Chapter 1 : Introduction

1. **Background of Wind Energy Harvesting**

Although for thousand years of utilization of windy energy for basic applications like windmills and water pumps, utilization of wind for energy harvest never preferred because of its fluctuating and unknown nature. Like many developments in technology, modern wind energy utilization by means of wind turbines started 40 years ago due to search for alternative energy sources except oil, whose deficiency and high prices were a global crisis issue. Besides, air pollution and other environmental problems made it indispensable to search for clean and renewable energy sources such as wind. At first times of development, countries excluding Denmark tried to produce these wind turbines by experiences used in aerospace technology which has very high power ratings of MWs. After the understanding of the fact that produced turbines were bulky and inefficient in terms of reasonable cost of energy and required different technology than aeroplanes motors, all governments started follow Denmarks' path. Denmark started the wind turbine technology by developing small wind turbines first and encouraged the individiuals and small companies.Today, more than 40 per cent of Denmark’s energy supply comes from wind power and the plan is to reach 50 per cent by 2020, as set out in the 2012 Energy Act.Total wind energy capacity in Denmark was 4,890 MW by the end of 2014, 3,620 MW onshore and 1,271 MW offshore[[1]](http://denmark.dk/en/green-living/wind-energy/). Denmark has some of most important wind energy manufacturers worldwide such as [Vestas](https://www.vestas.com/) and [Bonus Energy A/S-lately was acquired by Siemens](http://www.energy.siemens.com/hq/en/renewable-energy/wind-power/).

Global annual installed wind capacity between 2001-2016 and global cumulative installed wind capacity between same period is given Figures 1 and 2, respectively.

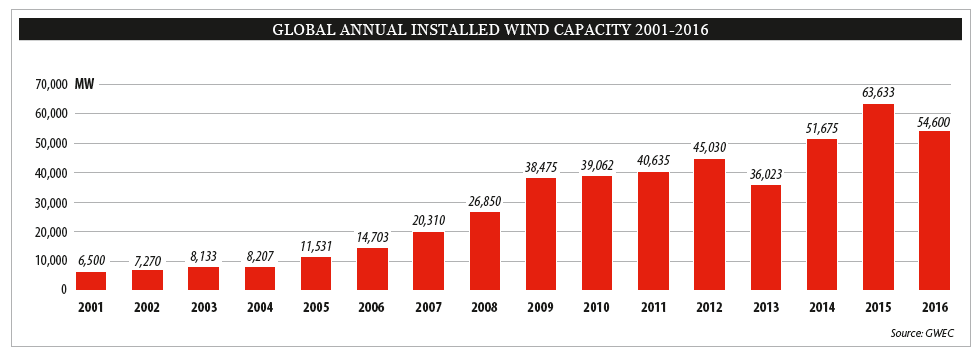


Figure 1. Global annual installed wind capacity 2001-2016 (GWEC report-2016)

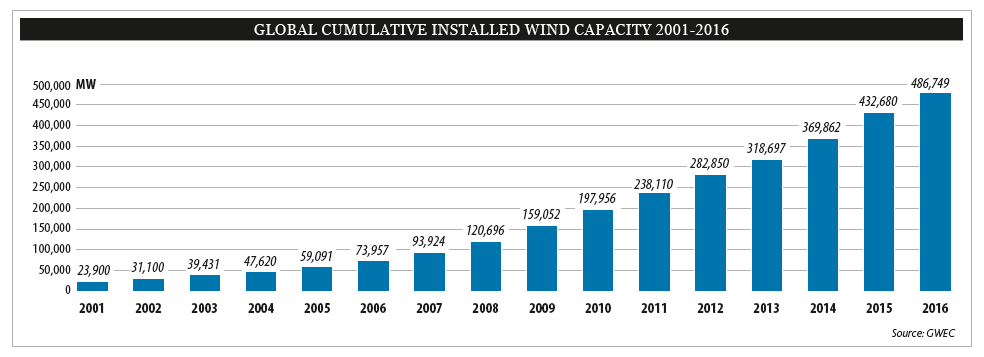


Figure 2. Global cumulative installed wind capacity 2001-2016 (GWEC report-2016)

According to annual market update report of GWEC, it’s expected to reach 791 GW of global cumulative wind energy capacity by 2020, although it’s estimated that annual capacity growth rate will be stabilize around five percent level. Detailed market forecast of GWEC for 2016-2020 is given in Figure 3.

