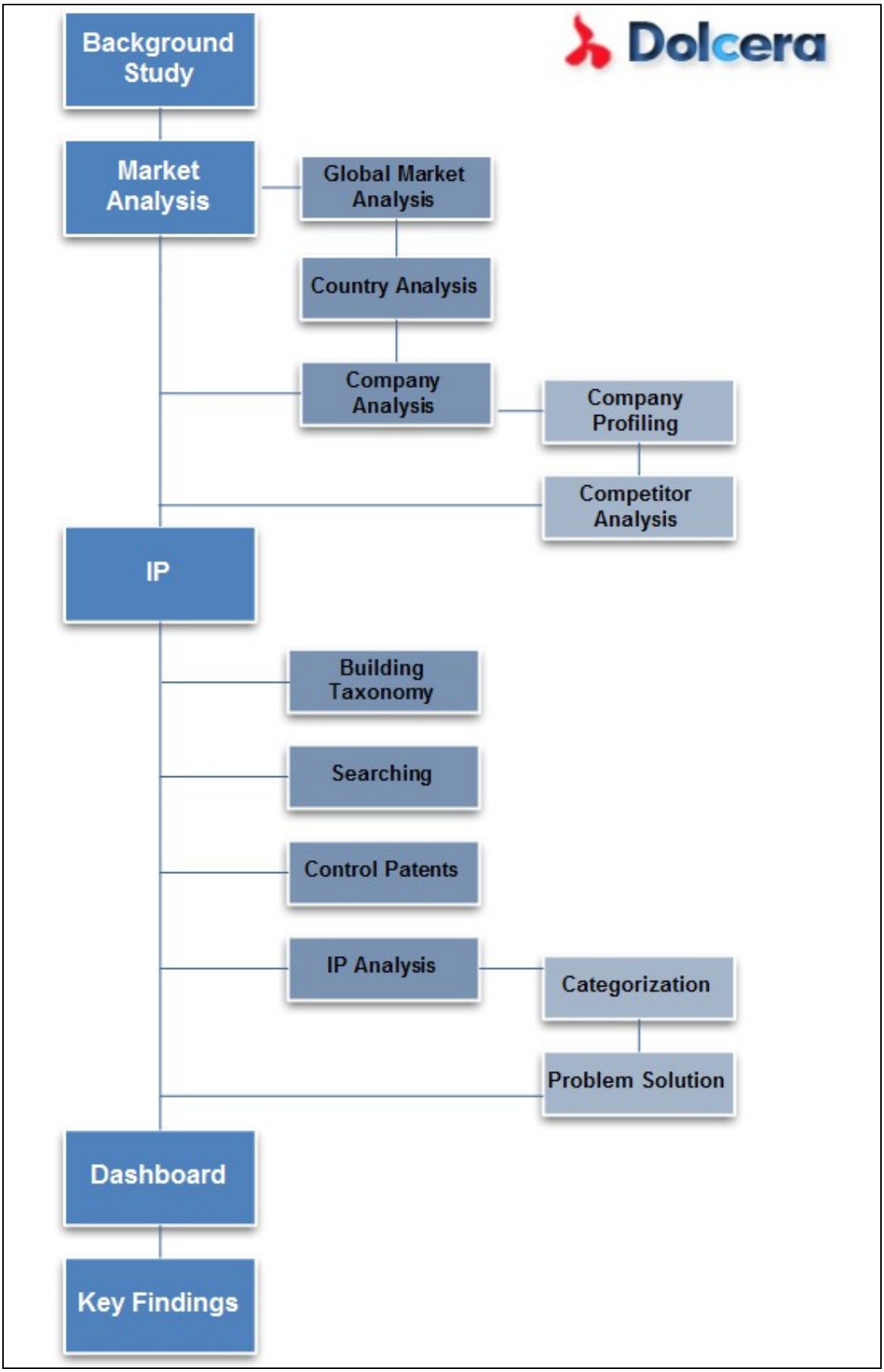
Wind Energy

This report presents a brief introduction to wind energy and technologies available for horizontal wind turbines. A detailed taxonomy for horizontal axis wind turbines is presented covering parts of the turbine, control systems, applications among others. A detailed landscape analysis of patent and non-patent literature is done with a focus on Doubly-fed Induction Generators (DFIG) used in the horizontal axis wind turbines for efficient power generation. The product information of major players in the market is also captured for Doubly-fed Induction Generators. The final section of the report covers the existing and future market predictions for wind energy-based power generation.



Process Flow

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Introduction

- We have been using wind power at least since 5000 BC to propel sailboats and sailing ships, and architects have used wind-driven natural ventilation in buildings since similarly ancient times. The use of wind to provide mechanical power came later.
- Harnessing renewable alternative energy is the ideal way to tackle the energy crisis, with due consideration given to environmental pollution, that looms large over the world.

- Renewable energy is also called "clean energy" or "green power" because it doesn?t pollute the air or the water. Wind energy is one such renewable energy source that harnesses natural wind power.

Read More?

Click on **Wind Energy Background** to read more about wind energy.

In order to overcome the problems associated with fixed speed wind turbine system and to maximize the wind energy capture, many new wind farms are employing variable speed wind energy conversion systems (WECS) with doubly-fed induction generator (DFIG). It is the most popular and widely used scheme for the wind generators due to its advantages.

For variable-speed systems with limited variable-speed range, e.g. ±30% of synchronous speed, the doubly-fed induction generator(DFIG) can be an interesting solution. This is mainly due to the fact that the power electronic converter only has to handle a fraction (20-30%) of the total power as the converters are connected to the rotor and not to the stator. Therefore, the losses in the power electronic converter can be reduced, compared to a system where the converter has to handle the total power. The overall structure of wind power generation through DFIG as shown in the figure below.

Market Research

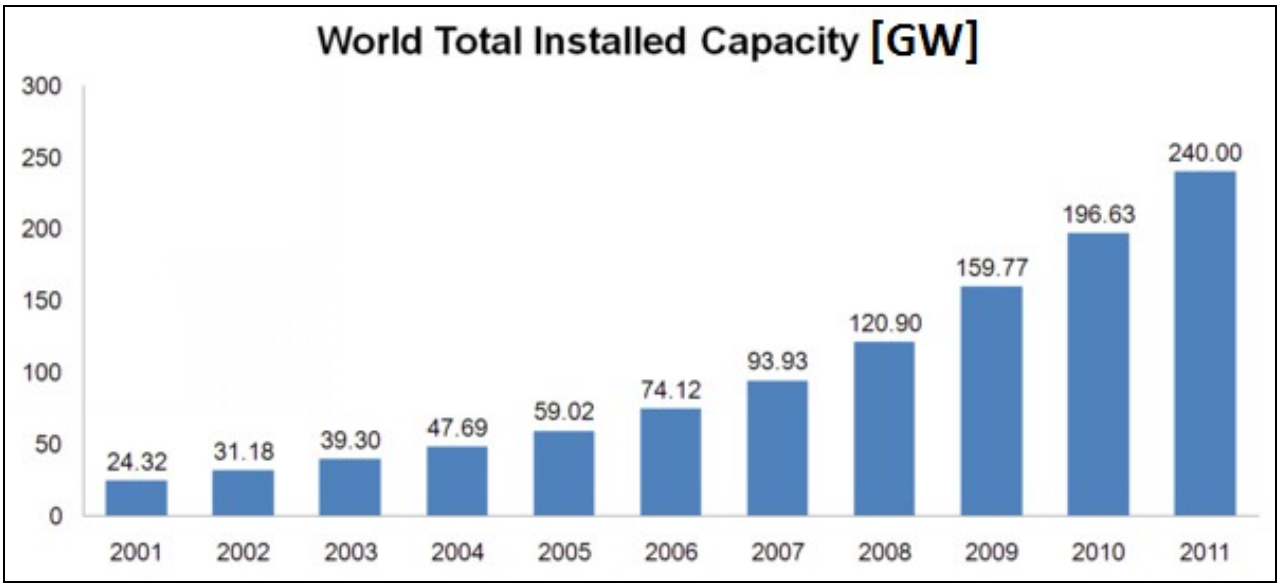
The History of Wind Energy

To read about **the History of Wind Energy**, **click here**

Global Wind Energy Market

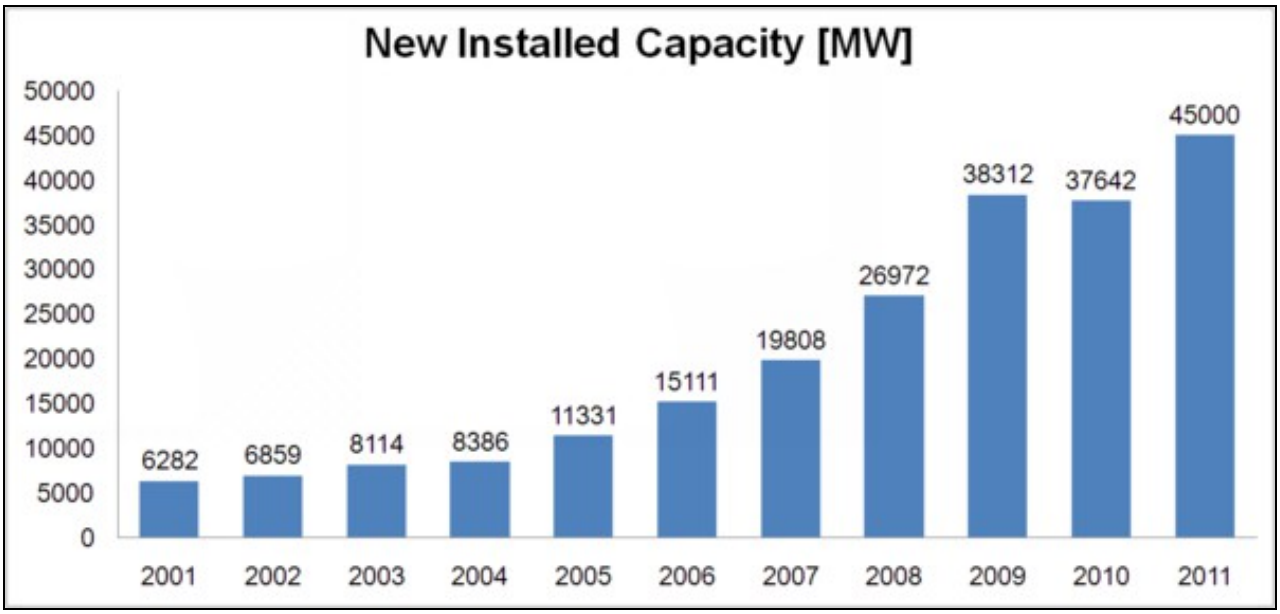
Market Overview

- In the year 2010, the wind capacity reached worldwide **196?630 Megawatt**, after **159?050 MW** in 2009, **120?903 MW** in 2008, and **93?930 MW** in 2007.



