Offshore Wind Farms

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Outline

I. Introduction of Offshore Wind Farms

II. Conventional Offshore Wind Farms

III. DC grid for offshore wind farms

1.1 Introduction

Why offshore wind power?

- **Better wind source**
- **High wind speed**
- **Constant wind speed**
- **More electricity**

AC Wind Farm

DC Wind Farm

1.2 Conventional Offshore Wind Farm

Offshore wind farms

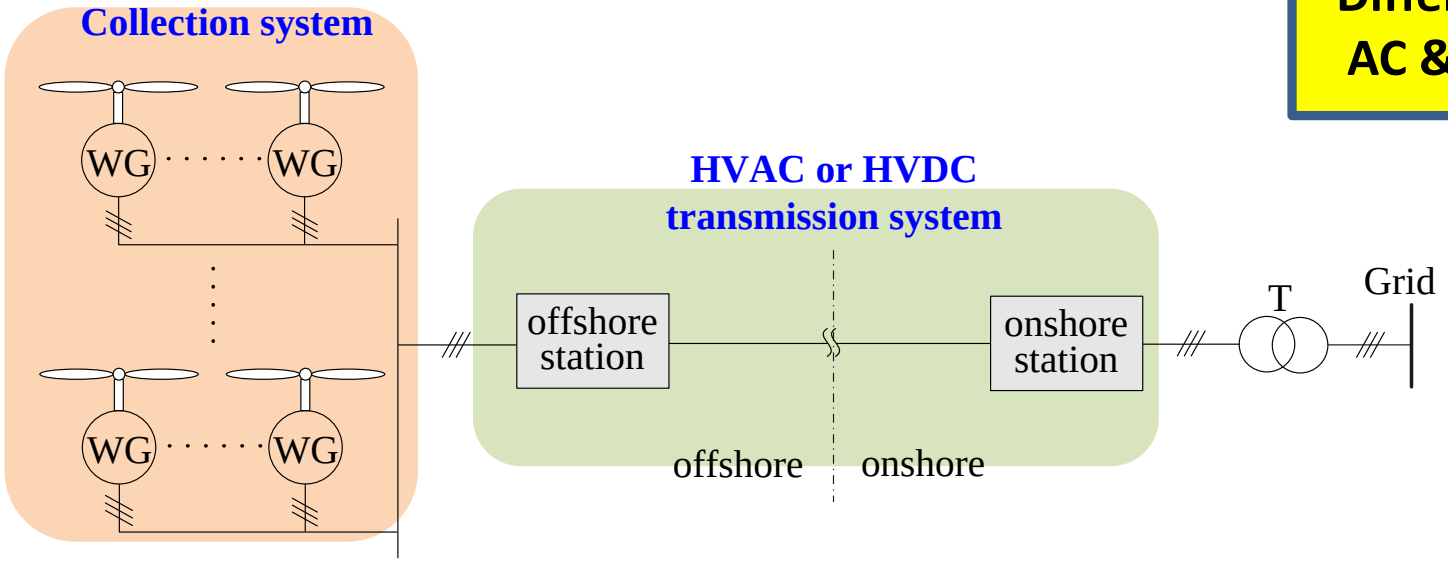
(1) Collection system

(2) Power transmission system

DC technology advantages

- Reduce cable costs
- No reactive power
- No frequency regulation
- Easy control

Difference AC & DC?



1.3 Wind Farm Configuration

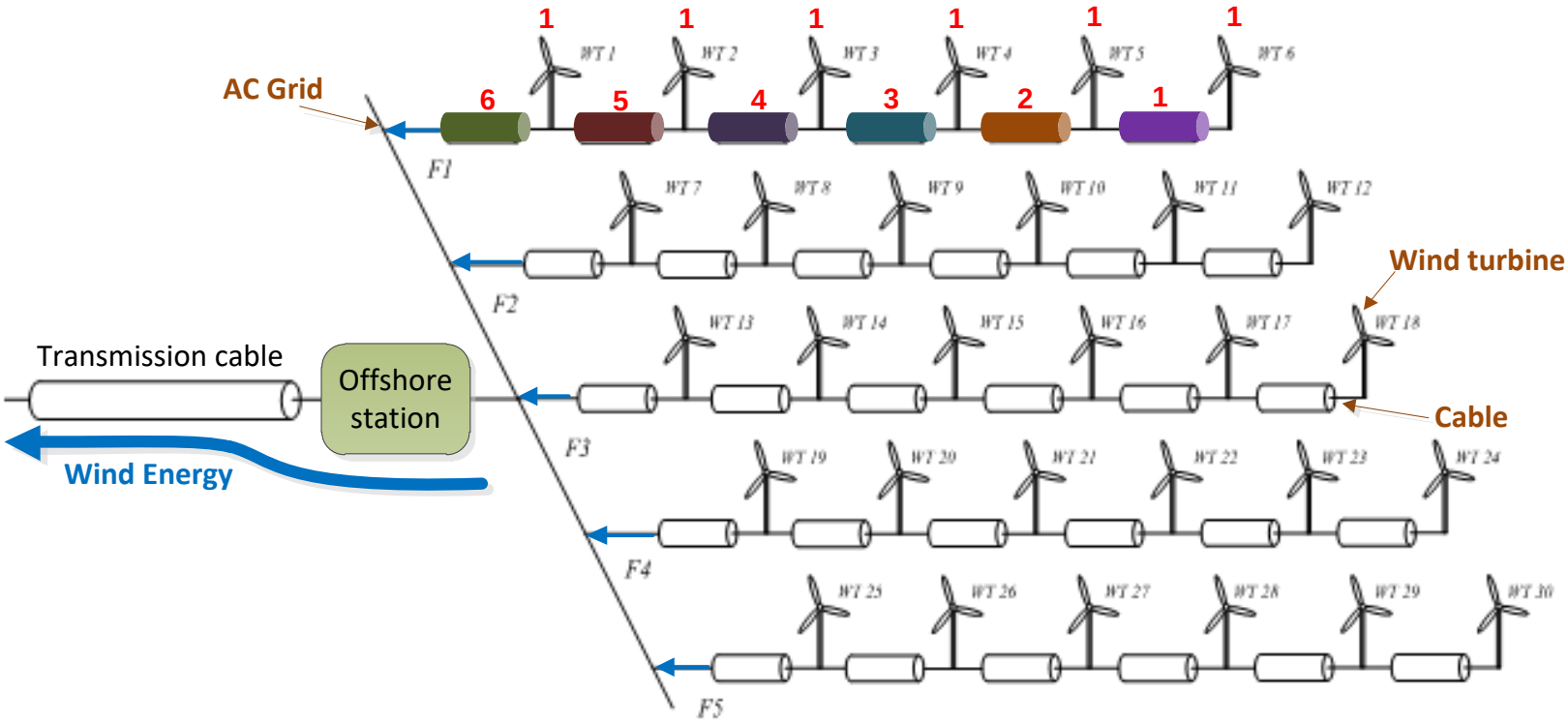
Mature AC Technology

- 33 kV collection AC voltage
- 50 Hz transformer at offshore station

50 Hz or others?

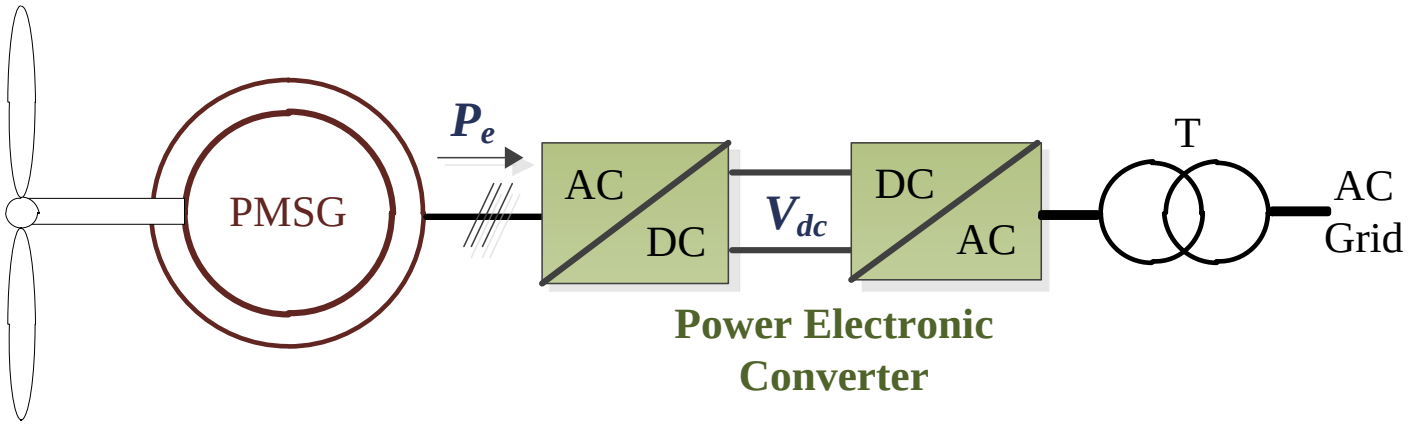
Variable-frequency control

- Reduce reactive power loss
- Long distance transmission
- Communications



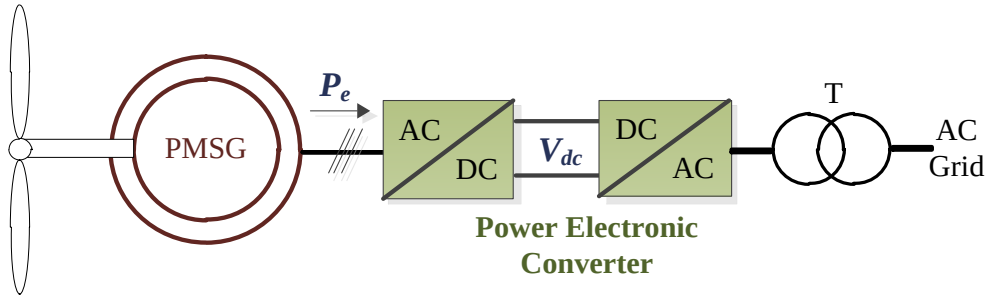
2.1 Conventional Wind Turbine in AC Grid

❖ **Typical configuration: PMSG-based Wind Turbine with BTB power converter**

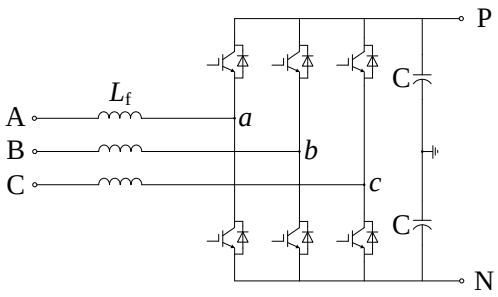


Advantage	Disadvantage
• Robust to grid • **Suitable for offshore wind power generation**	• Full rated power • High cost

2.1 Conventional Wind Turbine in AC Grid

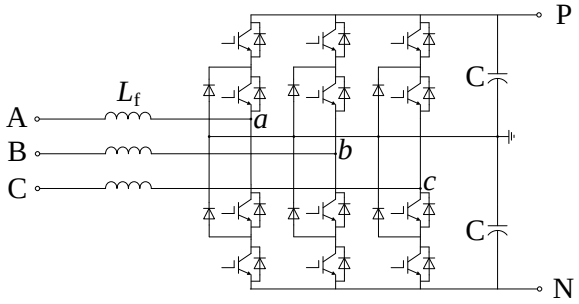


2-Level



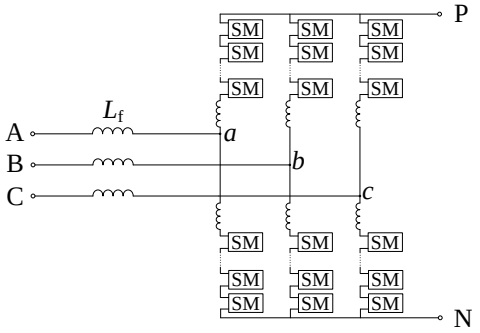
- Low voltage (e.g. 380V, 690V)
- High harmonics

3-Level



- Medium voltage (e.g. 3 kV)
- Low harmonics
- Capacitor voltage balancing issue
- Power device loss

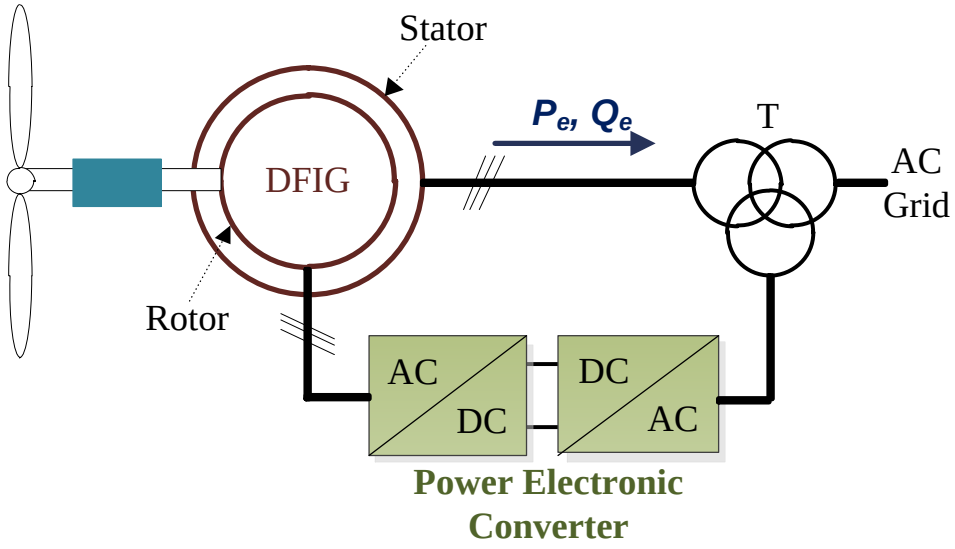
Multi-Level



- High voltage (e.g. >3 kV)
- Low harmonics
- Capacitor voltage ripple issue
- Size issue

2.1 Conventional Wind Turbine in AC Grid

- **Typical configuration: DFIG-based Wind Turbine with BTB power converter**

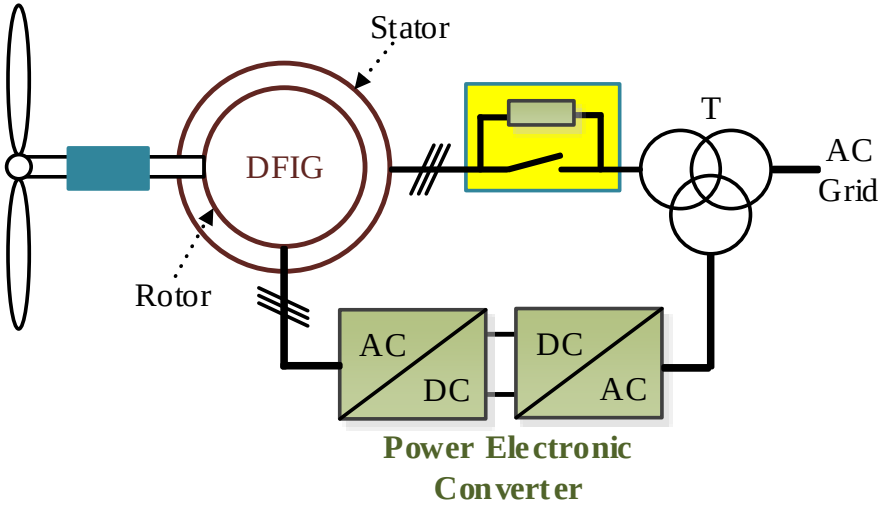


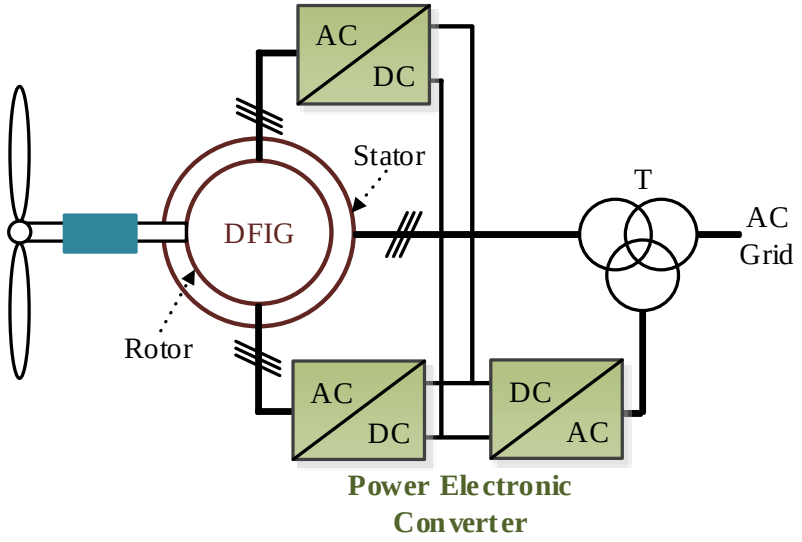
Challenge:
Grid disturbance?

