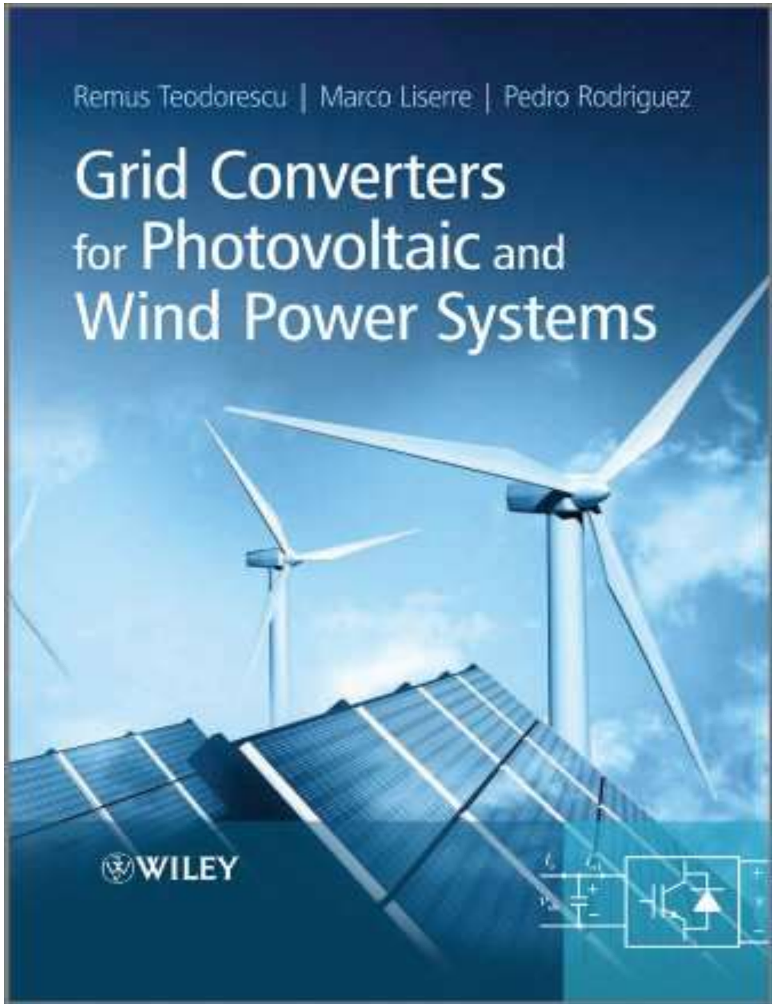
Renewable Electric Energy Systems EE—546

Wind Power Generation

Dr. U. T. Shami

Wind Power Generation Part—2: Slides are prepared



R. Teodorescu, M. Liserre, P. Rodr´ıguez—Grid Converters for Photovoltaic and Wind Power Systems

Advantages and disadvantages,
WTS Power Configurations,
Grid Power Converter
Topologies,
Single-Cell,
Multi-cell,
WTS Control,
Generator-Side Control,
WTS Grid Control.

Advantages and Disadvantages

Advantages

1. Wind energy is environment friendly as no fossil fuels are burnt to generate electricity from wind energy.

2. Wind turbines take up less space than the average power station.

3. Modern technologies are making the extraction of wind energy much more efficient. Wind is free, so only installation cost is involved and running costs are low.

4. Wind energy is the most convenient resource to generate electrical energy in remote locations, where conventional power lines cannot be extended due to environmental and economic considerations.

Advantages and Disadvantages

Disadvantages

1. The main disadvantage of wind energy is varying and unreliable wind speed. When the strength of the wind is too low to support a wind turbine, little electricity is generated.

2. Large wind farms are required to generate large amounts of electricity, so this cannot replace the conventional fossil fueled power stations. Wind energy can only substitute low energy demands or isolated low power loads.

3. Larger wind turbine installations can be very expensive and costly to surrounding wildlife during the initial commissioning process.

4. Noise pollution may be problem if wind turbines are installed in the densely populated areas.

WTS Power Configurations

The basic power configuration of a wind turbine system is made of two parts: a mechanical part and an electrical one (see Figure 6.1). The first subsystem extracts the energy from the wind and makes the kinetic energy of the wind available to a rotating shaft; the second subsystem is responsible for the transformation of the electrical energy, making it suitable for the electric grid. The two subsystems are connected via the electric generator, which is an electromechanical system and hence transforms the mechanical energy into electrical energy

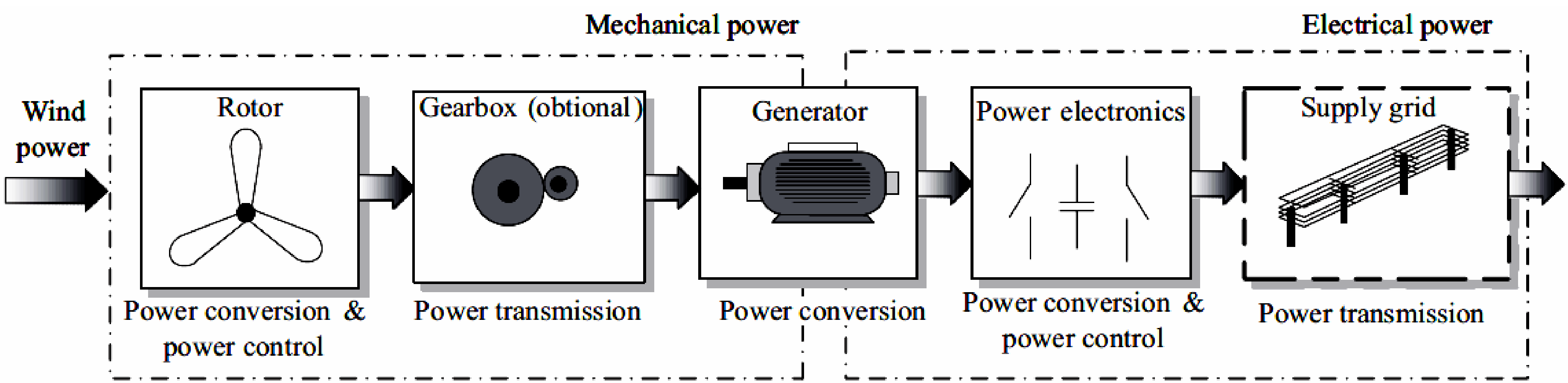


Figure 6.1 Basic power conversion wind turbine system

WTS Power Configurations

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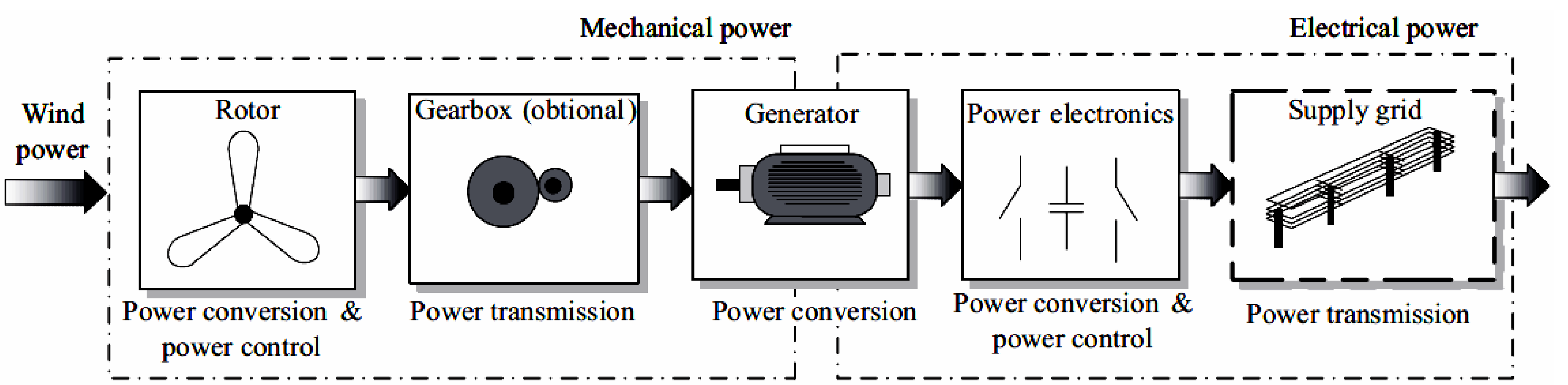


