Modern Wind Turbine Technologies and its application in KSA

Prof. Dr. Ali M. Eltamaly
SET Center,
King Saud University

Wind Energy Systems Overview

1.1 Historical Development

- Wind power in sailboats was used several thousand years ago
- The Babylonian emperor Hammurabi planned to use wind power for his ambitious irrigation project during seventeenth century B.C.
- The wind wheel of the Greek engineer Heron of Alexandria in the 1st century AD is the earliest known instance of using a wind-driven wheel to power a machine
- wind-driven wheel was the prayer wheel, which was used in ancient Tibet and China since the 4th century

By the 13th century, grain grinding mills were popular in most of Europe

French adopted this technology by 1105 A.D. and the English by 1191 A.D

Fig.1.1 Old windmill.

The era of wind electric generators began close to 1900's.

The first modern wind turbine, specifically designed for electricity generation, was constructed in Denmark in 1890.

The first utility-scale system was installed in Russia in 1931.

A significant development in large-scale systems was the 1250 kW turbine fabricated by Palmer C. Putman.

Fig.1.2 Mod-5B Horizontal axis wind turbine.

Fig.1.3 Darrieus wind turbine is vertical axis wind turbine.

Current status and future prospects

Wind is the world's fastest growing energy source today

The global wind power capacity increases at least 40% every year.

For example, the European Union targets to meet 30 per cent of their demand from renewable by 2016.

Spain also celebrates in Nov. 10, 2016 when the wind energy resources contribute 53% of the total generation of the electricity.

Installed capacity reaches a level of 1.2 million MW by 2020

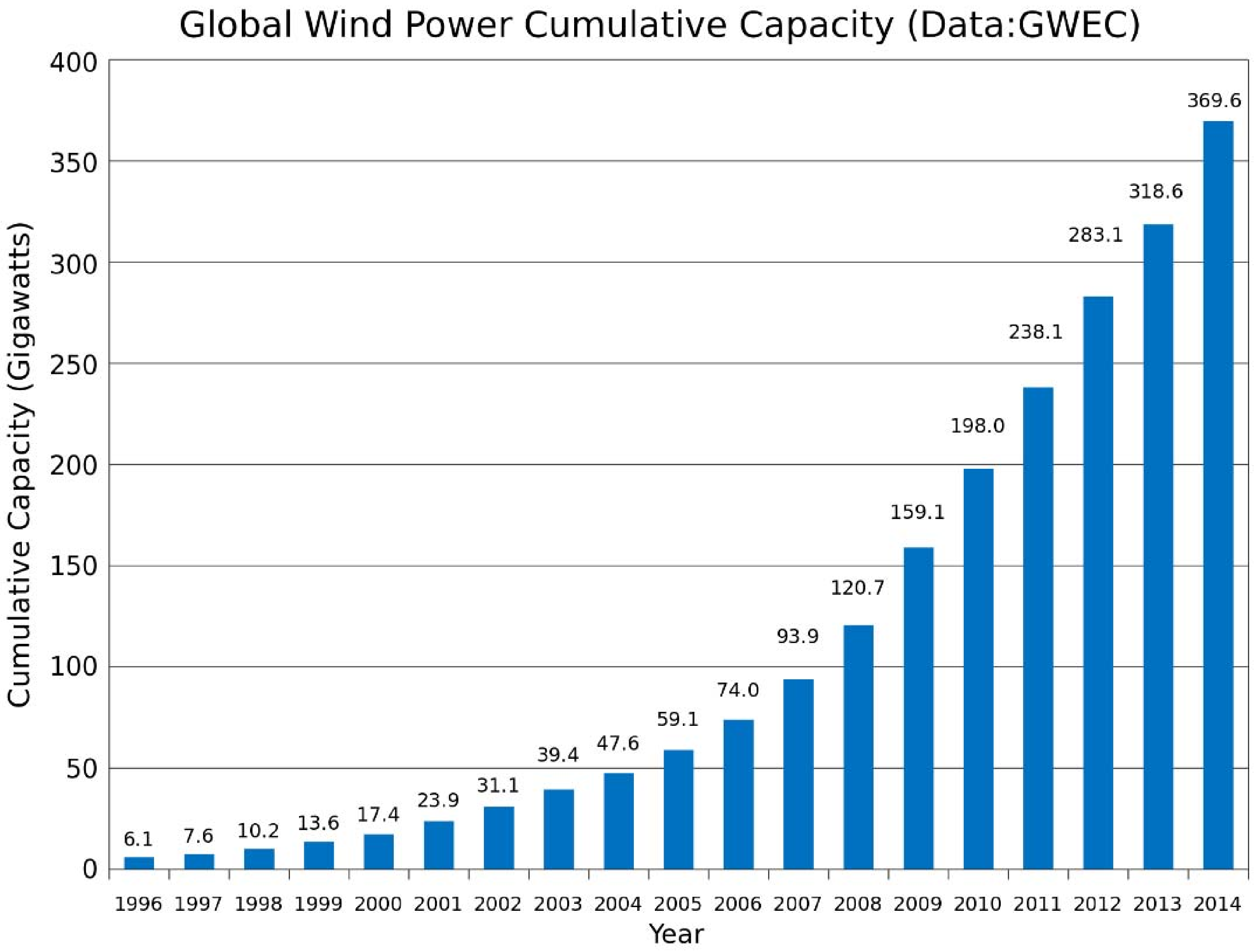
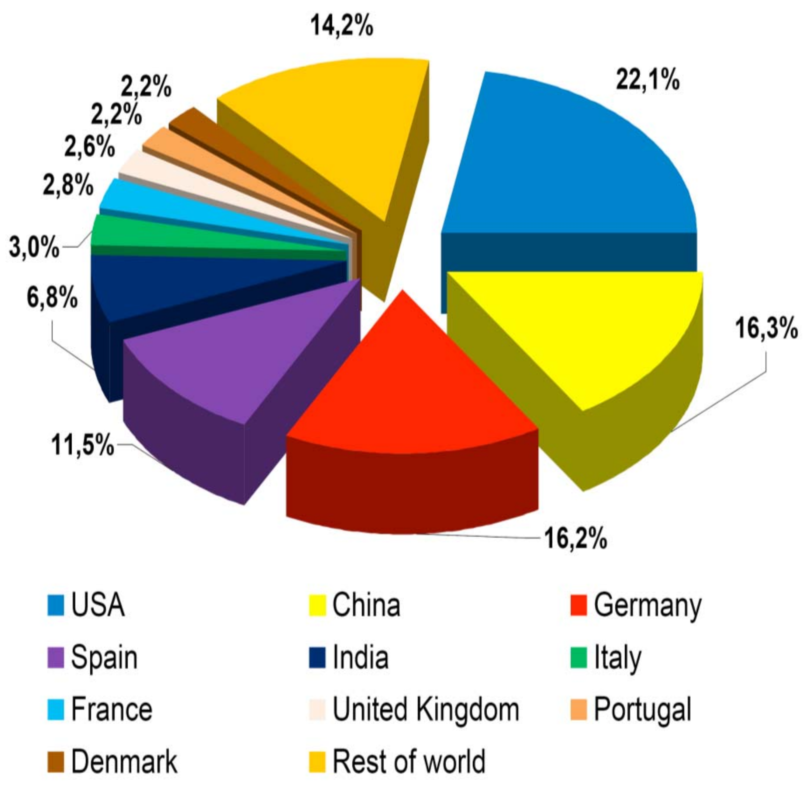


Fig.1.4 the installed capacity from the wind worldwide.



Wind Power Worldwide June 2010

Position	Country	Total capacity June 2010 [MW]	Added capacity June 2010 [MW]	Total capacity end 2009 [MW]
1	USA	**36.300**	1.200	35.159
2	China	**33.800**	7.800	26.010
3	Germany	**26.400**	660	25.777
4	Spain	**19.500**	400	19.149
5	India	**12.100**	1.200	10.925
6	Italy	**5.300**	450	4.850
7	France	**5.000**	500	4.521
8	United Kingdom	**4.600**	500	4.092
9	Portugal	**3.800**	230	3.535
10	Denmark	**3.700**	190	3.497
	Rest of the World	**24.500**	2.870	21.698
Total		**175.000**	**16.000**	**159.213**

Fig. 1.5 Installed capacity in different regions in the world, 2010.

(a) SWAY 10MW.

Enercon E126, 7.5MW, 126 diameter•

Table I.3.1: Design choices of leading manufacturers

		Share (%)	Model	Drive train	Power rating (kW)	Diameter (m)	Tip speed (m/s)	Power conversion
1	Vestas	22.8	V90	Geared	3000	90	87	Asynchronous
2	GE Energy	16.6	2.5XL	Geared	2500	100	86	PMG converter
3	Gamesa	15.4	G90	Geared	2000	90	90	DFIG
4	Enercon	14.0	E82	Direct	2000	82	84	Synchronous
5	Suzlon	10.5	S88	Geared	2100	88	71	Asynchronous
6	Siemens	7.1	3.6 SWT	Geared	3600	107	73	Asynchronous
7	Acciona	4.4	AW-119/3000	Geared	3000	116	74.7	DFIG
8	Goldwind	4.2	REpower750	Geared	750	48	58	Induction
9	Nordex	3.4	N100	Geared	2500	99.8	78	DFIG
10	Sinovel	3.4	1500 (Windtec)	Geared	1500	70		

