Wind Power Plant Integration to Power System Using HVDC and FACTS

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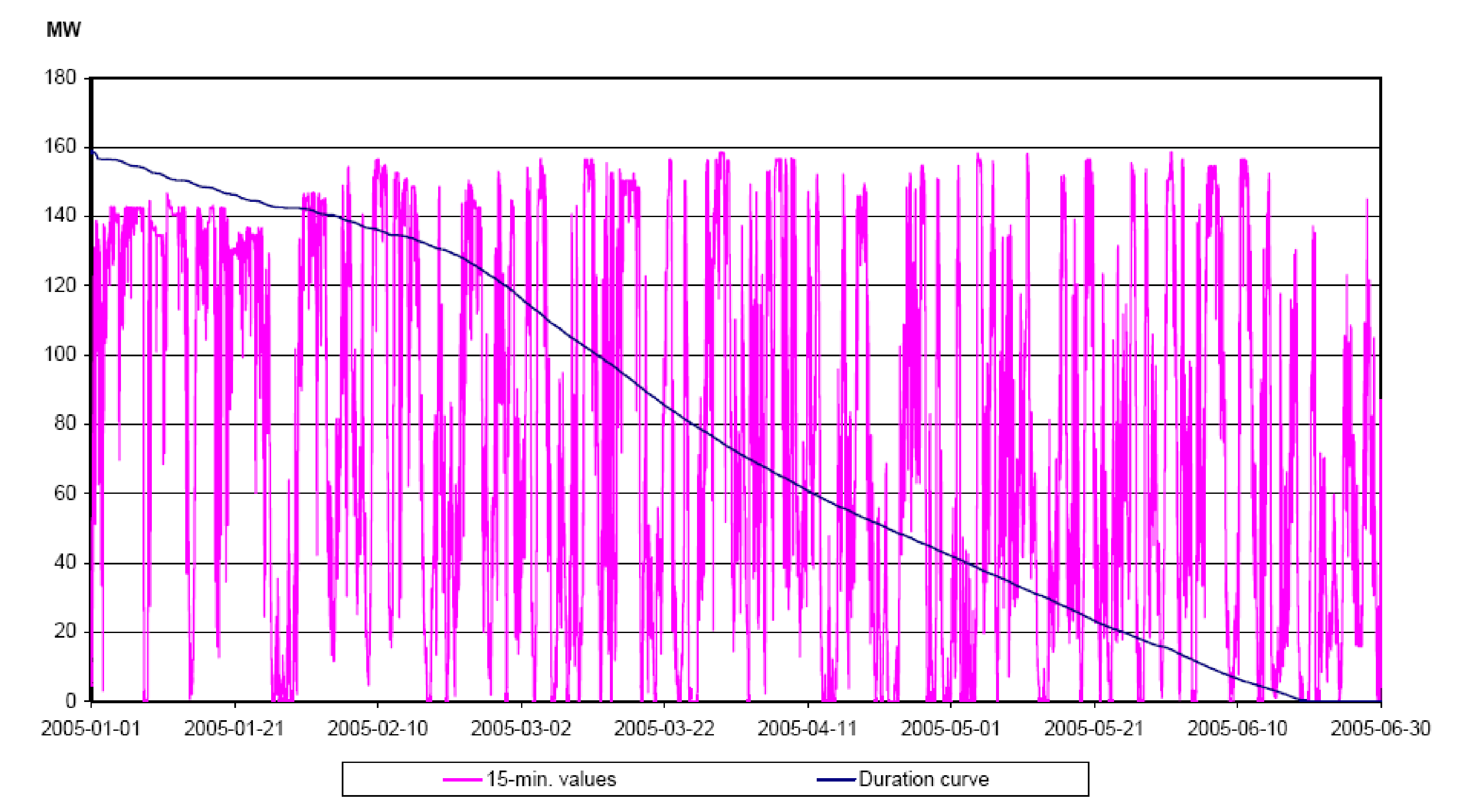
Contents

- Applicable machines overview
- Operating in power system
- Requirements of legislative
- FACTS application
- HVDC application
- Economical aspects
- Prospects

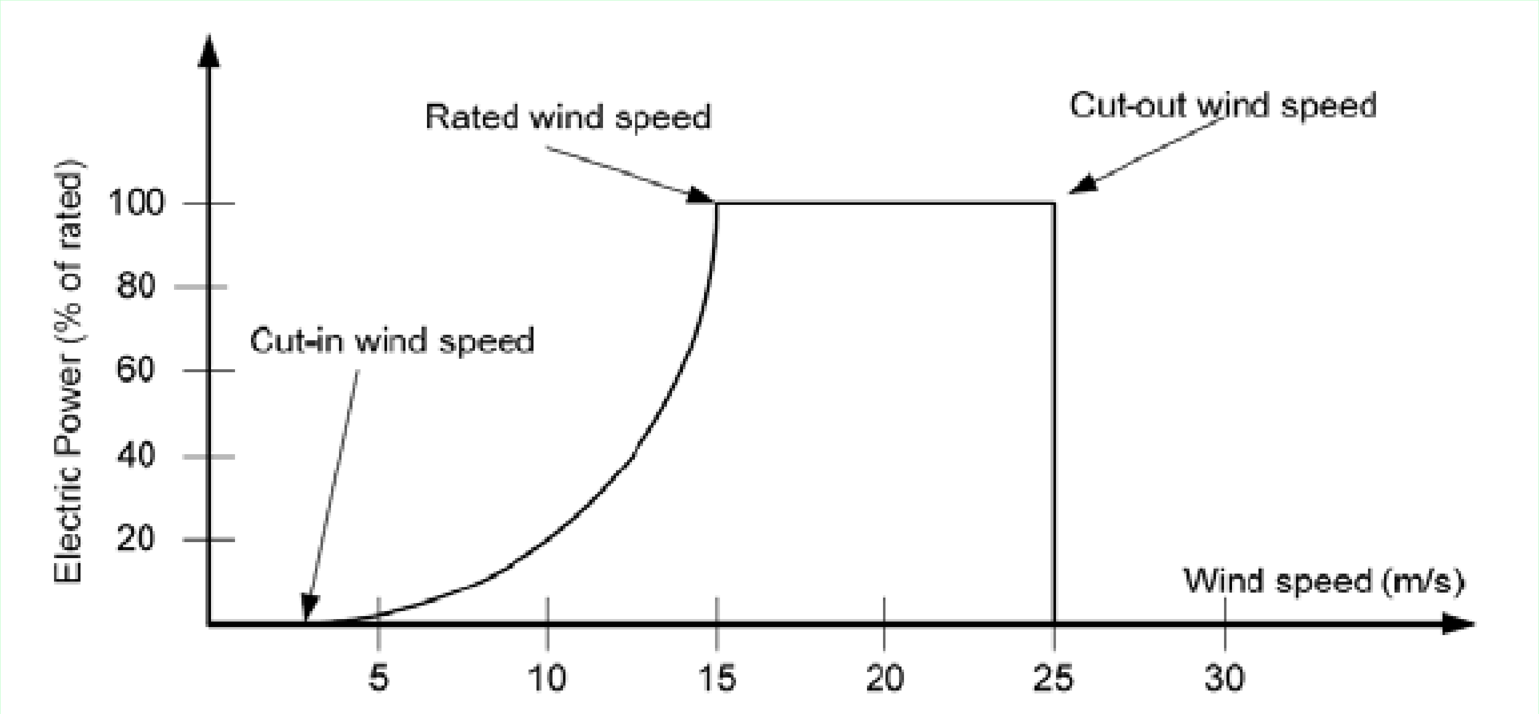
Introduction

- The rapidest growing part of power system
- Development is donated by state subsidies
- Regulation demand from the site of transmission system operator
- Big wind farm connection
- Transmission lines length increasing

