Chapter - 2

SOME ASPECTS OF MODELLING
2.1 Introduction:

Transformer is an essential element of power system. Its wide use makes it necessary to have not only proper understanding of its operation but also simulation of its characteristics during its steady state and transient conditions. Its operation as a circuit element can be divided into two modes. One is the loaded condition under which the behaviour of transformer is quite different from the other, namely, the no load condition. The characteristics of transformer at no load are of considerable importance in many situations such as the supply being given to the transformer through a cable or parallel connection of another transformer with it. Therefore the no load working of the transformer and changes in core flux are to be thoroughly investigated as the whole phenomenon at no load, associated with its flux, in turn gives some clue to explain certain peculiar behaviour of the apparatus. These peculiar operating condition includes (i) ferroresonance phenomena, (ii) transient over voltages, (iii) inrush current phenomenon and (iv) harmonic generation of an half cycle saturation.

Simulation of the above operating conditions can be brought out by mathematical representation of the core saturation phenomenon associated with its flux linkage and excitation current. This is called modelling of transformer at no load, which is similar to iron cored reactor.

Modelling may be done with the construction of scale model of the original or the equivalent circuit model of the transformer as was done by P.A.Abetti, H.P.Hart et al., I.D.Mayergoyz [2, 3, 4, 34, 36, 43, 61] for the determination of transient voltages. It may
also be accomplished by means of representation by mathematical expression describing the whole phenomenon at no load.

In some situations assumption like neglecting core loss, simplifies the process of modelling [1, 20, 38, 39, 70] without losing accuracy of representation of the saturation phenomenon. In the past various aspects of modelling of transformer and iron cored reactors were reported [1-9, 12-15]. Some authors concentrated on duplicating the single values saturation characteristics by some mathematical expressions [7, 8, 9, 40, 46, 48] and others have developed mathematical expression representing the magnetisation characteristics including hysteresis loop [5, 6, 38, 39, 43]. There was also conversion methods from r.m.s. form of saturation curve to the instantaneous form of saturation curve [1, 20, 38, 39] and vice versa. Hence the aim of this chapter is to present some elaboration of various aspects of transformer modelling and to list the situation demanding such modelling.

2.2 Meaning of transformer modelling:

The duplication of magnetisation characteristic of a transformer, which is useful to describe accurately the terminal quantities at different operating conditions. The operating condition may be at any voltage for given transformer. The terminal quantities are selected in such a way that they are useful to explain many phenomena of transformer, for example inrush current or ferroresonance phenomenon associated with transformer or choke coil. The nature of the characteristic for given transformer depends on the terminal quantities selected to be measured to describe it. But some characteristics yield incorrect results if they are used directly and such curves are to be transformed to other useful types.
of characteristics. The transformation of particular type of saturation characteristics to other type of saturation characteristics give good facility in the process of modelling. The first curve to be utilised in the process for a given transformer or choke coil is entirely a matter of convenience in measurement of the terminal quantities.

2.3 Necessity of transformer modelling:

The transformer modelling was attempted at much earlier times to determine the transient over voltage [2, 3, 4, 34, 36, 43] only, but after the introduction of the computers for the power system operation and control, it assumed quite an important place in the advanced and latest electrical technology. Thus it is useful for the purpose of digital and analog studies of system transients.

On line digital control of bus voltages by transformer tap changes and capacitor switching requires the use of mathematical models of the electric networks and connected equipments. In such cases modelling of transformer saturation is to be accomplished by representing the actual response very accurately.

The other cases, where modelling of transformer saturation is necessary, are the following transient simulation studies [28, 41, 42, 58, 65, 68, 76], the inrush current drawn by a transformer possessing a residual flux remaining in a transformer when it is deenergized, examination of ferroresonance phenomena, and determination of harmonic generated by extreme half cycle saturation of transformer.
2.4 Various aspects of transformer modelling:

In modelling of transformers two major effects are considered. Firstly saturation effects are taken to be modelled. A transformer becomes an ideal one if it is assumed to be loss free. As mentioned in the section 2.1, the modelling of transformer presented in this thesis pertains to no load condition of a transformer and in some transformers, the no load loss is negligible. Hence, for modelling the saturation of the core of a transformer, the hysteresis loss, which forms the major part of the no load loss, is neglected. So the magnetisation curve has only saturation effect on the core. The curve shows the relation between the flux linkage and the instantaneous current. The saturation characteristic is non-linear in nature exhibiting the magnetic saturation of the iron core as a result of excursion of flux to the normal or higher working values. It is represented by a two terms higher degree polynomial, which is an odd function, to take care of its symmetry about the origin in the first and the third quadrants. The polynomial representation has advantages of (i) simplicity in representation, (ii) quickness in computations using the expression and (iii) good accuracy in the representation of the curves. The other representations are exponential [7, 47, 48] and rational fraction approximation [8].

The second aspect of a transformer modelling is the hysteresis effect. The effect of hysteresis loss, which forms a larger part of the no load losses, is not negligible in some studies like the study of inrush currents, ferroresonance phenomena and transients [18, 69, 70, 71]. Including the hysteresis effect, the magnetisation characteristic of transformer with the terminal voltages as the ordinates and no load currents as abscissa is called saturation curve including hysteresis. The hysteresis loop modelling has also its
importance in the analysis of electro magnetic transients and switching surges [8, 60, 61, 68, 76, 77, 85].

In both the above aspects of modelling, the accuracy of the model is highly essential not only for its use in many situation but also to have a correct pre-assessment of some terminal values of the circuit including the transformer.

2.5 Accuracy in transformer modelling:

As described earlier, the modelling of transformer pertains mainly to represent its operating characteristic in terms of variables at the terminals by a mathematical expression and to pre-determine the expression with high accuracy.

Transformer and reactors models for their saturation characteristics at the working fluxes may be constructed with the help of constants R, L and C elements to derive the same relation between terminal variables as that of the actual case. But around the working value of flux linkage, transformer or iron cored reactor has non-linear relation between the flux linkage and the magnetising current. Moreover there is multivalued relationship between them depending on the condition of excitation stimuli. Hence in actual cases the models should exhibit the non-linear nature which is unavoidable in practice. The modelling of such non-linear characteristic by means of constant parameters of R, L and C is very simple and has single valued relationship of the characteristics, but in turn the accuracy with which the model duplicates the actual characteristics is not acceptable in all the situations. Hence in the next chapters, the accuracy for which the model stands to duplicate the practical behaviour of the transformer or non-linear inductor is also considered in the process of modelling. Methods are also suggested to have a
correct estimate of the accuracy with which the model for transformer saturation is represented.

**Conclusion:**

Modelling of a transformer or an iron cored inductor has become an essential requirement of any power system study for its proper operation and control. To obtain correct operation with the help of modelled representation, it is essential that the model should clearly represent the actual behaviour of transformer. It may be noted here that whenever the coreloss of the transformer is negligible, single value I.C. should be used to reduce the computation time.