POWER ELECTRONIC DEVICES FOR WIND TURBINES

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During the last two decades, the production of wind turbines has grown in size from 20 kW to 2 MW. The electrical part of a wind turbine is becoming more and more important and, it is very important to have this system highly integrated into the overall wind turbine design.

Electrical developments include the use of advanced power electronics in the wind generator system design, introducing a new control concept, namely variable speed. Due to the rapid development of power electronics, offering both higher power handling capability and lower price/kW, the application of power electronics in wind turbines will increase further. Another interesting issue is the efforts, which have been put into research and development of new motor/generator concepts for some years.

The following presentation will look deeper into old and new concepts of generators and power electronics.

Keywords: Power electronics, Wind turbines, Renewable energy sources

1. GENERAL PRESENTATION OF THE ELECTRICAL PART OF THE WIND TURBINES

The concepts using power electronics configurations most commonly applied in wind turbines are displayed in Figure 1 for asynchronous generators and in Fig 2 for synchronous generators.

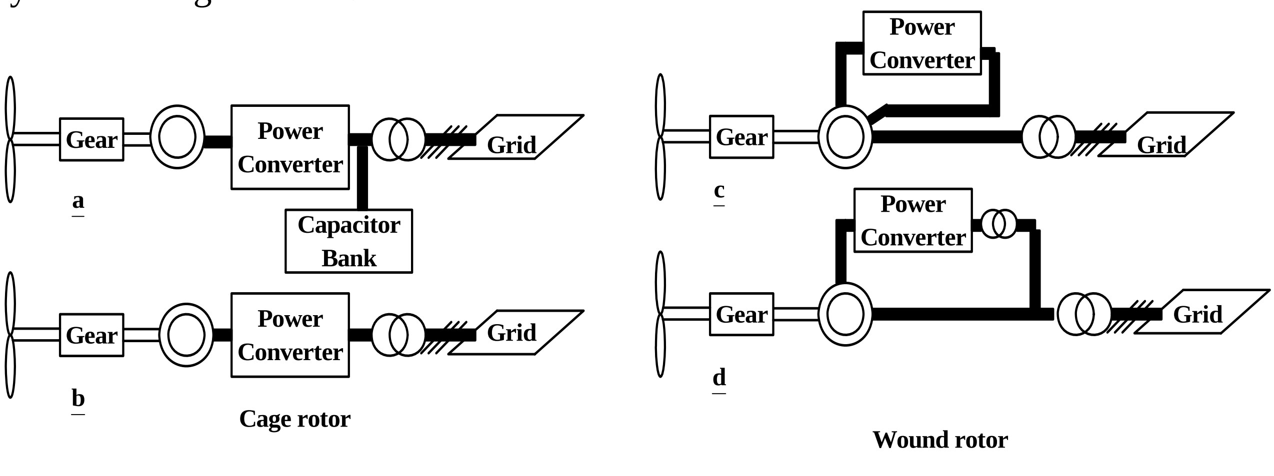

Fig. 1 - asynchronous generators

a) Conventional concept applied by many Danish wind turbine manufacturers. Stall regulated, three bladed wind turbine concepts using an induction generator (cage rotor). This concept was extended with a capacitor bank (for reactive power compensation) and a soft-starter (for smoother grid connection).

b) The capacitor bank and soft-starter are replaced by either a full-scale frequency converter or a low wind region sized frequency converter. This concept uses a smaller frequency converter (20-30% of nominal generator power) compared to the full-scale concept (approximately 120%). On the other hand the full-scale concept enables variable speed operation at all wind speeds.

c) This configuration employs a wound rotor. The basic idea of this concept is to control the total rotor resistance using a variable external rotor resistance by means of a power electronic (PE) converter. With the power electronic converter mounted on the rotor shaft, it is possible to control the slip (by controlling the external rotor resistance) over a 10% range. Control of the slip implies control of the power output in the system. However, this concept does not support controllable slip.

d) Other configuration in wind turbines employs a doubly fed induction generator. A frequency converter directly controls the currents in the rotor windings. This enables control of the whole generator output, using a PE converter, rated at 20-30% of nominal generator power. Introduction of this concept is mainly motivated by two reasons: 1) Variable speed in a wide speed range and 2) Less expensive compared to the full power control concept.