Source: Garrad Hassan

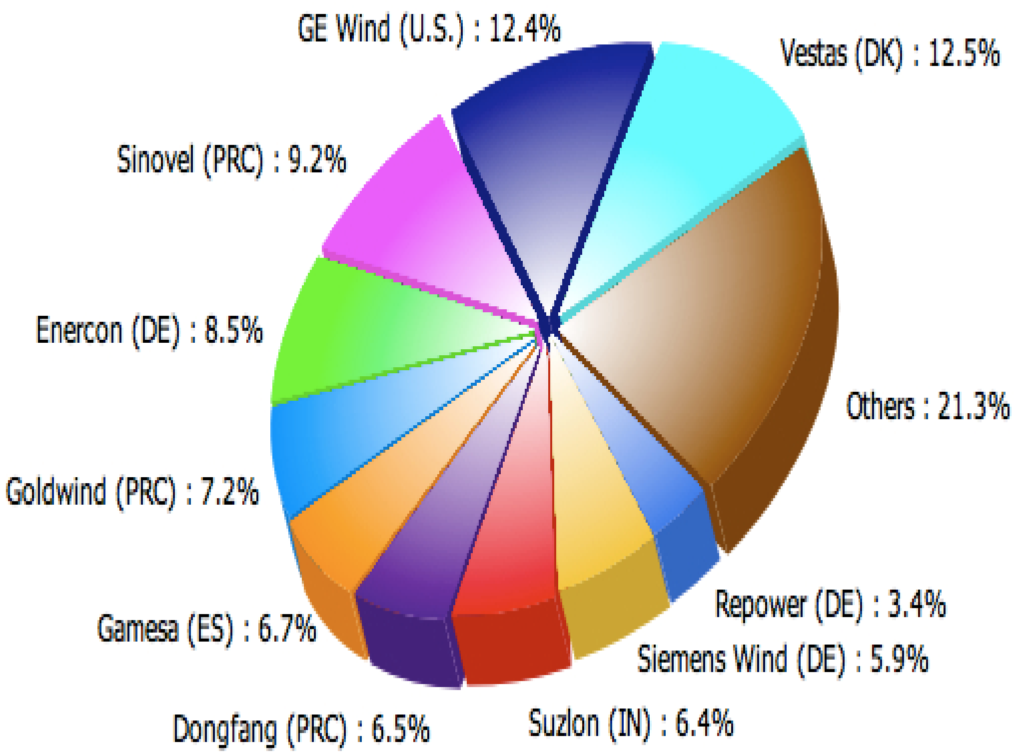


Fig.1.7 Top ten manufacturers of WTs, 2009.

1.3.1 Large Diameter

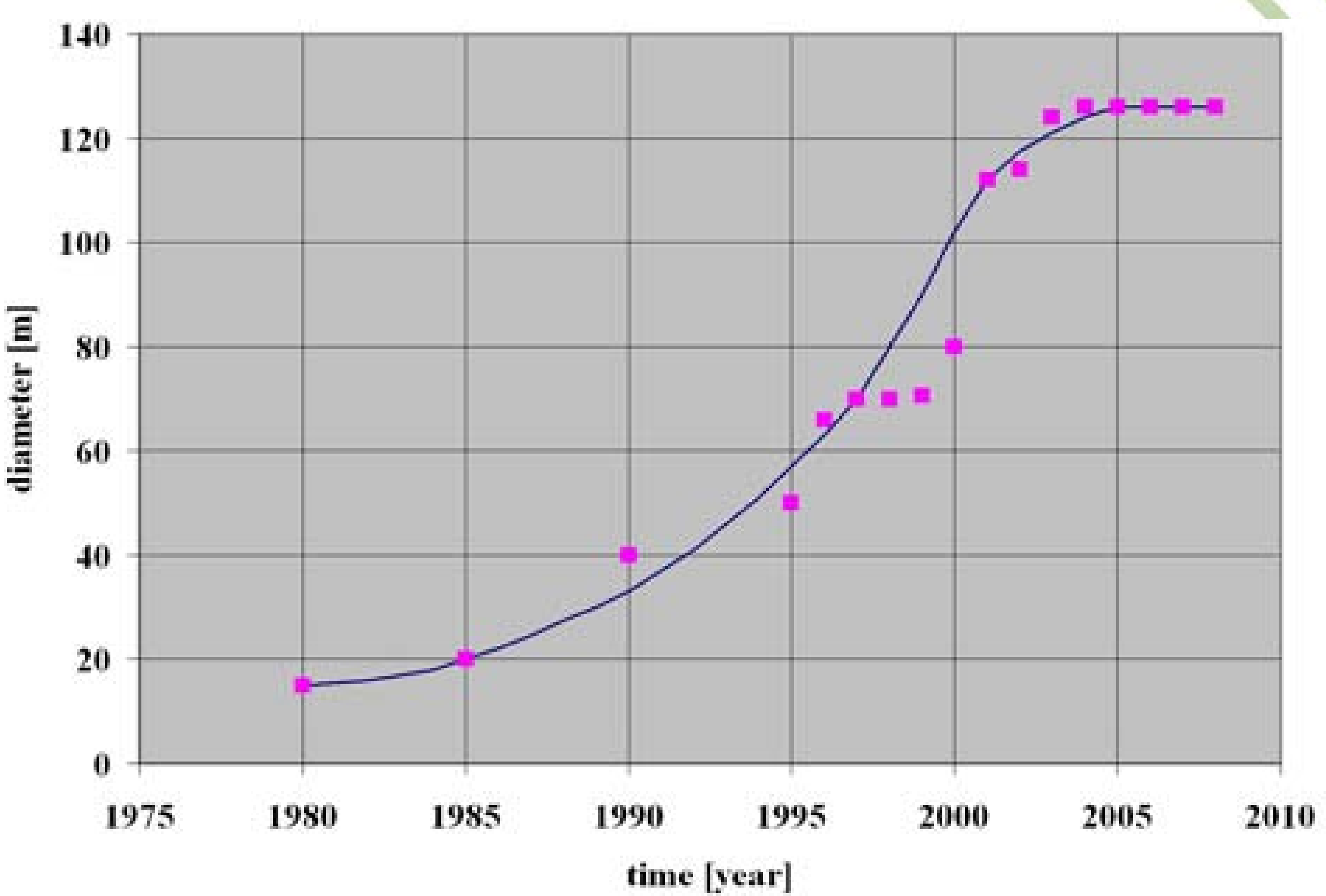
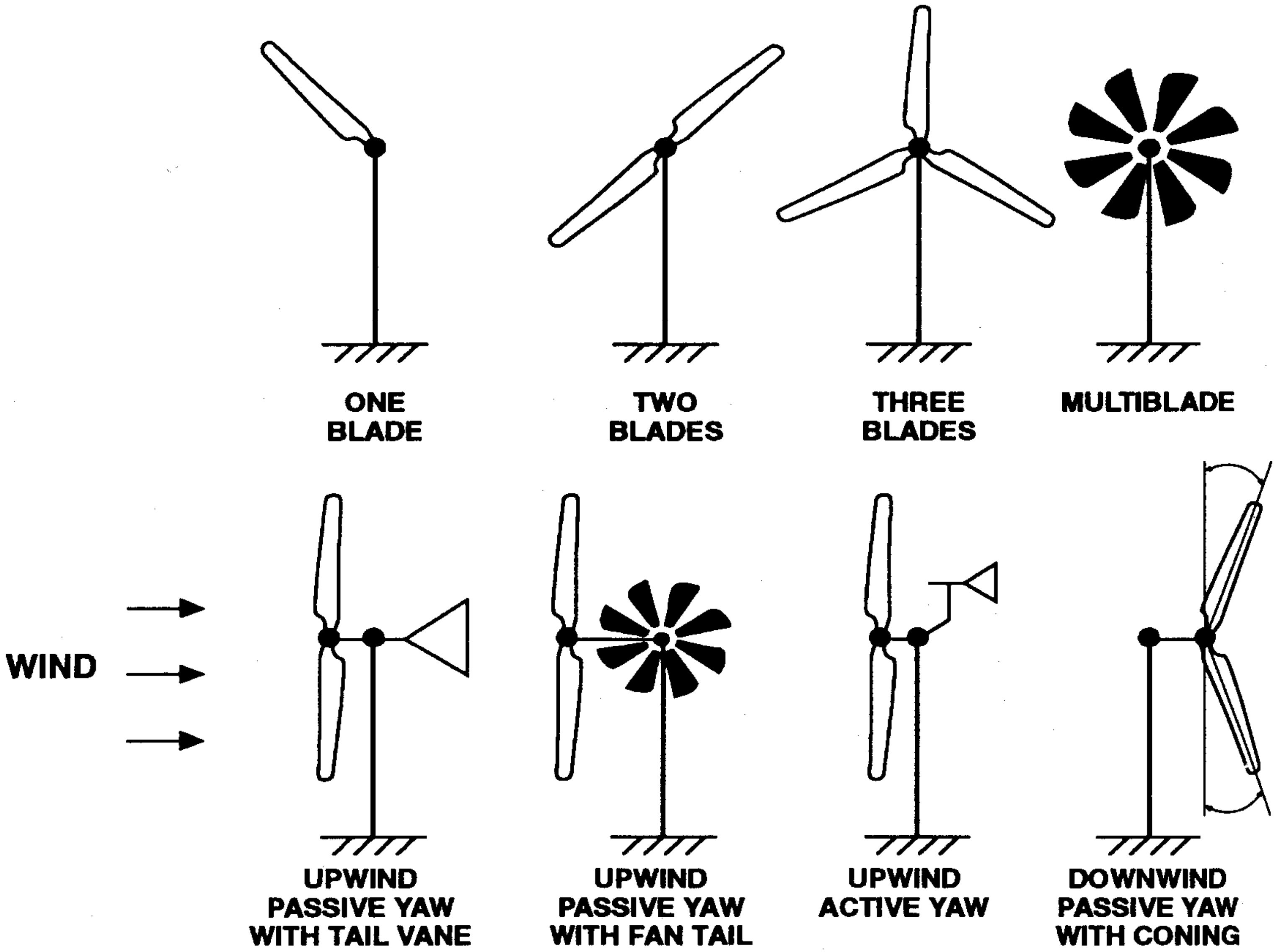


Fig.1.8 Turbine diameter growth with time.