Wind as energy source



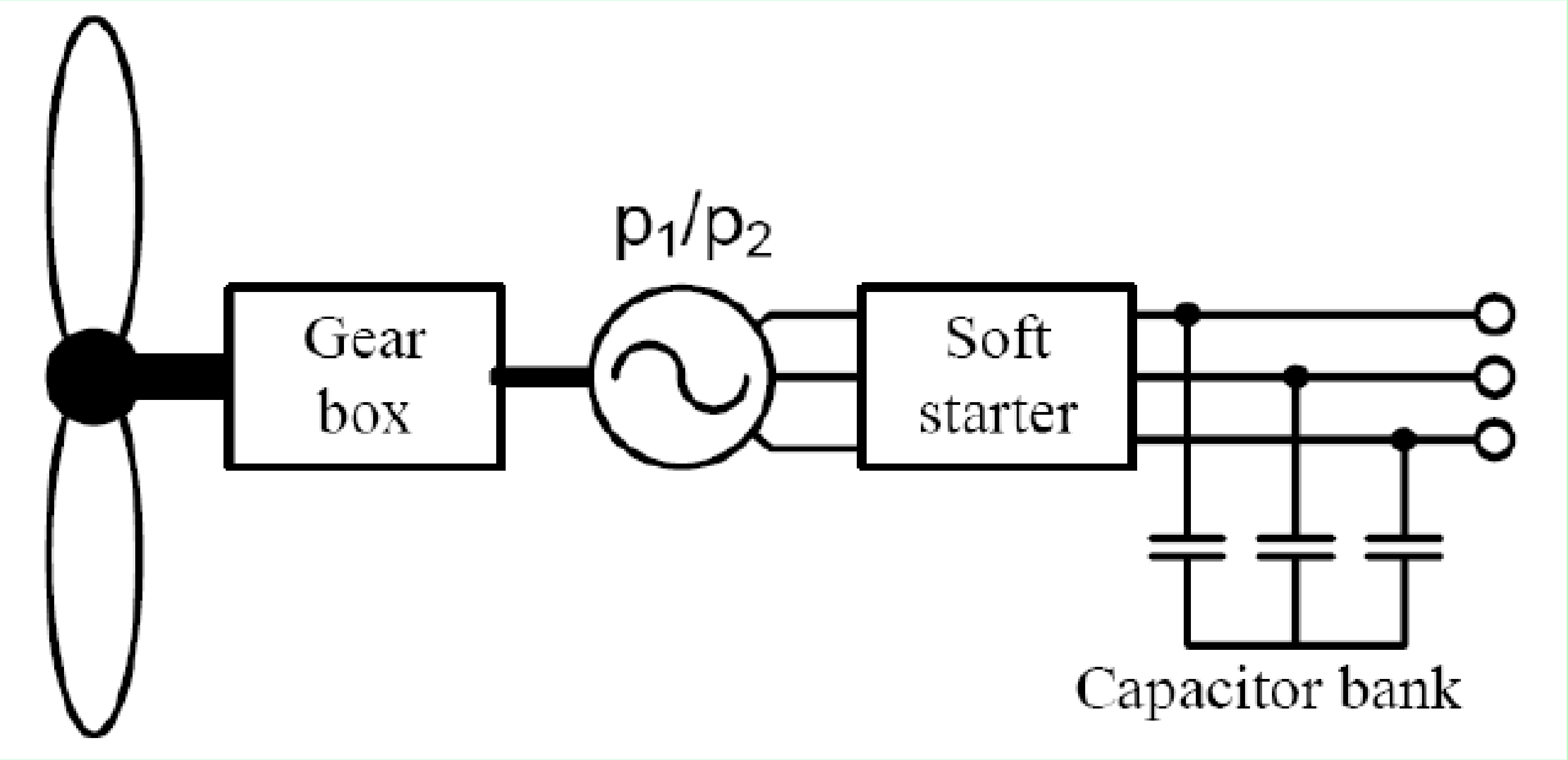
Wind as energy source



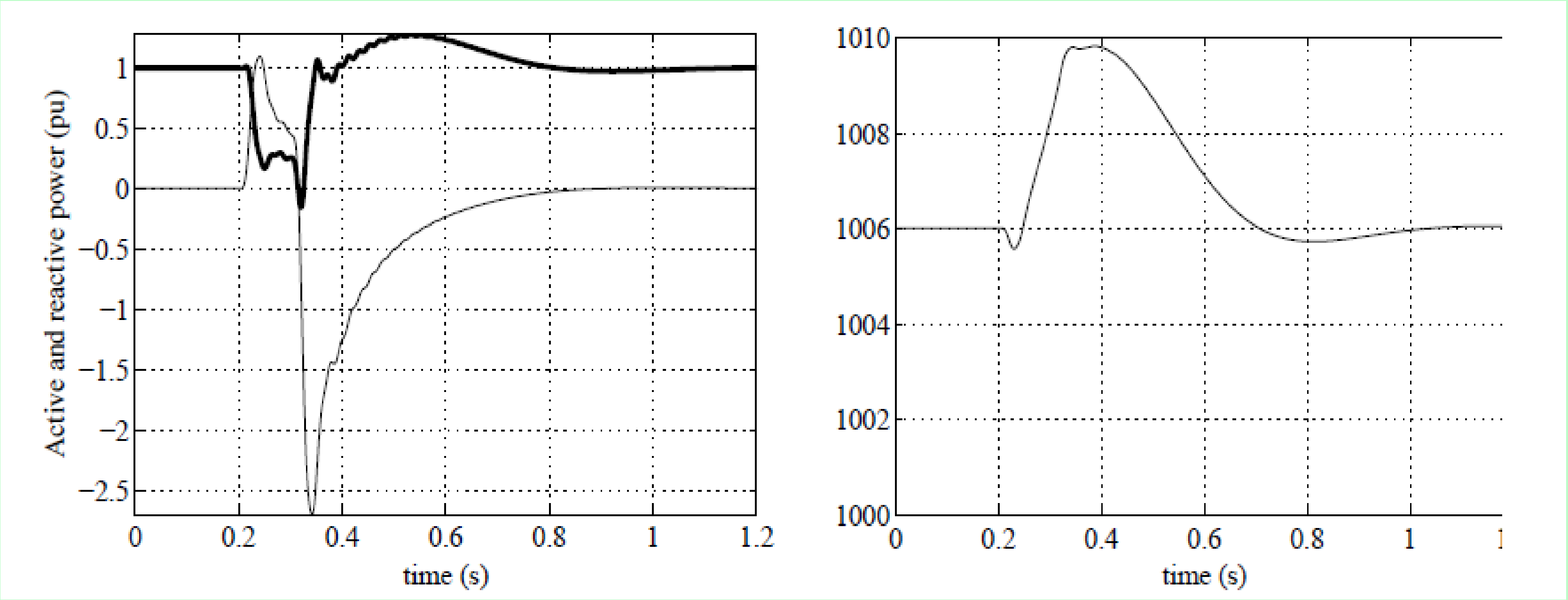
Applied solution - induction or asynchronous machine

- The oldest solution
- For higher power variable number of poles
- Slewing wings system
- Voltage stability – SVC or STATCOM