Advantage	Disadvantage
• Small rated power • Low cost	• Easily affected by grid (because the stator is directly connected to the grid)

2.1 Conventional Wind Turbine in AC Grid

❖ Solutions for Grid Disturbance Issue:





- Normal operation:

  Resistor is bypassed

- Grid disturbance situation:

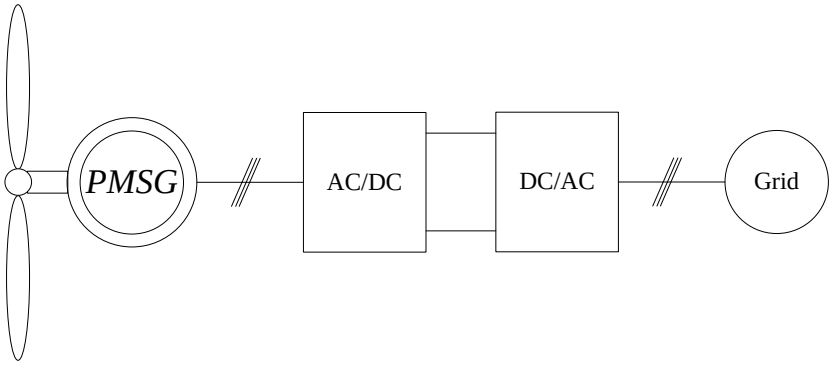
  Resistor is inserted into the grid between the stator and grid

- Normal operation:

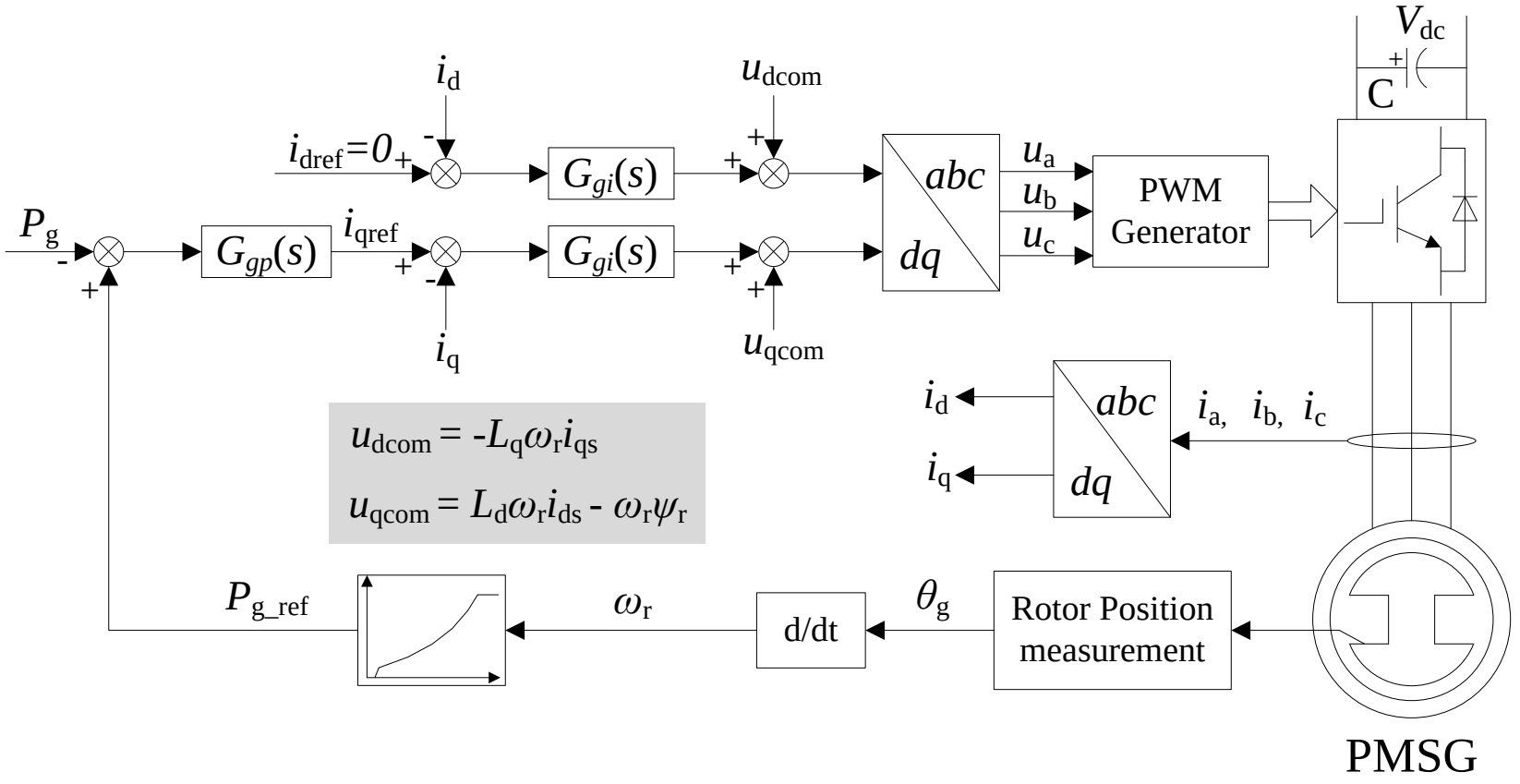
  AC/DC connected to rotor to produce the flux

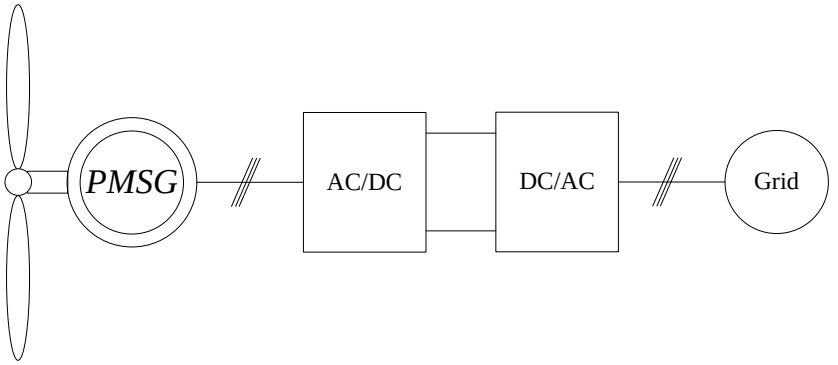
- Grid disturbance situation:

  AC/DC connected to rotor to regulate the flux

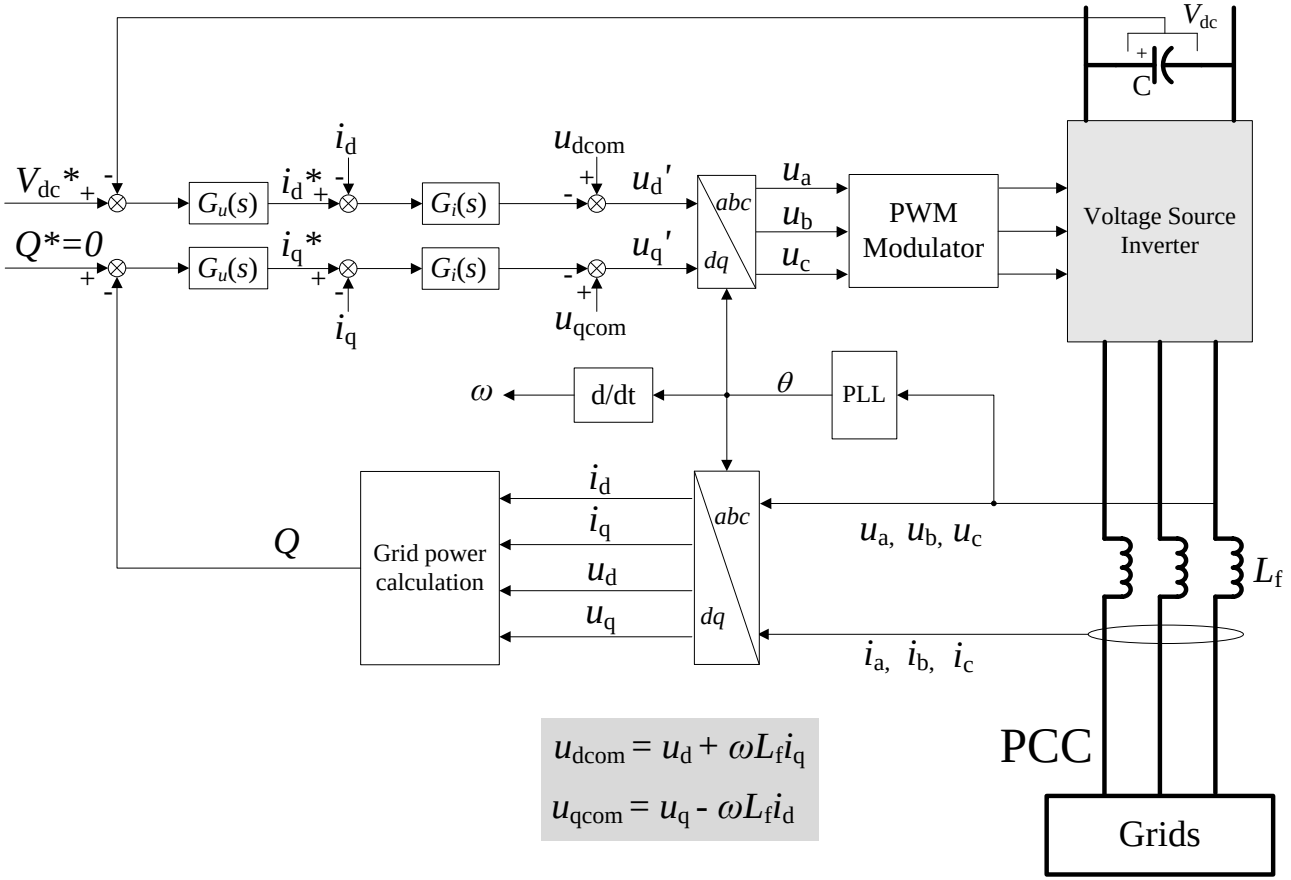


■ Control of Generator-side Converter





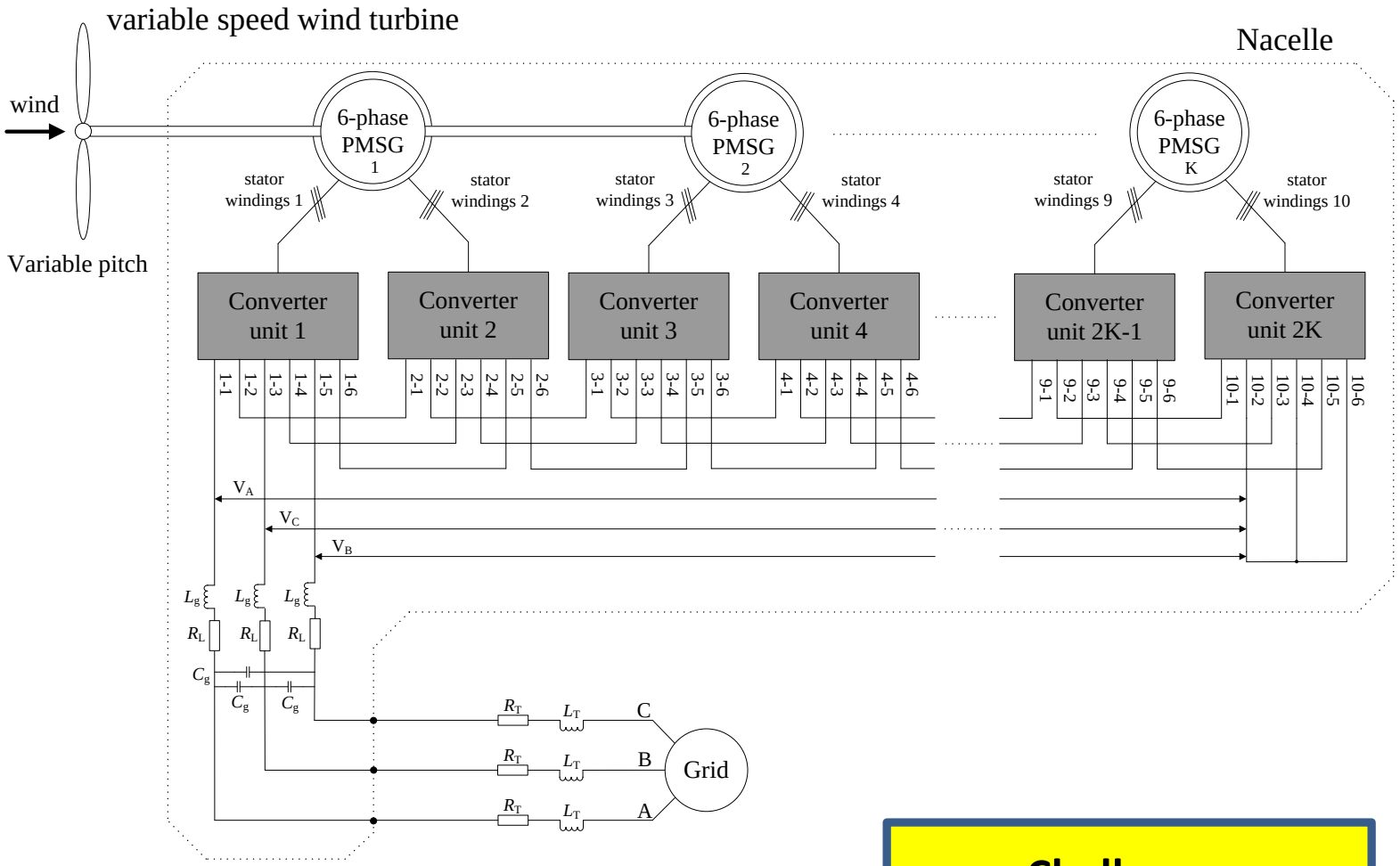
■ Control of Grid-side Converter



$$u_{dcom} = u_d + \omega L_f i_q$$

$$u_{qcom} = u_q - \omega L_f i_d$$

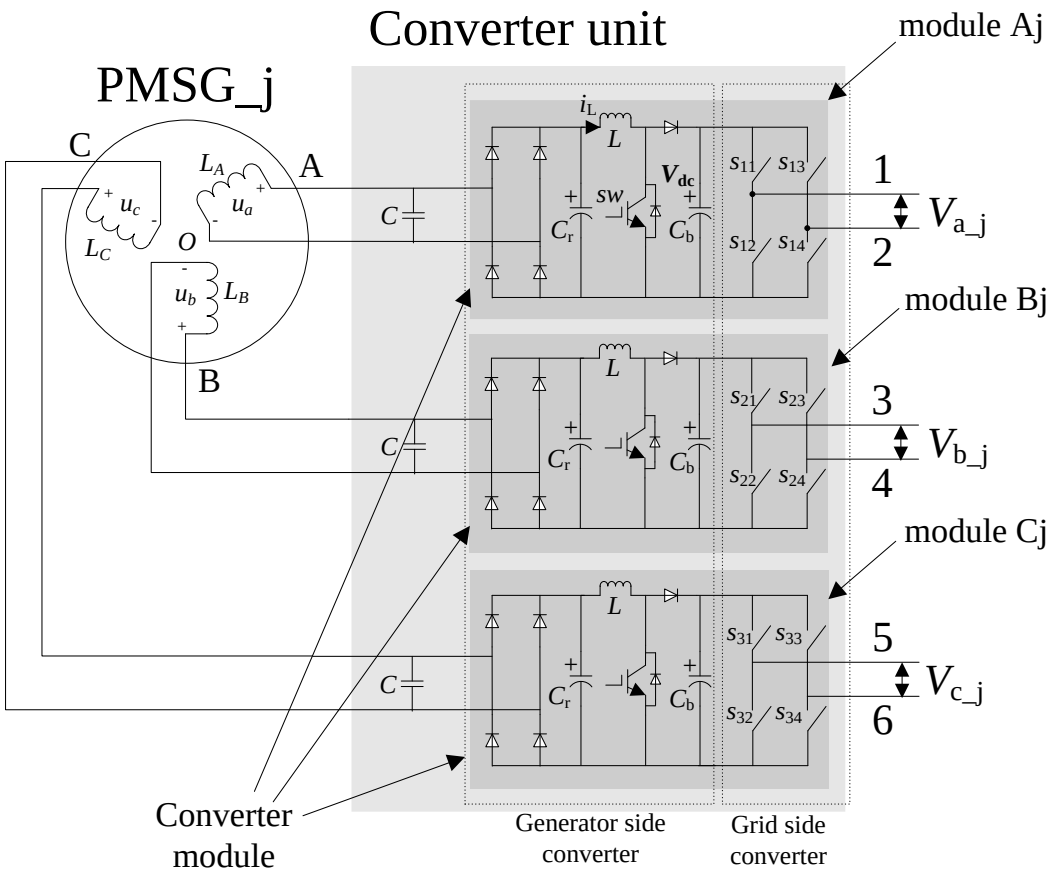
2.2 Other Wind Turbines - 1



Challenge:
High grid voltage?

