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Introduction

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The conventional energy sources such as oil, natural gas, coal, or nuclear are finite and generate pollution. Alternatively, the renewable energy sources like wind, fuel cell, solar, biogas/biomass, tidal, geothermal, etc. are clean and abundantly available in nature. Among those the wind energy has the huge potential of becoming a major source of renewable energy for this modern world. Wind power is a clean, emissions-free power generation technology. Like all renewable sources it is based on capturing the energy from natural forces and has none of the polluting effects associated with 'conventional' fuels. In 2008, 27 GW wind power has been installed all over the world, bringing world-wide installed capacity to 120.8 GW (GWEC publication, 2008). This is an increase of 36% compared with the 2007 market, and represents an overall increase in the global installed capacity of about 28.8%. From this scenario, it is clear that wind power is going to dominate the renewable as the conventional energy market in sooner future. Wind energy is the only power generation technology that can deliver the necessary cuts in CO2 emissions from the power sector in the critical period up to 2020, when greenhouse gas emissions must peak and begin to decline if we are to have any hope of avoiding the worst impacts of climate change . The 120 .8 GW of global wind capacity installed by the end of 2008 will produce 260 TWh of electricity and save 158 million tons of CO2 every year (GWEC publication, 2008).

2. Background of Wind Power

In the 1970s, concern for the limited fossil fuel resources and their impact on the environment awakened. Due to this growing concern, interest revived in using renewable energy sources to meet the constantly rising world electricity demand. In addition, the oil crises of 1973 and 1979 led to the awareness that the amount of energy imported should be decreased so as to become less dependent on oil ex-porting countries. The Gulf-War (1990-1991) confirmed this concern.

The increasing concerns over environmental issues and the depletion of fossil fuel demanded the search for more sustainable electrical sources. One technology for generating electricity from renewable resources is to use wind turbines that convert the energy contained by the wind into electricity. The wind is a vast, worldwide renewable source of energy. Since ancient times, humans have har-nessed the power of the wind. The earliest known use of wind power is the sail-boat. Boats propelled by wind energy sailed up the

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Nile against the current as early as 5000 B.C. By A.D. 1000, the Vikings had explored and conquered the North Atlantic. The wind was also the driving force behind the voyages of discovery of the Verenigde Oost-Indische Compagnie (VOC) between 1602 and 1799. Windmills have been providing useful mechanical power for at least the last thousand years, and wind turbines have generated electricity since 1888.

3. Current Installation Status of Wind Power Worldwide

Wind energy has become a mainstream energy source and an important player in the world's energy markets, with the 2008 market for turbine installations worth about € 36 .5 billion . The wind industry also creates many new jobs; over 400,000 people are now employed in this industry, and that number is expected to be in the millions in the near future .The following sub-sections will provide a condensed overview of wind energy status around the world until the year 2008. The prediction of future growth of wind energy until 2020 is also presented. This section is written in light of the data from Global Wind Energy Council (GWEC), European Wind Energy Association (EWEA), and Ameriical Wind Energy Association (AWEA).

Figure 1 shows the total wind power installation capacities throughout Europe at the end of 2008 (GWEC publication, 2008). Global cumulative installed capacity from 1996-2008, global annual installed capacity from 1996-2008, and annual installed capacity by region from 2003-2008 scenarios are shown in Figs. 2 to 4 (GWEC publication, 2008). The installation scenario for world top 10 countries in 2008 is shown in Fig. 5 (GWEC publication, 2008). The regional analyses are given in light of Global Wind Energy Council (GWEC) and American Wind Energy Association (AWEA) reports as shown below.

3.1 United States

In North America, the US market broke all previous records with new installations of 8.5 GW, reaching a total installed capacity of over 25 GW. In 2008 the US was the number one market both in terms of new capacity and in terms of total wind generation capacity. Fig. 5 shows that the US passed Germany to become the number one market in wind power. The massive growth in the US wind market in 2008 increased the country's total power generating capacity by half . The new wind projects completed in 2008 accounted for about 42% of the entire new power producing capacity added in the US last year, and created 35,000 new jobs, bringing the total employed in the sector up to 85,000 (GWEC publication, 2008).

The U.S. wind industry installed over 1,600 MW of new wind capacity in the third quarter of the year, bringing the wind power capacity installed so far in 2009 to over 5,800 MW and the total installed capacity in the U.S. to over 31,100 MW overall. Over 5,000 MW more are under construction for completion this year or next year (AWEA publication, 2009).

The following map (Fig. 6) shows the installed megawatts (MW) for each state of the United States, as of end June 2009. Wind power generating capacity existing and under construction at the 3rd quarter of 2009 is shown in Table 1 (AWEA resources, 2009). The top ten ranking of the wind power generating states are shown in Fig. 7 (AWEA publication, 2009).

In 2008, the US Department of Energy released a groundbreaking report, finding that wind power could provide 20% of US electricity by 2030 (GWEC publication, 2008).

		End 2007	New 2008	Total end 2008
AFRICA & MIDDLE EAST	Egypt	310	55	365
	Morocco	124	10	134
	Iran	67	17	85
	Tunisia	20	34	54
	Other[1]	17	14	31
	Total	**539**	**130**	**669**
ASIA	China	5,910	6,300	12,210
	India	7,845	1,800	9,645
	Japan	1,538	346	1,880
	Taiwan	281	81	358
	South Korea	193	43	236
	Philippines	25	8	33
	Other[2]	5	1	6
	Total	**15,795**	**8,579**	**24,368**
EUROPE	Germany	22,247	1,665	23,903
	Spain	15,145	1,609	16,754
	Italy	2,726	1,010	3,736
	France	2,454	950	3,404
	UK	2,406	836	3,241
	Denmark	3,125	77	3,180
	Portugal	2,150	712	2,862
	Netherlands	1,747	500	2,225
	Sweden	788	236	1,021
	Ireland	795	208	1,002
	Austria	982	14	995
	Greece	871	114	985
	Poland	276	196	472
	Norway	326	102	428
	Turkey	147	286	433
	Rest of Europe[3]	955	362	1,305
	Total Europe	**57,139**	**8,877**	**65,946**
	of which EU-27[4]	*56,531*	*8,484*	*64,948*
LATIN AMERICA & CARIBBEAN	Brazil	247	94	341
	Mexico	87	0	87
	Costa Rica	70	0	70
	Caribbean	55	0	55
	Argentina	29	2	31
	Other[5]	45	0	45
	Total	**533**	**95**	**629**
NORTH AMERICA	USA	16,824	8,358	25,170
	Canada	1,846	526	2,372
	Total	**18,670**	**8,884**	**27,542**
PACIFIC REGION	Australia	824	482	1,306
	New Zealand	322	4	326
	Pacific Islands	12	0	12
	Total	**1,158**	**486**	**1,644**
	World total	**93,835**	**27,051**	**120,798**

1 South Africa, Cape Verde, Israel, Lebanon, Nigeria, Jordan;
2 Thailand, Bangladesh, Indonesia, Sri Lanka;
3 Belgium,Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Faroe Islands, Finland, Hungary, Latvia, Lithuania, Luxembourg, Romania, Russia, Slovakia, Switzerland, Ukraine;
4 Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK;
5 Colombia, Chile, Cuba;

Please note: project decommissioning of 89 MW and rounding affect the final sums

Source: GWEC

Fig. 1. Regional distribution of global installed wind power capacity in MW (Source: Global Wind Energy Council, GWEC)

