CHAPTER 1

INTRODUCTION

1.1. GENERAL INTRODUCTION

Due to rapid decrease in fossil fuels and increase in global warming, the attention is diverting towards the importance of locally available natural resources. The natural resources will provide an alternative energy source with less cost and also be helpful in maintaining a pure and healthy atmosphere. Increasing use of renewable energy sources such as wind energy, bio-gas, solar, and hydro potential has become essential to adopt a low cost generating system, which is capable of operating in remote areas. Out of all renewable energy sources, wind energy seems to be prominent and quite promising for electric power generation [1]. Wind energy conversion has been found economic compared to the cost of fossil fuels which are rising at a much faster rate. Therefore, the study of induction generators has regained importance, as they are particularly suitable for wind and small hydro power plants.

The advantageous features of induction generators are less maintenance, operational simplicity, self-protection against faults, brush less and rugged construction [2-9]. The induction generators, in general, can be operated in two different modes; namely grid connected mode and isolated mode. In grid connected mode of operation, the terminal voltage and frequency are fixed by the grid. But, in isolated mode of operation, they depend upon load, speed and excitation capacitance. The isolated (or) self-excited induction generators are particularly suitable for
supplying loads in remote areas where grid is not available. The capability to generate power at varying speed is the feature of induction generator which helps it to operate in self-excited/isolated mode to supply far flung and remote areas where extension of grid is not economically feasible in order to fulfill the increased local power requirement [1].

Therefore, it is important to study the performance of self-excited induction generator (SEIG) under steady-state condition for the optimum utilization of its meritorious features. Moreover, for ensuring good quality power and for assessing the suitability of given configuration for a given application, the steady-state modeling and analysis of self-excited induction generators is essential.

### 1.2. STATE OF ART

Many researchers have reported on practical applications and computation of the steady-state performance of three-phase and single-phase self-excited induction generators [10-114] using steady-state equivalent circuit of the machine. From the above literatures, it is observed that there are different mathematical models namely; d-q reference frame model [16-21, 73-76], impedance-based model [22-38, 57-62, 77-83], admittance-based model [39-44, 63-72], operational circuit-based model [45] and power equation-based model [46-47]. Generally, the equivalent circuit of the machine is used to develop the mathematical models for computing the steady-state performance of three-phase and single-phase self-excited induction generators. In these mathematical models, equivalent impedance (complex impedance) or equivalent admittance (complex admittance) of the equivalent circuit is separated into real and
imaginary components. The two nonlinear equations (corresponding to real and imaginary components) are written in terms of the unknown quantities such as magnetizing reactance \(X_M\) and frequency \(F\) or capacitive reactance \(X_C\) and frequency \(F\) and treating the rest of the machine parameters and operating variables as constants. By employing a numerical method, such as Newton-Raphson method, these non-linear equations are solved for unknown quantities and the steady-state performance of the machine is computed.

But the drawback of these approaches is that they need manual separation of real and imaginary components of complex impedance or complex admittance and involve lengthy derivations. Also, the mathematical models are different for different types of loads and different combination of unknown quantities such as magnetizing reactance \(X_M\) and frequency \(F\) or capacitive reactance \(X_C\) and frequency \(F\) of the equivalent circuit. The same mathematical model cannot be used for different types of series capacitor connections like short shunt and long shunt connections at the machine terminals.

In most of the above analysis, Newton-Raphson method is applied to predict the unknown quantities of the equivalent circuit. In Newton-Raphson method, the two nonlinear equations have to be suitably rewritten in terms of the required unknown quantities. Also, to find the unknown quantities, Newton-Raphson method needs partial differentiation to compute Jacobian matrix as well as inverse of this matrix. Further, divergence of the solution process may occur due to improper initial guess of the unknown quantities.
To overcome the above drawbacks, the graph theory based approach is suggested [115-118] in which the mathematical model is in matrix form and fuzzy logic approach is implemented to solve the matrix equation. The graph theory based modeling eliminates the tedious manual derivation of separating real and imaginary parts of the complex impedance/admittance of the equivalent circuit. But, this model needs formation of graph, tree and tie-set/cut-set matrix to form the mathematical model in matrix form.