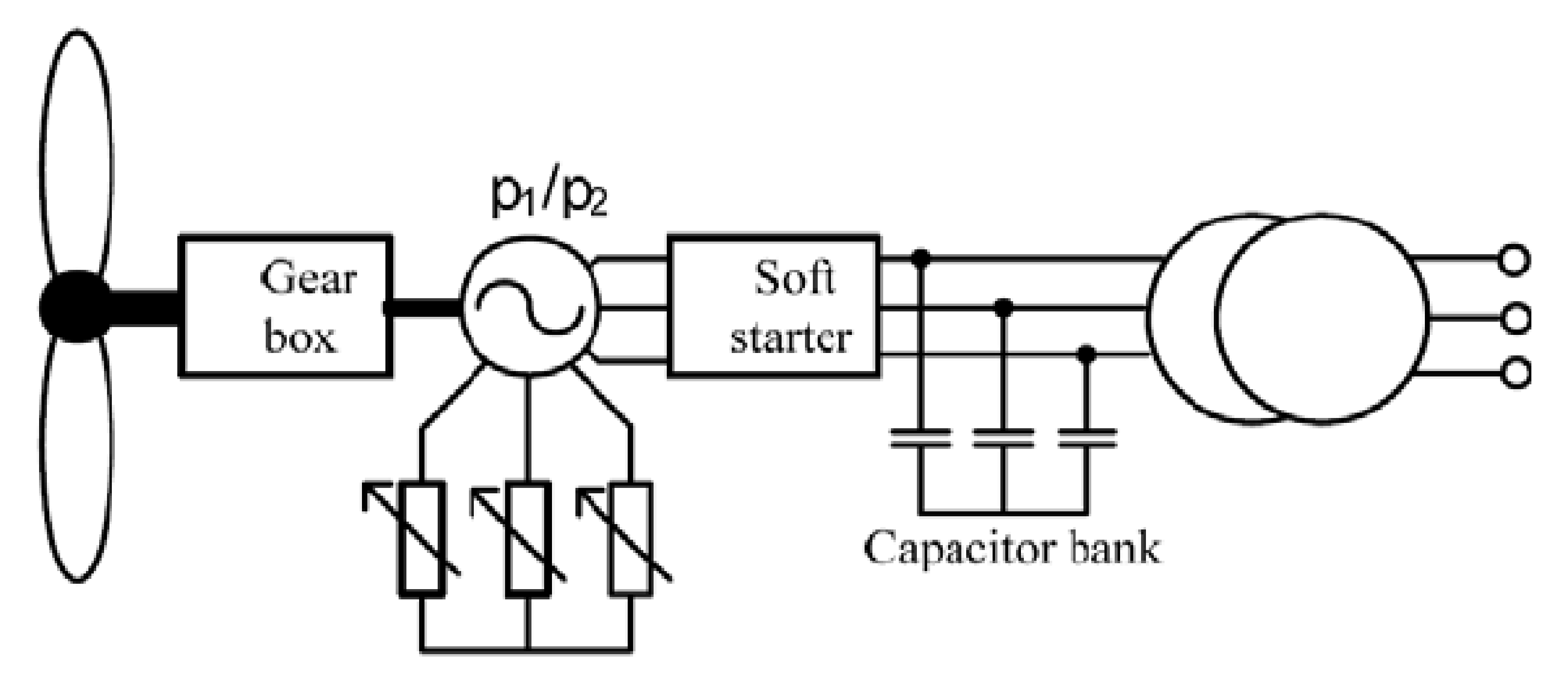
Applied solution – induction machine



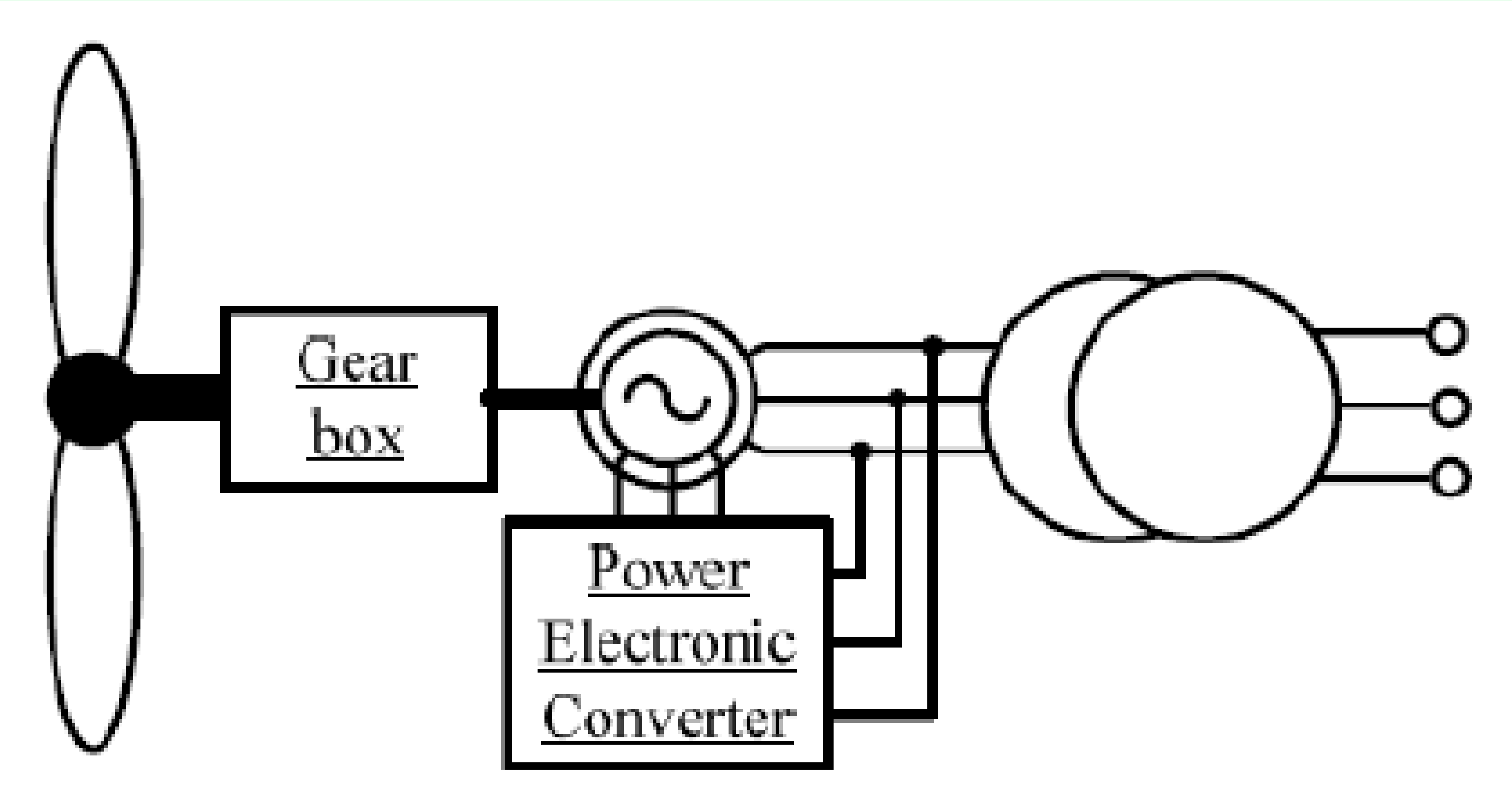
Applied solution – induction machine



Induction machine with variable rotor resistance



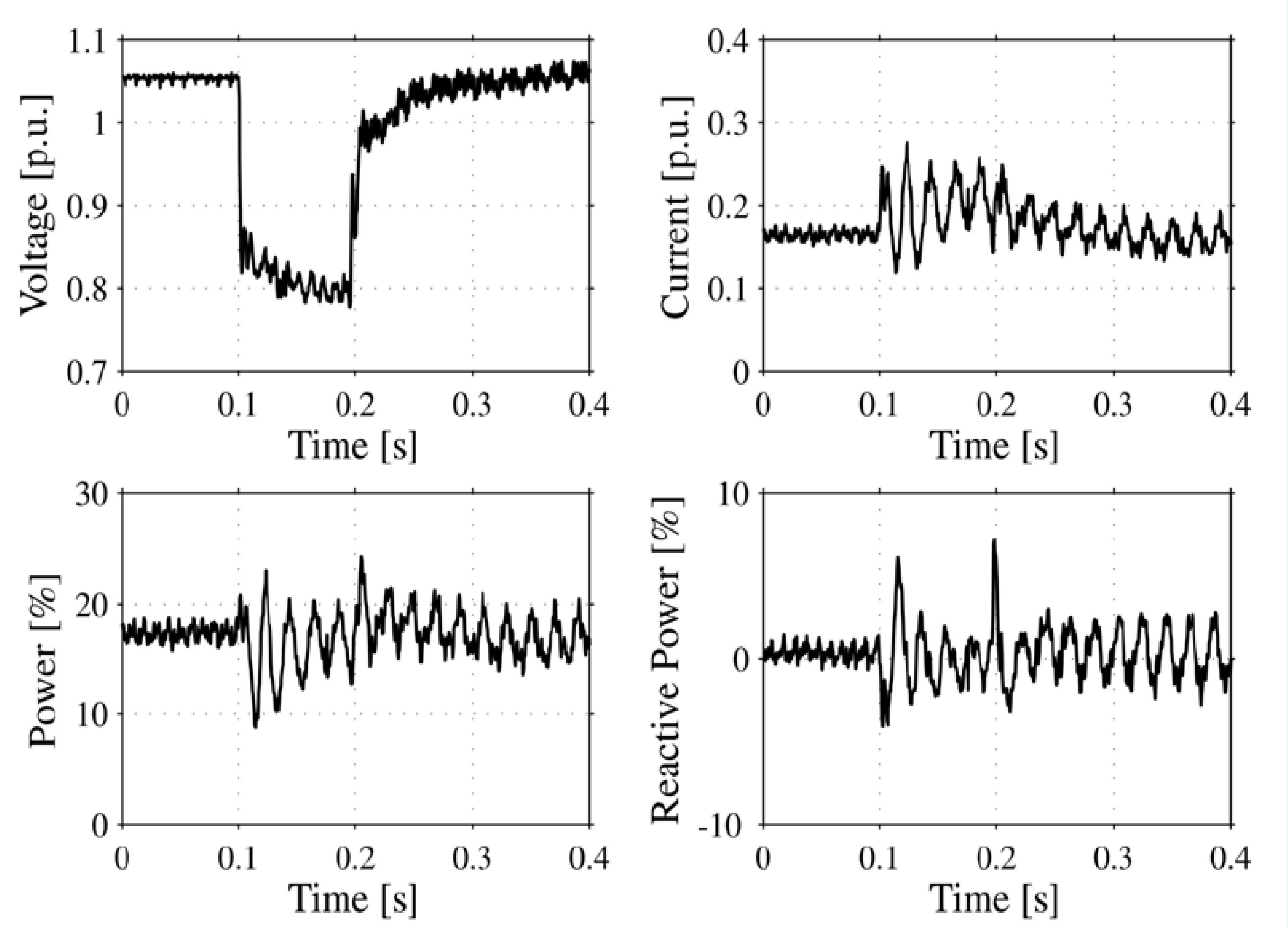
Doubly-fed induction generator



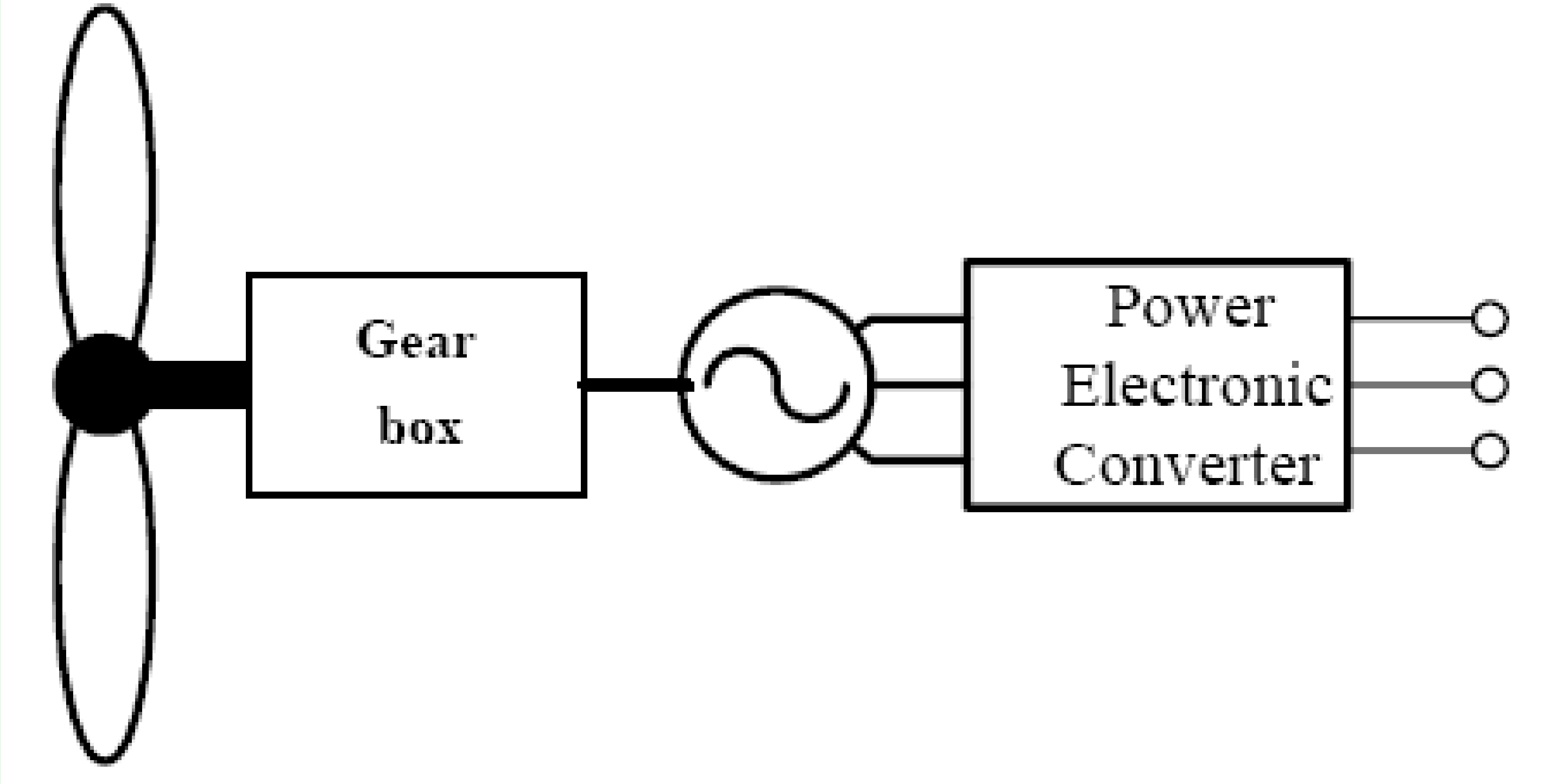
Doubly-fed induction generator

- 50% new installations in Europe
- Minimize convertors costs
- Variable speed (20 – 30%)
- Machine’s mechanical stress decrease

Doubly-fed induction generator

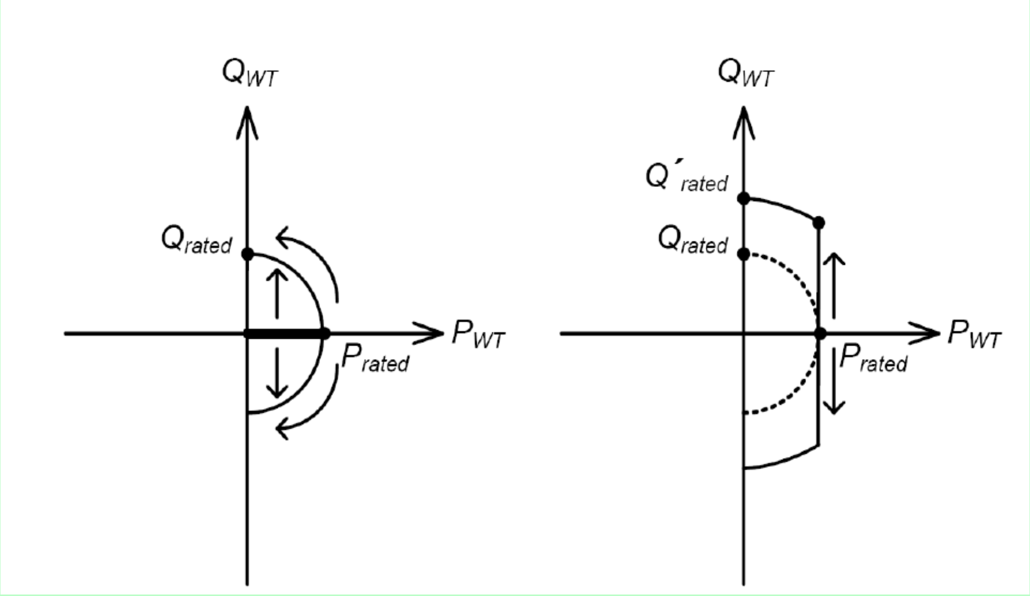


Solution with variable rotating speed



Solution with variable rotating speed

- Machine with or without gear
- Generator is connected to the grid through convertor
- Influence to the grid limitation
- Reactive power compensation

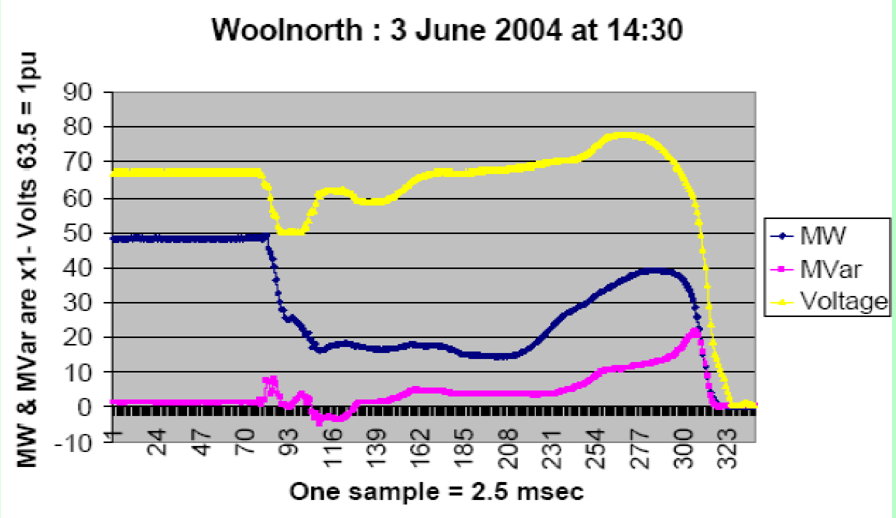


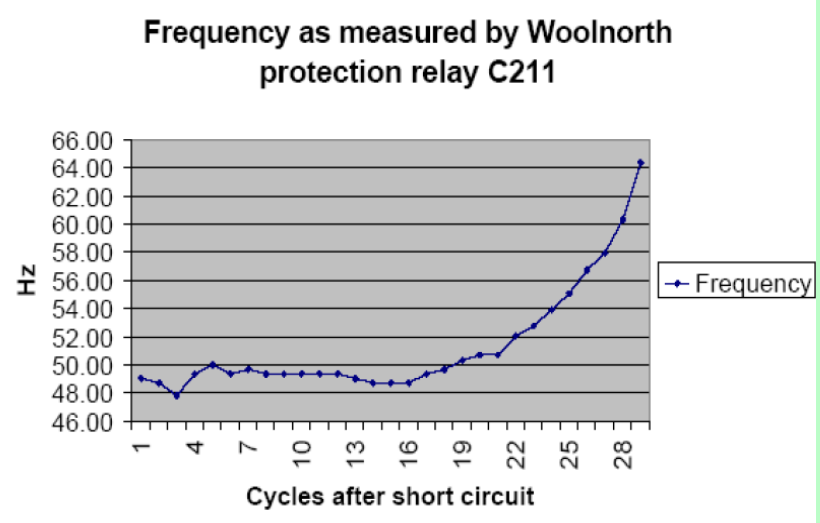
Wind power farms – operating in power system

- Complicated production planning
- Effect of sources penetration
- Long line connection – voltage control
- Power system operator control possibility
  - 1/3 of WPP installed power in Germany has possibility to be disconnected for system control
  - In some countries conditioned by the power system operator legislation

