CHAPTER 10
CONCLUSION AND SCOPE FOR FUTURE WORK

10.1 SUMMARY

The present work dealt with investigations on a train-lighting brushless alternator of inductor type. These investigations were carried out in two phases.

The objectives considered in the first phase were to pre-determine the no load generated voltage of the train-lighting brushless alternator by finite element method and to develop a closed form solution for this, the results of both of which were to be validated with experimental work. Different design parameters of the alternator were also to be optimised using finite element method, for significantly reducing the power-derating problem of the alternator. This could be achieved by reducing the harmonic content in its generated voltage waveform.

Design and optimisation of many practical electromechanical devices usually involve intensive field simulation studies. Since most of the assumptions regarding complex boundaries and boundary conditions can be eliminated and anisotropy or nonlinearity can be taken into account by using numerical techniques like finite element analysis, a FEM based geometrical shape searching technique was proposed, validated with theoretical and experimental results. In this method of optimisation of slot and rotor profiles, by predicting the voltage harmonic distortion factor, the calculations are based on a scaling factor on speed rather than on time thereby saving a considerable amount of calculation time. A two-dimensional multi-slice method
was also employed to take into account the effects due to rotor skew thus easing computational difficulty to a large scale. Moreover, the use of three commercial packages to form a single practical design tool provides designers easier access to finite element analysis. In the present work, a closed form expression for the no load generated voltage of train-lighting brushless alternator is derived, based on classical equations. Further, the results obtained by finite element analysis and by analytical calculations were validated with experimental results. The finite element simulated, the analytically computed and experimental waveforms of no load voltage compare well and a good correlation is achieved. This proposed methodology at the design level has contributed to the improvement of power quality also, as elaborated in Chapters 4, 5 and 6.

The second phase of investigation focused on unbalanced magnetic pull, since for machines like flexible-mounted train lighting alternators, which operate under extreme environmental conditions and which are constantly under the influence of vibrations, contributed by the movement of the coach itself, unbalanced magnetic pull is too significant to be ignored. Moreover in inductor alternators, air gap is too small for saturation to be neglected. The main objectives in the second phase of research were pre-determination of no load unbalanced magnetic pull in the alternator under static eccentricity conditions of the rotor using finite element method and development of a software based on a derived closed form expression for the same. Rotor skew and conical motion of rotor were also to be analysed under static eccentricity conditions. Another objective was the development of a technique to identify a
possible signature for condition monitoring of the alternator under static eccentricity conditions of the rotor.

A modified time stepping finite element method is proposed in this work to solve the magnetic field in the air gap and iron parts of a train-lighting brushless alternator of inductor type, for different degrees of static eccentricity. The distribution of the radial force due to eccentricity is then calculated using classical Maxwell stress tensor method. Thus, this method incorporates the versatility of finite element method into classical analysis. In the present work, dedicated software on a MATLAB platform for determining the unbalanced magnetic pull in inductor type alternators is developed based on a theoretical analysis. The finite element results show close agreement with the results obtained theoretically. As a corollary to this, an expression for the axial flux resulting from static eccentricity of the rotor is also developed. A simple method for detecting even a slight rotor asymmetry in train lighting brushless alternators, on the basis of the voltage waveform harmonic pattern has also been developed in the present work. This is extremely helpful to obtain a signature for condition monitoring so as to identify increasing static eccentricity of the rotor, over a period of time. Although, different techniques such as vibration analysis, thermal analysis, current spectrum analysis etc have been employed in the past for condition monitoring in induction motors, these may produce in erroneous results, when applied to a train lighting brushless alternator, considering its operating environment. Thus the proposed methodologies help to avoid rub contact between stator and rotor, during prolonged operations of these alternators, which is a major problem,
reported by Indian Railways and alternator manufacturers. A two-dimensional multi-slice method has also been developed for calculation of UMP for rotors undergoing conical motion and for skewed rotor machines under static eccentricity conditions. These aspects are dealt with in Chapters 7, 8 and 9.

10.2 **Scope for Future Work**

1. The investigations in the present work have been carried out under no load conditions of the train-lighting alternator. These can be extended to alternator performance evaluation under loaded conditions also.

2. The present study has chosen the mesh size in FEM models not based on any theoretical considerations related to the analysis of the problem, but as pragmatic considerations related to computational speed and time. A refined meshing of FEM models perhaps may contribute to further improvement of results, especially in condition monitoring field.

3. New algorithms can also be developed for the above-mentioned investigations based either on stochastic or deterministic techniques where a compromise is achieved between accuracy and speed of computation [125]. In such an approach termed combined Finite Element/Neural Network approach, a conventional magnetic circuit model of the device is developed to create a set of sensitivity rules, which guide the optimisation. The rules are coded in a knowledge-based neural network. An error network is also developed to correct the approximations inherent in the magnetic circuit approach and this combines with the first network to generate realistic outputs. Finally, the error network can be trained on-line with a finite element system. Over
time, the network replaces the finite element analysis, thus speeding up the optimisation process. Figure 10.1 shows the diagram of such a scheme. Each time a set of performance parameters is generated, the data is fed back to provide a new training set.

4. The proposed finite element techniques can be used in conjunction with other strategies involving generalized response surface methods, for developing cost effective optimal designs.

5. A single software package of detection and calculation of unbalanced magnetic pull can be developed by combining the proposed FEM based condition monitoring technique with the analytical procedure developed in the paper.

6. The dependence of unbalanced magnetic pull on rotor skew under both
balanced and unbalanced loaded conditions is also to be investigated in future.

7. In this study, analysis of waveforms was done using the classical Fourier analysis. In many engineering problems where Fourier analysis has been traditionally applied, alternate approaches have been now tried out with new advantages. One of them is the use of wavelet-based analysis, which has the ability to characterise conditions. Another method is to analyse waveforms for their fractal dimensions, thereby characterising them in a very different manner. Such novel methods could be investigated in place of Fourier analysis.

Thus there is clearly a scope for extension of the present work by logically expanding the scope of the problem and by applying alternate tools and methodology.