1.3.2 Types of Wind Turbine Generators (WT)



The HAWT configurations

Vertical Axis WTs (VAWTs)

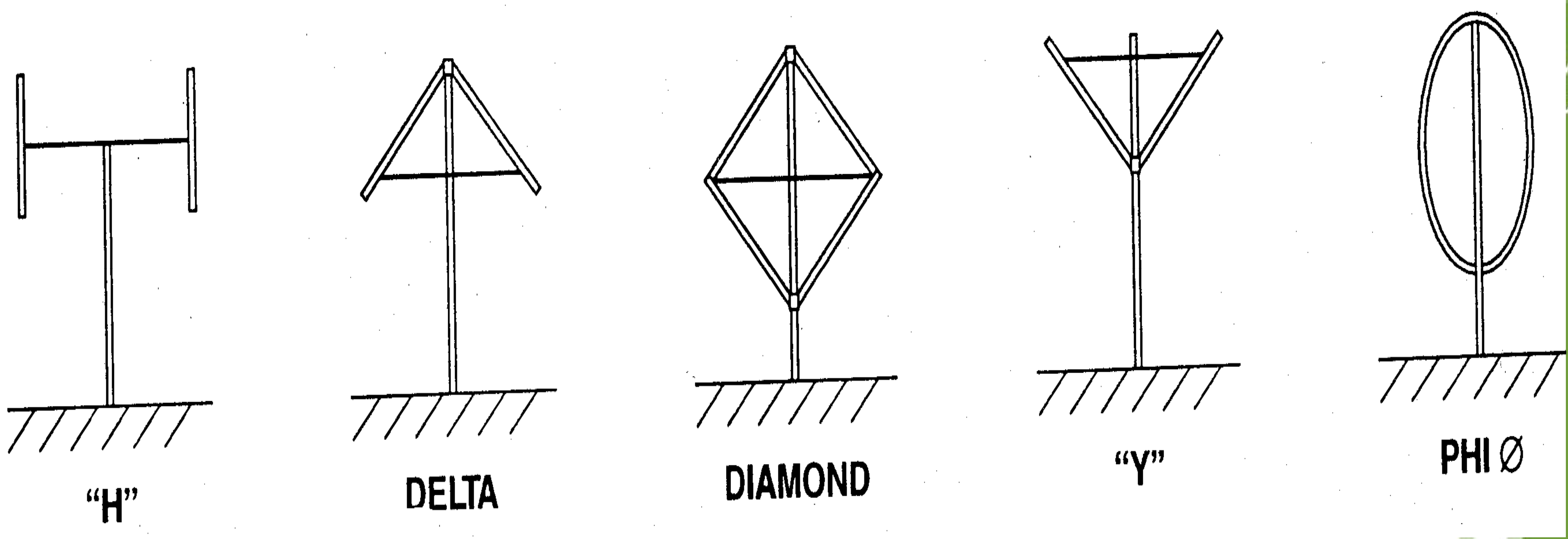
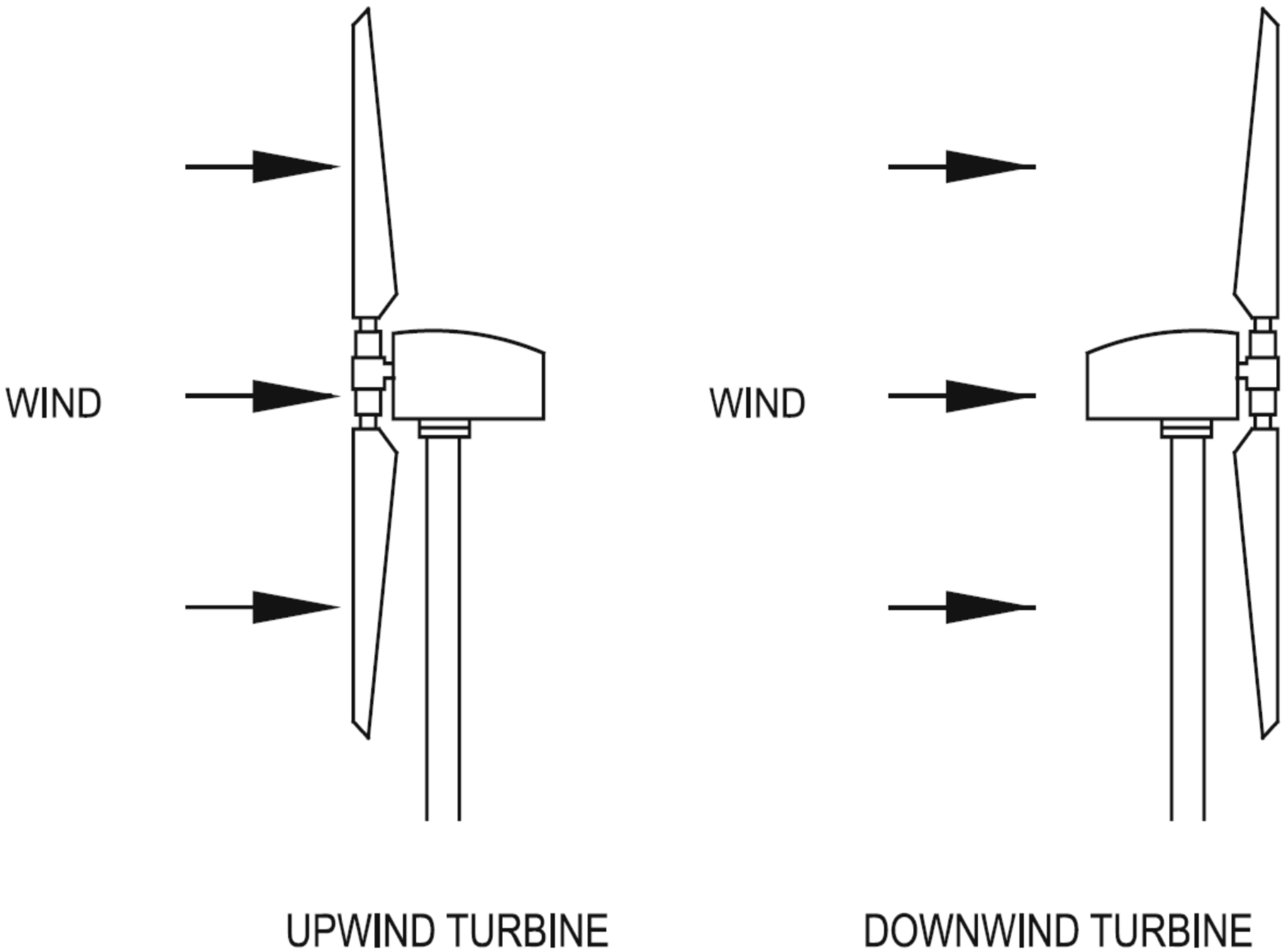


Fig. 1.10 The VA-WTs Configurations

Table (1.2) Comparison between HA-WTs and VA-WTs.

Items	**HA-WTs**	**VA-WTs**
Output power	Wide range	Narrow range
Starting	Self starting	Need starting means
Efficiency	Higher	Lower
Cost	Lower	Higher
Wind direction	Need redirected when the Wind change its direction	Does not needs redirected into the wind direction
Generator and gear box	At the top of the tower	At the ground level
Maintenance	Difficult	Easy

1.3.3 Upwind and Dawnwind WT



Upwind turbines have the rotor facing the wind as shown in Fig.1.11 (a). This technique has the following features:

- Avoids the wind shade that the tower causes which improve the power quality of the generated voltage and reduces the spicks in power when the blades move in front of the tower specially in constant speed systems.
- Fewer fluctuations in the power output.
- Requires a rigid hub, which has to be away from the tower. Otherwise, if the blades are bending too far, they will hit the tower.
- This is the dominant design for most wind turbines in the MW- range

Downwind WT have the rotor on the flow-side as shown in Fig.1.11 (b). It may be built without a yaw mechanism if the nacelle has a streamlined body that will make it follow the wind.

- Rotor can be more flexible: Blades can bend at high speeds, taking load off the tower. Allow for lighter build.
- Increased fluctuations in wind power, as blades are affected by the tower shade.
- Only small wind turbines.

