Wind Energy and Protection

Roy Moxley

Thanks to Reigh Walling, Walling Energy Systems Consulting LLC

You See Wind Machines Everywhere

(30 miles North of Pullman)

82 GW Capacity in the US as of January 2017

Wind Turbines

Self Protecting

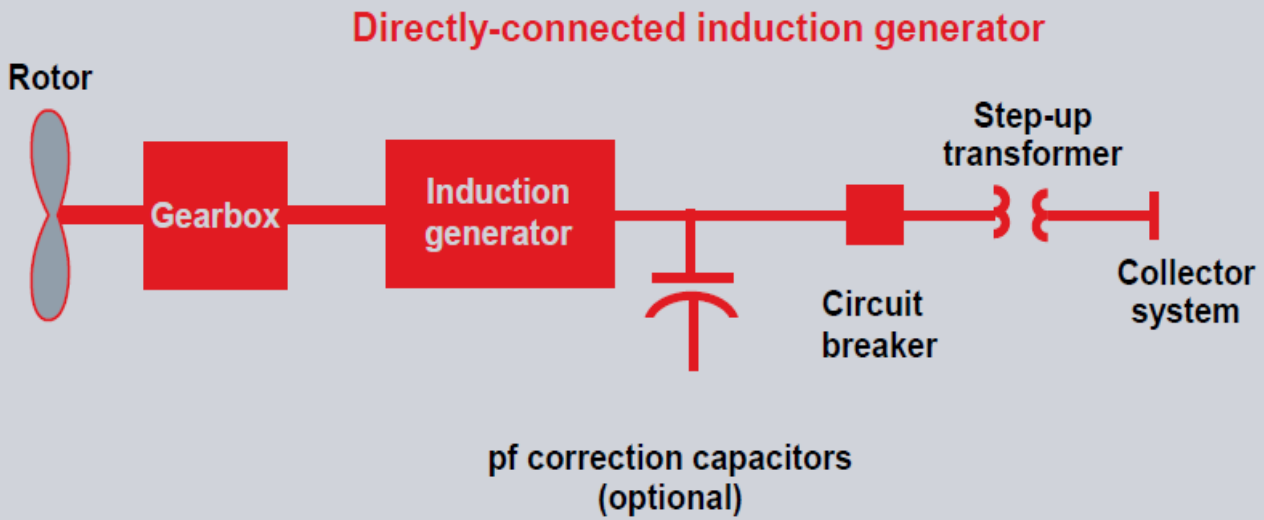
Size Increasing (today up to 8 MW)

No Zero Sequence

No (Presently) Negative Sequence

Type 1 and type 2 induction generator wind turbines

Basic operation of type 1 and 2 – typical configuration



Fixed speed system

- Capacitors supply magnetizing current and system reactive support
- Gearbox to increase shaft speed by, typically, ~100 times
- Slip rings for Type 2 (wound rotor), not for type 1 (squirrel cage)
- No inherent voltage regulation capability; must be supplemented by reactive sources (usually capacitors)
- Torque controlled by adjusting pitch (and/or rotor resistance in type 2)
- Susceptible to system conditions, especially low voltage

Type 1 and 2 IG wind turbines Advantages/disadvantages

Main Advantages

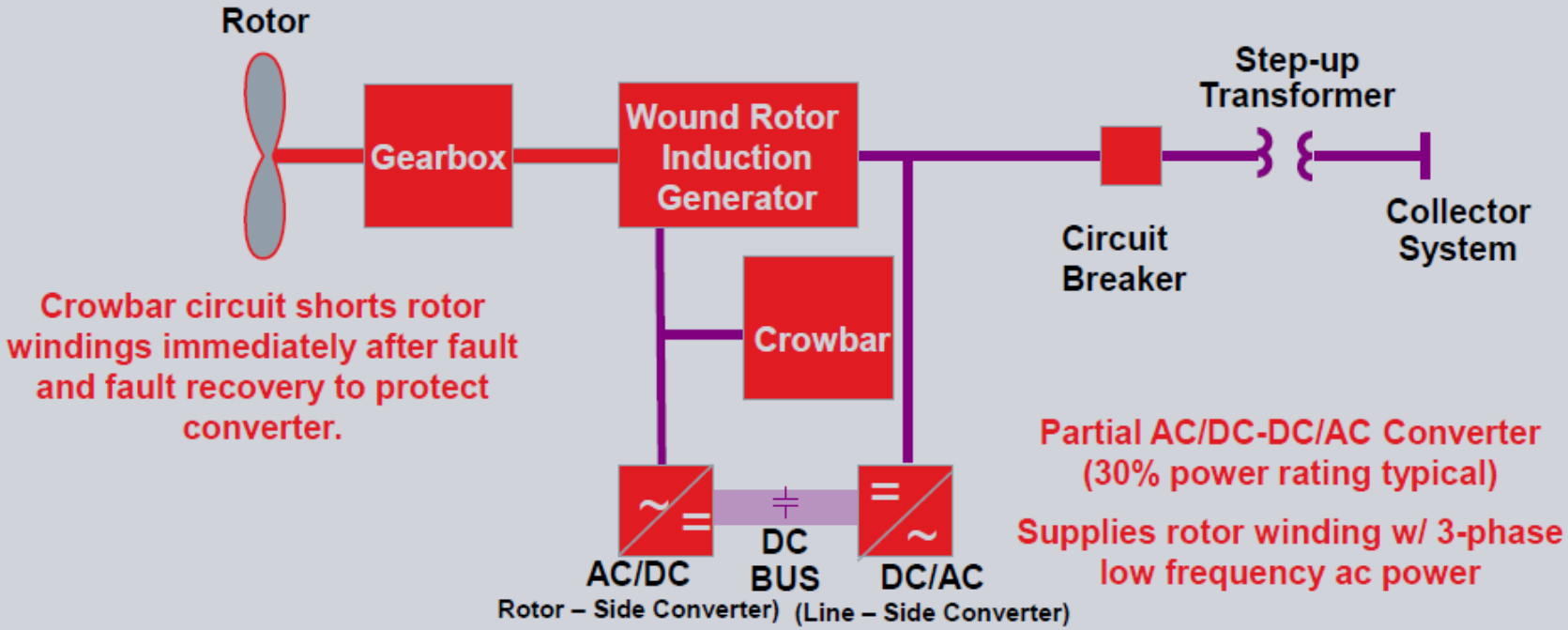
- Simple and low cost
- Rugged, low maintenance (esp. type 1)

Main Disadvantages

- Poor voltage control ability
- Large starting inrush; required capacitors and/or staggered starts
- Difficult to control output per schedule
- No speed control in type 1, very limited in type 2
- High mechanical stress on turbine components, especially gearbox, during system faults
- Slip ring/brush maintenance in nacelle for type 2
- Poor zero-voltage ride through capability

Not applied in North America for new transmission applications.

Type 3 – Doubly-fed induction generator (DFIG)
Basic operation of DFIG – typical configuration



DFIG system

- Rotor- and line-side converters (back-to-back, connected by dc bus) sized for, typically, ~30% of rated output
- Gearbox to increase shaft speed by, typically, ~100 times
- Rotor-side converter supplies (low) slip frequency magnetizing 3-phase AC voltage to wound rotor windings via slip rings
- Crowbar circuit often used to short rotor windings after fault and fault recovery to protect rotor-side converter

Type 3 – Doubly-fed induction generator (DFIG) Advantages/disadvantages

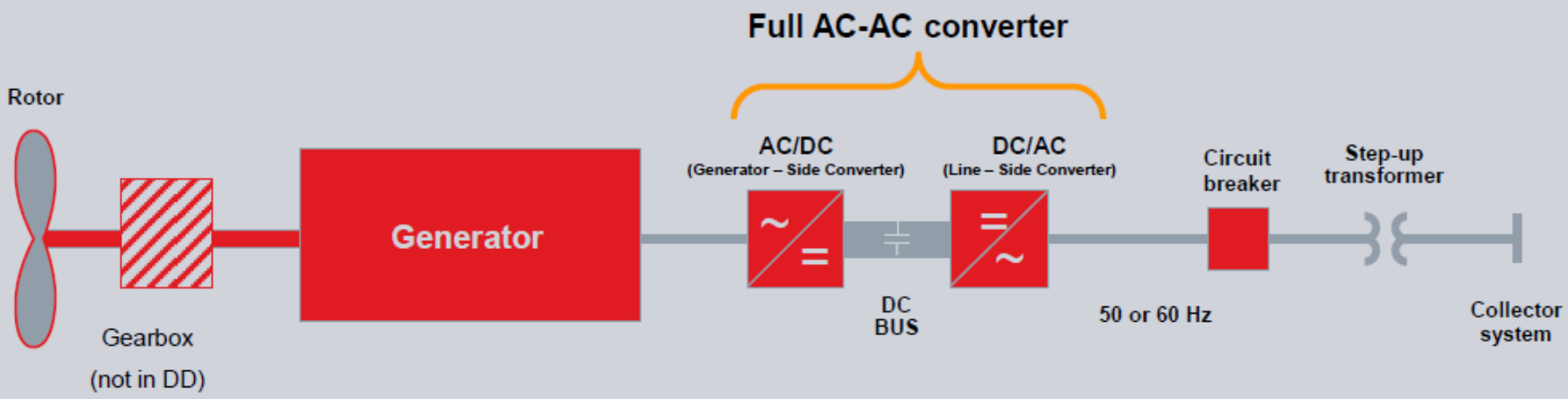
Main Advantages

- Good conversion efficiency
- Decoupled control of active/reactive power
- Capable of ancillary service (voltage/frequency regulation) support