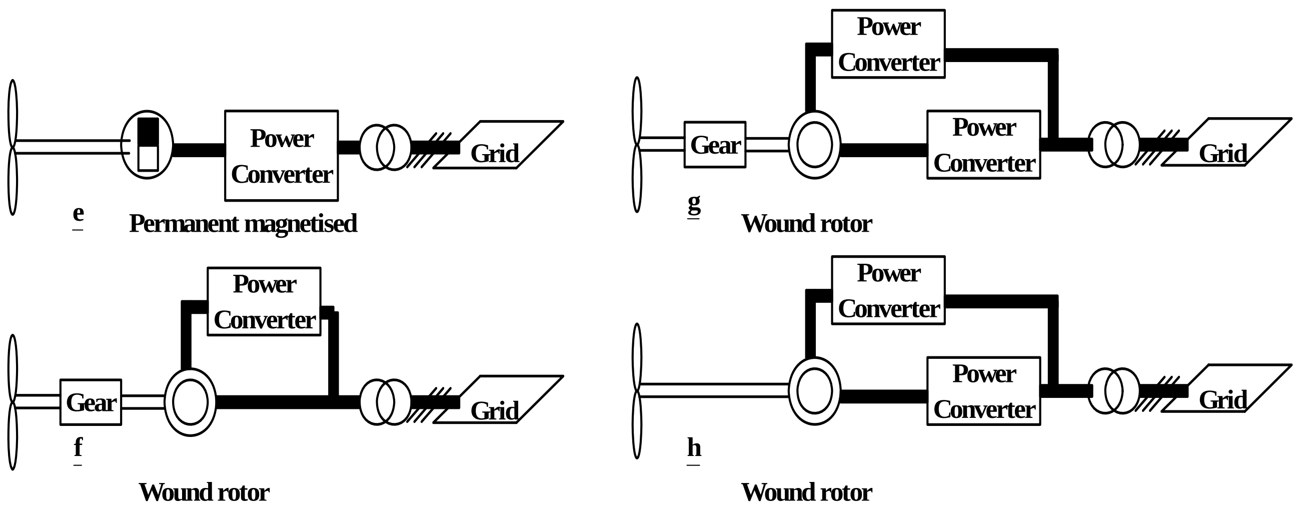

Fig. 2 - synchronous generators

e) This configuration is applied in wind turbines for home wind systems and hybrid systems, i.e. wind turbines larger than 1kW and smaller than approximately 20kW. A future concept using this configuration has been suggested in year 2000 by ABB with multipole 3.5MW PMG (Permanent Magnet Generator) and with a diode-rectifier produces 21kV DC. It is proposed to combine this configuration with a HVDC-light based grid.

f) This configuration is not widely used in wind turbines. It is externally excited as shown in the figure using a rectifier (the Power Converter). The low utilization could be due to three reasons:

- the need for an exciter circuit
- the need for slip rings and
- a more complex wind turbine safely strategy;

g) This configuration either is widely used in wind turbines. Compared to the previous configuration, this one supports variable speed, if the grid power converter is a four-quadrant frequency converter

h) In this configuration a multipole wound SG is used. In principle, it is the same as the previous configuration, but due to the multipole generator no gearbox is needed. The wind turbine companies Enercon and Lagerwey are examples of manufacturers using this configuration.

Configuration "a" is the only commonly applied control concept, which does not support variable speed operation.

2. ROAD MAP FOR CONVERSION OF MECHANICAL ENERGY INTO ELECTRICAL ENERGY

Excluding the presented configuration for a while, a road map for conversion of mechanical energy into electrical energy may be drawn, as presented in Figure 3. The focus in Figure 3 is the applied generator concept used in the conversion of a mechanical torque input at variable speed to an electrical power output at fixed frequency. Thus, except for configuration "a", the other configurations in Figures 1 and 2 (alias Table 1) are classified in the road map.