Wind farms – Technical impact

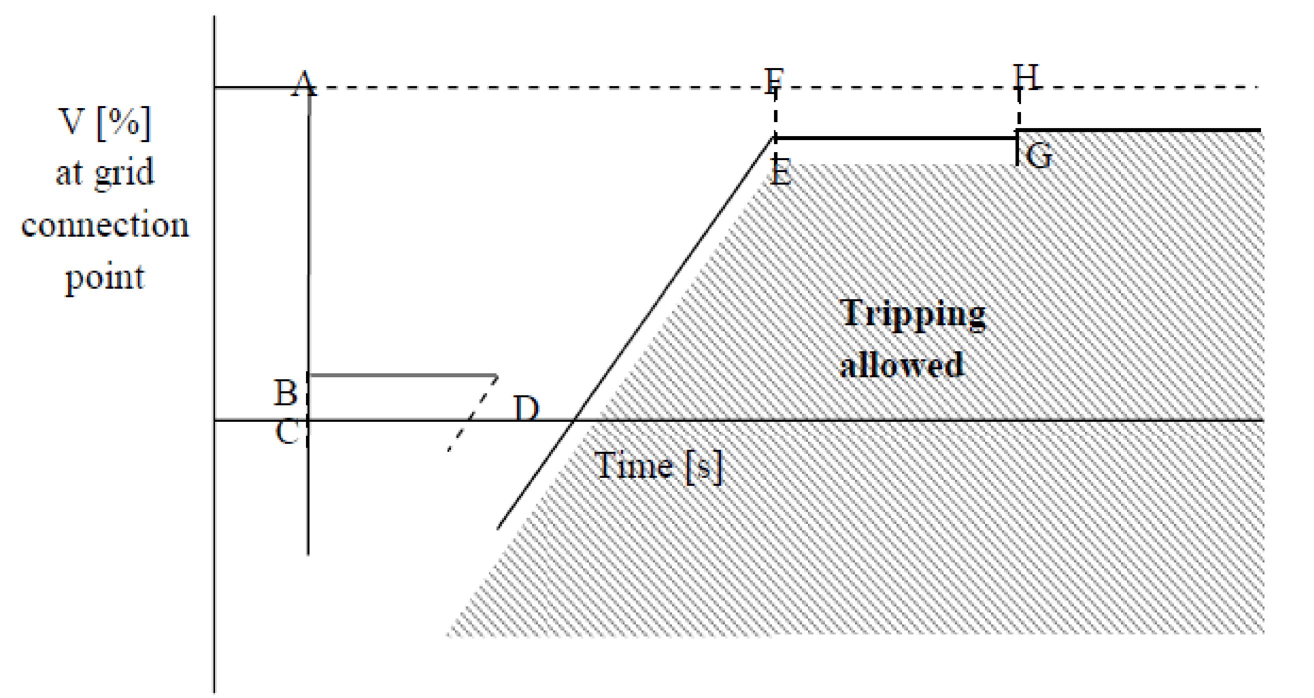
- Minimal allowance to system insertion
- Voltage and frequency regulation is limited
- Resistance to failures is limited





Wind farms – Technical impact

- Power quality
  - Higher harmonics
  - Flicker
  - Rezonance
    - Long lines
    - Resonance frequency is higher than 20^{th} harmonics



Grid Code	BC	BD	AF	FE	AH	HG
Denmark	25%	0.1 s	0.75 s	25%	10 s	NA
Germany (EON)[1]	0%	0.15 s	0.15 s	30%	0.7s	10%
Germany (EON)[2]	15%	0.625 s	3 s	10%	NA	NA
Ireland (EirGrid)	15%	0.625 s	3 s	10%	NA	NA
Spain	20%	0,5 s	1 s	20%	15 s	5%
Spain (Canary islands)	0%	0,5 s	1 s	20%	15 s	5%
UK (NG)	0%	0.14 s	1.2 s	20%	2.5 s	15%

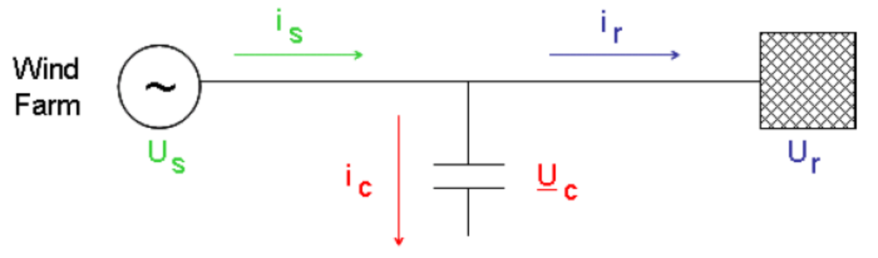
Economical aspects

- Investment and operating costs of wind farm
  - Choice of suitable area (climate conditions, connection to power grid)
  - Losses in power system
    - Application of HVDC
  - Reliability and accessibility to power grid integration

AC connection of WPP

- The most frequent connection
- Power electronics? – depends on length of connecting line and grid power stability at place of connection
- „Long lines“ – cable l>100km, overhead l>400km
- issues – reg. U, static and dynamic stability, power quality
- FACTS (Flexible AC Transmission System)
  - SVC, STATCOM, TCSC, SSSC
  - Energy accumulation
  - → higher transmission line capacity, better power dynamics, voltage control

Critical cable length

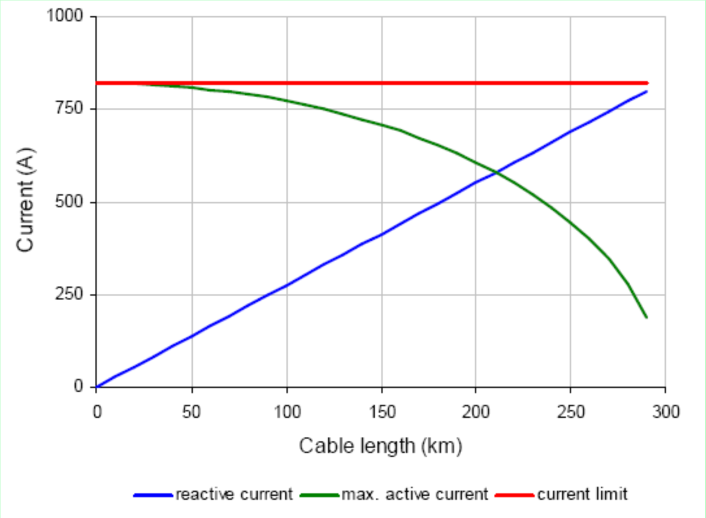


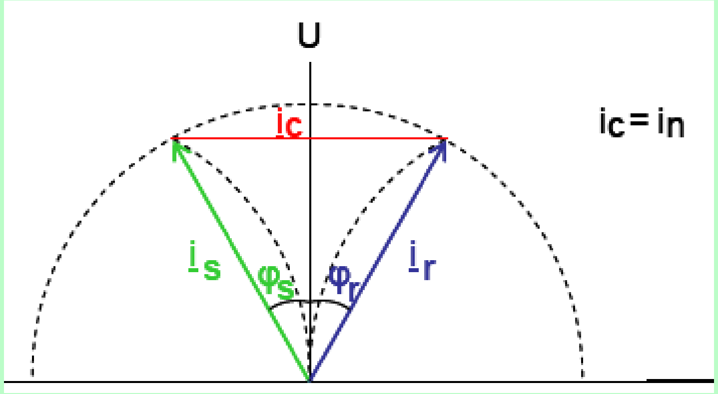
- line – $Q_C \sim U^2$, $Q_L \sim I^2$
- $Q_{Ccab} \sim 20 \div 50\ Q_{Covh}$ (losses)
- Critical length: $I_{charging} = I_{n(max)}$

$$I_\Sigma = \sqrt{I_P^2 + I_Q^2}$$

- I_{crit}: $P_{max} = U_C I_n \cos 30° = 87\%\, S_n$
- $I_{crit}/2$: $P_{max} = U_C I_n \cos 15° = 97\%\, S_n$
- $2 * I_{crit}$:

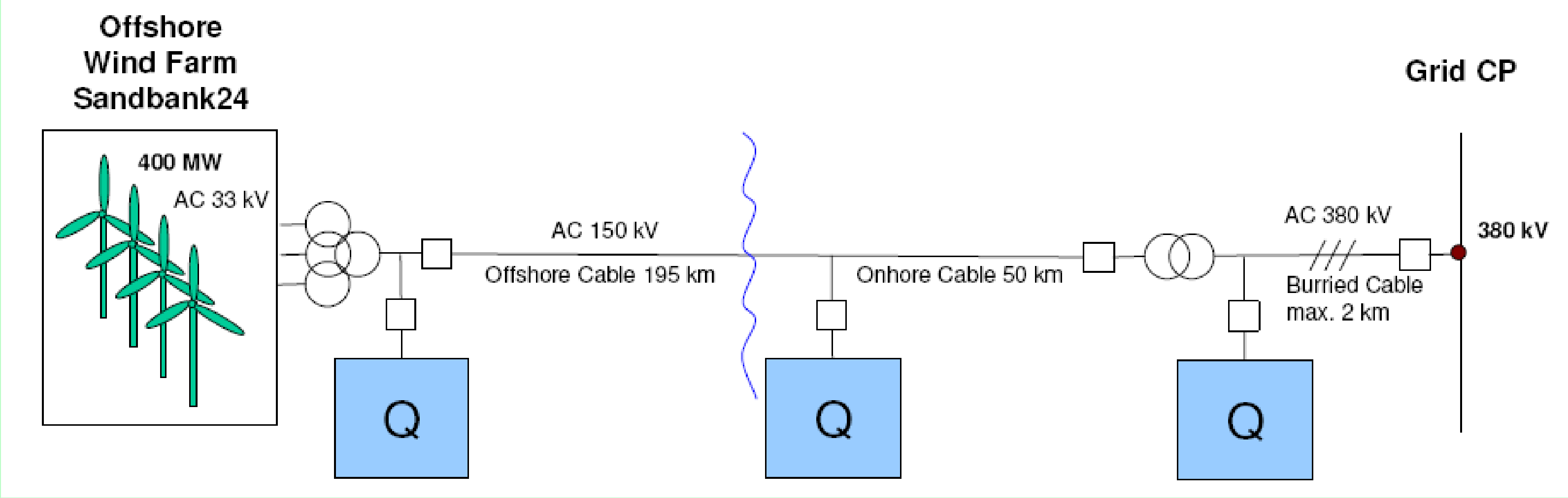
$$P_{max} = 0$$





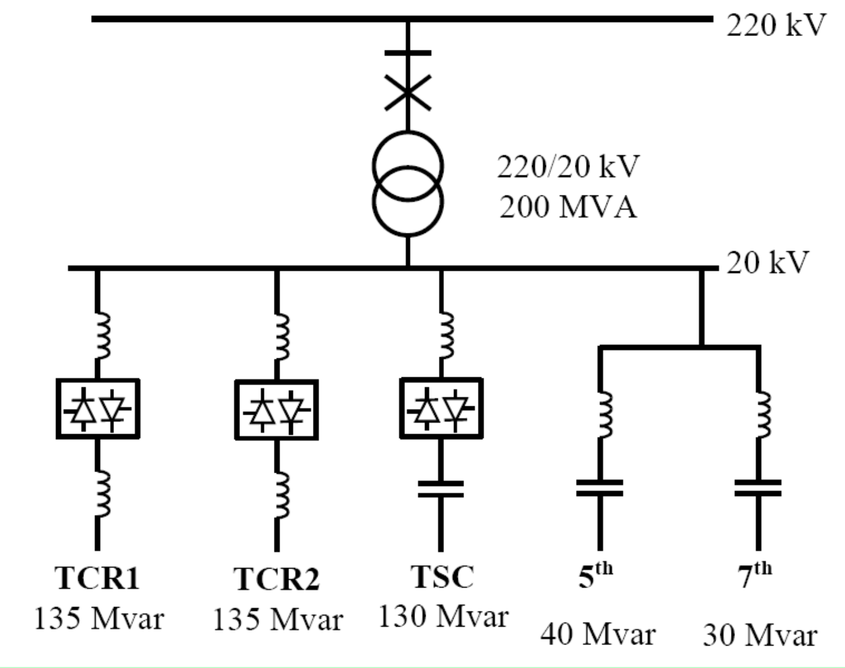
Compensation

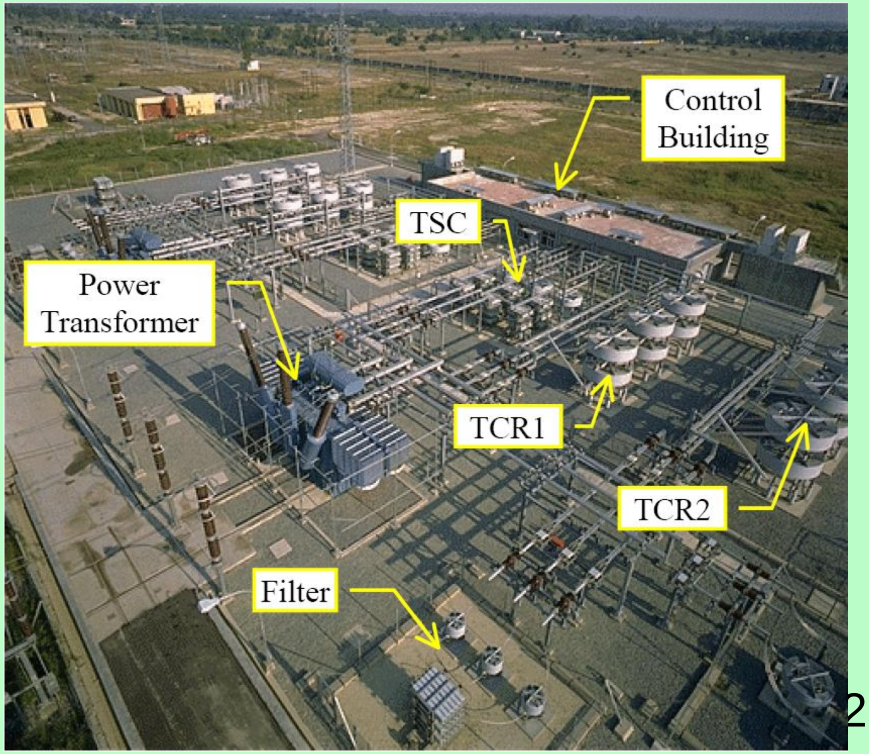
- L compensation (passive reactor, SVC) along cable
- commonly up to 50-60% Q_C (rest is series L)
- C compensation for inductive load, AM (AG)



SVC (Static Var Compensator)

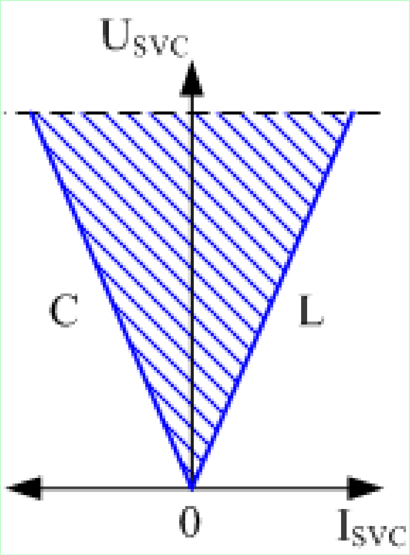
- Power quality – harmonics, flicker, asymmetry, Cos(φ)
- Application – EAF, rolling mill,… x and DS
- Components – TCR, TSC (BSC), filters
- smooth regulace L → Q





SVC (Static Var Compensator)

- regulation Q and U in connection node
- (+) fast regulation (thyristors)
- (-) current ~U, Q ~ U^2, worse in weak power grids
- Applicable fro WPP with constant rotating speed (without convertors)
- Good dynamic

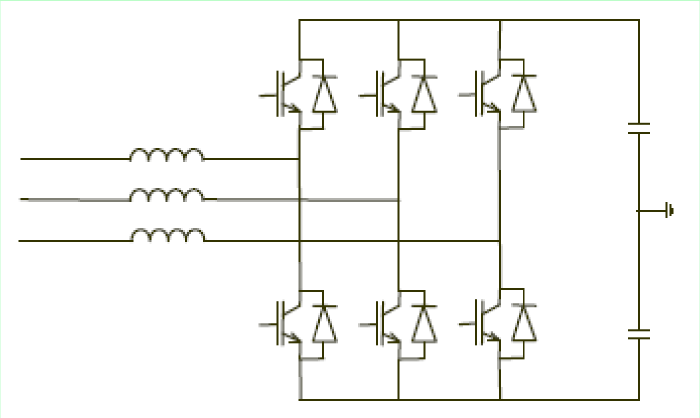


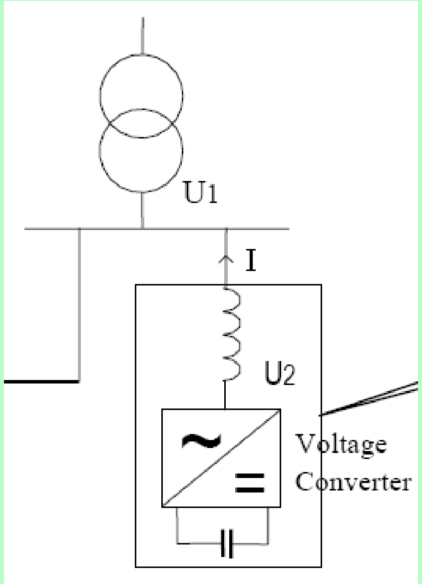
SVC - advantages

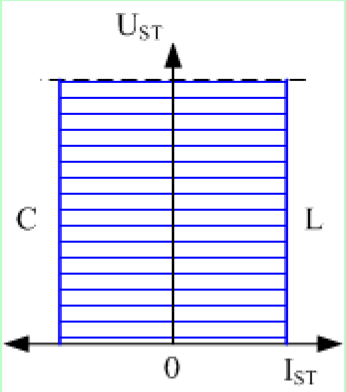
- SVC: voltage transient damping coming from grid → WPP stays connected
- Minimal C block switch – without voltage jump
- Voltage sag elimination caused by WPP operation
- Lower Q consumption
- Other voltage regulation is not needed
- helps WPP to stay during fault connected
- Regulation of Q allows fast return to normal operation
- Other lines voltage stabilization
- Defends against voltage sags (start/stop, wind change)
- Opportunity of support services

STATCOM
(Static Synchronous Compensator)

- Switching components (IGBT, GTO), faster
- U_{AC} determines gen./abs. Q (amplitude), P losses
- $I_{STATCOM}$ does not depend on grid U , only dimensioning
- Q ~ U, even for lower voltage levels than SVC
- Nowadays Q > 100 MVAr, dynamic ~ x ms

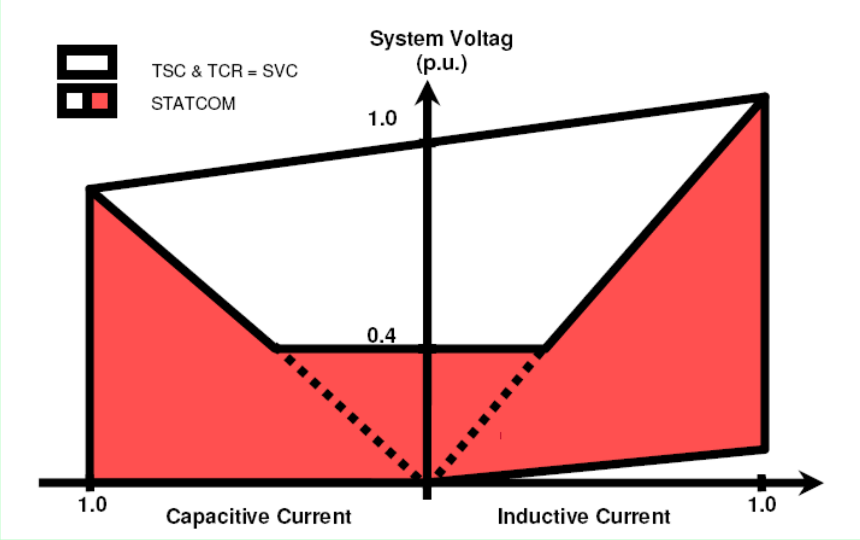






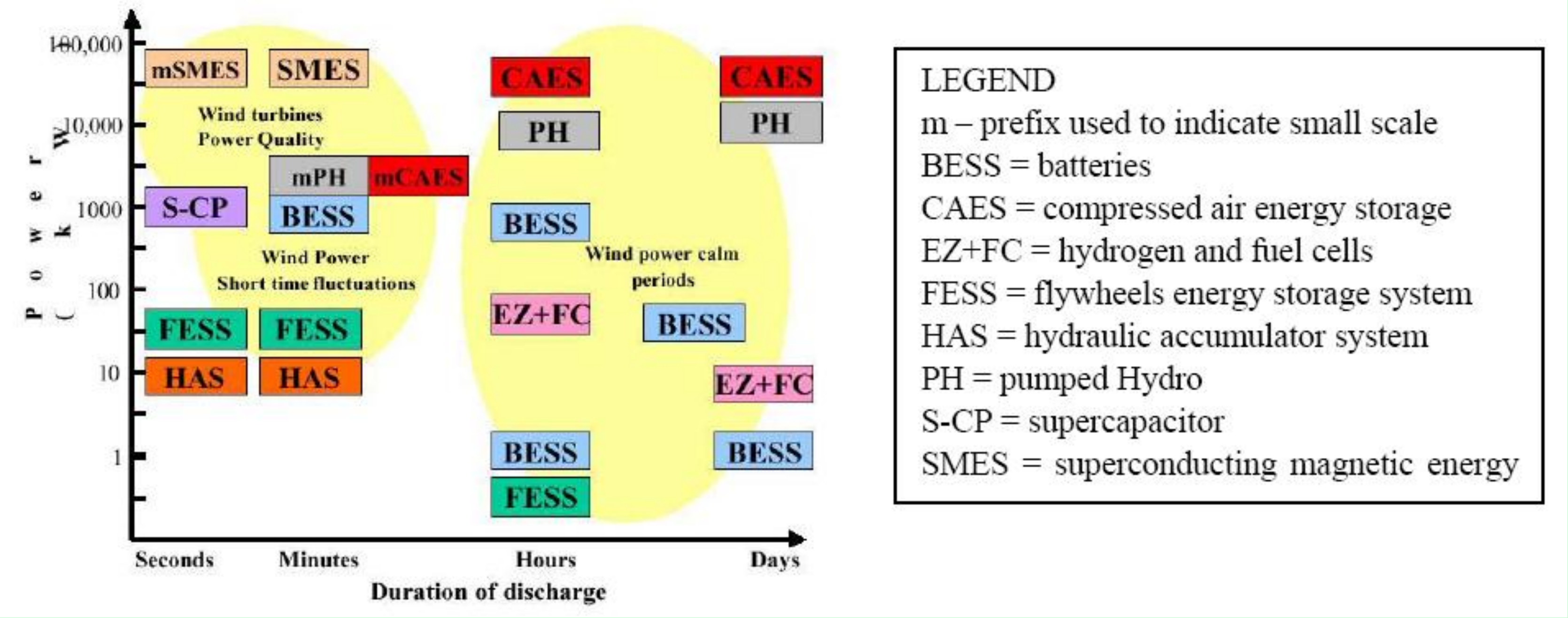
STATCOM - advantages

- Same as SVC + other:
- PWM (Pulse-width modulation)
- Without harmonics filters - less surface area
- Can contribute during short-circuit (higher current for protection relays)
- More efficient (faster) for flicker mitigation