1.3.4Number of Rotor Blades

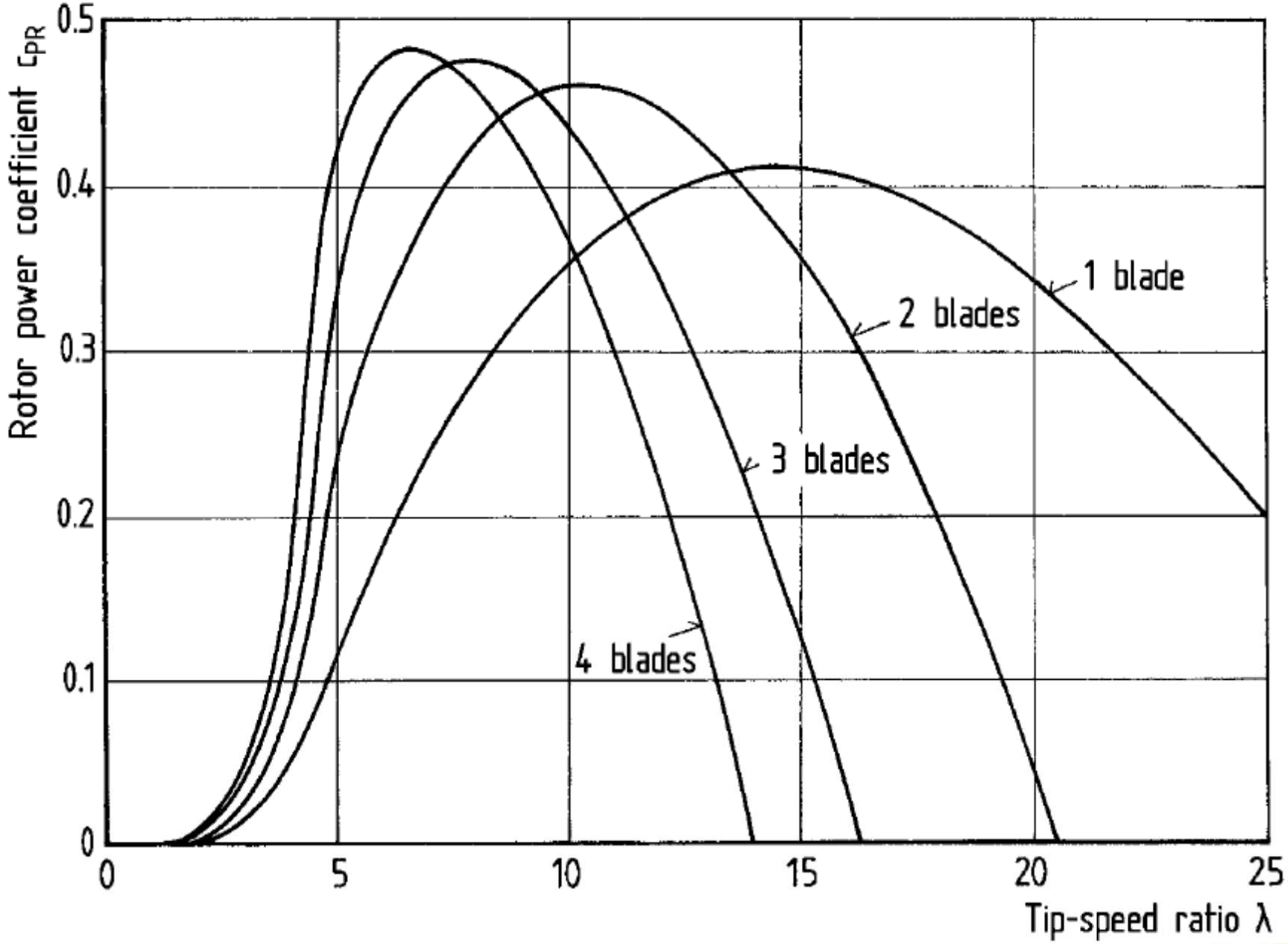


Fig.1.12. Influence of the number of blades on the rotor power coefficient (envelope) and the optimum tip-speed ratio.

Tip Speed Ratio

$$Tip\ speed\ ratio\ \lambda = \frac{u}{v_{\omega}} = \frac{tangential\ velocity\ of\ the\ rotor\ blade\ tip}{Speed\ of\ the\ wind}$$

Fig..13 shows one blade WT.

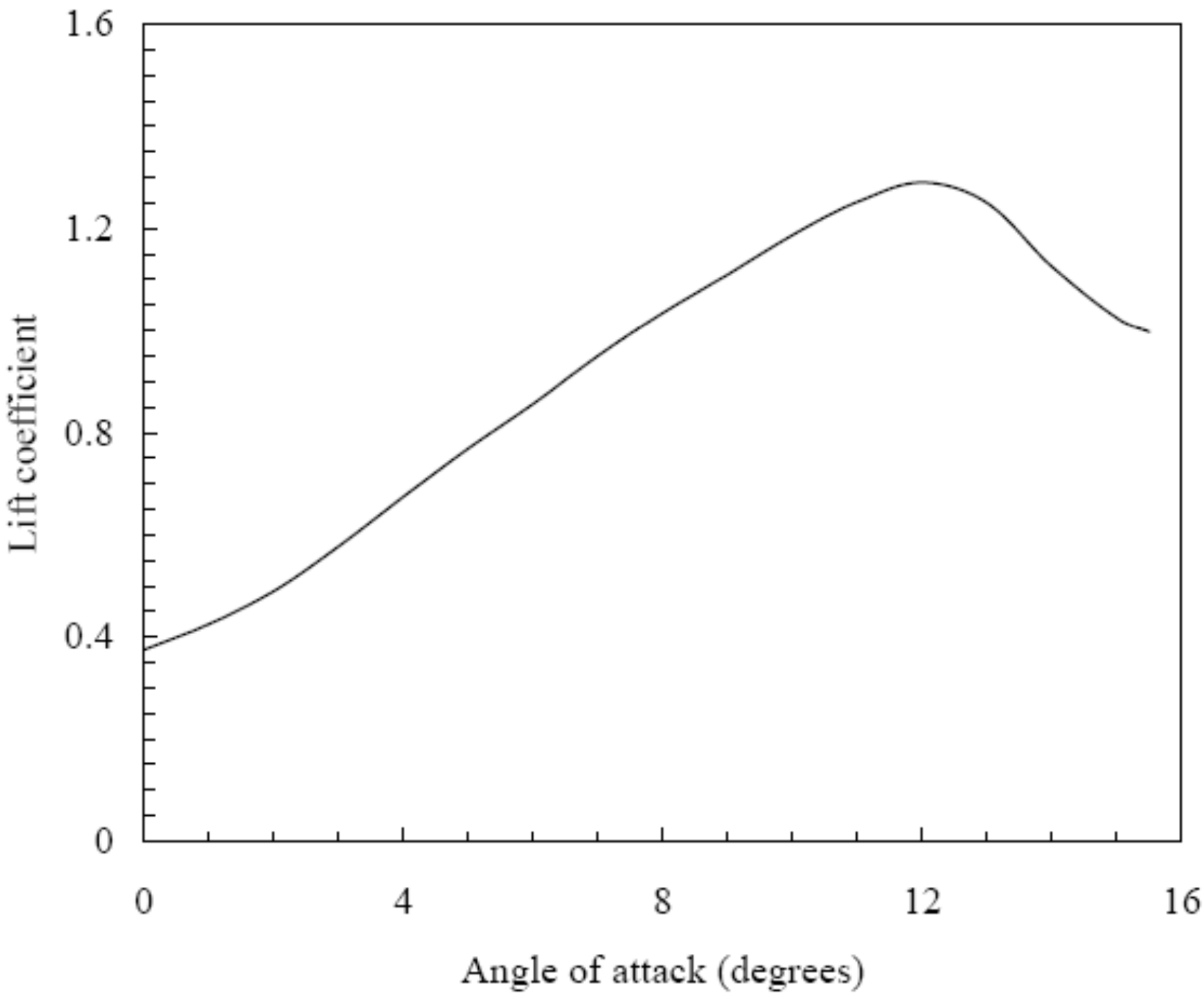


Fig.1.16. Effect of angle of attack on airfoil lift

1.Sitting of Wind Energy Plants

1.4.1 Wind Power

$$P_w = \frac{1}{2}\, \rho_a\, A\, V^3$$

where ρ_a : Air density, kg/m^3.

A: Cross sectional area of wind parcel, m^2.

V: The wind speed, m/sec.

$$V(Z) = V(Zg) * \left(\frac{Z}{Zg}\right)^{\alpha}$$

where Z : The height above the ground level, m.

Zg : The height of where the wind speed is measured, m.

α : The exponent, which depends on the roughness of the ground surface, its average value, is (1/7) [14].