Figure 6.1 Basic power conversion wind turbine system

WTS Power Configurations

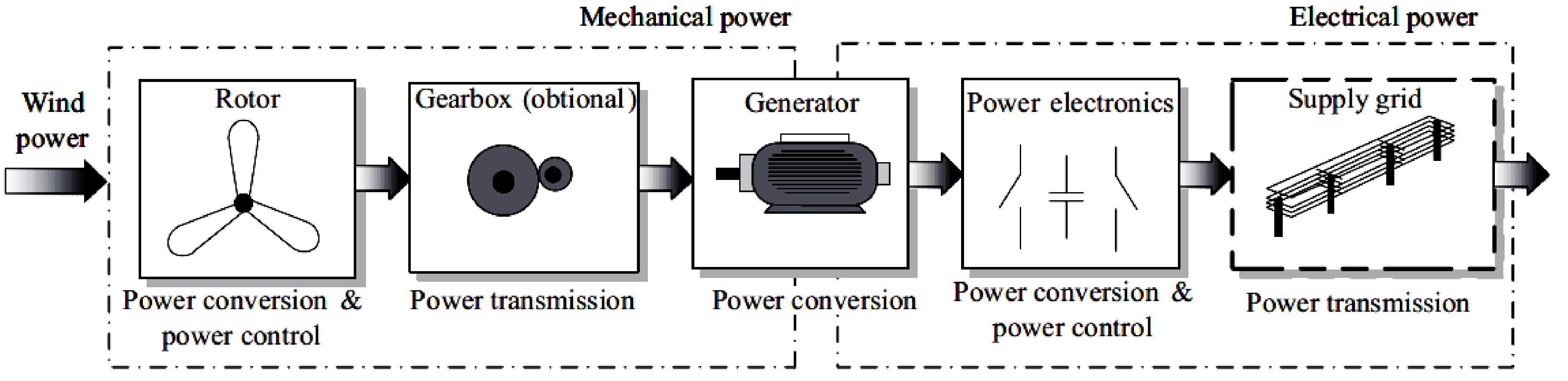


Figure 6.1 Basic power conversion wind turbine system

WTS Power Configurations

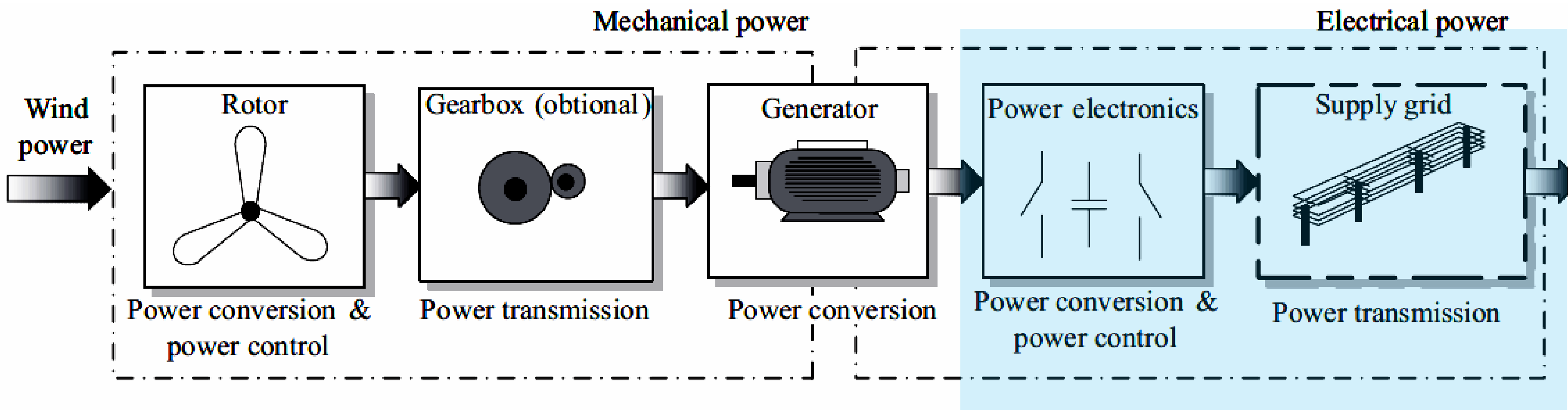


Figure 6.1 Basic power conversion wind turbine system

Power electronics converters may be present in the second and/or third stages

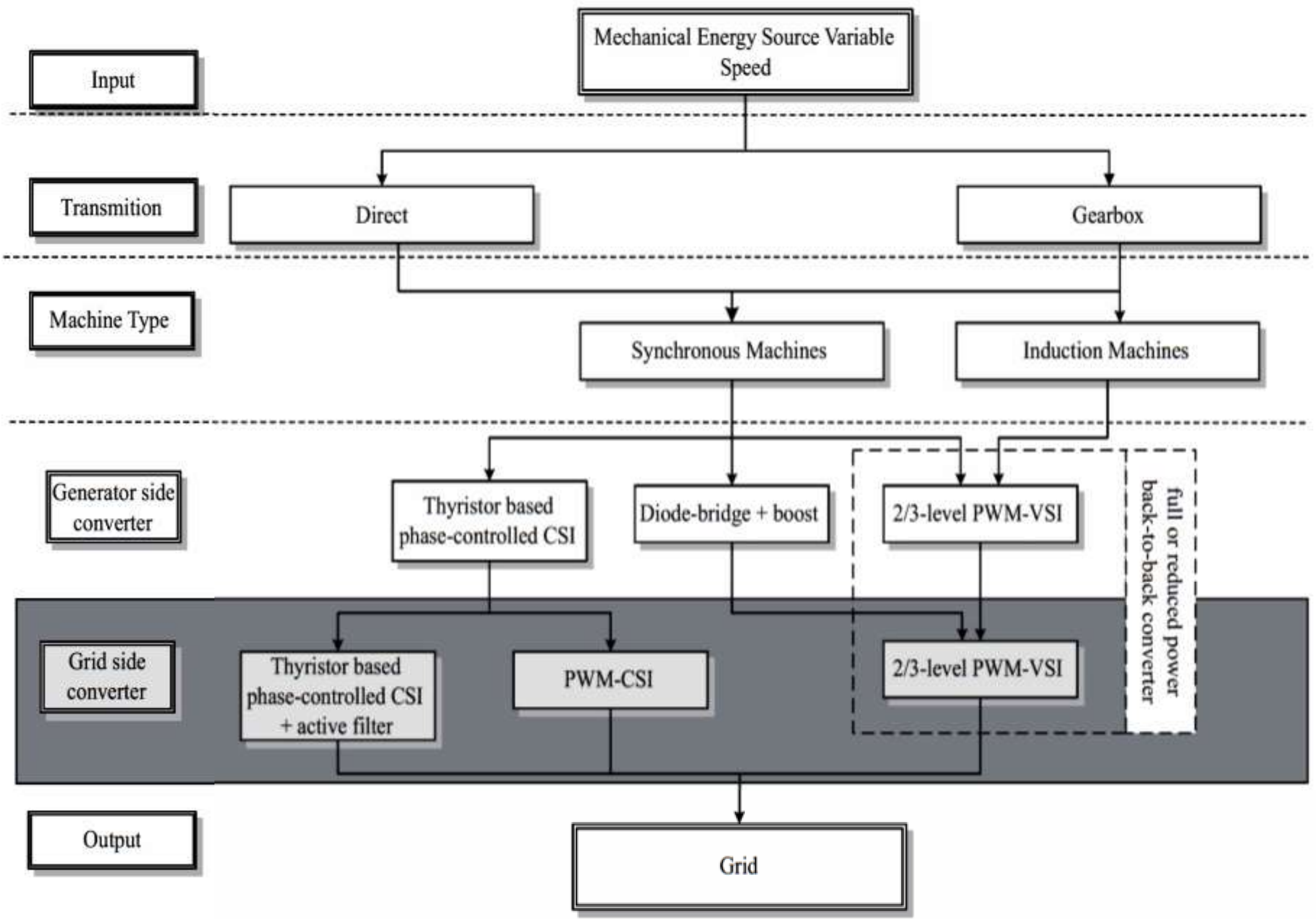
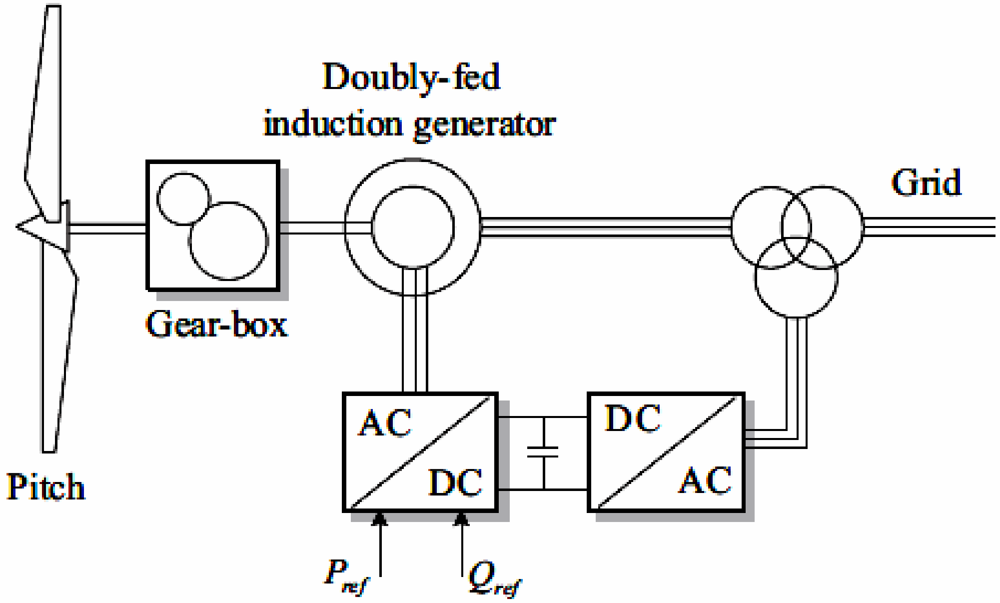


Figure 6.2 Scenario of the power conversion structures for variable-speed wind turbine systems

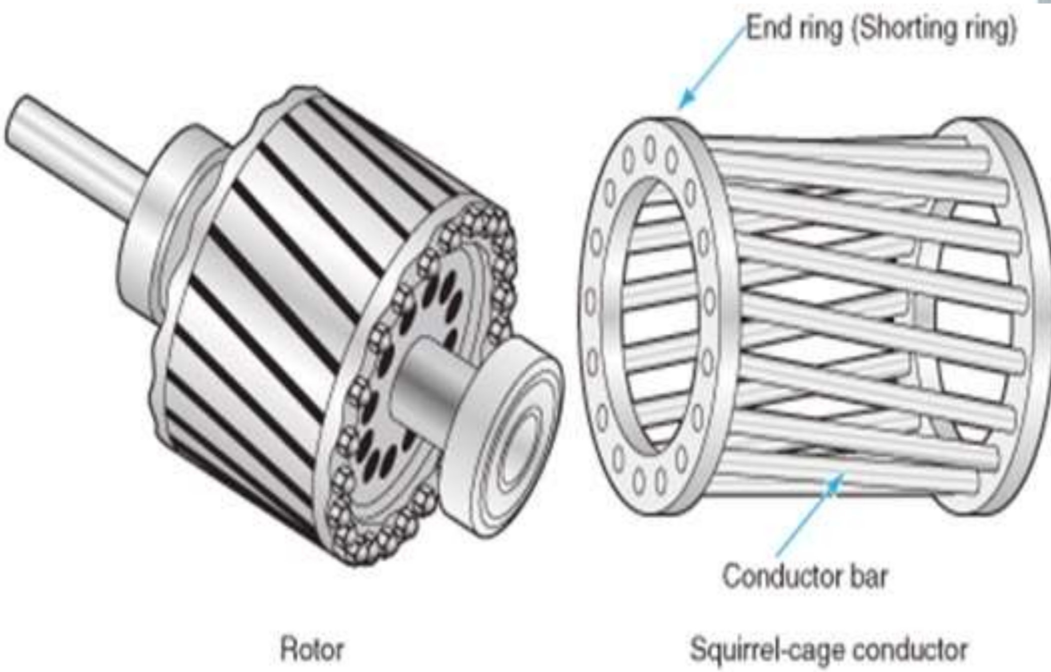
Doubly Fed Induction Generator

The main step that has led to controllable power electronics in a wind turbine has been made with the doubly fed induction generator (Figure 6.3(a)), where a wound rotor is fed by a back-to-back system with a rated power of 30% of the system power. However, in this case the speed range is quite limited (−30% + 30 %) and the slip rings are needed in order to connect the converter on the rotor. The gear is still needed and the speed regulation via the rotor is used only to optimize power extraction from the wind.

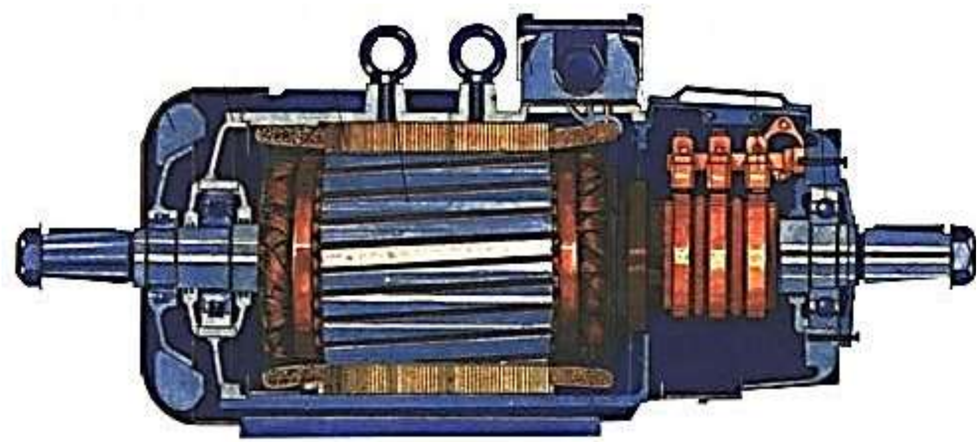


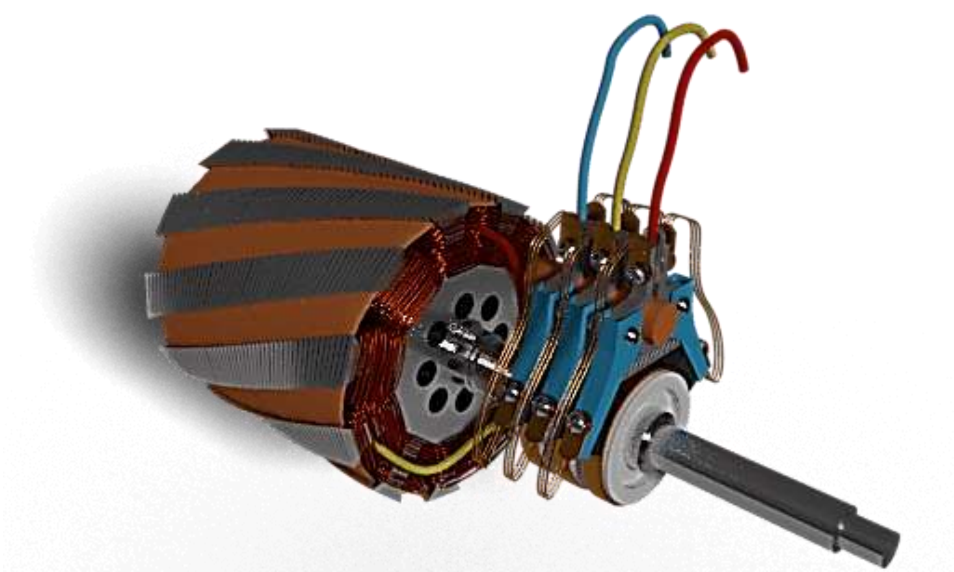
(a)

