

**ANALYZING THE MAXIMUM WIND  
POWER PENETRATION LEVEL AROUND  
KALPITIYA PENINSULA**

**Master of Science Dissertation**



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

**T.R. KOTHALAWALA**

**Department of Electrical Engineering  
University of Moratuwa, Sri Lanka**

**September 2010**

University of Moratuwa



96442

96442

## 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.




University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

T.R. Kothalawala

28/09/2010

I endorse the declaration by the candidate.

  
30/09/2010

Dr. J.P. Karunadasa

# CONTENTS

<b>Declaration</b>	<b>i</b>
<b>Abstract</b>	<b>v</b>
<b>Acknowledgement</b>	<b>vi</b>
<b>List of Figures</b>	<b>vii</b>
<b>List of Tables</b>	<b>viii</b>
<b>List of Appendices</b>	<b>ix</b>
<b>1. INTRODUCTION .....</b>	<b>1</b>
<b>1.1. Wind power status and challenges .....</b>	<b>1</b>
<b>1.2. Background study .....</b>	<b>2</b>
1.2.1. World wind picture .....	2
1.2.2. Sri Lankan power system .....	3
1.2.3. Sri Lanka wind potential .....	4
1.2.4. Wind turbine generator technologies .....	4
1.2.5. Impacts of wind power on power system .....	6
<b>1.3. Motivation .....</b>	<b>8</b>
<b>1.4. Research approach.....</b>	<b>8</b>
<b>1.5. Dissertation outline .....</b>	<b>10</b>
<b>2. WIND MODELLING .....</b>	<b>11</b>
<b>2.1. System configuration .....</b>	<b>11</b>
<b>2.2. Modelling in power flow .....</b>	<b>12</b>
<b>2.3. Modelling for dynamics .....</b>	<b>12</b>
<b>3. STEADY STATE SYSTEM ANALYSIS.....</b>	<b>14</b>
<b>3.1. Introduction .....</b>	<b>14</b>

<b>3.2. Transmission Transfer Limit Analysis.....</b>	<b>14</b>
<b>3.3. Load flow analysis.....</b>	<b>16</b>
3.3.1. Load flow solution .....	16
3.3.2. Planning criteria .....	16
<b>3.4. Steady state simulation procedure .....</b>	<b>17</b>
<b>3.5. Results and conclusions .....</b>	<b>17</b>
<b>4. FREQUENCY STABILITY ANALYSIS .....</b>	<b>19</b>
<b>4.1. Introduction .....</b>	<b>19</b>
<b>4.2. Evaluate frequency stability limit .....</b>	<b>19</b>
4.2.1. Factors affecting the frequency stability .....	19
4.2.2. Present practice in frequency controlling .....	20
4.2.3. Frequency stability limit for wind integration.....	20
<b>4.3. Data and assumptions.....</b>	<b>21</b>
<b>4.4. Methodology and Results.....</b>	<b>21</b>
4.4.1. System analysis – Year 2010.....	22
4.4.2. System analysis – Year 2012.....	22
4.4.3. System analysis – Year 2014.....	23
4.4.4. System analysis – Year 2016.....	24
<b>5. VOLTAGE STABILITY ANALYSIS.....</b>	<b>26</b>
<b>5.1. Interfacing standards.....</b>	<b>26</b>
<b>5.2. Voltage stability limit.....</b>	<b>26</b>
<b>5.3. Methodology and results.....</b>	<b>27</b>
5.3.1. System analysis – Year 2010.....	27
5.3.2. System analysis – Year 2012.....	28
5.3.3. System analysis – Year 2014.....	30
5.3.4. System analysis – Year 2016.....	31

<b>6. TRANSIENT STABILITY ANALYSIS .....</b>	<b>33</b>
<b>6.1. Introduction .....</b>	<b>33</b>
<b>6.2. Stability criteria .....</b>	<b>33</b>
<b>6.3. Transient stability studies year 2012, 2014 and 2016 .....</b>	<b>34</b>
6.3.1. Methodology .....	34
6.3.2. Transient stability results.....	34
<b>7. CONCLUSIONS AND FURTHER RESEARCH AREA.....</b>	<b>37</b>
<b>7.1. Conclusion .....</b>	<b>37</b>
<b>7.2. Further research area .....</b>	<b>38</b>
<b>REFERENCES.....</b>	<b>40</b>
<b>ABBREVIATIONS.....</b>	<b>41</b>



University of Moratuwa, Sri Lanka.  
 Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

## **Abstract**

The Government of Sri Lanka has declared the importance of developing renewable energy in line with the national policy of maximizing indigenous sources and ensuring fuel diversity. Sri Lanka has exploited hydropower resources to almost its maximum economical potential. Only a limited number of small and medium scale hydropower plants are yet to be developed, and these are already in various stages of development. Therefore, the country is now clearly at a cross road as far as future generation is concerned.

Wind is one of the promising renewable energy options available for grid connected power. In addition, wind-mapping results for Sri Lanka shows a very good wind potential in Kalpitiya area.