Main Disadvantages

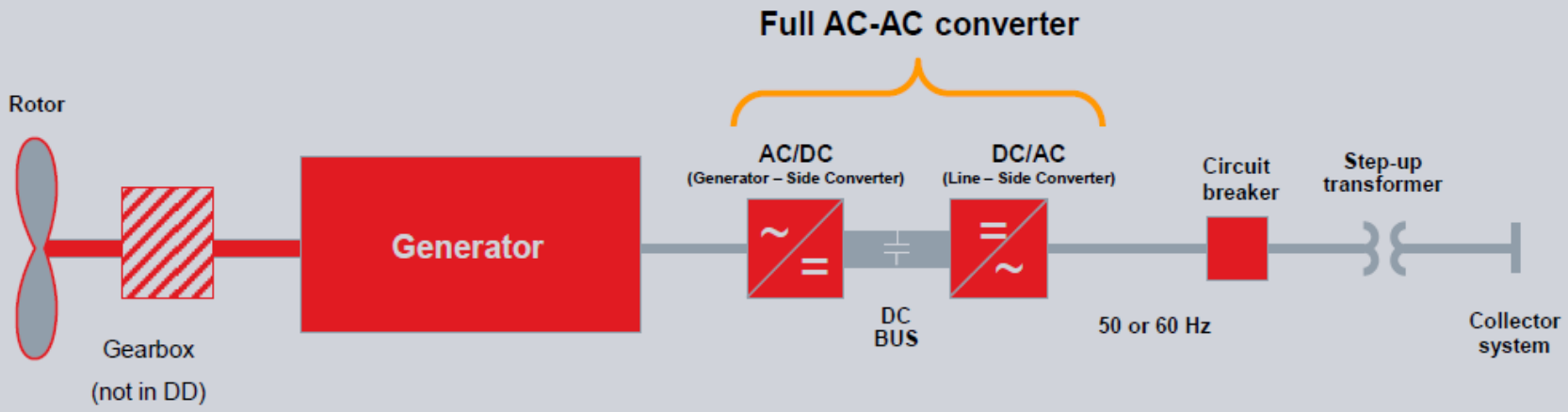
- Regular maintenance of slip ring and brush assembly in nacelle
- Limited fault ride-through and voltage regulation capability
- Rotor and gearbox stresses during system faults, esp. unbalanced faults
- Crowbar circuit limits system support during contingencies
- Negative sequence heating/vibrations in some power systems
- Large short circuit contribution
- Interactions between grid and generator; susceptible to subsynchronous interaction (SSI), system shorts, etc.
- Damage can result from improper synchronization

Full-Converter (type 4) system



- Rotor drives gearbox in geared systems – increases generator shaft speed
- Gearbox eliminated in DD (direct drive); rotor directly drives low-speed, multi-pole generator
- Generator converts mechanical power to AC electric power. Generator can be asynchronous, permanent magnet or synchronous for geared system, pm or synchronous for DD.
- Generator-side converter converts AC electric power to DC
- Line-side converter converts DC to system-frequency AC (50 Hz or 60 Hz, as appropriate) and provides voltage regulation capability
- Converter decouples machine from grid.

What are the advantages of the Full Converter system?



Variable Speed:

During abnormal conditions, can increase or decrease shaft speed/kinetic energy to satisfy system needs

- Increase shaft speed during low-voltage ride-through – extra kinetic energy stored in shaft when Pgen→0.
- Shaft can absorb energy from gusts without changing output

Full Converter:

Maximum flexibility and fast response; decouples machine:

- Rapid response – short time delays compared to directly connected magnetic machines, with winding time constants
- Full control of short circuit current from >100% of nominal output current to zero (standby); useful for voltage regulation during low-voltage ride-through and response to faults
- Precise control of output and rate of change of output as required (subject to availability of wind power)
- Turbine can be used for frequency response (for regulation down) or, with standby reserve, for spinning reserve/regulation up
- Decouples machine from power system – no SSTI, negative sequence heating concerns, minimal short circuit torques.

Type 4 Variable-speed, full-converter wind turbine-generator
Advantages/disadvantages

Main Advantages

- Maximum flexibility – fully controllable converter interface
- Decoupled control of active power and voltage regulation
- Controllable short circuit contribution
- Theoretically infinite duration low-voltage ride-through capability
- No exposure to system faults for generator, gearbox (in geared systems)
- No power system-machine interactions; SSR immunity possible
- Reactive capability curve – similar to synchronous machines
- Minimal moving parts in direct drive configuration
- No slip rings; easy maintenance
- Self-synchronizing; no supplemental equipment or capacitors required; no requirement for staggered startup

Possible Disadvantages

- Limited (but controllable) fault current contribution – may require sophisticated collector protection

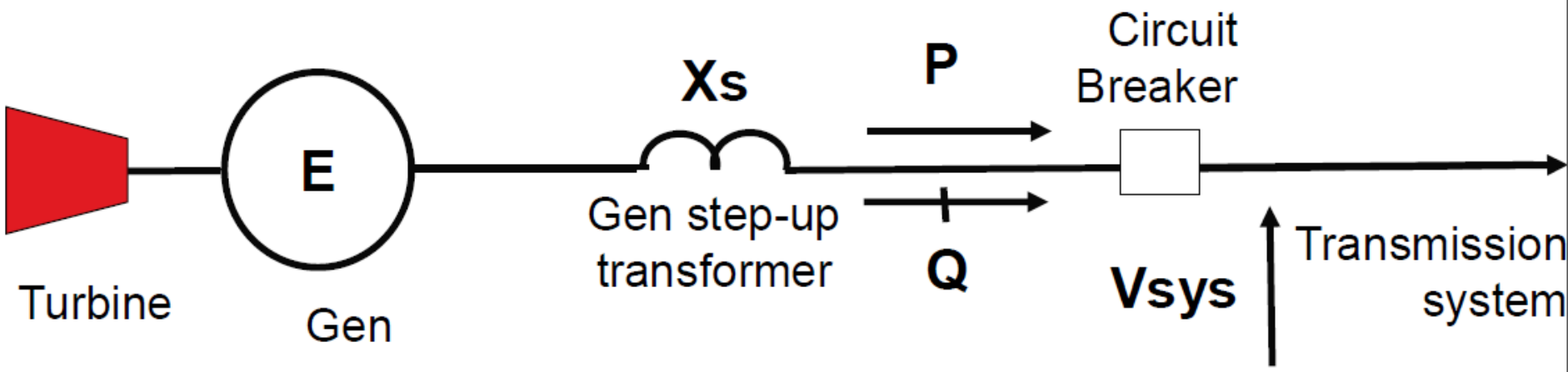
Comparison of WTG Designs to Comply with Interconnection Requirements

	Variable Speed Full Converter (FC)	Doubly –Fed Induction Generator (DFIG)	Traditional Induction Generator (IG)	Comments
LVRT/ZVRT	YYY	YY	X	FC capable of extended ZVRT. DFIG typically goes into "crowbar" during rapid voltage changes. IG must be supplemented for LVRT capability.
Fast Dynamic Voltage Regulation	YYY	YY	X	FC capable of STATCOM-like behavior. DFIG has machine time constants, limited reactive capability. IG has no voltage support capability.
Fast Active Power Regulation	YYY	YY	Y	FC has fast, precise converter response.
Frequency Response	YYY	YY	Y	FC has fast, precise converter response.
Ability to operate in series capacitor-compensated system	YYY	Y	X	DFIG and IG machines are susceptible to SSTI and/or SSCI; FC not susceptible to SSTI and can be tuned to avoid SSCI
Negative Sequence Withstand	YYY	Y	Y	Negative sequence causes heating and vibration in machines; std IEC limit is 2%
Generic Model Availability	YYY	Y	YY	FC generic model fidelity generally very good; few of the concerns that have shown up in other generic models

X = Capability generally not available w/o supplemental equipment

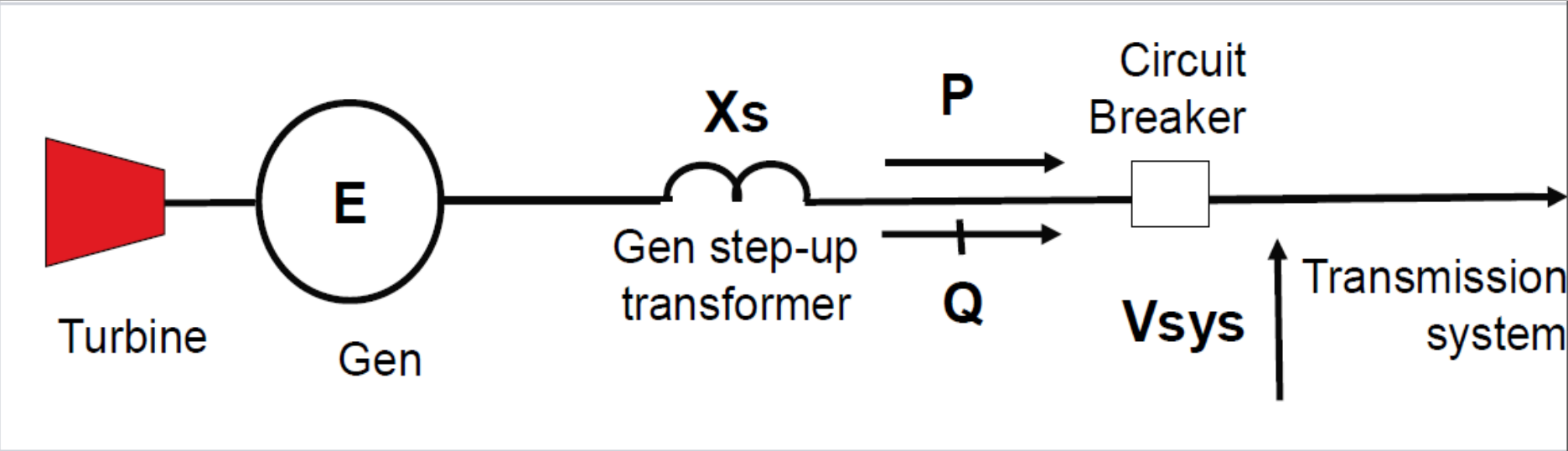
Y = Generally OK, but shortfalls in some apps YY = Generally acceptable YYY = Excellent

Comparison of Type 4 with Synchronous (conventional) generation



- **Turbine drives generator, which converts mechanical energy to electric power at synchronous speed (3600 or 1800 rpm, typically, in Americas)**
- **Generator step-up transformer steps output from generator (typically at voltage of 13.8 kV to 27 kV) to transmission voltage (usually 69kV, 115kV, 138kV, 161kV, 230kV, 345kV, 500kV or 765kV in North America)**
- **Inertial Response** – When system frequency drops suddenly, shaft kinetic energy is converted to electric power, which slows the frequency decline naturally – not a control action, but physics.
- **Voltage Regulation** – Adjusts system voltage by injecting reactive power to raise voltage or absorbing reactive power to decrease voltage; can operate in voltage regulation, power factor control (constant ratio of Q to P) or reactive power control (fixed Q).