Source: World Wind Energy Report, 2010

- Wind power showed a growth rate of **23.6 %**, the lowest growth since 2004 and the second lowest growth of the past decade.
- For the first time in more than two decades, the market for new wind turbines was smaller than in the previous year and reached an overall size of **37?642 MW**, after 38'312 MW in 2009.



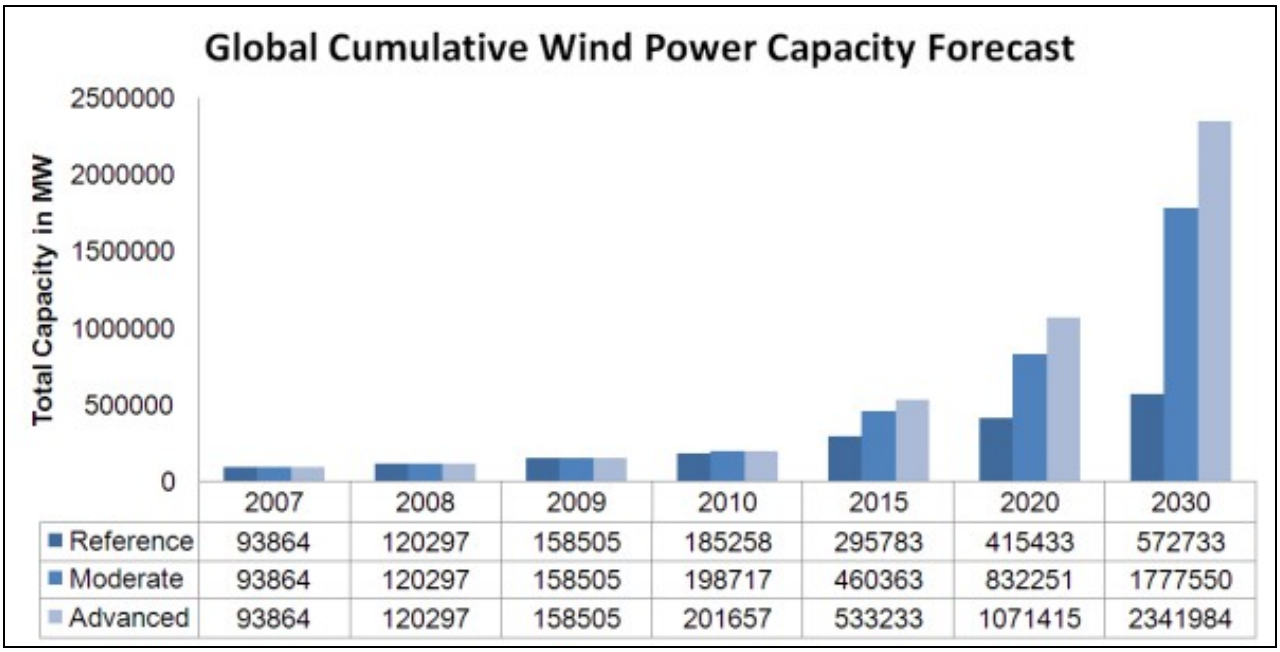
Source: World Wind Energy Report, 2010

- All wind turbines installed by the end of 2010 worldwide can generate **430 Tera watt hours per annum**, more than the total electricity demand of the United Kingdom, the sixth largest economy of the world, and equaling 2.5 % of the global electricity consumption.
- In the year 2010, altogether **83 countries**, one more than in 2009, used wind energy for electricity generation. 52 countries increased their total installed capacity, after 49 in the previous year.
- The turnover of the wind sector worldwide reached **40 billion Euros (55 billion US$) in 2010**, after 50 billion Euros (70 billion US$) in the year 2009. The decrease is due to lower prices for wind turbines and a shift towards China.
- China became number one in total installed capacity and the center of the international wind industry, and added **18?928 Megawatt** within one year, accounting for more than 50 % of the world market for new wind turbines.
- The wind sector in 2010 employed **670?000 persons** worldwide.
- Nuclear disaster in Japan and oil spill in Gulf of Mexico will have long-term impact on the prospects of wind energy. Governments need to urgently reinforce their wind energy policies.
- WWEA sees a global capacity of **600?000 Megawatt** as possible by the year 2015 and more than **1?500?000 Megawatt** by the year 2020.

Source: World Wind Energy Report, 2010

Global Market Forecast

- Global Wind Energy Outlook 2010, provides forecast under three different scenarios - Reference, Moderate and Advanced.
- The Global Cumulative Wind Power Capacity is estimated to reach 572,733 MW by the year 2030, under the Reference Scenario
- The Global Cumulative Wind Power Capacity is estimated to reach 1,777,550 MW by the year 2030, under the Moderate Scenario
- The Global Cumulative Wind Power Capacity is estimated to reach 2,341,984 MW by the year 2030, under the Advanced Scenario
- The following chart shows the Global Cumulative Wind Power Capacity Forecast,under the different scenarios:



	2007	2008	2009	2010	2015	2020	2030
Reference	93864	120297	158505	185258	295783	415433	572733
Moderate	93864	120297	158505	198717	460363	832251	1777550
Advanced	93864	120297	158505	201657	533233	1071415	2341984

Global Cumulative Wind Power Capacity Forecast, Source: Global Wind Energy Outlook 2010

Source: Global Wind Energy Outlook 2010

Market Growth Rates

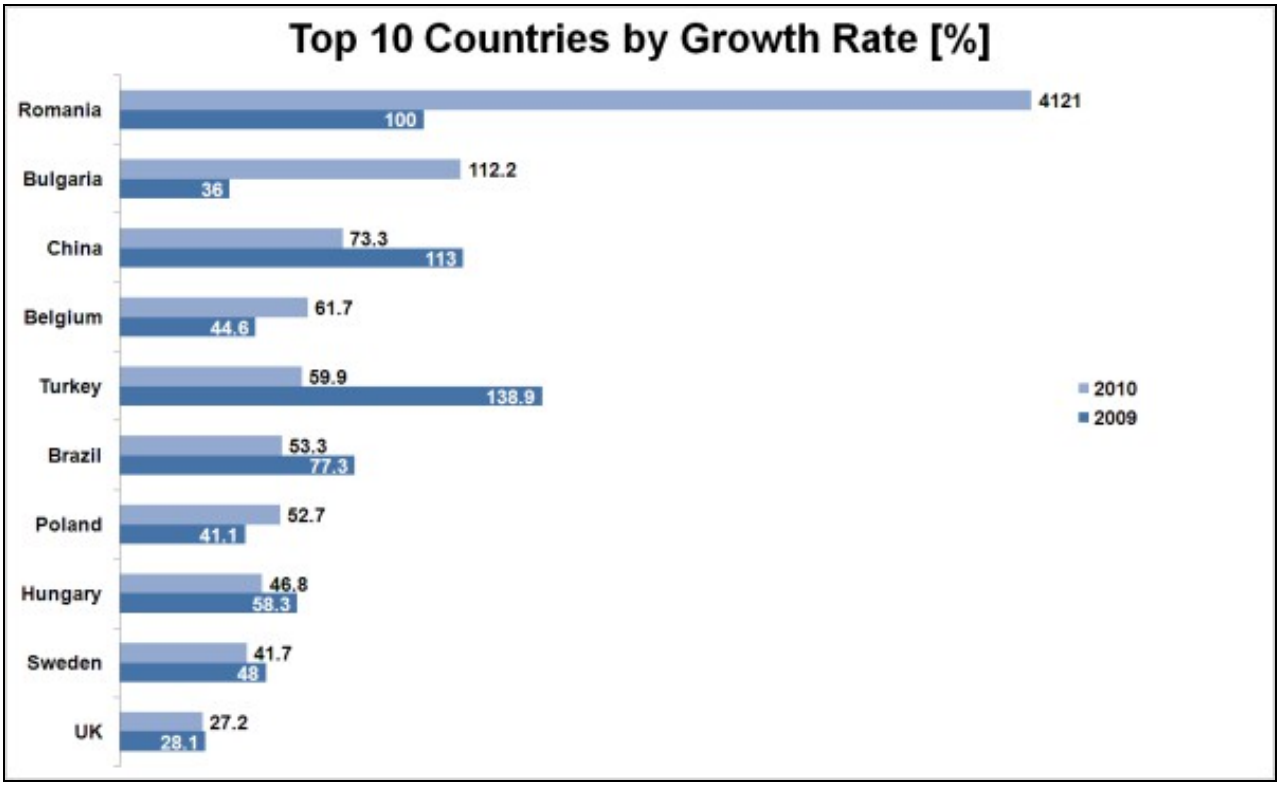
- The growth rate is the relation between the new installed wind power capacity and the installed capacity of the previous year.
- With **23.6 %**, the year 2010 showed the second lowest growth rate of the last decade.



World Market Growth Rates, Source: World Wind Energy Report, 2010

- Before 2010, the annual growth rate had continued to increase since the year 2004, **peaking in 2009 at 31.7%**, the highest rate since 2001.
- The highest growth rates of the year 2010 by country can be found in **Romania**, which increased its capacity by 40 times.
- The second country with a growth rate of more than 100 % was **Bulgaria (112%)**.
- In the year 2009, four major wind markets had more than doubled their wind capacity: **China, Mexico, Turkey, and Morocco**.
- Next to China, strong growth could be found mainly in **Eastern European and South Eastern European** countries: Romania, Bulgaria, Turkey, Lithuania, Poland, Hungary, Croatia and Cyprus, and Belgium.
- Africa (with the exception of Egypt and Morocco) and Latin America (with the exception of Brazil), are again lagging behind the rest of the world in the commercial use of wind power.

- The Top 10 countries by Growth Rate are shown in the figure listed below (only markets bigger than 200 MW have been considered):



Top Countries by Market Growth Rates, Source: World Wind Energy Report, 2010

Geographical Market Distribution

- China became number one in total installed capacity and the center of the international wind industry, and added **18'928 Megawatt** within one year, accounting for more than 50 % of the world market for new wind turbines.
- Major decrease in new installations can be observed in North America and the **USA lost its number one position** in total capacity to China.
- Many Western European countries are showing stagnation, whereas there is strong growth in a number of Eastern European countries.
- **Germany** keeps its number one position in Europe with **27'215 Megawatt**, followed by Spain with 20'676 Megawatt.
- The highest shares of wind power can be found in three European countries: **Denmark (21.0%), Portugal (18.0 %) and Spain (16.0%)**.
- **Asia** accounted for the largest share of new installations **(54.6%)**, followed by **Europe (27.0%)** and **North America (16.7 %)**.
- **Latin America (1.2%)** and **Africa (0.4%)** still played only a marginal role in new installations.
- Africa: North Africa represents still lion share of installed capacity, wind energy plays hardly a role yet in Sub-Sahara Africa.
- Nuclear disaster in Japan and oil spill in Gulf of Mexico will have long-term impact on the prospects of wind energy. Governments need to urgently reinforce their wind energy policies.