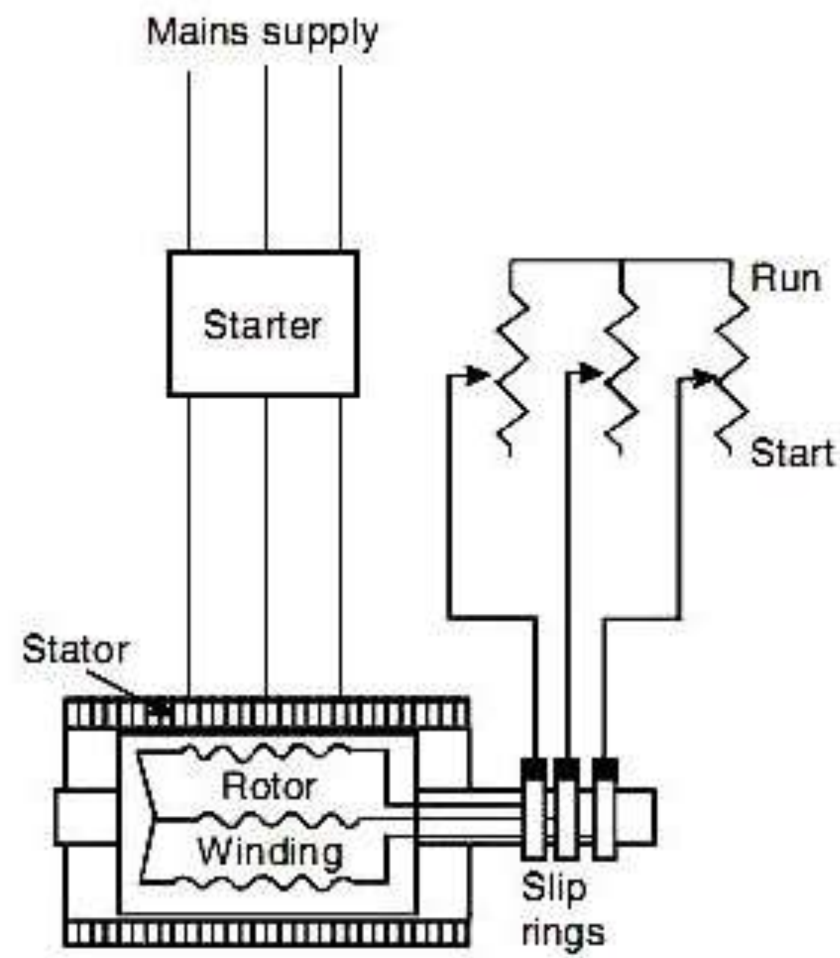
Squirrel Cage Type Induction Motor



How Wound Type Induction Motor works

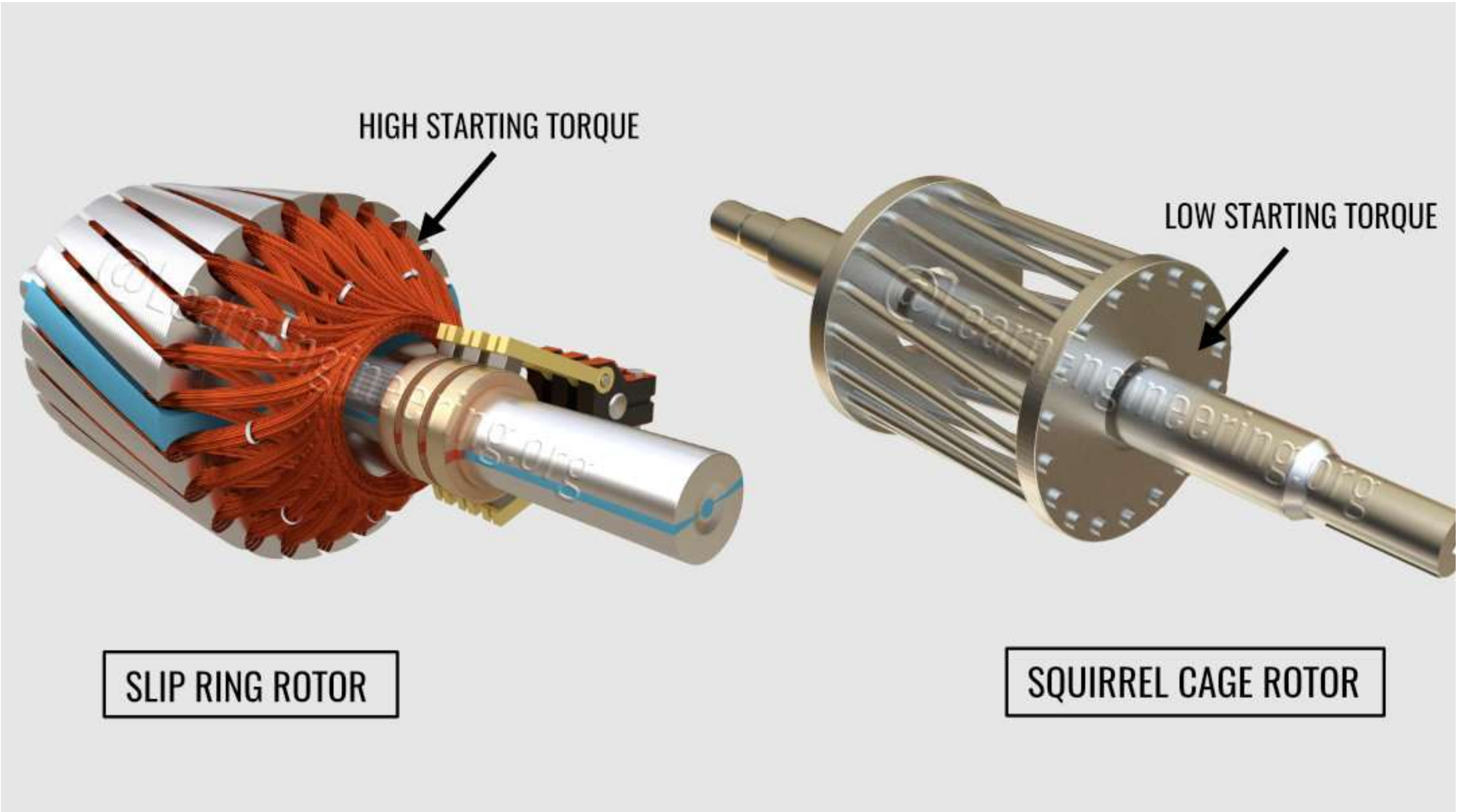






Wound-rotor induction motor

Difference Between Slip Ring & Squirrel Cage Induction Motor



Difference Between Slip Ring & Squirrel Cage Induction Motor

Squirrel Cage Induction Motor	Slip ring (wound rotor) Induction Motor
In Squirrel cage induction motors the rotor is simplest and most rugged in construction	In slip ring induction motors the rotor is wound type. In the motor the slip rings, brushes are provided. Compared to squirrel cage rotor the rotor construction is not simple.
Cylindrical laminated core rotor with heavy bars or copper or aluminium or alloys are used for conductors.	Cylindrical laminated core rotor is wound for as the number of poles of the stator.
Rotor conductors or rotor bars are short circuited with end rings.	At starting the 3 phase windings are connected to a star connected rheostat and during running condition, the windings is short circuited at the slip rings.
Rotor bars are permanently short circuited and hence it is not possible to connect external resistance in the circuit in series with the rotor conductors.	It is possible to insert additional resistance in the rotor circuit. Therefore it is possible to increase the torque (the additional series resistance is used for starting purposes)
Cheaper cost	Cost is slightly higher.
No moving contacts in the rotor.	Carbon brushes, slip rings etc are provided in the rotor circuit.
Higher efficiency.	comparatively less efficiency.
Low starting torque. It is 1.5 time full load torque.	High starting torque. It can be obtained by adding external resistance in the rotor circuit.
Speed control by rotor resistance is not possible.	Speed control by rotor resistance is possible.
Starting current is 5 to 7 times the full load.	Less starting current.

Doubly Fed Induction Generator

A Wind Turbine: The wind turbine is typically a fan consisting of 3 blades which rotate when wind strikes it. The rotation axis should be aligned with the wind direction.

Gear Box: It is a high precision mechanical system which uses a mechanical method to convert energy from one device to another.

Double Fed Induction Generator: It is an electrical generator used to convert mechanical energy to electrical energy which is in form of variable frequency.

Grid Side Converter: It is an AC-DC converter circuit which is used to provide a regulated DC voltage to the inverter. It is used maintain a constant DC link voltage.

Rotor Side Converter: It is a DC-AC inverter which is used to provide controlled AC voltage to the rotor.

Doubly Fed Induction Generator: Benefits

1. Constant frequency output signal to the grid irrespective of the variable rotor speed.

2. Low power rating required for the power electronic devices and hence low cost of control system.

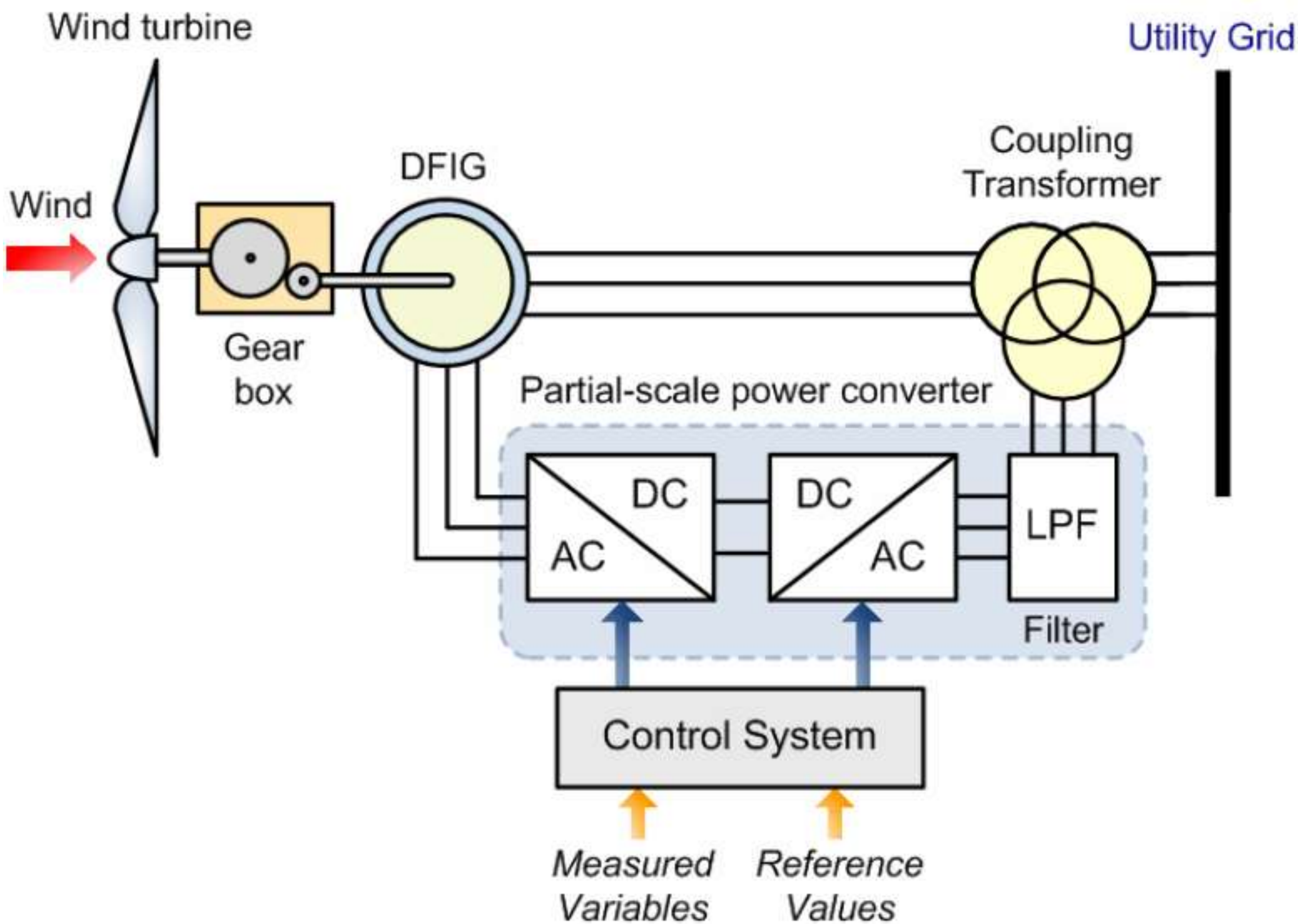
3. Power factor is controlled, i.e. maintained at unity.

4. Electric power generation at low wind speed.

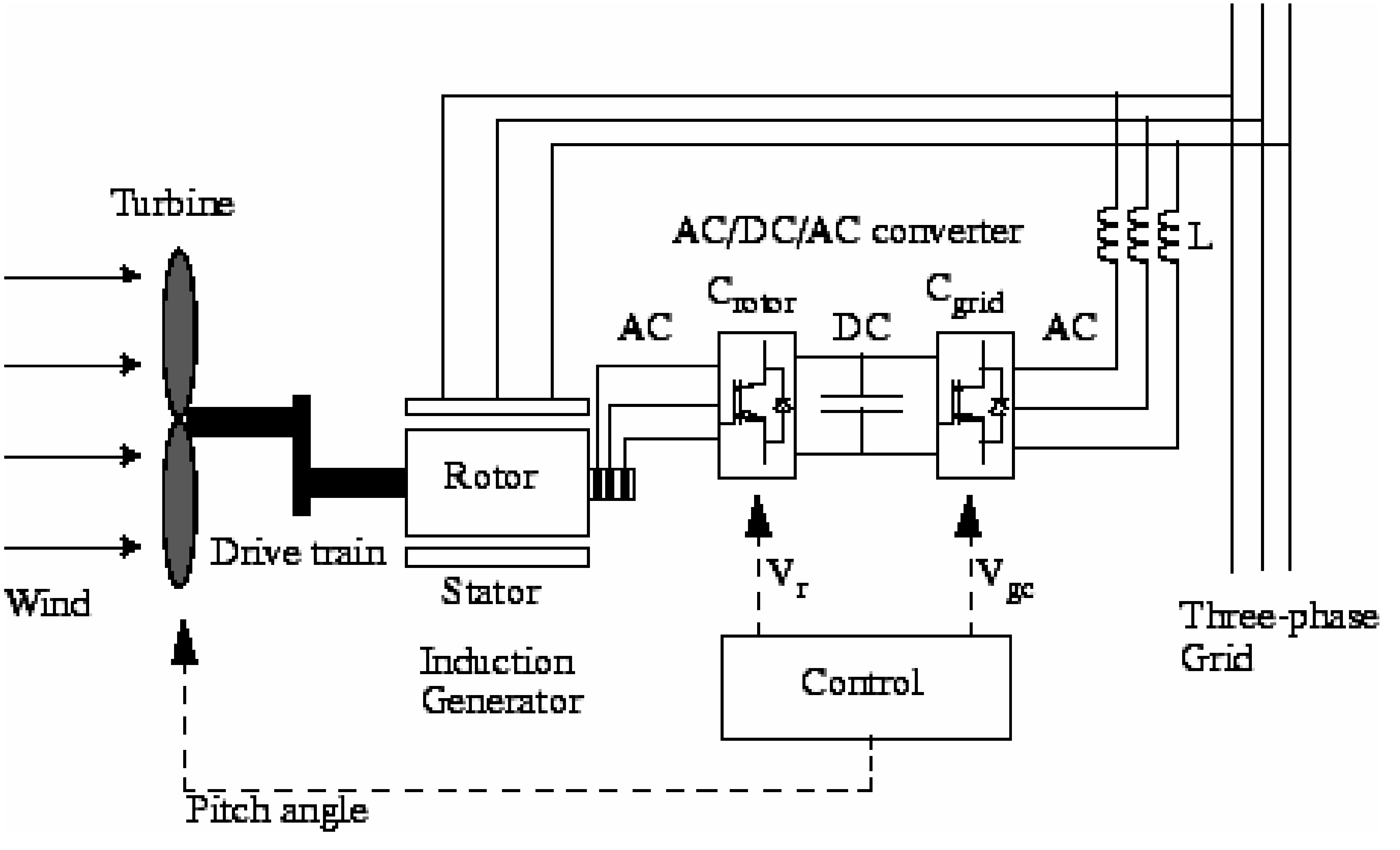
5. Power electronic converter has to handle the fraction of the total load i.e.,20-30% and also cost of this converter is low than in case of the other types of generators.

