CHAPTER 1
INTRODUCTION

1.1 General Background

The efficient and economical design of electrical machines requires accurate knowledge of magnetic field distribution. Several problems are encountered when the electromagnetic field of an electrical machine is modelled. The magnetic saturation of the iron core makes the equations nonlinear. The laminated parts of the iron core are anisotropic, since their permeability and conductivity depend on the direction of the field. The geometry of the end regions is complex because of the presence of various ferromagnetic and conducting parts for the support of the iron core. Hence in most situations, it becomes difficult to design a machine, which meets all the performance indices without certain major assumptions. Modern finite element based software for both electromagnetic design and magneto-thermal analysis and integrated programming languages, eliminate most of these simplifying assumptions regarding complex boundaries and boundary conditions. Even anisotropy or nonlinearity can be taken into account. Modelling capabilities of tools like AUTOCAD in conjunction with soft computing techniques can be used for design optimization. The versatility of this method can be exploited for developing new condition-monitoring techniques also.

With the recent quest for alternate energy schemes, especially small hydro and wind power, brushless alternators of inductor type are included in many research and development programmes. The ever-increasing emphasis on the exploitation of non-conventional energy resources, so as to reduce the
burden on grid power, the compelling need for alternate energy schemes and
the advent of new software tools have prompted researchers to focus more on
evolving a hybrid combination of inductor alternator and an electronic control
for use in different spheres of power. Projects are already underway to
enhance the performance of such alternators as brushless main exciters in
hydroelectric generating stations.

The University of Leicester is presently developing the prototype of 50kW
inductor alternator driven up to 60,000r/min by gas turbines and a new
electronic regulation circuit [1]. The use of inductor alternator, driven by diesel
engines run on biomass-based gasifiers, for supplying high frequency
industrial loads are being investigated [2]. The field winding in such cases can
be excited from photovoltaic panels, resulting in substantial saving in grid
power. Inductor alternators have to be operated over a wide range of speeds
in applications such as locomotive lighting and coach air-conditioning. Three
phase 25kW 120V homopolar inductor alternators are being manufactured for
air-conditioned railway coaches with a cut-in speed of 350 rpm and maximum
speed of 2500 rpm with bridge rectifier and magnetic amplifier controller unit.
The use of such alternators with electronic regulation for dc generation is an
area that is being examined in recent research work. The generator and its
power electronic controller constitute a simple and hence low cost brushless
dc generation scheme. The construction of this robust and inexpensive
machine as well as the theory of generation and the practical results from an
experimental alternator are explained in reference [3]. A Canadian research
programme has suggested the use of these alternators as wind turbine
generators for operating in artic conditions to supply power to the equipment at a Geo-stationary satellite relay station [4]. Due to its outstanding merits like robustness and economy of operation, this machine is replacing the conventional machines in new areas of application. A recently completed project of Massachusetts Institute of Technology, investigates the design and cost optimization of an inductor alternator for use as a high-speed high-power automotive power source [5]. The Hong Kong University is also pursuing research in this direction. The theory, performance and design of an axial field inductor alternator are being studied to formulate the steady state and transient state performance characteristics [6]. Aerospace power plants using high-speed homopolar inductor alternators are also mentioned [7], [8]. Other applications are in melting of metals and surface hardening of steel [9] and in ultrasonic cleaners [10].

Though inductor alternators were the subjects of research till mid 70’s, the work in this area remained dormant for a period up to the early 90’s and hence modern computational tools were seldom put into use in the design and performance of this machine. It is important to note that, since not many revolutionary ideas have evolved in this field in the last two decades, the theory put forward by earlier investigations is still valid and holds good in the present context also.

Condition monitoring is an emerging area in the railway industry and is widely seen as a key area for improved system reliability and reduced maintenance cost [11]. Rub impact between rotating and non-rotating parts in train lighting alternators either due to unbalanced magnetic pull or sideways
thrust of v-belt axle pulleys is also to be investigated. Experimental data is not available regarding the additional tooth ampere turns required to take into account high surface saturation when the flux is confined to enter through a reduced tooth surface, which happens when stator and rotor teeth are not exactly facing each other. Finite element analysis would also show how tooth tip saturation at various leading and lagging power factors travels over a skewed rotor tooth and the resultant surface heating. Now that the field of application of inductor alternators has widened many fold, it is highly imperative to develop newer techniques for the design and condition monitoring of this machine, thus improving its performance.

1.2 Objectives of the Present Investigation

- Pre-determination of no load generated voltage of Train-lighting Brushless Alternator of Inductor type by finite element method.
- Formulation of a closed form solution to pre-determine the no load generated voltage of the brushless alternator.
- Experimental verification of the results obtained by the above methods and comparison.
- Optimisation of different design parameters of the alternator using finite element method.
- Pre-determination of no load unbalanced magnetic pull in the alternator under static eccentricity conditions of the rotor using finite element method.
Development of a software based on a derived closed form expression for pre-determining the no load unbalanced magnetic pull in the brushless alternator.

- Comparison of the closed form solution and result obtained from finite element analysis.
- Pre-determination of no load unbalanced magnetic pull in the alternator under static eccentricity conditions for conical motion of the rotor using finite element method.
- Development of a technique to identify a possible signature for condition monitoring of the Train-lighting Brushless Alternator under static eccentricity conditions of the rotor.

1.3 OUTLINE OF THE THESIS

The thesis is organised in 10 chapters. A detailed literature review regarding the issues and concerns in the design and operation of the inductor alternator is presented in Chapter 2. They present the state of the art in the methods used to analyse the electromagnetic field of the machine as well as the various design techniques employed in earlier investigations. The problems faced by the industry in this area are also studied.

An overview of finite element method (FEM) and its application in the evaluation of electromagnetic fields are given in Chapter 3. The capabilities and limitations of the various FEM based software are also discussed.

Chapter 4 provides an insight into a novel technique based on FEM for the pre-determination of generated no load voltage of Train-lighting Brushless Alternator with both skewed and unskewed rotors. Further, this method is
extended for shape optimisation of certain design parameters of the machine, with a view to reduce the harmonics.

A theoretical analysis leading to a closed form solution for obtaining the generated no load voltage of Train-lighting Brushless Alternator, is described in Chapter 5.

In Chapter 6, the experimental results obtained from an inductor alternator, designed and fabricated for the purpose are given and compared with those obtained from finite element analysis and closed form solution.

Chapter 7 deals with the electromagnetic forces in inductor type brushless alternators, when the rotor is performing eccentric motion with respect to the stator. A modified time stepping finite element method is proposed to solve the magnetic field in the air gap and iron parts of the machine, for different degrees of static eccentricity. The distribution of the radial force due to eccentricity is then calculated using classical Maxwell stress tensor method.

Both the formulation and the finite element type chosen influence the accuracy of the solution. Therefore, a comparison of the values obtained by finite element analysis for unbalanced magnetic pull under static eccentricity conditions, is made with the solution obtained from a theoretical analysis, in Chapter 8.

Chapter 9 describes briefly how rotor eccentricity can be identified in the alternator by obtaining a suitable signature for condition monitoring. Finite element analysis along with harmonic analysis of certain generated voltage waveforms proved useful for this.

Chapter 10 summarises the work done and scope of future work in this area.