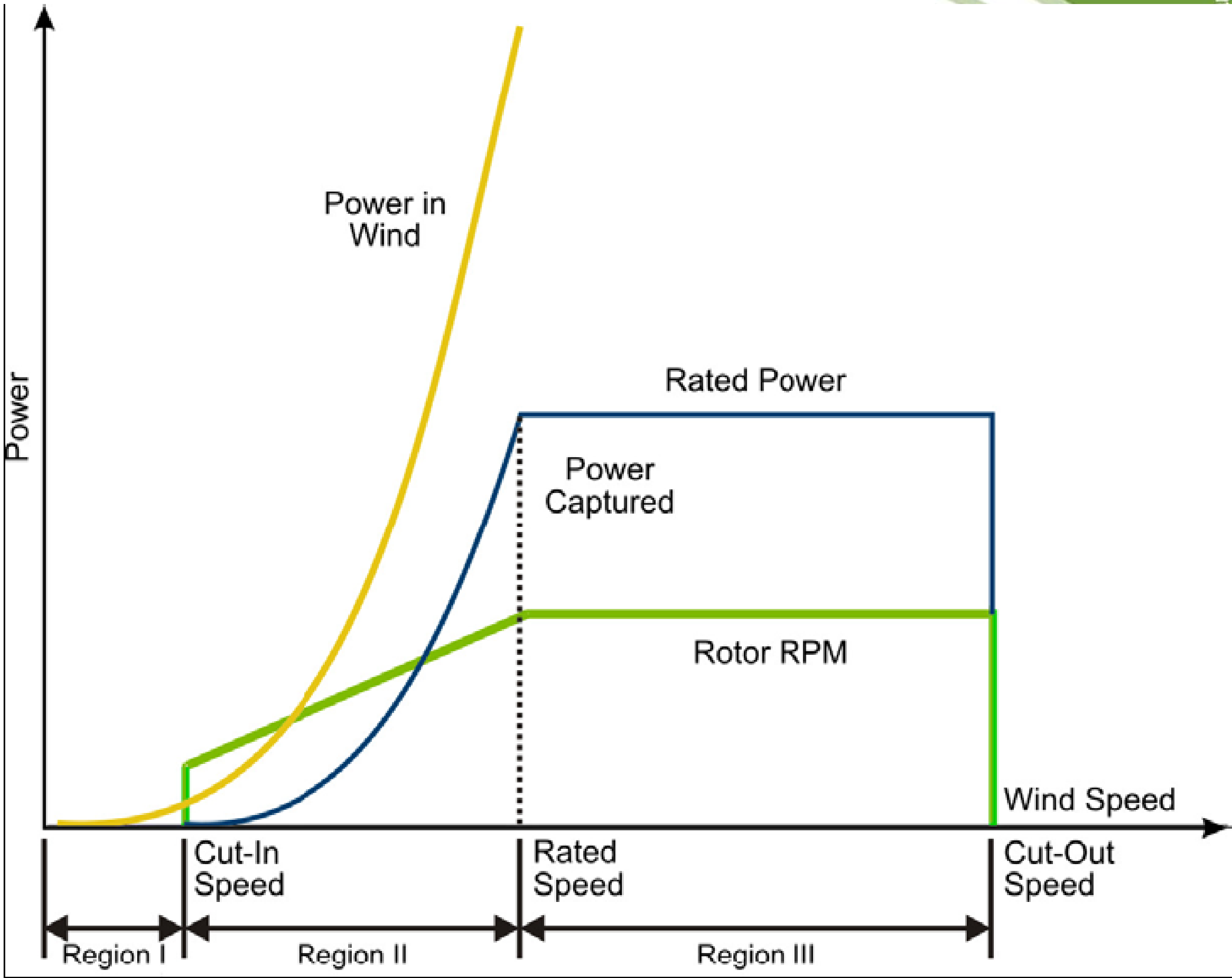


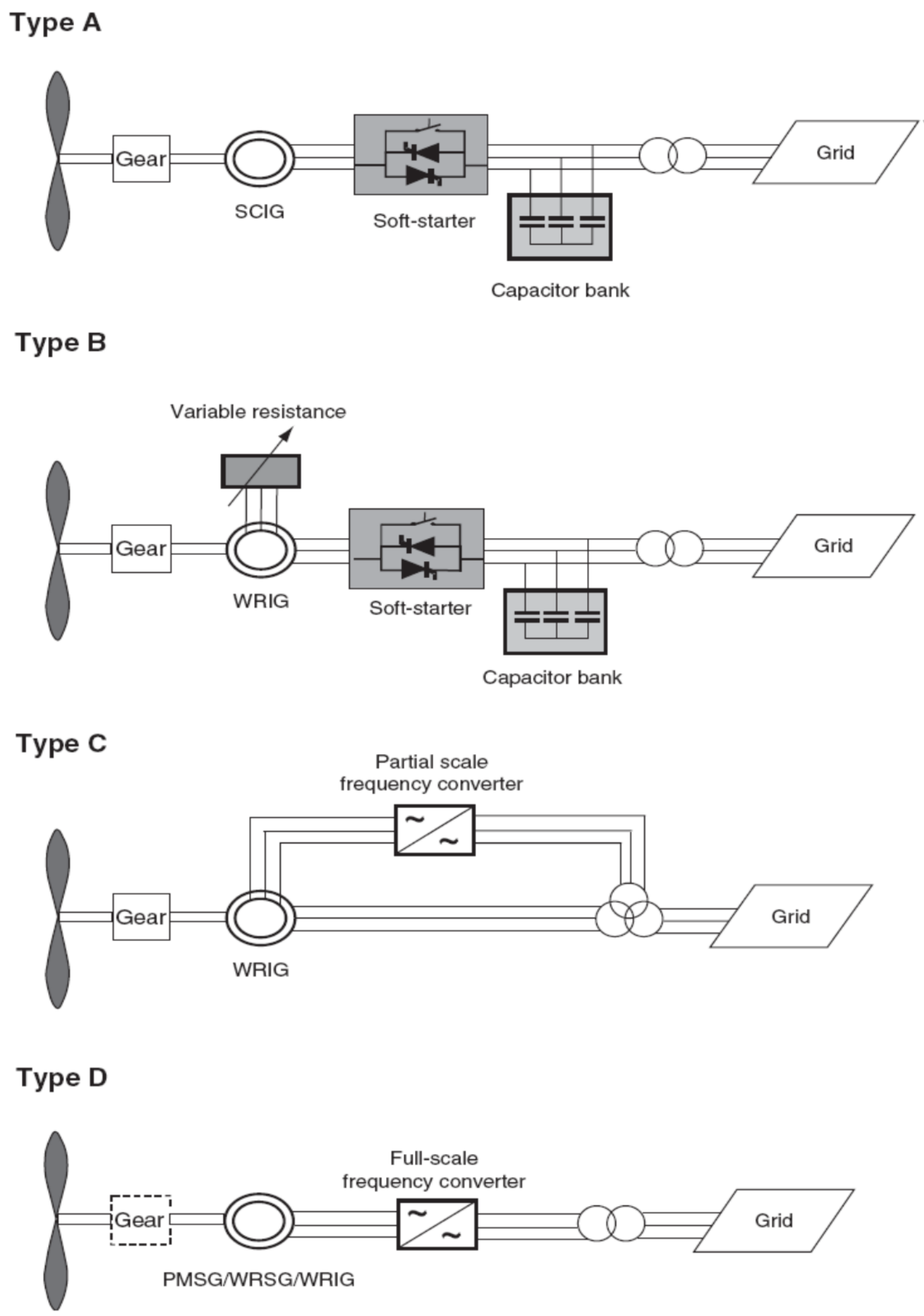
Fig. 1.22 Actual WT output power with the wind speed.

Project Development

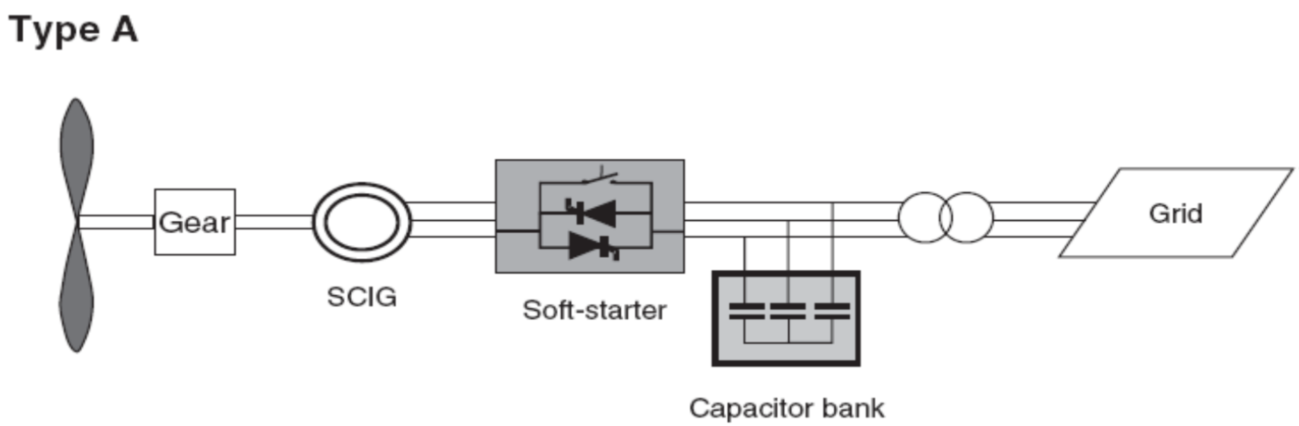
element of wind farm	% of total cost
Wind Turbines	65
Civil Works	13
Wind farm electrical infrastructure	8
Electrical network connection	6
Project development and management costs	8

Generators and Power Electronics for Wind Turbines.

