

ANALYSIS OF NOVEL STRATEGIES FOR
CONTROL OF AN AUTONOMOUS WIND-
DIESEL GENERATING UNIT

by

KHAMIS ALY NABWY ALLAM

Electrical Engineering Department

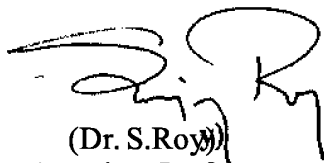
Submitted
in fulfillment of the requirements of the degree of Doctor of Philosophy
to the



Indian Institute of Technology, Delhi
May 2002.

CERTIFICATE

Certified that the thesis entitled "**Analysis of Novel Strategies for Control of an Autonomous Wind-Diesel Generating Unit**" which is being submitted by **Mr. Khamis Aly Nabwy Allam** for the award of the Degree of Doctor of Philosophy in the Department of 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.

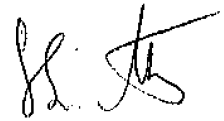


(Dr. S. Roy)

Associate Professor

Department of Electrical Engineering
Indian Institute of Technology, Delhi
New Delhi- 110016 (India)

27 May • 2002



(Dr. S. S. Murthy)

Professor

Department of Electrical Engineering
Indian Institute of Technology, Delhi
New Delhi- 110016 (India)

ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to Prof. S. S. Murthy and Dr. S. Roy for their guidance and inspiration in carrying out the work and for immense help in the preparation of this thesis.

The author thankfully acknowledges Prof S. S. Murthy for initially helping him to take up research at Indian Institute of Technology, Delhi. He is equally thankful to Dr. S. Roy for the constructive and useful discussions throughout the period of research.

The author is grateful to Prof. Bhim Singh and Prof B. P. Singh for their generous help and suggestions during the writing of this thesis.

The author is grateful to Prof. Eduard Muljadi from the National Renewable Energy Laboratory (NREL), U.S.A. for his generous help through emails.

The author is thankful to Department of Science and Technology (DST), Government of India for funding this work as a part of the wind diesel project.

The author is also thankful to the authorities of Indian Institute of Technology, Delhi for providing research facilities.

Special thanks are due to Mr. Meharban Singh of the Post Graduate Machine Laboratory for his sustained help and cooperation during the stay of the author in the institute.

New Delhi-110016

May 26th, 2002



Khamis Aly Nabwy Allam

ABSTRACT

The popularity of wind diesel power generation systems (WDPGS) stems from a reliable combination of continuously available diesel power and pollution-free wind power. Important problems in the current state of art for autonomous wind diesel power generation systems relate to operation and on line control of these units, particularly in case of weak systems with large penetration of wind power. Suitable control strategies are therefore required to take full advantage of wind energy during periods of its availability. These strategies must work to maintain power quality in terms of regulated voltage and frequency.

The unit configuration under consideration in this work consists of a diesel driven synchronous generator in parallel operation with a wind driven induction generator. This type of generation system is known to suffer from two problems:

- (i) Voltage dynamics due to the interaction between the induction generator and the automatic voltage regulator operating on the alternator field,
- (ii) Active power dynamics in presence of severe wind gusts.

The focus of this work is to develop prime mover and excitation control strategies that aim at improvement of system operation with reference to the problems (i) and (ii) listed above. A simple lag lead compensator is designed for the excitation system which regulates the terminal voltage of the unit to a desired set point, while mitigating voltage instabilities. Further, an improved wind turbine pitch angle controller is developed so as to regulate the energy extracted by the asynchronous generator in presence of wind

variations and gusts. Design for both controllers is based on suitable linear models of the entire generation system.

The entire control system is tested through simulation of large number of study cases using both static (resistive-inductive) and dynamic (induction motor) loads. System frequency variation, power output of the diesel unit, and load voltage variation are some of the dynamic conditions used to evaluate the effectiveness of the control algorithms.

Note:- The names MATLAB and SIMULINK as used in this thesis refer to software products that are manufactured by the Math Works Inc. The names are registered trade marks of this company.

CONTENTS

CERTIFICATE	ii
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
CONTENTS	vi
LIST OF FIGURES	x
LIST OF TABLES	xvi
LIST OF SYMBOLS	xvii
1. INTRODUCTION	1
1.1 Classifications of wind power generation systems	2
1.2 The challenges and difficulties associated with WDPGS operation	3
1.3 Power quality for hybrid wind diesel power generation systems	7
1.4 State of the art	8
1.5 Contribution of the proposed thesis and organisation of chapters	12
2. WIND POWER GENERATION UNIT	16
2.1 The MOD-OA wind turbine	18
2.2 Mathematical model for the MOD-OA wind turbine	21
2.3 Wind speed model	29
2.4 Simulation models for induction generator, terminal capacitor and load	33
2.5 The complete wind power generation unit	38
2.6 Summary	39

3. DIESEL POWER GENERATION UNIT	44
3.1 Dynamic features of the diesel prime mover	45
3.2 Mathematical model for the diesel prime mover	48
3.2.1 Engine torque generation	48
3.2.2 Dynamic effects of turbocharging	53
3.2.3 Actuator dynamics	55
3.2.4 Inertial components and couplings	55
3.2.5 Simulation procedure	57
3.3 Simulation model for synchronous generator	58
3.4 Simulation model for the excitation system	62
3.5 The complete diesel power generation unit	62
3.6 Summary	63
4. VALIDATION OF MODELS AND SIMULATION	70
4.1 Validation of wind model	71
4.2 Validation of wind diesel model	76
4.3 Summary	83
5. COMPENSATED EXCITATION CONTROL FOR THE ALTERNATOR	94
5.1 The nature of alternator/induction generator interaction	95
5.2 Linear small perturbations model for alternator/induction generator system	97
5.2.1 Linearised model of synchronous machine.	99
5.2.2 Linearised model of induction generator.	103

5.2.3	Linearised model of the load.	105
5.3	Design of the excitation compensator.	108
5.4	Simulation results.	110
5.5	Summary.	117
6.	A NOVEL DESIGN FOR TURBINE PITCH ANGLE CONTROL	118
6.1	The objectives of pitch angle control	120
6.2	The nature of pitch angle controller	121
6.3	A reduced order linearised model for the wind power generation unit	125
6.3.1	Linear model for the turbine plant	125
6.3.2	Model for the actuator	128
6.3.3	Model for pitch angle controller	128
6.3.4	Reduced order incremental model for the induction generator	128
6.4	Selection of the pitch angle controller parameters	130
6.5	Selection of the best stabilising signal	134
6.6	Summary	135
7.	PERFORMANCE OF THE WIND DIESEL GENERATION UNIT	141
7.1	The integrated wind diesel power generation unit (WDPGU)	142
7.2	Wind diesel power generation with resistive-inductive (R-L) loads	144
7.3	Wind diesel power generation with induction motor loads	147
7.4	Wind diesel generating unit with static and dynamic loads	151
7.5	Two wind unit and a single diesel unit with static and dynamic loads	151

7.6	Summary	160
8.	CONCLUSIONS	162
8.1	Concluding remarks on MATLAB/SIMULINK program and validation tests.	162
8.2	Concluding remarks on voltage control	163
8.3	Concluding remarks on pitch angle control	165
8.4	Concluding remarks on performance with dynamic loads	166
8.5	Possible trends for future work	167
	REFERENCES	169
	APPENDIX A: A LIST OF SOME WIND DIESEL PROJECTS IN THE WORLD	182
	A BRIEF BIOGRAPHY OF THE AUTHER	187