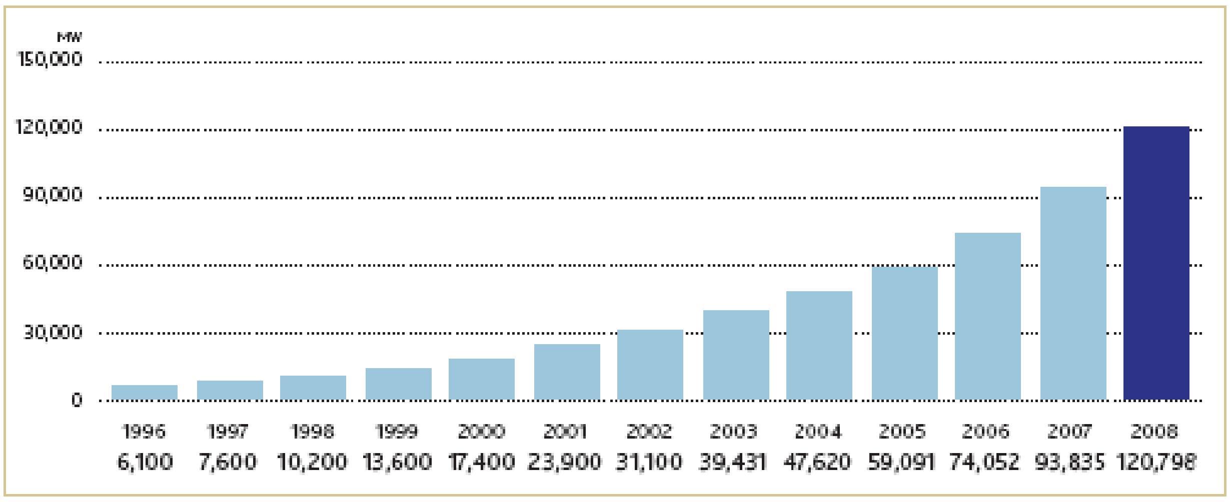


Fig. 2. Global cumulative installed capacity 1996-2008 (Source: Global Wind Energy Council, GWEC)

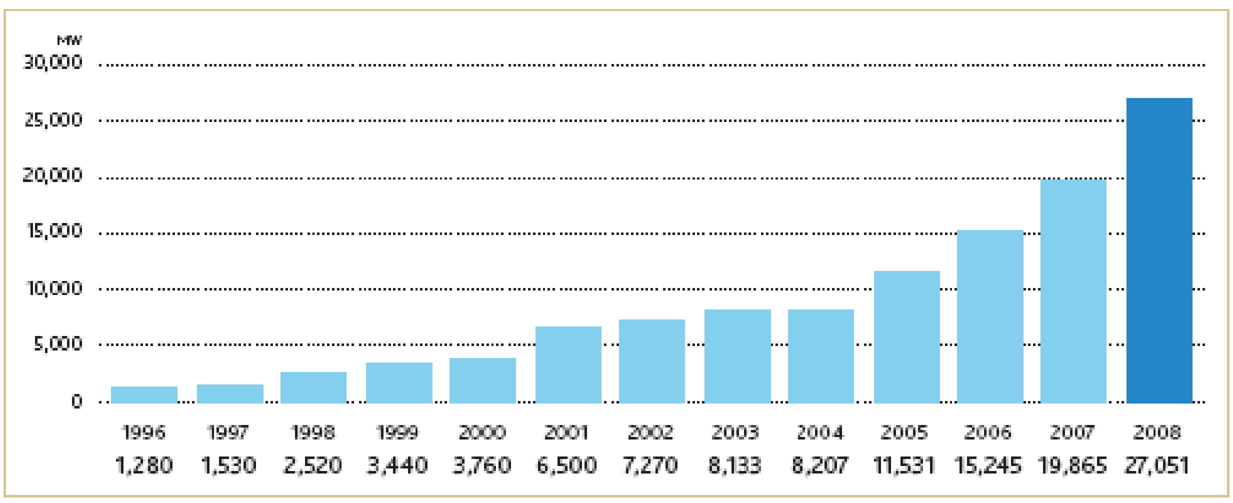


Fig. 3. Global annual installed capacity 1996-2008 (Source: Global Wind Energy Council, GWEC)

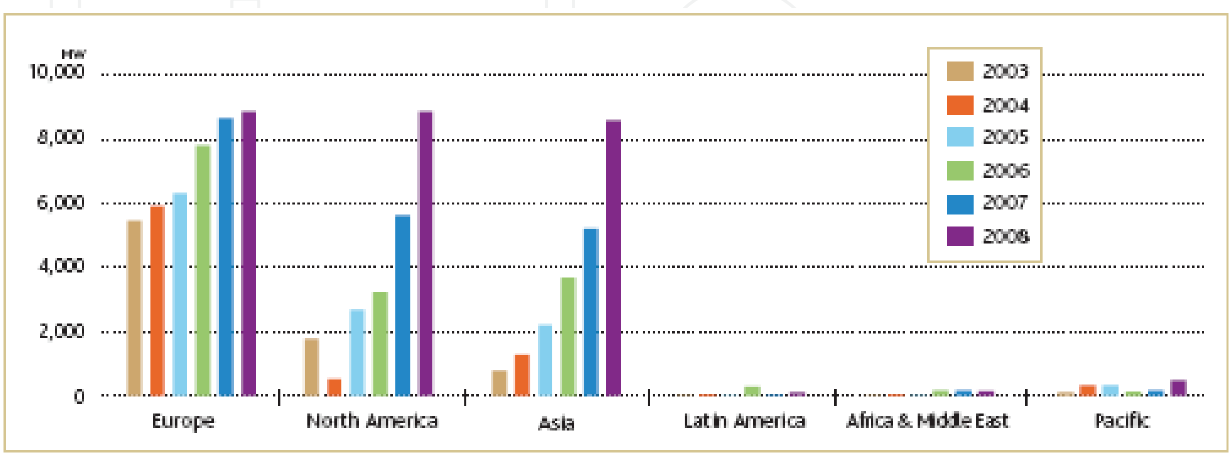
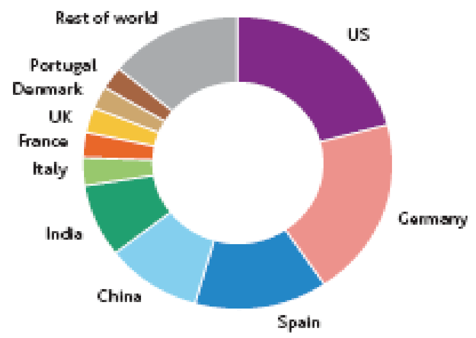


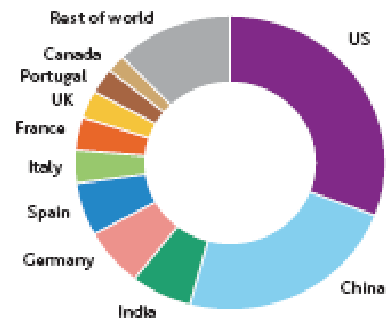
Fig. 4. Annual installed capacity by region 2003-2008 (Source: Global Wind Energy Council, GWEC)

TOP 10 TOTAL INSTALLED CAPACITY 2008



	MW	%
USA	25,170	20.8
Germany	23,903	19.8
Spain	16,754	13.9
China	12,210	10.1
India	9,645	8.0
Italy	3,736	3.1
France	3,404	2.8
UK	3,241	2.7
Denmark	3,180	2.6
Portugal	2,862	2.4
Rest of world	16,693	13.8
Total top 10	**104,104**	**86.2**
World total	**120,798**	**100.0**

TOP 10 NEW CAPACITY 2008



	MW	%
USA	8,358	30.9
China	6,300	23.3
India	1,800	6.7
Germany	1,665	6.2
Spain	1,609	5.9
Italy	1,010	3.7
France	950	3.5
UK	836	3.1
Portugal	712	2.6
Canada	526	1.9
Rest of world	3,285	12.2
Total top 10	**23,766**	**87.8**
World total	**27,051**	**100.0**

Fig. 5. Installation scenario for top 10 countries in 2008 (Source: Global Wind Energy Council, GWEC)