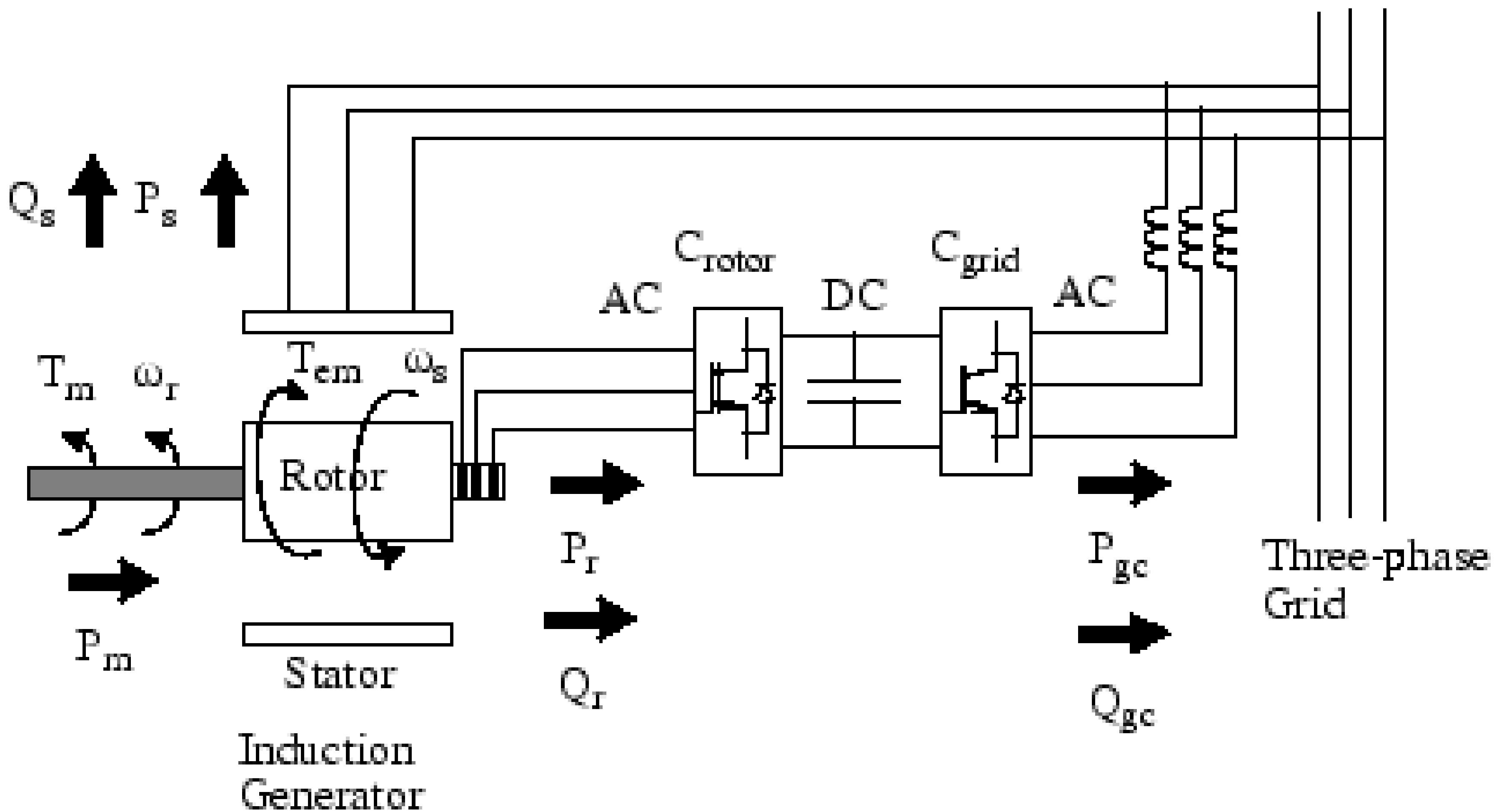
Doubly Fed Induction Generator

The whole system consists of two back to back converters – a **rotor side converter** and a **grid side converter**, connected in the feedback loop of the system. The **rotor side converter** is used to control the active and reactive powers by controlling the d-q components of the rotor and also torque and speed of the machine. The **grid side converter** is used to maintain a constant dc link voltage and ensures the unity power factor operation by making the reactive power drawn from the utility grid to zero. A capacitor is connected between the two converters such that it acts as an energy storage unit. This back to back arrangement provides a fixed voltage fixed frequency output irrespective of the variable frequency, variable voltage output of the generator. Other applications of the induction generators are fly-wheel energy storage systems, pumped storage power plants, power converters feeding a railway power grid from public grid where the frequency is fixed.


Wind turbine
Utility Grid
Coupling
Transformer
DFIG
Wind
Gear
box
Partial-scale power converter
DC
AC
DC
AC
LPF
Filter
Control System
Measured
Variables
Reference
Values

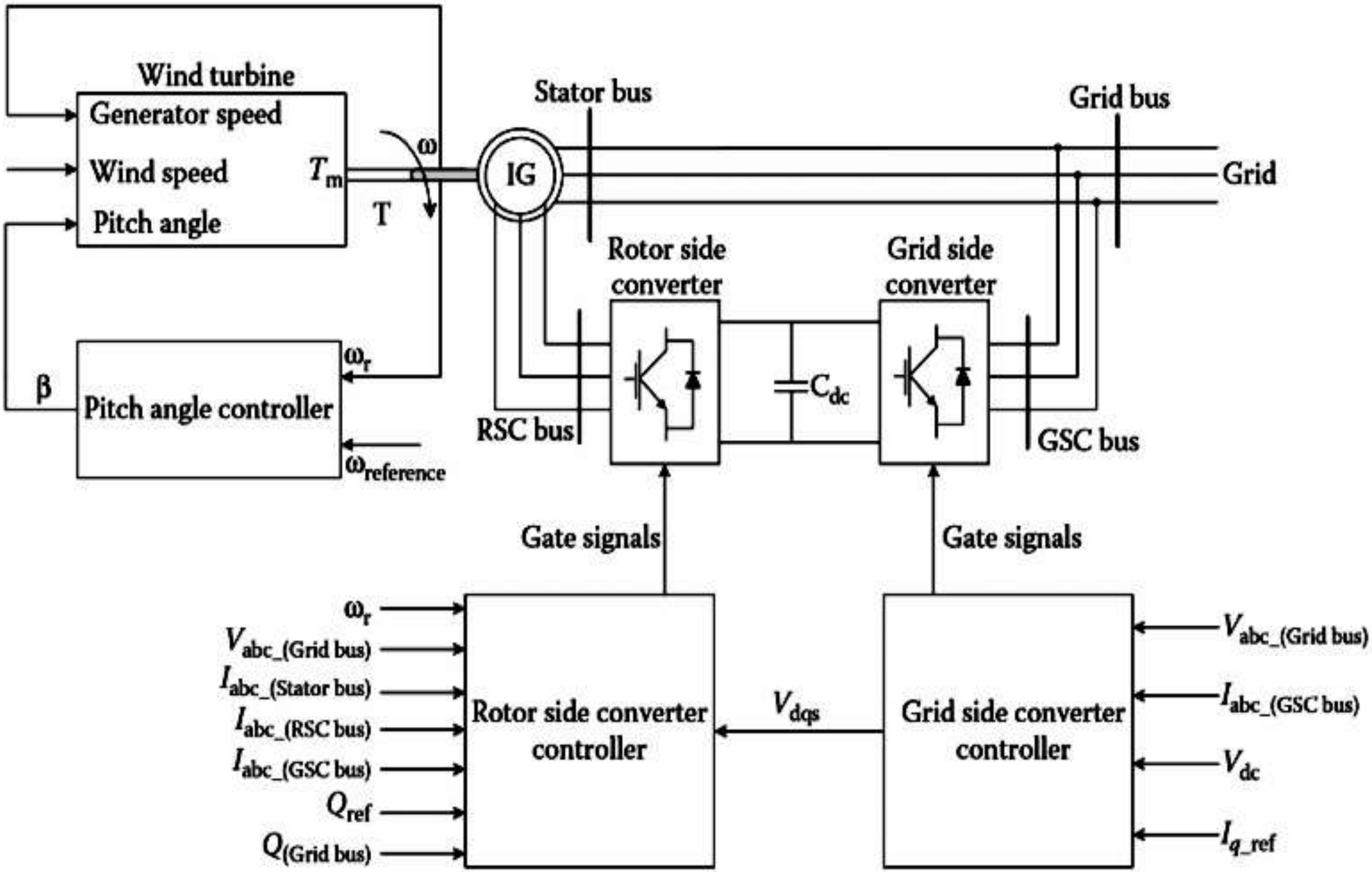
How Doubly Fed Induction Generator System Works





Q_s
P_s
C_{rotor}
C_{grid}
AC
DC
AC
T_m
ω_r
T_{em}
ω_s
Rotor
P_r
P_{gc}
Three-phase Grid
P_m
Stator
Q_r
Q_{gc}
Induction Generator

P_m	Mechanical power captured by the wind turbine and transmitted to the rotor
P_s	Stator electrical power output
P_r	Rotor electrical power output
P_{gc}	C_{grid} electrical power output
Q_s	Stator reactive power output
Q_r	Rotor reactive power output
Q_{gc}	C_{grid} reactive power output
T_m	Mechanical torque applied to rotor
T_{em}	Electromagnetic torque applied to the rotor by the generator
ω_r	Rotational speed of rotor
ω_s	Rotational speed of the magnetic flux in the air-gap of the generator, this speed is named synchronous speed. It is proportional to the frequency of the grid voltage and to the number of generator poles.
J	Combined rotor and wind turbine inertia coefficient



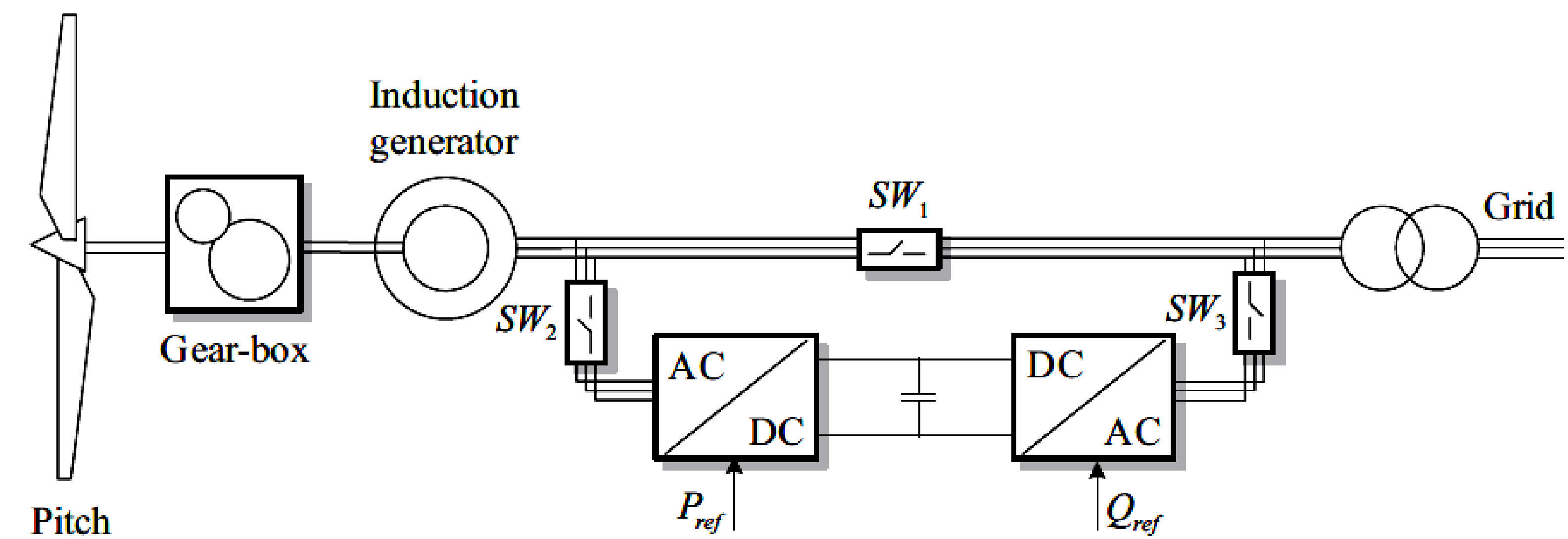
Wind turbine
Generator speed
Wind speed
Pitch angle
T_m
ω
T
Stator bus
Grid bus
IG
Grid
Rotor side converter
Grid side converter
C_{dc}
RSC bus
GSC bus
ω_r
β
Pitch angle controller
$\omega_{reference}$
Gate signals
Gate signals
ω_r
$V_{abc\_(Grid\ bus)}$
$I_{abc\_(Stator\ bus)}$
$I_{abc\_(RSC\ bus)}$
$I_{abc\_(GSC\ bus)}$
Q_{ref}
$Q_{(Grid\ bus)}$
Rotor side converter controller
V_{dqs}
Grid side converter controller
$V_{abc\_(Grid\ bus)}$
$I_{abc\_(GSC\ bus)}$
V_{dc}
I_{q_ref}

Doubly Fed Induction Generator

In fact, acting on a back-to-back converter it is possible to vary the injected active and reactive power [11]. In particular the rotor-side converter controls the rotor current in order to control the active and reactive power injected into the grid.
The current-controlled rotor-side inverter can be seen as a controlled current source in parallel with the DFIG magnetization reactance. If in parallel to these two elements a Thevenin equivalent is substituted, the DFIG model will match the model of a synchronous generator and the active/reactive power control will be straightforward [11].

