UNIVERSITI PUTRA MALAYSIA

DYNAMIC INVESTMENT MODEL FOR THE RESTRUCTURED POWER MARKET IN THE PRESENCE OF WIND SOURCES

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

Dedicated to my best companion in life, Saeideh,

and to my beloved parents to whom I owe my everything
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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October 2014

Chairman : Mohd. Zainal Abidin Ab Kadir, PhD
Faculty : Engineering

The short term and long term revenues of the wind firm encounters more uncertainties which include the forecasted load, fuel price and output power of wind units. Furthermore, in short and medium terms the wind firm faces with Market clearing price’s fluctuations, which is affected by some uncertain parameters including the demand, fuel price, wind fluctuations and the operational strategic behaviour of other investors. These uncertainties increase the risk of investment. Therefore, the private wind investors require a set of decision tools to evaluate and analyse the investment strategies in the long term planning by considering the existence of uncertainties, regulatory policies, which include the incentive policies for wind power plants and CO$_2$ tax, and the realities in the restructured power market such as the bilateral contracts.

The main objective of this thesis is to determine the long term optimal investment strategies of the hybrid wind-thermal investor in the restructured power market. To accomplish this purpose, three main steps have been conducted in this thesis. In the first step, the hybrid Autoregressive Moving Average – Monte Carlo method proposes to simulate the hourly wind speed as well as the hourly wind turbine generators. The uncertainties of the output power of wind turbine generators are modelled based upon the scenario-based method and data mining techniques. In the second step, a model developed in this work is proposed to simulate the medium term restructured power market. The scenarios of the output power of wind turbines, which are generated through the first step in terms of the outputs power of wind farm together with their occurrence probability, are used to estimate the maximum profit of investors as well as the average Market clearing price with the proposed model in the restructured power market. The stochastic uncertainties include the demand and fuel price fluctuations in the restructured power market simulated based on the Monte Carlo method. In addition to the stochastic uncertainties in the medium term power market which are considered in the proposed model, the operational strategic behaviour of other investors considered in this study is based upon the game theory concepts using the Cournot game. In the third step, the long term optimal investment strategies of the hybrid wind-thermal investor are determined based on the dynamic programming algorithm by considering the long term states of demand growth and fuel price uncertainties.
The proposed framework has been implemented in the hypothetical restructured power market using the IEEE Reliability Test System. Well-established renewable energy-based power generation in the countries like Spain and Germany for instance, can provide strong and useful information for this study. With that justification, fixed Feed in Tariff’s incentive policy was adopted in the case of wind investor. Conducted case studies have confirmed that this framework provides robust decisions and precise information about the restructured power market for hybrid wind-thermal investors.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MODEL PELABURAN DINAMIK DI DALAM PASARAN KUASA TERSUSUN DENGAN KEHADIRAN SUMBER ANGIN

Oleh

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Jangka pendek dan jangka panjang pendapatan bagi firma tenaga angin melibatkan lebih banyak ketidak pastian termasuklah beban yang diramalkan, harga bahan api dan kuasa keluaran unit tenaga angin. Selain itu, dalam jangka pendek dan sederhana, firma tenaga angin menghadapi kekangan dengan turun naik harga jelas pasaran yang terkesan oleh parameter ketidak pastian termasuk permintaan, harga bahan api, turun naik angin dan tingkah laku strategik operasi pelabur-pelabur lain. Kesan-kesan ini meningkatkan risiko pelaburan. Oleh itu, pelabur tenaga angin swasta memerlukan satu kaedah keputusan untuk menilai dan menganalisis strategi pelaburan dalam perancangan jangka panjang dengan mempertimbangkan ketidakpastian wujud, dasar mengawal selia iaitu termasuklah dasar insentif bagi loji kuasa angin dan cukai CO\textsubscript{2}, serta kesedaran dalam pasaran kuasa tersusun- semula contohnya kontrak dua hala.

