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EXCERPT

TRANSFORMER ENGINEERING

A Treatise on the Theory, Operation, and Application of Transformers

By

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CHAPTER I

THE GENERAL NATURE OF TRANSFORMER PROBLEMS

BY THE LATE L. F. BLUME

The Transformer as a Factor in the Development of the Electrical Art. The almost universal use of the alternating-current system for the transmission and distribution of electrical energy is largely due to the fact that circuits of different voltages can be linked by a simple, convenient, and reliable device—the static transformer—making it possible for the generator, the transmission line, the secondary distribution system, and, finally, the great variety of loads to be operated at their most suitable voltages. Without this unique ability of the transformer to adapt the voltage to the individual requirements of the different parts of a system, and to maintain substantially constant voltage regardless of the magnitude of the load, the enormous development and progress in the transmission and distribution of electric energy during the past sixty years would not have been possible.

This ability is derived from the simple fact that it is possible to couple the primary and secondary windings of the transformer in such a way that their turn ratio will determine very closely their voltage ratio and the inverse of their current ratio, with the result that the output and input volt-amperes and output and input energies are approximately equal. By virtue of these simple relationships, the transformer serves as an economical and efficient means of deriving that voltage which is best suited to the needs of each individual application, and at the same time connecting all into one system.

Dominant Factors in Transformer Progress. The development of the transformer, especially in the early period of its growth, took the form of a persistent attempt to approach more closely this ideal condition of the loss-less transformation of power. The most notable means by which this has been accomplished have been:

(*a*) The development of non-aging low-loss silicon steels by virtue of which all transformers have become smaller, lighter, less costly, and more efficient for a given output.

(*b*) The use of oil as an insulating and cooling medium, thereby in-

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creasing greatly the permissible voltages for a given insulation spacing, and at the same time greatly facilitating the carrying away of the internal heat through small ducts from the interior. This second factor alone has made it possible to extend vastly the sizes of transformers. The consequence of these two developments has been that large power transformers have reached efficiencies of approximately 99.5 per cent, 110,000 kv-a. units are now in successful operation, 145,000 kv-a. units under construction, and still larger units are under consideration. The significance of these figures can best be appreciated by noting that during the first decade of the transformer business, efficiencies better than 90 per cent were not attainable, and, in that period, it was seriously debated whether transformers could be successfully built and operated in sizes greater than 10 kv-a.

(*c*) The improvements in solid insulating materials, methods of impregnation, design structure, and shielding, whereby the voltages for which transformers could be insulated economically, have been increased indefinitely, so that today ten million volts are commonplace in the laboratory. Although the highest transmission voltage at the present time is 287,000 volts, the reason is not a limitation in the transformer design but present lack of economical projects for higher voltage transmission.

The Practical Significance of the Equality of Input and Output. So closely does the average transformer approach the ideal that, for many purposes of calculation, without serious error, the transformer may be assumed to be a perfect device for the transformation of power. Accordingly, the turn ratio may be taken as the voltage ratio and the inverse of the current ratio. As an example of the usefulness of this approximation, the determination of current and voltage relations in polyphase transformer connections may be cited, for, by simply equating the input and output kilovolt-amperes, the primary and secondary currents in most cases can be quickly determined. Thus, in three-phase to two-phase transformations, as the three-phase kv-a. is $1.73E_1I_1$ and the two-phase kv-a. $2E_2I_2$, it follows that the equation

$$1.73E_1I_1 = 2E_2I_2$$

is useful to determine the currents and voltages for the majority of transformer connections involving the transformation of three-phase to two-phase circuits.

Diversity of Transformer Problems and Their Origin. To the casual reader, it may appear that this simple, approximate relationship is quite inconsistent with the large variety of complicated transformer problems

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