Source: World Wind Energy Report, 2010

The regional breakdowns for the period 2009-2030 has been provided for the following three scenarios:

1. Regional Breakdown: Reference scenario (GWEO 2010)
2. Regional Breakdown: Moderate scenario (GWEO 2010)
3. Regional Breakdown: Advanced scenario (GWEO 2010)

*Note: To know more about the **Forecast Scenarios** click here*

Country-wise Market Distribution

- In 2010, the Chinese wind market represented more than half of the world market for new wind turbines adding **18.9 GW**, which equals a market share of **50.3%**.
- A sharp decrease in new capacity happened in the USA whose share in new wind turbines fell down to **14.9% (5.6 GW)**, after 25.9% or 9.9 GW in

the year 2009.

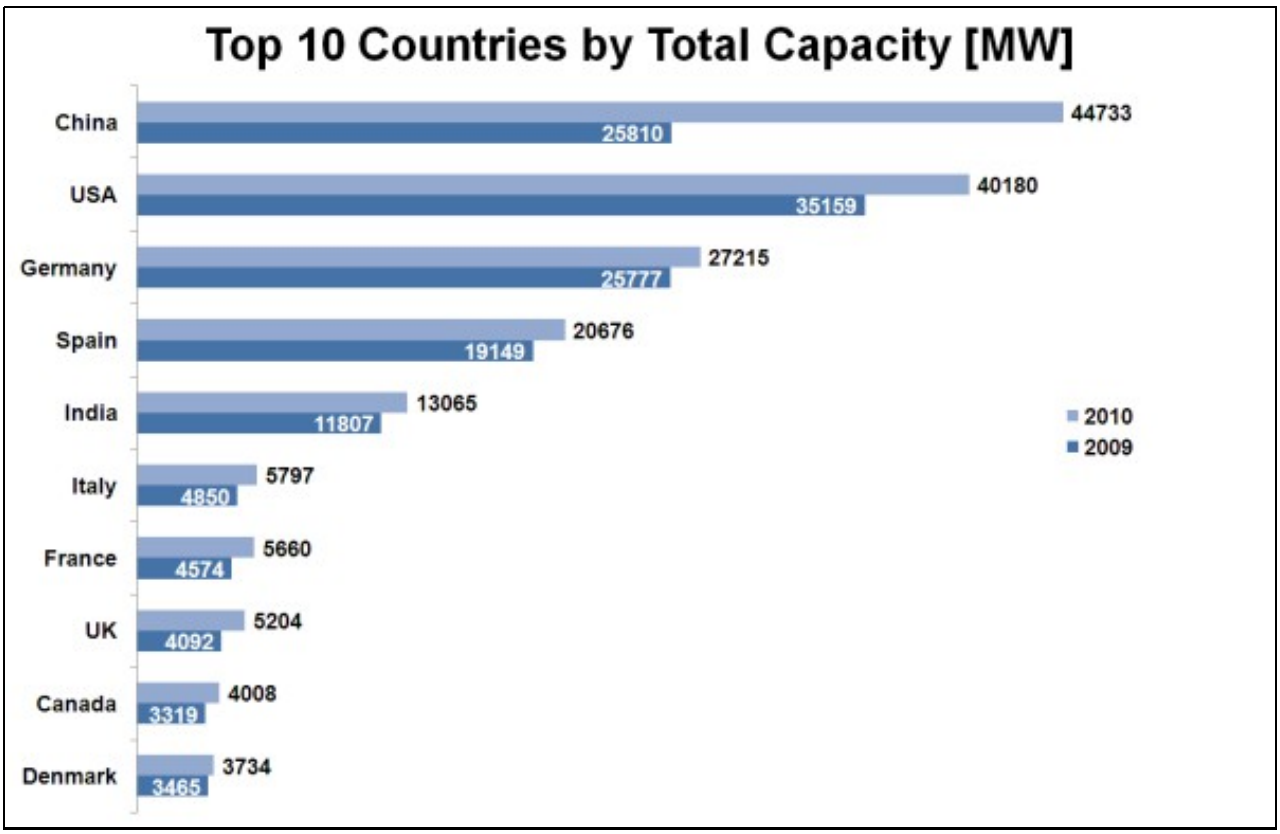
- **Nine further countries** could be seen as major markets, with turbine sales in a range **between 0.5 and 1.5 GW**: Germany, Spain, India, United

Kingdom, France, Italy, Canada, Sweden and the Eastern European newcomer Romania.

- Further, **12 markets** for new turbines had a medium size **between 100 and 500 MW**: Turkey, Poland, Portugal, Belgium, Brazil, Denmark, Japan, Bulgaria, Greece, Egypt, Ireland, and Mexico.
- By end of 2010, **20 countries** had installations of **more than 1 000 MW**, compared with 17 countries by end of 2009 and 11 countries byend of 2005.
- Worldwide, **39 countries** had wind farms with **a capacity of 100 Megawatt** or more installed, compared with 35 countries one year ago, and 24 countries five years ago.
- The top five countries (USA, China, Germany, Spain and India) represented **74.2%** of the worldwide wind capacity, significantly more than 72.9 % in the year.
- The **USA and China** together represented **43.2%** of the global wind capacity (up from 38.4 % in 2009).
- The newcomer on the list of countries using wind power commercially is a Mediterranean country, **Cyprus**, which for the first time installed a larger grid-connected wind farm, with 82 MW.

Source: World Wind Energy Report, 2010

The top 10 countries by Total Installed Capacity for the year 2010, is illustrated in the chart below:



Top Countries by Market Growth Rates, Source: World Wind Energy Report, 2010
To view the Top 10 countries by different other parameters for the year 2010, click on the links below:

1. Top 10 countries by Total New Installed Capacity
2. Top 10 countries by Capacity per Capita (kW/cap)
3. Top 10 countries by Capacity per Land Area (kW/sq. km)
4. Top 10 countries by Capacity per GDP (kW/ million USD)

To view the **Country-wise Installed Wind Power Capacity** (MW) 2002-2010 (Source: World Wind Energy Association), **click here**

Country Profiles

China

Wind Energy Outlook for China - 2011 & Beyond
Despite its rapid and seemingly unhampered expansion, the Chinese wind power sector continues to face significant challenges, including issues surrounding grid access and integration, reliability of turbines and a coherent strategy for developing China?s offshore wind resource. These issues will be prominent during discussions around the twelfth Five-Year Plan, which will be passed in March 2011. According to the draft plan, this is expected to reflect the Chinese government?s continuous and reinforced commitment to wind power development, with national wind energy targets of 90 GW for 2015 and 200 GW for 2020.

For a detailed country profile of China please visit this China Wind Energy Profile Link

India

Wind Energy Main market developments in 2010
Today the Indian market is emerging as one of the major manufacturing hubs for wind turbines in Asia. Currently, seventeen manufacturers have an annual production capacity of 7,500 MW. According to the WISE, the annual wind turbine manufacturing capacity in India is likely to exceed 17,000 MW by 2013.
The Indian market is expanding with the leading wind companies like Suzlon, Vestas, Enercon, RRB Energy and GE now being joined by new entrants like Gamesa, Siemens, and WinWinD, all vying for a greater market share. Suzlon, however, is still the market leader with a market share of over 50%. The Indian wind industry has not been significantly affected by the financial and economic crises. Even in the face of a global slowdown, the Indian annual wind power market has grown by almost 68%. However, it needs to be pointed out that the strong growth in 2010 might have been stimulated by developers taking advantage of the accelerated depreciation before this option is phased out.

For a detailed country profile of India please visit this India Wind Energy Profile Link

Market Share Analysis

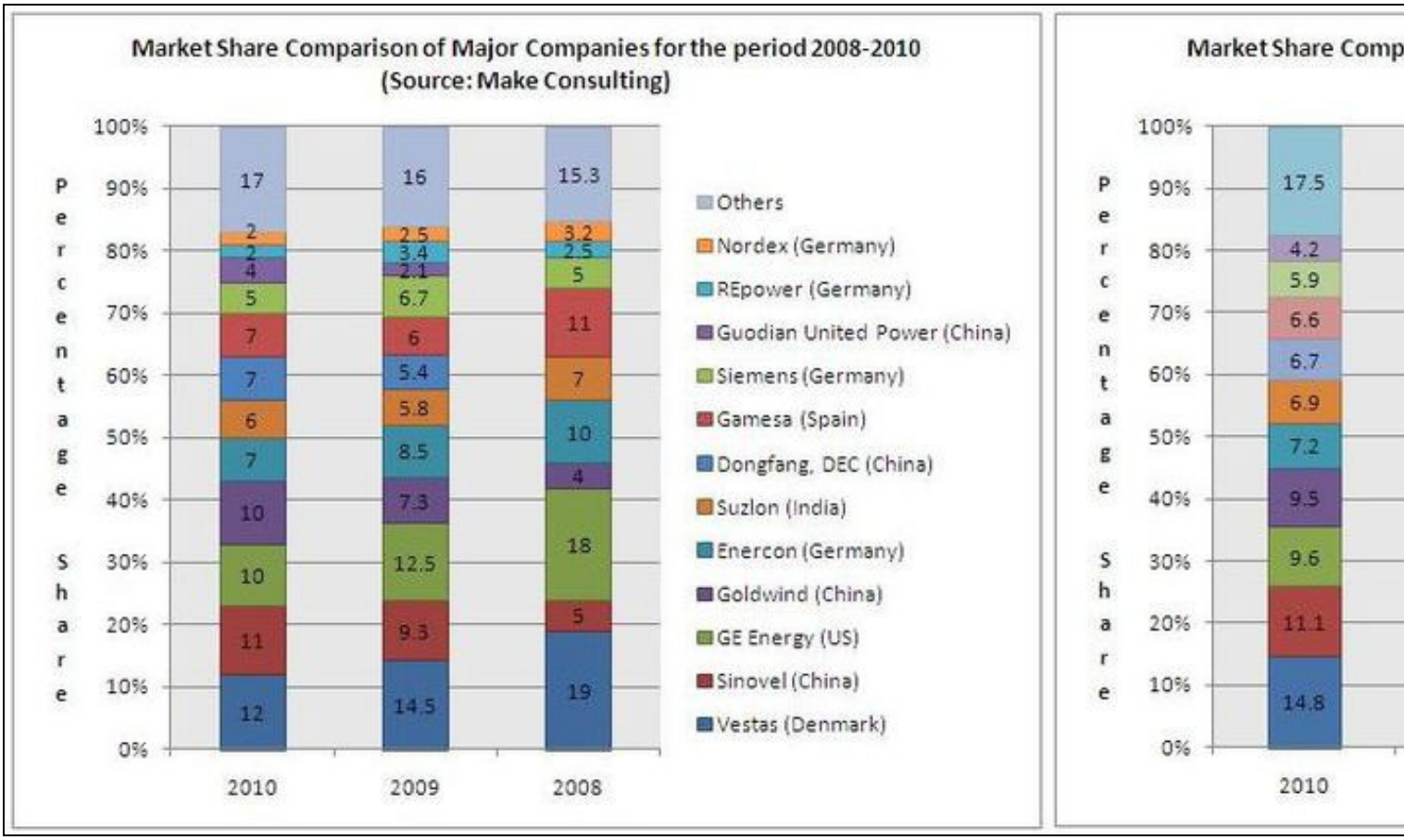
Global Market Share

- Vestas leads the Global Market in the 2010 with a 12% market share according to Make Consulting, while BTM Consulting reports it to have a 14.8% market share.

