



DESIGN AND DEVELOPMENT OF AN
IMPELLER WIND TURBINE

by

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Thesis submitted in fulfillment of the requirements for the degree of
Doctor of Philosophy (Mechanical Engineering)

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2013

ACKNOWLEDGEMENT

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Praise be to Allah, the Most Gracious and the Most Merciful and may His salawat and salaam always be with Prophet Mohammad (p.b.u.h) and his holy progeny eternally. Uncountable thanks are due to my parents for their love and blessings. They provide me the strength to go through life and all the challenges it brings forth. I would also like to thank them for their continuous support, patience, encouragement and extra care. The deepest thanks from my heart go to my precious wife and my children (Ghada, Abdulla and Farah) who have really changed my life for the better during my study. I would also like to thanks my brothers Dr. Omar and Mr. Habib. Thanks to my friends Dr. Yarub Al-Duri and Mr. Ziad Al-ani. I would also like to express my gratitude and thanks to Professor Dr. Ryspek Usumabatov for his patience during the supervision of my work. He has only the highest quality standard in mind. My most sincere thanks are also accorded to my co-supervisors Associate Professor Dr. Ghulam Abdul Quadir and Professor Dr. Zuraidah Mohd Zain. Without their help and encouragement, I would not have achieved what I have now. My appreciation also goes to my colleagues in UniMAP's labs, as well as the Iraqi postgraduate students' research group for all the useful discussions that we had, as well as for all the encouragement rendered. I feel so proud working hand in hand with them throughout my study.

TABLE OF CONTENT

	Page
DECLARATION OF THESIS.....	I
ACKNOWLEDGEMENT	II
TABLE OF CONTENT	III
LIST OF FIGURES	VIII
LIST OF SYMBOLS, ABBREVIATIONS	XV
LIST OF NUMENCLATURE.....	XVI
ABSTRAK.....	XVIII
ABSTRACT.....	XIX
CHAPTER 1 - INTRODUCTION.....	1
1.1 Background.....	1
1.2 Wind energy	2
1.3 Type of wind turbine	3
1.3.1 The horizontal axis wind turbine (HAWTs).....	3
1.3.2 Vertical axis wind turbine (VAWTs)	4
1.4 Advantage and disadvantage of VAWT compared to HAWT	6
1.4.1 Advantages of VAWTs	6
1.4.2 Disadvantages of VAWTs.....	6
1.5 Problem statement	7
1.6 The aims of this study	8
1.7 Thesis overview.....	9
CHAPTER 2 - LITERATURE REVIEW	10
2.1 Introduction	10

2.2 Introduction to the wind energy	10
2.2.1 Properties of the wind.....	10
2.2.2 Wind Speed and Power Variation with Elevation	11
2.3 Introduction to wind turbine technology	13
2.3.1 Advance ratio or tip speed ratio (TSR, λ).....	13
2.3.2 Power coefficient (C_p)	14
2.3.3 The starting wind speed and the cut-in wind speed.....	15
2.3.4 Basic theory of wind turbine	15
2.4 Modern vertical axis wind turbine types	16
2.4.1. Darrieus type wind turbine	17
2.4.1.1. Egg-beater type Darrieus wind turbine.....	17
2.4.1.2. Giromill (straight bladed type Darrieus) wind turbine	19
2.4.1.3 Twisted three bladed Darrieus rotor	24
2.4.2 Savonius rotor.....	25
2.4.3 Combined rotor.....	37
2.4.4 The Sistan vertical axis windmill	40
2.5 Improving the wind turbine design by augmentation.....	43
2.6 Space between two plate and effected on drag coefficient	48
2.7 Weight affected on power coefficient	49
2.8 Summary of literature.....	50
CHAPTER 3 - RESEARCH METHODOLOGY	53
3.1 Introduction:	53
3.2 Drag force wind turbine	54
3.2.1 Energy Capture using the Drag Principle	55