Even though three-phase induction generators are used for wind energy applications, many research articles have been reported [119-129] on multiphase (more than three phase) induction machine due to their advantages like higher power rating and improved reliability. In recent years, six-phase self-excited induction generators have attracted a considerable attention [130-141] due to certain advantages such as improved reliability, possibility of supplying two different and independent three phase loads. Failure of one three phase generator winding in this case does not mean the shutdown of the system [137], since the load can still be supplied through the remaining healthy generator winding (with an appropriate reduction of the delivered power).

The equivalent circuit for the six-phase induction machine was derived by T.A.Lipo [119]. G.K.Singh et al. [138-141] made suitable modifications in the equivalent circuit [119] and applied graph theory based model [115-118] for the computation of steady-state performance of six-phase self-excited induction generator. G.K.Singh et al. [141] developed separate mathematical models for simple
shunt, short shunt and long shunt configurations using graph theory approach. The graph theory based model needs formation of graph, tree and tie-set/cut-set matrix to form the final mathematical model in matrix form. But, a much simplified approach is possible by writing the nodal admittance matrix directly from the equivalent circuit rather than deriving it using graph theory.

Therefore, in this research work, a generalized and simplified mathematical model [142-144] for the steady-state analysis of six-phase SEIG is developed. To prove the validity of the proposed method, it is extended for the steady-state analysis of three-phase and single-phase SEIGs. The proposed model is based on nodal admittance method by inspection in which the nodal admittance matrix can be directly formed from the equivalent circuit of SEIG. Therefore, it neither requires manual separation of real and imaginary terms of the complex impedance nor the formation of graph and tie-set/cut-set matrix from the equivalent circuit. The proposed model is flexible so that any equivalent circuit components may be included or eliminated from the model. The same model with suitable modifications can be utilized for the steady-state analysis of the SEIG without/with series compensation. Moreover, the model enables us to find any combination of unknown quantities of the equivalent circuit. The proposed model is also applied for three-phase [145] and single-phase [146] SEIGs. Genetic algorithm is implemented for the steady-state analysis of six-phase, three-phase and single-phase SEIGs.
1.3 SCOPE AND OBJECTIVES

In this research work, an attempt has been made to develop a new, generalized and simplified mathematical model for six-phase, three-phase and single-phase SEIGs using nodal admittance method based on inspection. The main objectives of the research work are:

1. To develop generalized steady-state mathematical model using nodal admittance method by inspection and formulate genetic algorithm approach for the following cases.

   i. Capacitance requirements to maintain desired terminal voltage of six-phase self-excited induction generators.


2. To prove the validity of the proposed method, it is also extended for the following cases.


1.4 OUTLINE OF THE THESIS

Chapter 1 presents general introduction to the problem, state of art, and the scope and objectives of the present research work.

Chapter 2 presents a mathematical model using nodal admittance method based on inspection for the steady-state analysis of six-phase SEIG. The detailed winding design of six-phase induction machine used for experimental setup is presented in this chapter. Genetic algorithm based approach is presented and explained to obtain unknown quantities (X_C and F) of the equivalent circuit of six-phase SEIG. The capacitance requirements to maintain desired terminal voltage under varying operating conditions and steady-state performance of six-phase SEIG are determined in this chapter using the proposed mathematical model and genetic algorithm process. The analytical results have been verified by experiments on a six-phase SEIG.

The steady-state performance analysis of six-phase SEIG without series compensation is presented in Chapter 3. The same mathematical model and solution technique (as in Chapter 2) is applied to compute the steady-state performance of six-phase SEIG with X_M and F as unknown quantities. Various capacitance and loading configurations are discussed and the results are tabulated.

To improve the voltage regulation of the six-phase SEIG and study the effect of series capacitor excitation, an investigation is carried out as part of this research work in Chapter 4. This chapter analyses the short shunt and long shunt
configurations of capacitive series compensation of six-phase SEIG using the proposed method. Different capacitance and loading configurations are considered and the results are tabulated.

In order to validate the proposed model, the method is extended for the steady-state analysis of three-phase SEIG in Chapter 5. The analytical results have been verified by experiments on a laboratory setup. Also, the effect of series compensation (short shunt and long shunt configurations) to regulate the terminal voltage of three-phase SEIG is discussed.

The proposed model and the steady-state analysis are also extended for single phase SEIG in Chapter 6. Single-phase single winding and two winding (main and auxiliary windings) SEIG configurations are analyzed in this chapter. The analysis has been verified by experiments on a laboratory setup. Also, short shunt and long shunt configurations of series compensation are analyzed.

A review of the significant contributions of the research work and scope for further work are given in Chapter 7.