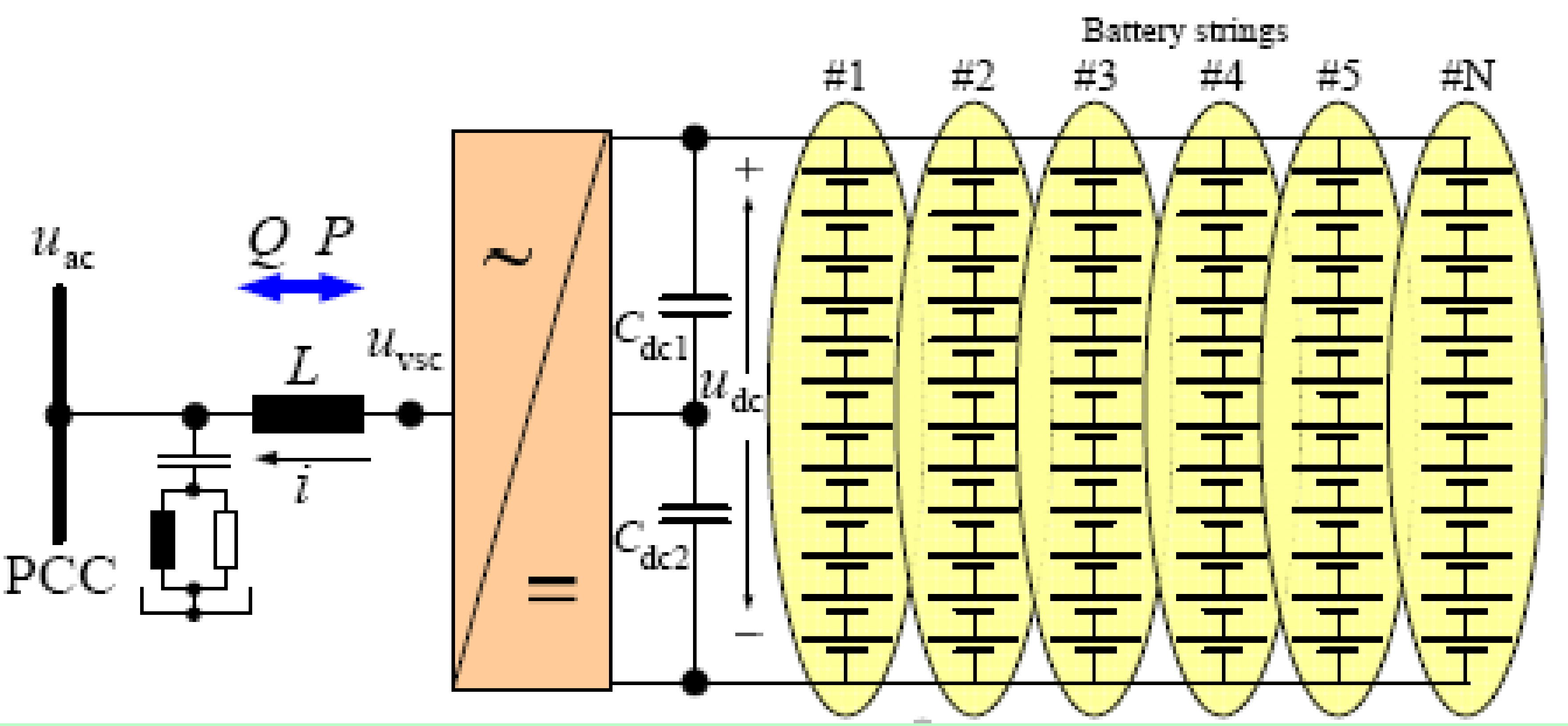
WPP and energy accumulation

- Caused by variable power output from WPP
  - High wind speed, climate conditions, high percent of WPP
- Some combinations with PV sources are exist
- Other technologies are more expensive, efficiency max. 60-70%



WPP and energy accumulation

- Invertors in battery based on STATCOM principle



WPP and energy accumulation - advantages

- Power quality improvement
- Smooth changes U and P during wind speed decrease
- Constant P supply in longer period
- Possible U and f control in power grids
- Helps WPP to stay voltage sag
- Securing P supply to the grid
- Possible to sell power during higher energy price

WPP and FACTS

- WPP with power electronics (DFAG, SG + convertor)
  - ability U and Q regulation at output
  - ability of smooth control during changes in P and U
  - add to the grid limited short-circuit power
  - ability to stay during fault without disconnection
- Weak grids and long lines – SVC or STATCOM
- AG – SVC (STATCOM) could be applied for fault overstay, stabilisation U, power quality.

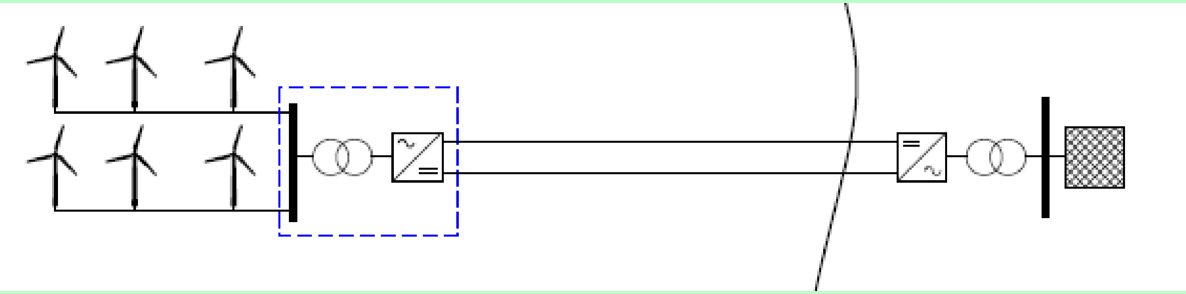
HVDC (High Voltage Direct Current) - application reasons

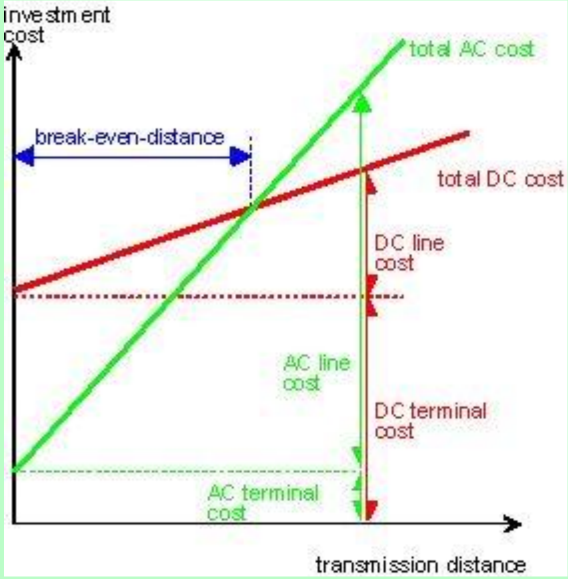
- economic
  - DC lines and cables are cheaper than AC of the same transmission capacity

    x DC substations are more expensive, hence, there is economic brake point (overhead line 500 – 1000 km, cable 50 – 125 km)
  - no Q flow – lower losses, transmission capacity does not decrease along the line
- technical
  - connection of asynchronous power systems is possible
  - no critical length of DC cable, shunt compensation is not needed
- environmental
  - less overhead lines, more cable usage is possible
  - Higher transmission capacity of one route corridor

HVDC (High Voltage Direct Current) - advantages

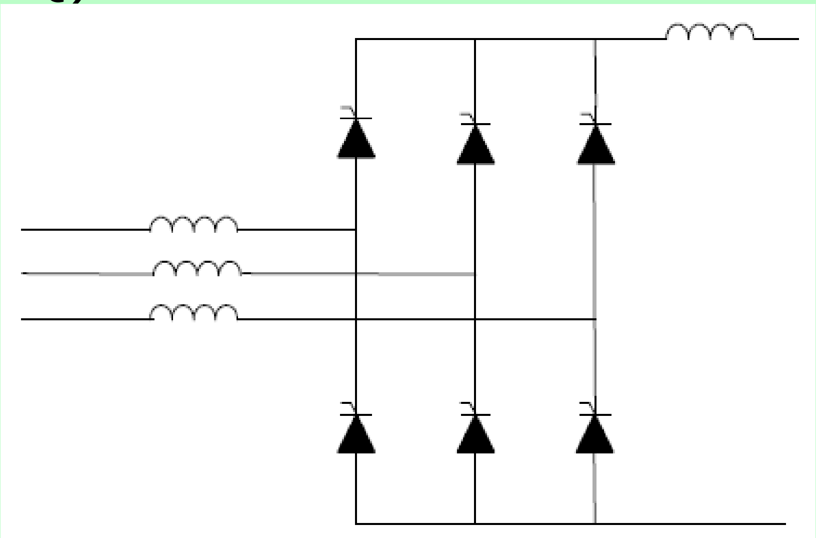
- Independent operation of connected systems
- Active power flow P is fully controlled
- Faults and rapid voltage drops do not spread through the line





LCC HVDC
(Line Commutated Converters)

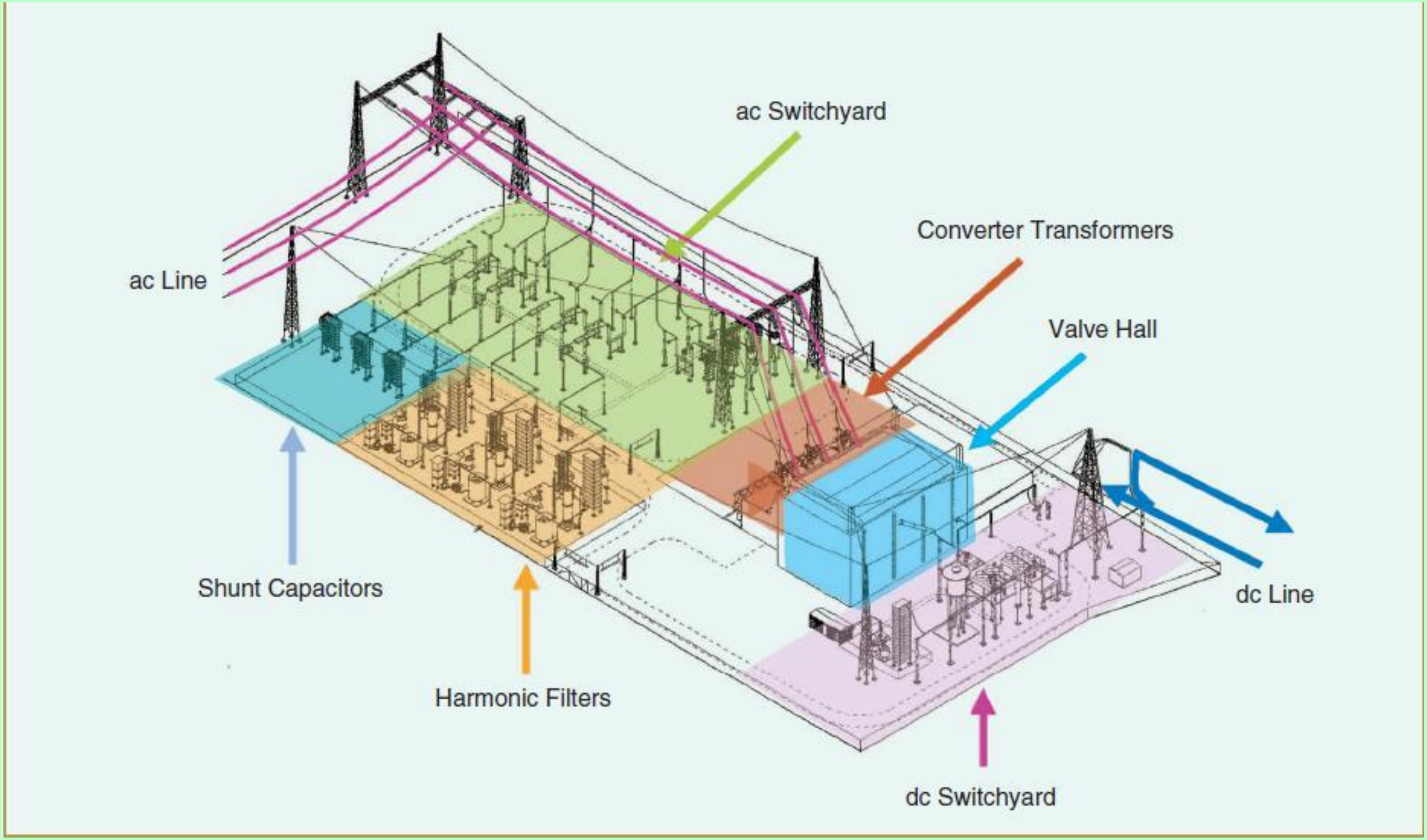
- thyristor bridge converter (6, 12 pulse)
- Ac voltage is needed (current stimulation, commutation)
- Current flows through thyristors just one way
- consumes Q (rectifier and convertor)
- AC filters are needed (harm., Q)
- Commutation faults at invertor caused by U_{AC} drop