Advantages and Disadvantages of Conventional generation



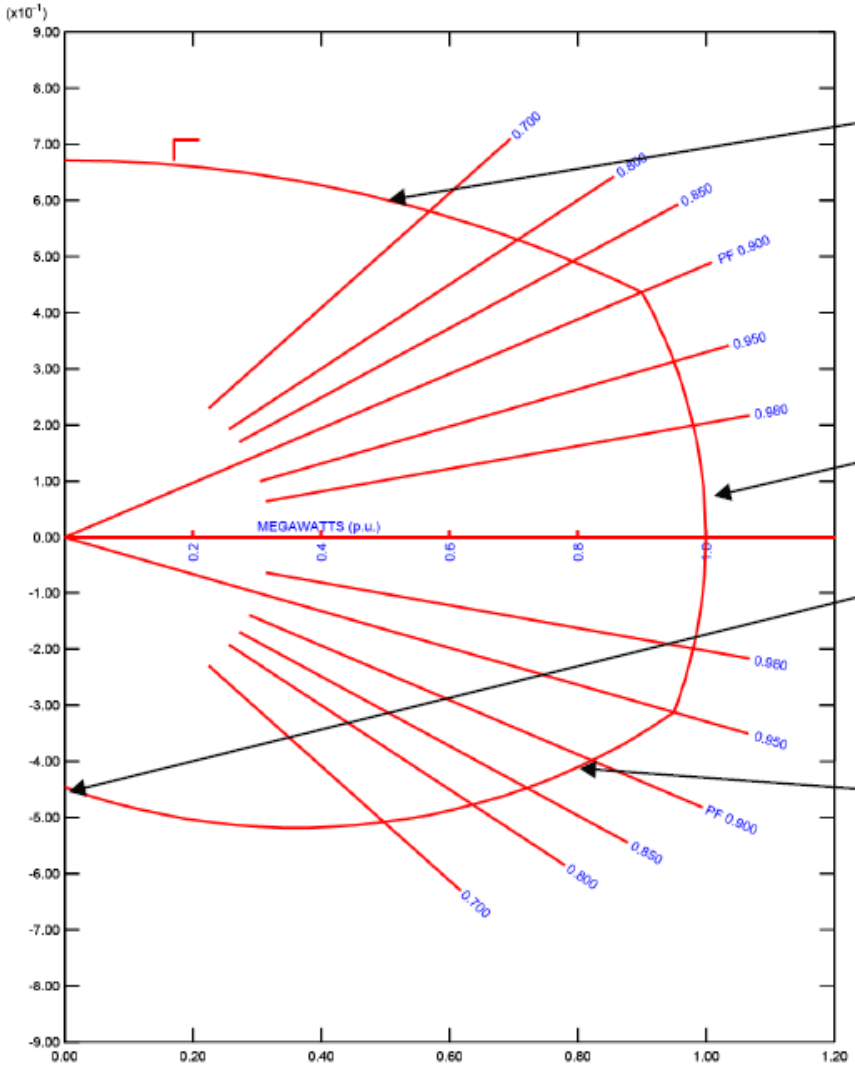
Advantages:

- Long history and familiarity with operation.
- Excellent controllability, both for active power control and reactive (voltage) control.
- Inertial Response is a function of shaft inertia, not controls

Disadvantages:

- Speed of response, especially active power control
- Lose synchronism during power system faults
- Limited range of voltage regulation- susceptible to voltage collapse
- Large short circuit contributions

Reactive capability characteristic of synchronous generator



Rotor coil (field current) heating limit

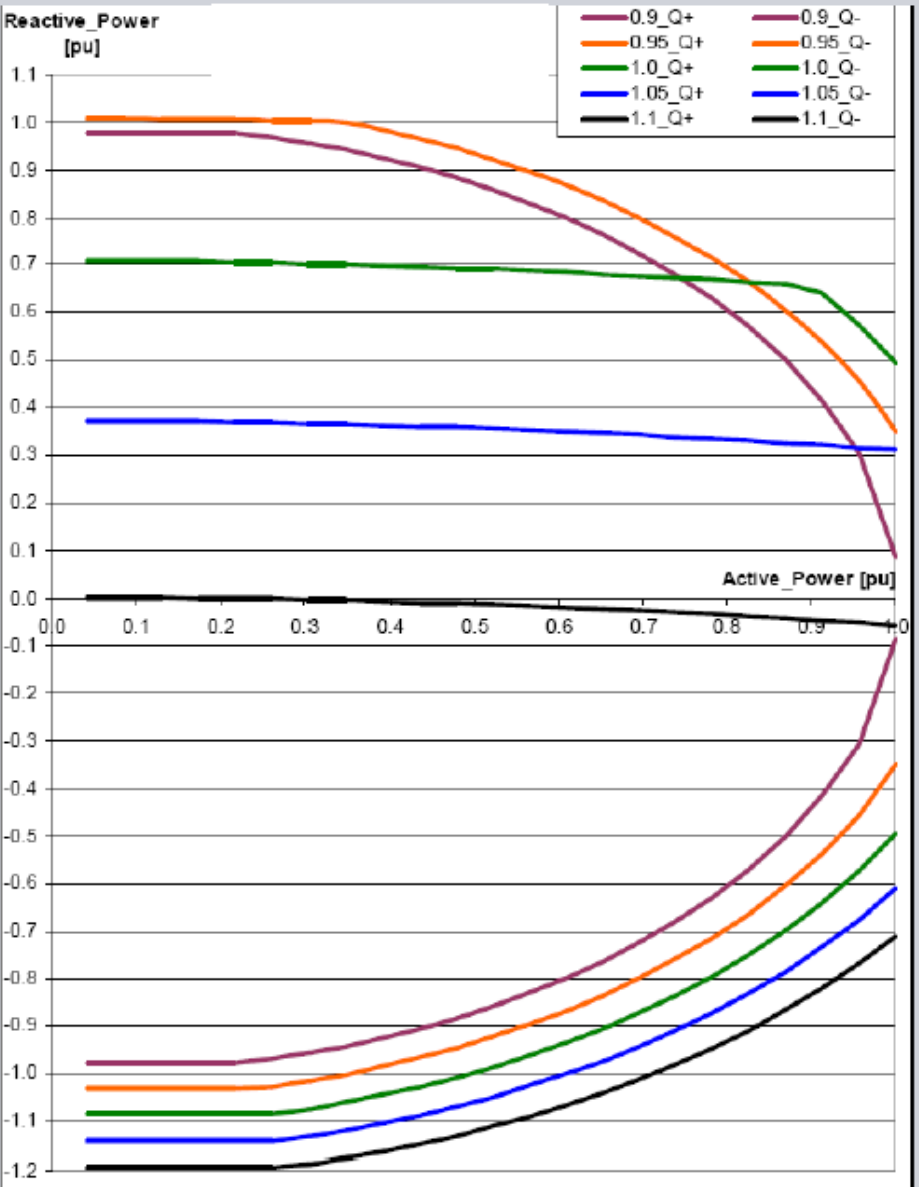
Stator coil heating limit

Minimum field current (stability) limit

Stator end turns heating limit

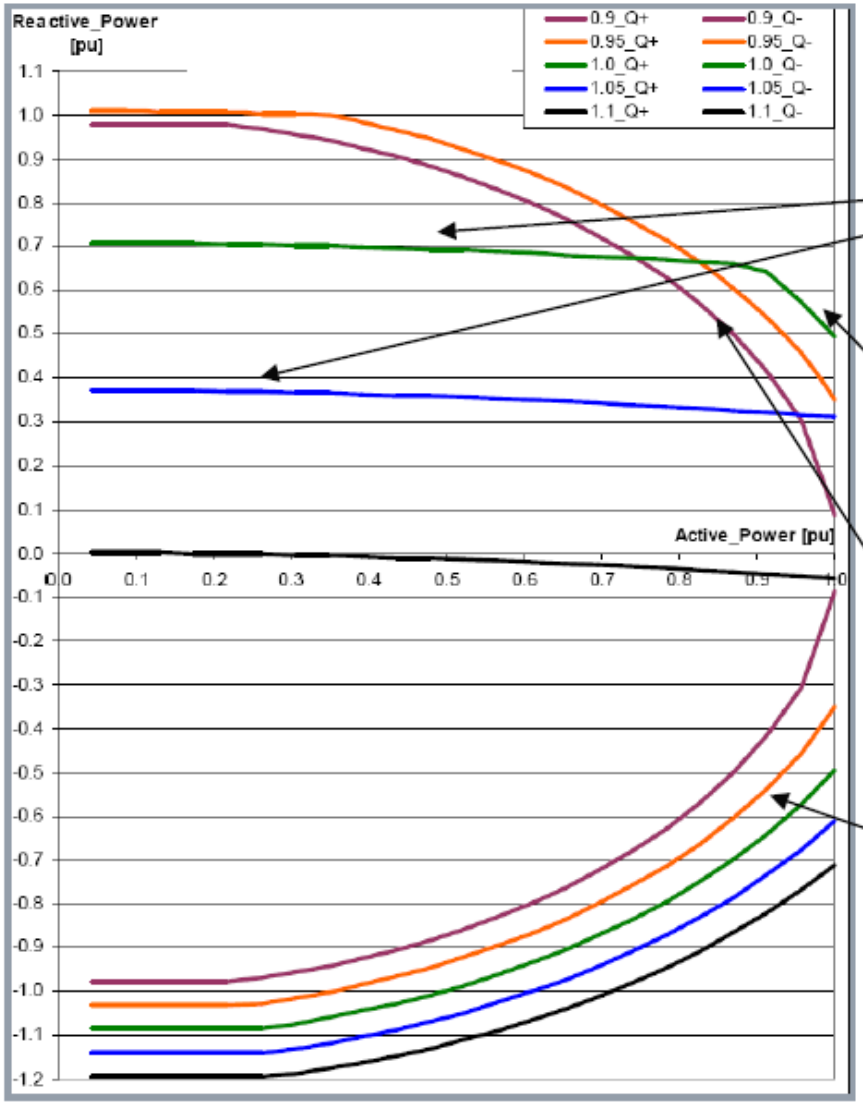
Synch generators are power limited; reactive power does not vary with Vt in small (0.95 to 1.05 pu) voltage range.

Modeling Full Converter Machines – Reactive Capability



Converters have distinct voltage and current limits and a relatively wide voltage range (90% to 110% of nominal, so reactive capability varies with terminal voltage, unlike synchronous generator, which has a power-invariant reactive capability characteristic.