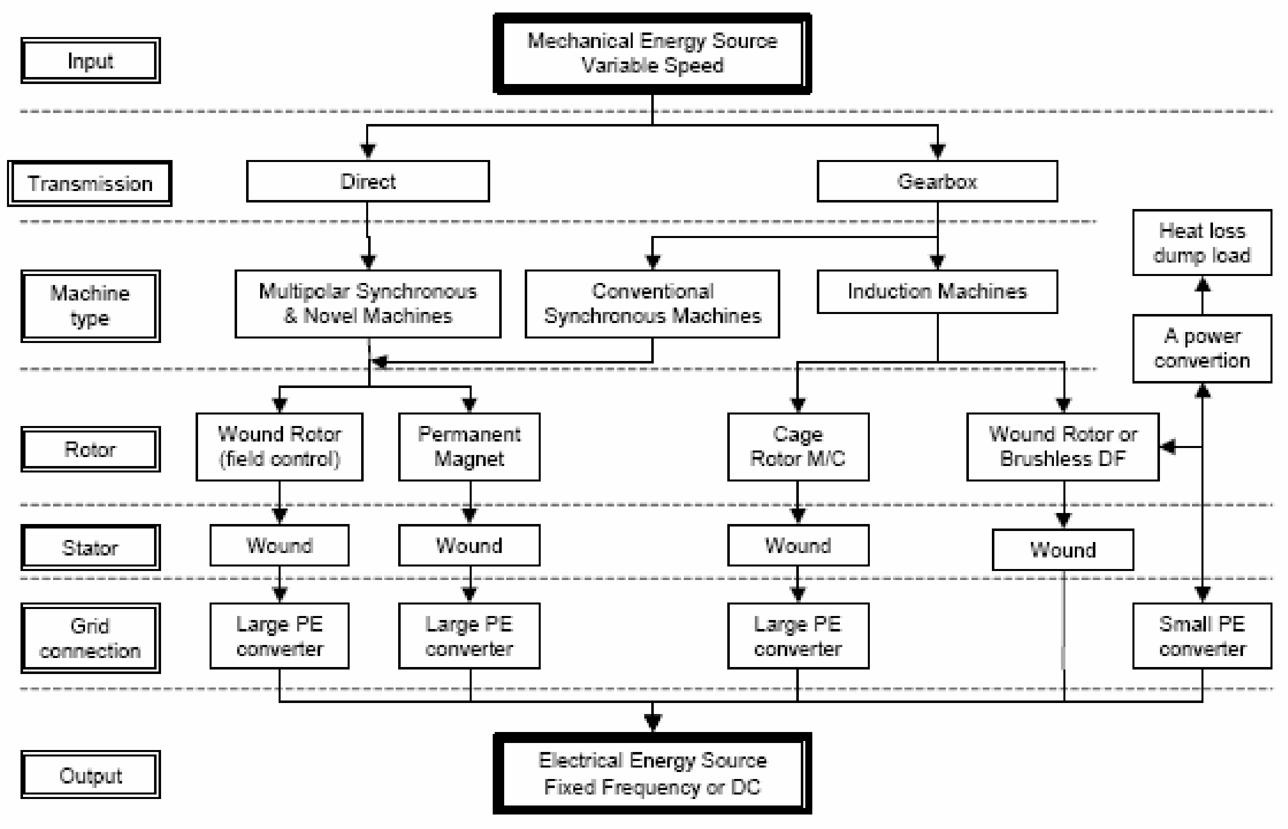

Fig. 3

In Table 1 the voltage and current are presented with their maximum ratings. The switch off time is related to the circuit-commutated recovery time, while the pulse bandwidth defines the operational frequency range. A traditional AC frequency converter (also called a drive), as seen from the grid, consists of a rectifier (AC to DC unit), energy storage, and an inverter (DC to AC with controllable frequency).