LCC HVDC - components

- transformer
  - withstand mix of AC and DC stress
  - operate with high harmonics stress
  - commonly tap changer is installed
- Q compensation – filters, C blocks, SVC, STATCOM,…
- AC filters
- smoothing L at DC side – damp harmonics at DC
- control and communication between DC ends
- DC cable – withstand polarity change while active power flow reversion

HVDC substation

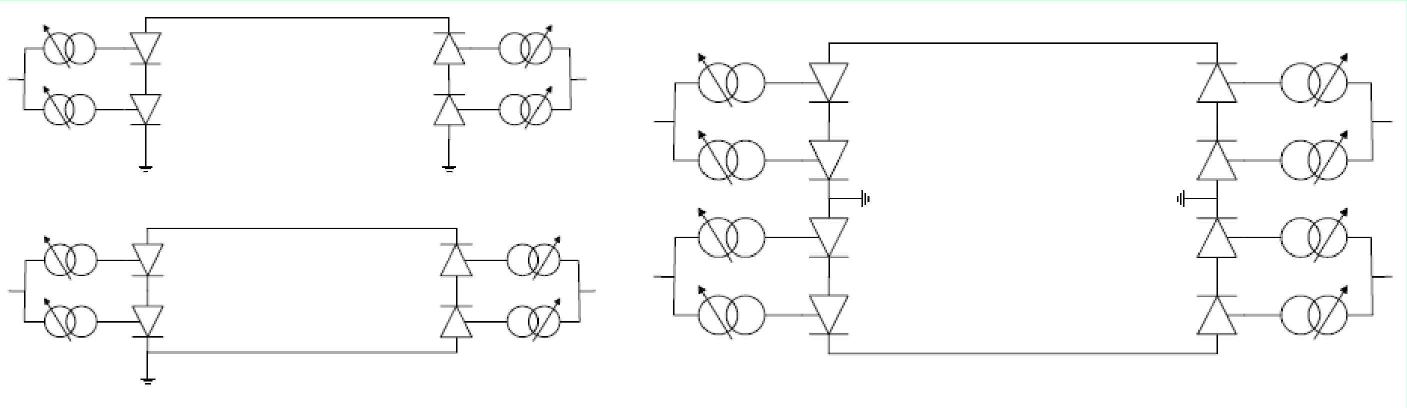


LCC HVDC - operation

- short-circuit power Sks min. 2,5*Sn, otherwise voltage instability, commutation fault
  - Sks increased by synchr. compensator, U by SVC (STATCOM)
- low short-circuit contribution
  - (+) strong grid, (-) weak grid (current for protection relays)
- one way DC current flow because of thyristors
  - reversion of P by U_{DC} polarity change (2 quadrant)
- can not operate with P < 5-10% Pn
  - DC harmonics would switch off thyristors
- both sides consume Q ~ 0,5P
- losses in invertor are about 0,8% P

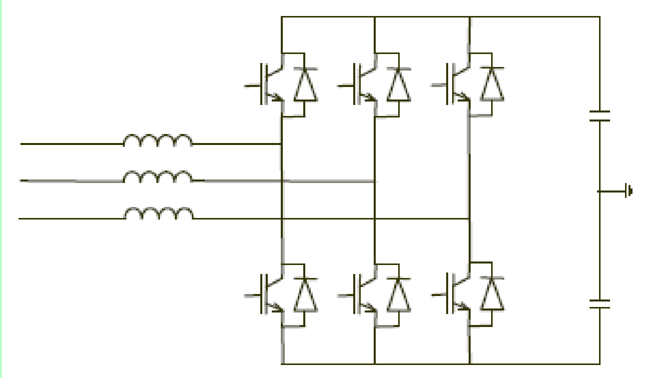
LCC HVDC - systems

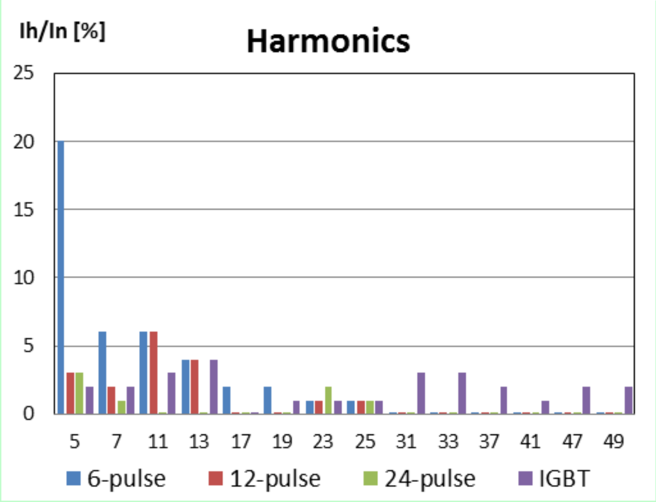
- back-to-back
- monopolar
  - simple, losses in the ground < in cables (x corrosion)
- bipolar
  - 2 independent poles, without 1 pole transmits 50% P
- dimensioning (on land – area for filters and L)
  - 150-3000 MW, 180-500 kV (R&D 800 kV, 6000 MW)



VSC HVDC
(Voltage Sourced Converters)

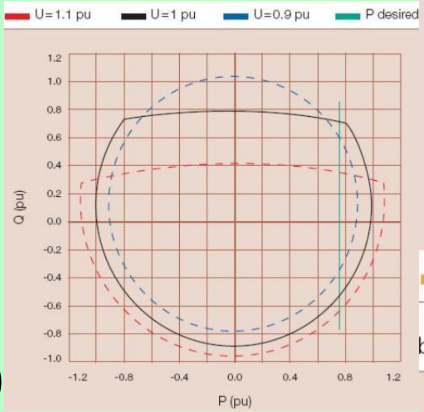
- Bridge convertor with switching components
  - mostly IGBT (PWM 1kHz)
  - 3f U_{AC} voltage allows independent reg.P, Q
  - C compensation is not needed
- filters
  - PWM (1-2 kHz) at higher f – lower
  - not for Q compensation (not switching)
  - multilevel – less filters, better sin curve
- AC reactor
  - damps transients, stabilize VSC
  - DC capacitor

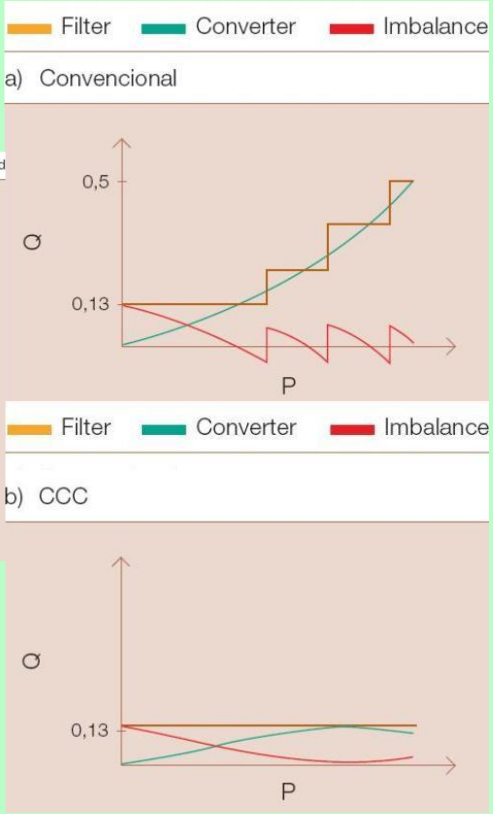




VSC HVDC

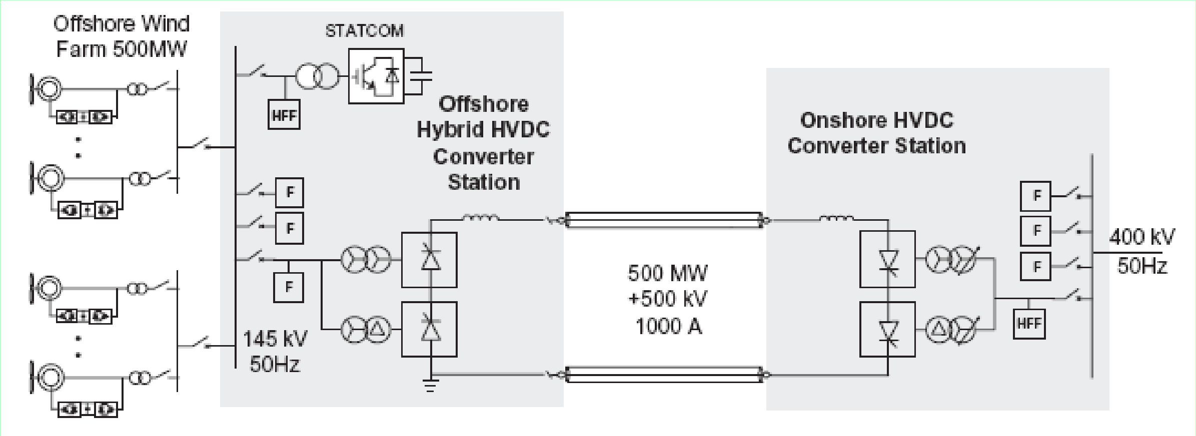
- control system
  - convertor voltage affects: 1 – U, 2 – P, both – Q
- DC cable
  - constant polarity U_{DC}
  - polymer. cables (cheaper)
- operation
  - 4 quadrants (P,Q independent)
  - short-circuit contribution up to I_n
  - U_{AC} is not needed – even for passive grid
- losses
  - higher than LCC (IGBT > thyristors, PWM, more components)
  - convertor around 2% P x minimum Q

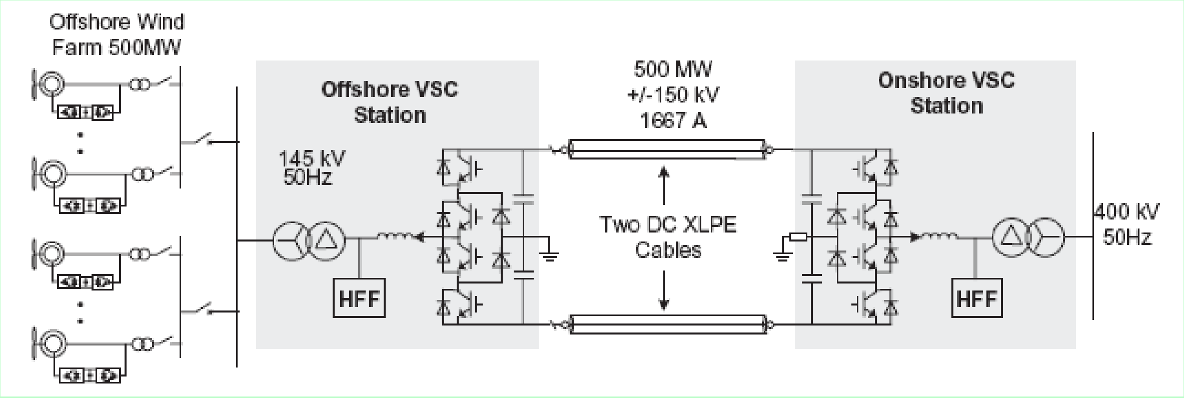




HVDC (VSC x LCC)