State-of-the-art Technologies



Type A: Fixed Speed Concepts



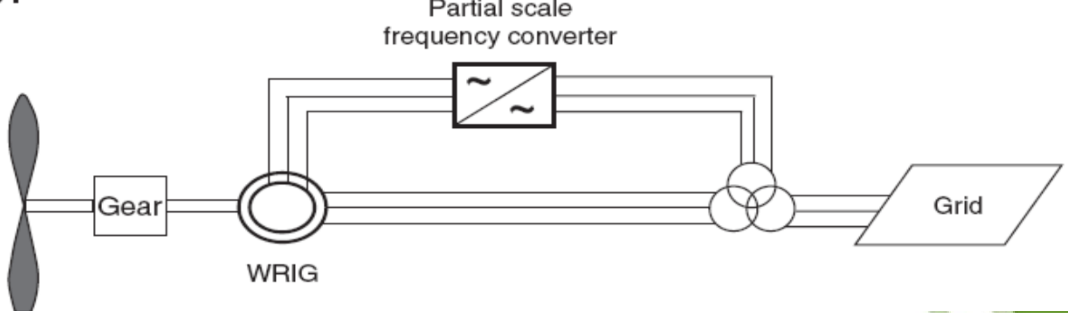
Type A0: Stall Control

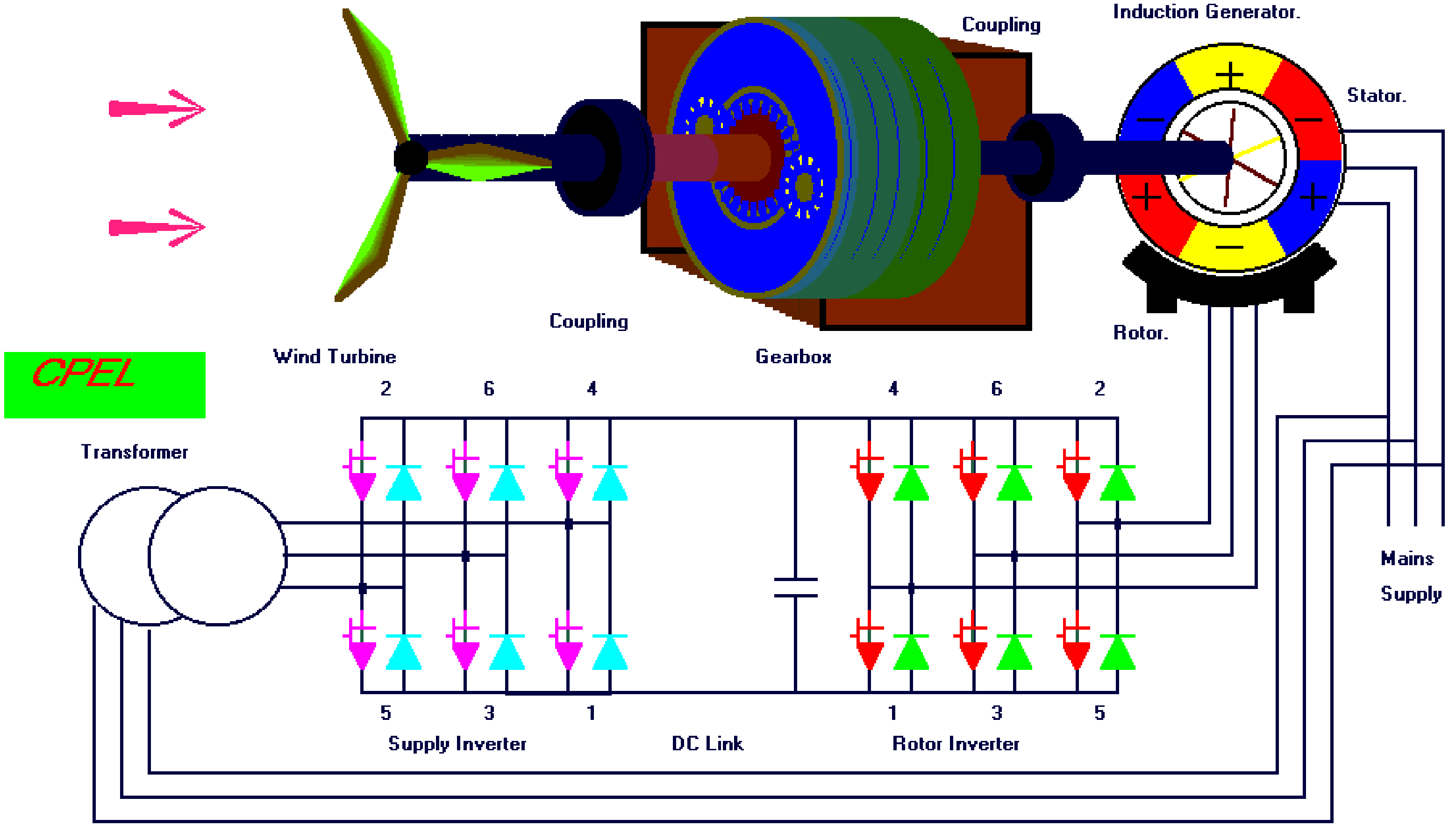
the wind fluctuations are converted into mechanical fluctuations and consequently into electrical power fluctuations.

very popular because of its relatively low price, its simplicity and its robustness. Stall-controlled wind turbines cannot carry out assisted startups.

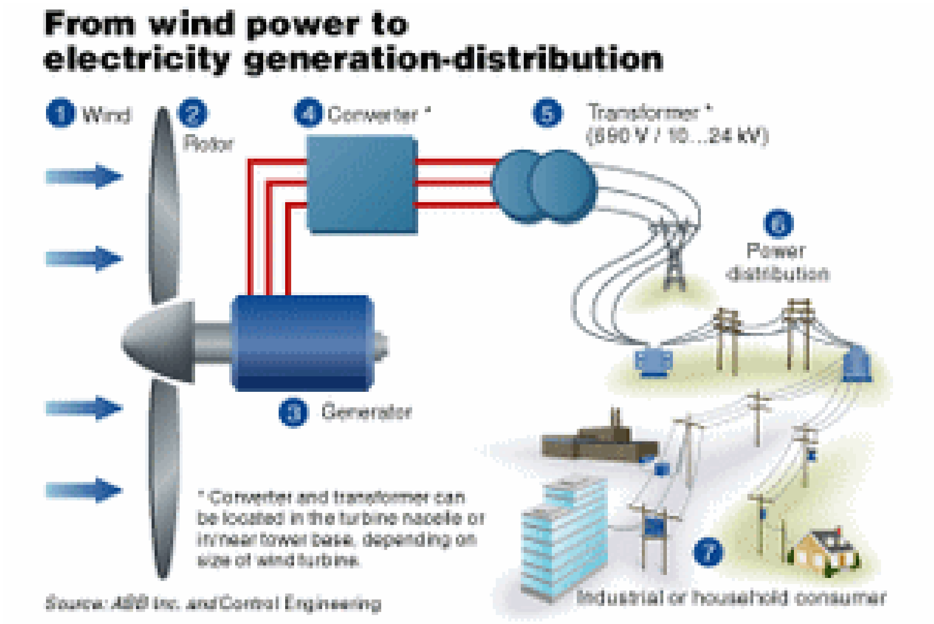
Type C: Variable Speed with Partial Scale Frequency Converter