A further step in the improvement of the grid-side behavior of the wind turbine system is made with the use of **a squirrel cage induction generator** and a reduced scale back-to-back power converter (Figure 6.3(b)). The back-to-back converter is only connected in two cases:

1. At medium and low power the converter is used to optimize the power extraction and transfer to the grid (***SW*1** open, *SW*2 and *SW*3 closed).
2. At full power only the grid-side converter is connected to perform harmonic and reactive power compensations (***SW*2** open, *SW*1 and *SW*3 closed).



The use of a full-power back-to-back converter (Figure 6.4) leads to an induction generator completely decoupled from the grid, and as a consequence this system has a capacity to contribute to the limitation of the effects of grid faults and to the restoration of the normal grid operation after the fault. However the system does not contribute to the short-circuit power because the grid converter limits the fault current. This system can completely be at stand-by and operate in an island [13]. However, the gear is still needed and the power converter is full-scale.

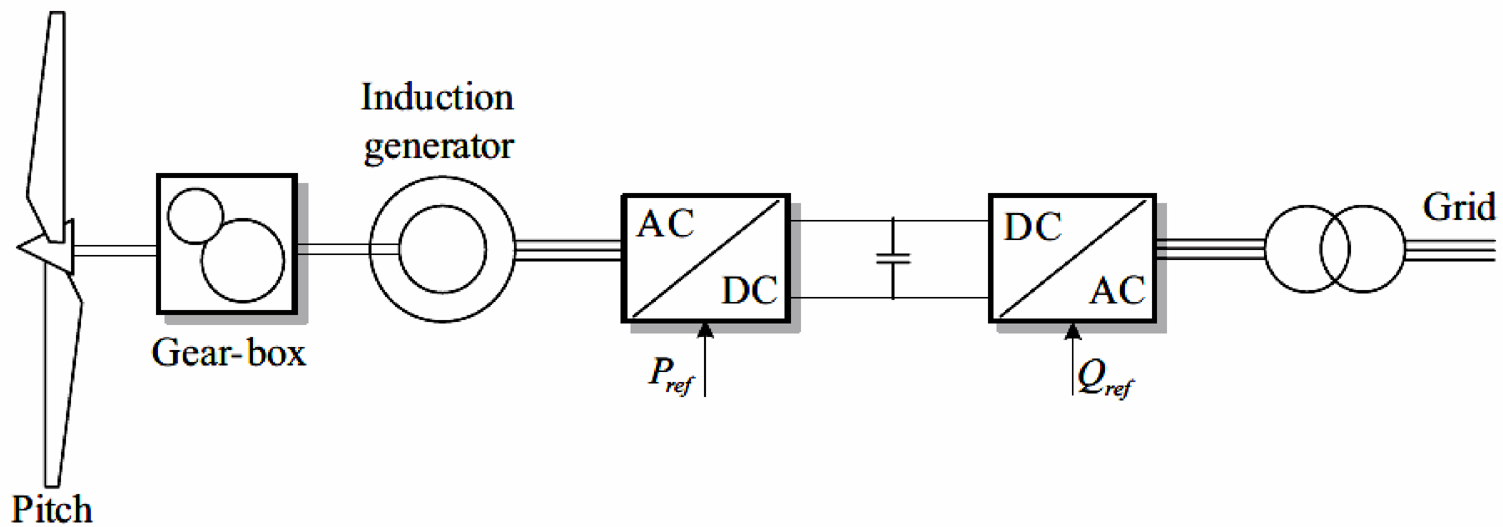
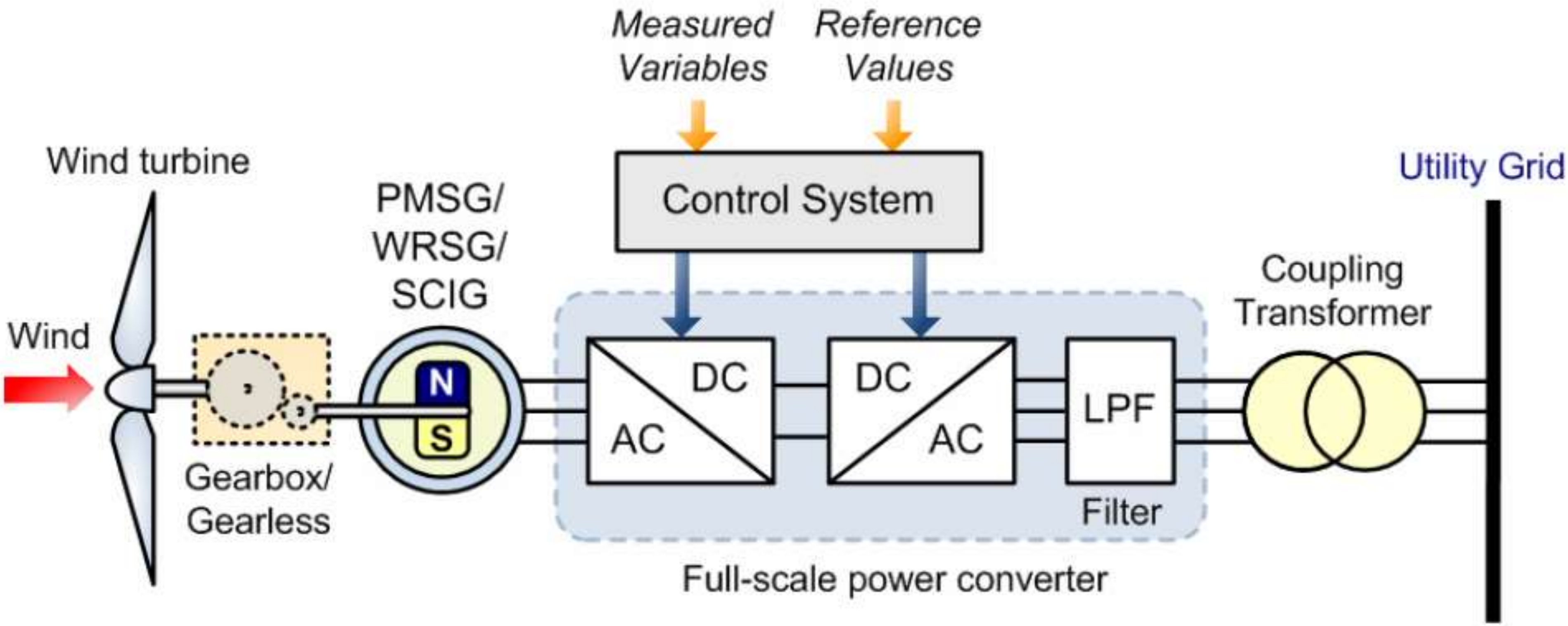


Figure 6.4 Full-power back-to-back converter with an induction generator


Measured
Variables
Reference
Values
Control System
Wind turbine
Utility Grid
PMSG/
WRSG/
SCIG
Coupling
Transformer
Wind
N
S
DC
AC
DC
AC
LPF
Filter
Gearbox/
Gearless
Full-scale power converter

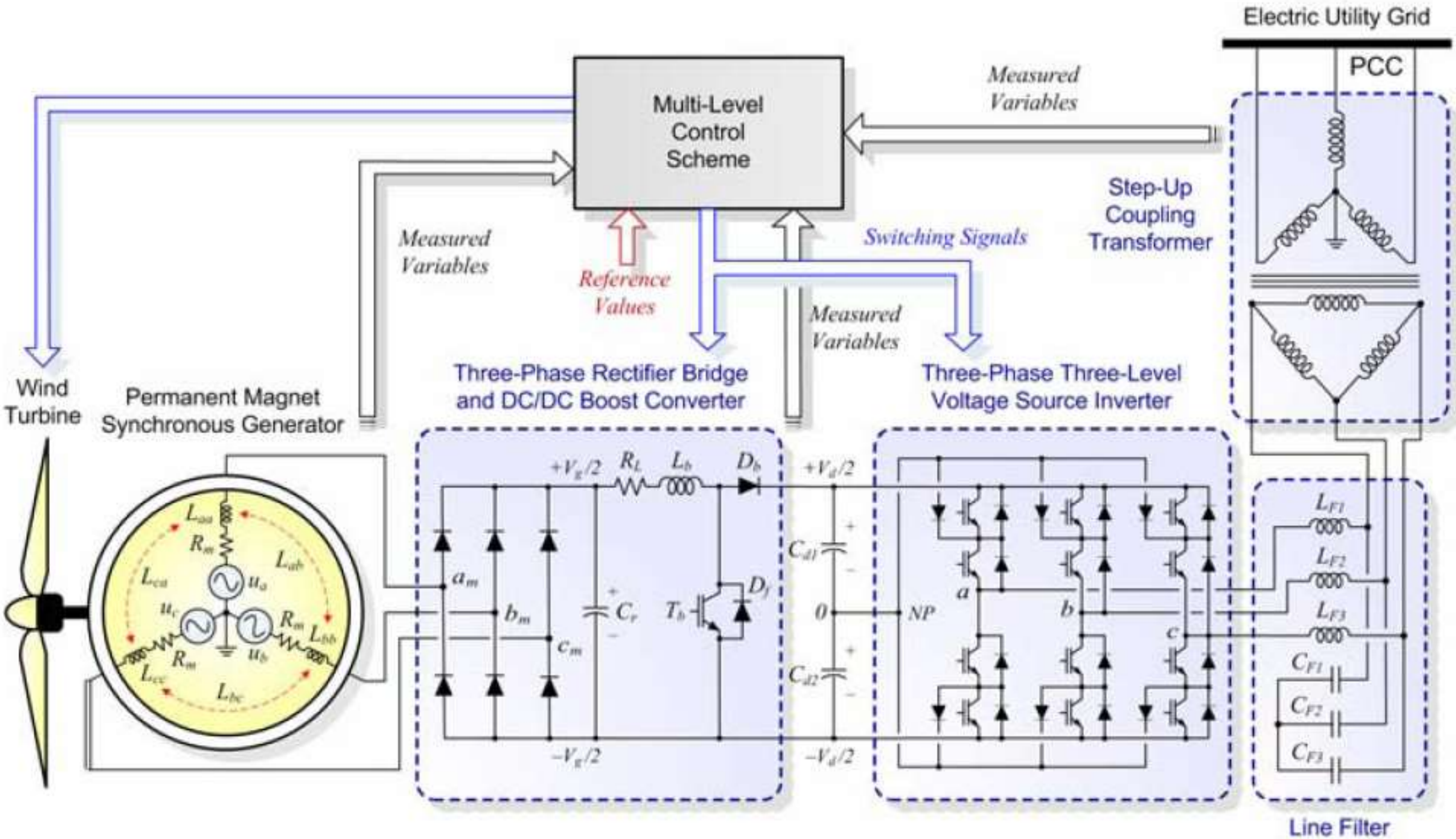
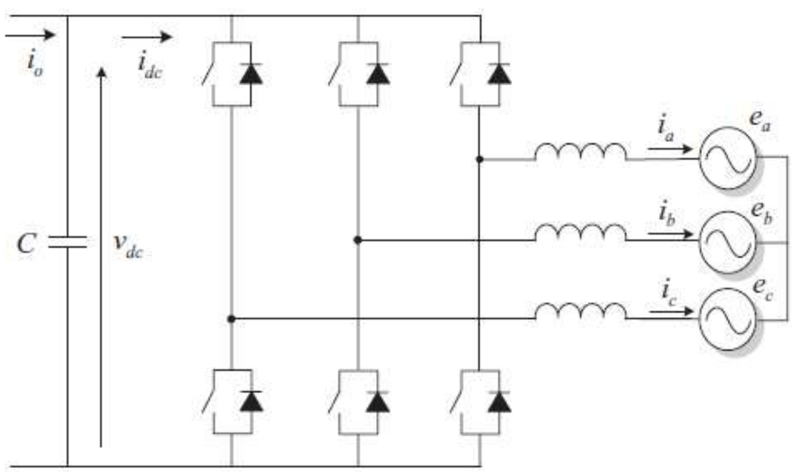


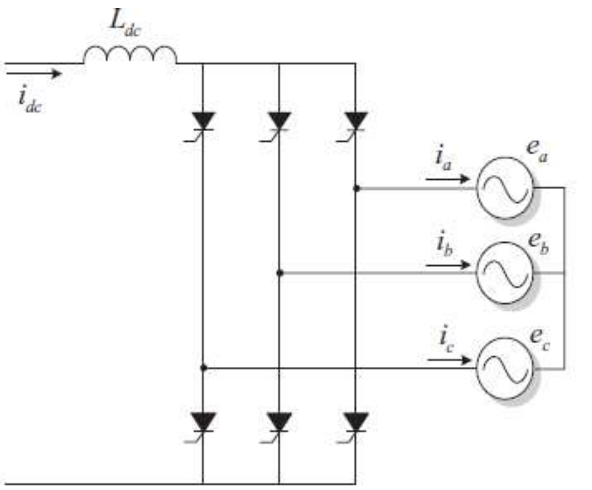
Fig. 10. Detailed model of a modern variable-speed direct-driven PMSG wind turbine connected to the utility distribution grid