- According to Make Consulting, the global market share of Vestas has decreased from 19% in 2008, to 14.5% in 2009, to 12% in 2010.
- According to BTM Consulting, the global market share of Vestas has changed from 19% in 2008, to 12% in 2009, to 14.8% in 2010.
- According to Make Consulting, the global market share of GE Energy has decreased from 18% in 2008, to 12.5% in 2009, to 10% in 2010.
- The market share of world no. 2 Sinovel, has been constantly increasing, from 5% in 2008 , to 9.3% in 2009, to 11% in 2010
- The top 5 companies have been occupying more than half of the Global Market Share from 2008 to 2010

Source: Make Consulting, BTM Global Consulting

The chart given below illustrates the Global Market Share Comparison of Major Wind Energy Companies for the period 2008-2010, as provided by two different agencies, Make Consulting and BTM Consulting:



Global Market Share Comparison of Major Companies for the period 2008-2010 , Source: Make Consulting, BTM Global Consulting

Market Share - Top 10 Markets

- While Vestas is the Global Leader, it is the leader in only one of Top 10 markets, which is 10th placed Sweden
- But, Vestas is ranked 2nd in 5 of Top 10 markets
- Sinovel, ranked 2nd globally, features only once in the Top 3 Companies list in the Top 10 markets, but scores globally because it leads the largest market China
- The table given below illustrates the Top 3 players in Top 10 Wind Energy Markets of the world:

Market	MW	No. 1	No. 2	No. 3
China	18928	Sinovel	Goldwind	Dongfang
USA	5115	GE Energy	Vestas	Siemens
India	2139	Suzlon	Enercon	Vestas
Germany	1551	Enercon	Vestas	Suzlon
UK	1522	Siemens	Vestas	Gamesa
Spain	1516	Gamesa	Vestas	GE Energy
France	1186	Enercon	Suzlon	Vestas
Italy	948	Gamesa	Vestas	Suzlon
Canada	690	Siemens	GE Energy	Enercon
Sweeden	604	Vestas	Enercon	Siemens
Source: BTM Consult - part of Navigant Consulting - March 2011				

Source: BTM Consult

Company Profiles

1. **Vestas Wind Systems A/S**
2. **Suzlon Energy**

Major Wind Turbine Suppliers

Turbine maker	Rotor blades	Gear boxes	Generators	Towers	Controllers
Vestas	Vestas, LM	Bosch Rexroth, Hansen, Wingery, Moventas	Weier, Elin, ABB, LeroySomer	Vestas, NEG, DMI	Cotas (Vestas), NEG (Dancontrol)
GE energy	LM, Tecsis	Wingery, Bosch, Rexroth, Eickhoff, GE	Loher, GE	DMI, Omnical, SIAG	GE
Gamesa	Gamesa, LM	Echesa (Gamesa), Winergy, Hansen	Indar (Gamesa), Cantarey	Gamesa	Ingelectric (Gamesa)
Enercon	Enercon	Direct drive	Enercon	KGW, SAM	Enercon
Siemens wind	Siemens, LM	Winergy	ABB	Roug, KGW	Siemens, KK Electronic
Suzlon	Suzlon	Hansen, Winergy	Suzlon, Siemens	Suzlon	Suzlon, Mita Teknik
Repower	LM	Winergy, Renk, Eickhoff	N/A	N/A	Mita Teknik, ReGuard
Nordex	Nordex	Winergy, Eickhoff, Maag	Loher	Nordex, Omnical	Nordex, Mita Teknik
Source: BTM Consult					

Products of Top Companies

S.No.	Company	Product	Specifications
1	Vestas	V80	**Rated Power:** 2.0 MW, **Frequency:** 50 Hz/60 Hz, **Number of Poles:** 4-pole, **Operating Temperature: -**30°C to 40°
2	Vestas	V90	**Rated Power:** 1.8/2.0 MW, **Frequency :** 50 Hz/60 Hz, **Number of Poles :** 4-pole(50 Hz)/6-pole(60 Hz), **Operating Temperature: -**30°C to 40°
3	Vestas	V90 Offshore	**Rated Power:** 3.0 MW, **Frequency:** 50 Hz/60 Hz, **Number of Poles:** 4-pole, **Operating Temperature:** -30°C to 40°
4	North Heavy Company	2 MW DFIG	**Rated Power:** 2.0 MW, **Rated Voltage:** 690V, **Rated Current:** 1670A, **Frequency:** 50Hz, **Number of Poles :** 4-pole, **Rotor Rated Voltage:** 1840V, **Rotor Rated Current** 670A, **Rated Speed:** 1660rpm; **Power Speed Range:** 520-1950 rpm, **Insulation Class:** H, **Protection Class:** IP54, **Motor Temperature Rise** =<95K
5	Gamesa	G90	**Rated Voltage:** 690 V, **Frequency:** 50 Hz, **Number of Poles:** 4, **Rotational Speed:** 900:1,900 rpm (rated 1,680 rpm) (50Hz); **Rated Stator Current:** 1,500 A @ 690 V, **Protection Class:** IP 54, **Power Factor(standard):** 0.98 CAP - 0.96 IND at partial loads and 1 at nominal power, **Power Factor(Optional):** 0.95 CAP - 0.95 IND throughout the power range
6	Nordex	N80	**Rated Power:** 2.5 MW, **Rated Voltage:** 690V, **Frequency:** 50/60Hz, **Cooling Systems:** liquid/air
7	Nordex	N90	**Rated Power:** 2.5 MW, **Rated Voltage:** 690V, **Frequency:** 50/60Hz, **Cooling Systems:** liquid/air
8	Nordex	N100	**Rated Power:** 2.4 MW, **Rated Voltage:** 690V, **Frequency:** 50/60Hz, **Cooling Systems:** liquid/air
9	Nordex	N117	**Rated Power:** 2.5 MW, **Rated Voltage:** 690V, **Frequency:** 50/60Hz, **Cooling Systems:** liquid/air
10	Converteam	DFIG	NA
11	Xian Geoho Energy Technology	1.5MW DFIG	**Rated Power:** 1550KW, **Rated Voltage:** 690V, **Rated Speed:** 1755 r/min, **Speed Range:** 975~1970 r/min, **Number of Poles:** 4-pole, **Stator Rated Voltage:** 690V±10%, **Stator Rated**

			Current: 1115A; **Rotor Rated Voltage:** 320V, **Rotor Rated Current:** 430A, **Winding Connection:** Y / Y, **Power Factor:** 0.95(Lead) ~ 0.95Lag, **Protection Class:** IP54, **Insulation Class:** H, **Work Mode:** S1, **Installation Model:** M B3, **Cooling Mode:** Air cooling, **Weight:** 6950kg
12	Tecowestinghouse	TW450XX (0.5-1 KW)	**Rated Power:** 0.5 -1 KW, **Rated Voltage:** 460/ 575/ 690 V, **Frequency:** 50/ 60 Hz, **Number of Poles:** 4/6, **Ambient Temp.(°C): -**40 to 50, **Speed Range (% of Synch. Speed):** 68% to 134%, **Power Factor (Leading): -**0.90 to +0.90 , **Insulation Class:** H/F, **Efficiency:** >= 96%
13	Tecowestinghouse	TW500XX (1-2 KW)	**Rated Power:** 1-2 kW, **Rated Voltage:** 460/ 575/ 690 V, **Frequency:** 50/ 60 Hz, **Number of Poles:** 4/6, Ambient Temp.(°C): -40 to 50; **Speed Range (% of Synch. Speed):** 68 to 134%, **Power Factor(Leading): -**0.90 to +0.90, **Insulation Class:** H/F, **Efficiency:** >= 96%
14	Tecowestinghouse	TW560XX (2-3 KW)	**Rated Power:** 2-3kW, **Rated Voltage:** 460/ 575/ 690 V, **Frequency:** 50/ 60 Hz, **Number of Poles:** 4/6, **Ambient Temp(°C):** -40 to 50, **Speed Range(% of Synch. Speed)**: 68 to 134%, **Power Factor(Leading):** -0.90 to +0.90, **Insulation Class:** H/F, **Efficiency:** >= 96%.
15	Acciona	AW1500	**Rated Power:** 1.5MW, **Rated Voltage:** 690 V, **Frequency:** 50 Hz, **Number of Poles:** 4, **Rotational Speed:** 900:1,900 rpm(rated 1,680 rpm) (50Hz), **Rated Stator Current:** 1,500 A @ 690 V, **Protection Class:** IP54, **Power Factor(standard):** 0.98 CAP - 0.96 IND at partial loads and 1 at nominal power, **Power factor(optional):** 0.95 CAP - 0.95 IND throughout the power range
16	Acciona	AW3000	**Rated Power:** 3.0MW, **Rated Voltage:** 690 V, **Frequency:** 50 Hz, **Number of Poles:** 4, **Rotational Speed:** 900:1,900 rpm(rated 1,680 rpm) (50Hz), **Rated Stator Current:** 1,500 A @ 690 V, **Protection Class:** IP54, **Power Factor(standard):** 0.98 CAP - 0.96 IND at partial loads and 1 at nominal power, **Power Factor (optional):** 0.95 CAP - 0.95 IND throughout the power range
17	General Electric	GE 1.5/2.5MW	**Rated Power:** 1.5/2.5 MW, **Frequency(Hz):** 50/60

IP Search & Analysis

Doubly-fed Induction Generator: Search Strategy

The present study on the IP activity in the area of horizontal axis wind turbines with focus on ***Doubly-fed Induction Generator (DFIG)*** is based on a search conducted on Thomson Innovation.