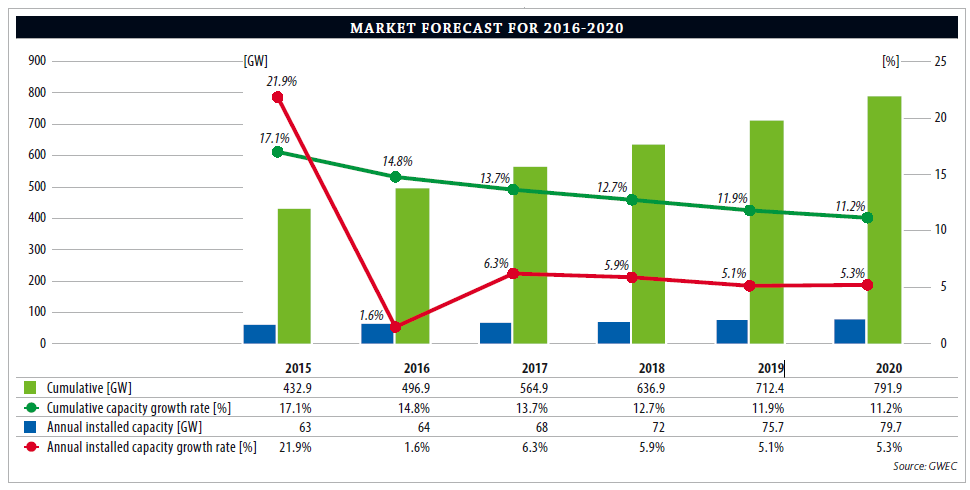


Figure 3. Global wind energy market forecast (GWEC report-2015)

Wind turbine is an important issue for renewable energy. Especially for the last decade its technology is substantially matured.By this improved technology both in power electronics and generators, manifacturing and installation costs are reduced. Therefore, wind energy harvesting concept started to penetrate the global markets. According to [[2]](http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6216474) the global installed utility scale wind power was 197 GW at the end of 2010 (an increase of 24.1%) while the global market for small wind turbines (SWTs) grew by only 4%. Evolution of wind turbine size and power electronics can be seen in Figure 4.

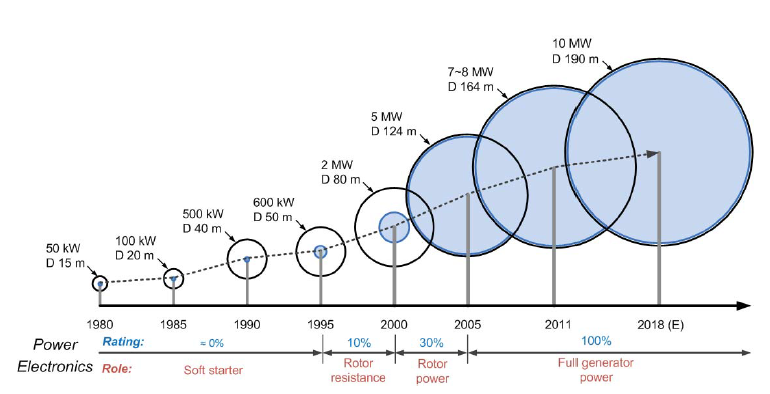


Figure 4. Evolution of wind turbines[4]

Wind turbine generators dominating the markets nowadays have 300-800 kW power output capacity in average.But the challenges and trends are toward to 1 MW per turbine thanks to promising concepts such as direct-drive[3].

Increase in utilization of wind energy in Turkey is very similar to global trends.Wind power supplied about 6% Turkey’s electricity consumption in 2015 [7]. Turkey has nearly stable increase rate of installation rate of wind power plants for past 5 years. Figure 5 below shows the variation of cumulative installations for wind power plants in Turkey. Figure 6 shows the global statistics of top 10 new installed capacity between January-December 2016. It can be concluded from wind power capacity installation performance in last decade, Turkey show some promise to become in top 5 countries of wind energy capacity in next years.

The cost per swept area is used rather than just the cost of the turbines or cost per rated power since the swept area gives a better indication of the total energy that can be generated by the turbine than the rated power given by the manufacturer. Besides that, when designing and investing a wind power stations,3 main properties which are necessary to validate are given as follows:

* Low cost
* long-lasting
* Low service requirement

These are called L3 conditions[1]