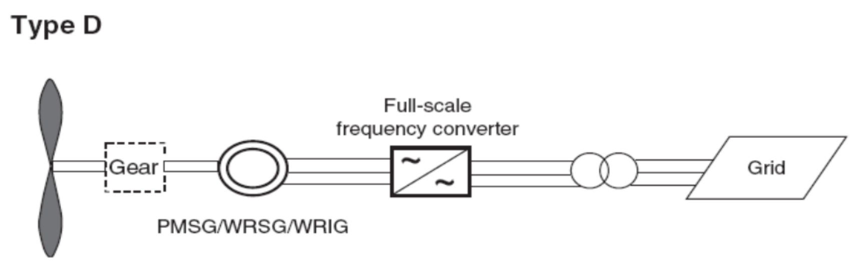
Type C





Type D: Variable Speed with Full-Scale Frequency Converter

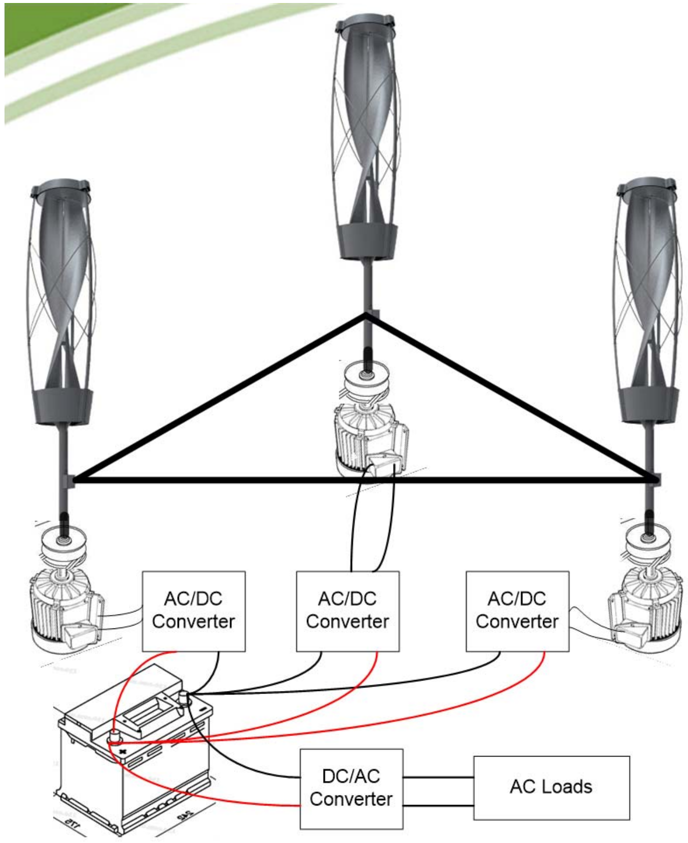


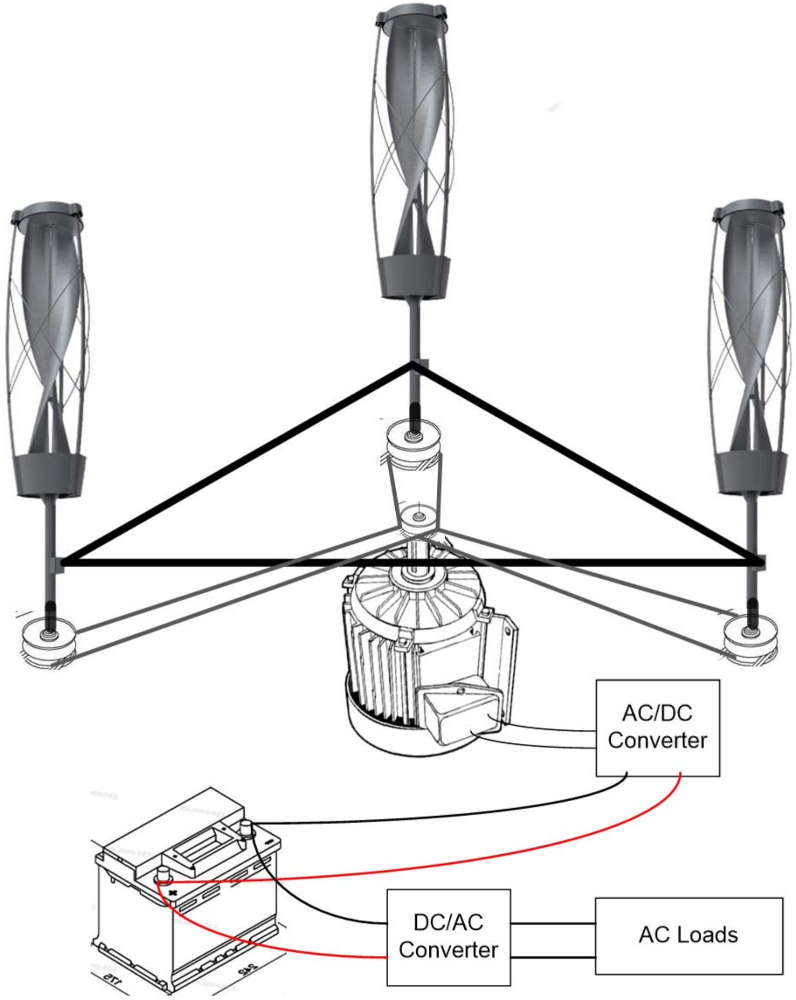


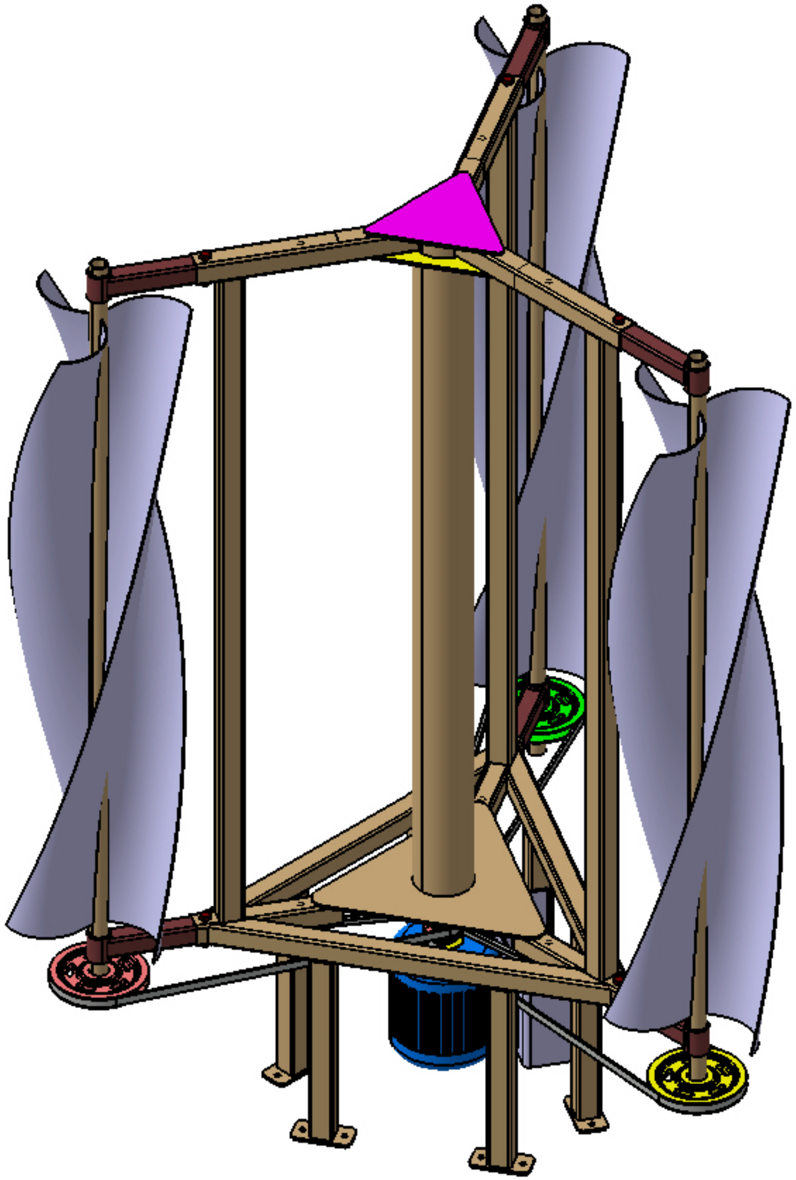
The frequency converter performs the reactive power compensation and the smoother grid connection.

The generator can be excited electrically as in case of WRSG or WRIG) or by a permanent magnet

New Multi Rotor One Generator Vertical Axis Wind Turbines







Innovative
wind turbine
design to
power the new
SET Building
with low cut-in
wind speed

US009752556B1

(12) **United States Patent**
Al-Saud et al.

(10) **Patent No.: US 9,752,556 B1**
(45) **Date of Patent: Sep. 5, 2017**

(54) **MULTI-ROTOR VERTICAL AXIS WIND TURBINE**

(71) Applicant: **KING SAUD UNIVERSITY**, Riyadh (SA)

(72) Inventors: **Mamdooh Saud Thinyyan Al-Saud**, Riyadh (SA); **Ali Mohamed Ahmed Eltamaly**, Riyadh (SA); **A. M. A. Al-Ahmari**, Riyadh (SA)