Control Patents

S. No.	Patent/Publication No.	Publication Date (mm/dd/yyyy)	Assignee/Applicant	Title
1	US6278211	08/02/01	Sweo Edwin	Brush-less doubly-fed induction machines employing dual cage rotors
2	US6954004	10/11/05	Spellman High Voltage Electron	Doubly fed induction machine
3	US7411309	08/12/08	Xantrex Technology	Control system for doubly fed induction generator
4	US7485980	02/03/09	Hitachi	Power converter for doubly-fed power generator system
5	US7800243	09/21/10	Vestas Wind Systems	Variable speed wind turbine with doubly-fed induction generator compensated for varying rotor speed
6	US7830127	11/09/10	Wind to Power System	Doubly-controlled asynchronous generator

Patent Classes

S. No.	Class No.	Class Type	Definition
1	F03D9/00	IPC	Machines or engines for liquids; wind, spring, or weight motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for / Wind motors / **Adaptations of wind motors for special use; Combination of wind motors with apparatus driven thereby (aspects predominantly concerning driven apparatus)**
2	F03D9/00C	ECLA	Machines or engines for liquids; wind, spring, or weight motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for / Wind motors / Adaptations of wind motors for special use; Combination of wind motors with apparatus driven thereby (aspects predominantly concerning driven apparatus) / **The apparatus being an electrical generator**
3	H02J3/38	IPC	Generation, conversion, or distribution of electric power / Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy / Circuit arrangements for ac mains or ac distribution networks / **Arrangements for parallely feeding a single network by two or more generators, converters or transformers**
4	H02K17/42	IPC	Generation, conversion, or distribution of electric power / Dynamo-electric machines / Asynchronous induction motors; Asynchronous induction generators / **Asynchronous induction generators**
5	H02P9/00	IPC	Generation, conversion, or distribution of electric power / Control or regulation of electric motors, generators, or dynamo-electric converters; controlling transformers, reactors or choke coils / **Arrangements for controlling electric generators for the purpose of obtaining a desired output**
6	290/044	USPC	Prime-mover dynamo plants / electric control / Fluid-current motors / **Wind**

7	290/055	USPC	Prime-mover dynamo plants / Fluid-current motors / **Wind**
8	318/727	USPC	Electricity: motive power systems / **Induction motor systems**
9	322/047	USPC	Electricity: single generator systems / Generator control / **Induction generator**

Concept Table

S. No.	Concept 1	Concept 2	Concept 3
	Doubly Fed	**Induction**	**Generator**
1	doubly fed	induction	generator
2	double output	asynchronous	machines
3	dual fed		systems
4	dual feed		
5	dual output		

Thomson Innovation Search

Database: Thomson Innovation
Patent coverage: US EP WO JP DE GB FR CN KR DWPI
Time line: 01/01/1836 to 07/03/2011

S. No.	Concept	Scope	Search String	No. of Hits
1	Doubly-fed Induction Generator: Keywords(broad)	Claims, Title, and Abstract	(((((doubl*3 OR dual*3 OR two) ADJ3 (power*2 OR output*4 OR control*4 OR fed OR feed*3)) NEAR5 (induction OR asynchronous)) NEAR5 (generat*3 OR machine*1 OR dynamo*1)) OR dfig or doig)	873
2	Doubly-fed Induction Generator: Keywords(broad)	Full Spec.	(((((doubl*3 OR dual*3 OR two) ADJ3 (power*2 OR output*1 OR control*4 OR fed OR feed*3)) NEAR5 (generat*3 OR machine*1 OR dynamo*1))) OR dfig or doig)	-
3	Induction Machine: Classes	US, IPC, and ECLA Classes	((318/727 OR 322/047) OR (H02K001742))	-
4	Generators: Classes	US, IPC, and ECLA Classes	((290/044 OR 290/055) OR (F03D000900C OR H02J000338 OR F03D0009* OR H02P0009*))	-
5	Combined Query	-	2 AND 3	109
6	Combined Query	-	2 AND 4	768
7	French Keywords	Claims, Title, and Abstract	((((doubl*3 OR dual*3 OR two OR deux) NEAR4 (nourris OR feed*3 OR puissance OR sortie*1 OR contrôle*1)) NEAR4 (induction OR asynchron*1) NEAR4 (générateur*1 OR generator*1 OR machine*1 OR dynamo*1)) OR dfig or doig)	262
8	German Keywords	Claims, Title, and Abstract	(((((doppel*1 OR dual OR two OR zwei) ADJ3 (ausgang OR ausgänge OR kontroll* OR control*4 OR gesteuert OR macht OR feed*1 OR gefüttert OR gespeiste*1)) OR (doppeltgefüttert OR doppeltgespeiste*1)) NEAR4 (((induktion OR asynchronen) NEAR4 (generator*2 OR maschine*1 OR dynamo*1)) OR (induktion?maschinen OR induktion?generatoren OR asynchronmaschine OR asynchrongenerator))) OR dfig)	306
9	Doubly-fed Induction Generator: Keywords(narrow)	Full Spec.	(((((((doubl*3 OR dual*3) ADJ3 (power*2 OR output*4 OR control*4 OR fed OR feed*3))) NEAR5 (generat*3 OR machine*1 OR dynamo*1))) SAME wind) OR (dfig SAME wind))	1375
10	Top Assignees	-	(vestas* OR (gen* ADJ2 electric*) OR ge OR hitachi OR woodward OR repower OR areva OR gamesa OR ingeteam OR nordex OR siemens OR (abb ADJ2 research) OR (american ADJ2 superconductor*) OR (korea ADJ2 electro*) OR (univ* NEAR3 navarra) OR (wind OR technolog*) OR (wind ADJ2 to ADJ2 power))	-
11	Combined Query	-	2 AND 10	690
12	Top Inventors	-	((Andersen NEAR2 Brian) OR (Engelhardt NEAR2 Stephan) OR (Ichinose NEAR2 Masaya) OR (Jorgensen NEAR2 Allan NEAR2 Holm) OR ((Scholte ADJ2 Wassink) NEAR2 Hartmut) OR (OOHARA NEAR2 Shinya) OR (Rivas NEAR2 Gregorio) OR (Erdman NEAR2 William) OR (Feddersen NEAR2 Lorenz) OR (Fortmann NEAR2 Jens) OR (Garcia NEAR2 Jorge NEAR2 Martinez) OR (Gertmar NEAR2 Lars) OR (KROGH NEAR2 Lars) OR (LETAS NEAR2 Heinz NEAR2 Hermann) OR (Lopez NEAR2 Taberna NEAR2 Jesus) OR (Nielsen NEAR2 John) OR (STOEV NEAR2 Alexander) OR (W?ng NEAR2 Haiqing) OR (Yuan NEAR2 Xiaoming))	-
13	Combined Query	-	((3 OR 4) AND 10)	899
14	Final Query	-	1 OR 5 OR 6 OR 7 OR 8 OR 9 OR 11 OR 13	**2466(1060 INPADOC**

				Families)

Taxonomy

- *Use the mouse(click and drag/scroll up or down/click on nodes) to explore nodes in the detailed taxonomy*
- *Click on the red arrow adjacent to the node name to view the content for that particular node in the dashboard*

Sample Analysis

A sample of 139 patents from the search is analyzed based on the taxonomy. Provided a link below for sample spread sheet analysis for doubly-fed induction generators.

Patent Analysis

S.No.	Patent/Publication No.	Publication Date (mm/dd/yyyy)	Assignee/Applicant	Title	Dolcera Analysis	
					Problem	Solution
1	US20100117605	05/13/10	Woodward	Method of and apparatus for operating a double-fed asynchronous machine in the event of transient mains voltage changes	The short-circuit-like currents in the case of transient mains voltage changes lead to a corresponding air gap torque which loads the drive train and transmission lines can damages or reduces the drive train and power system equipments.	The method presents that the stator connecting with the network and the rotor with a converter. The converter is formed to set a reference value of electrical amplitude in the rotor, by which a reference value of the electrical amplitude is set in the rotor after attaining a transient mains voltage change, such that the rotor flux approaches the stator flux.
2	US20100045040	02/25/10	Vestas Wind Systems	Variable speed wind turbine with doubly-fed induction generator compensated for varying rotor speed	The DFIG system has poor damping of oscillations within the flux dynamics due to cross coupling between active and reactive currents, which makes the system potentially unstable under certain circumstances and complicates the work of the rotor current controller. These oscillations can damage the drive train mechanisms.	A compensation block is arranged, which feeds a compensation control output to the rotor of the generator. The computation unit computes the control output during operation of the turbine to compensate partly for dependencies on a rotor angular speed of locations of poles of a generator transfer function, so that the transfer function is made independent of variations in the speed during operation of the turbine which eliminates the oscillations and increases the efficiency of the wind turbine.
3	US20090267572	10/29/09	Woodward	Current limitation for a double-fed asynchronous machine	Abnormal currents can damage the windings in the doubly- fed induction generator. Controlling these currents with the subordinate current controllers cannot be an efficient way to extract the maximum amount of active power.	The method involves delivering or receiving of a maximum permissible reference value of an active power during an operation of a double-fed asynchronous machine, where predetermined active power and reactive power reference values are limited to a calculated maximum permissible active and reactive power reference values, and hence ensures reliable regulated effect and reactive power without affecting the power adjustment, the rotor is electrically connected to a pulse-controlled inverter by slip rings with a static frequency changer, and thus a tension with variable amplitude and frequency is imposed in the rotor.
4	US20090008944	01/08/09	Universidad Publica De Navarra	Method and system of control of the converter of an electricity	Double-fed asynchronous generators are very sensitive to the faults that may arise in the	During the event of a voltage sag occurring, the converter imposes a new set point current which is the result of adding to the

				generation facility connected to an electricity network in the presence of voltage sags in said network	electricity network, such as voltage sags. During the sag conditions the current which appears in said converter may reach very high values, and may even destroy it.	previous set point current a new term, called demagnetizing current, It is proportional to a value of free flow of a generator stator. A difference between a value of a magnetic flow in the stator of the generator and a value of a stator flow associated to a direct component of a stator voltage is estimated. A value of a preset calculated difference is multiplied by a factor for producing the demagnetizing current.
5	US7355295	04/08/08	Ingeteam Energy	Variable speed wind turbine having an exciter machine and a power converter not connected to the grid	a) The active switching of the semiconductors of the grid side converter injects undesirable high frequency harmonics to the grid. b) The use of power electronic converters (4) connected to the grid (9) causes harmonic distortion of the network voltage.	Providing the way that power is only delivered to the grid through the stator of the doubly fed induction generator, avoiding undesired harmonic distortion. Grid Flux Orientation (GFO) is used to accurately control the power injected to the grid. An advantage of this control system is that it does not depend on machine parameters, which may vary significantly, and theoretical machine models, avoiding the use of additional adjusting loops and achieving a better power quality fed into the utility grid.
6	US20080203978	08/28/08	Semikron	Frequency converter for a double-fed asynchronous generator with variable power output and method for its operation	Optislip circuit with a resistor is used when speed is above synchronous speed, results in heating the resistor and thus the generator leads to limitation of operation in super synchronous range which results in tower fluctuations.	Providing a back-to-back converter which contains the inverter circuit has direct current (DC) inputs, DC outputs, and a rotor-rectifier connected to a rotor of a dual feed asynchronous generator. A mains inverter is connected to a power grid, and an intermediate circuit connects one of the DC inputs with the DC outputs. The intermediate circuit has a semiconductor switch between the DC outputs, an intermediate circuit condenser between the DC inputs, and a diode provided between the semiconductor switch and the condenser. Thus the system is allowed for any speed of wind and reduces the tower fluctuations.
7	US20070210651	09/13/07	Hitachi	Power converter for doubly-fed power generator system	During the ground faults, excess currents is induced in the secondary windings and flows into power converter connected to secondary side and may damage the power converter. Conventional methods of increasing the capacity of the power converter increases system cost, degrade the system and takes time to activate the system to supply power again.	The generator provided with a excitation power converter connected to secondary windings of a doubly-fed generator via impedance e.g. reactor, and a diode rectifier connected in parallel to the second windings of the doubly-fed generator via another impedance. A direct current link of the rectifier is connected in parallel to a DC link of the converter. A controller outputs an on-command to a power semiconductor switching element of the converter if a value of current flowing in the power semiconductor

