Comparison of Leakage Impedances of Two Single-phase Transformers

Aim

- To understand the effect of core construction on leakage impedance in a single-phase transformers
- To understand factors affecting leakage impedance of a transformer

Preliminary Questions

1. How do you understand a transformer as a magnetic circuit?
2. What is the leakage impedance of a transformer and why is it important to minimize the same?
3. What are the principle construction types of a transformer?
4. What is the core of a transformer made of ?

Theory

Leakage Impedance in a Transformer

A transformer is fundamentally a magnetically coupled circuit. For a practical transformer there exists some leakage flux apart from the core flux. Most of the flux produced by one winding passes through the ferromagnetic core and links the other winding whereas a small fraction links the same winding through surrounding air. It is modeled as a series reactance in the equivalent circuit and the associated impedance affects voltage regulation in a transformer under loaded conditions. As beginners, it would be useful to get an overview of aspects of a transformer's physical construction such as core geometry, winding type, insulation, number of flux paths. In laboratory, for a suitably sized transformer, one can experimentally determine the leakage impedance parameters through the open Circuit or 'OC' and short circuit or 'SC' tests. The SC test estimates series leakage impedance parameters. In this section, we first briefly review the transformer construction types and then study the Short-circuit test used to calculate series leakage impedance parameters. We intend to perform the short-circuit test on two single-phase transformers having identical electrical parameters but having different core construction. Differences in the leakage impedances observed thereby can be attributed to difference in flux paths offered in the two transformers.

The practical transformer has coils of finite resistance. Though this resistance is actually distributed uniformly, it can be conceived as concentrated. Also, all the flux produced by the primary current cannot be confined into a desired path completely as an electric current. Though a greater proportion links both the coils(known as mutual flux), a small proportion called the leakage flux links one or other winding, but not both. It does not contribute to the transfer of energy from primary to secondary.

Fig.1 shows the mutual and leakage fluxes in a transformer. The red dotted line indicates the flux that passes through the core linking both windings while the blue colored dotted loop depicts the leakage flux. On account of the leakage flux, both the windings have a voltage drop which is due to 'leakage reactance'. As a result, under usual operation, the leakage impedance is an undesirable property as it degrades the voltage regulation of a transformer. The transformer shown in Fig.1 can

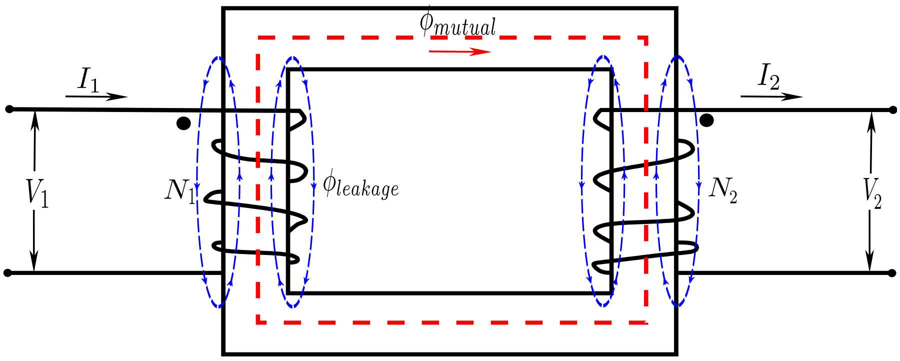


Figure 1: The Elementary Transformer

be resolved into an equivalent circuit as shown in Fig.2 in which the resistance and leakage impedance of primary $(R_1 + jX_1)$ and secondary (referred to primary) $(R_2' + jX_2')$ are represented.