(73) Assignee: **KING SAUD UNIVERSITY**, Riyadh (SA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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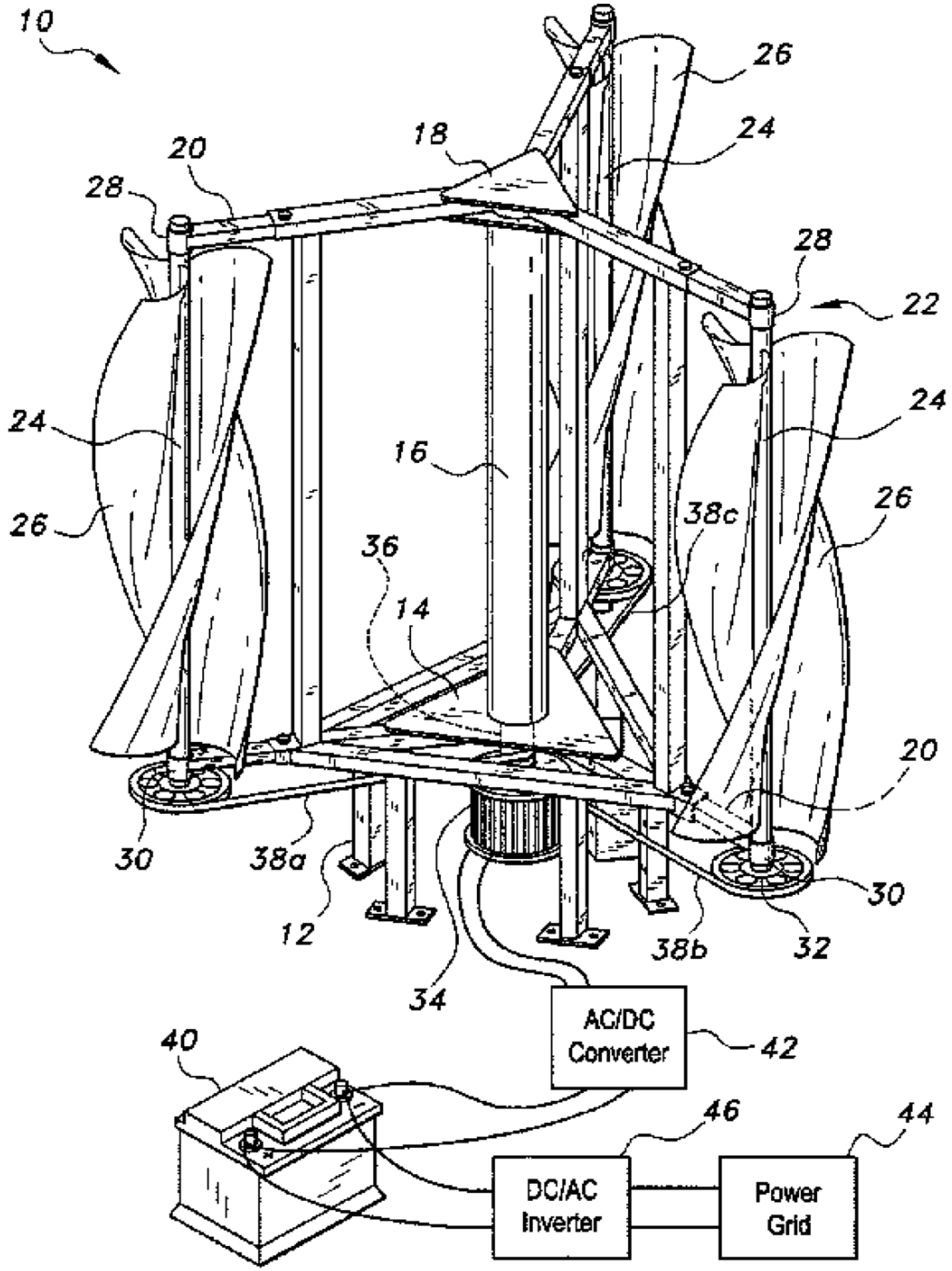
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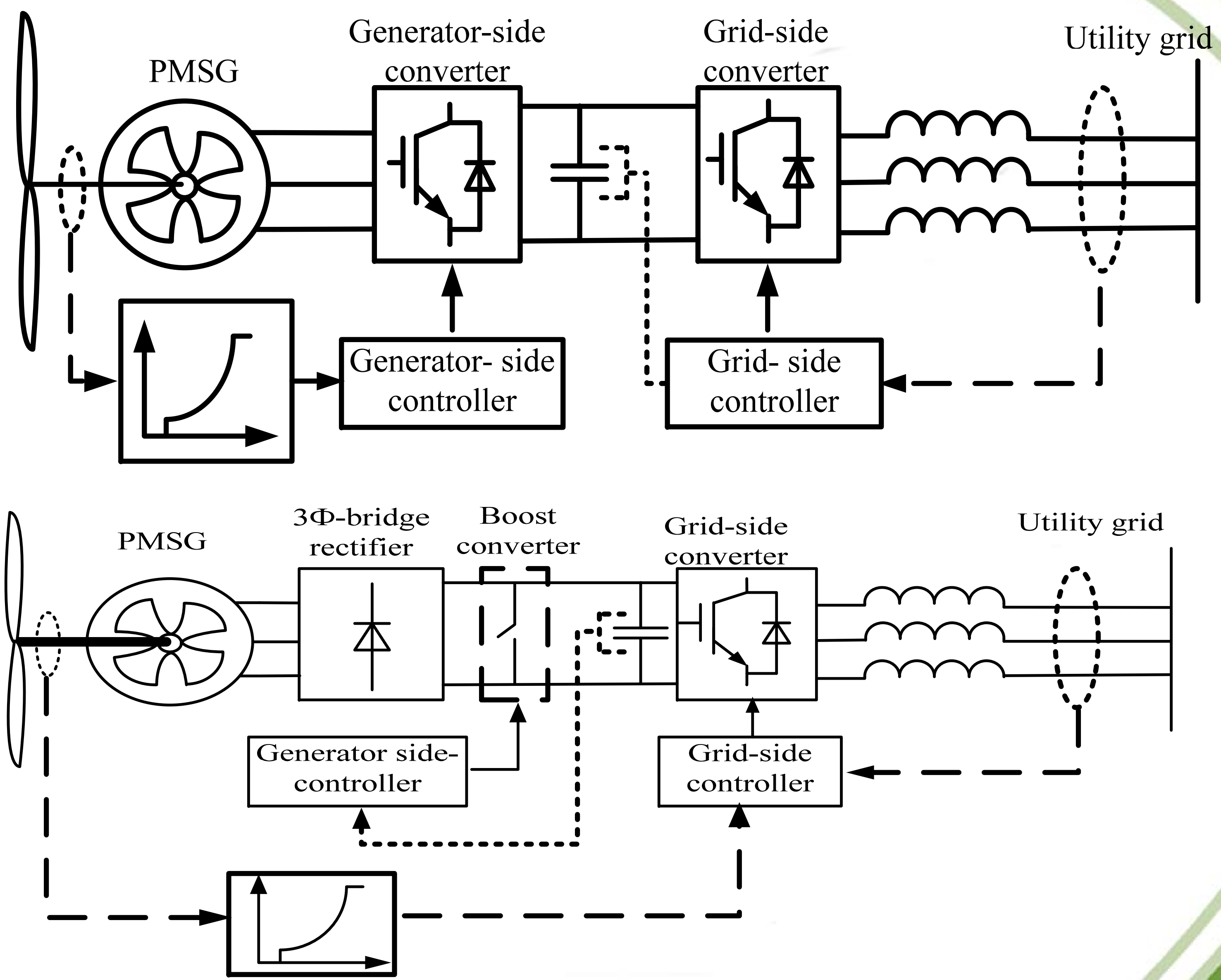
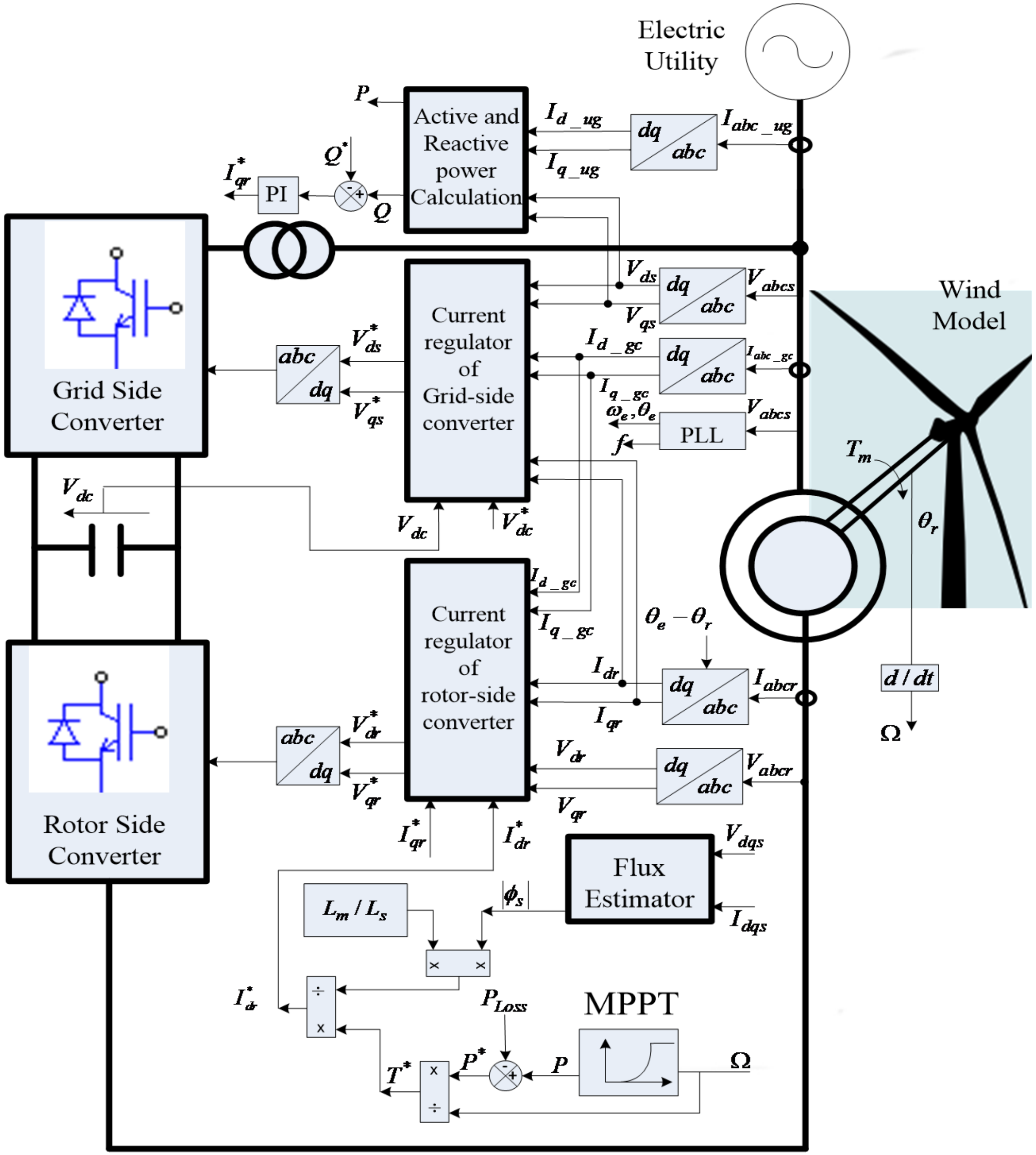
DC/AC
Inverter
Power
Grid

Maximum Power Extraction from WTs

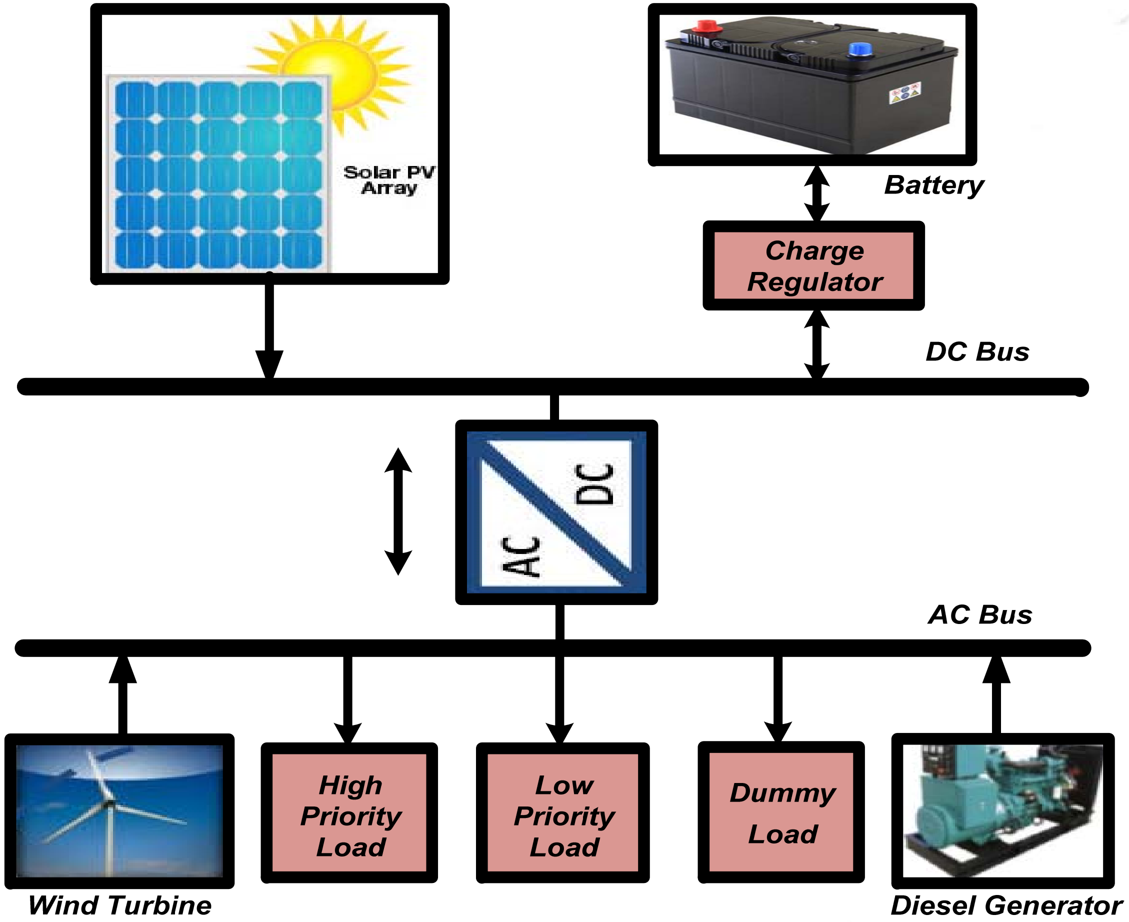


Maximum Power Extraction from DFIG



Smart Grid applications in HRES

Design and Implementation of Smart Grid for Hybrid Renewable Energy System using Smart Techniques



A Novel Neural Network Harmonic Reduction Technique for Controlled Converter by Third Harmonic Current Injection