						switching element is a predetermined value or larger.
8	US20070132248	06/14/07	General Electric	System and method of operating double fed induction generators	Wind turbines with double fed induction generators are sensitive to grid faults. Conventional methods are not effective to reduce the shaft stress during grid faults and slow response and using dynamic voltage restorer (DVR) is cost expensive.	The protection system has a controlled impedance device. Impedance device has bidirectional semiconductors such triac, assembly of thyristors or anti-parallel thyristors. Each of the controlled impedance devices is coupled between a respective phase of a stator winding of a double fed induction generator and a respective phase of a grid side converter. The protection system also includes a controller configured for coupling and decoupling impedance in one or more of the controlled impedance devices in response to changes in utility grid voltage and a utility grid current. High impedance is offered to the grid during network faults to isolate the dual fed wind turbine generator.
9	US20060192390	08/31/06	Gamesa Innovation	Control and protection of a doubly-fed induction generator system	A short-circuit in the grid causes the generator to feed high stator-currents into the short-circuit and the rotor-currents increase very rapidly which cause damage to the power-electronic components of the converter connecting the rotor windings with the rotor-inverter.	The converter is provided with a clamping unit which is triggered from a non-operation state to an operation state, during detection of over-current in the rotor windings. The clamping unit comprises passive voltage-dependent resistor element for providing a clamping voltage over the rotor windings when the clamping unit is triggered.
10	US20050189896	09/01/05	ABB Research	Method for controlling doubly-fed machine	Controlling the double fed machines on the basis of inverter control to implement the targets set for the machine, this model is extremely complicated and includes numerous parameters that are often to be determined.	A method is provided to use a standard scalar-controlled frequency converter for machine control. A frequency reference for the inverter with a control circuit, and reactive power reference are set for the machine. A rotor current compensation reference is set based on reactive power reference and reactive power. A scalar-controlled inverter is controlled for producing voltage for the rotor of the machine, based on the set frequency reference and rotor current compensation reference.

Click **here** to view the detailed analysis sheet for doubly-fed induction generators patent analysis.

Article Analysis

S.No.	Title	Publication Date (mm/dd/yyyy)	Journal/Conference	Dolcera Summary
1	Study on the Control of DFIG and its Responses to Grid Disturbances	01/01/06	Power Engineering Society General Meeting, 2006. IEEE	Presented dynamic model of the DFIG, including mechanical model, generator model, and PWM voltage source converters. Vector control strategies adapted for both the RSC and GSC to control speed and reactive power independently. Control designing methods, such as pole-placement method and the internal model control are used. MATLAB/Simulink is used for simulation.
2		05/23/06		

	Application of Matrix Converter for Variable Speed Wind Turbine Driving an Doubly Fed Induction Generator		Power Electronics, Electrical Drives, Automation and Motion, 2006. SPEEDAM 2006.	A matrix converter is replaced with back to back converter in a variable speed wind turbine using doubly fed induction generator. Stable operation is achieved by stator flux oriented control technique and the system operated in both sub and super synchronous modes, achieved good results.
3	Optimal Power Control Strategy of Maximizing Wind Energy Tracking and Conversion for VSCF Doubly Fed Induction Generator System	08/14/06	Power Electronics and Motion Control Conference, 2006. IPEMC 2006. CES/IEEE 5th International	Proposed a new optimal control strategy of maximum wind power extraction strategies and testified by simulation. The control algorithm also used to minimize the losses in the generator. The dual passage excitation control strategy is applied to decouple the active and reactive powers. With this control system, the simulation results show the good robustness and high generator efficiency is achieved.
4	A Torque Tracking Control algorithm for Doubly?fed Induction Generator	01/01/08	Journal of Electrical Engineering	Proposed a torque tracking control algorithm for Doubly fed induction generator using PI controllers. It is achieved by controlling the rotor currents and using a stator voltage vector reference frame.
5	Fault Ride Through Capability Improvement Of Wind Farms Using Doubly Fed Induction Generator	09/04/08	Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International	An active diode bridge crowbar switch presented to improve fault ride through capability of DIFG. Showed different parameters related to crowbar such a crowbar resistance, power loss, temperature and time delay for deactivation during fault.

Click **here** to view the detailed analysis sheet for doubly-fed induction generators article analysis.

Top Cited Patents

S. No.	Patent/Publication No.	Publication Date (mm/dd/yyyy)	Assignee/Applicant	Title	Citation Count
1	US5289041	02/22/94	US Windpower	Speed control system for a variable speed wind turbine	80
2	US4982147	01/01/91	Oregon State	Power factor motor control system	62
3	US5028804	07/02/91	Oregon State	Brushless doubly-fed generator control system	51
4	US5239251	08/24/93	Oregon State	Brushless doubly-fed motor control system	49
5	US6856038	02/15/05	Vestas Wind Systems	Variable speed wind turbine having a matrix converter	43
6	WO1999029034	06/10/99	Asea Brown	A method and a system for speed control of a rotating electrical machine with flux composed of two quantities	36
7	WO1999019963	04/22/99	Asea Brown	Rotating electric machine	36
8	US7015595	03/21/06	Vestas Wind Systems	Variable speed wind turbine having a passive grid side rectifier with scalar power control and dependent pitch control	34
9	US4763058	08/09/88	Siemens	Method and apparatus for determining the flux angle of rotating field machine or for position-oriented operation of the machine	32
10	US7095131	08/22/06	General Electric	Variable speed wind turbine generator	25

Top Cited Articles

S. No.	Title	Publication Date	Journal/Conference	Citations Count
1	Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation	May. 1996	IEEE Proceedings Electric Power Applications	906
2	Doubly fed induction generator systems for wind turbines	May. 2002	IEEE Industry Applications Magazine	508
3	Dynamic modeling of doubly fed induction generator wind turbines	May. 2003	IEEE Transactions on Power Systems	274
4	Modeling and control of a wind turbine driven doubly fed induction generator	Jun. 2003	IEEE Transactions on Energy Conversion	271
5	Ride through of wind turbines with doubly-fed induction generator during a voltage dip	Jun. 2005	IEEE Transactions on Energy Conversion	246
6	Dynamic modeling of a wind turbine with doubly fed induction generator	July. 2001	IEEE Power Engineering Society Summer Meeting, 2001	196
7	Modeling of the wind turbine with a doubly fed induction generator for grid integration studies	Mar. 2006	IEEE Transactions on Energy Conversion	174

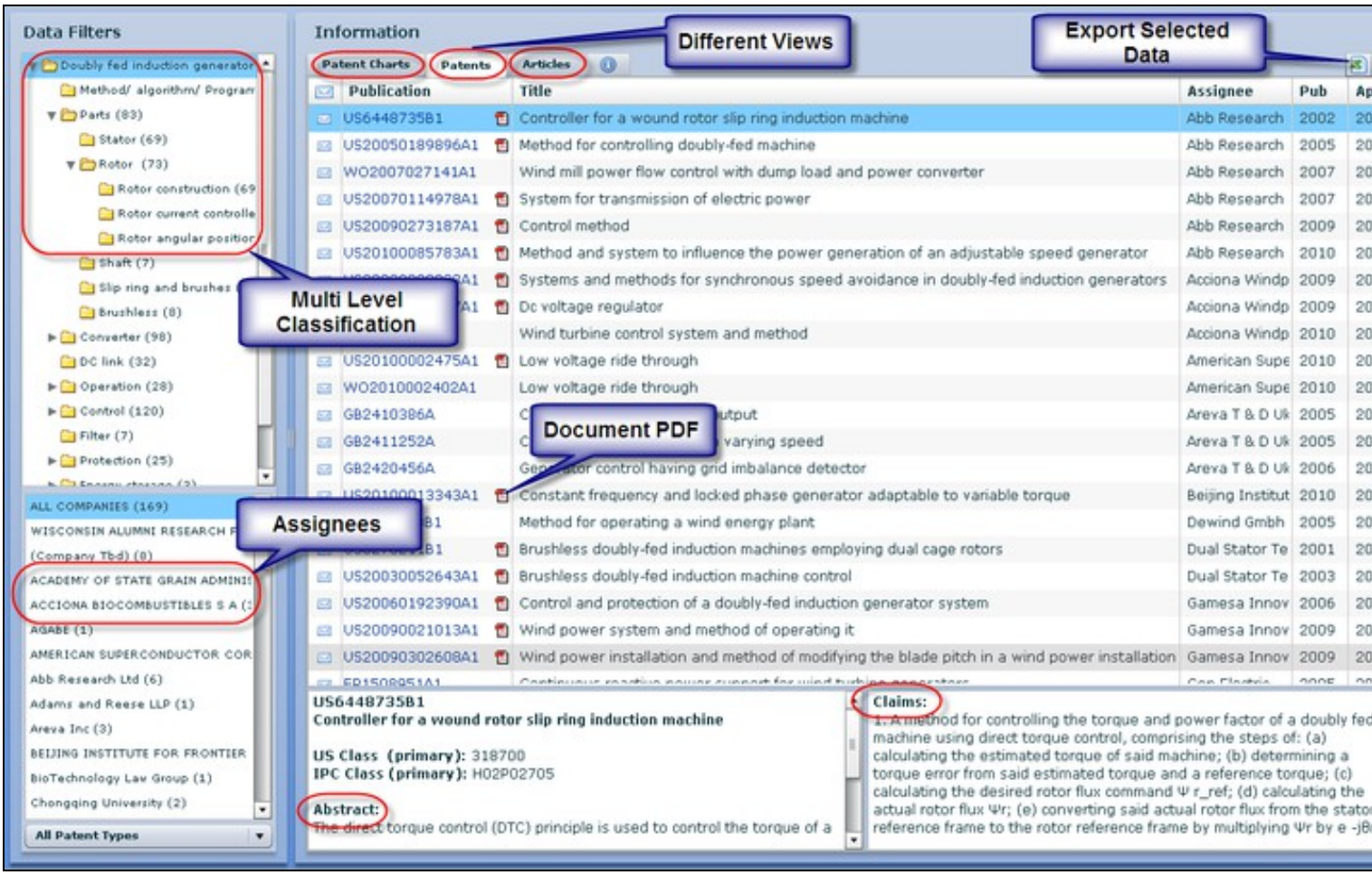
8	A doubly fed induction generator using back-to-back PWM converters supplying an isolated load from a variable speed wind turbine	Sept. 1996	IEEE Proceedings Electric Power Applications	150
9	Doubly fed induction generator model for transient stability analysis	Jun. 2005	IEEE Transactions on Energy Conversion	106
10	Control of a doubly fed induction generator in a wind turbine during grid fault ride-through	Sept. 2006	IEEE Transactions on Energy Conversion	112

White Space Analysis

- White-space analysis provides the technology growth and gaps in the technology where further R&D can be done to gain competitive edge and to carry out incremental innovation.
- Dolcera provides White Space Analysis in different dimensions. Based on Product, Market, Method of Use, Capabilities or Application or Business Area and defines the exact categories within the dimension.
- Below table shows a sample representation of white space analysis for controlling DFIG parameters with converters, based on the sample analysis.

