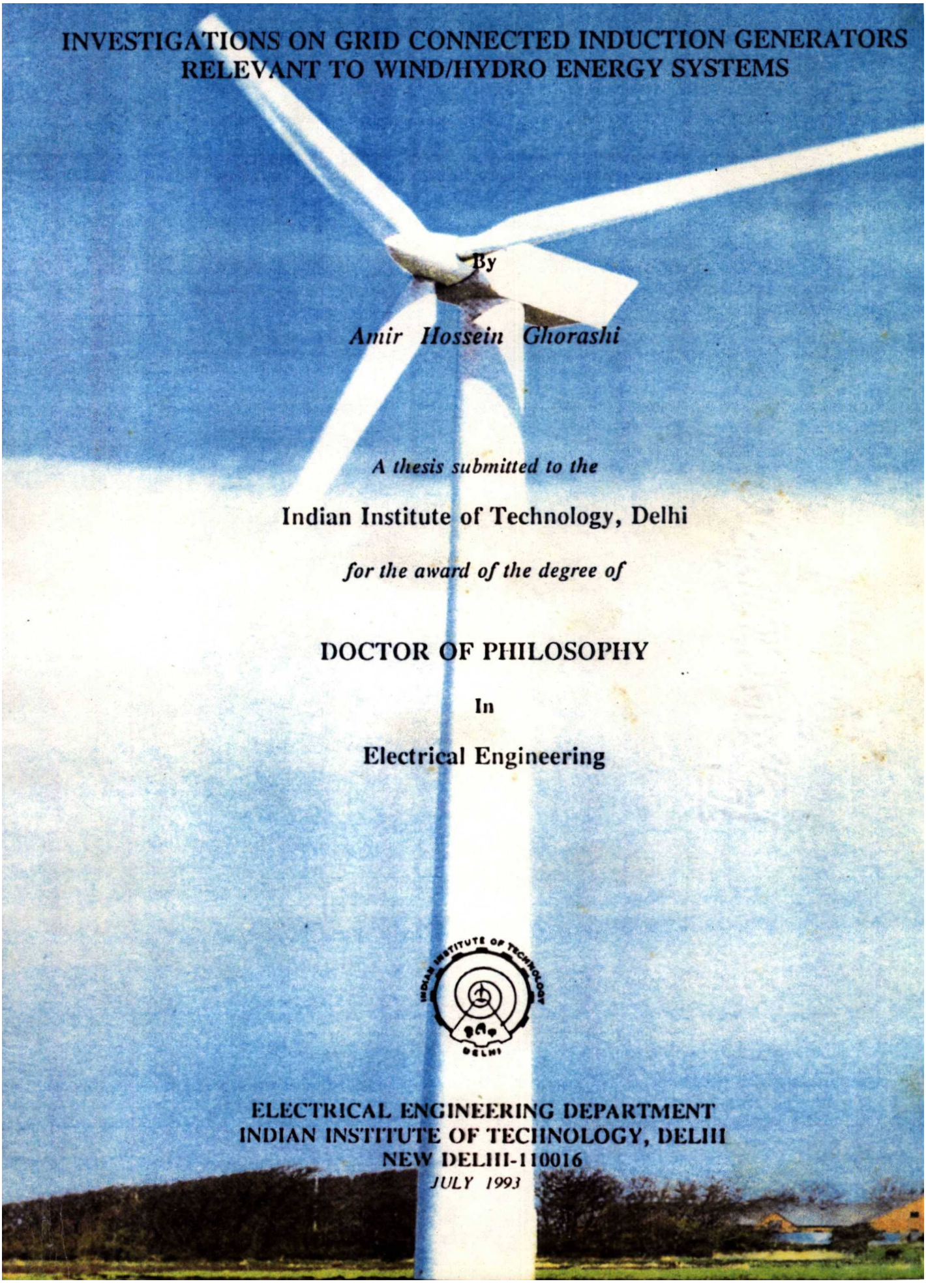
INVESTIGATIONS ON GRID CONNECTED INDUCTION GENERATORS RELEVANT TO WIND/HYDRO ENERGY SYSTEMS



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In the Name of Allah, Most Gracious, Most Merciful

Dedicated

to

THE LATE IMAM KHOMAINI

The founder of Islamic Republic Of Iran

CERTIFICATE

Certified that the thesis entitled *"**Investigations on Grid Connected Induction Generators Relevant to Wind/Hydro Energy Systems**"*, which is being submitted by *Mr. Amir Hossein Ghorashi,* in partial fulfillment for the award of the ***Degree of Doctor of Philosophy*** in Electrical Engineering of the Indian Institute of Technology, Delhi, is a record of the student's own work carried out by him under our joint supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

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ABSTRACT

In recent years due to the increased emphasis on renewable energy sources, such as wind, hydro and wave energy, there has been a rapid expansion in activities relating to the energy conversion from these natural resources to electricity. Of late, the wind and mini hydro energy systems have proven to be attractive options for augmenting power generation.