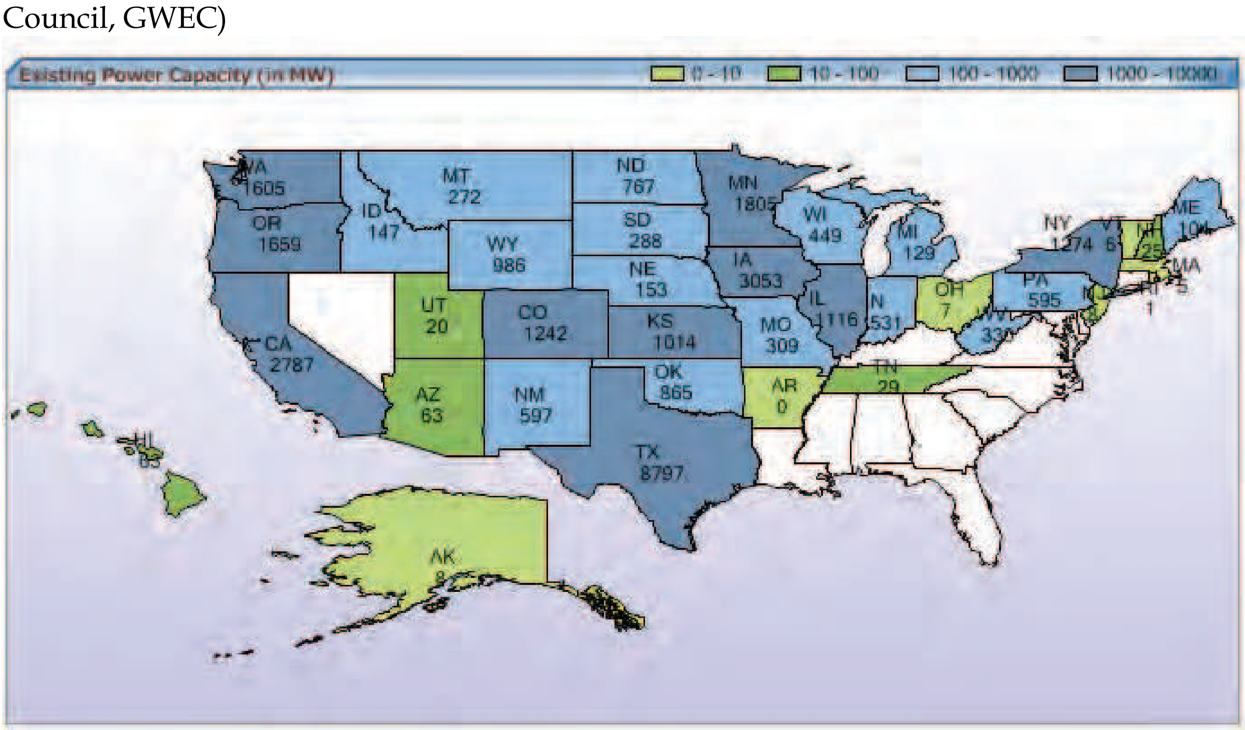


Fig. 6. AWEA 3rd quarter 2009 market report (Source: American Wind Energy Association, AWEA)

Existing	Under Construction
16818.78	3506.38

Table 1. National Total Power Capacities from Wind Energy (MW) in U.S (Source: American Wind Energy Association, AWEA)

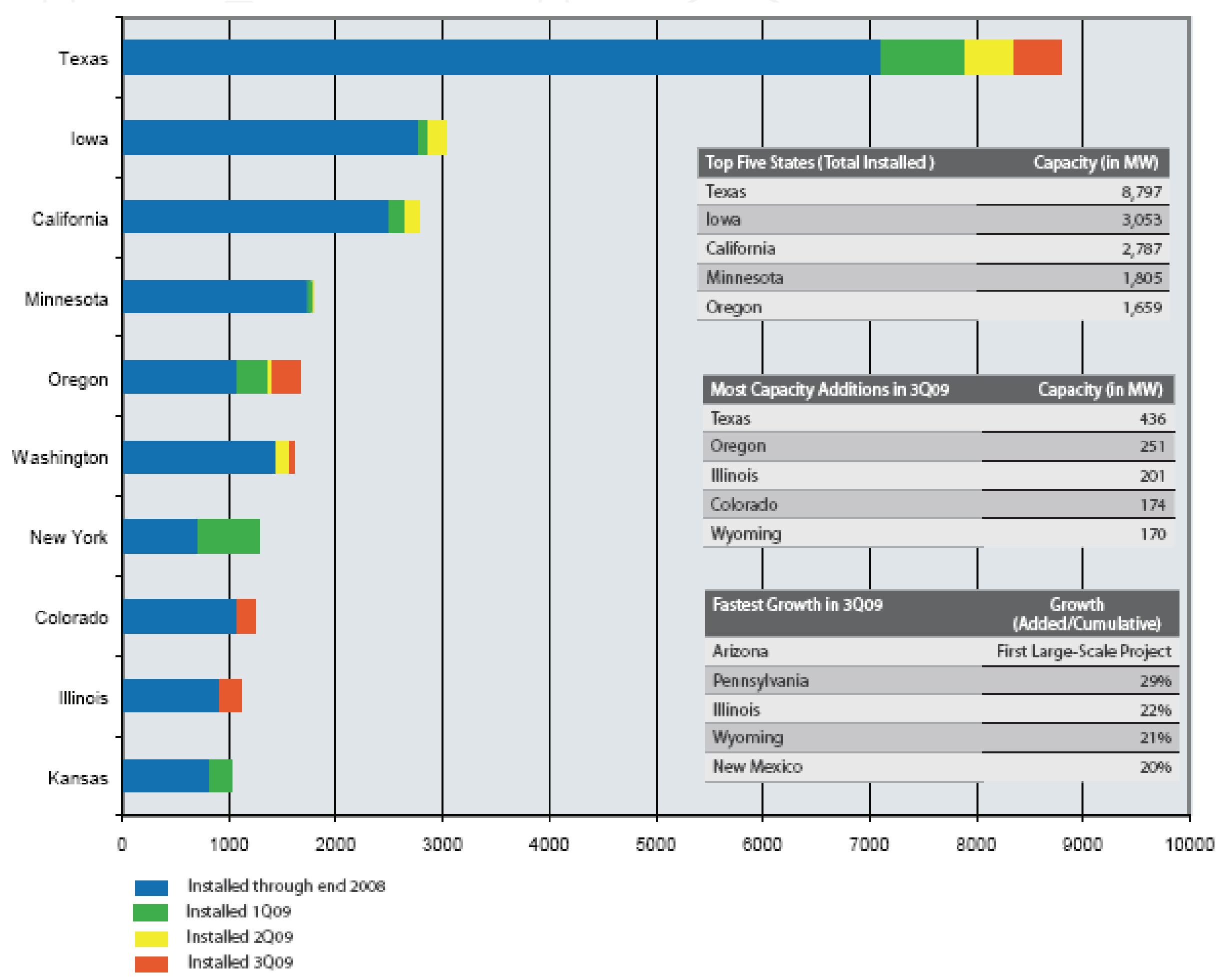


Fig. 7. Wind Project Installations by Top Ten States (Source: American Wind Energy Association, AWEA)

3.2 Canada

Canada in 2008 surpassed the 2 GW mark for installed wind energy capacity, ending the year with 2 .4 GW. Canada's wind farms now produce enough power to meet almost 1% of Canada's total electricity demand. 2008 was Canada's second best ever year for new wind energy installations with ten new wind farms coming online, representing 526 MW of installed wind energy capacity. Included in this total were the first wind farms in the provinces of New Brunswick, Newfoundland and Labrador. In British Columbia, the only Canadian province without a wind farm, construction began on the first wind farm with completion expected in early 2009 (GWEC publication, 2008).

3.3 Asia

The growth in Asian markets has been breathtaking, as nearly a third of the 8 .6 GW installed in 2008 was installed in Asia (GWEC publication, 2008).

China continued its spectacular growth in 2008, once again doubling its installed capacity by adding about 6 .3 GW, to reach a total of 12 .2 GW. The prospects for future growth in the Chinese market are very good. In response to the financial crisis, the Chinese government has identified the development of wind energy as one of the key economic growth areas, and in 2009, new installed capacity is expected to nearly double again. At this rate, China is on its way to overtake Germany and Spain to reach second place in terms of total wind power capacity in 2010. This means that China would have met its 2020 target of 30 GW ten years ahead of time.

The growing wind power market in China has also encouraged domestic production of wind turbines and components, and the Chinese manufacturing industry is becoming increasingly mature, stretching over the whole supply chain. According to the Chinese Renewable Energy Industry Association (CREIA), the supply is starting to not only satisfy domestic demand, but also meet international needs, especially for components. In 2009, Chinese companies are set to start entering the UK and Japanese markets. There are also ambitions for exploring the US market in the coming years.