Reactive capability characteristic of full-converter wind turbine



Voltage-limited;
linear with shallow slope

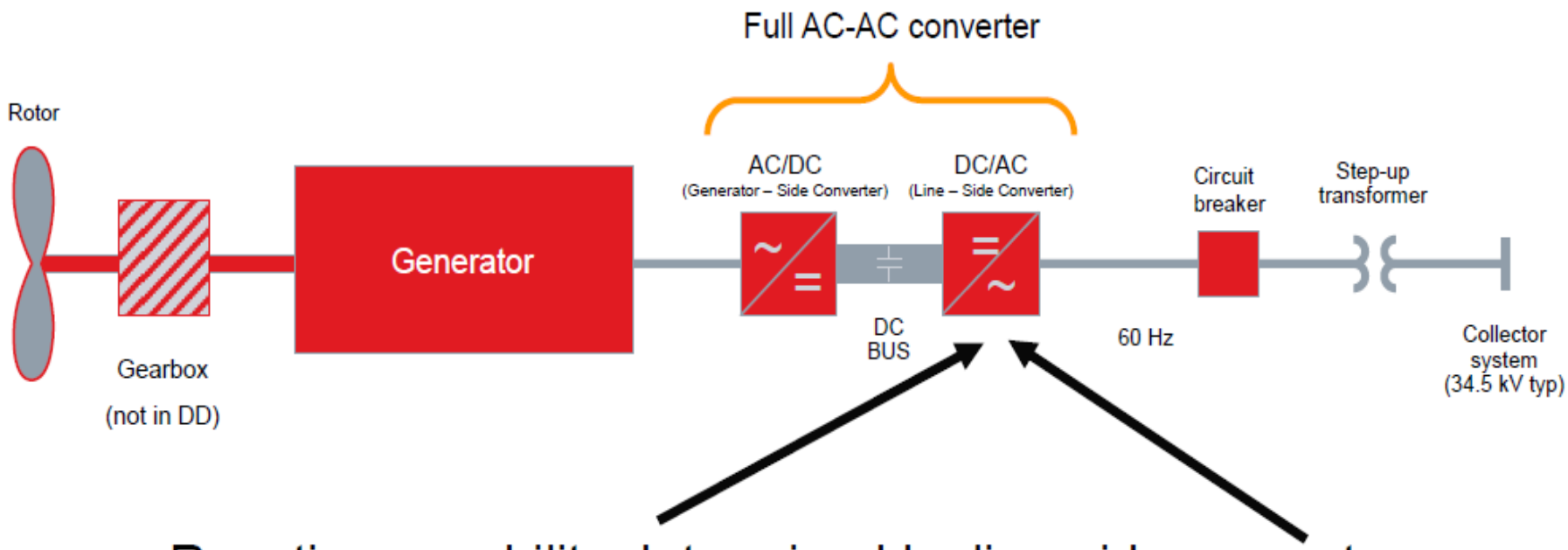
Voltage and current-limited;
linear with steep slope

Current-limited; arcs

Reactive capability characteristic of full-converter wind turbine

Why?

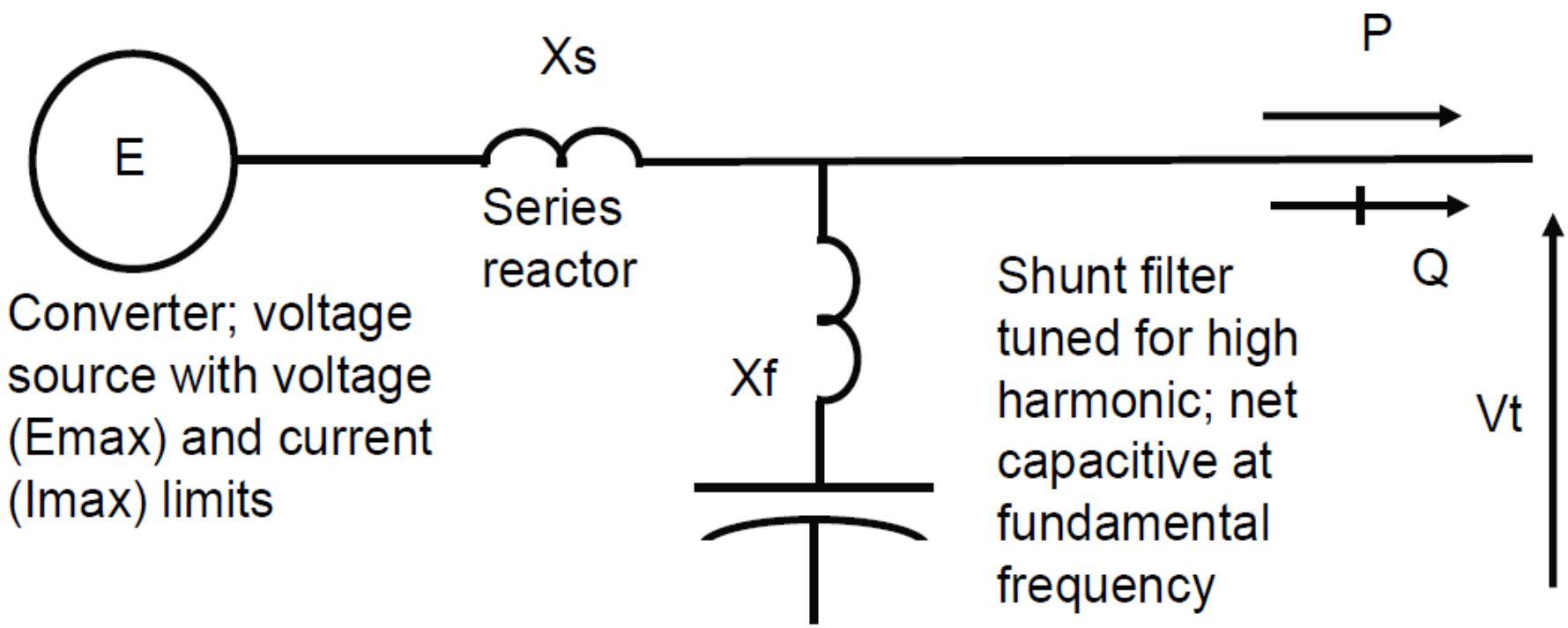
Schematic of full-converter wind turbine:



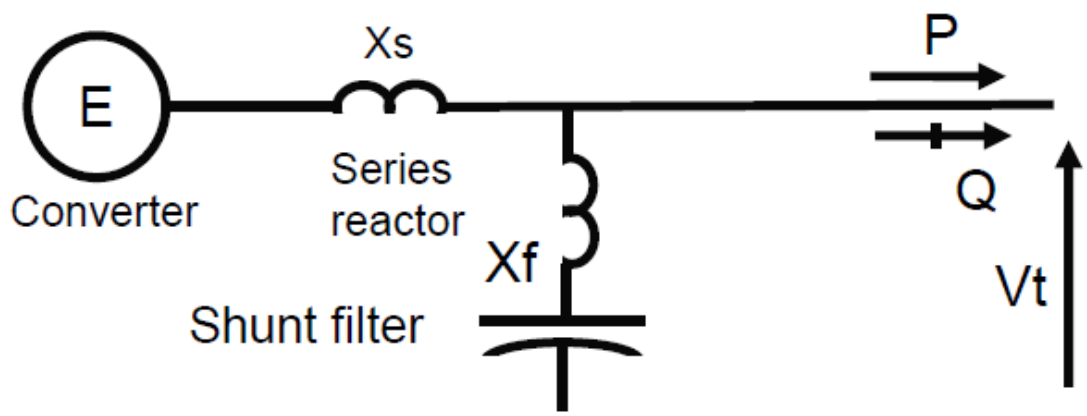
Reactive capability determined by line-side converter

Reactive capability characteristic of full-converter wind turbine

Equivalent circuit of representative line-side converter used in WTs:



Reactive capability characteristic of full-converter wind turbine



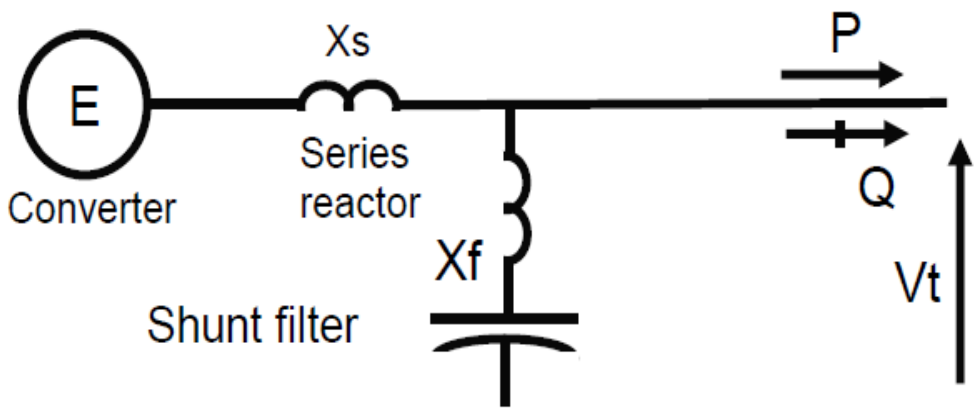
For any terminal voltage, Vt, and converter voltage, E∠δ (using Vt as reference), after some algebra:

$P = Vt * E / Xs * \sin \delta$

$Q = (Vt / Xs) * (E * \cos \delta - Vt) + Vt^2/Xf$

Note: δ is sometimes called the “power angle”.

Reactive capability characteristic of full-converter wind turbine



$P = Vt * E/Xs * \sin \delta$

At internal voltage limit, E = Emax (lagging pf only), and

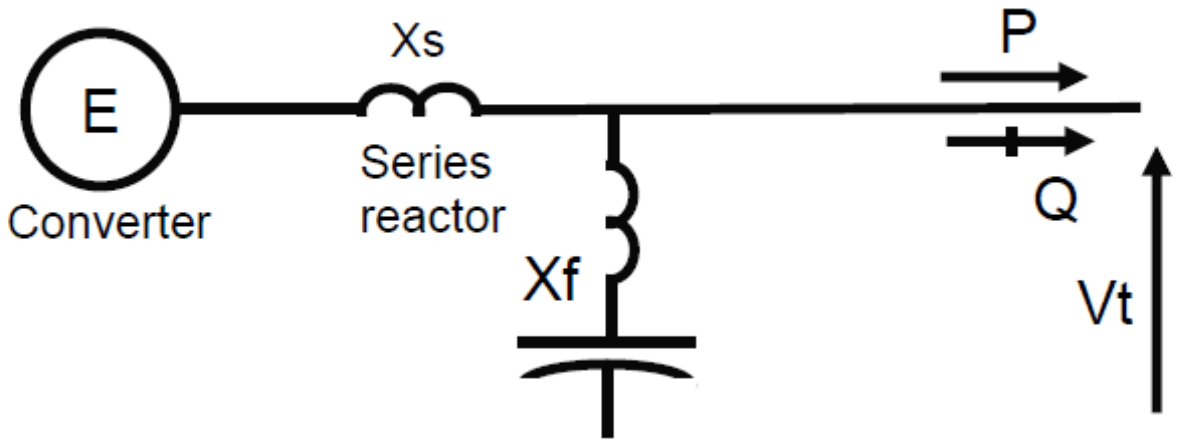
$$Qe = (Vt / Xs) * (E * \cos \delta - Vt) + Vt^2/Xf$$

At current limit, $Qi = \sqrt{((Vt * Imax)^2 - P^2)} + Vt^2/Xf$ (lagging pf; producing VArs)

$Qi = -\sqrt{((Vt * Imax)^2 - P^2)} + Vt^2/Xf$ (leading pf; absorbing VArs)

Lagging (Producing): Q = Min (Qe, Qi). Leading (Absorbing): Q = Qi

Reactive capability characteristic of full-converter wind turbine



Example:

Vt = 1.0 pu

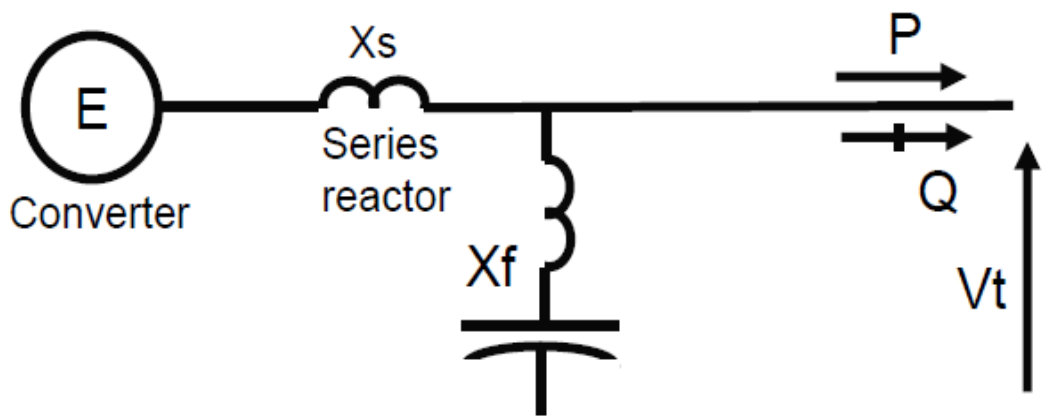
Xs = 0.15 pu

Xf = 15 pu (capacitive, so Zf = -j15 pu)

Imax = 1.2 pu; Emax = 1.1 pu

Calculate reactive capability from P = 0 to P=1.0

Reactive capability characteristic of full-converter wind turbine



P = 1; lagging case

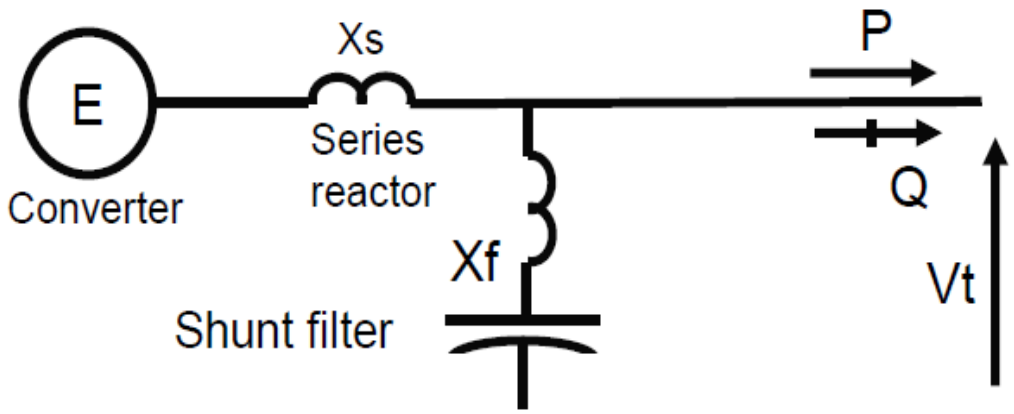
Assume E = Emax = 1.1

$P = Vt * E/Xs * \sin \delta$ so $\delta = \sin^{-1}(Xs*P)/(Vt*E) = 7.8°$

$Qe = (Vt/Xs)*(E*\cos \delta - Vt) + Vt^2/Xf = (1/0.15)*(1.1 \cos 7.8° - 1) + 1/15$

Qe = 0.6 + 0.07 = 0.67 pu, based on Emax

Reactive capability characteristic of full-converter wind turbine

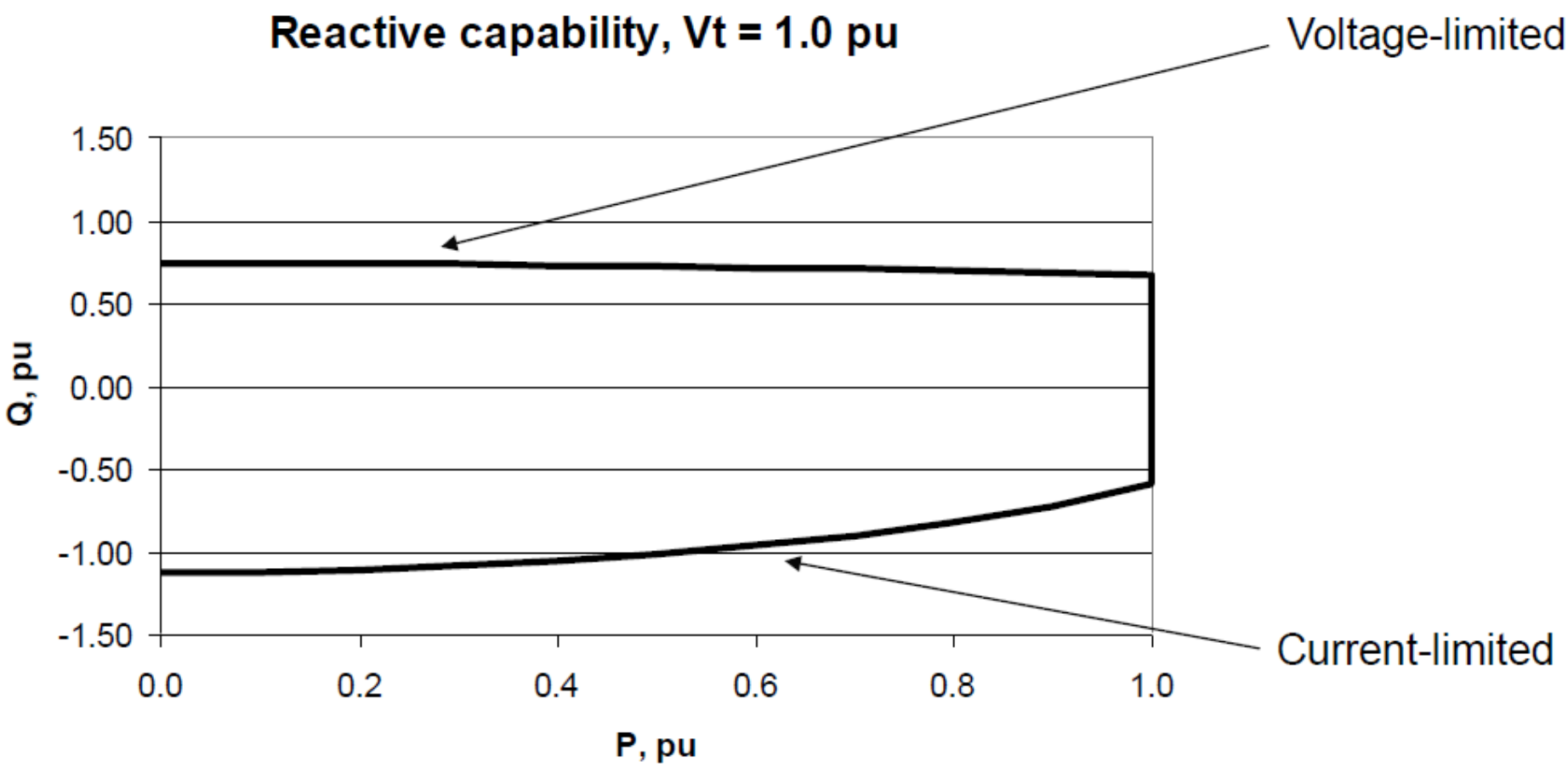


Other cases can be done the same way.

Tips:

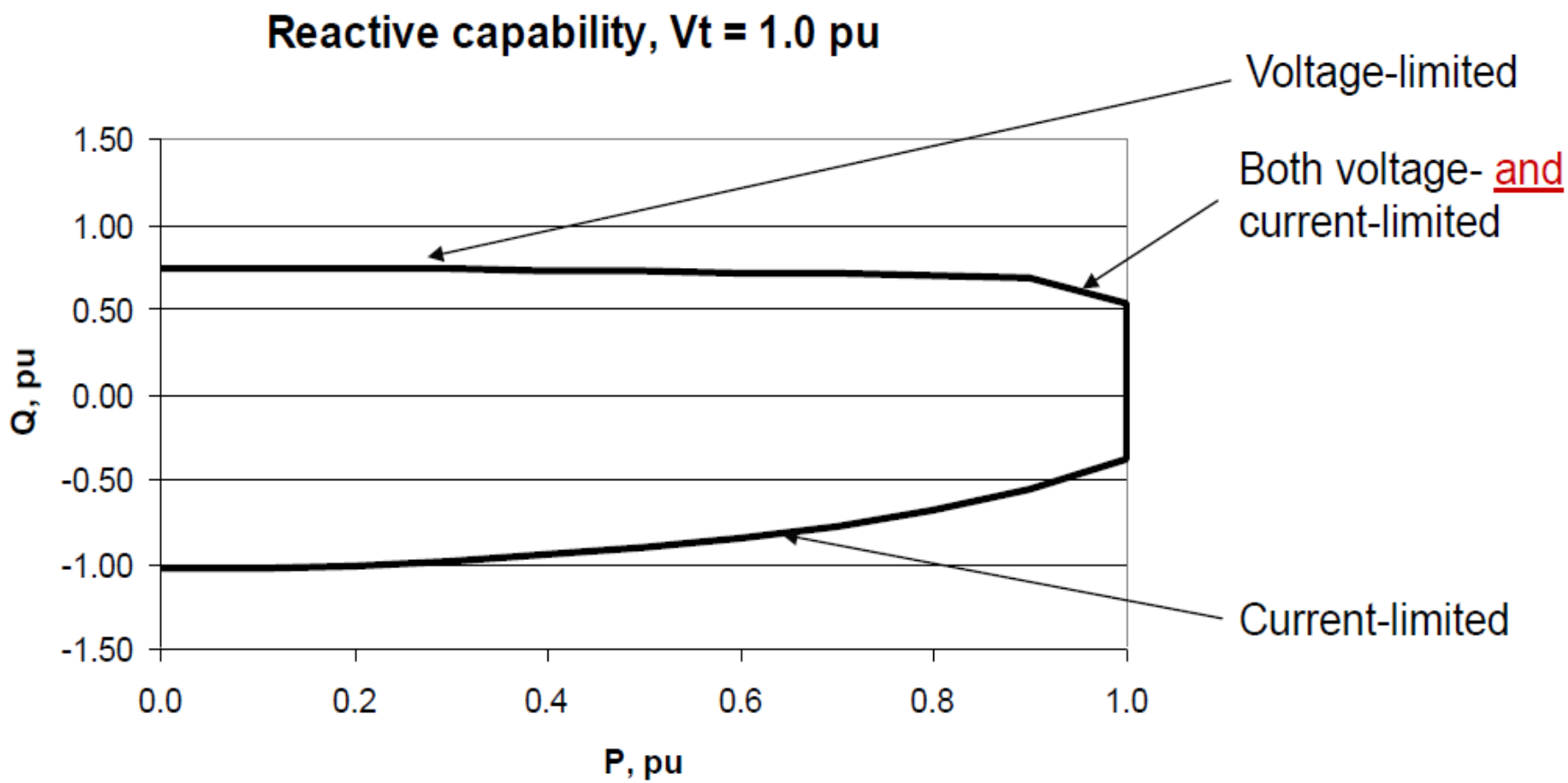
- Leading pf (turbines absorbing VArs) cases generally current limited, but some vendors may have a leading pf current restriction or Emin
- Lagging pf (turbines producing VArs) cases can be voltage- or current-limited; sometimes both.
- Not generally necessary to check power angle ($\delta<90°$) with typical parameters used in full converters.