Grid Power Converter Topologies

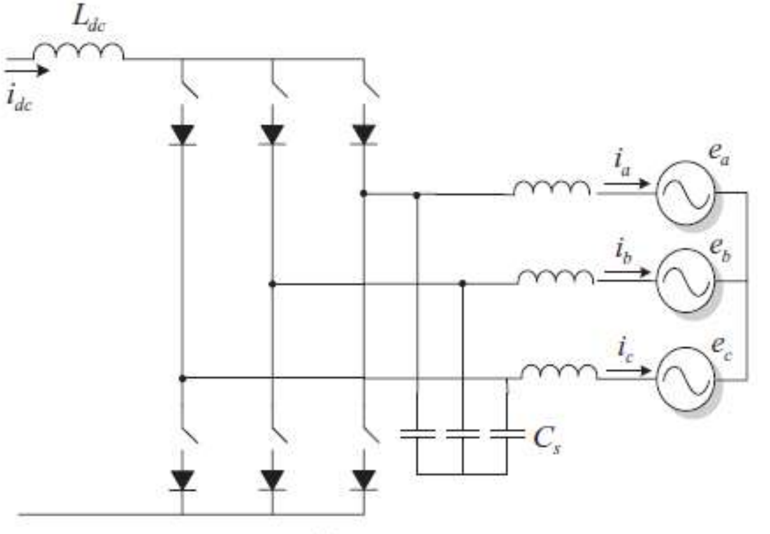
Single-Cell (VSC or CSC)



(a)



(b)



(c)

Medium-Power Converter

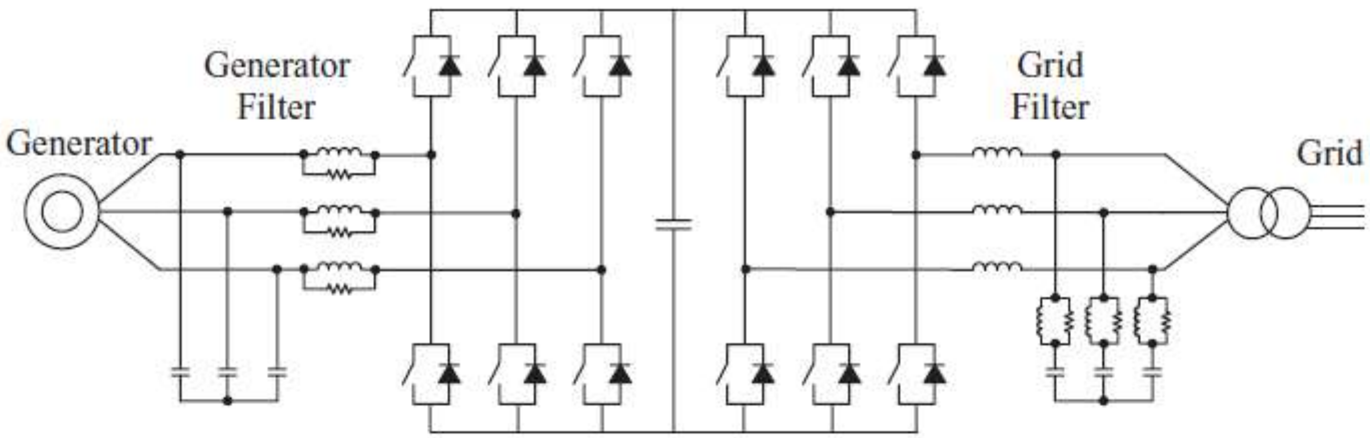


Figure 6.7 Two-level back-to-back PWM-VSI

Medium-Power Converter

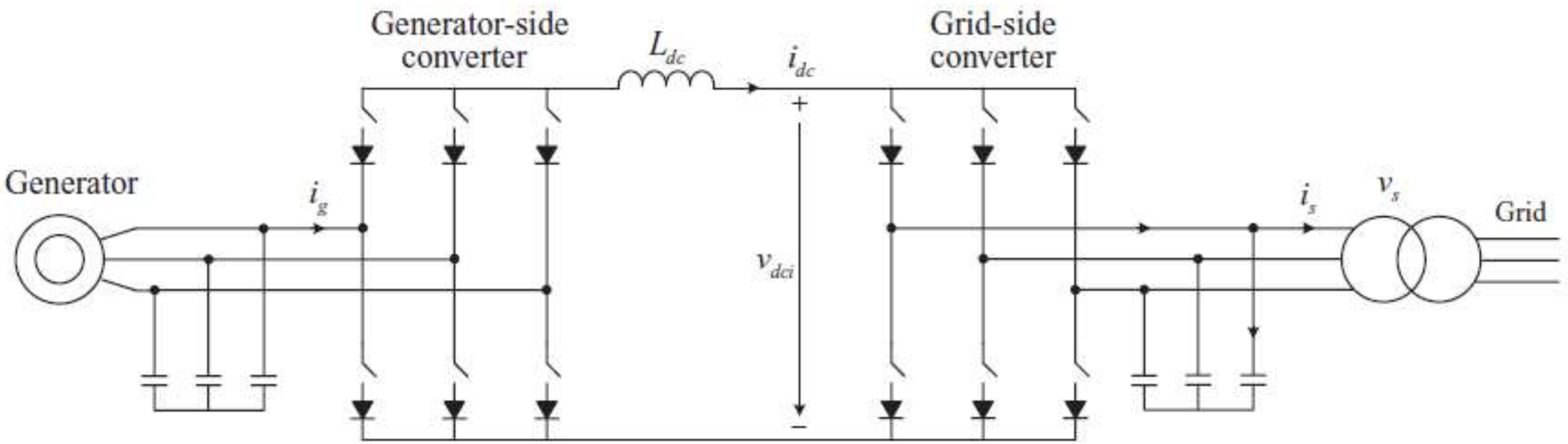


Figure 6.8 Two-level back-to-back PWM-CSI

High-Power Converter

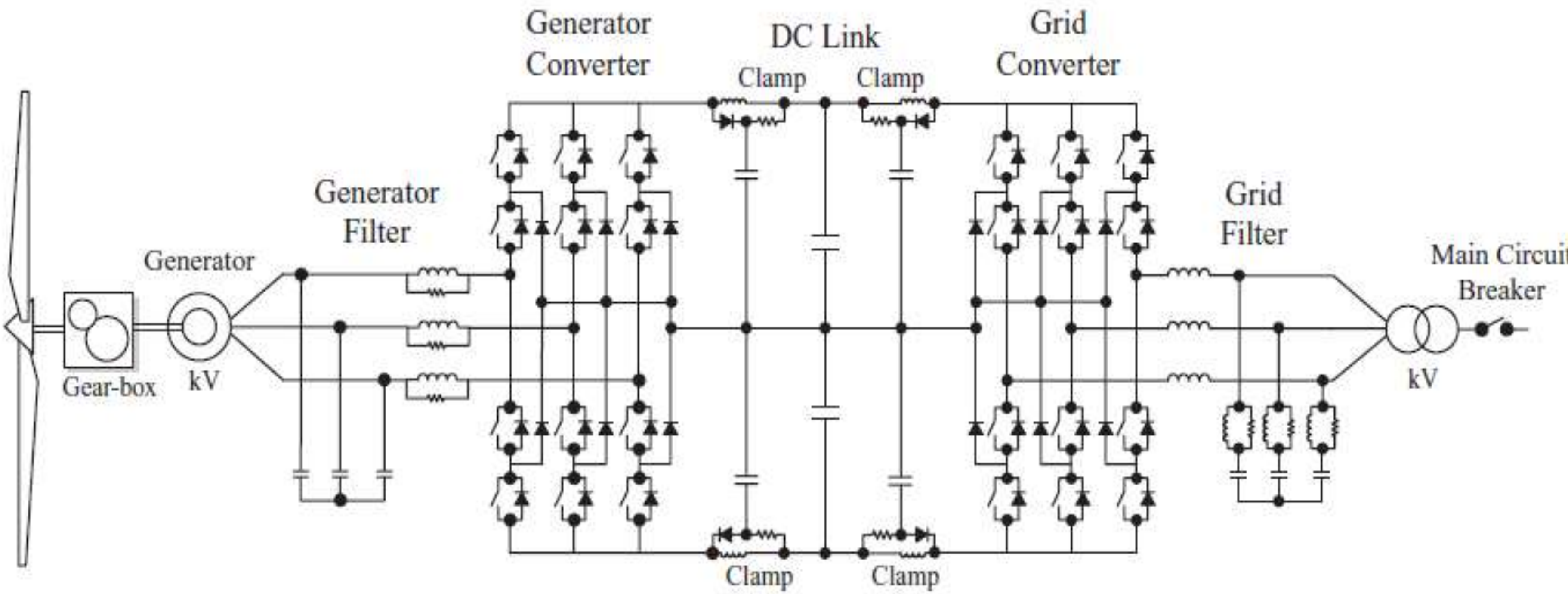


Figure 6.9 Three-level back-to-back PWM VSI

Multicell (Interleaved or Cascaded)

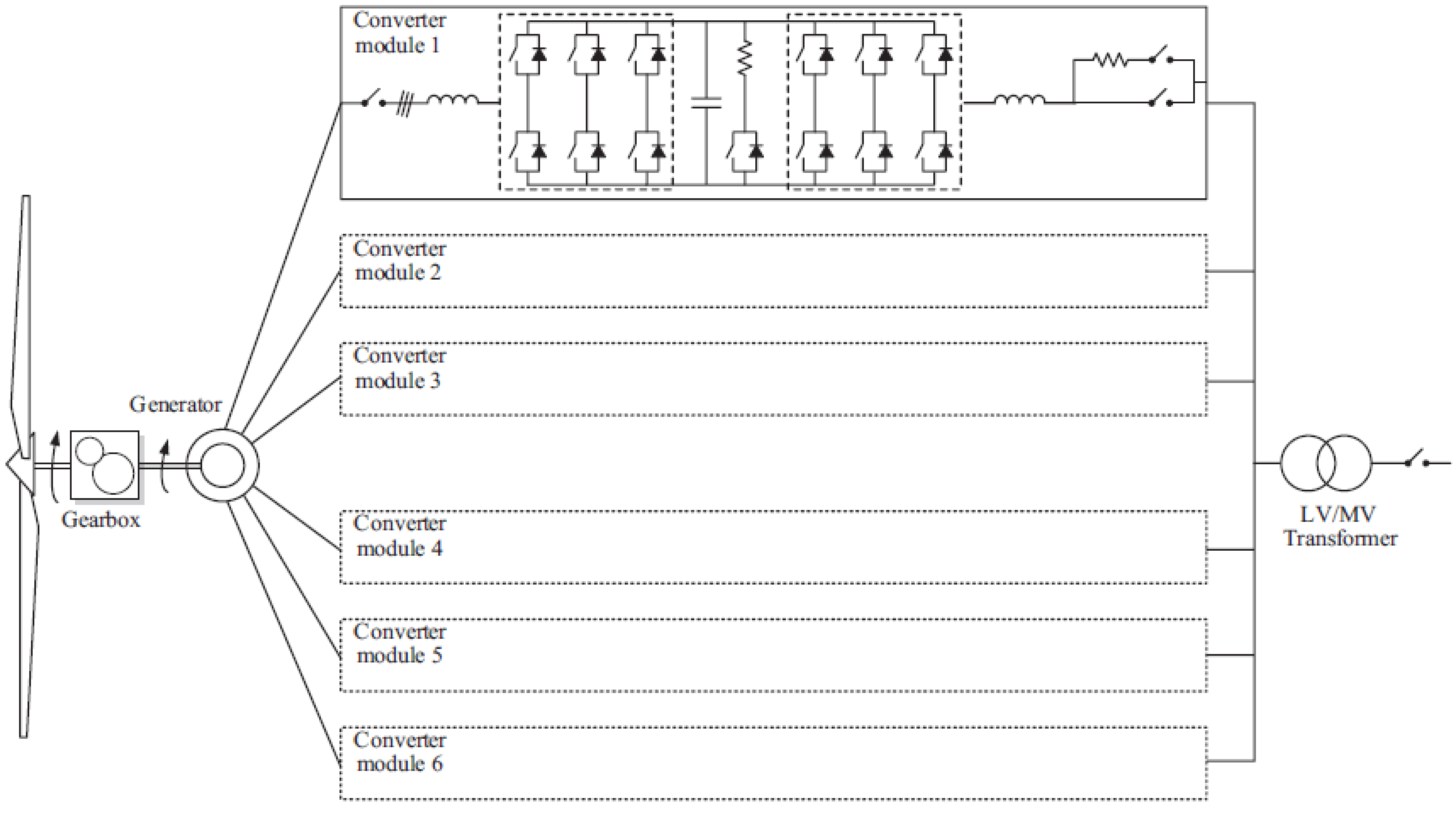


Figure 6.10 Back-to-back converters fed by a six-phase generator and connected in parallel and interleaved on the grid side

