# HANDBOOK OF TRANSFORMER DESIGN AND APPLICATIONS

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CHAPTER 1

# Magnetic and Electrical Fundamentals

## 1.1 INTRODUCTION

Transformers are passive devices for transforming voltage and current. They are among the most efficient machines, 95 percent efficiency being common and 99 percent being achievable. There is practically no upper limit to their power-handling capability, and the lower limit is set only by the allowable no-load loss. Transformers and inductors perform fundamental circuit functions. They are a necessary component in electrical systems as diverse as distribution terminals for multimegawatt power-generating stations to hand-held radio transceivers operating on a fraction of a watt. This book is intended to ease some of the difficulties users and designers face from the limitations of these components, the resolution of which is still painfully evolving.

Transformers are the largest, heaviest, and often costliest of circuit components. The geometry of the magnetic circuit is three-dimensional. This property places a fundamental restraint on reducing transformer size. The properties of available materials limit weight reduction. The high cost of transformers is due to the impracticability of standardization, the materials needed, and the processes inherent in their manufacture. The problems associated with the use of magnetic devices can be minimized by the employment of astute application practices.

Transformers are indispensable for voltage transformation in power applications. Their ability to isolate circuits and to alter ground conventions can often be matched in no other convenient manner. They are needed in frequency selective circuits whose operation depends on the response of inductances. They are rugged, being capable of withstanding severe environmental conditions.

Transformers are essentially single-application devices. Designed for specific requirements, they do not offer optimum performance over a wide range of operation. They are not outstanding performers in applications requiring high-fidelity reproduction of audio or video signals. Wideband and high-impedance circuits often experience serious degradation when transformers are used. Transformers do not perform well in circuits which apply dc magnetization to the core. They are a problem in equipment in which size and weight must be kept to a minimum.

Transformers can sometimes be eliminated by circuit artifices. A bridge rectifier directly across the power line can replace a power transformer and rectifier if the voltage level and ground isolation can be accommodated. This is often done to obtain dc voltage for inverter circuits. Needed voltage transformation is then done at high frequency with a much smaller transformer. The direct coupling of semiconductor devices to loads eliminates audio transformers. Operation of driving circuits at voltages which will provide the desired output voltage by direct coupling may eliminate the need for voltage transformation at the output.

Closely related in both theory and construction to transformers are other magnetic devices which include inductors, saturable reactors, and magnetic amplifiers. Much of the discussion on transformers is applicable to them. The unique features of these devices are discussed separately.

## 1.2 FUNDAMENTALS OF MAGNETIC CIRCUITS

The literature on magnetic devices uses a vocabulary which may be unfamiliar to some readers. It is not difficult to learn these terms and to master the fundamentals of magnetic circuits. This section provides an introduction to the subject.

The study of magnetics begins with Coulomb's law for magnetic poles:

$$F = \frac{m_1 m_2}{\mu r^2} \tag{1.1}$$

where $F$ = repulsive force between two magnetic poles of like polarity $m_1$ and $m_2$
$r$ = distance between the two poles
$\mu$ = constant of proportionality called *permeability*