Curves for different terminal voltages (example)

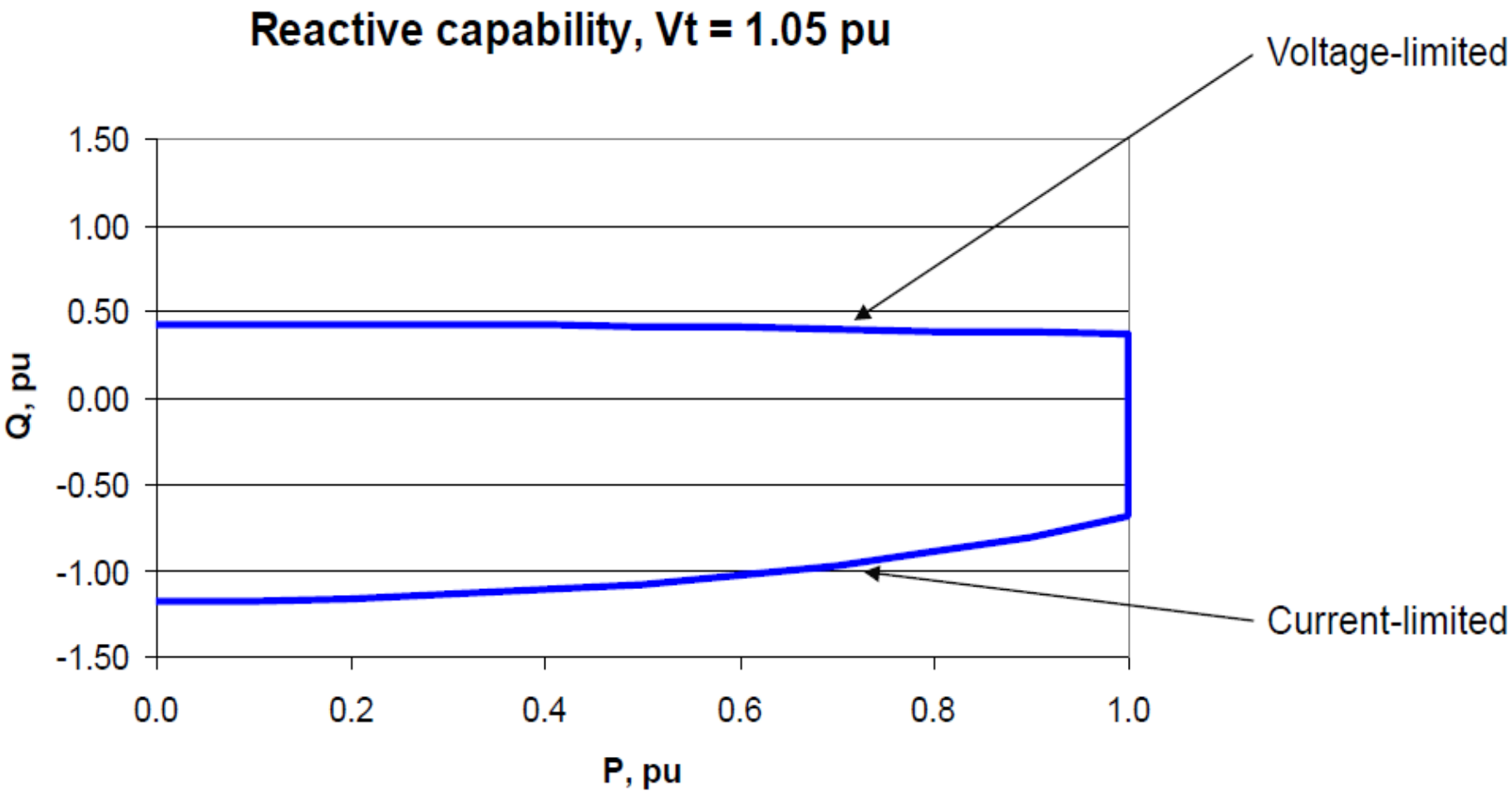


Curves for different terminal voltages (example)

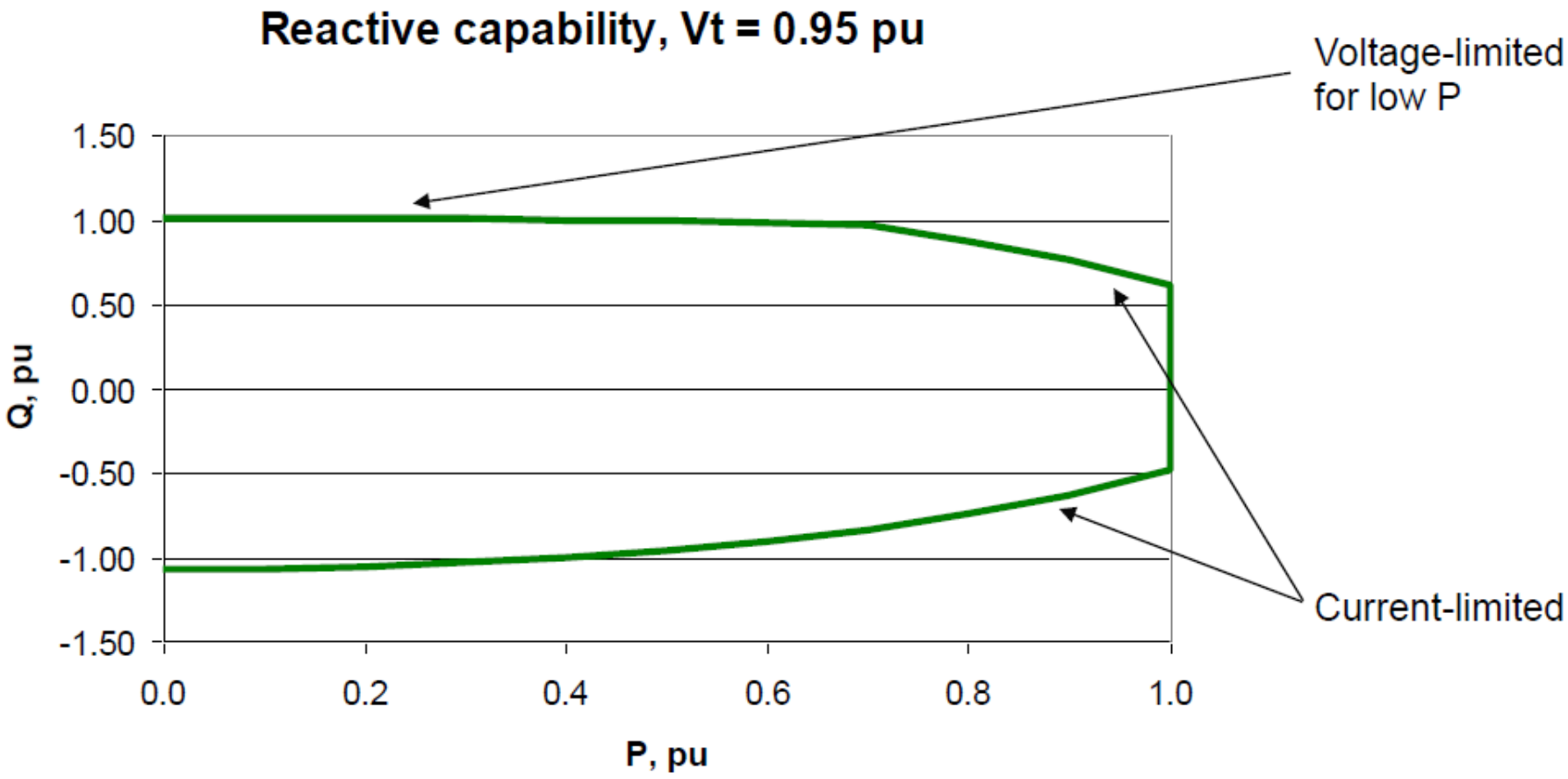
It is possible to have voltage and current limits simultaneously.
Consider what would happen if we reduced the current limit to 110%:



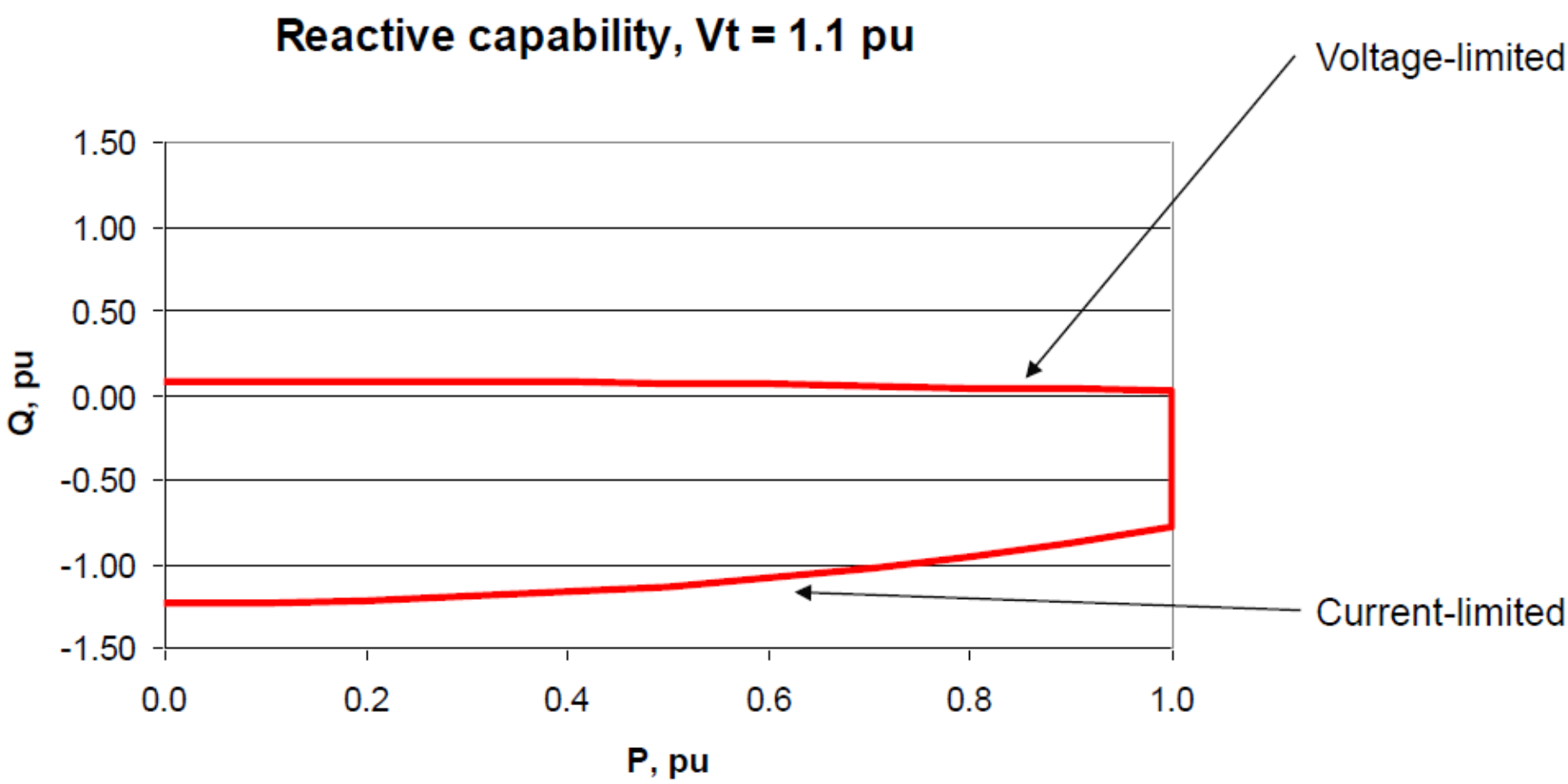
Curves for different terminal voltages (example)