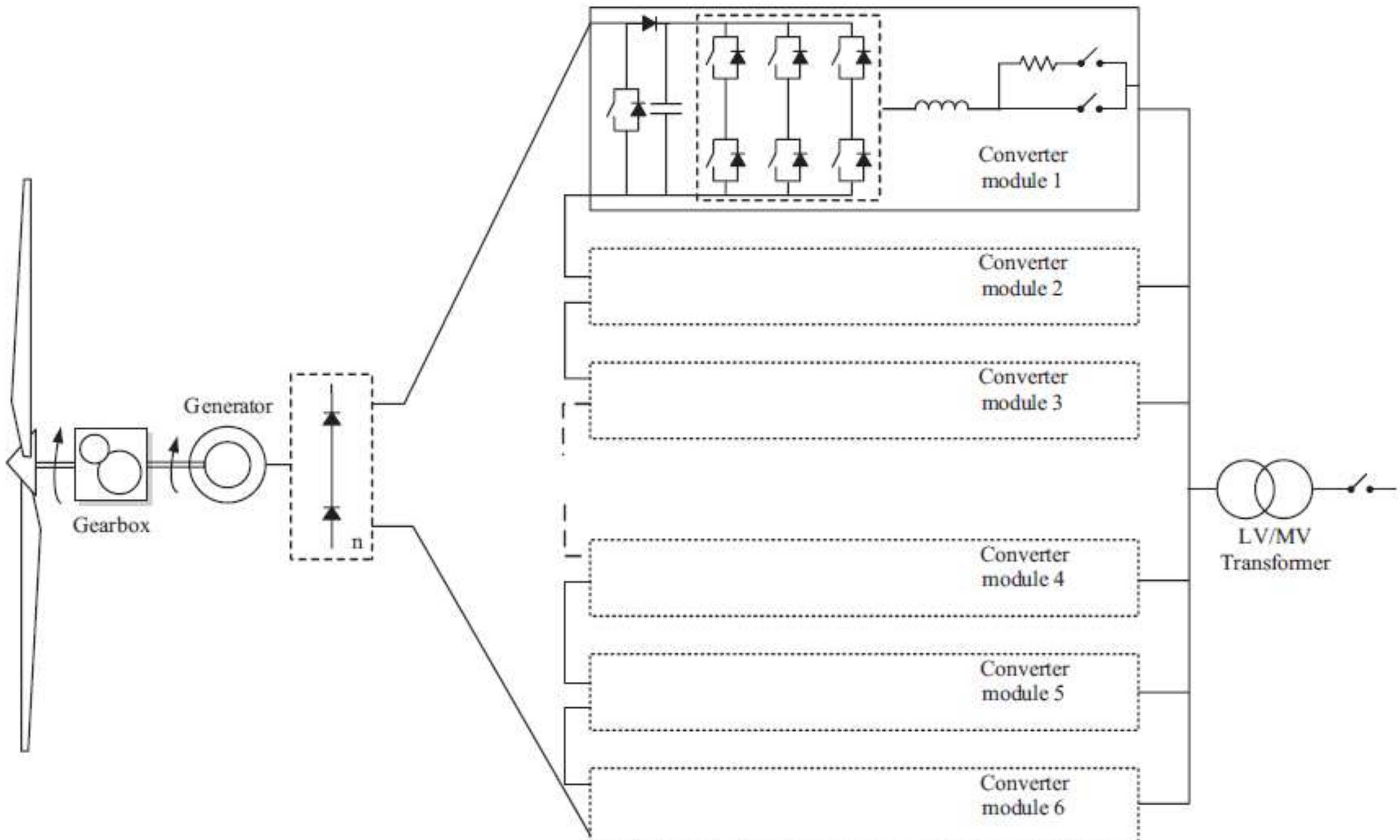


Figure 6.11 An *n*-leg diode bridge fed by a synchronous generator producing a high DC voltage shared among several grid/converters connected in parallel and interleaved on the grid side

WTS Control

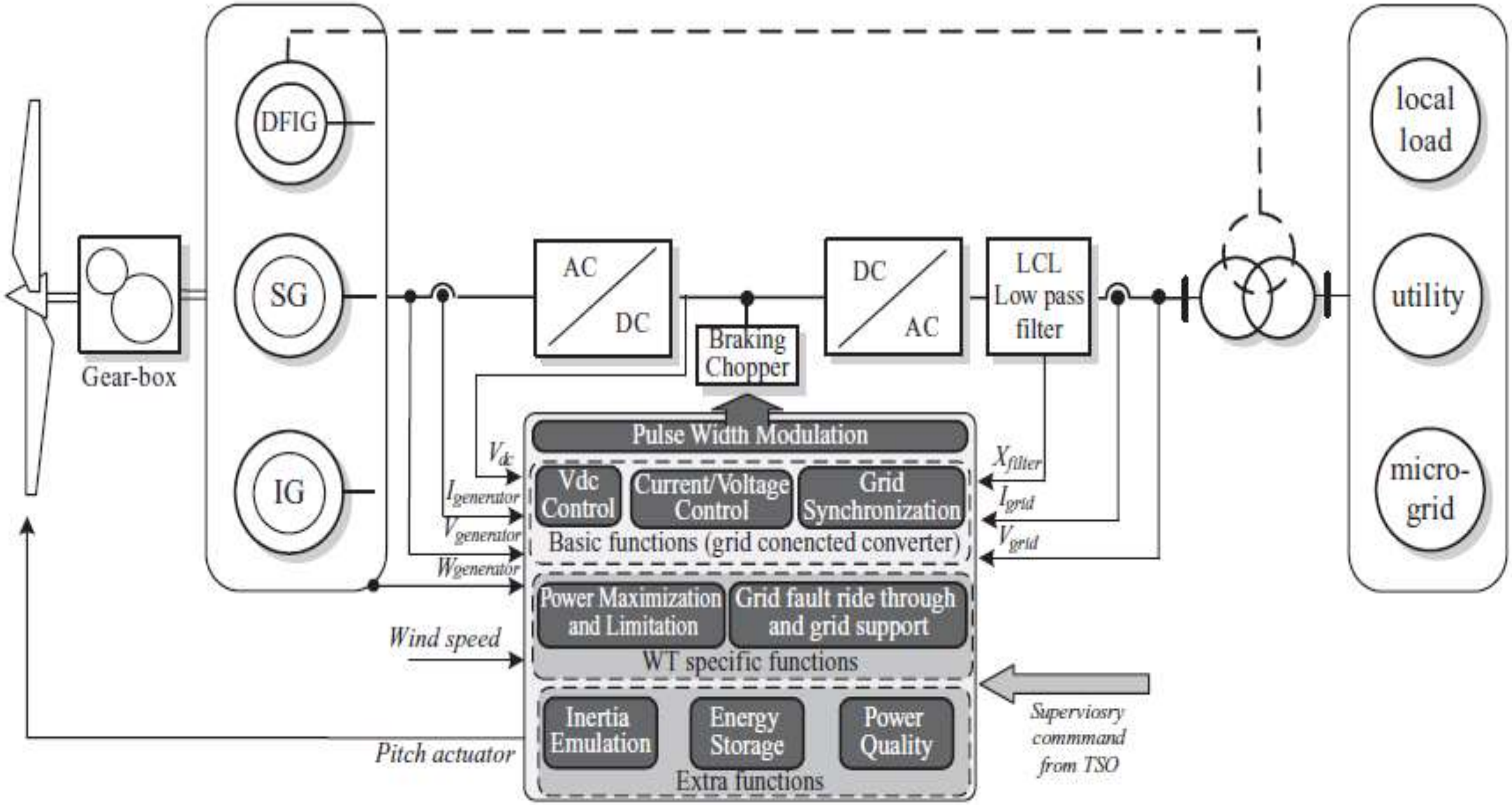


Figure 6.13 Wind turbine control structure

Squirrel Cage Induction Generator Control

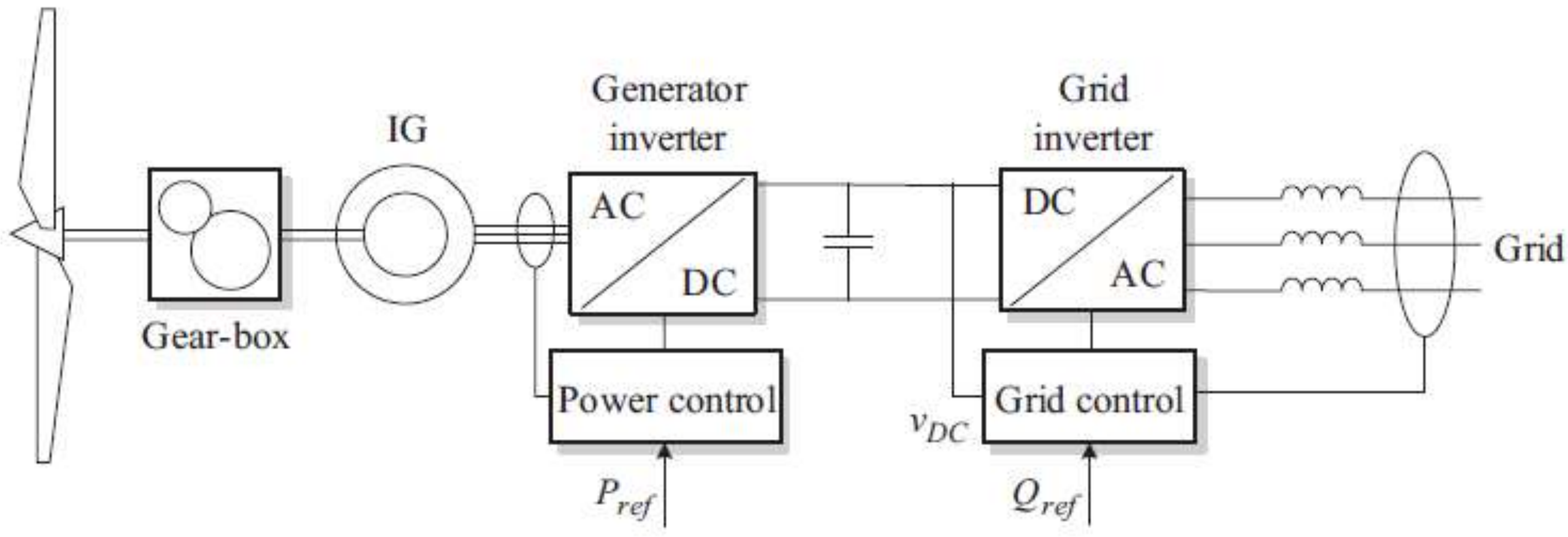


Figure 6.14 Induction generator with a full-scale back-to-back converter

Synchronous Generator Control

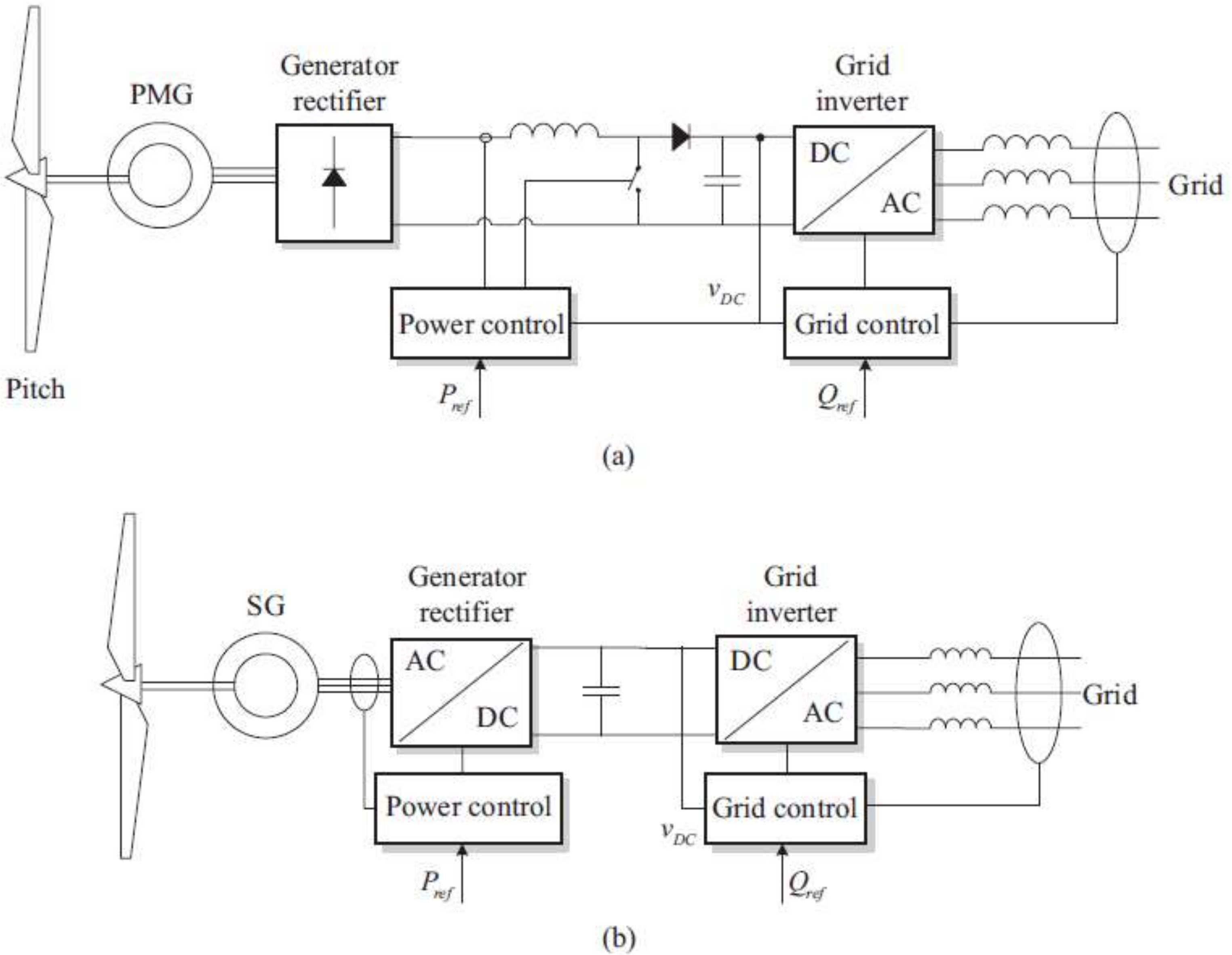


Figure 6.15 Synchronous generator with: (a) diode bridge + VSI and (b) back-to-back converter