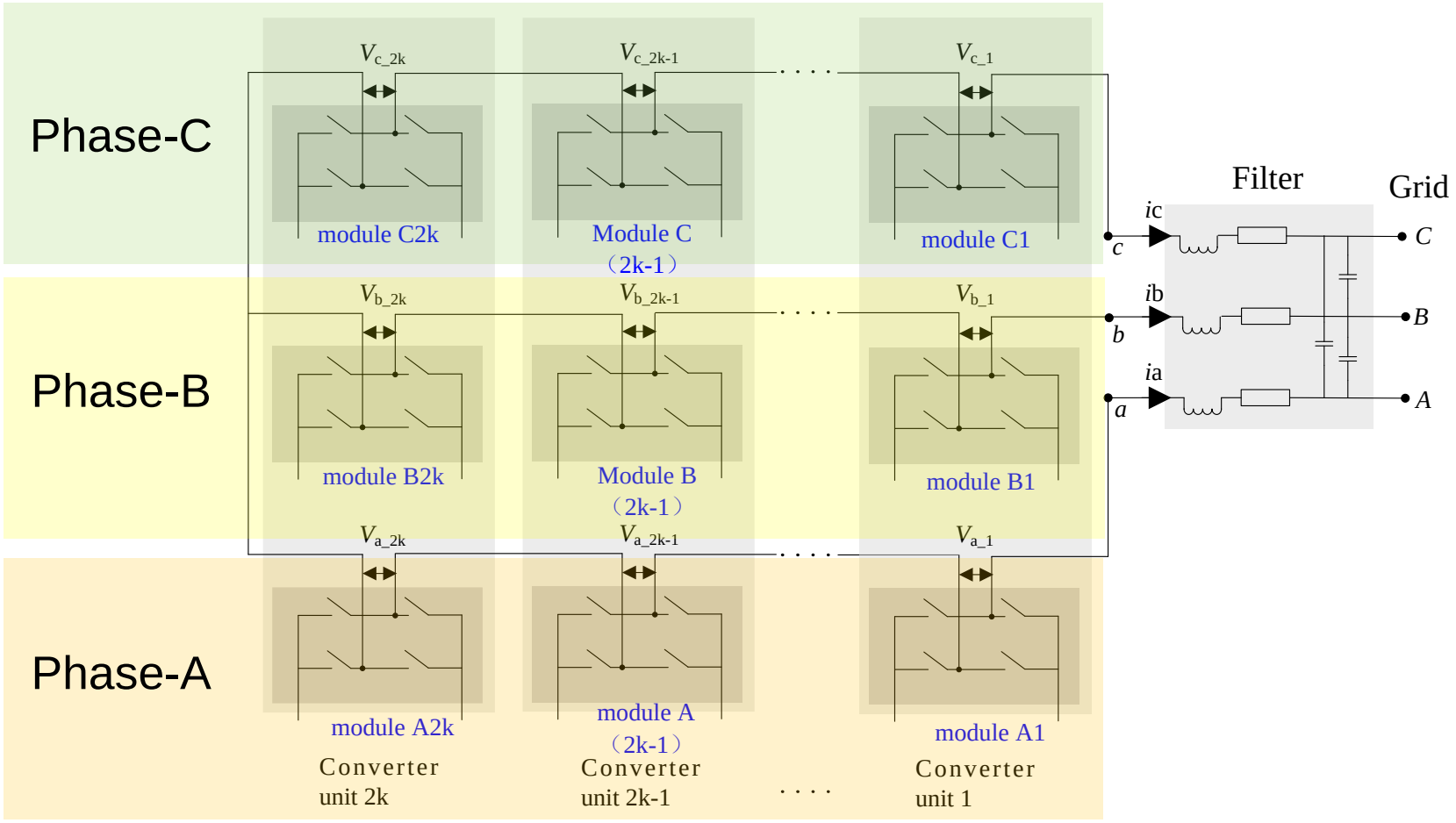
2.2 Other Wind Turbines - 1

Converter unit topology:



2.2 Other Wind Turbines - 1

Cascaded multilevel converter



2.2 Other Wind Turbines - 1

Control strategy

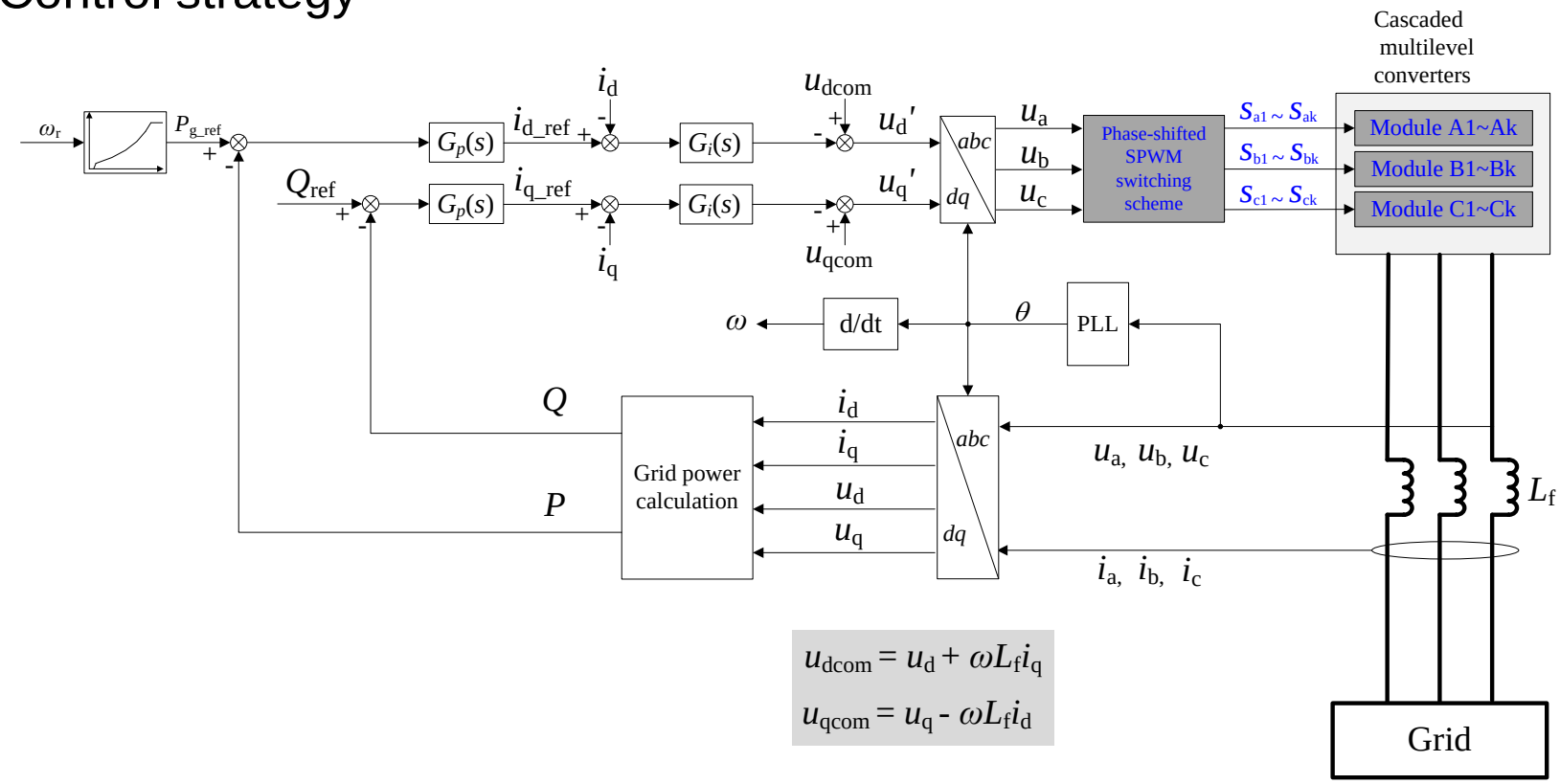
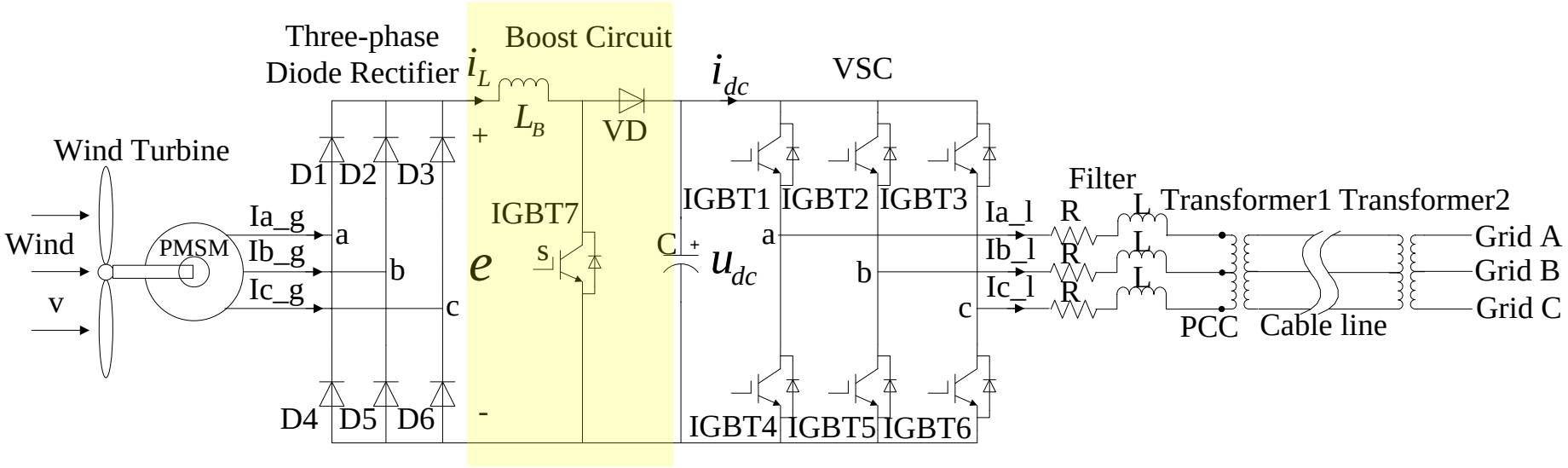


Fig. 5. Block diagram of the control strategy for the cascaded multilevel converter.

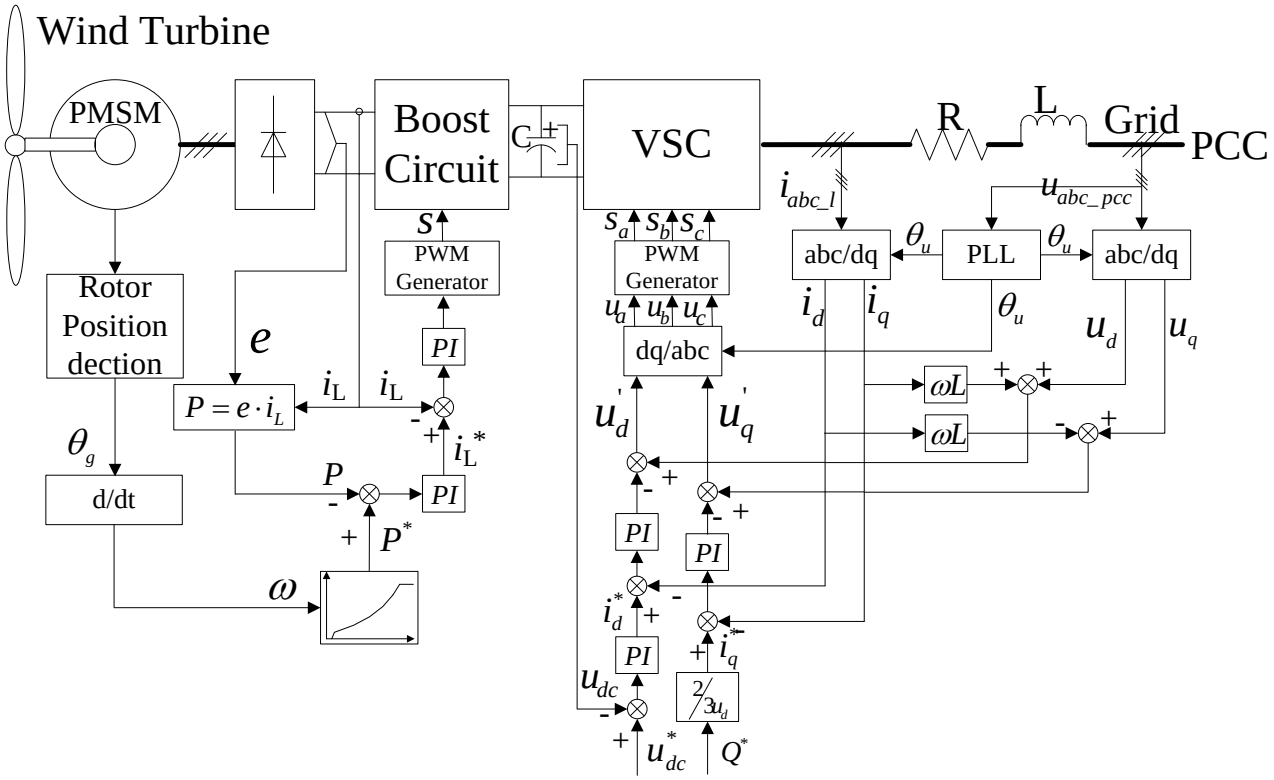
2.3 Other Wind Turbines - 2

- Permanent Magnet Synchronous Generator (PMSG)
- Three-phase Diode Rectifier
- Boost Converter
- Voltage Source Converter (VSC)