In 2008, the newly-established National Energy Bureau established wind energy as a priority for diversifying China's energy mix away from coal, and it implemented the 10 GW-Size Wind Base Program (Wind Base) in order to achieve this. The bureau selected six locations for Wind Base projects; Xinjiang, Inner Mongolia, Gansu, Hebei, and Jiangsu. The objective is to install of 10 GW or more of new wind generating capacity by 2020 on each of these Wind Base sites.

India is continuing its steady growth, with 1,800 MW of wind energy capacity added in 2008, bringing the total up to 9 .6 GW. The leading wind producing state in India is Tamil Nadu, which hosts over 4 GW of installed capacity, followed by Maharashtra with 1 .8 GW and Gujarat with 1 .4 GW.

Other Asian countries with new capacity additions in 2008 include Japan (346 MW, taking the total to 1 .9 GW), Taiwan (81 MW for a total of 358 MW) and South Korea (43 MW for a total of 236 MW) (GWEC publication, 2008).

3.4 Europe

Although Europe was home to only one third of the world's new installed capacity in 2008, the European market continues its steady growth, and wind power is now the fastest growing power generation technology in the EU. Indeed, more than 35% of all new energy installations in 2008 were wind power, which meant that renewable energy accounted for more than half of all new power generation capacity in the EU considering the fact of 4.2 GW of PV installation (GWEC publication, 2008).

Overall, almost 8 .9 .GW of new wind turbines brought European wind power generation capacity up to nearly 66 GW. There is now clear diversification of the European market, relying less and less on the traditional wind markets of Germany, Spain and Denmark. 2008 saw a much more balanced expansion, with a 'second wave' led by Italy, France and the UK. Ten of the EU's 27 member states now have more than 1 GW of wind power capacity.

In 2008 the European wind turbine market was worth € 11 billion. The entire wind fleet will produce 142 TWh of electricity, or about 4 .2% of EU demand in an average wind year. This will save about 100m tons of CO_2 each year.

While at the global level, Germany has been surpassed by the US, it continues to be Europe’s leading market, both in terms of new and total installed capacity. Over 1 .6 GW of new capacity was installed in 2008, bringing the total up to nearly 24 GW.

Wind energy is continuing to play an important role in Germany’s energy mix. In 2008, 40 .4 TWh of wind power were generated, representing 7 .5% of the country’s net electricity consumption. In economic terms too, wind power has become a serious player in Germany, and the sector now employs close to 100,000 people.

Spain is Europe’s second largest market, and has seen growth in line with previous years (with the exception of 2007, when regulatory change brought about a higher than usual amount of new wind capacity). In 2008, 1 .6 GW of new generating equipment was added to the Spanish wind fleet, bringing the total up to 16 .8 GW. This development confirms Spain as a steadily growing market, which at this rate is likely to reach the government’s 2010 target of 20 GW of installed wind capacity. In 2008, wind energy generated more than 31,000 GWh, covering more than 11% of the country’s electricity demand.

One noteworthy newcomer among the growing European markets in 2008 was Italy, which experienced a significant leap in wind power capacity. Over 1,000 MW of new wind turbines came on line in 2008, bringing total installed capacity up to 3 .7 GW. At the end of 2008, the Italian government passed an important decree that resolves many of the main problems related to the value of green certificates. This measure is designed to avoid speculative fluctuations in the price of green certificates that negatively affected the Italian market in the past.

France is also continuing to see strong growth, after progressing steadily in recent years. At the end of 2008, the total installed capacity stood at 3 .4 GW, representing an annual growth rate of 38%.

3.5 Latin America

The Latin American market, despite the tremendous wind resources in the region, saw only slow growth in 2008. The only country installing substantial new capacity was brazil, which added 94 MW of wind energy across five wind farms, mostly located in Ceará in the north east of the country.

3.6 Australia

After several years of stagnation in Australia’s wind market, the speed of development picked up again in 2008, with 482 MW of new installations, a 58% leap in terms of total installed capacity. Australia is now home to 50 wind farms, with a total capacity of 1 .3 GW. Six additional projects totalling 555 MW are currently under construction and expected to become operational in 2009.

3.7 Africa and Middle East

In North Africa, the expansion of wind power continues in Egypt, Morocco and Tunisia, with 55 MW, 10 MW and 34 MW of new capacity installed respectively. In the Middle East, Iran installed 17 MW of new capacity. The total for Africa and the Middle East now stands at 669 MW.

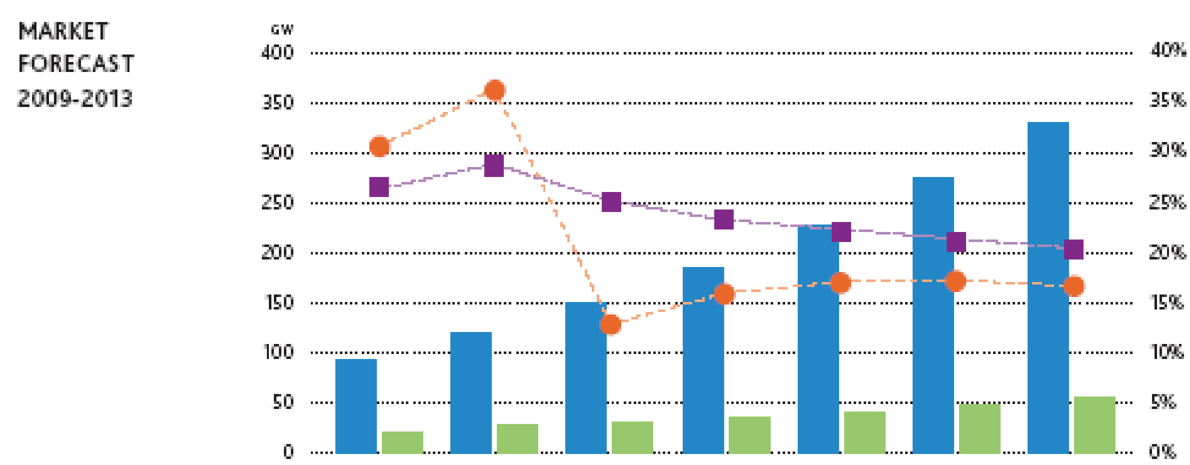
3.8 United Kingdom

In 2008, the UK installed 3,240 MW of wind energy capacity, and there are another 8, 827 MW of projects either under construction or awaiting planning permission. After failing to pick up the pace of development in the 1990s and struggling to reach 1 GW of installed capacity, a clearly revitalized and reenergized UK wind sector has delivered over 2 GW since 2006, and continues to attract interest from developers and investors. The UK government published a Renewable Energy Strategy in June 2008 which proposes 14 GW of onshore and 14 GW of offshore wind by 2020. This would increase the current installed capacity by eight times in 12 years (GWEC publication, 2008).

3.9 Market Forecast for 2009-2013

GWEC predicts that in 2013, five years from now, global wind generating capacity will stand at 332 GW, up from 120 GW at the end of 2008. During 2013, 56 .3 GW of new capacity will be added to the global total, more than double the annual market in 2008 (GWEC publication, 2008).

The annual growth rates during this period will average 22 .4% in terms of total installed capacity, and 15 .8% for the annual market. These rates are modest compared to past developments: in the last ten years, we have seen an average increase of 28 .2% for total capacity and 28 .3% for annual capacity.



	2007	2008	2009	2010	2011	2012	2013
Annual installed capacity (GW)	19.9	27.1	30.4	35.2	41.2	48.2	56.3
Cumulative installed capacity (GW)	93.8	120.8	151.2	186.4	227.6	275.8	332.1
Annual install capacity growth rate	30.7%	36.2%	12.5%	15.7%	17.0%	17.0%	16.8%
Cumulative capacity growth rate	26.7%	28.7%	25.2%	23.3%	22.1%	21.2%	20.4%

Fig. 8. Market forecast for 2009-2013 (Source: Global Wind Energy Council, GWEC)

4. Technology and Trend

4.1 Wind Energy Technology

GWEC published an excellent report on wind energy technology in light of past and present wind turbine development (GWEC publication, 2008)

Since the 1980s, when the first commercial wind turbines were deployed, their installed capacity, efficiency and visual design have all improved enormously.

