

LB/DON/33/2012

LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

VOLTAGE STABILITY ANALYSIS OF A GRID CONNECTED WIND FARM

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Science

by



University of Moratuwa, Sri Lanka.
R.D. Nagodavithana
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

University of Moratuwa



102531

Supervised by:

Dr. *Narendra De Silva*

Dr. J.P. Karunadasa

621.3
621.3(043)

Department of Electrical Engineering

University of Moratuwa, Sri Lanka

102531

October, 2011

102531

Declaration

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

.....

R.D. Nagodavithana

25/10/2011



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

We endorse the declaration of the candidate

UOM Verified Signature

.....

Dr. Narendra DeSilva

UOM Verified Signature

.....

Dr. J.P. Karunadasa

Contents

Declaration	i
Contents	ii
Abstract	v
Acknowledgement	vi
List of Figures	vii
List of Tables	ix
1 Introduction	1
2 Theoretical Development	4
3 Development of system component models	6
3.1 Transmission Line Model	6
3.1.1 Extension to three phase system	8
3.2 Induction motor model	13
3.2.1 Dynamic equation of induction motor	13
3.3 Wind turbine model	23
3.4 Generator soft starter	23
3.5 Capacitor bank	24
3.6 Power transformer	24
4 Calculation of model parameters	25
4.1 Transmission line parameters	25
4.1.1 Self Impedance	25
4.1.2 Mutual impedance	27
4.1.3 Transmission Line Capacitance	29
4.2 Transformer impedance	31

4.3	Capacitor bank	31
4.4	Turbine parameters	31
4.5	Induction Generator Parameters	34
4.6	Conversion to per unit parameters	35
4.6.1.1	Induction Motor Performance Data as Given by the Model	36
4.7	Performance data for a single generator	36
4.7.1	Simulation at Zero Wind Speed	37
4.7.2	Simulation at 15m/s Wind Speed	39
4.7.3	Torque vs Speed characteristics	40
4.7.4	Simulation of Single Generator at end of long transmission line	40
4.7.4.1	Varying voltage profile with constant wind speed	42
4.7.4.1.1	Case 1: Wind speed 3m/s & voltage at increase from -10% to +10% in 2.5% steps	42
4.7.4.1.2	Case 2: Wind speed 5m/s & voltage at increase from -10% to +10% in 2.5% steps	45
4.7.4.1.3	Case 3: Wind speed 9m/s & voltage at increase from -10% to +10% in 2.5% steps	47
4.7.4.1.4	Case 4: Wind speed 15m/s & voltage at increase from -10% to +10% in 2.5% steps	50
5	Stability Analysis	53
5.1	Case 1: Wind speed 0m/s & voltage at increase from -10% to +10% in 2.5% steps	55
5.2	Case 2: Wind speed 5m/s & voltage at increase from -10% to +10% in 2.5% steps	58



5.3	Case 3: Wind speed 9m/s & voltage at increase from -10% to +10% in 2.5% steps	61
5.4	Case 4: Wind speed 15m/s & voltage at increase from -10% to +10% in 2.5% steps	64
5.5	Low voltage ride through behavior	67
6	Conclusions	70
	References	71
	Annexure A: Calculation and plotting of simulation data	72
	Appendix B: Simulink model of induction motor	75
	Appendix C: Simulink model of wind farm	76
	Appendix D: Calculation of model parameters within matlab	77
	Annexure E: Datasheet of Induction Generator	83



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Abstract

Voltage instability is one of the problems that can cause a wind farm to shut down without any warning. The resulting sudden drop or generation can lead to large power system faults. The voltage instability issue mainly plagues one type of wind farm. The squirrel cage induction generator fed wind farms. This is due to the lack of reactive power support in this type of generators.

To assess the stability of such wind farms a dynamic model of wind farm has been developed by accumulating the following models.

1. Squirrel cage induction machine
2. Wind turbine
3. Transmission line
4. Transformer
5. Capacitor bank

Model parameters were calculated and simulations were performed for a wind farm consisting of eight wind turbine generators each with a capacity of 1805kVA.

Stability was assessed for normal 33kV national grid level network voltage variations of $\pm 10\%$ of rated Voltage. The wind farm is shown to be stable for this variation and operated within normal parameters.

