References

(1) P.S.Bimbhra, "Electrical Machinery", Ch.1

(2) A.E. Fitzgerald, C. Kingsley Jr., S.Umans, "Electric Machinery", 6th Ed., Ch.2

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