Although many different pathways towards the ideal turbine design have been explored, significant consolidation has taken place over the past decade. The vast majority of commercial turbines now operate on a horizontal axis with three evenly spaced blades. These are attached to a rotor from which power is transferred through a gearbox to a generator. The gearbox and generator are contained within a housing called a nacelle. Some turbine designs avoid a gearbox by using direct drive. The electricity is then transmitted down the tower to a transformer and eventually into the grid network.

Wind turbines can operate across a wide range of wind speeds - from 3-4 metres per second up to about 25 m/s, which translates into 90 km/h (56 mph), and would be the equivalent of gale force 9 or 10.

The majority of current turbine models make best use of the constant variations in the wind by changing the angle of the blades through 'pitch control', by turning or "yawing" the entire rotor as wind direction shifts and by operating at variable speed. Operation at variable speed enables the turbine to adapt to varying wind speeds and increases its ability to harmonise with the operation of the electricity grid. Sophisticated control systems enable fine tuning of the turbine's performance and electricity output.

Modern wind technology is able to operate effectively at a wide range of sites – with low and high wind speeds, in the desert and in freezing arctic climates. Clusters of turbines collected into wind farms operate with high availability, are generally well integrated with the environment and accepted by the public. Using lightweight materials to reduce their bulk, modern turbine designs are sleek, streamlined and elegant.

The main design drivers for current wind technology are:

- reliability
- grid compatibility
- acoustic performance (noise reduction)
- maximum efficiency and aerodynamic performance
- high productivity for low wind speeds
- offshore expansion

Wind turbines have also grown larger and taller. The generators in the largest modern turbines are 100 times the size of those in 1980. Over the same period, their rotor diameters have increased eight-fold. The average capacity of turbines installed around the world during 2007 was 1,492 kW, whilst the largest turbine currently in operation is the Enercon E126, with a rotor diameter of 126 metres and a power capacity of 6 MW.

The main driver for larger capacity machines has been the offshore market, where placing turbines on the seabed demands the optimum use of each foundation. Fixing large foundations in the sea bed, collecting the electricity and transmitting it to the shore all increase the costs of offshore development over those on land. Although the offshore wind farms installed so far have used turbines in the capacity range up to 3.6 MW, a range of designs of 5 MW and above are now being deployed and are expected to become the 'standard' in the coming years.

For turbines used on land, however, the past few years have seen a levelling of turbine size in the 1.5 to 3 MW range. This has enabled series production of many thousands of turbines of the same design, enabling teething problems to be ironed out and reliability increased.

Ongoing innovations in turbine design include the use of different combinations of composite materials to manufacture blades, especially to ensure that their weight is kept to a minimum, variations in the drive train system to reduce loads and increase reliability, and improved control systems, partly to ensure better compatibility with the grid network.

4.2 Variability of Wind Power

In 2008 the article variability of wind power is reported by GWEC (Angelika et. Al, 2008). The interested readers may have a look at EWEA report (EWEA Publication, 2009). Wind power is often described as an "intermittent" energy source, and therefore unreliable. Iin fact, at power system level, wind energy does not start and stop at irregular intervals, so the term "intermittent" is misleading. The output of aggregated wind capacity is variable, just as the power system itself is inherently variable.

Since wind power production is dependent on the wind, the output of a turbine and wind farm varies over time, under the influence of meteorological fluctuations. Variations occur on all time scales: by seconds, minutes, hours, days, months, seasons and years. Understanding and predicting these variations is essential for successfully integrating wind power into the power system and to use it most efficiently.

Electricity flows – both supply and demand – are inherently variable, as power systems are influenced by a large number of planned and unplanned factors, but they have been designed to cope effectively with these variations through their configuration, control systems and interconnection.

Changing weather makes people switch their heating, cooling and lighting on and off, millions of consumers expect instant power for TVs and computers. On the supply side, when a large power station, especially, if it is a nuclear reactor, goes offline, whether by accident or planned shutdown, it does so instantaneously, causing an immediate loss of many hundreds of megawatts. By contrast, wind energy does not suddenly trip off the system. Variations are smoother because there are hundreds or thousands of units rather than a few large power stations, making it easier for the system operator to predict and manage changes in supply. Especially in large, interconnected grids, there is little overall impact if the wind stops blowing in one particular place.

Predictability is key in managing wind power's variability, and significant advances have been made in improving forecasting methods. Today, wind power prediction is quite accurate for aggregated wind farms and large areas. Using increasingly sophisticated weather forecasts, wind power generation models and statistical analysis, it is possible to predict generation from five minute to hourly intervals over timescales up to 72 hours in advance, and for seasonal and annual periods. Using current tools, the forecast error for a single wind farm is between 10 and 20% of the power output for a forecast horizon of 36 hours. For regionally aggregated wind farms the forecast error is in the order of 10% for a day ahead and less than 5% for 1-4 hours in advance.

The effects of geographical distribution can also be significant. Whereas a single wind farm can experience power swings from hour to hour of up to 60% of its capacity, monitoring by the German ISET research institute has shown that the maximum hourly variation across 350 MW of aggregated wind farms in Germany does not exceed 20%. Across a larger area, such as the Nordel system covering four countries (Finland, Sweden, Norway and Eastern Denmark), the greatest hourly variations would be less than 10%, according to studies [1]

4.3 Storage Option

Storage option is described in GWEC publication in 2008 (Angelika et al., 2008). There is increasing interest in both large scale storage implemented at transmission level, and in smaller scale dedicated storage embedded in distribution networks. The range of storage technologies is potentially wide.

For large-scale storage, pumped hydro accumulation storage (PAC) is the most common and best known technology, which can also be done underground. Another technology option available for large scale is compressed air energy storage (CAES).

On a decentralized scale storage options include flywheels, batteries, possibly in combination with electric vehicles, fuel cells, electrolysis and super-capacitors. Furthermore, an attractive solution consists of the installation of heat boilers at selected combined heat and power locations (CHP) in order to increase the operational flexibility of these units.

However, it has to be pointed out that storage leads to energy losses, and is not necessarily an efficient option for managing wind farm output. If a country does not have favourable geographical conditions for hydro reservoirs, storage is not an attractive solution because of the poor economics at moderate wind power penetration levels (up to 20%). In any case, the use of storage to balance variations at wind plant level is neither necessary nor economic.

4.4 Grid Infrastructures

GWEC and Greenpeace International also reported on grid infrastructure in its 2008 report (Angelika et al., 2008). The specific nature of wind power as a distributed and variable generation source requires specific infrastructure investments and the implementation of new technology and grid management concepts. High levels of wind energy in system can impact on grid stability, congestion management, transmission efficiency, and transmission adequacy.

In many parts of the world, substantial upgrades of grid infrastructure will be required to allow for the levels of grid integration proposed in this report. Significant improvements can be achieved by network optimisation and other ‘soft’ measures, but an increase in transmission capacity and construction of new transmission lines will also be needed. At the same time, adequate and fair procedures for grid access for wind power need to be developed and implemented, even in areas where grid capacity is limited.

However, the expansion of wind power is not the only driver. Extensions and reinforcements are needed to accommodate whichever power generation technology is chosen to meet a rapidly growing electricity demand. The IEA estimates that by 2030, over 1.8 trillion USD will have to be invested in transmission and distribution networks in the OECD alone.

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[1] Holttinen, H. (2004): The impact of large scale wind power on the Nordic electricity system

In the present situation wind power is disadvantaged in relation to conventional sources, whose infrastructure has been largely developed under national vertically integrated monopolies which were able to finance grid network improvements through state subsidies and levies on electricity bills. But while a more liberalised market has closed off those options in some countries, numerous distortions continue to disadvantage renewable generators in the power market – from discriminatory connection charges to potential abuse of their dominant power by incumbent utilities.

4.5 Grid Integration Issues

A grid code covers all material technical aspects relating to connections to, and the operation and use of, a country's electricity transmission system. They lay down rules which define the ways in which generating stations connecting to the system must operate in order to maintain grid stability (Angelika et al., 2008).