Switch type	GTO	IGCT	BJT	MOSFET	IGBT
Voltage (V)	6000	4500	1200	1000	3300
Current (A)	4000	2000	800	28	2000
Switched-off time (μs)	10-25	2-5	15-25	0.3-0.5	1-4
Pulse bandwidth (kHz)	0.2-1	1-3	0.5-5	5-100	2-20
Drive requirements	High	Low	Medium	Low	Low

Table 1

Type of the semiconductors is following:
GTO – Gate Turn Off Thyristor
IGCT – Integrated Gate Commutated Thyristors
BJT – Bipolar Junction Transistor
MOSFET – Metal-Oxide-Semiconductor Field Effect Transistor
IGBT – Insulated Gate Bipolar Transistor

A diagram of the basic inverter concepts is shown in Figure 4.

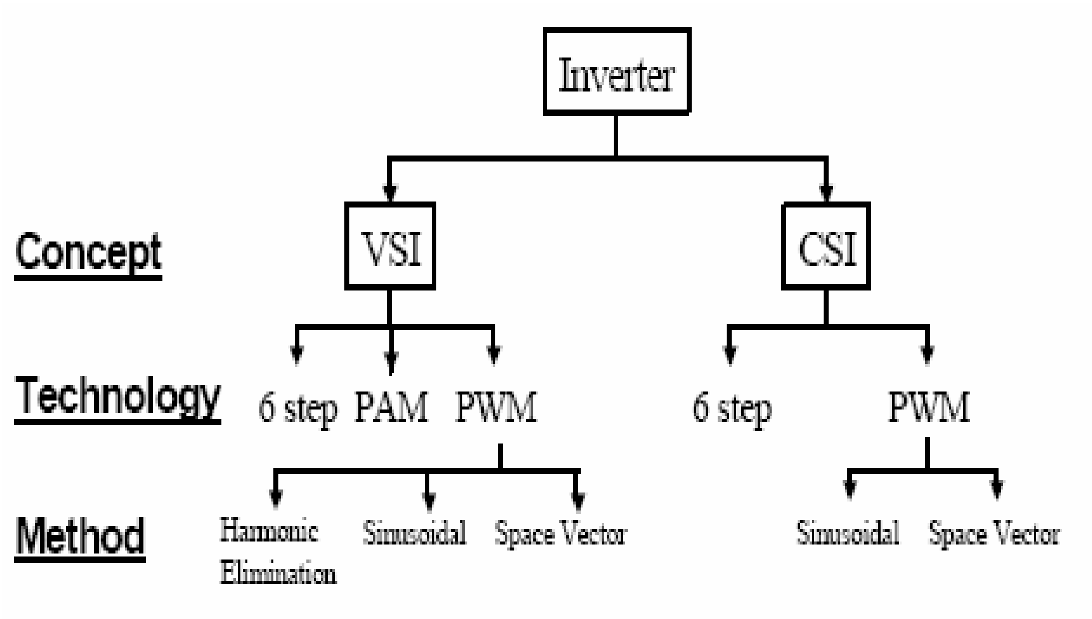

Fig. 4

VSI – Voltage Source Inverter
CSI – Current Source Inverter
PWM – Pulse Width Modulation
PAM – Pulse Amplitude Modulation

VSI creates a relatively well-defined switched voltage waveform at the terminals of the electrical machine. In the case of a VSI, the voltage in the energy storage (the DC bus) is maintained stiff by a large capacitor or a DC source e.g. a battery, while the resulting current is primarily formed by the load and speed.

In a CSI the opposite is the case, the current in the energy storage (the DC bus) is maintained stiff using a large inductor, while the resulting voltage is primarily formed by load and speed. Thus, Voltage source inverter and Current source inverter are dual. It must be paid attention that VSI and CSI are quite different concepts. As indicated in Figure 4, the concepts of VSI and CSI may both be implemented by the following three methods:

- Six step inverter
- Pulse amplitude modulated PAM
- Pulse width modulated inverter PWM.