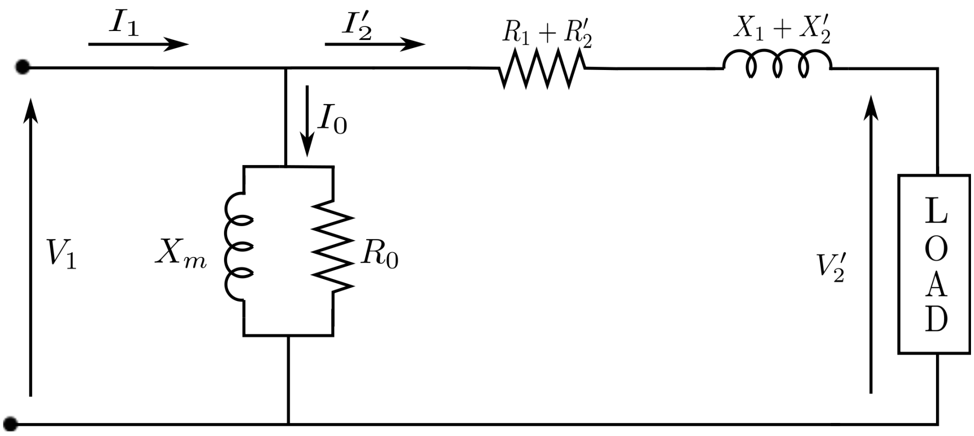


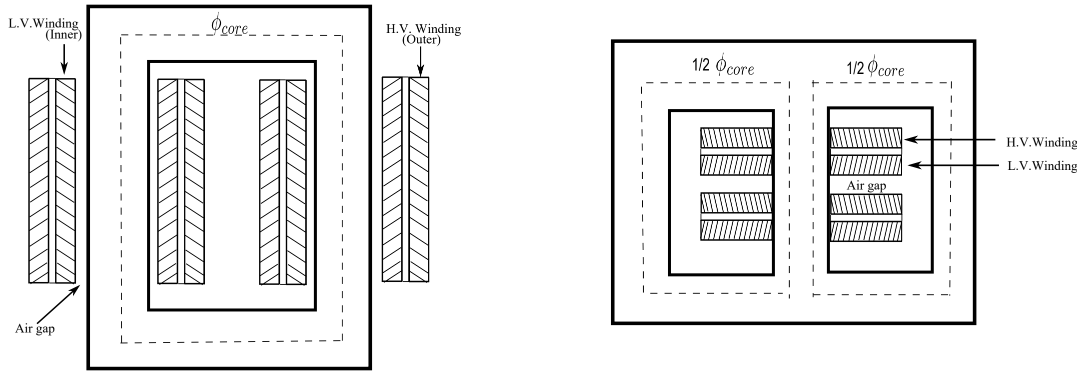
Figure 2: Equivalent Circuit of a Transformer

Ultimately, we would want to observe the effect of leakage impedance on the magnitudes of secondary currents in the two transformers. Thus, if rated voltage is applied at the primaries with secondaries connected to identical loads, effect of leakage impedance on load currents drawn can be observed. We expect that the transformer with higher leakage impedance will draw greater load current for the same load. The equivalent circuit shown in Fig.2 helps explain the observation. We know that when a load is connected across the secondary, the resulting current through secondary winding distorts the already established flux in the transformer core. To maintain the core flux constant, required amount of current is drawn from the source at the primary. For a transformer with higher leakage impedance, greater amount of current will be required to maintain the core flux constant.

Construction of a Single-phase Transformer

The magnetic core of a transformer is a stack of thin silicon-steel laminations. The laminations are interleaved with insulating materials to reduce circulating currents called the eddy current. Transformers are classified based on the way their windings are wound around the core into two types, namely, core type and shell type.

In the core type transformers, the windings surround much of the core while (Fig.3(Left)) in the shell-type, the core surrounds the windings on the middle limb or the vertical section of the core(Fig.3(Right)). In order to reduce the leakage flux, following is usually done,



Core–type Transformer　　　Shell–type Transformer

Figure 3: Types of Transformer Based on Construction

- In core type, half the low voltage winding is placed on one leg of the core while the other half is placed on the other leg. The high voltage windings are then placed in a similar manner over the low voltage ones.
- In shell type, the low and high voltage windings are sandwiched alternatively over one another.

In essence, to minimize the leakage flux and thereby impedance, the windings are subdivided into sections and placed as close together as possible. Thus it is clear that, introduction of air-gaps within the core-winding structure would increase the leakage flux and thus the leakage impedance of a transformer.

Fig.4 below shows two single-phase transformers in our machines lab. As one can observe, they have different geometries of core and windings with regards to their height to breadth ratio. In the top-view part of the figure, the vertical-geometry transformer has more percentage of core surrounded by the windings compared to the other with a horizontal geometry. Both are rated at 230/23 V and –kVA.

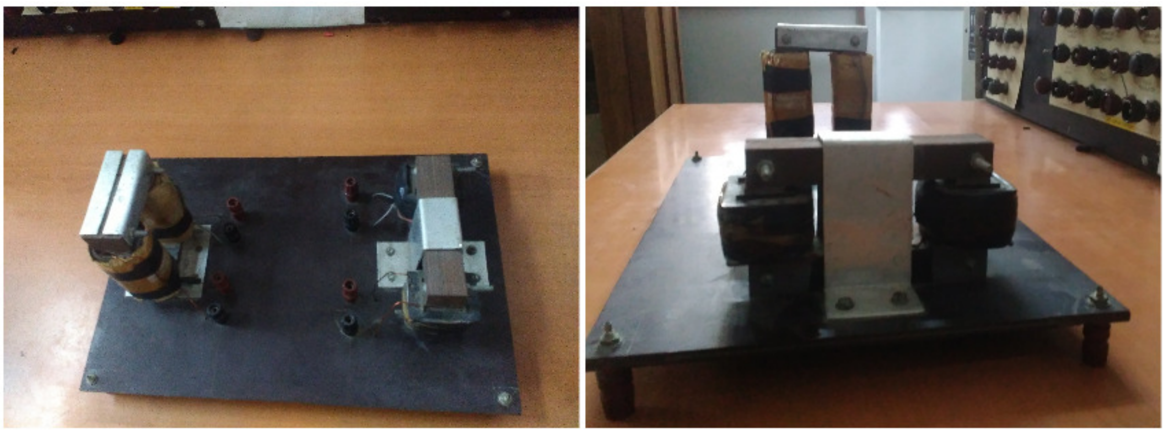


Figure 4: Two Single-phase Transformers in Machines Lab

Fig. 5 and Fig. 6 shows the flux lines in the transformers obtained using finite element method. Red coloured lines indicates the leakage flux lines. From the data given in the figure we can verify through simulation that leakage flux is more in case of short limbed transformer

In order verify the results that were obtained through simulation using practical transformers, the short-circuit or 'SC' test is first performed individually on the two single-phase transformers to find their leakage impedance.