Technical requirements within grid codes vary from system to system, but the typical requirements for generators normally concern tolerance, control of active and reactive power, protective devices and power quality. Specific requirements for wind power generation are changing as penetration increases and as wind power is assuming more and more power plant capabilities, i.e. assuming active control and delivering grid support services (Angelika et al., 2008).

In response to increasing demands from the network operators, for example to stay connected to the system during a fault event, the most recent wind turbine designs have been substantially improved. The majority of MW-size turbines being installed today are capable of meeting the most severe grid code requirements, with advanced features including fault-ride-through capability. This enables them to assist in keeping the power system stable when disruptions occur. Modern wind farms are moving towards becoming wind energy power plants that can be actively controlled (Angelika et al., 2008).

Grid codes developed in many countries are more or less similar. The rest of the system is written in light of the grid code reports developed in different countries (Zavadil R. et al., 2005), (FERC Report, 2005), (Tsili M. et al., 2009), (P. Gardner et al., 2009), (Qiao W. et al., 2009), (ING Report, 2007), (E. On Netz Resources, 2006), and (Bharat Singh, S.N. Singh, 2009).

4.5.1Transient Fault Ride Through

The fault ride-through (FRT) requirement is imposed on a wind power generator so that it remains stable and connected to the network during network faults. In the past, the common practice was to disconnect the wind turbine generator unit during network disturbance. However, disconnection from the grid may worsen a critical grid situation and can threaten the security standards when wind penetration is high. In Germany, wind generating plants are expected to acquit themselves during a low-voltage disturbance as summarized in a voltage versus time curve shown in Fig. 9. Wind turbines are required to stay on the grid within areas 1 and 2 (E. On Netz Resources, 2006), and (Bharat Singh, S.N. Singh, 2009).

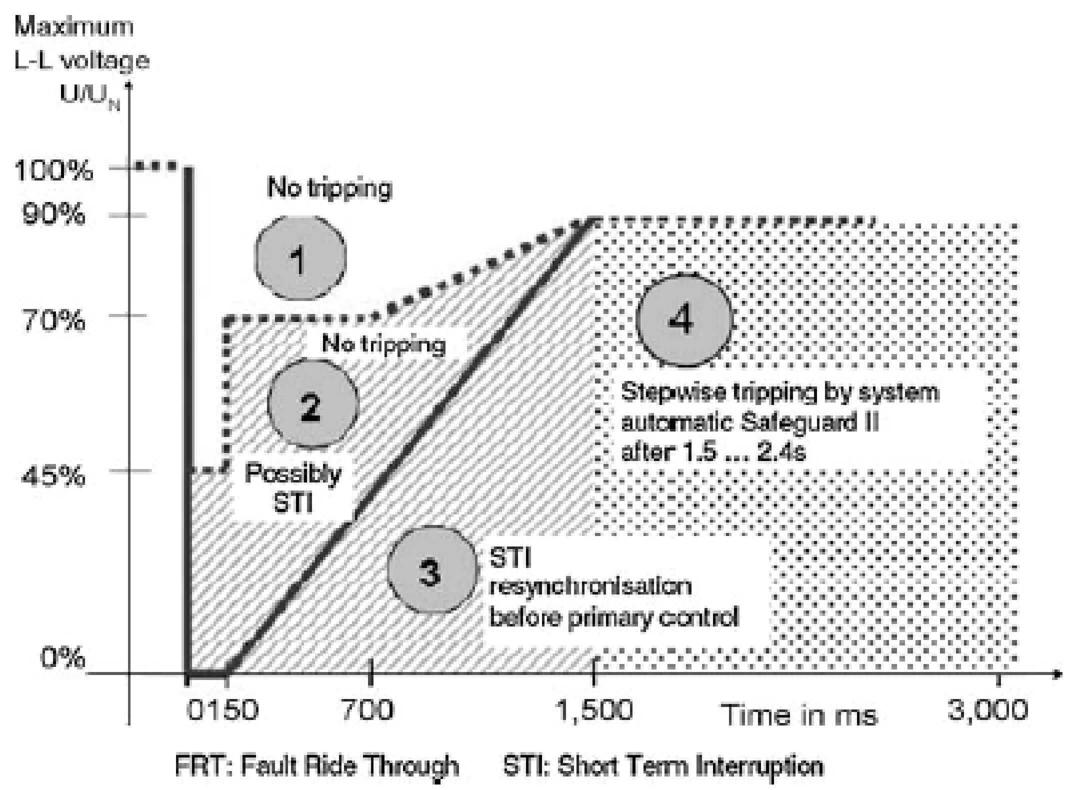

Fig. 9. Low voltage ride-through standard set by E.On Netz..

4.5.2 Active Power Control

Active power control means to control the system frequency by changing the real power into the grid. This is a requirement for generating units to be able to deliver power and remain connected to the network even if the system frequency deviates from the specified one. It gives the flexibility to ensure power quality, avoid large voltage steps and inrush currents during startup and shutdown of wind turbines. It has also an influence on voltage and transient stability augmentation.

4.5.3 Power Quality Ensure

The fluctuating nature of wind arises the issue of power quality such as flicker, voltage fluctuation, etc. At the present, wind generator uses the frequency converter for its variable speed operation. However, it introduces harmonics into the power system and there is also high possibility of resonant effect due to the reactance of wind turbine generator system electrical unit. Therefore most grid code will request wind power plant to maintain voltage fluctuations, flickers and harmonic current/voltage in the desired range.

4.5.4 Frequency Control

For secure grid operation the frequency of the power system should be maintained constant to its rated value. However, when the power imbalance occurs between supply and demand, the frequency varies from its rated value, which is undesarable. Frequency control is a requirement for generating units to be able to increase or decrease power output with falling or rising frequency. The acceptable frequency deviation varies in different countries. As for example, according to E.On, wind turbines have to stay connected in the grid within the frequency range of 47.5–51.5 Hz. Outside this range, disconnection without any time delay is necessary.

4.5.5 Voltage Control

Voltage control requirement defines that the wind power station should be capable of automatic regulating its terminal voltage according to the given set point. The dynamic performance of voltage control is normally defined as rise time, overshoot and settling time. Voltage control has the relation with leading/lagging reactive power at the grid connection point of wind power station. Among the different grid codes, this requirement can be classified as constant reactive power mode or constant power factor mode.

5. Wind Power Explained in this Book

The chapters of the book are written in light of recent development of wind power industry by many renowned authors in the wind energy arena. The chapters of the book are described under 4 parts.

In part A, the recent trend of wind turbine generator systems are presented where both large and small scale wind generators including their control strategies are described.

Chapter 2 discusses about active rectifier and voltage source inverter based topology for permanent magnet synchronous wind generator that connects the grid. The active rectifier and voltage source inverter based topology are well studied at a constant frequency and voltage of the generator. However, this chapter considered the factors to operate the system at variable speed operation of wind generator. Changing the frequency and the voltage of the synchronous generator, as well as dependence of the generated power on shaft speed of the wind turbine are discussed. The detailed mathematical modeling of the overall system are presented in detail including choice of control algorithm and structural circuits.

The permanent magnet synchronous generator (PMSG) is becoming popular in wind power industry using a full capacity frequency converter for grid interconnection. PMSG is recognized as a promising technology for using as wind generator, both in direct-drive system and the system using a simple single-stage gearbox. One of the major advantages is the high power density of this type of machine. The transverse flux design of it makes it possible to fish out some other benefits. The use of PMSG seems to be more prospective in wind power application from now on because the price for the rare-earth magnets decreases remarkably, in the last few years. In chapter 3, the author proposed new types of permanent magnet machine for wind power application considering its reliability issue. The reliability of the PM wind power generators can be increased by using multiple stator modules, or stator segments, independent of each other. These segments can be considered, for example, as independent stator parallel windings which are each fed by an own frequency converter. If one of the frequency converters fails, other ones can continue the operation while the failed units are changed. In this chapter, the redundant drive concept is introduced based on the modular drive concept. Then, the speed sensorless vector control theory applied to wind power generators is discussed. Simulations as well as experimental results are presented from which the effectiveness of the proposed control strategy can be verified.