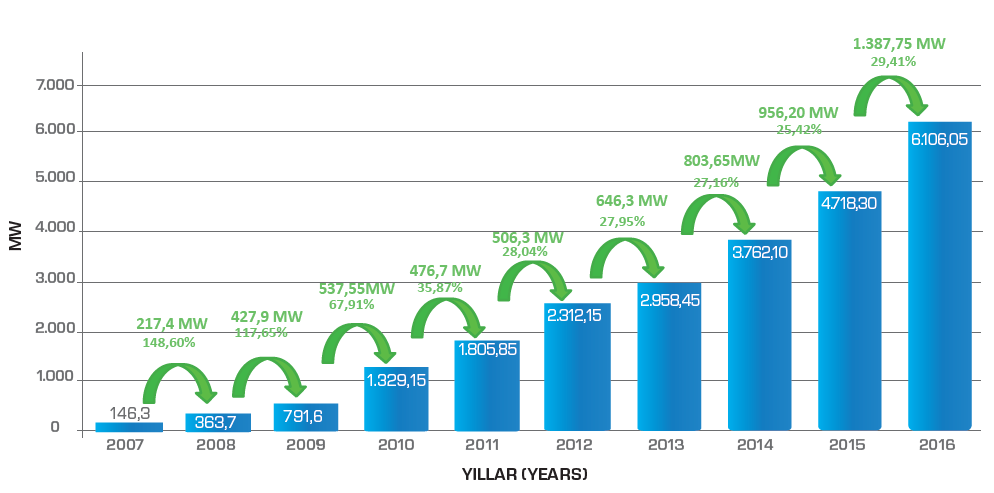


Figure 5. Cumulative installations for wind power plants in Turkey (TUREB-Turkish Wind Energy Statistics Report/January 2017)

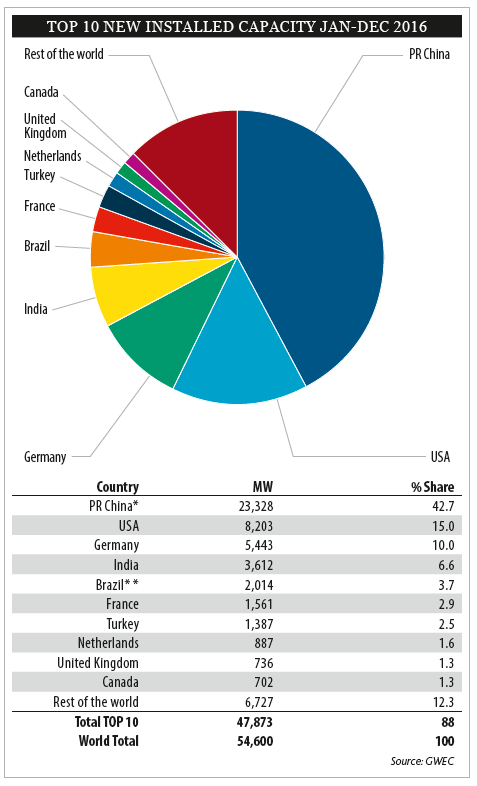


Figure 6. Top 10 new installed WPP(Wind Power Plant) capacity between January-December 2016 (GWEC report-2016)

Small wind turbines(there is no certain definition about the scale but we can assume that for kw scale ones) can be categorized in two types:

* Horizontal axis wind turbines (HAWT)
* Vertical axis wind turbines (VAWT)

In general, the efficiency of small wind turbines is low compared with large wind turbines. There are no standards about what wind speed manufacturers should give the output power of their turbine (rated power). Therefore, there are some differences between the manufacturer's plate values and actual measured values.

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*Horizontal axis wind turbine Vertical axis wind turbine*

Another important issue is the speed control of these turbine blades in terms of aerodynamic means. At this point two main control techniques are exist: stall control and pitch control . Generally in stall controlled technique, turbine blades are fixed aerodynamic structure and these turbines need high peak torque to limit turbine speed while in pitch control technique, blades angle can be changed during operation of turbine i.e angle of attack of air can be adjusted therefore these turbines do not need overtorque for limit the speed [5].

Main parts of the wind turbine consist of turbine blades and shaft, gearbox and generator. In conventional applications gearbox is connected between turbine shaft and generator and used for increasing the low speed of turbine blades to high speed of generator. In direct drive drive wind turbines, generator directly connected to main shaft of the turbine and operate at low speeds. Geared and direct drive schematics of wind turbines are shown in Figure 7.

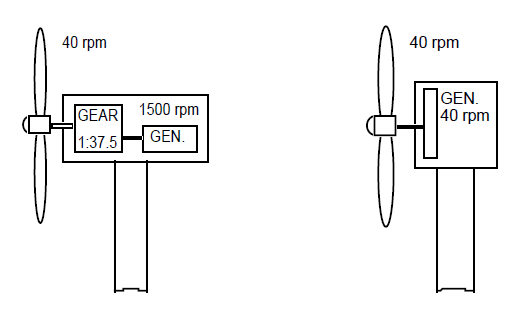


Figure 7. Conventional geared (left) and direct drive wind turbines [6]

1. **Problem Statement and Research Objective**

As the wind energy conversion systems become more capable player of the global energy sector and installed capacities of the WECs increased every year, reliability for these systems becomes important issue. Especially with the increased power rates of these turbines, size and volumes are also increase and modularity becomes vital.

In this thesis work, a Direct Drive Axial Flux Permanent Magnet wind turbine generator is chosen and designed because of its high torque density and volume advantage. Gearless drive train is chosen especially for increase overall efficiency and reduce maintanence costs. Proposed generator also has a modular structure, thus reliability and high efficiency is desired even in a fault-state. When increasing importance of “reliability”, “modularity” and “fault-tolerance” taken into account, proposed generator system and its comparison with existed commercial counterparts will contribute significantly in the wind energy harvesting technologies.

**References**

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