	US20070052394A1 US20060028025A1	US20100148508A1 US20100133816A1 EP2166226A1 US20070132248A1 US20070052394A1 US20100096853A1	US20100114388A1			
	US20030151259A1	US20030151259A1				
	US20100142237A1 US20070052394A1 US20060028025A1	US20100096853A1 US20100148508A1 US20100133816A1 US20070132248A1 US20070052394A1	US20100114388A1			
		US20020079706A1		US20070216164A1	US20090265040A1	

Dolcera Dashboard



Dashboard Link

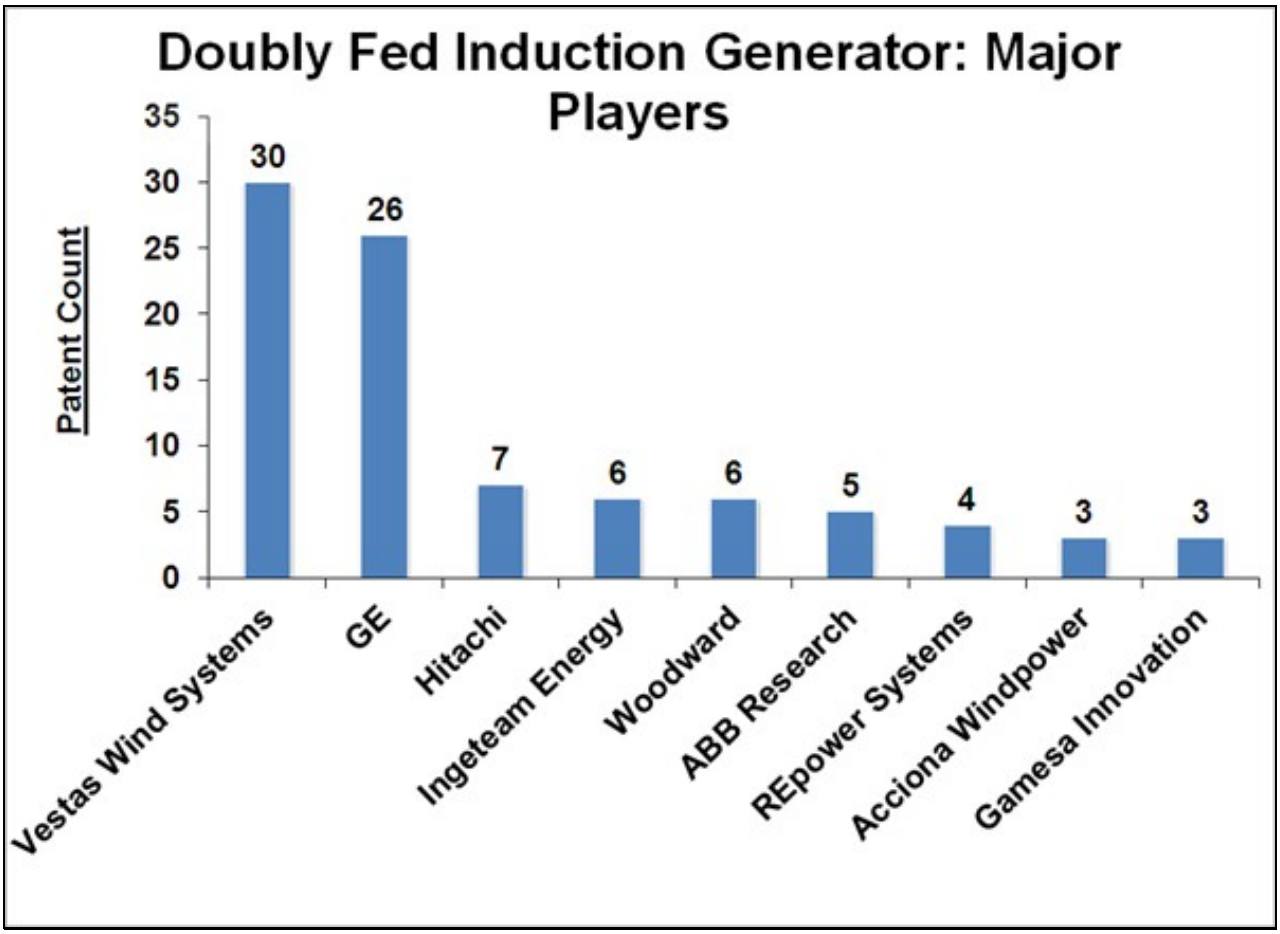
Doubly Fed Induction Generator - Dashboard	

- Flash Player is essential to view the Dolcera dashboard

Key Findings

Major Players

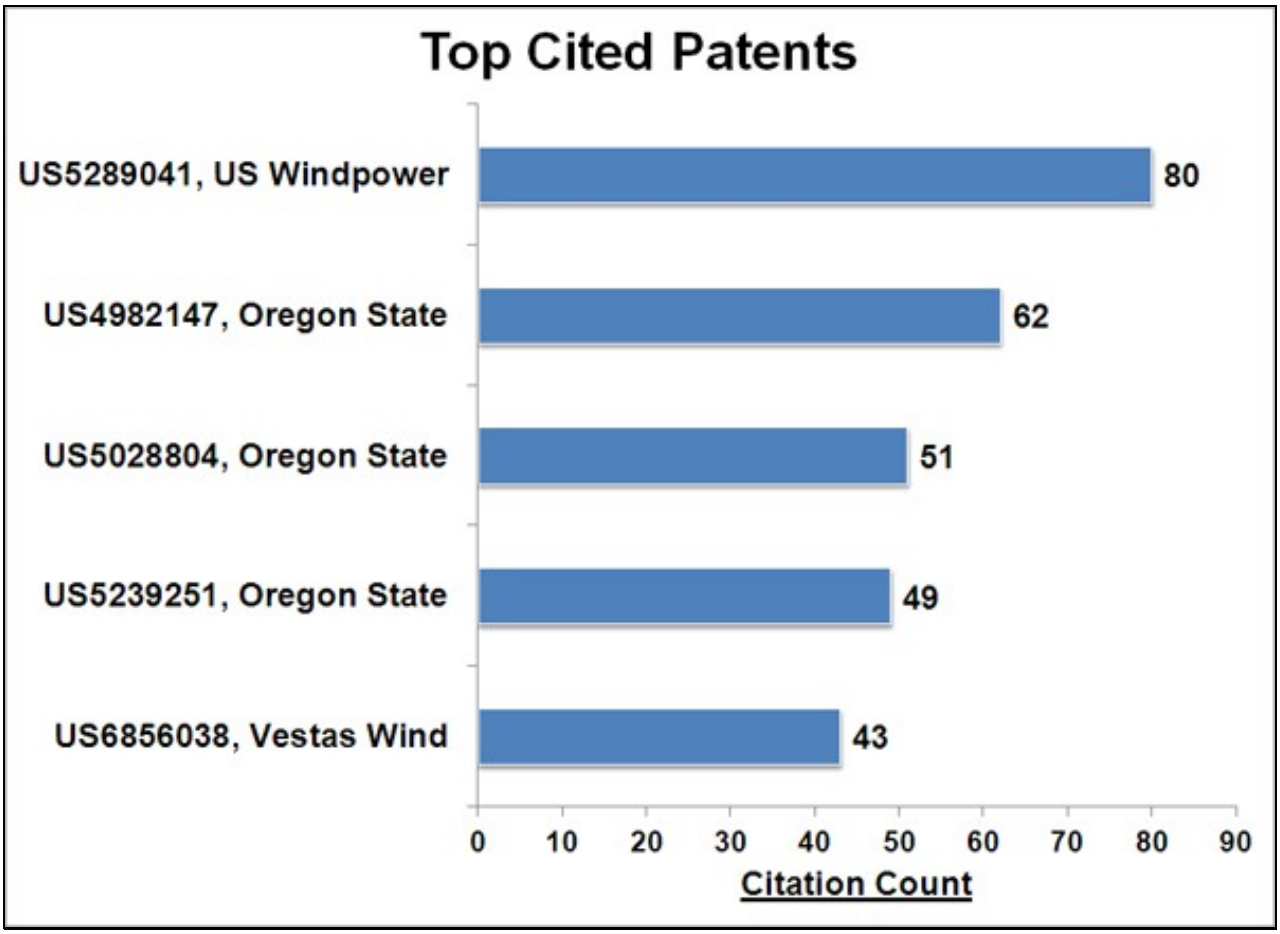
- Vestas Wind Energy Systems and General Electric are the major players in wind energy generation technology.