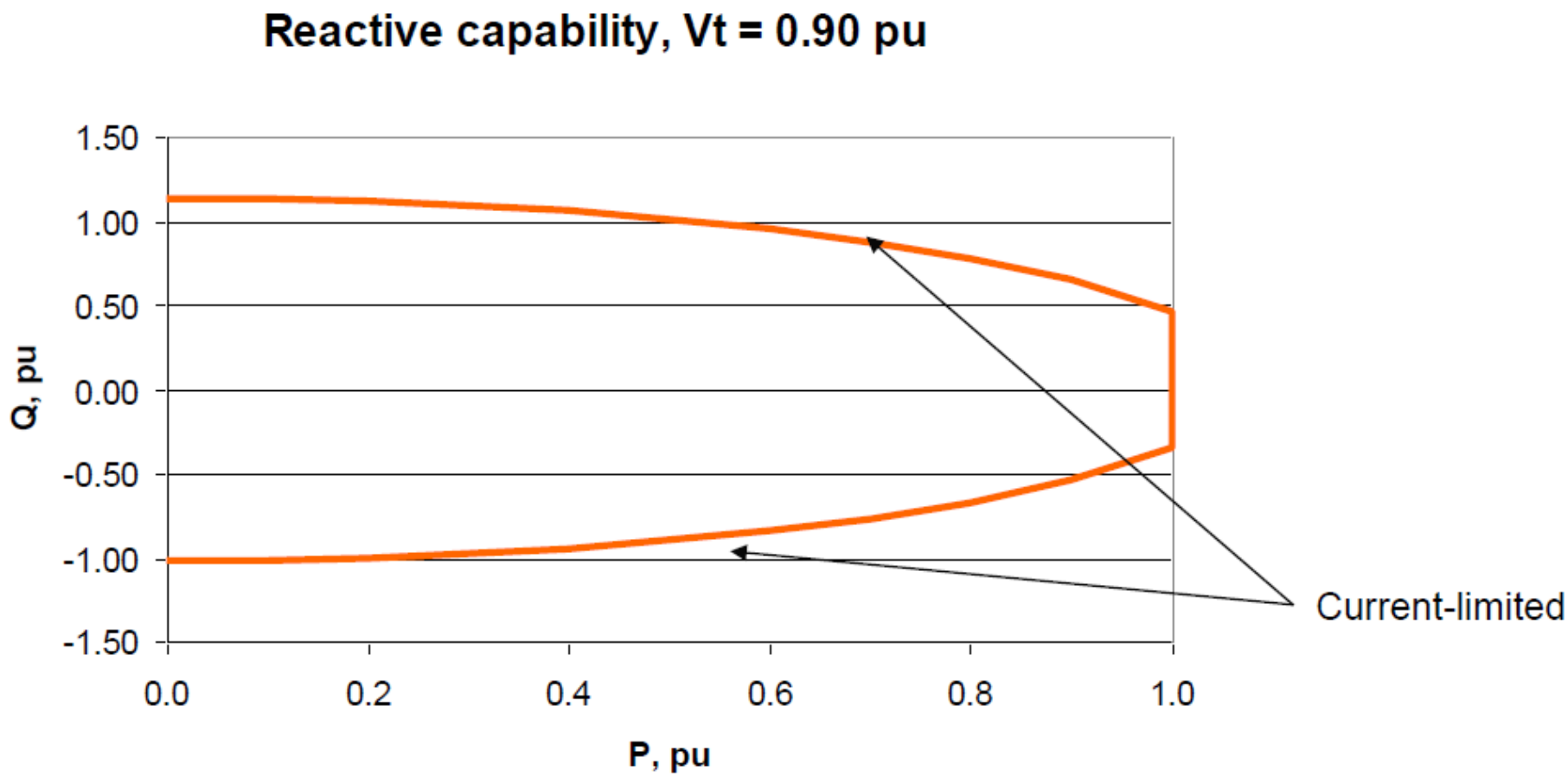
Curves for different terminal voltages (example)



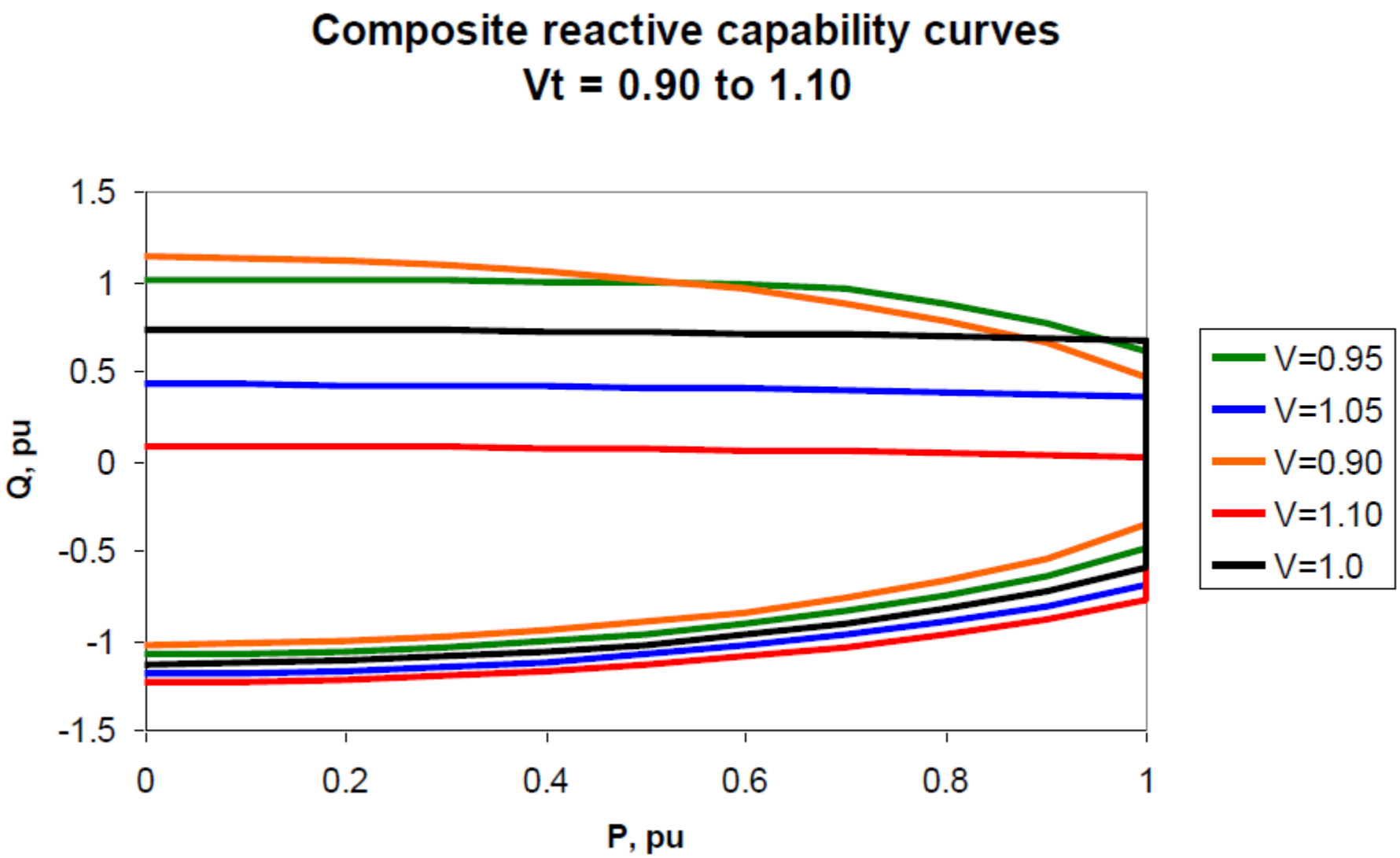
Curves for different terminal voltages (example)



Curves for different terminal voltages (example)



Curves for different terminal voltages (example)

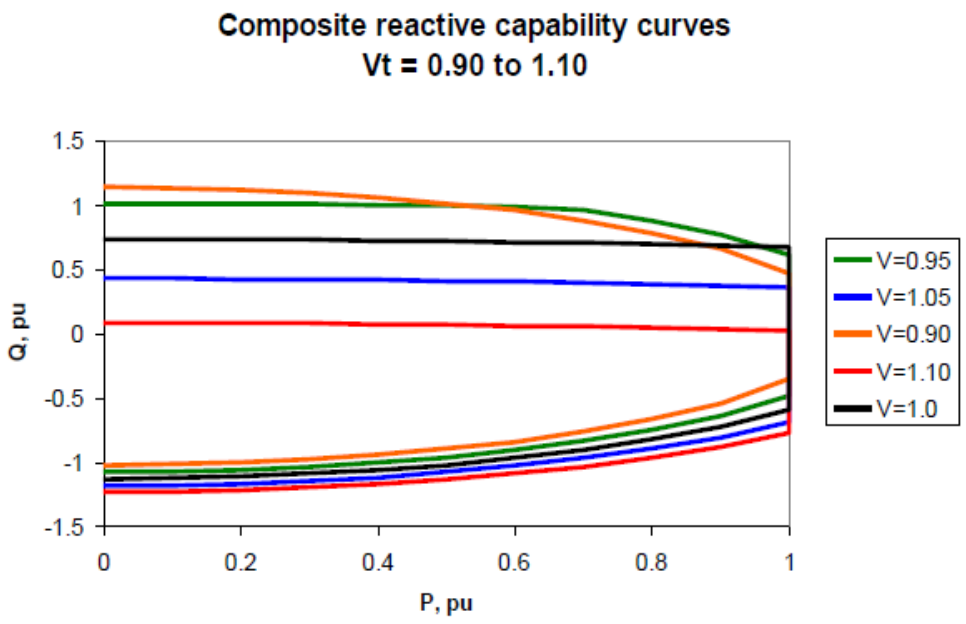


Curves for different terminal voltages (example)

Observations:

Most of the lagging and leading capability is available in typical operating range of Vt = 0.95 to 1.05 pu.