Few types of variable speed wind turbine (VSWT) generator systems are commercially available, nowadays. Doubly fed induction generator (DFIG) is holding the major market share in wind power industry. Chapter 4 describes the detailed modeling and controls strategies of VSWT driven DFIG, which might be pretty much effective for the students or researchers to build the simulation model and learn the characteristics of DFIG. The simulation model is developed in Matlab Simulink environment. The chapter includes both dynamic and transient analyses.

Doubly-fed Induction Generator (DFIG) is most commonly used wind generator, nowadays, in wind energy conversion system. In Chapter 5, the authors present theoretical basics for doubly-fed induction generator that can be considered for the electrical power generation using wind power. The chapter includes the space vector theory, mathematical modeling of DFIG, electromechanical energy conversion process, active and reactive power flow issues, filter, topological overview, and steady state analysis. The chapter is written in an easy way for the students and researchers who are interested about doubly-fed machine for wind power application.

In Chapter 6, the theoretical fundamental of wind energy converter controls is presented. The energy conversion chains in light of fixed and variable speed wind turbine generator systems are described. The control path and basic control structure of variable speed wind turbine driven synchronous generator are described in detailed. Process control and operation management for variable speed wind energy converters are presented in detail. The conventional and the proposed methods are also compared therein.

Chapter 7 focuses on the control of a small size wind turbine generator system. Larger wind turbine systems have complex control systems such as advanced power maximizing control, blade pitch angle control, gearing control, etc. Compared to that small wind turbine unit used in the past were not designed sophistically. However, the level of sophistication of theses small wind turbine generator systems has been steadily improving nowadays. In this chapter, the authors investigated the controls associated with small wind turbine generator systems, culminating in a detailed description of the Peak Power Tracking controller utilizing a microcontroller running an impedance matching DC-DC converter between the turbine and the load.

Chapter 8 discusses on the small scale wind energy conversion system suitable for home in remote areas. The problem of transfer of energy from small wind turbine generator system to the power grid is presented. The scheme of that small wind turbine generator system, theoretical and simulation analyses of the proposed system along with the design and control are demonstrated throughout the chapter. The laboratory plant description, cost and reliability analyses of the converter design are also presented in the chapter.

Chapter 9 describes the variable speed fixed pitch wind turbine design and operations. Wind turbine nonlinear model, linearization around a set of equilibrium points, open loop characteristics to analyze the dynamic behavior are presented. To describe the control objectives for variable speed fixed pitch wind turbines, three important issues are emphasized. First is maximization of extracted energy, second, is limitation of extracted

energy with active stall with rotational speed control, and the third is the control of maximum power point tracking and stall regulation at the overlapping region. The MPPT algorithms are implemented on a low cost DSC board and tested with a developed wind turbine simulator. In general, the hardware as well as software implementation for the control algorithm are explained throughout the chapter.
The real time simulation helps to validate the control system, control algorithm of a system. In Chapter 10, authors discussed about real-time physical simulation for wind energy conversion system along with its control units. The authors demonstrated the way to build physical simulator as well as the implementation and assessment techniques. This chapter is pretty useful for the readers who are interested about physical simulation of horizontal-axis wind turbines (HAWT), though the procedure will not differ so much for vertical-axis wind turbine (VAWT).

In Part B, the variability of wind power is described.

Wind energy in Netherlands by 2020 is reported in chapter 11. This chapter presents in a national context energy balancing requirements due to the variability and the limited predictability of wind energy in the thermal energy system of the Netherlands. The chapter includes different scenarios for wind and other energy capacity in the Netherlands, balancing energy reduction options in the context of some other countries in Europe, wind modeling aspects of wind energy integration, impact of extra variability due to wind, impact of limited wind predictability, and options to reduce extra balancing energy requirements in terms of short term forecast, aggregation, pumped storage, compressed air energy storage and so on.
Wind varies in space and in time and therefore the wind power is a fluctuating quality. Chapter 12 discusses about the variability of wind and wind power. A significant amount of this renewable electricity is likely to come from wind, and the variability of this power needs to be managed. The chapter discusses, relationship between wind power variability and its forecast, influence of the wind variability on the grid, geographical diversity on wind power, estimated cost of wind power variability, classification of wind and wind power oscillations,, turbulence characterization, equivalent wind of turbine clusters, spectrum and coherence estimated from weather station, and so many useful topic related to wind and wind power variability.
In chapter 13, the impact of bulk wind power penetration to the transmission system is analyzed by the authors. Stochastic electrical production from wind is expected to play a vital role in power systems, in the near future. Due to that reason, the authors proposed and developed stochastic wind generation models into an HLI Monte Carlo simulation tool that will assist system planners and transmission system operators (TSOs) to qualitatively assess the system impact of wind production. This will be helpful to take the managerial decision for integrating large scale wind farm to the existing grid. The methodology used to efficiently introduce wind generation in HLI simulation tool is presented. Then the hypotheses based on real observations are given in order to introduce wind generation into an economic dispatch with classical parks and transmission constraints. Finally, the reliability and reinforcement analysis for transmission system is computed using Ray Billinton Test System (RBTS).

Chapter 14 focuses on a very interesting area of wind energy conversion system which has significant importance on the future growth of wind power industry at the sea. As well as the onshore trend, offshore wind farms have also been continuing its growth rapidly. Some leading countries in wind energy arena are focusing more on offshore technology. The main reasons for adopting offshore are lack of the suitable onshore sites and much better wind conditions of offshore sites (wind is much stronger and more constant). However, the wind information at the sea came from merchant ships or Numerical Weather Prediction (NWP). NWP hugely depends on numerical models as well as statistical data. Chapter 14 discussed about the space-based microwave sensors which give the wind information with sufficient temporal and spatial sampling in clear and cloudy condition during day and night time. Both active and passive filters are discussed in detailed to measure wind speed and direction.

In part C, the grid integration issues are described.

Integration of power converter with variable speed wind generator causes high levels of low and high frequency emission which worsen the quality of consumed electric power, increase power losses as well as adversely affect reliability of connected appliances. Chapter 15 is focused on a simulation-based spectral technique for power quality and EMC design of wind power systems including a power source or synchronous generator (G), an AC/DC/AC converter and electronic equipment with power supplies connected to a power distribution network. Mathematical models of single- and three-phase devices in WPS are obtained as a particular case of multi-phase B-element concept. The computational experiments demonstrated the efficiency of the developed mathematical model in designing of the power quality and EMC in the wind power system.

In chapter 16, a robust power system stabilizer is proposed to stabilize wind farm interconnected power system. The power output fluctuations from wind power generation causes low frequency oscillation, which deteriorate the power system stability. To overcome this problem, the fixed structure robust PSS design by the $H\infty$ loop shaping technique is proposed by the author. The normalized coprime factor is used to model system uncertainties. To optimize the control parameters, the performance and robust stability conditions in the $H\infty$ loop shaping technique are formulated as the objective function. As a result, the proposed PSSs are very robust against various uncertainties. The configuration of PSS is a conventional second-order lead-lag compensator. To tune the PSS parameters, the concept of enhancement of system robust stability margin is formulated as the optimization problem. The genetic algorithm (GA) is applied to solve the problem and achieve the PSS parameters. The author validates the robustness of the proposed PSS by simulation analyses considering a two areas four machines power system model that interconnects wind farm.

The integration of a bulk amount of wind power in isolated electrical network needs special attention considering the reliability and security aspects. In chapter 17, the impact of large scale wind power generation on the dynamic performance especially of islands power systems are discussed. During the dynamic behavior analysis, modeling of the system is emphasized for examining the impact of higher wind penetration up to 40%. Create Island of Greece is taken as the base model system for the analysis. It is reported that spinning reserves of the conventional units have a great influence on the stability of isolated network when high wind power penetration is considered. The authors found that wind turbine affect the transient stability of the isolated network though it may not be the main obstacle for secure and reliable operation of the power system. By taking preventive actions, improving control technique the overall stability of the isolated network can be maintained even if the high wind power penetration is considered.