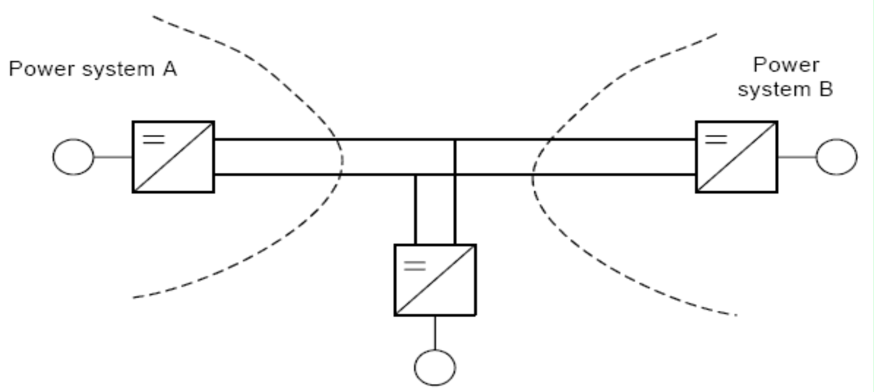
- 2 cables
  - LCC up to 1400 MW at ±500 kV
  - VSC up to 500 MW at ±150 kV (future. 1000 MW at ±300 kV)





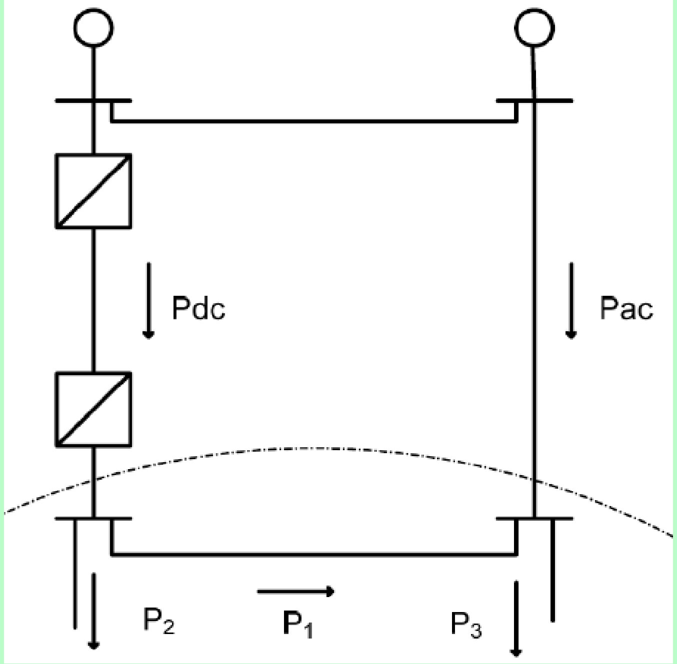
Multi-terminal HVDC

- 2 classic convertors with one DC connection
- more conv. can be used – one reg. U, other P flow
- possible LCC and VSC
- advantages VSC
  - no commutation faults and full system restart needed
  - operation does not depend on Sks
  - reversion without U_{DC} polarity change (LCC can have special design)
  - without telecommunication



Parallel HVDC and AC

- power flow division by HVDC control
- with VSC additional reg. U
- for example, with WPP increase
  - HVDC fully control active power flow – no circle flow
- DC strengthen offshore grid
  - and for LCC



Advantages of HVDC for WPP

- asynchronous operation is available (AG)
- fault in the grid does not transit to WPP
  - better stands during fault without disconnection
  - during fault f increase at WPP, AC grid does not accept P
  - special control measures at convertors or additional resistor
- damp power oscillations – regular WPP operation
- Advantages VSC
  - does not require commutation voltage
  - operate smoothly at any active power flow
  - without commutation faults
  - smaller (compact) station than LCC
  - for AC grid operate as gen. without Q
  - low short-circuit contribution

Future and trends

- application of FACTS and HVDC

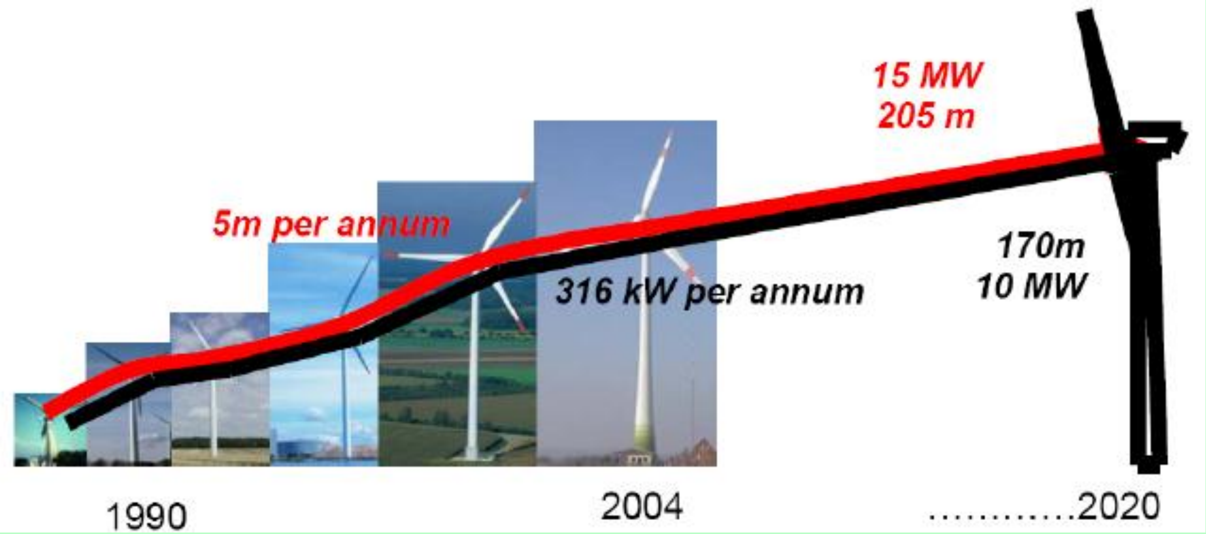
  (+) according to locality, grid, legislation

  (-) development of turbines and generators with power electronics

- environmental aspects
  - protest against overhead lines – cables (FACTS, next HVDC)
- inaccurate production prediction
  - development of accurate methods
  - applications of storage technologies
  - areas interconnection – lower effects of changes (wind fronts)
- grid requirements
  - approximate WPP characteristics to classical sources (dynamic regulation of U and f, oscillation damping)

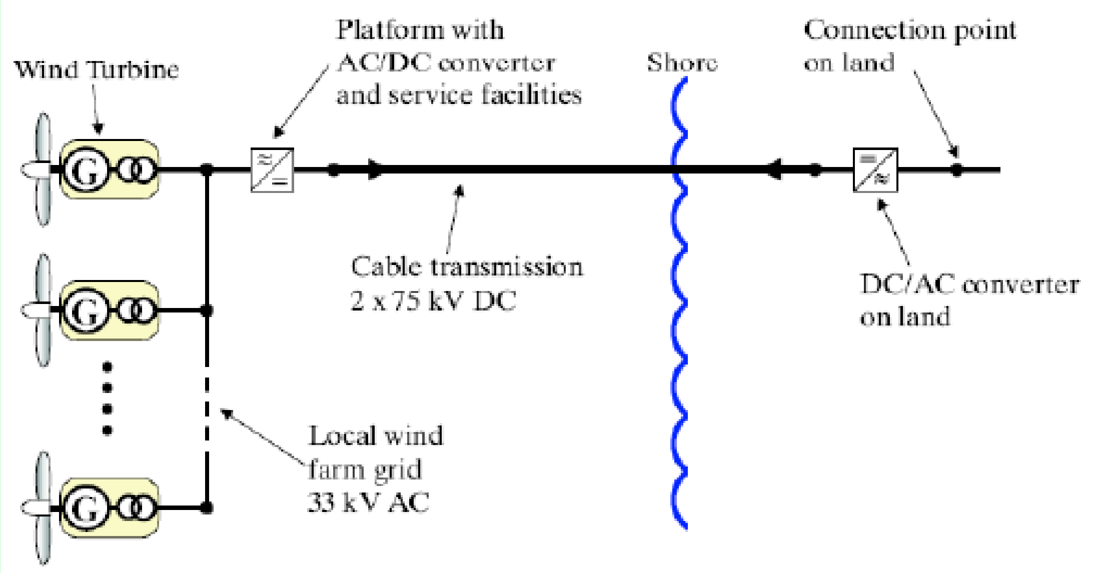
Future and trends

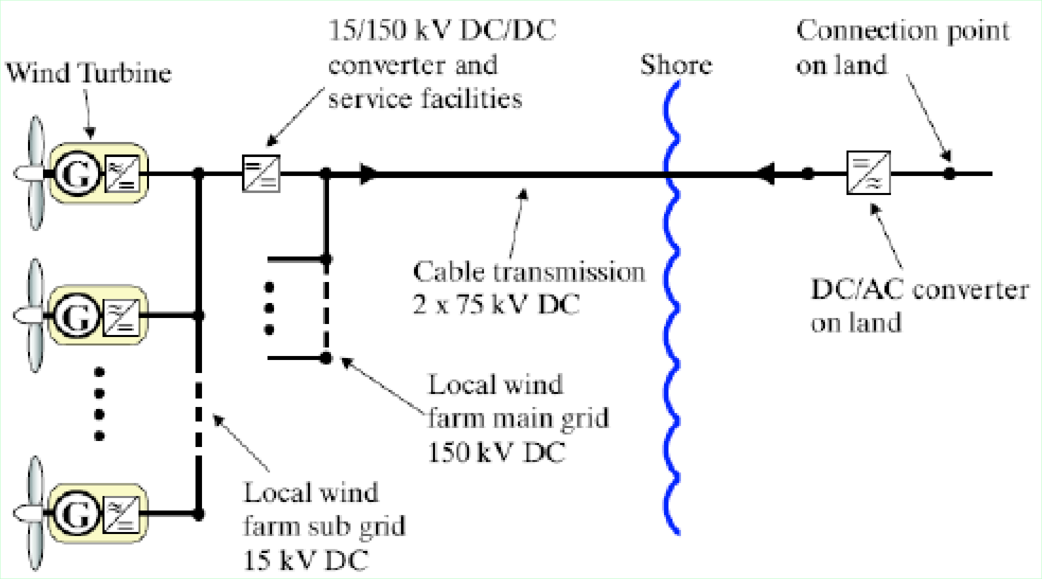
- offshore
  - less envirom. aspects, noise, easier transmission
- often distant areas, for weak grid – power electronics.
- energy storage
  - quality – UPS, C, flywheel, SMES (ms-s)
  - energy manegament – PVE, hydrogen, batteries (hours, days)



Future and trends

- DC systems





DC supergrid

- connection – elimination of inaccurate prediction in big systems, mutual systems help
- more connections to AC grid
- multiterminal system – VSC
- requirement of investments and international (political) support
- connection of places at weaker grids (shore)
  - energy to consumption centers – further strengthen – HVDC?

DC supergrid