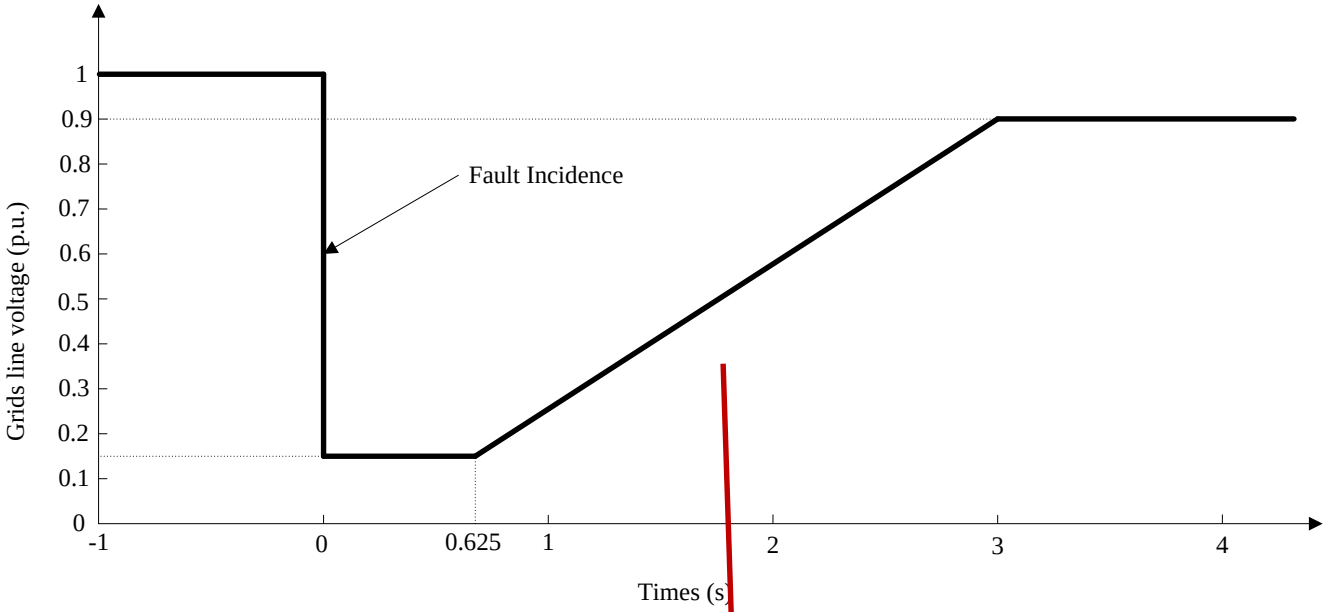


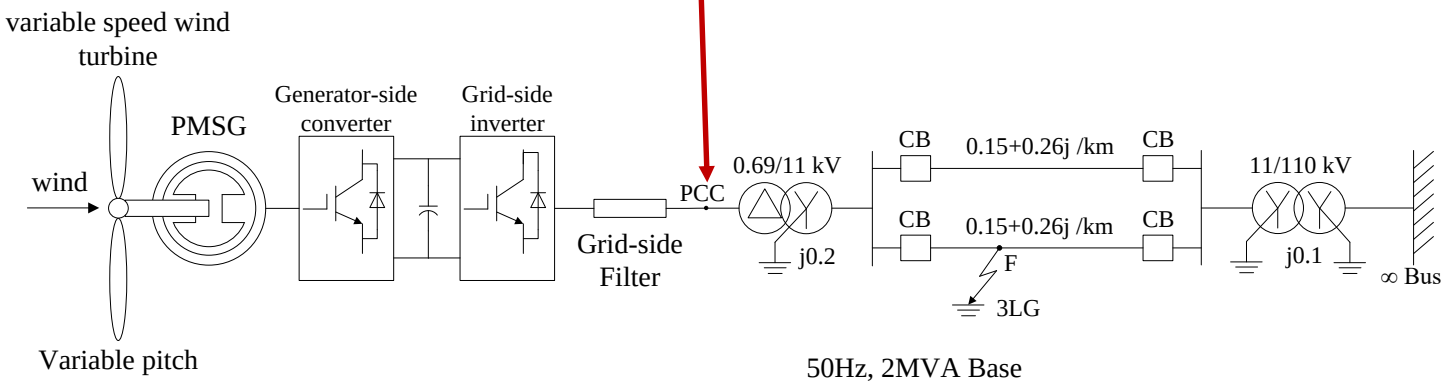
Conventional Control

- Boost DC/DC Converter → P
- Voltage Source Converter → Udc & Q



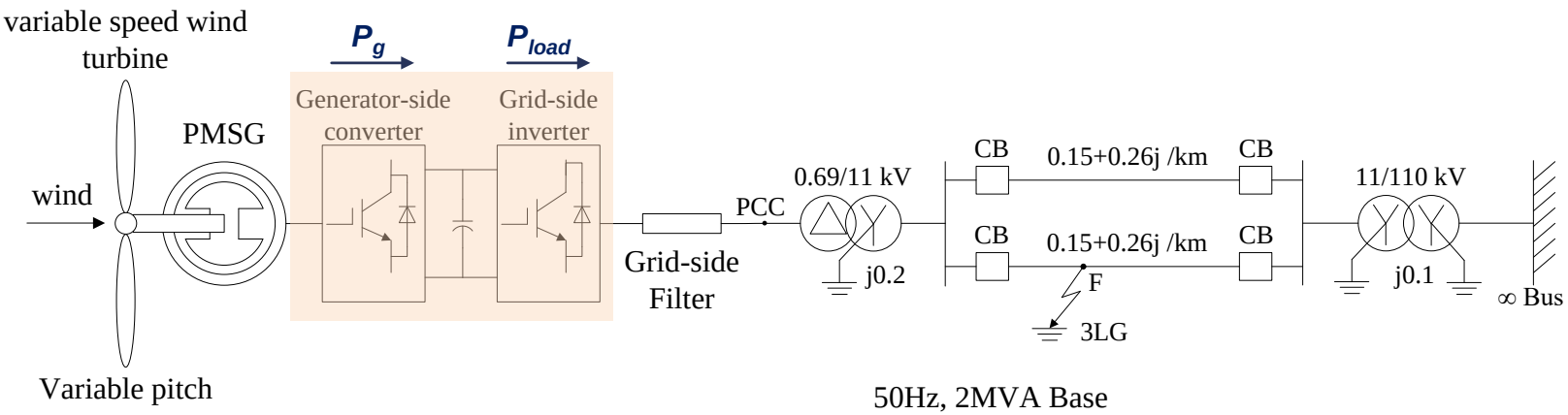
Grid Code (Low Voltage)

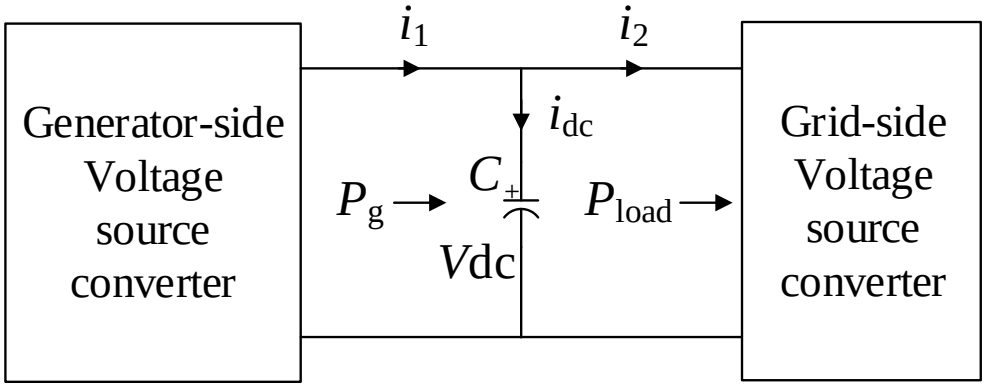




50Hz, 2MVA Base

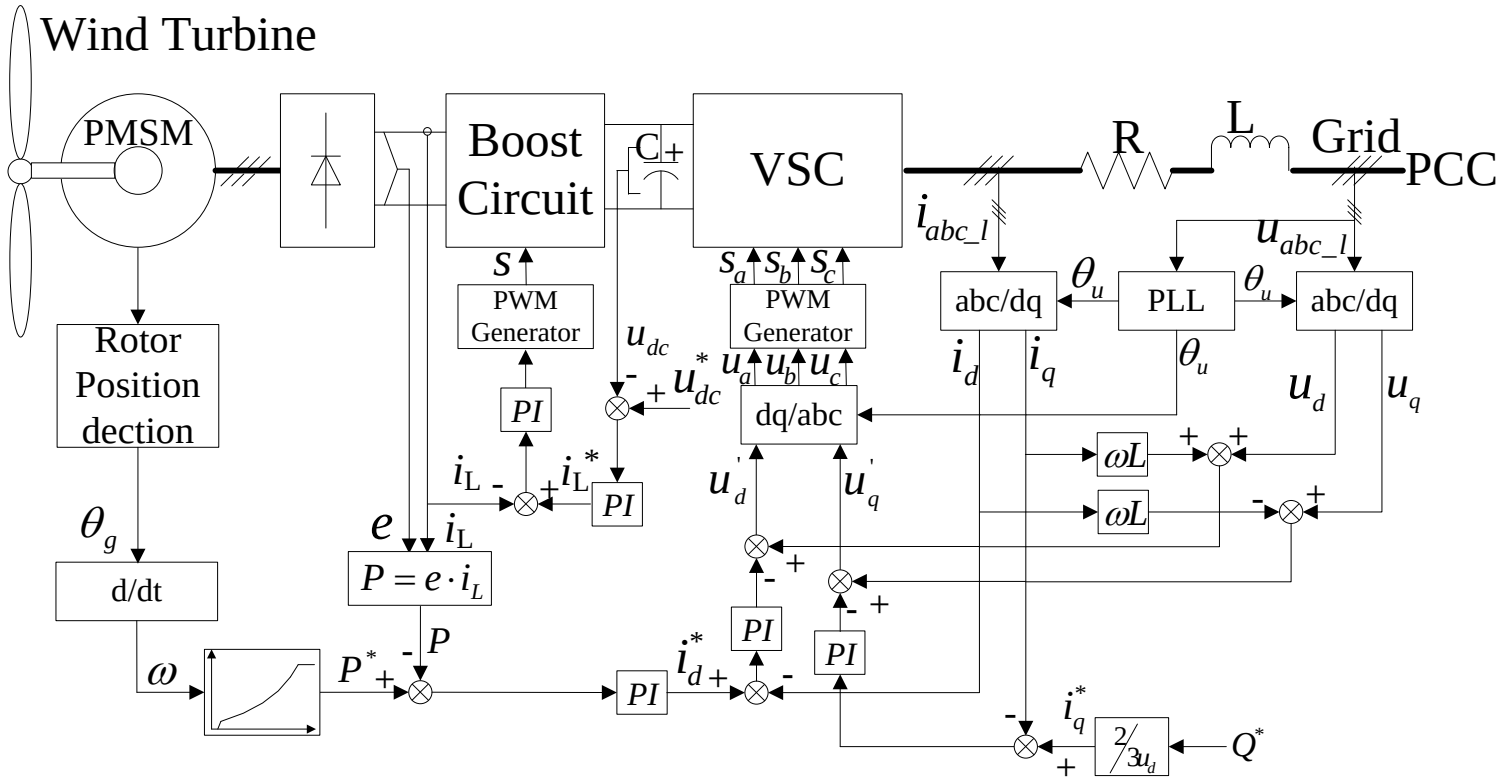
DC-link voltage ripple





Control for DC-link Ripple Elimination:

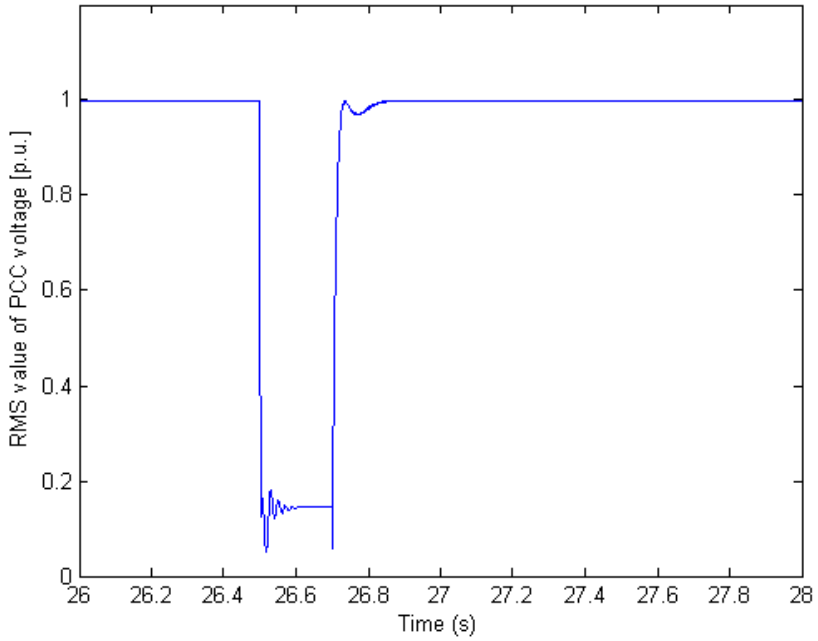
- Boost DC/DC Converter → Udc
- Voltage Source Converter → P & Q

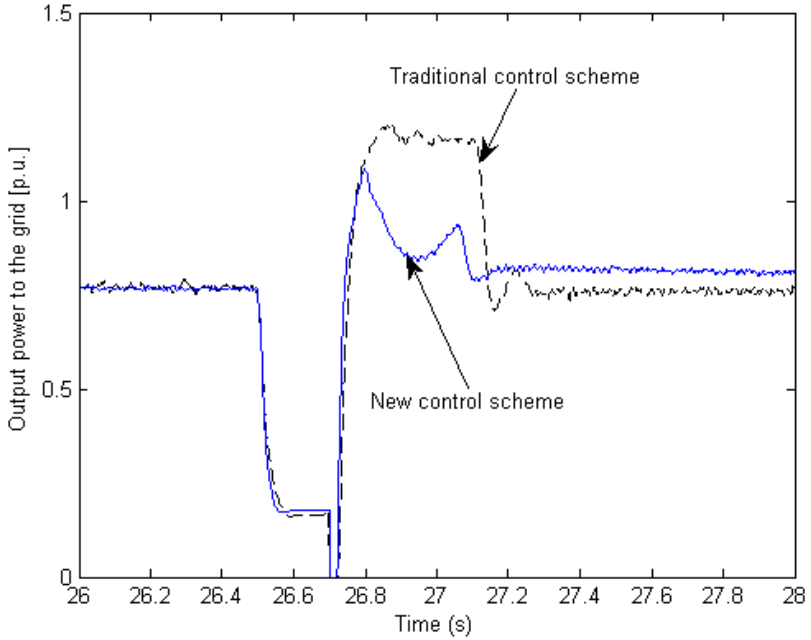


Simulation

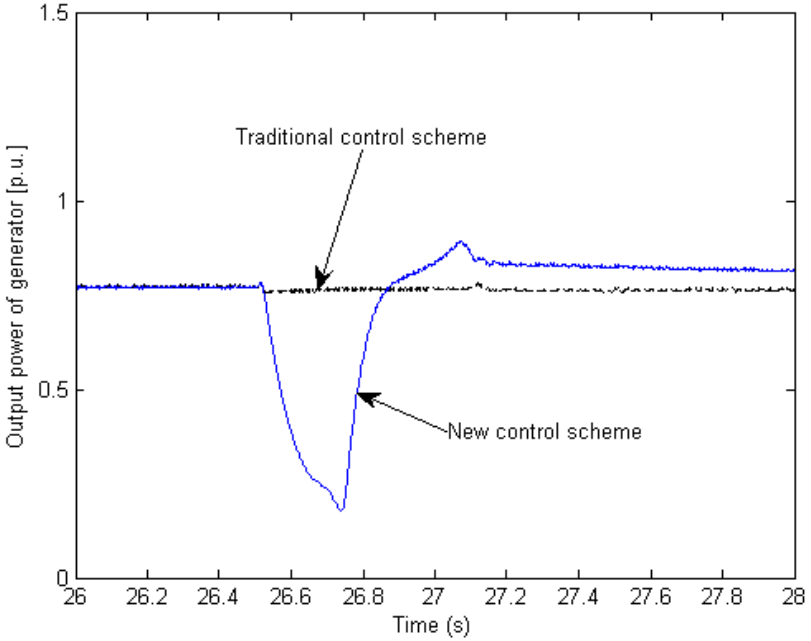
Condition:

- Wind speed is constant as 11m/s
- PCC voltage dips to 15% of rated value

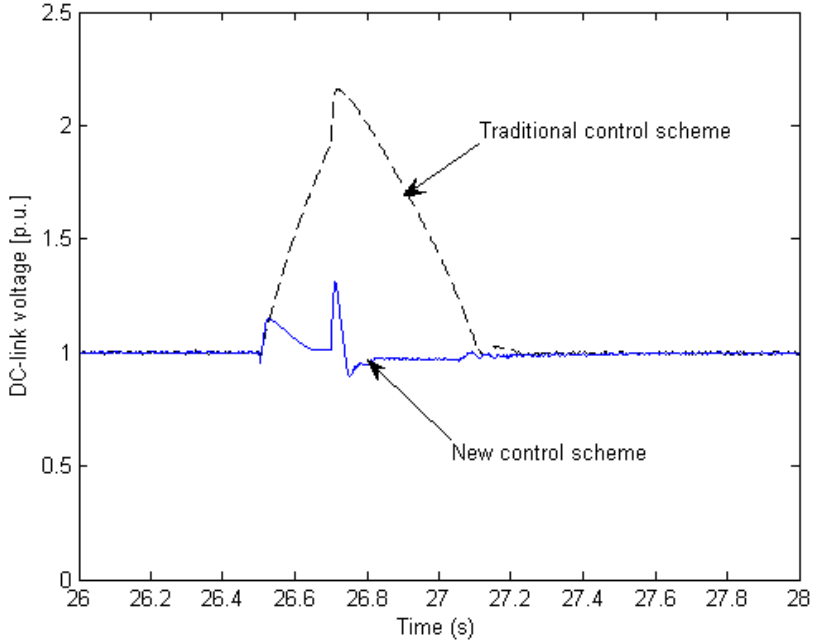




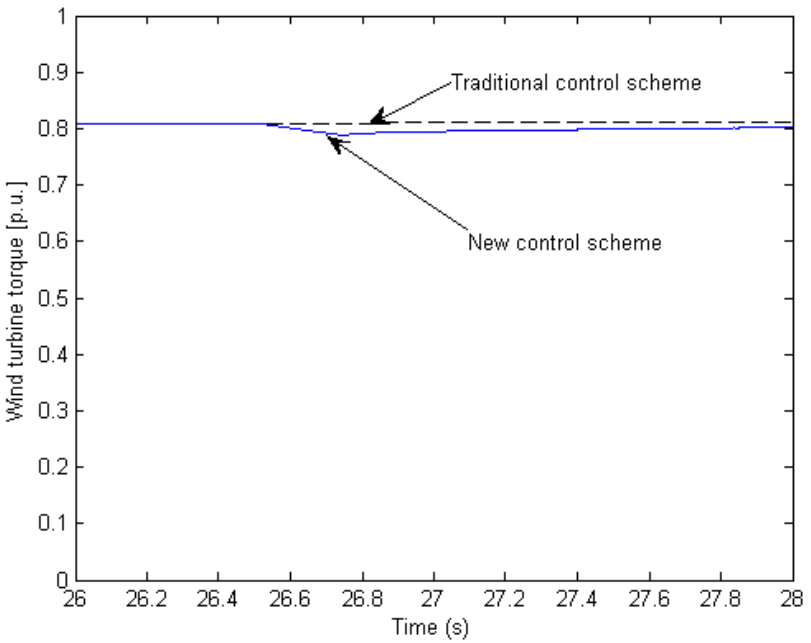
Output power to the grid



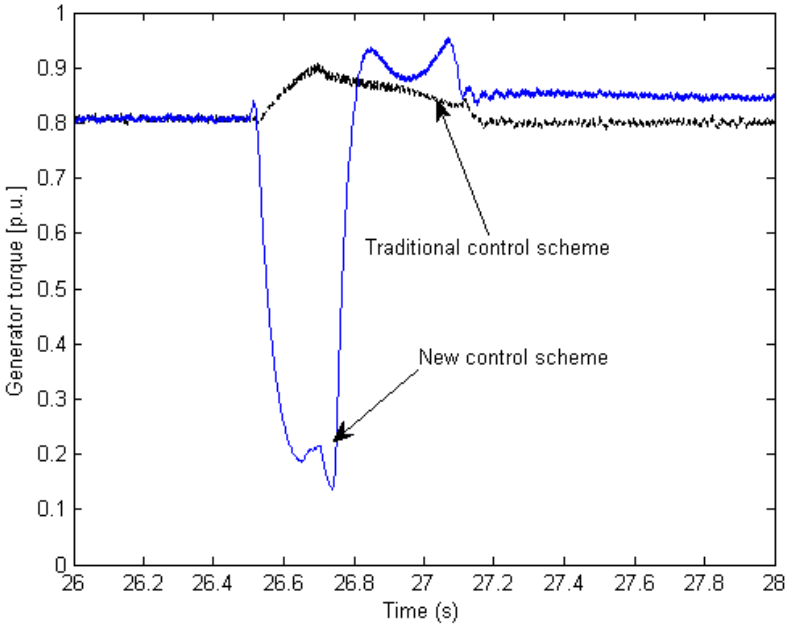
Generator output power



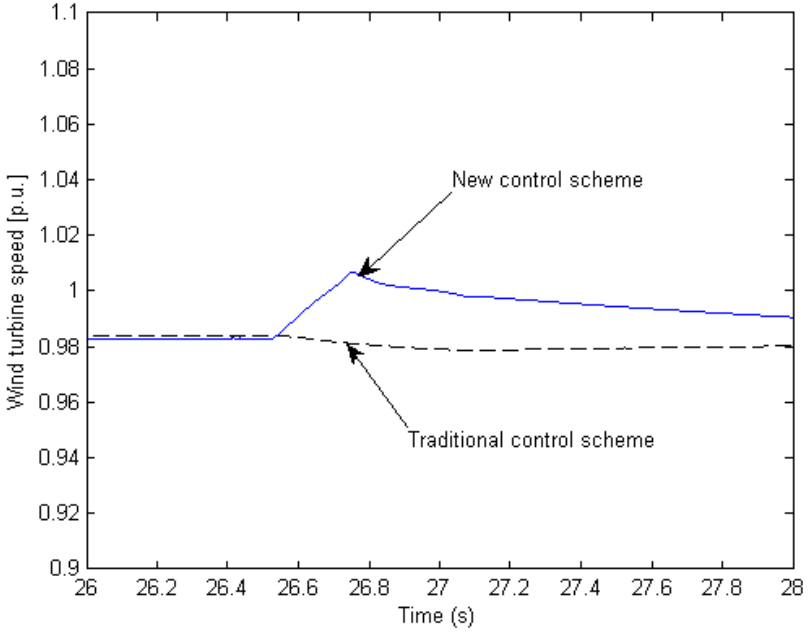
DC-link voltage



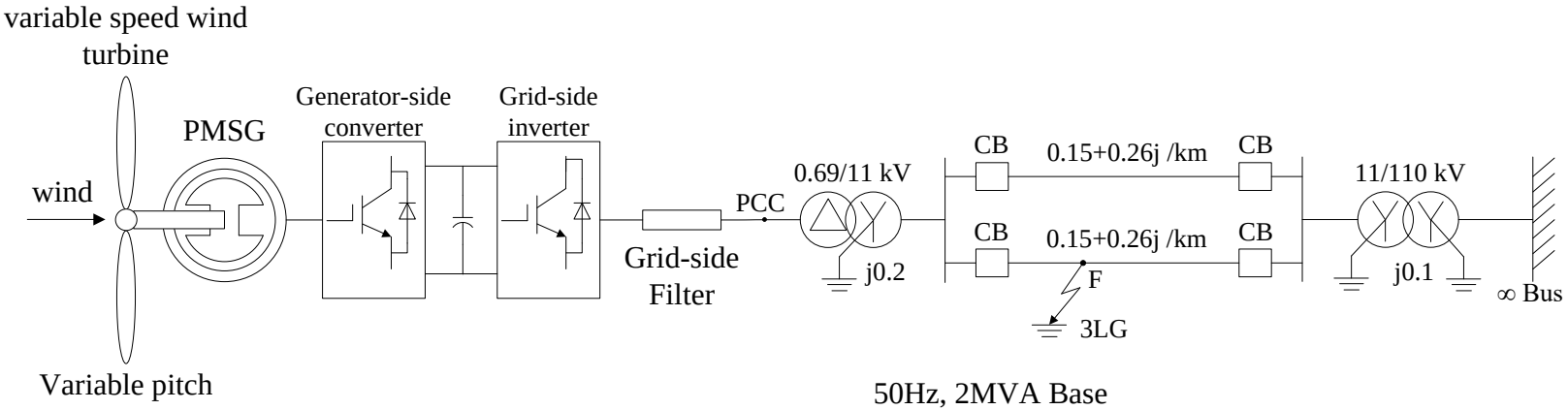
Wind turbine torque



Generator electromagnetic torque



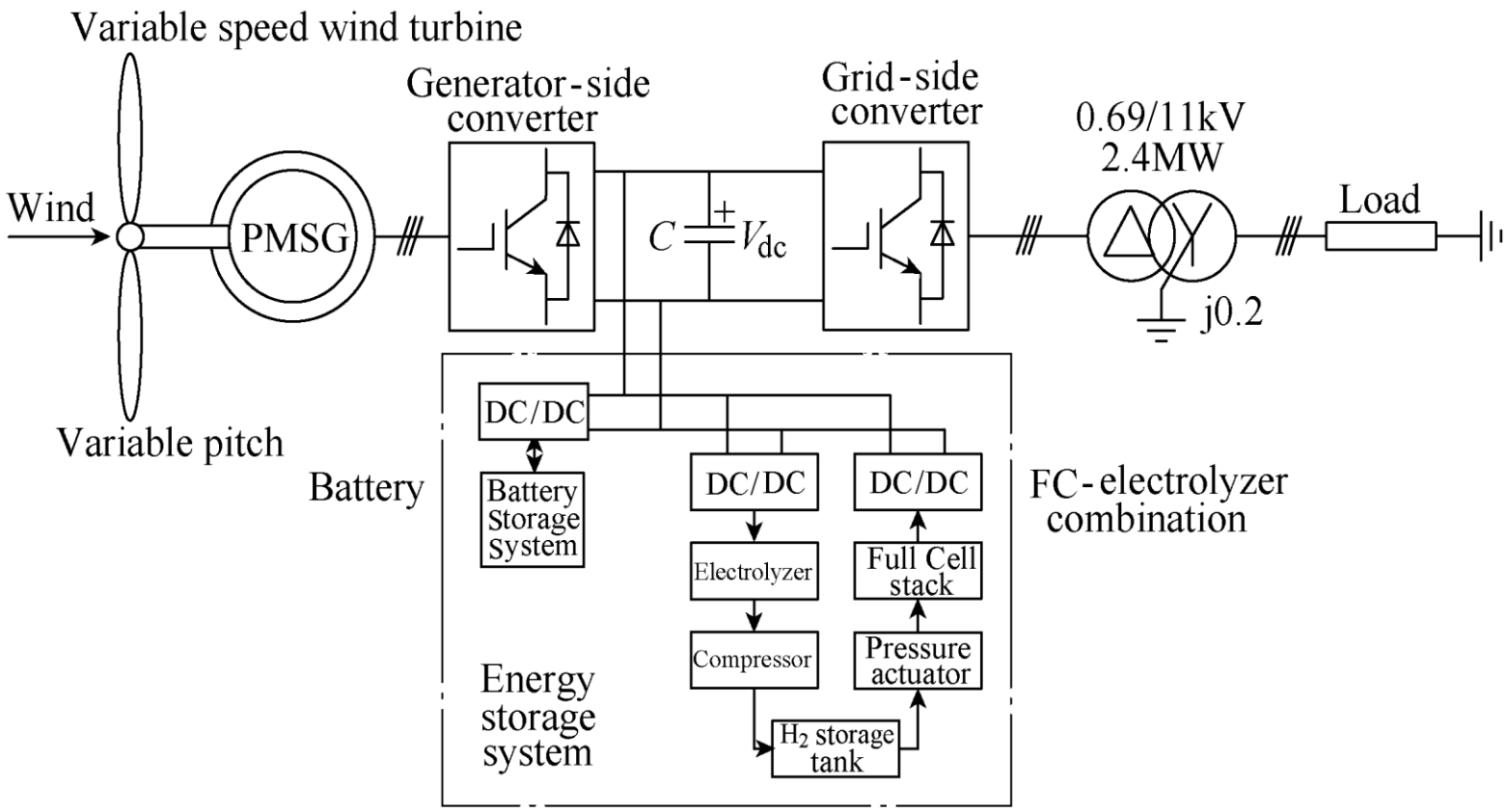
Wind turbine speed



50Hz, 2MVA Base

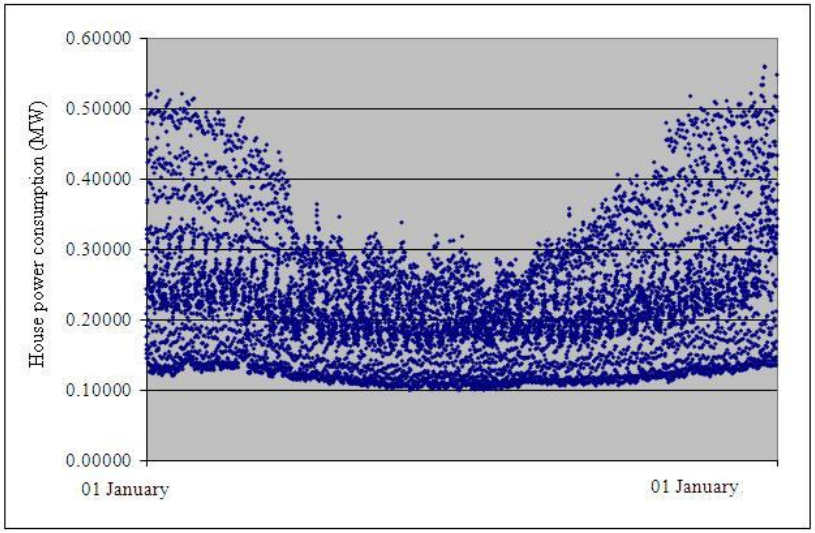
2.4 Other Wind Turbines - 2

- Wind Turbine in Stand-Along System

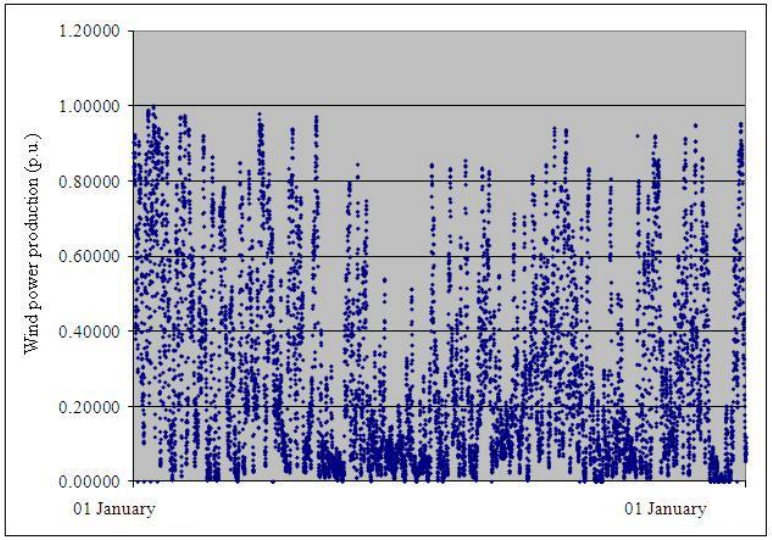


Selection of Wind Turbine

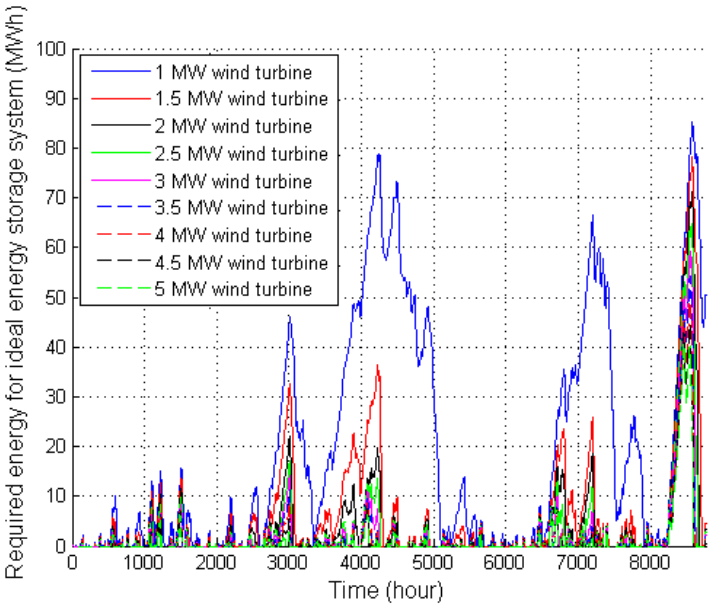
- House power consumption in 2019



- Wind power production in 2019



- Energy required for ideal energy storage system

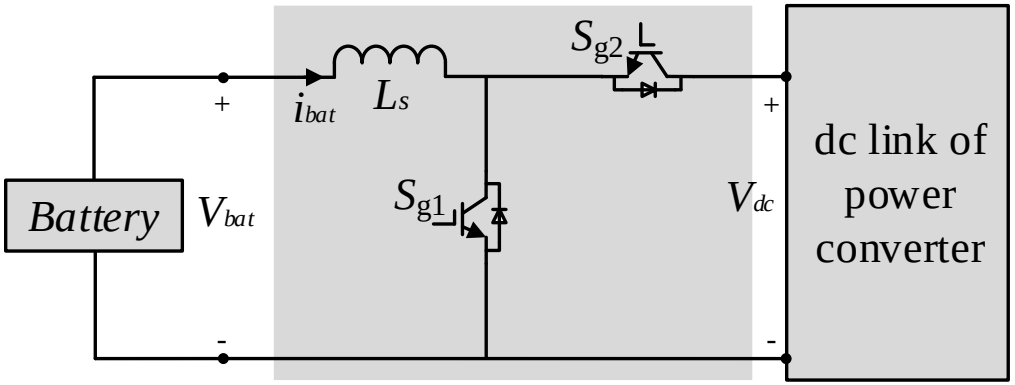


Selecting wind turbine size based on

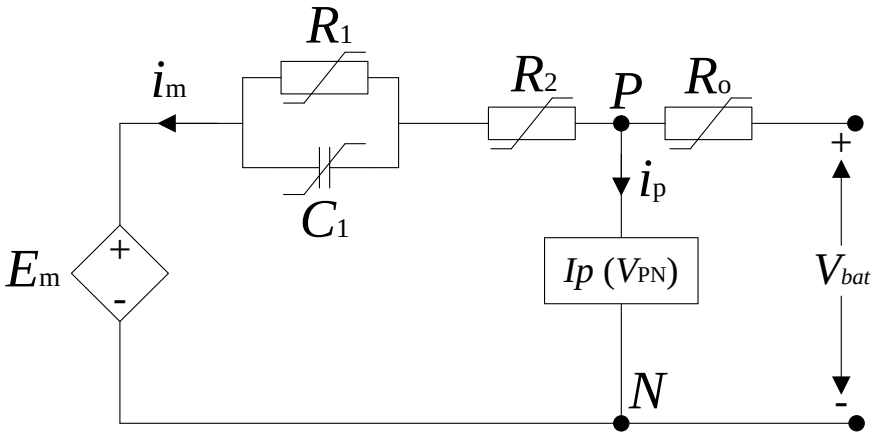
- ✓ Size of energy storage system
- ✓ Cost of WT
- ✓ Cost of ESS