In Chapter 18, integration of wind farm with bulk energy storage system has been discussed which is one of the major challenge of wind energy conversion system. The author proposed 100 MW class Compressed Air Energy Storage (CAES) as the bulk energy storage system which might be suitable for large scale wind farm application. Stored energy integration into the generation-grid system is also explained. This covers a wide field in every aspect of generation- transmission and distribution. Converting the stored energy back to electricity readily provides three primary functions: Energy Management (hours of duration) load leveling or peak period needs; Bridging Power (seconds or minutes duration) assuring continuity of service, contingency reserves or UPS (Uninterruptible Power Supply); and Power Quality & Reliability (milliseconds or seconds duration) in support of manufacturing facilities, voltage and frequency controls. The chapter broadly discussed principal of CAES system, storage concept, application, benefits, future prospects, projects in development, and economics of CAES system.

Chapter 19 focuses on the stand-alone wind-diesel power system emphasizing to determine the optimum spinning reserve for managing unforeseen power unbalances. The problem of keeping the power balance is not so easy in stand-alone wind-diesel power systems, since these systems are additionally subjected to random power fluctuations originated in the stochastic and intermittent nature of the wind resource. Therefore, the authors proposed a novel method for determining the optimal amount of spinning reserve that should be carried in autonomous hybrid wind-diesel generation systems. The optimal spinning reserve is determined by comparing the cost of its provision with the economic benefits it delivers in terms of supply reliability. Global search methods like Particle Swarm Optimization (PSO) are proposed for finding the optimal scheduling policy and spinning reserve requirement that minimizes the sum of the expected operation costs and the expected costs of the energy not served.

Chapter 20 discussed about a micro-grid system composed of fuel cell and wind turbine generator system. The author considered Proton Exchange Membrane (PEM) type fuel cell installed at few locations of the micro-grid system. The home equipped with the fuel cell is also connected to the city gas network considering the issue of hydrogen gas. Wind generator is directly connected to the micro-grid system and the author investigated its influence on the micro-grid system. Adjustment of the production of electricity of each fuel cell connected to the micro-grid may operate some fuel cell with a partial load with low efficiency. Therefore, the number of operations of fuel cells is controlled to follow fluctuations in the electricity demand. The wind power to the micro-grid causes grid power instability because of the supply and demand difference, especially when the load is small compared to the electricity generation from wind turbine. When wind power equipment is connected to the micro-grid with load fluctuation, the operating point of the fuel cell system may shift and power generation efficiency may improve.

Chapter 21 presents variations in wind power generation and its impact on the thermal plants. The impact of load variation on thermal plant is another feature of this chapter. The integration of different types of storage such as pumped hydro power, compressed air energy storage (CAES), flow batteries, and sodium sulphur batteries are also discussed to moderate variations from wind power. The authors proposed to use Plug-in Hybrid Electric Vehicle (PHEV) to handle the demand side management by choosing appropriate charging strategies. The authors chose the data from the power system of western Denmark to illustrate various aspects influencing the ability of a power system to accommodate wind power.

Wind power penetration to the power grid is increasing rapidly throughout the world. This requires additional attention from different transmission system operators, regulatory official agencies along with the wind park developers to secure the power quality and other grid interfacing issues. In chapter 22, the author attempts to emphasize on such issues, which is a timely reporting at the present development of wind power. This chapter discussed on technical barriers and solutions of high wind penetration to power grid. Detail of large scale wind power integrations issues are discussed as well.

In Part D, the environmental issues are presented.

In chapter 23, the authors analyzed about environmental impact due to the manufacturing process of the wind turbine and the disposal process at the end of the wind turbine life cycle. The Life Cycle Assessment (LCA) model is developed with the purpose of determining and quantifying the related emissions and the impact of wind energy production technology. The model can even be used to define the energy payback time. The authors reported on the significant impact of wind turbine blades from the viewpoint of their non-recycling status. Some good conclusions are also given about the environmental impact and energy payback time of wind turbines and other conventional power plants. The LCA methodology is explained in terms of method and scope, system boundary, functional unit, data collection, key assumptions, and analyses scenarios. The results on environmental impact, cumulative energy demand, and recycling process are also described inside the chapter.

In chapter 24, a super sense is applied by designing wind-solar based hybrid ventilators for domestic, commercial, and industrial buildings. It is necessary to provide an optimum or at least a satisfactory environment to where we are living. Current ventilation devices are using conventional electric power or solar or wind power to drive the turbines. The author and his team at University of North South Wales (UNSW) have been working in the area of ventilation research, design and performance studies for over a decade. The turbine ventilator relies entirely of the prevailing wind conditions with no facility to extract energy from the sun. The solar ventilator is at the complete mercy of ambient solar radiation conditions and cannot extract energy from the wind. In this chapter, the author proposes wind-solar driven natural hybrid electrical ventilators which is environment friendly and cost-effective also. The horizontal axis ventilator might be a solution to the marginal performance of a turbine ventilator at low wind speeds. Testing of the horizontal axis ventilator found significantly improved performance at low wind speed conditions.

6. Conclusion

Wind energy is playing a vital role in the world's energy markets nowadays, considering it's striking growth rate in the last few years. The wind turbine and generator technology has reached to a matured stage. The developments and improvements of the power electronic devices added an extra pace in its overall growth and therefore hundreds of MW level wind farms are available these days. However, the high penetration of wind power to the electrical network needs further consideration of the existing grid infrastructures. Grid integration issues of wind farms are the most important challenge for the future growth of this technology, which must be handled carefully.

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8. References

GWEC Publications (2008). Global Wind 2008 Report, The Global Wind Energy Council, 2008

AWEA Resources (2009). AWEA Third Quarter 2009 Market Report, The American Wind Energy Association, 2009

AWEA Resources (2009). Projects (US), The American Wind Energy Association, 2009

GWEC Publication (2009). About Wind-Technology, The Global Wind Energy Council, 2009

Angelika Pullen, Steve Sawyer, Sven Teske, Crispin Aubrey (2008). Global Wind Energy Outlook, The Global Wind Energy Council and Greenpeace International, 2008

EWEA Publication (2009). Wind Energy The FACTS, The European Wind Energy Association, 2009, Vol. 2

Zavadil R., Miller N., Ellis A., Muljadi E. (2005). Making connections, IEEE Power Energy Mag., Vol.3, No.6, pp.20

FERC Report (2005). Interconnection for Wind Energy, Federal Energy Regulatory Commission (FERC), United States of America, Docket No. RM05-4-000 – Order No. 661, Issued June 2

FERC Report (2005). Interconnection for Wind Energy, Federal Energy Regulatory Commission (FERC), United States of America, Docket No. RM05-4-001; Order No. 661-A, Issued December 12

Tsili M., Papathanassiou S. (2009). A review of grid code technical requirements for wind farms, IET-Renewable Power Generation, Vol.3, No.3, pp.308-332.

P. Gardner, M. Tremblay, D. Price (2009). Technical requirements for high-penetration wind : what system operators need, and what wind technology can deliver, Integration of wide-scale renewable resources into the power delivery system, CIGRE/IEEE PES Joint Symposium

Qiao W. Harley R.G. (2008). Grid connection requirements and solutions for DFIG wind turbines, Energy 2030 Conference, IEEE.

ING Report (2007). Wind Farm Power Station Grid Code Provisions, WFPS1, Ireland National Grid, Grid Code Version 2, pp.213-216, January

E.On Netz Resources (2006). E.On Netz, Grid Code, High- and Extra-High Voltage, available at www.eon-netz.com/

Bharat Singh, S.N. Singh (2009). Wind Power Interconnection into the Power System: A Review of Grid Code Requirements, The Electricity Journal, Vol.22, No.5, pp. 54-63

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This book is the result of inspirations and contributions from many researchers of different fields. A wide verity of research results are merged together to make this book useful for students and researchers who will take contribution for further development of the existing technology. I hope you will enjoy the book, so that my effort to bringing it together for you will be successful. In my capacity, as the Editor of this book, I would like to thanks and appreciate the chapter authors, who ensured the quality of the material as well as submitting their best works. Most of the results presented in to the book have already been published on international journals and appreciated in many international conferences.

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