3.3 Brief description of proposed design:	58
3.4 The study of blade ratio effect ($\frac{C}{r}$)	65
3.5 Analytical approach.....	67
3.5.1 Vane-type turbine with three frames	71
3.5.2 Vane-type turbine with four frames	77
3.6 Block diagram representation of the wind turbine	80
3.7 Fabricate of wind turbine model	82
CHAPTER 4 - RESULTS AND DISCUSSION.....	88
4.1 Wind tunnel setup.....	88
4.2 Test of blade frame model.....	89
4.3 Mathematical calculations.....	106
4.3.1 Three frames blade wind turbine.....	106
4.3.2 Two frames blade wind turbine.....	116
4.3.3 Four frames blade wind turbine.....	119
4.4 Experimental testing of impeller movable vanes wind turbine model:.....	127
4.4.1 Test model in wind tunnel	128
4.4.2 The discussion of number of frame effect.....	136
4.4.3 Test the three frames movable vanes model in CFD software	139
4.4.3.1 The two closed frames position in the wind direction ($\gamma=30^\circ, 150^\circ$):	139
4.4.3.2 The one closed frames position in the wind direction ($\gamma=90^\circ$):	144
4.4.4 Test three frames movable vanes model with amplifier gear	148
4.5 Compare results for three frames movable vane model with another model:.....	154
4.5.1 Three frames fixed vanes wind turbine model	154

4.5.2 Three frames movable vanes wind turbine model with double thickness (weight effect).....	158
4.5.3 Flat plate vanes frame wind turbine model	162
4.6 Similarity between model and prototype of the vane type wind turbine.....	166
4.7 Comparison with other model	178
4.7.1 Saha (2006) design:	178
CHAPTER 5 - CONCLUSIONS	181
5.1 Summary of the design.....	181
5.2 Conclusions	181
5.3 Recommendation:.....	185
REFERENCES.....	186
LIST OF PUBLICATION	196
APPENDIX A	198
APPENDIX B	201
APPENDIX C	204

LIST OF TABLES

Table No.		Page
2.1	Comparison of diffuser exit area ratio ε and relative power coefficient C_p/ C_{p0} with C_{p0} the Power coefficient of the un augmented turbine	45
3.1	List of Material for model	87
4.1	Drag force for shaft device in wind tunnel	91
4.2	Drag force test for flat plat blade in wind tunnel	92
4.3	Drag force test for scoop vane frame in wind tunnel	93
4.4	Drag coefficients for different shapes experimental in the wind tunnel	98
4.5	Drag force test for frame design in wind tunnel and CFD software	102
4.6	The mathematical calculation of the torque created on the output shaft of the three frames wind turbine	113
4.7	The torque created on the output shaft of the two frame vane type wind turbine	117
4.8	The torque created on the output shaft of the four frames vane type wind turbine	124
4.9	Calculation of rotor speed (RPM) for different wind velocities (3.75-12 m/s)	173
4.10	Calculation of power prototype rotor scale ratio (1/10) for different wind velocities (3.75-12 m/s) at different angular velocity	175
4.11	Calculation of drag force and power of prototype rotor scale ratio (1/10) for different wind velocities (3.75-12 m/s)	178
4.12	Parameters for proposed design and Saha design wind turbine models	180

LIST OF FIGURES

No		Page
1.1	Wind turbine configurations	5
2.1	The wind power and speed profile with height	11
2.2	Mean velocity profiles for various types of environments	12
2.3	Darrieus rotor – egg beater shaped wind turbine	19
2.4	Darrieus rotor – straight bladed wind turbine	20
2.5	El-samanoudy turbine diagram	22
2.6	Assembly models of the turbine and the model turbine in the wind tunnel	23
2.7	Diagram of top view of the rotor variable pitch mechanism	24
2.8	A low cost Savonius wind turbine with rotors arranged 90° out of phase	26
2.9	Twisted-blade savonius rotor	27
2.10	Power coefficients for twisted-blade savonius rotor	28
2.11	Savonius rotor using a guide-box tunnel	29
2.12	Solid models of single, two stage rotor systems	30
2.13	Variation of power coefficient with velocity for semicircular Savonius rotor system	31
2.14	Design of the curtain arrangement placed in front of the Savonius wind rotor	32
2.15	Rotor positions (a) $\theta = 90^\circ$, (b) $\theta = 60^\circ$ and (c) $\theta = 45^\circ$	33
2.16	Five bladed vertical axis vane type rotor	34
2.17	Basic modified Savonius rotor with shaft	35
2.18	Descriptions of the geometry modify the position of the obstacle, Top: two-blade Savonius rotor; bottom: three-blade Savonius rotor	36
2.19	Performance of the optimized configuration compared to the conventional Savonius turbine with and without obstacle plate power coefficient	37
2.20	The combine rotor vertical axis wind turbine	38
2.21	Combined three-bucket Savonius three-blade Darrieus rotor with Provision for overlap variations	39