Apart from autonomous generating systems, installed for relatively low power units for supplying power to the localized loads, the grid connected systems in which the converted power is fed to the utility grid have become very common. The large number of existing wind farms are examples of this new developments, where Induction Generators (IG) are widely employed.

The operation of grid connected induction generators are not without problems. It requires proper match between the system variables of generating unit and the grid. For instance, the utility companies often try to limit the growth in the number of wind turbine generators connected to their grid systems as they consider them as added irritants. On the other hand, the poor quality of the electricity produced by the utilities has been brought to light by windmill owners.

The influence of poor grid on the performance of grid connected induction generators used in a wind or hydro system is not well known to the system engineers, as not much work has been reported on the abnormal operation of the grid connected systems. This lack of information results in frequent disconnection of the units from the grid and hence affects the energy transfer. It may result in the damage to the equipments or their poor performance.

It is aimed in this doctoral thesis to firstly identify some of the prevailing abnormalities in the operation of the grid connected induction generators based on which detailed investigations pertaining to operation under each irregularities are carried out with a view to finding appropriate technical solutions.

In order to have a first hand information regarding different realistic operating conditions of IG installed in the field, a comprehensive survey of wind farms in the state of Gujarat, India, was undertaken. These field information are detailed in Chapter two of the thesis which portrays the realistic problems faced by the wind farms. This survey supports the necessity and importance of the investigations presented in subsequent chapters.

Two practical field models one of 55 kW wind turbine generator and the other of 220 kW hydro system are chosen for analytical investigations. This study is further augmented by conducting experiments on a 3.7 kW laboratory model so as to validate the analytical results.

Depending upon the loading and other system conditions, both the grid and the primary distribution network are subjected to wide variation in voltage and/or frequency. On the other hand, at the turbine end, due to varying nature of wind/hydro power the generator will be receiving varying amount of input power. In this study, the impact of variation in the grid voltage and frequency for a given input power is analyzed considering an appropriate voltage dependent parameter. Total system modelling and computer simulation are undertaken to predict the performance. The effect of varying the input power is also studied. The required value of terminal capacitor, the extent of VAR drain and the current are studied in each case. Appropriate prediction and suggestions pertaining to the level of the power handling capacity of the machines in such abnormal conditions are given in this study.

Wind/hydro driven induction generator feeding power to the grid has been analyzed under the abnormal condition of unbalanced grid voltages. Using the symmetrical component and double revolving field theory, appropriate equivalent circuits and model equations have been derived for the generating mode with suitable realistic modifications. It is emphasized that the flow of active and reactive power components and their directions for both positive and negative sequence systems need to be properly identified in order to obtain the cumulative response of the generator under different wind/hydro power conditions. In view of the fact that the reactive power is drawn from the grid while the active power is fed into the grid, the extent of variations in power fed to the grid and the reactive VAR due to unbalanced grid voltages for different wind/hydro power conditions need to be estimated so as to provide guidelines for the design and operation of wind energy conversion system. Both experimental and theoretical results have been presented, which validate the theoretical formulations.

The extreme case of grid unbalance occurs when one of the lines gets disconnected while the input power remains the same. It is felt that this study is very essential in view of the realistic situation encountered in the field wherein a single phasing is not an uncommon feature. The performance of IG under this particular case of unbalance has been studied and the extent of power that the IG can handle has been predicted. Further, the study is extended to the case in which the grid voltage is also varied.

The transient performance of IG has a direct bearing on the system behaviour. Some important transients which commonly occur in the field are Run-up, Re-switching, short circuit, single phasing and abrupt change in the input power. Analytical technique to study the above problems are presented and appropriate computer algorithms are developed. Besides studying the wind and hydro models a wave energy conversion system has also been chosen for the study of the transient response when there is a periodic change in the power

input based on the wave pattern.

It is hoped that this doctoral thesis would provide some useful information on the effect of different kinds of irregularities prevailing in the Grid Connected Induction Generators (GCIG) operation most of which can be attributed to the grid abnormalities. The results of these investigations are felt to be useful for design and operation of such systems.

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