This research covers the impact of wind integrations on the power system of Sri Lanka and analyzes the maximum wind penetration levels around Kalpitiya peninsula for the proposed years 2010, 2012, 2014 and 2016 transmission networks.

A steady state system analysis as well as a frequency and voltage stability analysis are used appropriately to figure out the wind penetration limits. Finally, a transient stability analysis is performed to confirm the stable operation of the wind integrated power systems.

The widely known power system simulation software package PSS<sup>®</sup>E is used to model wind turbines and perform steady state and stability analyses.

This research project concludes that 20MW; 70MW, 185MW and 220MW wind absorptions are feasible respectively in the years 2010, 2012, 2014 and 2016 at Puttlam GS/PS. Approximately 30% wind availability is considered for the steady state system analysis. In addition, 5% spinning reserve response on droop is assumed for year 2010 and 2012 and 10% spinning reserve response on droop is assumed for year 2012 and 2014.

Analyzing the most economical wind penetration limit with net work modifications is beyond the scope of this research and is open for further research study.

## **Acknowledgement**

Thanks are due first to my supervisor, Dr. J.P. Karunadasa, for his great insights, perspectives, guidance and sense of humor. My sincere thanks also go to the officers in Post Graduate Office, Faculty of Engineering, University of Moratuwa, Sri Lanka for helping in various ways to clarify the things related to my academic work in time with excellent cooperation and guidance. Sincere gratitude is also extended to those who serve in the Department of Electrical Engineering office.

The author extends sincere gratitude to the officers in Transmission Planning Branch, Ceylon Electricity Board for their guidance and support.

This dissertation would not have been possible unless the understanding, encouragement and patience provided by my family. Therefore I owe my deepest gratitude to my family.

Lastly, I am indebted to many individuals- friends and colleagues- who have not been mentioned here personally in making this educational process a success; maybe I could not have made it without your support.

## List of Figures

Figure 1.1: Worldwide wind energy by continents .....	3
Figure 1.2: Worldwide wind energy by continents .....	3
Figure 1.3: Generating systems used in wind turbines: (a) Squirrel cage induction generator, (b) Direct drive synchronous generator and (c) Doubly fed induction generator.....	5
Figure 2.1: Proposed system configuration .....	12
Figure 2.2: Simplified wind farm power flow model.....	12
Figure 2.3: Connectivity diagram.....	13
Figure 3.1: TLTG approach .....	15
Figure 3.2: Study system (A) opposing system (B) and interface use in TLTG .....	15
Figure 4.1: System response at 5% spinning reserve- off peak loading scenario-90MW generation outage .....	22
Figure 4.2: System frequency response for wind input variations – Year 2012 at 90MW wind integration level.....	23
Figure 4.3: System frequency response for wind input variations – Year 2014 at 185MW wind integration level.....	24
Figure 4.4: System frequency response for wind input variations – Year 2016 at 220MW wind integration level.....	25
Figure 5.1: Proposed Puttlam GS arrangement for year 2010 .....	27
Figure 5.2: Proposed network arrangement for year 2012 .....	29
Figure 5.3: Proposed network arrangement for year 2014 .....	30
Figure 5.4: Proposed network arrangement for year 2016 .....	31



## List of Tables

Table 1-1: Local and system wide impacts of wind power .....	6
Table 2-1: Data for GE 3.6 MW WTG model. ....	11
Table 3-1 : Study, opposing and interface elements for TLTG analysis.....	16
Table 3-2: Allowable range of voltage variations .....	16
Table 3-3: Steady state power absorption capability at Puttlam 132kV level .....	18
Table 3-4: Steady state wind power absorption capability at Puttlam 132kV level ....	18
Table 4-1: System demand- off peak.....	21
Table 5-1: Observed voltage fluctuatiions at 33kV level of Puttlam GS .....	28
Table 5-2: Wind power as a percentage of SCC – Year 2010 .....	28
Table 5-3: Observed voltage fluctuations at 132kV and 220kV busbars at Puttlam- Year 2012. ....	29
Table 5-4: Wind power as a percentage of SCC – Year 2012 .....	29
Table 5-5: Observed voltage fluctuations and SCC at 132kV and 220kV busbars at Puttlam- Year 2014. ....	30
Table 5-6: Observed voltage fluctuations and SCC at 132kV and 220kV busbars at Puttlam- Year 2016. ....	31
Table 6-1: System stability analysis results, year 2012.....	35
Table 6-2: System stability analysis results, year 2014.....	35
Table 6-3: System stability analysis results, year 2016.....	36
Table 6-1: Wind absorption capability of the Sri Lankan power system around Puttlam area .....	38

## List of Appendices

Appendix A: Sri Lanka Wind Resource Map.....	A
Appendix B: Wind speed and power by hour at Narakkalliya site .....	B
Appendix C: Map of Sri Lanka Transmission System in Year 2016.....	C
Appendix D: Proposed Transmission Network – Year 2016 .....	D



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)