■ Battery Energy Storage System

- DC/DC Buck/Boost Converter



- Third-order battery mode

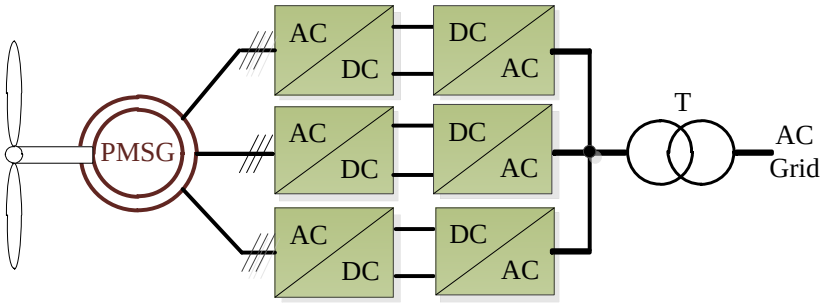


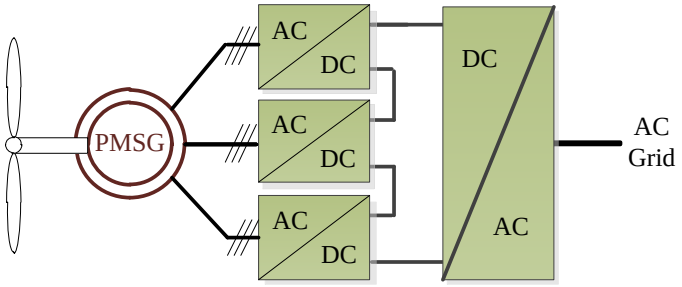
Researches

- **DC/DC converter**
- **Control of DC/DC converter**
- **Cooperation control of Generator-side converter, DC/DC converter, grid-side converter**
- **Lifetime analysis of battery**
- **Control optimization for battery lifetime**

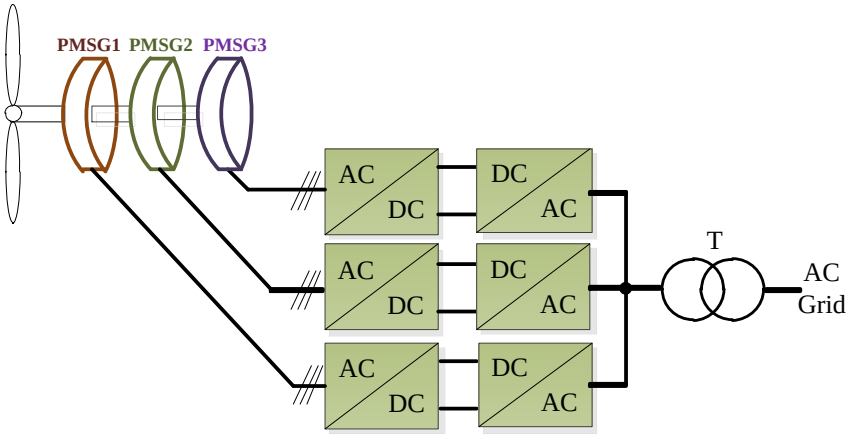
2.5 Other Wind Turbines - 3

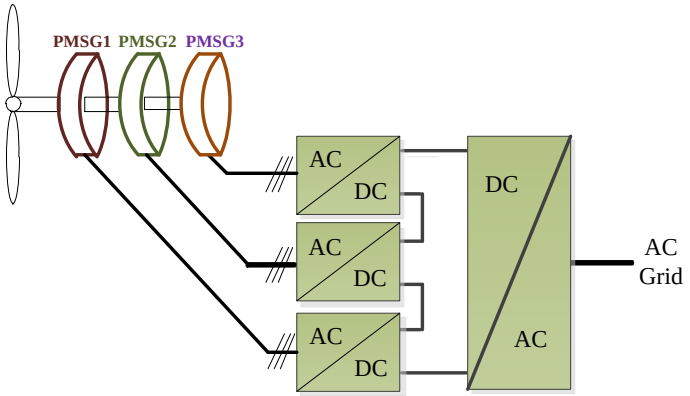
- **WT configuration 1 (Multiple-windings)**





- **WT configuration 2 (Multiple-windings)**



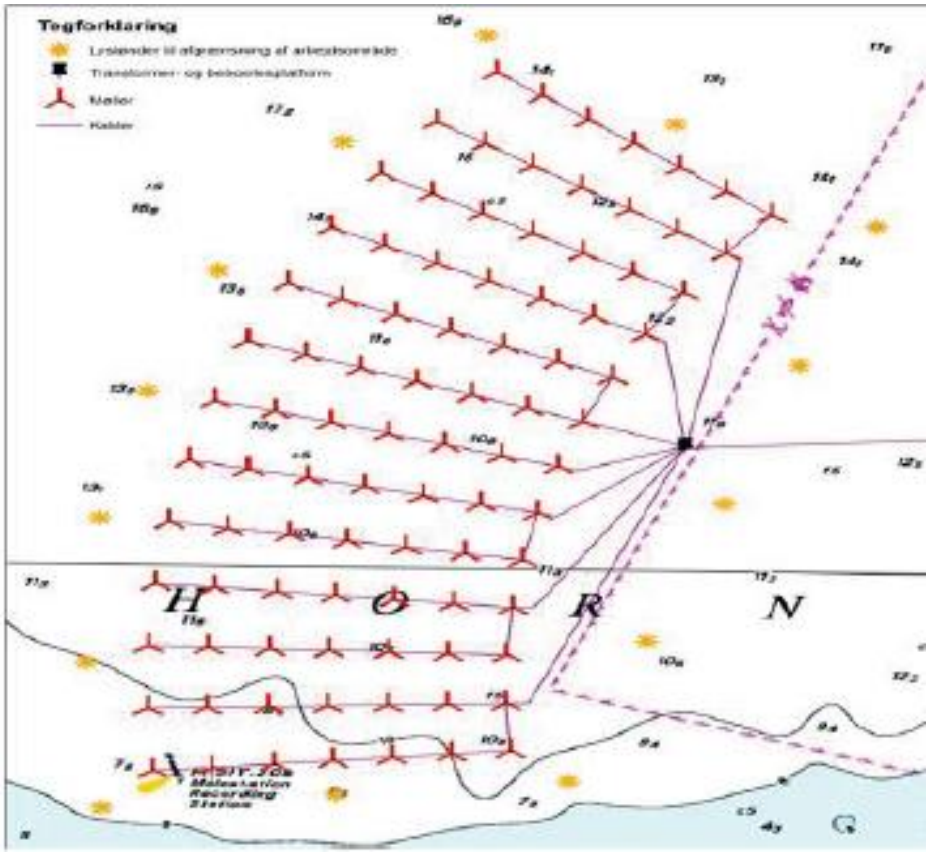


2.6 Wind Farm Configuration

Researches point

- **Topologies of wind farms** ⟶ **Optimization**
- **Control of wind turbines** ⟶ **Optimization**

⟶ **Optimization**



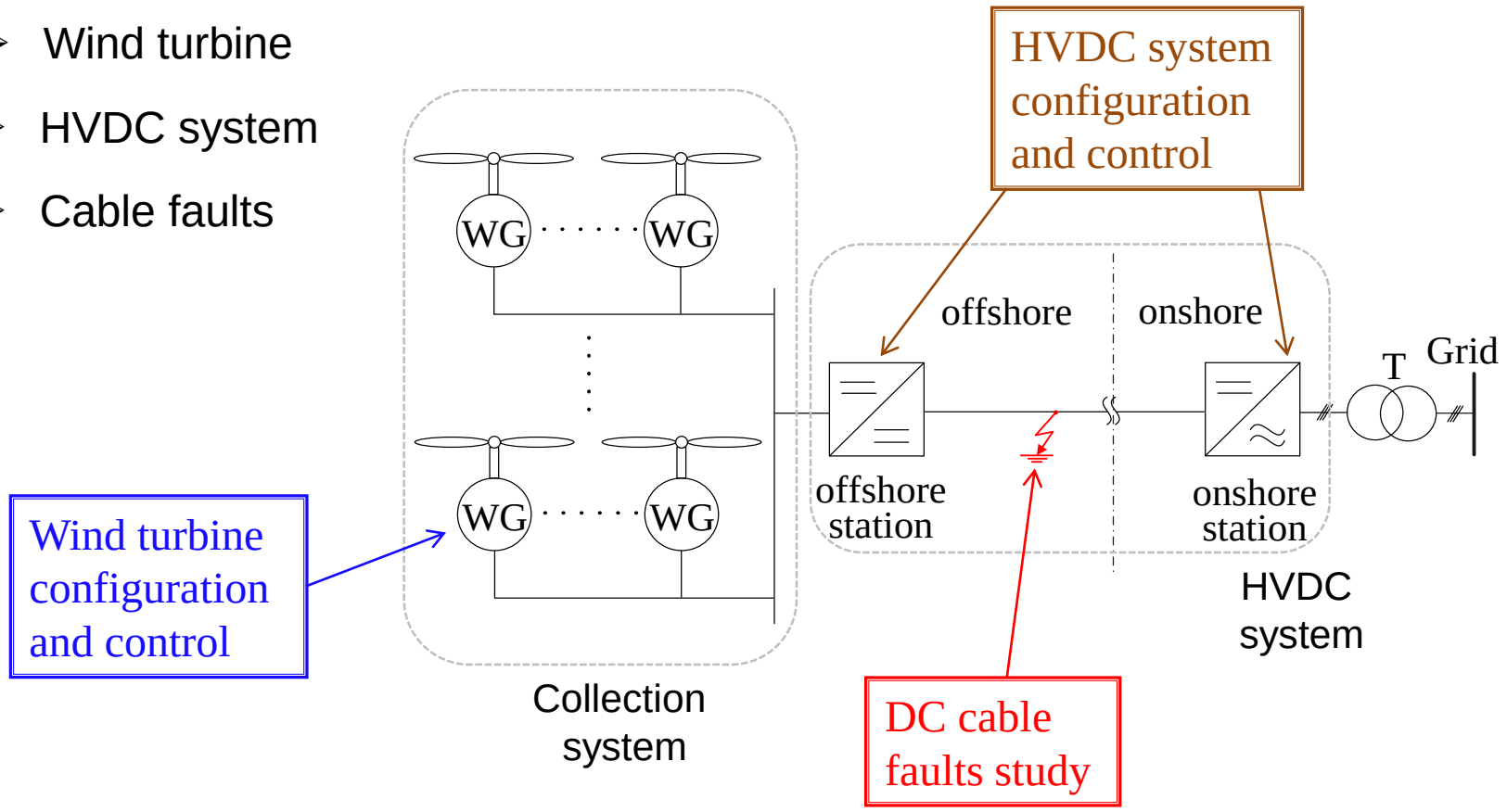
Main effects:

- **Topology affects the wind power capture**
- **Topology affects the size of cables and power losses in collection system**
- **Control of wind farm affect the optimal wind power capture**
- **Control of wind farm affect the power loss**

3.1 DC Grid for Offshore Wind Farms

Main researches

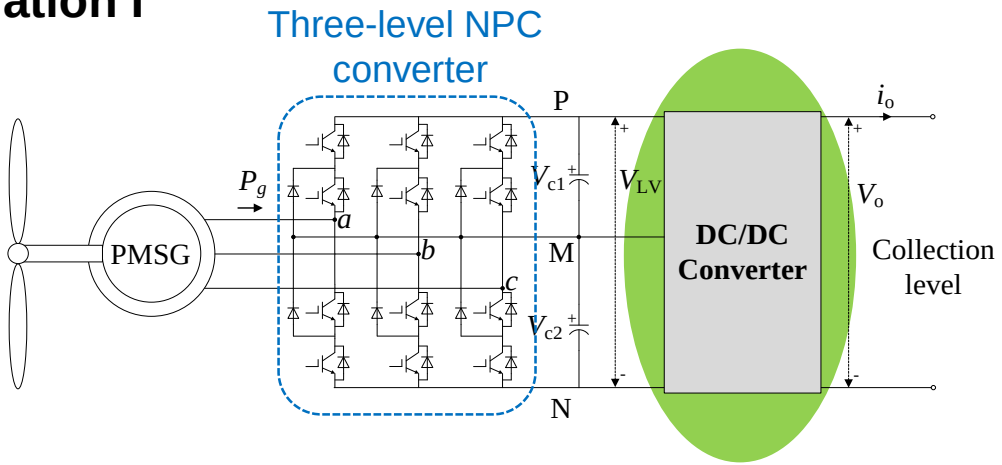
- Wind turbine
- HVDC system
- Cable faults