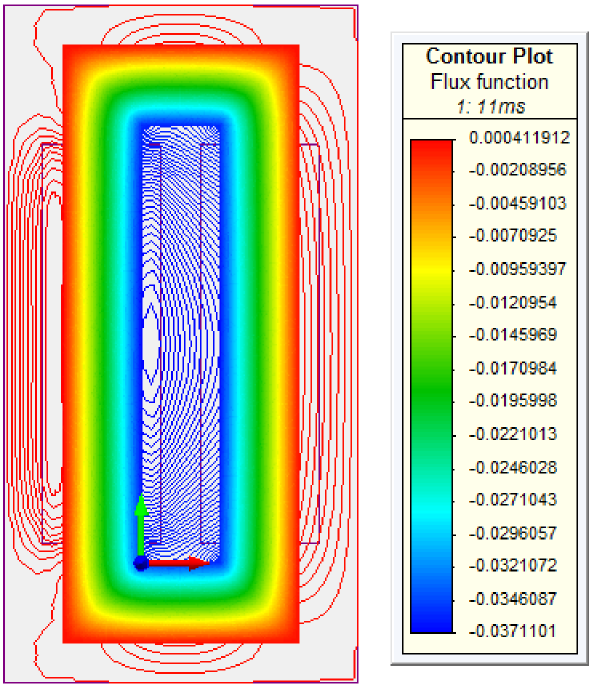


Figure 5: FEA of tall limbed transformer

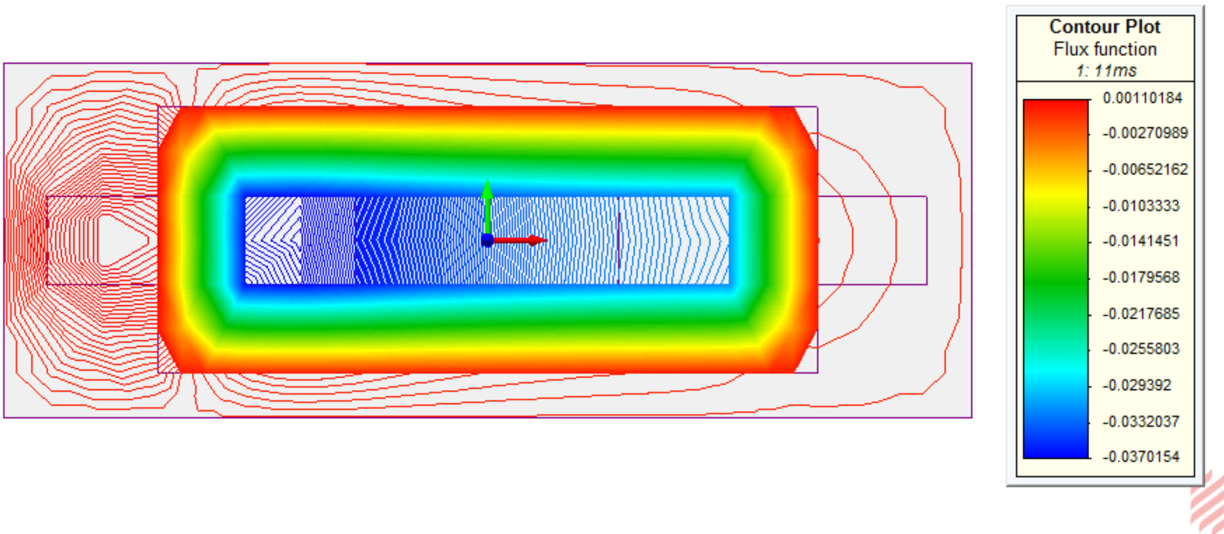


Figure 6: FEA of short limbed transformer

Procedure

- For each of the transformers, note down the name plate ratings and determine the rated currents for both the windings. Ensure that the transformers are identical in ratings and have similar construction.
- Assuming that the SC test has already been performed, connect rated load across the secondary of Transformer-I.
- Adjust the autotransformer until rated current flows in the load.
- After making required measurements, reduce the output voltage of the autotransformer to zero and put off the supply.
- Repeat the same procedure for Transformer-II

Record

- Load current of each transformer at rated condition

Follow-up Questions

- Identify the type of transformers given to you based on their construction
- Which construction type would consume more core material and which one would require more conductor material?
- Think of a scenario or condition when higher leakage impedance could in fact prove helpful to have
- Examine the flux plot obtained from both transformers. This is obtained using a "FEM" analysis software.

References

(1) W. Flanagan, "Handbook of Transformer Design and Applications", 2nd Ed., Ch. 7,10

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

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

Write-up prepared by - *Aditya D Nadkarni* (Research Scholar, 2014 batch)