Objektif utama tesis ini adalah untuk menilai dan menganalisis strategi pelaburan jangka panjang yang optimum bagi pelabur tenaga angin-haba yang digabungkan dalam pasaran kuasa tersusun-semula. Bagi mencapai tujuan ini, tiga langkah utama telah dijalankan di dalam tesis ini. Dalam langkah pertama, kaedah Autoregresi hibrid purata bergerak Monte Carlo dicadangkan untuk mensimulasikan kelajuan angin setiap jam serta penjanaan turbin angin setiap jam. Ketidak pastian dalam kuasa pengeluaran WTGs yang dimodelkan berdasarkan kaedah keberangkungan-keadaan dan teknik perlombongan data. Dalam langkah kedua, model yang dibangunkan di dalam projek ini dicadangkan untuk simulasi pasaran kuasa jangka sederhana tersusun-semula. Senario kuasa keluaran turbin angin yang dihasilkan melalui langkah pertama dari segi kuasa keluaran oleh ladang angin beserta kebarangkalian kejadian, digunakan untuk menganggarkan keuntungan maksimum pelabur dan juga purata harga jelas pasaran dengan model yang dicadangkan dalam pasaran kuasa tersusun-semula. Ketidak pastian stokastik termasuklah permintaan dan bahan api turun naik harga dalam simulasi pasaran kuasa tersusun-semula adalah berdasarkan kaedah Monte Carlo. Selain daripada ketidak pastian stokastik dalam pasaran tenaga jangka sederhana yang dipertimbangkan dalam model yang dicadangkan itu, tingkah laku strategik operasi pelabur-pelabur lain dipertimbangkan dalam kajian ini berdasarkan konsep-konsep teori permainan dengan menggunakan permainan Cournot. Dalam langkah ketiga, strategi pelaburan yang optimum jangka panjang pelabur tenaga angin panas hibrid ditentukan berdasarkan algoritma
pengaturcaraan dinamik dengan mempertimbangkan jangka panjang pertumbuhan permintaan dan ketidaktentuan harga bahan api.

Rangka kerja yang dicadangkan itu telah dilaksanakan dalam pasaran kuasa tersusun-semula hipotesis menggunakan Sistem Ujian IEEE Kebolehpercayaan. Firma yang kukuh dalam tenaga boleh diperbaharui adalah berdasarkan penjanaan kuasa di negara-negara seperti Sepanyol dan Jerman misalnya memberikan maklumat yang kukuh dan berguna untuk kajian ini. Dengan justifikasi itu, dasar-dasar insentif Feed in Tariff telah diterima pakai dalam kes pelabur tenaga angin. Kajian kes yang dijalankan mengesahkan bahawa rangka kerja ini dengan syarat keputusan yang mantap dan maklumat yang tepat mengenai pasaran kuasa tersusun-semula untuk pelabur hibrid tenaga angin-haba.
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Thank you and May Allah reward them all.
I certify that a Thesis Examination Committee has met on 2 October 2014 to conduct the final examination of Mohammad Tolou Asakri Sedehi Esfahani on his thesis entitled “Dynamic Investment Modeling In The Restructured Power Market With The Presence Of Wind Sources” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>v</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>vi</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xiv</td>
</tr>
</tbody>
</table>

## CHAPTER

### 1 INTRODUCTION

1.1 Background 1
1.2 Problem statement 2
1.3 Objectives 3
1.4 Significance and contribution of the study 4
1.5 Scope and limitations 5
1.6 Thesis outline 5

### 2 LITERATURE REVIEW

2.1 Background 7
2.2 Power market structures 8
2.3 Power market uncertainties 10
2.4 Generation Expansion Planning 15
2.5 Wind penetration 19
2.6 Wind turbine generators simulating and modelling 20
2.7 Generation expansion planning of wind sources 23
2.8 Summary 25

### 3 METHODOLOGY

3.1 Introduction 27
3.2 Methodology of the study 27
3.3 Proposed framework to generate scenarios for wind power 29
3.4 Market clearing price in a deregulated power market 36
    3.4.1 Proposed mathematical model to develop the medium term restructured power market model 37
    3.4.2 Market clearing price 39
    3.4.3 Validation and verification of the developed model 43
3.5 Proposed framework to calculate the long term optimal investment strategies for wind investor 44
3.6 Summary 48

### 4 RESULTS AND DISCUSSIONS

4.1 Results and discussion 49
4.2 Simulating and clustering the output power of wind turbines 49
4.2.1 Numerical study for hybrid ARMA-MC method 50
4.2.2 Numerical study on the seasonal scenario generation for a wind farm 52
4.3 Numerical study for simulating the medium term restructured power market 56
4.3.1 Case study 56
4.3.2 Implementation of the proposed model for predefined scenarios 58
4.3.3 Sensitivity analysis 65
4.4 Numerical study for solving the GEP problem by using the proposed model 68
4.5 Summary 69

5 CONCLUSIONS AND FUTURE WORKS 71
5.1 Conclusions 71
5.2 Future research 73

REFERENCES 75
APPENDICES 83
Part A 83
Part B 84
BIODATA OF STUDENT 90
LIST OF PUBLICATIONS 91