Moreover, the implementation of a Pulse Width Modulation inverter for a VSI e.g. may be realized by the following three methods:

- Harmonic elimination
- A sinusoidal PWM converter
- A space vector strategy converter.

3. THE GRID PERFORMANCE OF THE VARIOUS CONFIGURATIONS

The grid performance of the various configurations of Figures 1 and 2 depends on the applied frequency converter technology. In Table 2, some grid performance issues are presented for each configuration.

Config.	Voltage Control	Reactive power control	Grid demand
a	No	No, reactive power consumer with step-wise compensation	Stiff
b	1) Yes 2) Yes	1) No, reactive power consumer 2) Yes, constant cos(φ) or constant reactive power	1) Stiff 2) Stiff or weak
c	2) Yes	2) Constant cos(φ) or constant reactive power could be made possible	2) Stiff or weak
d	1) Yes 2) Yes	1) No, reactive power consumer 2) Yes, constant cos(φ) or constant reactive power	1) Stiff or weak 2) Stiff or weak
e	1) Yes 2) Yes	1) No, reactive power consumer 2) Yes, constant cos(φ) or constant reactive power	1) Stiff 2) Stiff or weak
f	No	Yes, e.g. constant cos(φ)or constant reactive power	Stiff
g	1) Yes 2) Yes	1) No, reactive power consumer 2) Yes, constant cos(φ) or constant reactive power	1) Stiff 2) Stiff or weak
h	1) Yes 2) Yes	1) No, reactive power consumer 2) Yes, constant cos(φ) or constant reactive power	1) Stiff 2) Stiff or weak

Table 2

The applied concepts of the top-10 world manufacturers is presented at Table 3.

Manufacture (top 10 supp.)	Wind turbine	Conf. Fig. 2	Power control features	Comments
NEG Micon	NM 2000/72	a	Active stall	Two speed
	NM 1500C/64	a	Stall	Two speed
Vestas	V80 – 2MW	d	Pitch and variable speed	905rpm-1915rpm
	V66 – 1.65 MW	c	Pitch and OptiSlip	1500rpm-1650rpm
Gamesa	G52 – 850 kW	d	Pitch and variable speed	900rpm-1650rpm
	G47 – 660 kW	d	Pitch and variable speed	1200rpm-1626rpm
Enercon	E-66 – 1.8 MW	h	Pitch and variable speed	Gearless 10-20rpm

	E-58 – 1 MW	h	Pitch and variable speed	Gearless 10-24rpm
Enron Wind	1.5s – 1.5 MW	d	Pitch and variable speed	989rpm-1798rpm
	900s – 900kW	d	Pitch and variable speed	1000rpm-2000rpm
Bonus	2 MW	a	Active stall	Two speed
	1.3 MW	a	Active stall	Two speed
Nordex	N80/2500 kW	d	Pitch and variable speed	700rpm-1303rpm
	N60/1300 kW	a	Stall	Two speed
Made	No technical information was available on the Internet			
Ecotecnia	No technical information was available on the Internet			
Dewind	D4 – 600 kW	d	Pitch and variable speed	680rpm-1327rpm
	D6 – 1.25 MW	d	Pitch and variable speed	700rpm-1350rpm

Table 3

There could be seen the maximum power ratings of the real actually manufactured wind turbines.

4. CONCLUSION

On the base of the analysis of the applied concepts could be summarized the following:

- The manufacturers applying configuration "d" and "h" all use IGBT based converters. The present state of the art - large wind turbine may be summarized as a 3-bladed upwind turbine (with tubular tower) using: Active stall with a two speed asynchronous generator or Pitch control combined with variable speed. The variable speed concept is mainly realized using configuration "d", i.e. a doubly-fed induction generator with a rotor connected IGBT based frequency converter.
- The concepts, which were presented, are interesting for the power electronics specialists at the moment of the increasing application of the wind turbines all over the world and particularly in Bulgaria.

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