Doubly Fed Induction Generator Control

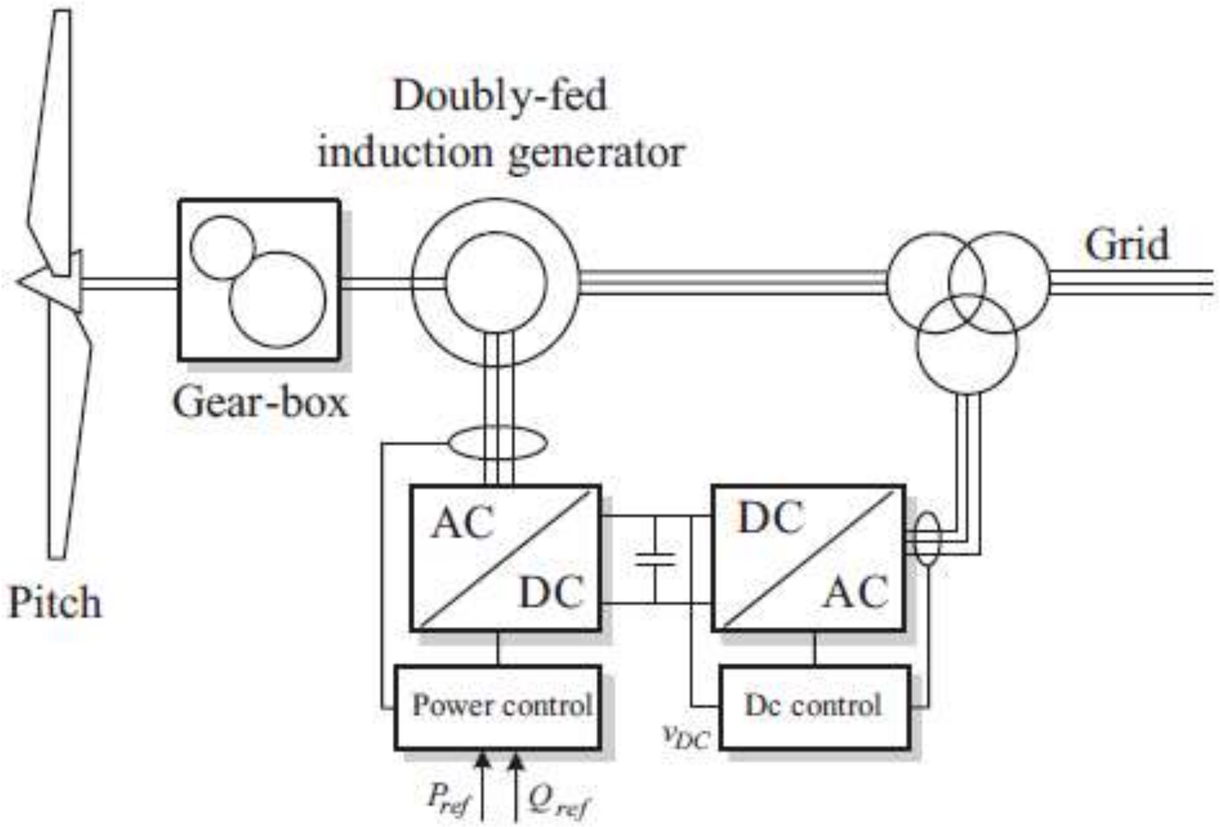


Figure 6.16 Doubly fed induction generator control

MPPT with Turbine Power Profile

The wind speed is measured in real time by a wind speed sensor. According to the MPPT profile provided by the manufacturer, the power reference *P** is generated and sent to the generator control system, which compares the power reference with the measured power *Pm* from the generator to produce the control signals for the power converters.

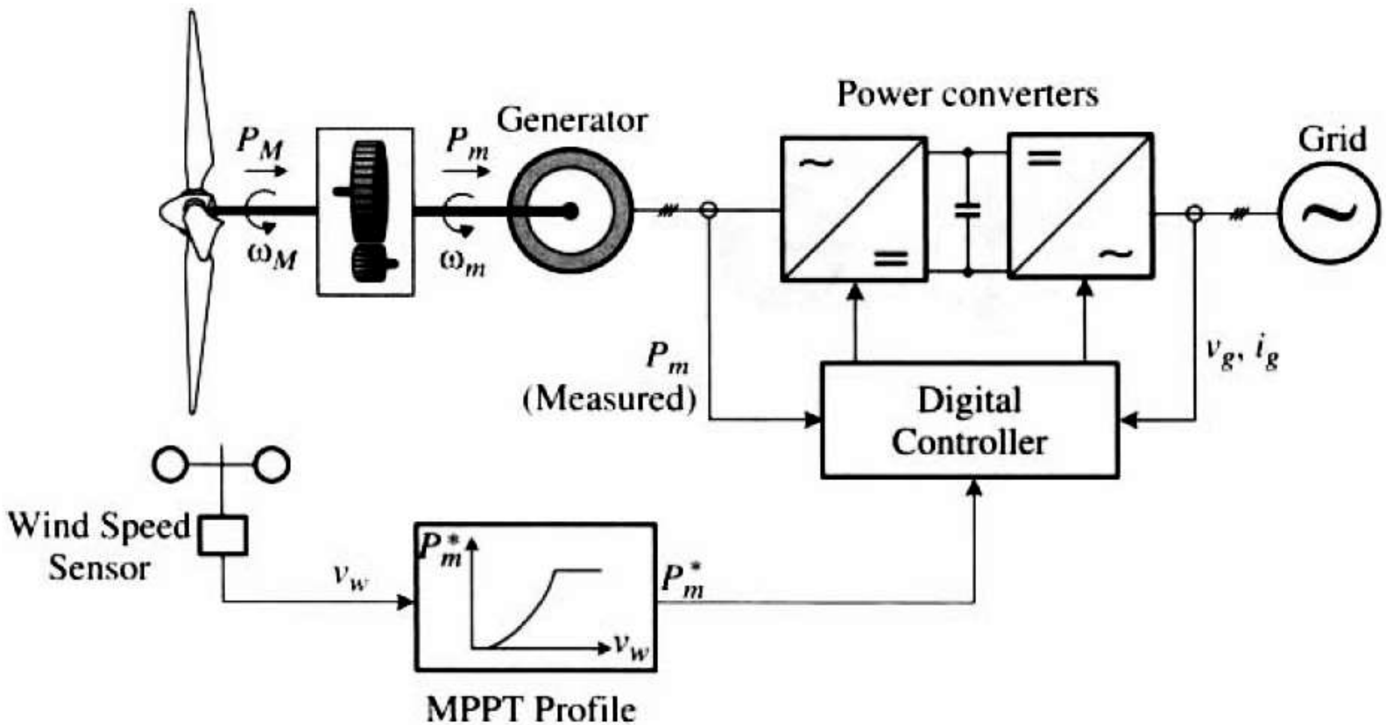


Figure 2-19. Maximum power control with wind turbine power profile.

MPPT with Optimal Torque Control

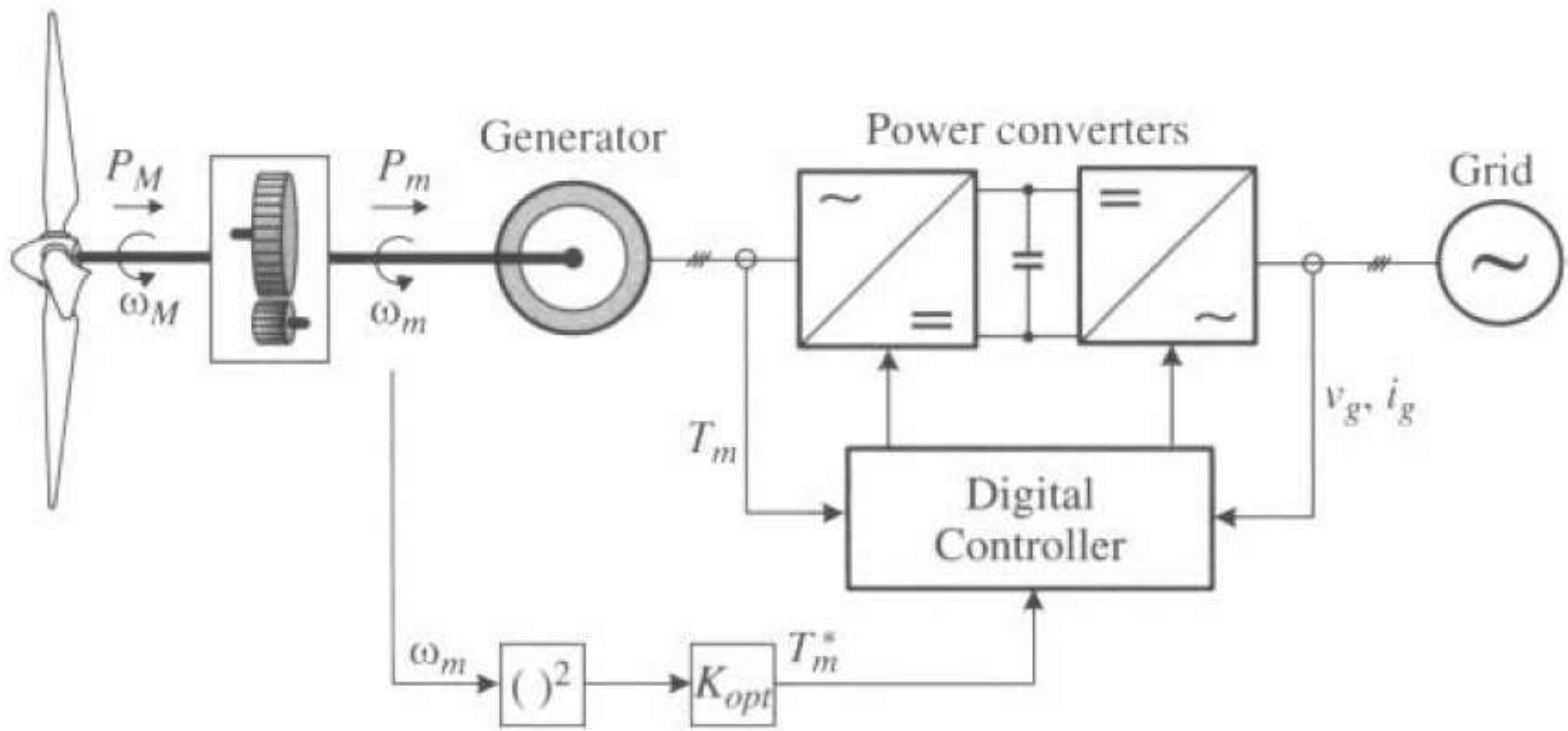


Figure 2-21. MPPT with optimal torque control of wind turbines.

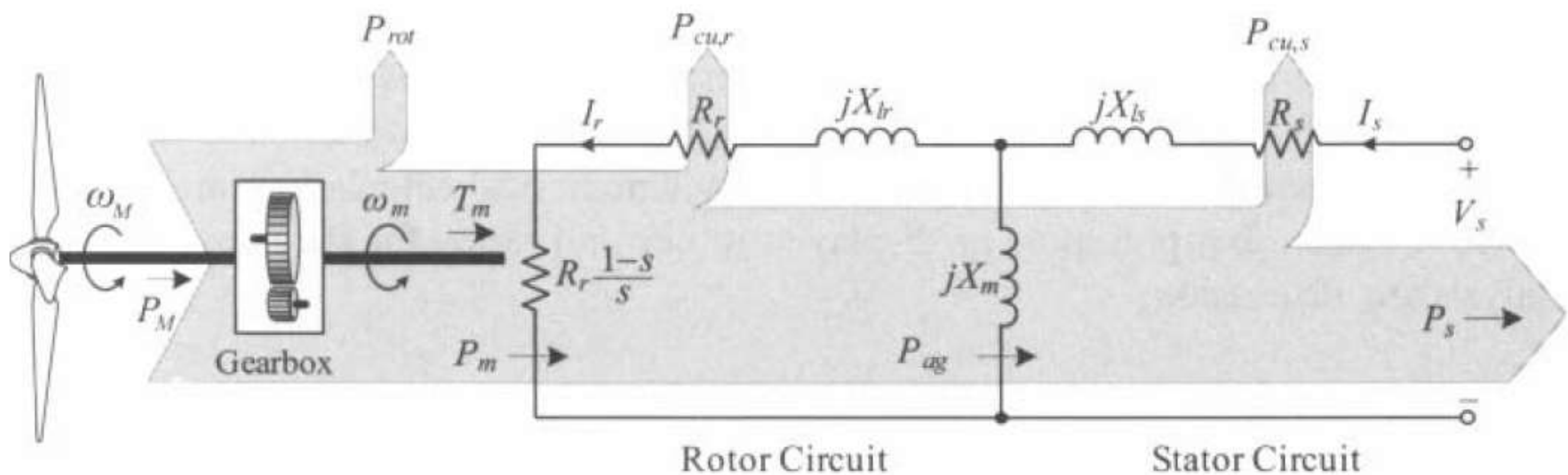


Figure A-1. Power flow of an induction generator in a wind energy system.

End of Wind Power Generation—Part 2
Course Work