3.2 Wind Turbine for DC Grid

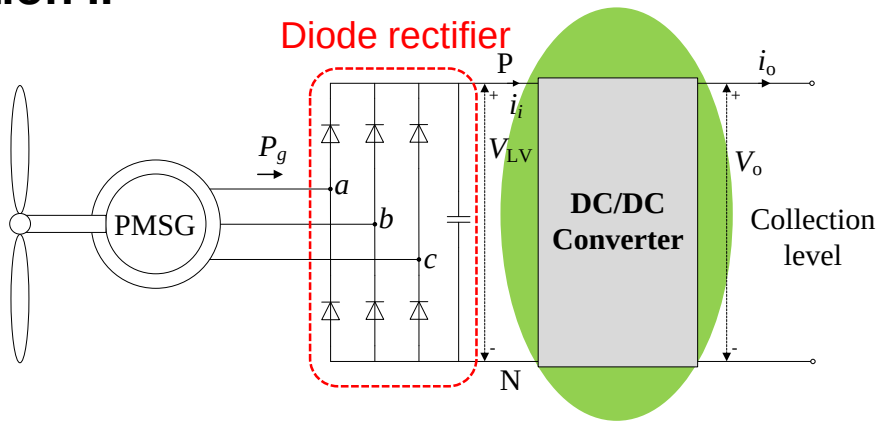
1. Wind turbine configuration I

3-L NPC converter
+
DC/DC converter



2. Wind turbine configuration II

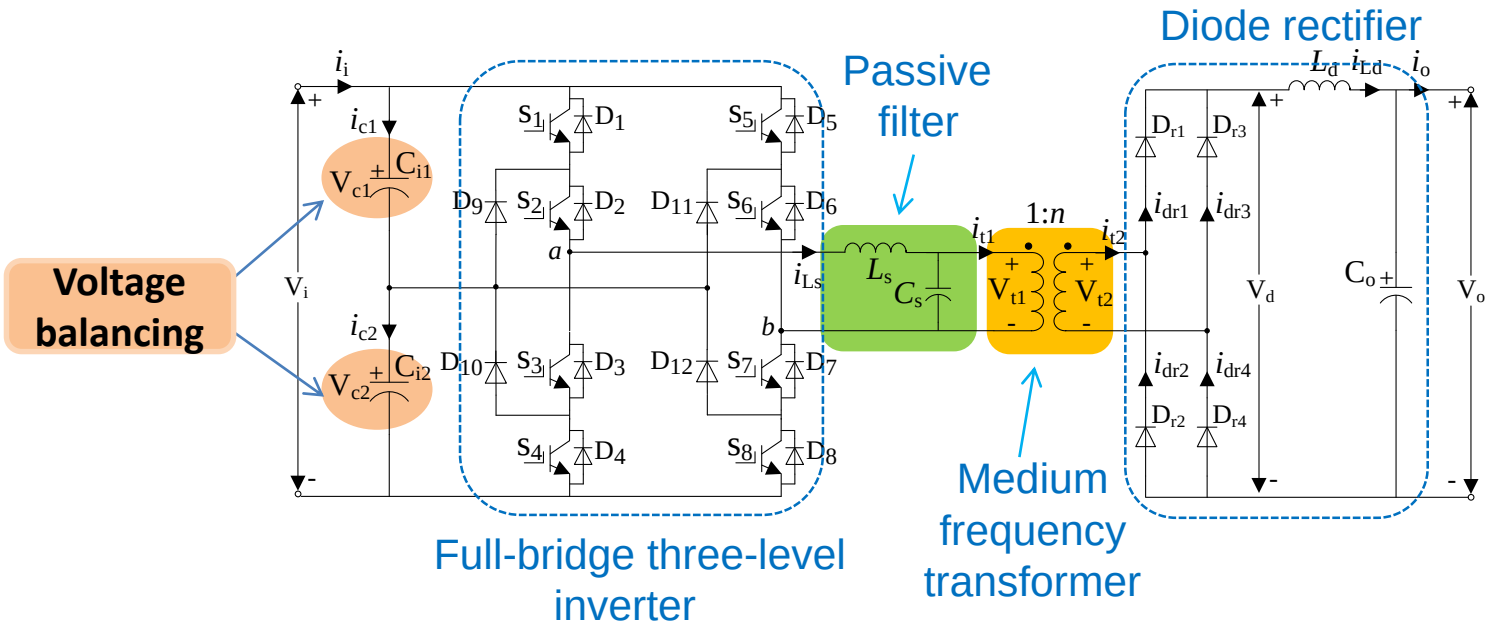
Diode rectifier
+
DC/DC converter



3.3 A DC/DC Converter

Isolated full-bridge three-level DC/DC converter

- Isolated DC transformer
- 3-level configuration
- Medium switching frequency

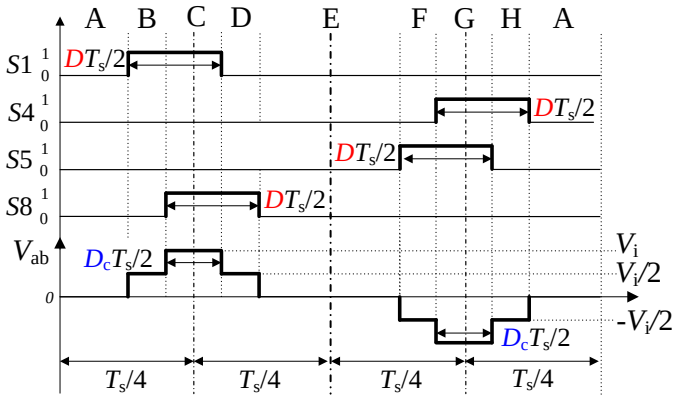


Modulation Strategy

Modulation mode I

D →

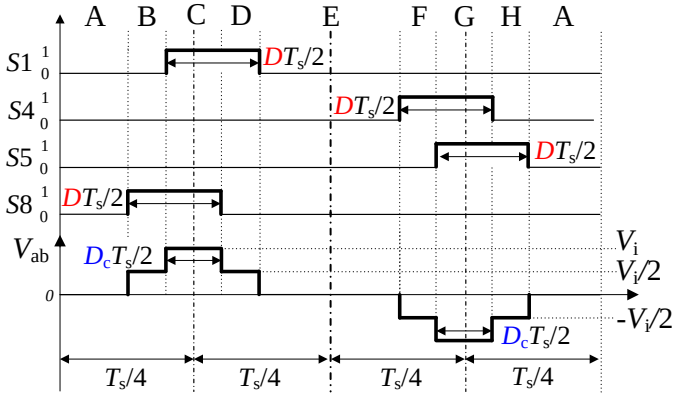
Dc →



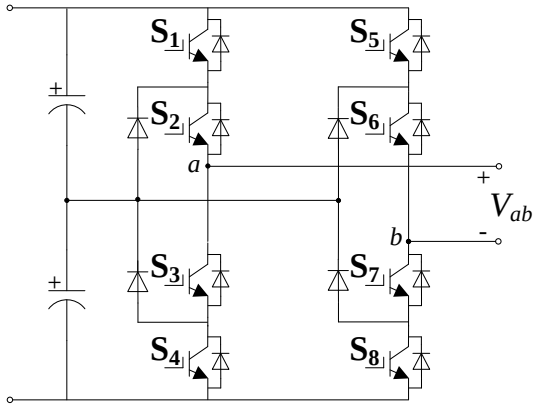
Modulation mode II

D →

Dc →



Full-bridge 3-L inverter

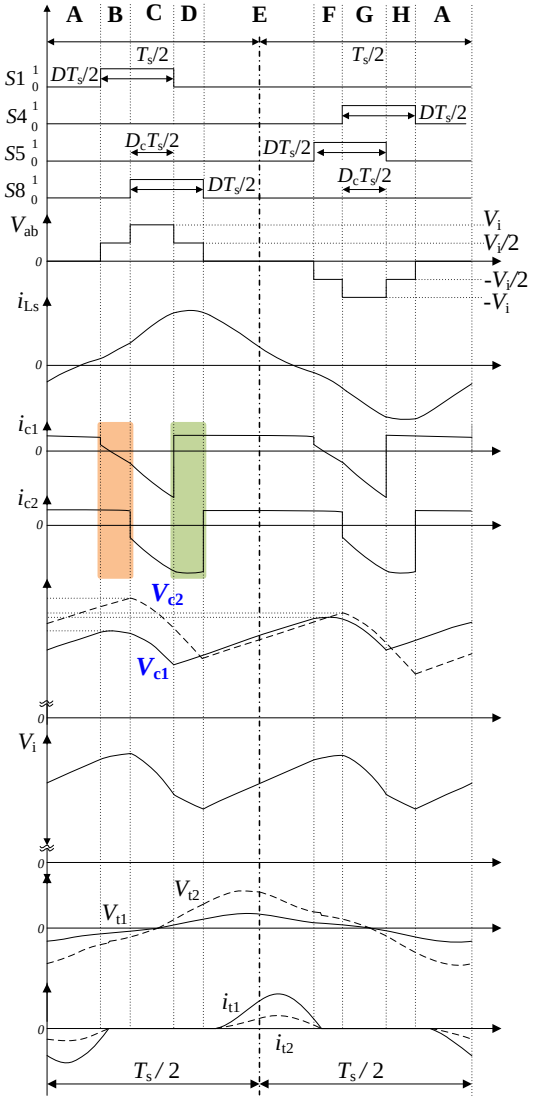


$$S_3 = \overline{S_1} \qquad S_6 = \overline{S_8}$$

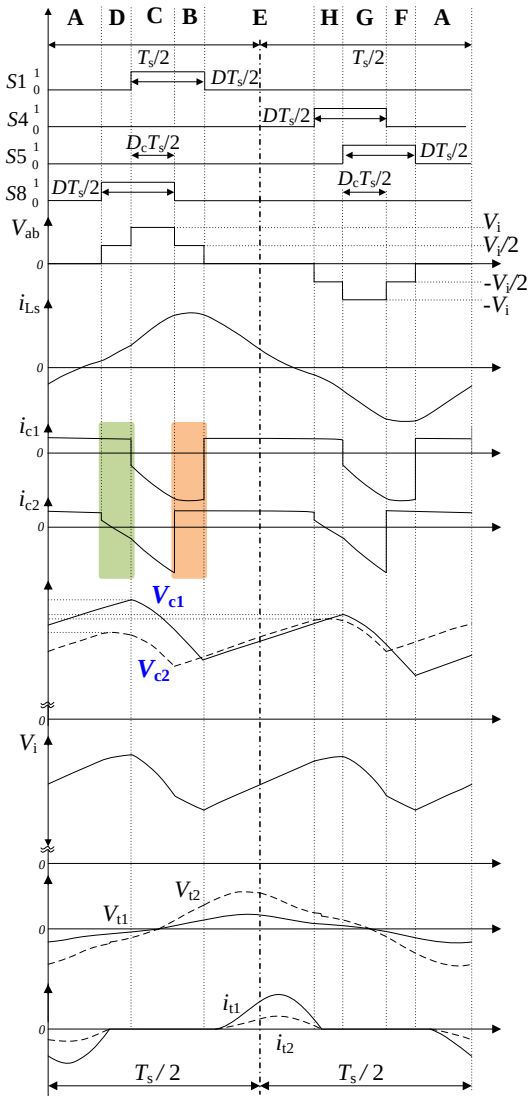
$$S_2 = \overline{S_4} \qquad S_7 = \overline{S_5}$$

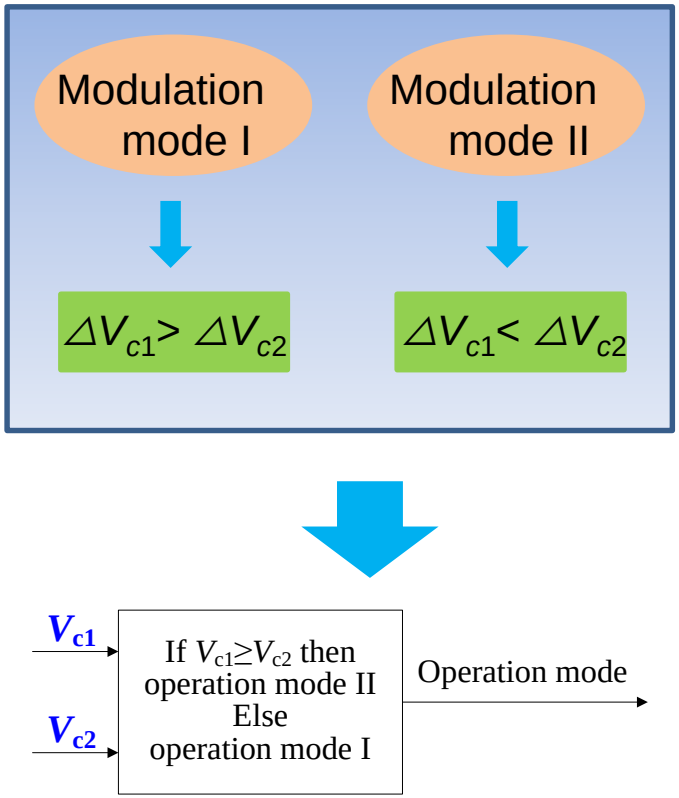
DC Capacitor Voltage Balancing Control

Modulation mode I



Modulation mode II





Wind Turbine Control 1

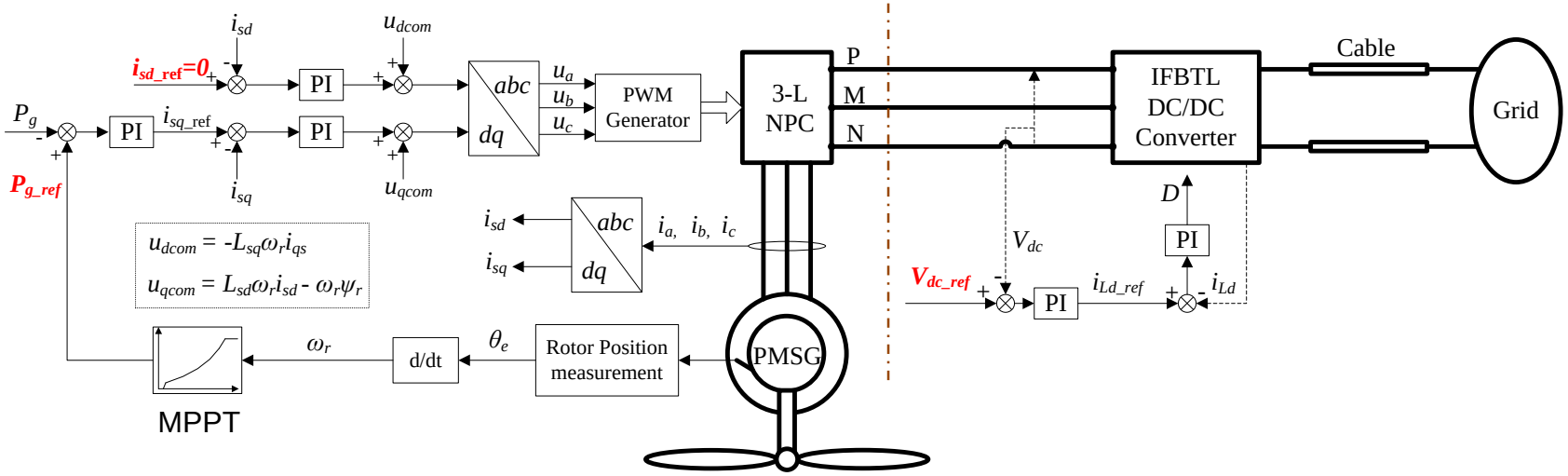
1. Control of wind turbine configuration I