2.22	Vertical axis resistance type windmill of the Sistan Basin in the Border region of Iran and Afghanistan	41
2.23	Sketch of the flat plate horizontal vanes type wind turbine	42
2.24	Vertical axis turbine with concentrator	43
2.25	Flow augmented VAWT delta wind turbine	44
2.26	Visualization of the VAWT-diffuser combination for four of the simulated cases	46
2.27	Torque coefficient contribution of single blade for different nozzle areas	46
2.28	Savonius rotor with concentrator	47
2.29	Drag coefficient for two square plates in series	48
2.30	Power coefficient for different mass of clay attached	50
3.1	Overview of Methodology	54
3.2	Simplified model of the (Drag only) VAWT	55
3.3	(a) Sketch of the vane type wind turbine, (b) and general view of wind station	59
3.4	Top view frame prepare to open vanes	60
3.5	Gear and ratchet of vanes	61
3.6	Top view belt and gear and ratchet for vanes	61
3.7	Front view impeller wind turbine	63
3.8	Top view impeller three frame wind turbine	63
3.9	Top view impeller four frame wind turbine	64
3.10	Complete assembly of the cavity frame wind turbine	65
3.11	Force and torque diagram for frame	66
3.12	Analysis of vane type wind turbine three frames	71
3.13	Frame with open vanes in opposite direction of wind	75
3.14	Sketch of the four frame wind turbine	77
3.15	Analysis of vane type four frames wind turbine	78
3.16	Wind electric system	80
3.17	Block diagram for input and output parameters	82

3.18	Vane of wind turbine frame	84
3.19	Upper and lower board of four frame	85
3.20	Components on the turbine assembly	86
4.1	Scoop-vane models in wind tunnel	91
4.2	Drag force for different frame versus wind speed	95
4.3	Drag coefficient for different frame versus wind speed	95
4.4	Drag force for cavity vane with different vane angle (Ψ) versus wind speed	96
4.5	Drag coefficients for cavity vane with different vane angle (Ψ) versus wind speed	97
4.6	Air flow behavior in front and behind the frame test by CFD software	100
4.7	Air flow behavior in back of frame test by CFD software	101
4.8	CFD software test for wind behavior behind the frame	101
4.9	Drag force versus wind velocity for frame test in wind tunnel compared with CFD test	103
4.10	Drag coefficients for frame with vane angle 45° versus turn angle (γ) at different wind speed	104
4.11	Test open vanes frame in wind tunnel	105
4.12	Drag force versus wind velocity in a wind tunnel, for open vane frame	105
4.13	Double frames in one side for impeller at ($\gamma = 30^\circ$)	108
4.14	Drag force versus wind velocity test for double frame ($\theta = 120^\circ$) & single frame at ($\gamma = 30^\circ$)	108
4.15	Drag coefficient for first frame in wind shadow test at ($\alpha_f = 150^\circ$)	109
4.16	Torque of each frame versus the angle of output shaft rotation, for three frame model at wind speed 6 m/s	114
4.17	Radar chart for torque of each frame versus the angle of output shaft rotation, for three frame model at wind speed 6 m/s	114
4.18	Torque versus the angle of output shaft rotation, for three frames at wind speed 6 m/s.	115
4.19	Radar chart for torque versus the angle of output shaft rotation, for three frames at wind speed 6m/s.	116

4.20	Torque for each frame versus the angle of output shaft rotation, for two frames model at wind speed 6m/s	117
4.21	Torque average versus frame angle, for two frames	118
4.22	Radar chart for torque versus the angle of output shaft rotation, for two frames at wind speed 6m/s.	119
4.23	double frames in one side full shadow for impeller wind turbine	120
4.24	Drag force versus wind velocity test for double frame $\theta = 90^0$ and single frame at $\gamma = 45^\circ$	121
4.25	Drag force for first frame in wind shadow test at $\gamma = 45^\circ$	121
4.26	Torque of each frame versus the angle of shaft rotation, for four frames model at wind speed 6 m/s.	125
4.27	Radar chart for torque of each frame versus the angle of shaft rotation, for four frames model at wind speed 6m/s.	125
4.28	Torque of output shaft rotation versus the angle of impeller rotating, for three and four frames at wind speed 6m/s.	126
4.29	Radar chart for torque frames versus the angle of impeller rotation for three and four at wind speed 6m/s.	127
4.30	Wind turbine model tests in wind tunnel	128
4.31	Rpm of three and four frames movable vane's movable vane's model versus the wind velocity	131
4.32	Power coefficient for three and four frames movable vane's model versus the tip speed ratio	132
4.33	Power coefficient for three and four frames movable vane's model versus the wind velocity	132
4.34	Torque coefficient for three and four frames movable vane's model versus the tip speed ratio	133
4.35	Torque coefficient for three and four frames movable vanes model versus the wind velocity	134
4.36	Distance between Two blades a) correct distance b) small distance	137
4.37	Double vanes in wind tunnel	138

4.38	Test double frame scoop-vanes in wind tunnel with different distance versus wind speed	139
4.39	Diagram for a rotor at frame angle ($\gamma = 30$)	140
4.40	Top view velocity distribution diagram for a rotor at frame angle ($\gamma = 30^\circ, 150^\circ, 270^\circ$)	141
4.41	Top view Pressure distribution diagram for a rotor at frame angle ($\gamma = 30^\circ, 150^\circ, 270^\circ$)	141
4.42	Side view for velocity distribution diagram for two frame closed vane in the rotor at frame angle ($\gamma = 30, 150^\circ$)	142
4.43	Side view Pressure distribution diagram for two frames closed vane in the rotor at frame angle ($\gamma = 30, 150^\circ$)	142
4.44	Side view velocity distribution diagram for one frame open vane in a rotor at frame angle ($\gamma = 270^\circ$)	143
4.45	Side view Pressure distribution diagram for one frame open vane in a rotor at frame angle ($\gamma = 270^\circ$)	143
4.46	Diagram for a rotor at frame angle ($\gamma = 90$)	144
4.47	Top view velocity distribution diagram for a rotor at frame angle ($\gamma = 90, 210, 330$)	145
4.48	Top view pressure distribution diagram for a rotor at frame angle ($\gamma = 90, 210, 330$)	146
4.49	Side view velocity distribution diagram for one frame closed vane in a rotor at ($\gamma = 90$)	146
4.50	Side view pressure distribution diagram for one frame closed vane in a rotor at ($\gamma = 90$)	147
4.51	Side view velocity distribution for two frame open vane at position ($\gamma = 210, 330$)	147
4.52	Side view pressure distribution for two frame open vane at position ($\gamma = 210, 330$)	148
4.53	Three frames wind turbine with amplifier gear in wind tunnel	149
4.54	Rpm of three frames movable vanes with amplifier gear and without gear versus wind speed	150
4.55	Turbine efficiency for three frames movable vanes with amplifier gear and without gear versus tip speed ratio	151

4.56	Turbine efficiency for three frames movable vanes with amplifier gear and without gear versus wind speed	151
4.57	Torque coefficients for three frames movable vanes with amplifier gear and without gear versus tip speed ratio	152
4.58	Torque coefficients for three frames movable vanes with amplifier gear and without gear versus wind speed	153
4.59	Fixed vanes three frames wind turbine in wind tunnel	154
4.60	Rpm of three frames impeller fixed and movable vanes versus wind speed	155
4.61	Power coefficients for three frames fixed & movable vanes versus tip speed ratio	156
4.62	Power coefficients for three frames (fixed & movable vanes) versus wind speed	156
4.63	Torque coefficient for three frames (fixed & movable vanes) versus tip speed ratio	157
4.64	Torque coefficients for three frames (fixed & movable vanes) versus wind speed	158
4.65	Rpm of three frames different weight impeller versus wind speed	159
4.66	Power coefficient for three frames different weight versus tip speed ratio	160
4.67	Power coefficient for three frames different weight versus wind speed	160
4.68	Torque coefficients for three frames different weight versus tip speed ratio	161
4.69	Torque coefficients for three frames different weight versus wind velocity	161
4.70	Flat plate vanes frame wind turbine model	162
4.71	Number of revolutions of the wind turbine shaft versus the wind velocity	163
4.72	Power coefficient and Torque coefficient versus tip speed ratio for 3 frames wind turbine	165
4.73	Power coefficient and Torque coefficient versus wind speed for 3 frames wind turbine	166
4.74	Power coefficient VS tip speed ratio for experimental results of the proposed wind turbine model	172
4.75	Power coefficient versus each rotor speed (RPM) for model at wind speed 3.75-12 m/s	173

4.76	Power coefficient versus each rotor speed (RPM) for prototype at wind speed 3.75-12 m/s	176
4.77	Power generate VS wind speed for prototype scale ratio (1/10)	178
4.78	Solid models of single-, two-, and three-stage rotor system	179
4.79	Variation of power coefficient with velocity for, a) Twisted b) Semicircular, Savonius rotor	181

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LIST OF SYMBOLS, ABBREVIATIONS

Symbol	Description	Unit
A	Area	m^2
A_s	Swept area	m^2
B	Blade area	m^2
b	Width of blade	m
C	Blade length	m
C_p	Power coefficient	
C_t	Torque coefficient	
CD	Drag coefficient	kg/s
D	Turbine diameter or width of the wind turbine	m
E	Kinetic energy	m^2/s^2
F_a	Axial force	kg/s
F_D	Drag force	N
h	High of the swept area (Impeller)	m
i	Gear speed ratio	
K	Turbulent kinetic energy	
n	Number of frame	
N	Number of rotate	
N_b	Gear box efficiency	

N_g	Generator efficiency	
P	Pressure	N/m^2
ΔP	Pressure different	N/m^2
r	Impeller radius	m
Re	Reynolds number	
R	Force radius	m
T	Torque	N.m
t	Thickness	m
u	Blade velocity	m/s
V	Wind velocity	m/s
W_{gen}	Power produce by generator of turbine	W
W_{wind}	Power produce by wind turbine	W
W_m	Mechanical power	W
W	power	W
Z	Vane width	M
β	Shadow angle	deg

LIST OF NUMENCLATURE

γ	Angle of frame position	Deg
θ	Angle between frames	deg
Ψ	Vanes frame angle	deg
λ	Tip speed ratio	
σ	Solidity	
\dot{m}	Mass flow rate	Kg/s
μ	Kinetic viscosity	N.s/m ²
ρ	Density	kg/m ³
ω	Angular velocity of the rotating turbine	rad/s
η	Wind turbine efficiency	
α	Beginning of wind shadow angle for second frame	deg
α_1	Beginning of wind shadow angle for first frame	deg

Reka bentuk dan pembangunan turbin angin pendesak

ABSTRAK

Dalam bidang reka bentuk turbin angin, masih terdapat skop penambahbaikan. Hari ini, tenaga angin - terutamanya oleh turbin skru angin - menghasilkan kurang daripada 1.0% daripada jumlah tenaga yang digunakan di seluruh dunia. Hampir, kecekapan standard tiga bilah turbin skru angin adalah sekitar 30%. Ini jenis turbin adalah berdasarkan daya angkat angin pada turbin berputar. Ini turbin agak mahal kerana bentuk aerodinamik yang kompleks pisau yang diperbuat daripada bahan komposit. A paksi menegak turbin angin boleh direka dengan nilai yang tinggi faktor seretan. Kerja-kerja ini berkaitan dengan reka bentuk jenis pendesak paksi menegak turbin angin baru, yang menggunakan tenaga angin dengan lebih berkesan. Reka bentuk ini membentangkan reka bentuk bingkai khas dengan bilah. Turbin angin bingkai direka untuk meningkatkan pengeluaran turbin angin yang menggunakan tenaga kinetik angin. Lima model yang berbeza daripada paksi menegak turbin angin yang direka dan diuji dalam terowong angin dalam kerja-kerja ini. Mereka adalah tiga frame alih ram bentuk rongga, tiga frame alih ram bentuk rongga dengan gear penguat, tiga tetap frame bentuk rongga ram, empat bingkai alih ram bentuk rongga dan tiga rangka alih ram bentuk plat rata. Ram yang terletak di bar menegak dipasang di bergantung daripada bingkai. Seperti reka bentuk yang membolehkan putaran bar dengan bingkai di bawah tindakan tenaga angin serentak pada satu arah dan bebas pada arah yang lain. Bingkai yang berkaitan dengan batang, di mana satu hujung adalah berkaitan dengan penjana elektrik. Bingkai direka dengan kecenderungan sudut bilah yang mewujudkan rongga apabila ram ditutup. Di sisi lain pendesak, apabila ram alih yang terbuka, dan kerangka adalah di bawah tindakan angin, udara pas bebas melalui bingkai, dan mengurangkan tork negatif. Dalam semua model menggunakan bilah berbentuk rongga, 45 ° sudut ram digunakan. Keputusan dibentangkan dalam bentuk pekali seretan, pekali kuasa, nisbah kelajuan tip untuk halaju angin berbeza-beza dari 5 m / s hingga 17 m / sec. Ia didapati bahawa tiga frame alih ram rongga model bentuk mempunyai pekali kuasa maksimum (C_{pmax}) 0.32 pada kelajuan 8 m / s dan hujung nisbah kelajuan angin 0.31. Semua model lain memberikan nilai C_{pmax} lebih rendah daripada nilai ini untuk julat yang sama halaju angin. Baru yang dicadangkan pendesak jenis menegak paksi turbin angin boleh digunakan di seluruh dunia kerana kecekapan yang tinggi, pembinaan mudah, dan teknologi mudah. Di samping itu, turbin angin yang dicadangkan juga boleh dibuat daripada bahan-bahan murah.

Design and development of an impeller wind turbine

ABSTRACT

In the area of wind turbine design, there is still scope of improvement. Today, wind energy - mainly by wind screw turbines - produces less than 1.0% of the total energy used worldwide. Practically, the efficiency of the standard three-blade wind screw turbines is around 30%. This type of turbine is based on the wind lift force on rotating turbine. These turbines are quite expensive due to the complex aerodynamic shape of blades that are made of composite materials. A vertical axis wind turbine can be designed with high value of the drag factor. The present work relates to the design of a new impeller type vertical axis wind turbine, which uses wind energy more effectively. This design presents a special frame design with vanes. The frame wind turbine is designed to increase the output of a wind turbine that uses kinetic energy of the wind. Five different models of the vertical axis wind turbine are fabricated and tested in a wind tunnel in the present work. They are three frame movable vane cavity shape, three frame movable vane cavity shape with amplifier gear, three frame fixed vane cavity shape, four frame movable vane cavity shape and three frame movable vane flat plate shape. The vanes are located on vertical bars installed in hinges of the frames. Such a design enables the rotation of the bars with frames under the action of wind force simultaneously at one direction and independently at other directions. The frames are connected with the shaft, of which one end is connected with the electric generator. The frames are designed with angular inclinations of vanes that create cavities when vanes are closed. On the other side of the impeller, when the movable vanes are open, and the frame is under wind action, the air passes freely through the frame, and decreases the negative torque. In all the models using cavity shaped vanes, 45° vane angle is used. The results are presented in the form of drag coefficient, power coefficient, tip speed ratio for wind velocities varying from 5 m/sec to 17 m/sec. It is found that a three-frame movable vane cavity shape model has a maximum power coefficient ($C_{p_{max}}$) of 0.32 at a wind velocity 8 m/s and tip speed ratio 0.31. All other models give the values of $C_{p_{max}}$ lower than this value for the same range of wind velocity. The proposed new impeller type vertical axis wind turbine can be used worldwide due to its high efficiency, simple construction, and simple technology. Further, the proposed wind turbine can also be made from cheap materials.

CHAPTER 1

INTRODUCTION

1.1 Background

The power from the wind will never cease while the sun is still rising and the earth is revolving. Wind exists everywhere on the earth, and in some places with considerable energy density. This thesis aims to study this renewable energy, which will remain a useful power source until the end of this world. Wind has been used in the past to generate mechanical power. Nowadays wind power has become a promising source to generate electricity because it is clean, quiet and efficient. It reduces acid rain, smog and pollutants to the atmosphere. Renewable energy has become popular in recent years, due to the need for the utilization of more environmentally friendly energy sources. In generating wind power, both the vertical axis wind turbines (VAWTs) and the horizontal axis wind turbines (HAWTs) play significant roles.

Wind power is the conversion of wind kinetic energy into a useful form, such as mechanical or electrical energy that can be harnessed for practical use by using wind turbines. Wind energy is one of the cheapest and cleanest of the renewable energy technologies than all other known ones. The potential energy created by wind power is plentiful, and reduces greenhouse gas emissions when it displaces fossil fuel derived electricity. Wind turbine technology has lately been steadily improved.

1.2 Wind energy

When the earth is irradiated by the sun, the ground absorbs some of this radiation. This heated ground warms the air above it. Hot air rises in what are called convection currents. The uneven heating of the earth's surface causes winds. For example, if the sun's rays fall on land and sea, the land heats up more quickly. This results in the air above the land moving upwards more quickly than that over the sea, (hot air rises). As a result the colder air over the sea will rush in to fill the gap left by the rising air. This process gives rise to high and low pressure areas, and thus to winds.

Wind energy is non-polluting and is freely available in many areas. Wind turbines are becoming more efficient, making the cost of the electricity generation to fall. Large balancing areas and aggregation benefits of large areas help to reduce the variability and forecast errors of wind power as well as in pooling more cost effective balancing resources (Holtinen et al. 2009). There are already several power systems and control areas coping with large amounts of wind power (Saoder et al. 2007). Denmark, Germany, Spain, Portugal and Ireland have integrated 9-20 % of wind energy (of yearly electricity demand). However, the disadvantages of wind energy exist as well. To be efficient, wind turbines need to be linked together in wind farms, often with 20 turbines or more. This looks unsightly, and can be noisy. The wind farms also need to be sited reasonably close to populations so that the electricity generated can be distributed. Another disadvantage is that winds are intermittent and do not blow all the time. In this thesis, one turbine used to convert wind energy is optimized in order to improve the output power.

1.3 Type of wind turbine

There are many concepts to classify the types of wind turbine which are used. All of the wind turbines fall into two types, depending on whether the turbine blade rotates about a horizontal axis or a vertical axis as shown in Figure (1.1).

1.3.1 The horizontal axis wind turbine (HAWTs)

The favored form of turbines used for electricity generation purposes is the horizontal axis wind turbine (HAWT) with low solidity ratio (ratio of blade area to swept area) and high tip speed ratio. This type of turbine has a high efficiency or power coefficient, but relatively low torque. By contrast, the traditional “American Windmill” or “Southern Cross”, used throughout Australia and the USA for water pumping purposes, is a high solidity, low tip speed ratio device that produces a high torque suitable for direct drive of relatively simple mechanical pump systems. The HAWTs have a maximum theoretical power coefficient of approximately 0.45. However, in reality this wind turbine can only achieve an average power coefficient of approximately of 0.3 (Usubamatove et al. 2010). Figure (1.1) shows the main components of modern propeller type HAWTs. The main advantage of this machine is its high power coefficient compared to the other types. Nevertheless, the disadvantages of HAWTs include their operation at high starting wind velocity, low starting torque, the requirement of a yaw mechanism to turn the rotor toward the wind and the power loss when the rotors are tracking the wind directions. These are the problems of the HAWTs, which are difficult to solve.

1.3.2 Vertical axis wind turbine (VAWTs)

The second major groups of wind turbine types are the vertical axis wind turbines (VAWTs). A wide variety of VAWT configurations have been proposed, dating from the Persian VAWTs used for milling grain over thousands of years ago, through to the Darrieus turbine, invented in 1926 by Georges Darrieus, which has been used extensively for power generation. One of the largest turbines ever built was the 96 m high 64 m diameter Éole Darrieus built in Canada, with a rated power output of 3.8 MW and a rotor weighing 100 tones. Other VAWT configurations include the Savonius VAWT, which is popular because of the simplicity of manufacture, as well as the straight-bladed VAWTs. The straight-bladed VAWT includes the Musgrove turbine, which led to the successful testing of a 500 kW device at Carmarthen Bay, UK (Peace, 2004).

There are many variants of the vertical axial Darrieus and Savonius turbines design, as well as a number of other similar devices under development Figure (1.1). The propeller type turbine is most commonly used in large-scale applications constituting nearly all of the turbines in the global market, while the vertical axis turbines are more commonly implemented in medium and small-scale installations. This type of wind turbine is the main focus of this research, whereby the rotor of the wind turbine rotates perpendicular to the direction of the wind.

Although VAWTs can capture ground-level winds, just like any turbine installed on a short tower, ground-level winds are subject to friction. This slows wind down as it sweeps across the land. Both friction drag and turbulence in lower-level winds around buildings and trees decrease the power available to a turbine mounted at ground level, resulting in very little extractable energy in them. The lower the wind speed, the less electricity a turbine will produce.

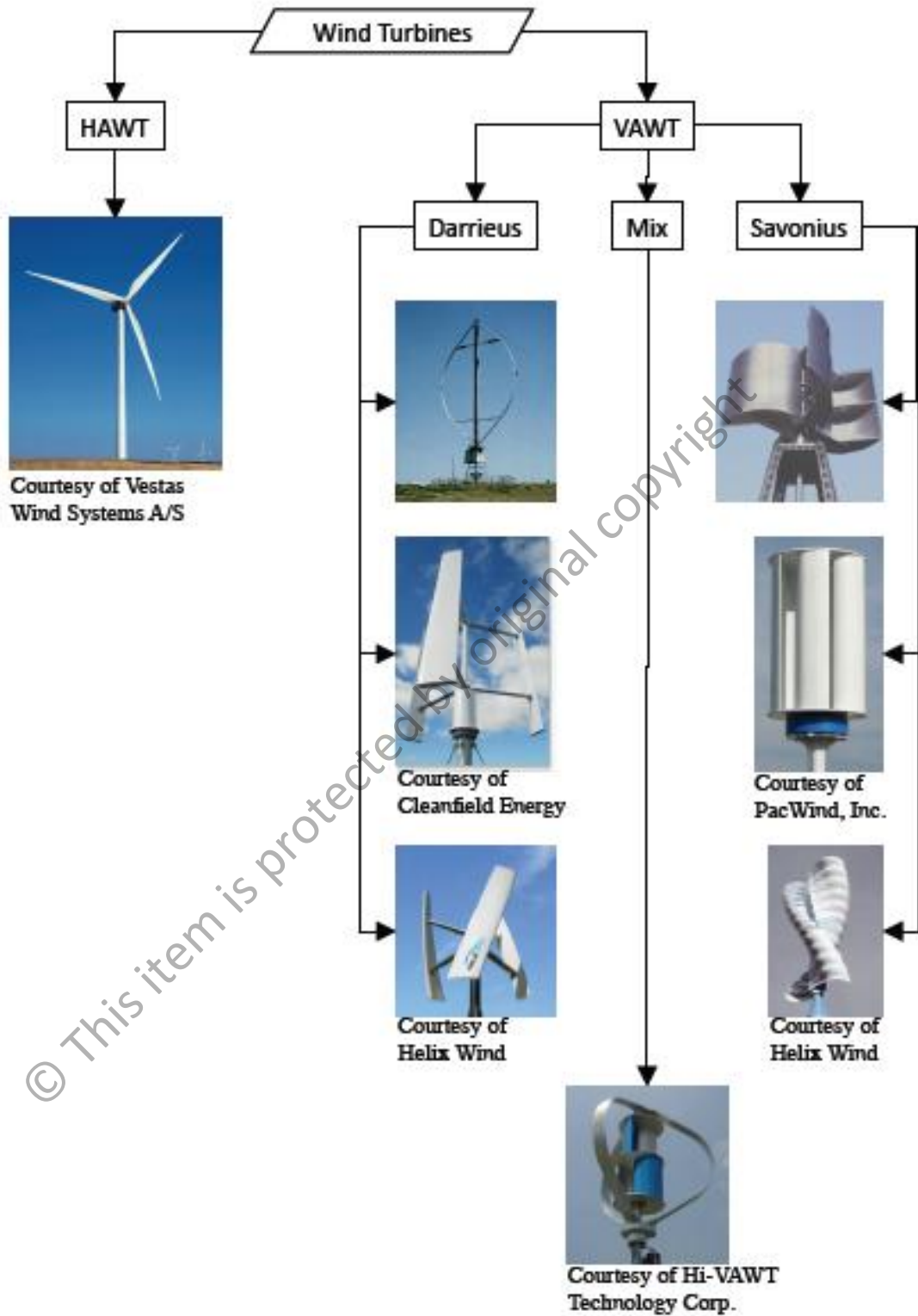


Figure 1.1: Wind turbine configurations