Major Players

Key Patents

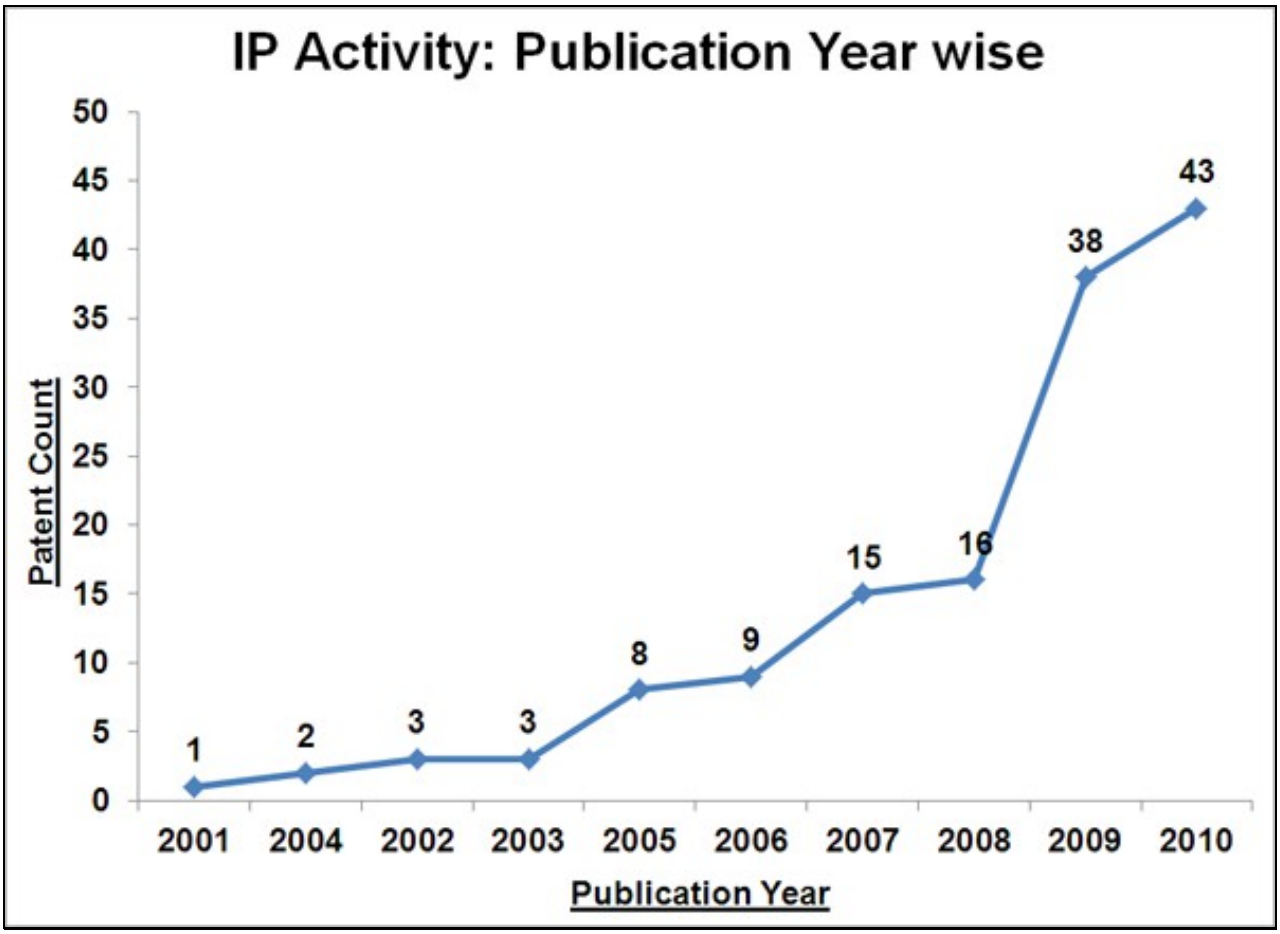
- The key patents in the field are held by US Windpower, Oregon State and Vestas Wind Energy Systems.



Key Patents

IP Activity

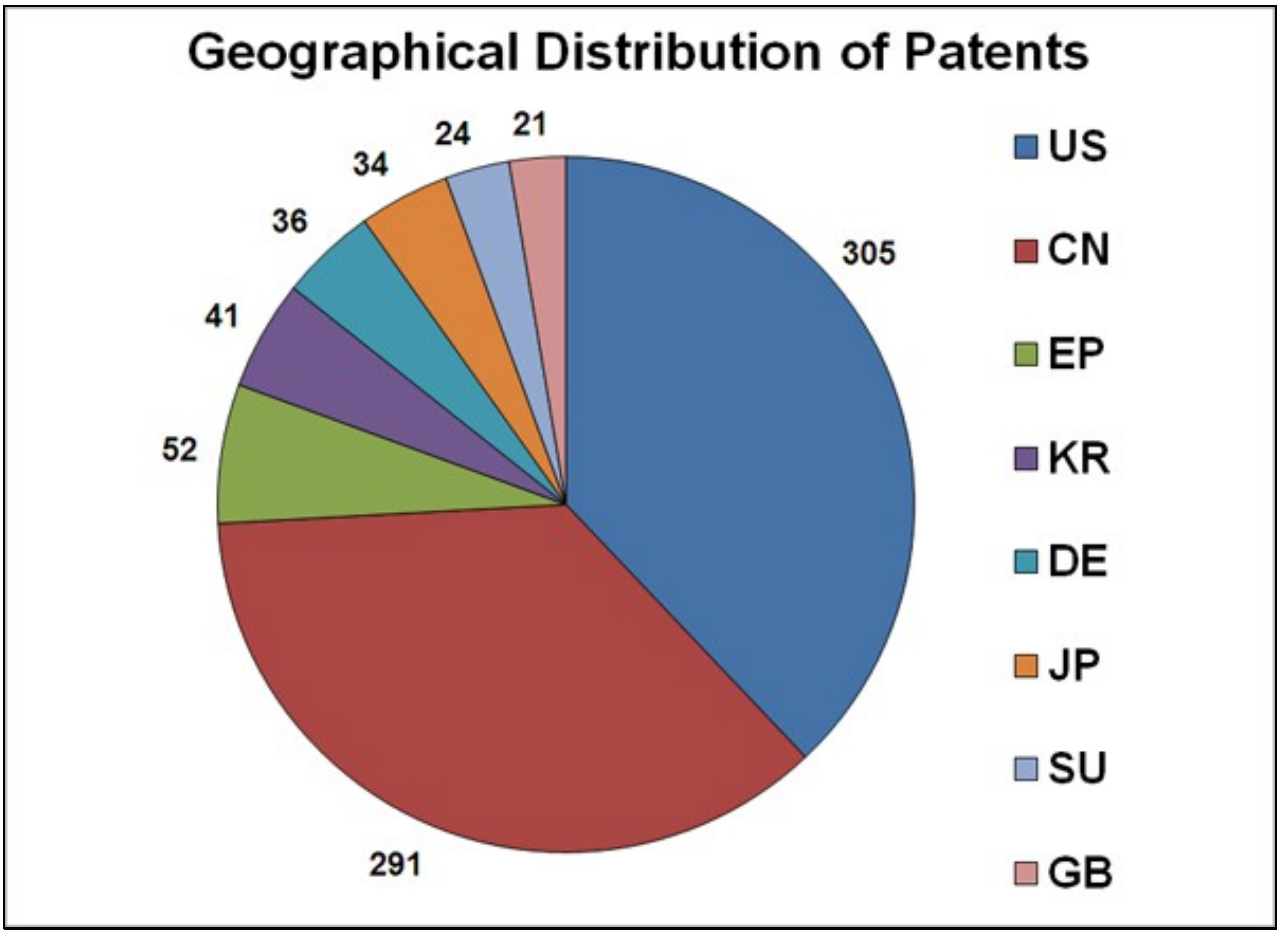
- Patenting activity has seen a very high growth rate in the last two years.



Year wise IP Activity

Geographical Activity

- USA, China, Germany, Spain, and India are very active in wind energy research.



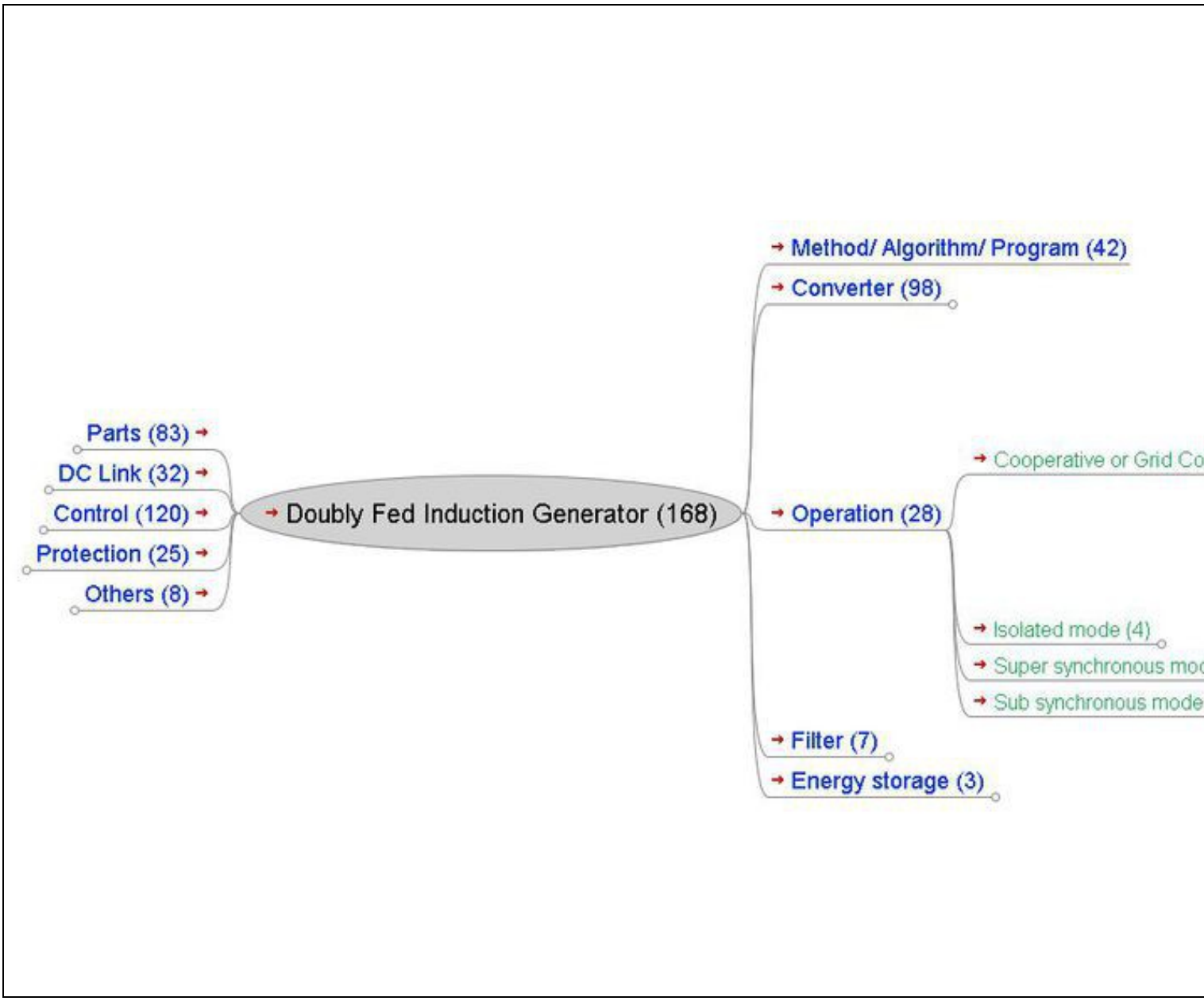
Geographical Activity

Research Trend

- Around 86% patents are on controlling the doubly-fed induction generation(DFIG) which indicates high research activity going on in rating and controlling of the DFIG systems.

Issues in the Technology

- 86% of the patent on DFIG operation are focusing on grid connected mode of operation, suggesting continuous operation of the DFIG system during weak and storm winds, grid voltage sags, and grid faults are major issues in the current scenario.



Problem Solution Mapping

Emerging Player

- Woodward is a new and fast developing player in the field of DFIG technology. The company filed 10 patent applications in the field in year 2010, while it has no prior IP activity.

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18. Two blade turbine
19. Three blade turbine
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21. Rotor hub
22. Shaft system
23. Gear box
24. Anemometer & Wind vane

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