The wind farm was also checked for LVRT capability and found to be within CEB specifications.

Acknowledgement

My sincere gratitude is extended to Dr. Narendra DeSilva and Dr. J.P. Karunadasa for their guidance in completing this work. Further I would like to mention my course coordinators Professor Ranjith Perera and Dr. 'Asanka Rodrigo for making the M.Sc program an enjoyable one to me.

My thanks also goes to my parents for their encouragement to pursue this program. Further I would also like to thank all the lecturers that have taught me at the M.Sc. program.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Figures

Figure	Page
Figure 3.1: Single Phase Transmission Line Model	7
Figure 3.2: Cascaded Single Phase Transmission Line Model	7
Figure 3.3: Three Phase Line Section	8
Figure 4.1: Transmission Line Capacitance	29
Figure 4.2: Turbine Power Curve	33
Figure 4.3: Simulation of Single Generator at Zero Wind Speed	37
Figure 4.4: Simulation of Single Generator at 15m/s Wind Speed	39
Figure 4.5: Torque Vs Speed characteristics at various terminal voltages	40
Figure 4.6: Grid Voltage - Case 1	42
Figure 4.7: Grid Current - Case 1	43
Figure 4.8: Transformer Voltage - Case 1	43
Figure 4.9: Active & Reactive Power - Case 1	44
Figure 4.10: Rotor Speed - Case 1	44
Figure 4.11: Grid Voltage - Case 2	45
Figure 4.12: Grid Current - Case 2	45
Figure 4.13: Transformer Voltage - Case 2	46
Figure 4.14: Active & Reactive Power - Case 2	46
Figure 4.15: Rotor Speed - Case 2	47
Figure 4.16: Grid Voltage - Case 3	47
Figure 4.17: Grid Current - Case 3	48
Figure 4.18: Transformer Voltage - Case 3	48
Figure 4.19: Active & Reactive Power - Case 3	49
Figure 4.20: Rotor Speed - Case 3	49
Figure 4.21: Grid Voltage - Case 4	50
Figure 4.22: Grid Current - Case 4	50
Figure 4.23: Transformer Voltage - Case 4	51
Figure 4.24: Active & Reactive Power - Case 4	51
Figure 4.25: Rotor Speed - Case 4	52
Figure 5.1: Grid Voltage - Case 1	55

Figure 5.2: Grid Current - Case 1	55
Figure 5.3: Voltage at Common Point - Case	56
Figure 5.4: Current at Common Point - Case 1	56
Figure 5.5: Active & Reactive Power - Case 1	57
Figure 5.6: Rotor Speed - Case 1	57
Figure 5.7: Grid Voltage - Case 2	58
Figure 5.8: Grid Current - Case 2	58
Figure 5.9: Voltage at Common Point - Case 2	59
Figure 5.10: Current at Common Point - Case 2	59
Figure 5.11: Active & Reactive Power - Case 2	60
Figure 5.12: Rotor Speed - Case 2	60
Figure 5.13: Grid Voltage - Case 3	61
Figure 5.14: Grid Current - Case 3	61
Figure 5.15: Voltage at Common Point - Case 3	62
Figure 5.16: Current at Common Point - Case 3	62
Figure 5.17: Active and Reactive Power - Case 3	63
Figure 5.18: Rotor Speed - Case 3	63
Figure 5.19: Grid Voltage - Case 4	64
Figure 5.20: Grid Current - Case 4	64
Figure 5.21: Voltage at Common Point - Case 4	65
Figure 5.22: Current at Common Point - Case 4	65
Figure 5.23: Active & Reactive Power - Case 4	66
Figure 5.24: Rotor Speed - Case 4	66
Figure 5.25: Grid Voltage – LVRT	67
Figure 5.26: Grid Current – LVRT	68
Figure 5.27: Voltage at Common Point - LVRT	68
Figure 5.28: Current at Common Point - LVRT	68
Figure 5.29: Active & Reactive Power - LVRT	69
Figure 5.30: Rotor Speed - LVRT	69

List of Tables

Table	Page
Table 4.1: Turbine Power Curve Data	32
Table 4.2: torque coefficients of turbine	34
Table 4.3: Generator Details	35
Table 4.4: Comparison of Datasheet values and Simulation values	36



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk