Proceedings of the
International Conference on Mechanical Engineering 2011
(ICME2011) 17- 19 December 2011, Dhaka, Bangladesh

ICME11-RE-008

A REVIEW OF POWER GENERATION FROM WIND IN AUSTRALIA

Abdulkadir Ali, Firoz Alam, Victor Djamovski and Simon Watkins

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Australia

ABSTRACT

With recent surge in fossil fuel prices, demands for cleaner renewable energy sources, wind turbines have become a viable technology for power generation. Greenhouse gases such as carbon dioxide emitted into our atmosphere have resulted on what many scientists believe is due to climate change. To tackle climate change, many of world's developed countries have agreed on a policy to cut down on its carbon emission. Australia has agreed on a renewable energy target of 20 per cent by the year 2020. Twenty per cent of Australia's energy generation must come from renewable energy sources by this period. This paper will examine the importance wind energy as an alternative source of energy to fossil fuel based energy both globally and locally. Wind energy is fastest growing renewable energy in the world. It has the potential to rival the cost competitiveness of conventional energy sources. Wind energy is a reliable and sustainable with a mature technology and a proven track record.

Keywords: Wind Energy, Horizontal Axis Wind Turbine, Vertical Axis Wind Turbine, MRET.

1. INTRODUCTION

One of the key challenges being faced by developed countries, such as Australia as well as rapidly developing countries, is population growth and finding a sustainable source of energy for that population. As population and industrialization increase so will the consumption of energy and demand. Today, there are many viable alternatives to fossil fuel based energy, including solar, tidal wave and geothermal. However, wind energy is considered as the most reliable and sustainable source of energy with a proven track record not just in Australia but around the world. Over the past decade, the Australian wind energy sector has had an average annual growth rate of 30 per cent [1]. It is estimated that wind energy alone currently supplies more than 5,100 gigawatt hours (GWh) of electricity annually to Australian homes. That is equivalent to 2 per cent of national electricity consumption.

Greenhouse gases emitted into the atmosphere such as carbon dioxide, methane and nitrous oxide from burnt fossil fuels has resulted in what many scientists believe a global warming. Climate change together with increasing energy demand and energy security is the key driving force that has led to many countries investing heavily in renewable energy sources. Wind power is the fastest growing source of renewable energy in Australia and around the world especially in China, India and European Union nations. Like many other nations, Australia has an obligation to meet its mandatory renewable energy target (MRET). As part of the renewable energy target in Australia, it is expected by 2020 20 per cent of Australia's electricity will be generated from renewable energy sources [1].

Coal burning is without a doubt by far the most polluting way to generate electricity, both globally and locally. 170 million tonnes of carbon dioxide is released into the atmosphere every year in Australia alone [2]. This puts Australia as one of the largest per capita greenhouse gas emitters in the world. To achieve a sustainable energy future, Australia must dramatically reduce coal burning. In order to do this, an improved efficiency of energy use is necessary. Of all the renewable energy sources that are available today, wind energy is the cleanest and more importantly it is readily available. A wind farm, when installed on agricultural land, has one of the lowest environmental impacts of all energy sources. It also occupies less land area per kilowatt hour of electricity generated than any other energy conversion system.

In order to reach this target, the Australian government has proposed new renewable energy projects of 10,000 MW around the country of the next decade. With some of the best wind resources available, Australia has the potential to become a world leader in wind energy extraction. Currently, South Australia has the majority of installed capacity of wind turbines in Australia with around 48.6 per cent of the states total capacity. The Australian government policies of carbon emission reductions and mandatory renewable energy target (MRET) are vital in utilizing Australia's wind energy resources. Since the start of 2000, wind energy in Australia had experienced slow growth but gradually

picked up momentum in 2007, when the new government was sworn in.

2. TYPES OF WIND TURBINES

Extracting power from the wind is not a new technology into our world. The Use of wind power existed for many centuries. In fact, the first known use of wind power is traced back to be in 644 AD [3]. Of course in those days wind power were used to grind grain and pump water. Although wind power is still used to pump water in many rural areas, modern wind power are primarily used to generate electricity. Modern wind turbines come in many different sizes and shapes. The most common types of wind turbine are: Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT). Regardless of the type of wind turbine, the main goal of a wind turbine is to extract as much energy as possible from the wind. Every object, including air, in motion will have some sought of kinetic energy. The kinetic energy of air passing through the turbines is converted into mechanical energy and ultimately into electrical energy. To determine the amount of power available in the wind, the following equations are used.

$$E_K = \tfrac{1}{2} m V^2 \qquad (1)$$

$$\dot{m} = \rho A V \qquad (2)$$

Substituting Eq. (2) into Eq. (1), the idealized equation for power generated from wind by the turbine is obtained as shown in Eq. (3):

$$P = \tfrac{1}{2} \rho A V^3 \qquad (3)$$

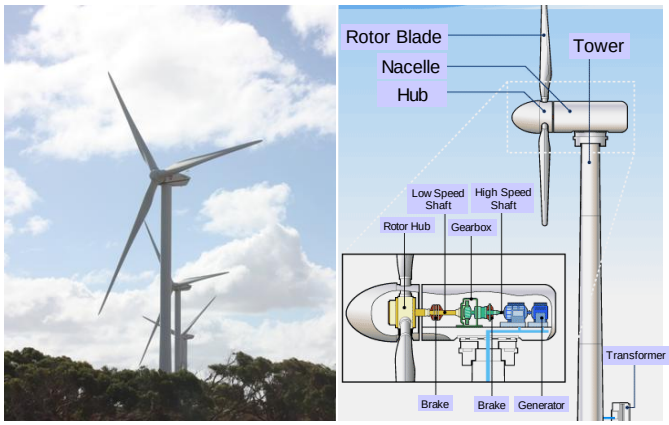
The maximum theoretical coefficient of performance or otherwise known as Betz limit is defined as 16/27 or 0.59 [4]. What this actually means is that for any given wind turbine, the maximum energy it can extract from the wind is 59 per cent of the winds energy. In practice however, the best modern wind turbine can achieve a coefficient of performance of about 40 per cent. This is the maximum value, achievable over a narrow band of wind speeds. The actual coefficient of performance will vary with wind speeds.

2.1. Horizontal Axis Wind Turbine (HAWT

Horizontal axis wind turbine (HAWT) is the most common type of wind turbine both commercially and domestically. This type is normally classified as either a downwind or an upwind. A downwind HAWT has the rotor positioned on the lee side of the tower. An upwind rotor position however, faces the wind. The primary reason an upwind rotor is commonly used is that it avoids the problem of wind shade behind the tower. The geometrical shape and size of the blades are very critical as they ultimately determine how much energy is extracted from the wind. Horizontal axis wind turbines (HAWT) are more efficient in extracting more energy than vertical axis wind turbines (VAWT) and it is currently the most used design in the world. A typical HAWT is shown in Figure 1.

The most significant technological change in wind turbines has been the increase in size and height of the rotor. The size of the rotor is determined by the aerodynamic efficiency, which is adjusted to keep the tip speed ratio under control and therefore minimize aerodynamic noise generation at the tip of the blades. As shown in Figure 2, the size of wind turbines has more than doubled over the last 20 years.

Modern turbines have a diameter of more than 124 meters and much more efficient. Thanks to the bigger blade length, the blades can utilise or extract more power from the wind and therefore generate more electricity. By producing more power, this means the cost of renewable energy of wind turbines will be cost competitive to coal generated electricity. This is further proven by the fact that, over last 25 years, the cost of producing energy from wind had dropped by 80 per cent [5]. This trend will continue over the next decade and will establish wind energy as a cost competitive form of electricity generation considering that wind energy in Australia has significantly more growth potential because of the greater level of unutilised resources



a) Wanthagi Wind Farm, near Melbourne b) Schematic of a typical HAWT

Fig 1. Horizontal axis wind turbine (HAWT)

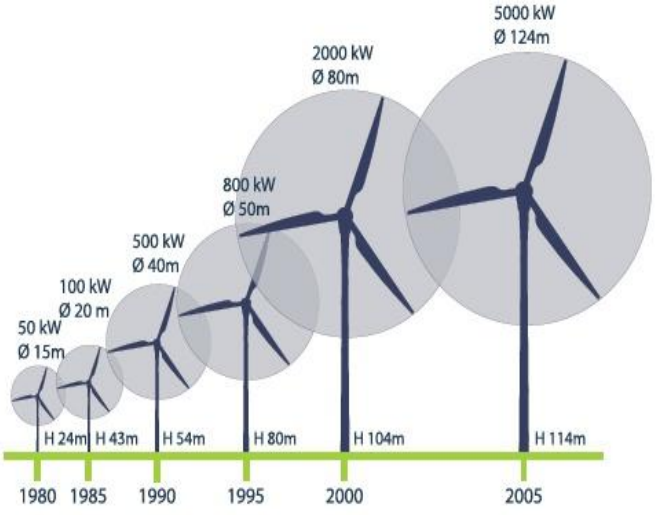


Fig 2. Wind turbine sizes [9].

Wind energy is the fastest growing source of renewable energy in the world. This is because it is a proven technology and has relatively low operating cost and environmental impact. Two decades of technological advancement has resulted in what is today's state of the art wind turbine technology. In comparison to the old wind turbines, current wind turbines can produce 200 times more power [6]. The first Australian wind farm was built in 1987 at salmon beach, Esperance in Western Australia. This wind farm, which is home to 6 wind turbines, produced 360 kW of power. However, Modern wind farms in Australia are capable of producing more than 100 Megawatts of power. As shown in Figure 3, wind turbine technology in Australia has dramatically changed in both its size and power capability. The expansion of wind energy in Australia over last decade is as a result of government policies such as the Renewable Energy Targets (RET) which favors low emission sources of energy.

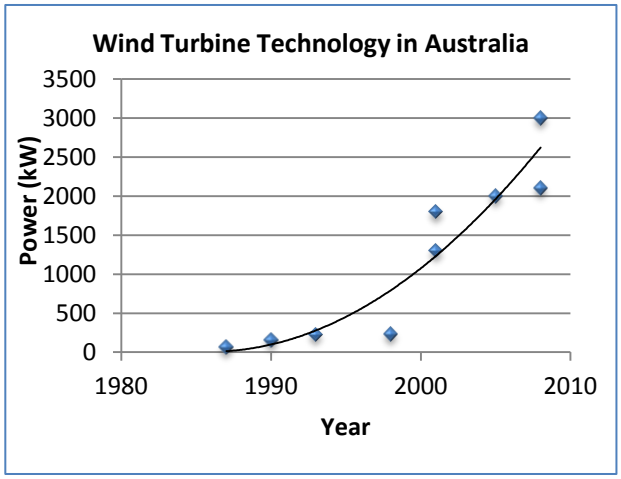


Fig 3. Wind turbine technology

Although it has not been utilised in Australia yet, an offshore wind farm is gaining more awareness globally. This is due to the fact that there are higher wind speeds available offshore. A growing market for offshore wind power is now the main driver for the developments of larger wind turbines. This has raised new technical demands with logistics involved in the manufacture, transport, erection and maintenance of offshore turbines. Australia has a large amount of sea area and meets the requirements for an offshore wind farm. Areas that have acceptable wind resource, water depth and wave energies low enough for it to be technically possible to build offshore wind farms. However, the added expense of offshore construction is seen as the stumbling block for offshore wind farms.

2.2 Vetical Axis Wind Turbine (VAWT)

There are many types of vertical axis wind turbines (VAWT). The VAWT is classified as either drag type rotors or lift type rotors. Drag type rotors such as a Savonius rotor are typically curved plates that are pushed along the wind. The drag force, which is caused by the wind moving past the rotor, has a component in the direction that causes torque. These types of rotors operate at low wind speeds with amount of torque. Its coefficient of performance is very low and therefore is not used in electricity generation. Darrieus and H rotor wind turbines however, rely on lift. The coefficient of performance for these types of rotors is relatively high. The advantage of having a VAWT is that, it is a lot quieter than HAWT and is more suitable for use in urban areas. It also has the advantage of not requiring any yaw mechanism to respond to changes in wind direction. The fact that the generators of VAWT are located on the ground, it makes it easier to maintain and access it. Although a VAWT is an ideal design, it is not often used in the commercial industry of wind energy purely on the fact that it has a low coefficient of performance. As shown in Figure 4, the lift force acting on the rotor blades tangentially to the plane of rotation of the blades produces a torque. High lift is generated by the blades when the blade cuts across the wind direction. However, when the blades are parallel to the wind flow direction, there is zero lift generated by the blades. In fact in this position only drag is generated. A typical VAWT is designed to have a symmetrical airfoil. Some typical VAWTs are shown in Figure 5.

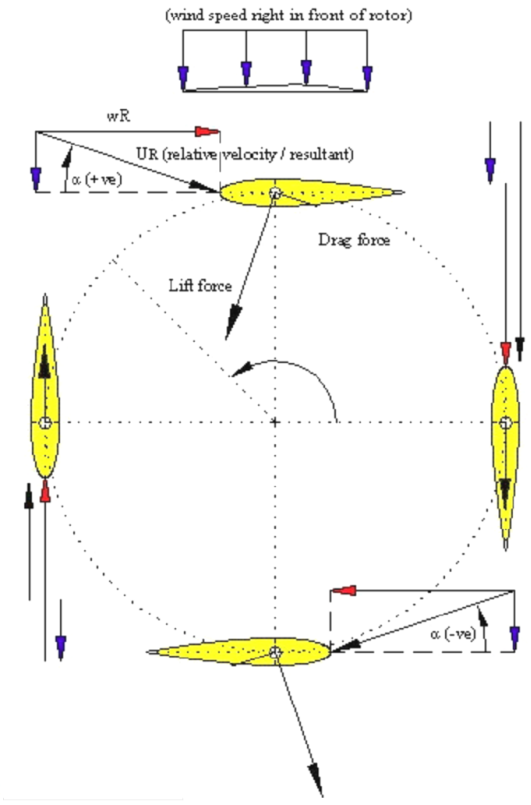


Fig 4. Aerodynamics of VAWT [16]

Fig 5. H-Rotor and Darrieus rotor [14]

3. WIND ENERGY IN AUSTRALIA

It is estimated that by 2050, Australia's demand for electricity will more than double. The current capacity electricity generation is around 48,000MW [7]. Wind energy is set to play a vital role to meet Australia's energy demand than any other source of renewable energy. By international standards Australia has some of the best wind resources in the world in places such as South Australia and Western Australia. There are 52 wind farms in operation currently in Australia with further expansion being made for the future to meet the government's renewable energy target of 20 per cent by 2020. This target of 20 per cent requires that large scale wind turbines in Australia generate about 41,000 GWh of electricity by 2020 [5]. However, for small wind turbines, the expected target is around 4000 GWh.

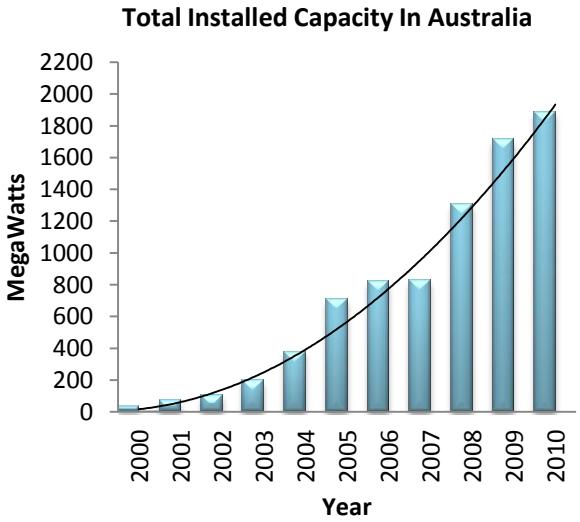


Fig 6. Total installed capacity in Australia

Power generation from wind is gaining momentum in recently. For example, in 2010 alone, 1,880MW of wind capacity was installed in Australia, which is generated by 1,052 operating wind turbines. With more projects on the way, the size of Australian wind farms is continually increasing. Acciona's 192 MW Waubra wind farm in Victoria is currently the biggest wind farm in Australia with 128 wind turbines across 173 square kilometres. However, in the future there will be bigger wind farms which will house more than 500 wind turbines. For example, the New South Wales Government has recently proposed its biggest wind farm project of 1,000 MW, consisting of 598 wind turbines. As shown in table 2, South Australia has the largest installed capacity in Australia of 907 MW followed closely by Victoria of 428 MW installed capacities. Australia has the potential to be a world leader in wind energy because of the vast amount of resources that is available in the country. With more projects on the way, wind energy looks promising as an alternative source of energy to fossil fuel. Currently, Australian wind turbines are located along the coastal belt as can be seen in Figure 7.

As mentioned earlier, South Australia currently has the most installed capacity by state in Australia with 48 per cent of Australia's total capacity followed by Victoria As shown in Figure 7. Overall Australia has 52 wind farms which consist of 1,052 operating wind turbines producing around 1,880 MW.

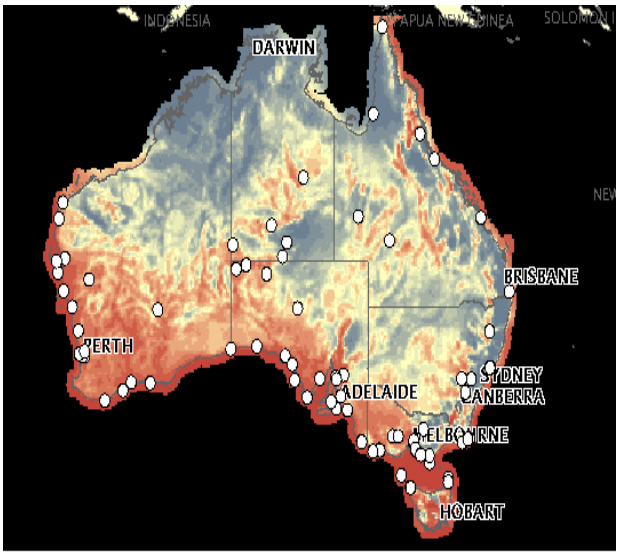


Fig 7. Wind turbines installation in Australia [10]

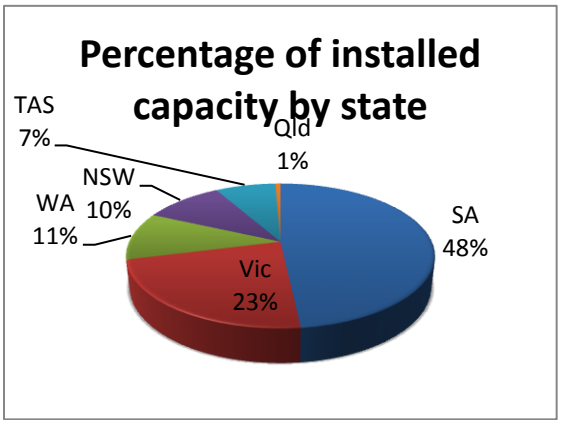


Fig 8. Percentage of Australian installed power generation from wind by state

Globally, wind power has increased at a rapid rate. In the year 2010, global wind capacity reached an incredible 196 630 Megawatt [8]. In 2009, the American market dominated with a total capacity of 35,159 Megawatt. However, in 2010, the us market installed 50 per cent less than in 2009. That paved the way for china to become the world's largest market in 2010. China currently represents more than half of the world market for new wind turbines. In a space of a year, china has added a staggering 18.9 Gigawatt. The growing wind power in china has encouraged domestic production of wind turbines and components, and also the Chinese manufacturing industry is increasing at a rapid rate. The top 10 wind energy utilising countries are shown in Figure 9. China is now the leading wind energy market leader with a growth rate of 73 per cent followed by the US.

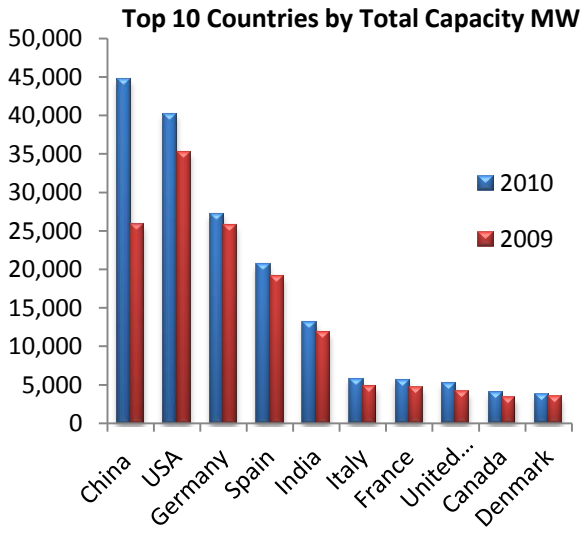


Fig 5. Ten top nations for power their power generation from wind in 2009 and 2010

4. GLOBAL WIND TURBINE MANUFACTURER

The design configuration adopted in the commercial industry of wind energy is a horizontal axis wind turbine. As mentioned earlier, horizontal axis wind turbines (HAWT) are more efficient in capturing the winds energy than vertical axis wind turbines (VAWT). Perhaps the biggest problem of having a horizontal axis wind turbine is the location of the generator. The generator, located significantly high above ground, can represents a great logistical challenge and maintenance issues.

Over the last 25 years, the wind energy industry has become notably advanced in technology. The industry has become more mature and complex particularly as the size of wind turbines has significantly increased. Many companies in the developed countries have set up R&D centres and as a result they have decades of experience in wind turbine design. With the industry only 25 years old, only four companies have dominated the wind energy market. Companies such Vestas (Denamrk), GE Wind USA), Enercon (Germany) and Gamesa (Spain) have built strong global reputations and have also benefited through strategic mergers and buyouts. Vestas has long been the world's leading supplier of wind turbines. However, recent market activity indicates that there is an increasing competition from emerging players from china and other countries and as a result has caused Vestas market share to fall significantly in recent years. Large wind turbine manufacturers have started to put their investments in key Asian countries which are developing wind energy as an alternate and cleaner, greener power source. R&D is a critical component of wind turbine design. There is no doubt that the research and development carried out by many manufacturers has led to bigger turbines which means more energy is extracted from the wind. In a market dominated by Europe and America, Australian wind energy relies on foreign companies for the supply of wind turbines. With a market share of 39 per cent, Vestas is the leading supplier of wind turbines in Australia, followed by Suzlon (India) and NEG Micon (Denmark) with 26 per cent and 11 percent respectively.

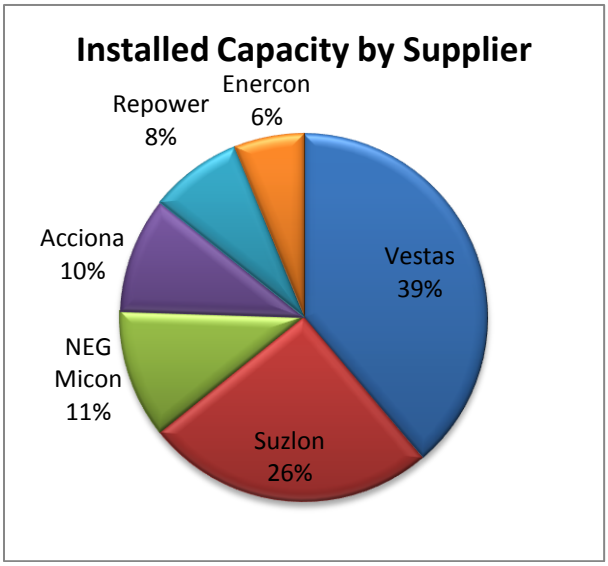


Fig 10. Installed capacity by World's leading manufacturer

5. CURRENT STATE OF DOMESTIC SCALE POWER GENERATION IN AUSTRALIA

Although Australia does not design and manufacture commercial wind turbines, the same cannot be said for small scale wind turbines. A according to the International Electrotechnical Commission (IEC), a small scale wind turbines is a turbine that produces less than 50kW of rated output. Small scale wind turbines allow home and business owners to contribute to their own energy usage by harnessing the clean and renewable power of the wind. However, the development of the technology of small wind turbines is at its early stages. There are several companies in Australia who design and manufacture its own small wind turbines. The difference in domestic wind power and commercial wind power is the level of R&D work carried out. Until recently, small wind turbines had received little awareness in the wind energy market. The domestic environment has unique challenges to the development of wind energy systems. The wind profile in domestic areas tends to be more

turbulent due to the fact that there are more buildings which obstruct the wind flow. Installing wind turbines in domestic areas is ideal as the energy it produces is used in the same location. One of the problems faced by the commercial wind turbines is the ability to integrate the power produced by the turbines into a grid connection. Energy loses will occur in the transmission lines before it reaches households. Small wind turbines in domestic areas reduce the loss of energy in the distribution network and the cost of additional electric network.

The cost of installing small wind turbines can be expensive. A 10kW system can cost as much as AU $60,000 but with government incentives, this cost can be reduced. In comparison to small wind turbines, large wind turbines have an installation cost of US $2 per kW which is relatively cheaper due to its mass production globally. Although small wind turbines have a significant installation cost, they can be quite competitive with conventional energy sources when you account for a lifetime reduced or avoided utility cost. Currently in Australia, companies such as Aerogenesis, Soma, WestWind and Flowtrack design and manufacture domestic scale wind turbines. Many research groups especially Wind Energy Research Group led by Dr Firoz Alam at RMIT University are heavily involved in research and development of small wind turbines for domestic and semi commercial use. It is critical for the small wind turbine market to invest research and development as this will ultimately improve the efficiency of the turbine and lead to low installation costs.

6. CONCLUSIONS

Wind energy, both locally and globally is expanding at a rapid rate. For the government to cut down Australia's annual green house gas emissions, it is very important that by 2020 20 per cent of our electricity is generated by a renewable source of energy. Wind energy, one of many renewable sources of energy available today, is the most cost effective, clean and efficient way of generating electricity than perhaps any other renewable energy. With very little impact on the environment, wind energy will no doubt contribute the most in reaching the renewable energy target of 20 per cent. Technological advancement in wind turbines over the last decade has allowed us to capture more power than ever before. At this rate of growth, wind energy will have the potential to be a cost competitive source of energy to coal. As the cost of electricity is expected to double than what it is today, coupled with increasing demand for energy and limited coal resources, the future no doubt lies in wind energy as a sustainable source of energy.

Domestic wind turbines have important role to play in the future to meet the needs of energy consumers. Although the technology of small wind turbines is not as advanced as large wind turbines, small wind turbines offer low maintenance costs over a life time period of 20 years.

7. REFERENCES

1. Clean Energy Council (2010), 2010 Clean Energy Australia annual report. Retrieved from http://www.cleanenergycouncil.org.au
2. Diesendorf, M. (2003), Australia's polluting power: coal fired electricity and its impact on global warming, WWF Australia, Sydney. Downloadable from www.wwf.org.au
3. Hau, E. (2005), Wind Turbines: Fundamentals, Technologies, Application, Economics, 2nd edition, Springer Verlag, United States
4. Jain, P. (2011), Wind Energy Engineering, 1st edition, McGraw Hill, United States.
5. Clean Energy Council (2010). There is power in the wind. A resource for the wind industry [PowerPoint Slides] Retrieved from http://www.cleanenergycouncil.org.au
6. Hassan, G.L (2010), Review of Australian wind industry, presented at CEC Conference 2010 [PowerPoint Slides]. Retrieved from http://www.gl-garradhassan.com/en
7. Australian Energy Structure (2008). Retrieved October 3, 2011, from http://www.solarpoint.com.au/
8. Global Wind Energy Market (2010). Retrieved October 3, 2011, from http://www.gwec.net/
9. European Wind Energy Association. (2011). Retrieved from http://www.ewea.org/
10. Global Wind Energy Council. (2011). Retrieved from http://www.gwec.net/
11. Yusaf, T., Goh, S. and Borserio, J. A. (2011), Potential of renewable energy alternatives in Australia, *Renewable and Sustainable Energy Reviews*, 15: 2214-2221
12. Valentine, S.V. (2011), Understanding the variability of wind power costs, *Renewable and Sustainable Energy Reviews*, 15: 3632-3639
13. MacGill, I. (2010), electricity market design for facilitating the integration of wind energy: Experience and prospects with the Australian National Electricity Market, *Energy Policy*, 38: 3180-3191
14. http://www.ece.umr.edu/links/power/wind1, retrieved on 27 August 2010
15. http://www.windturbine-analysis.com/, accessed on 24 September 2010

8. MAILING ADDRESS

Mr Abdulkadir Ali
School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
Plenty Road, Bundoora
Melbourne, VIC 3083, AUSTRALIA
Telephone: +61 3 99256103
Fax: +61 3 99256108
E-mail: s3137717@student.rmit.edu.au or, firoz.alam@rmit.edu.au