(1) Generator-side converter control

- Optimal power control **Pref**
- Reactive current control **isd_ref=0**

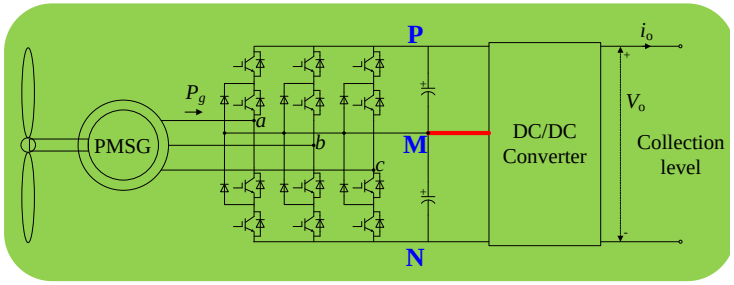
(2) Grid-side converter control

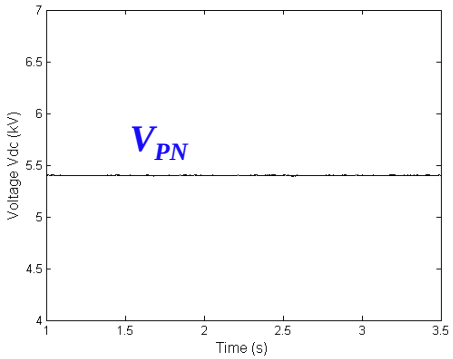
- DC-link voltage control **Vdc_ref**

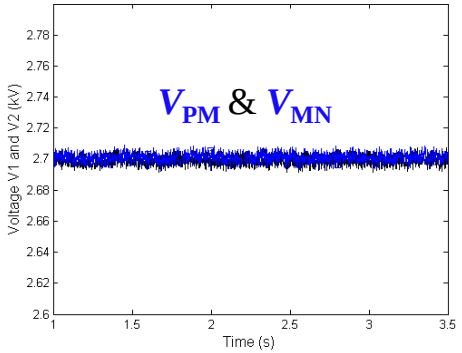


Control Performance

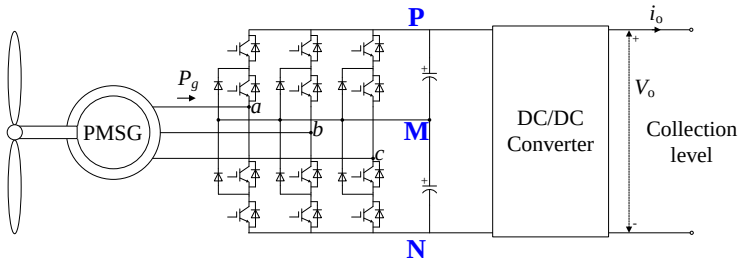
1. 1st-situation

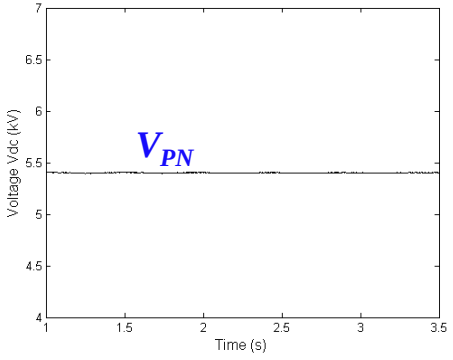


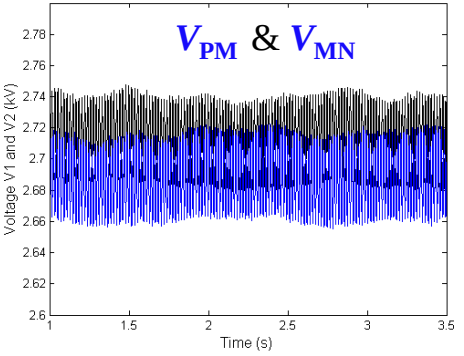




2. 2nd-situation





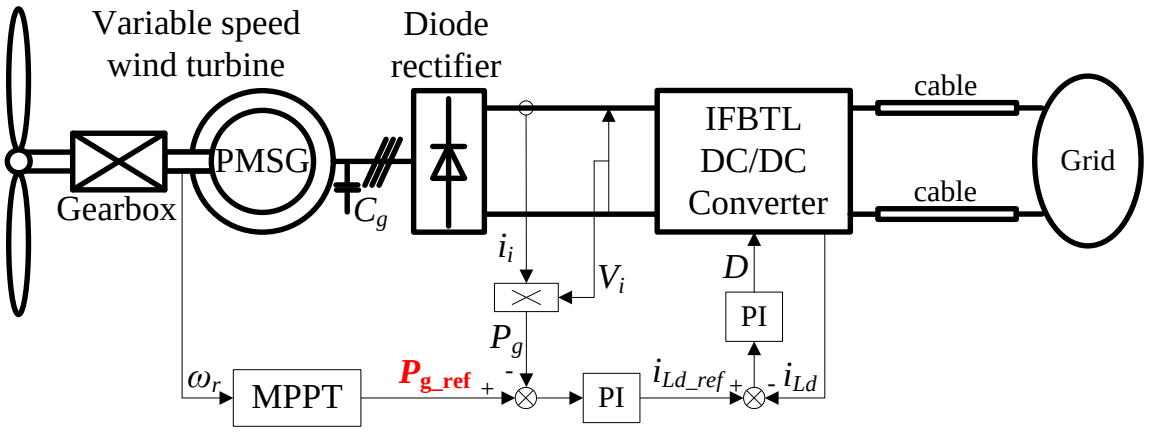


Wind Turbine Control 2

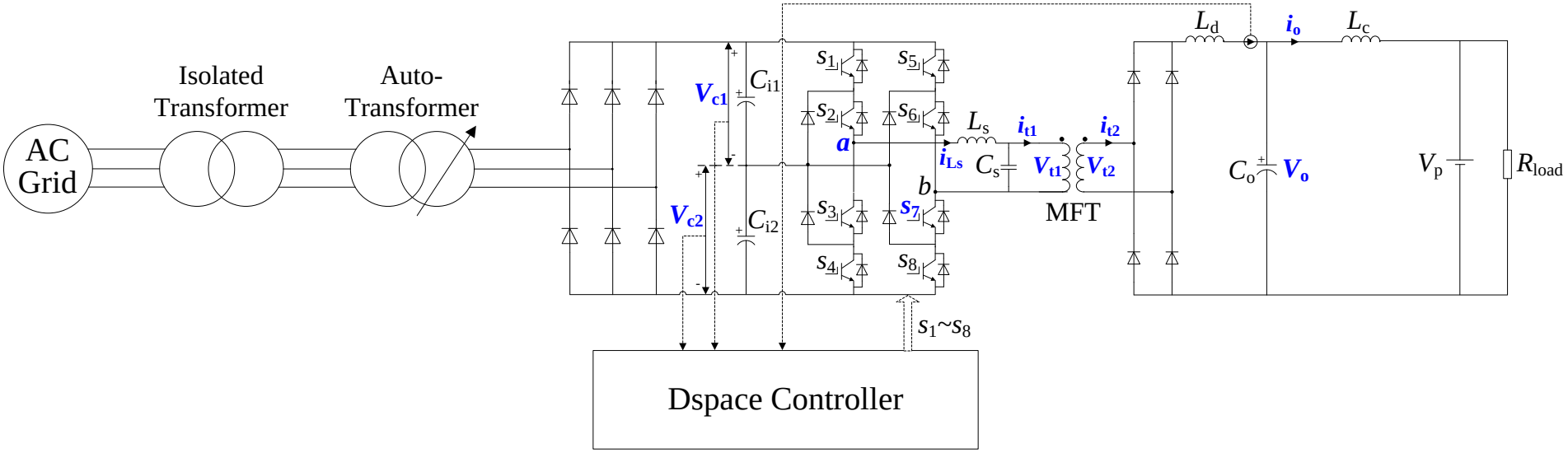
2. Control of wind turbine II

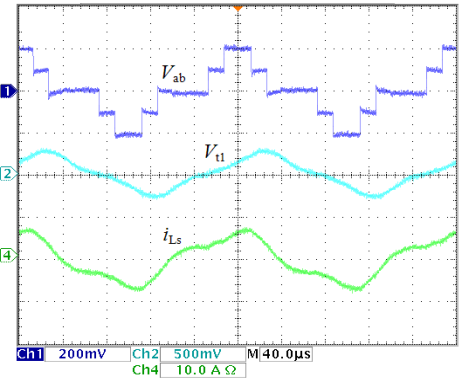
(1) Generator-side converter control

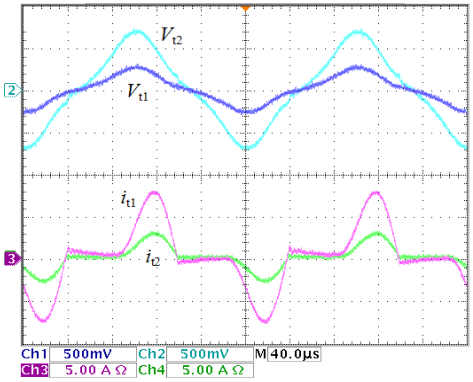
- Optimal power control **P_{ref}**

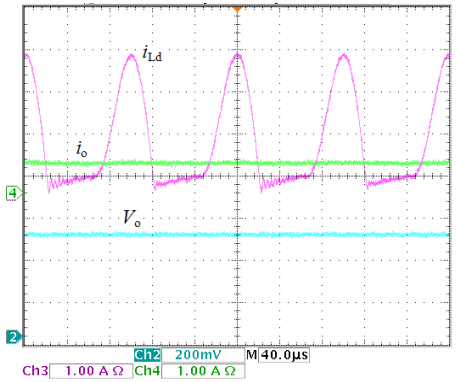


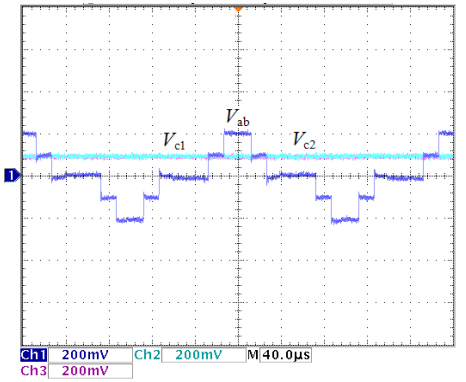
Experiment Test





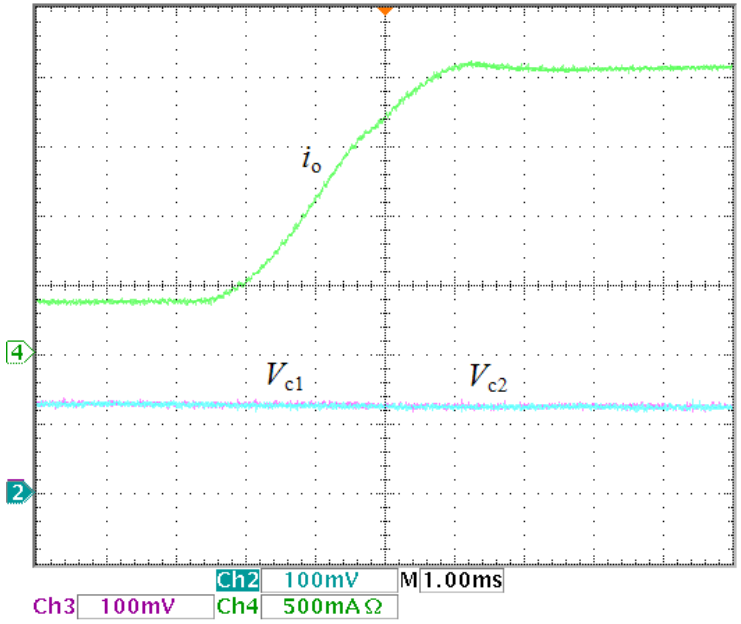




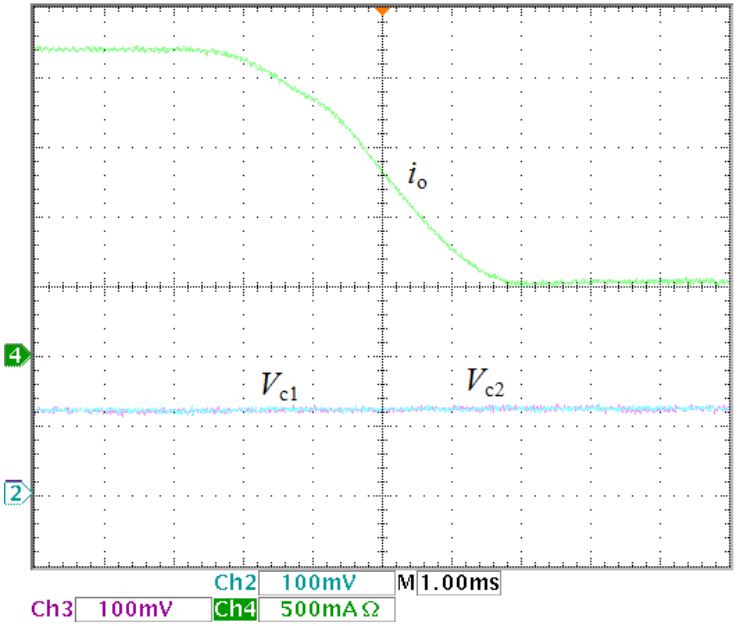


Dynamic Response

1. Current step up

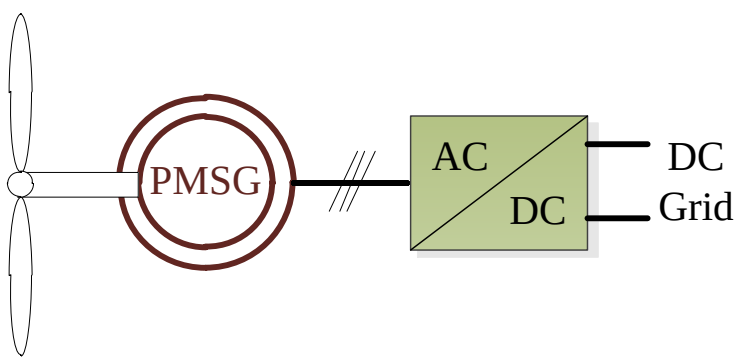


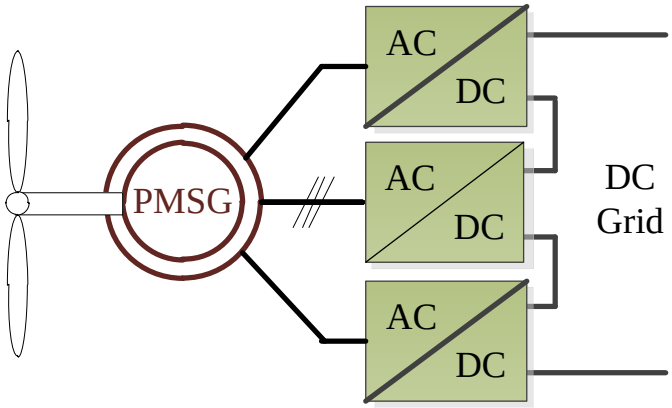
2. Current step down



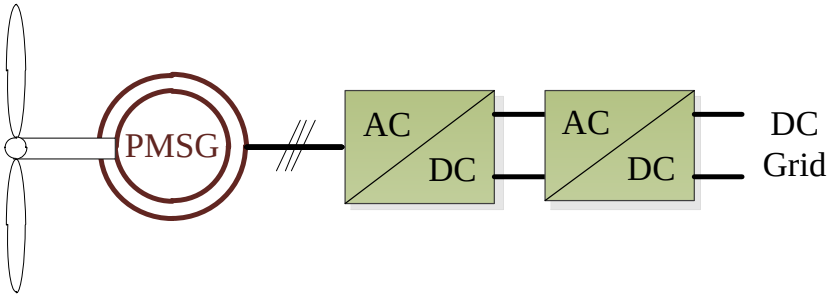
3.4 Wind Turbine for DC Grid

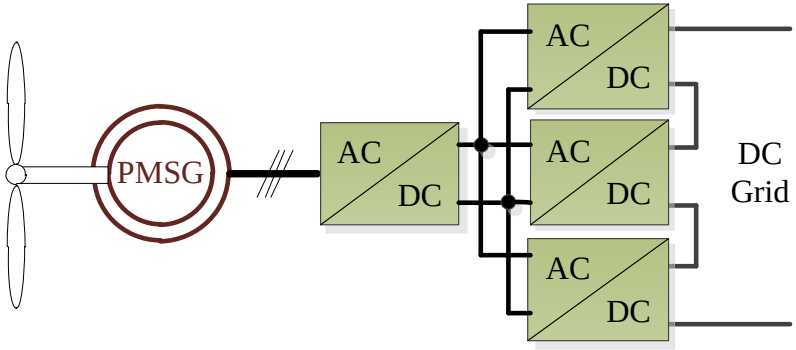
- **WT Configure 1: 1 stage**





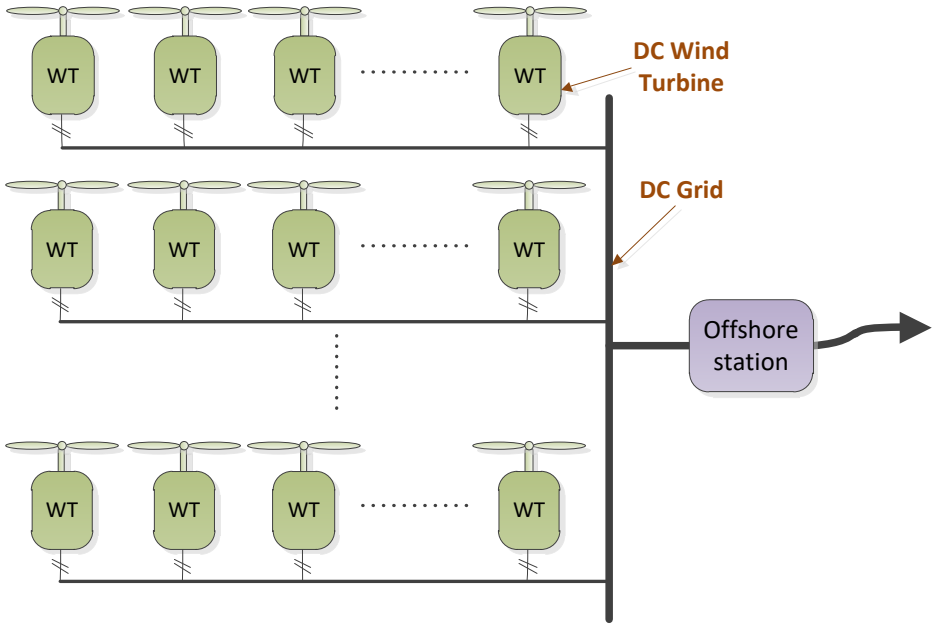
- **WT Configure 2: 2 stages**





3.5 DC Wind Farm

❖ Configuration 1

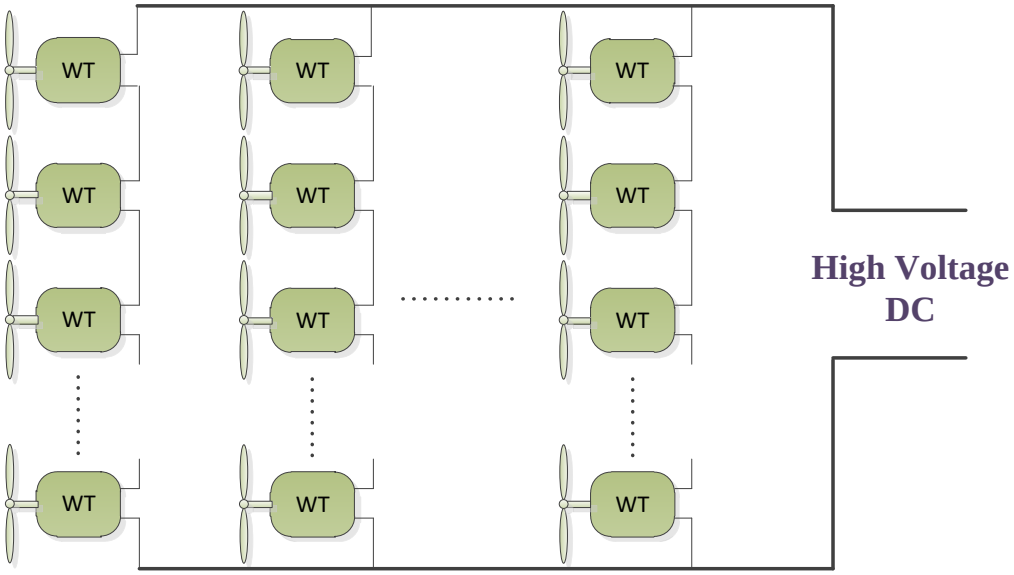


Characteristics:

✓ Similar to AC collection system

3.5 DC Wind Farm

❖ **Configuration 2**



Characteristics:

- ✓ Avoid offshore station
- ✓ Low cost
- ✓ Wind turbines are connected in series
- ✓ Avoid overvoltage of some wind turbine
- ✓ Effect between wind turbines in one cluster
- ✓ Effect among clusters

Conclusions

I. Offshore Wind Farms

- **Power converter**
- **Wind farm configuration**

II. DC grid for offshore wind farms

- **Power converter**
- **Wind farm configuration**

Thanks !