Lagging capability drops off sharply outside of this range; important to adjust transformer taps to be compatible with system operation.



What Are Common Reactive Control Requirements ?

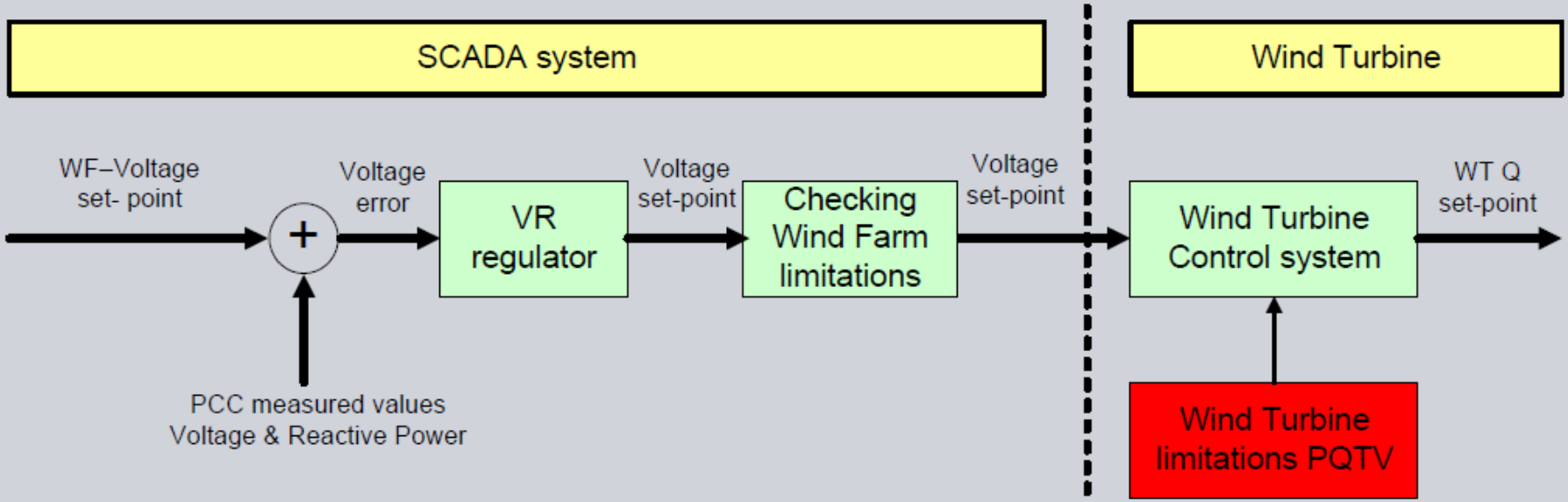
Existing:

- Voltage Regulation
- Reactive Power Control (constant Q)

- Power Factor Control (constant ratio of Q to P)

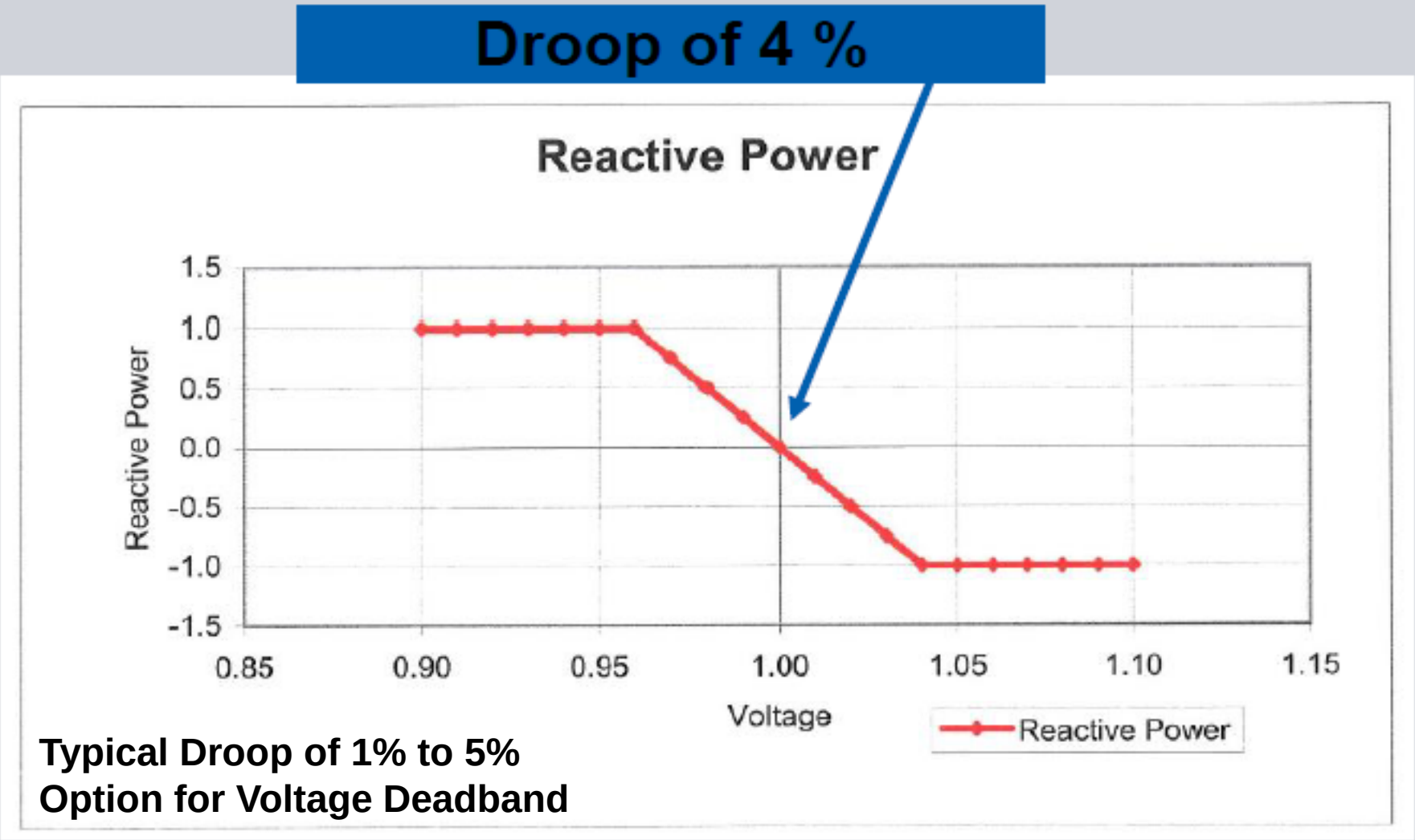
- Reactive Control without Active Power Production
- Voltage Regulation (adjustment of reactive power to satisfy voltage regulation schedule)
- Reactive Power Control All are capabilities currently provided on a routine basis by synchronous generators, except reactive power control without active power production (“synchronous condenser operation”), which typically requires extra equipment.

Wind Plant Reactive Power and Voltage Control



- Distribution of voltage set-points
- Wind turbine limitations secured by the embedded WT control system – PQTV (Active Power, Reactive Power, Temperature, Voltage)
- Can operate in voltage regulation, reactive power control (constant Q), or power factor control (constant ratio of P to Q)

Wind Plant Voltage Control – Reactive Droop



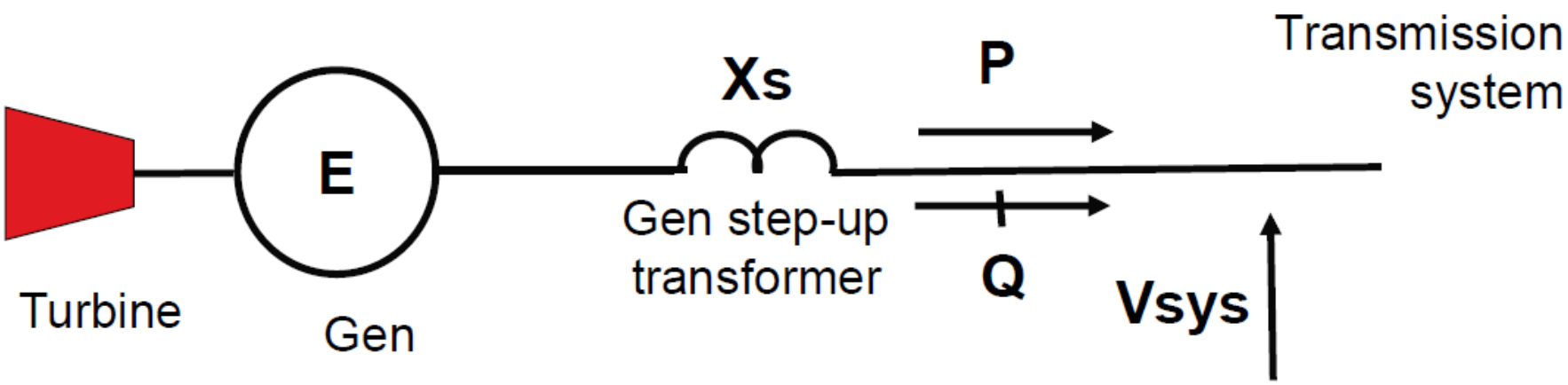
Typical Droop of 1% to 5%
Option for Voltage Deadband

Exercise – Draw Rough Sketch:

How does a full-converter wind park compare with a synchronous generator for steady-state voltage control?

Compare reactive capability of 100 MW (rated pf of 0.9 lag to 0.95 lead) synch generator with Xt = 13% with 100 MW wind park with equivalent reactance (inc. turbine transformer, park transformer and collector system) of 22% and RC curve developed in example. Assume both are connected to a 230kV transmission system and the collector system is 34.5kV; ignore resistance and collector charging.

1) Determine how much lagging reactive power can be delivered to transmission system, varying Vsys from 0.85 to 1.0 pu, with P=1.0 pu
2) Determine how much reactive power can be absorbed from the transmission system, varying Vsys from 1.0 to 1.15 pu, with P=1.0 pu



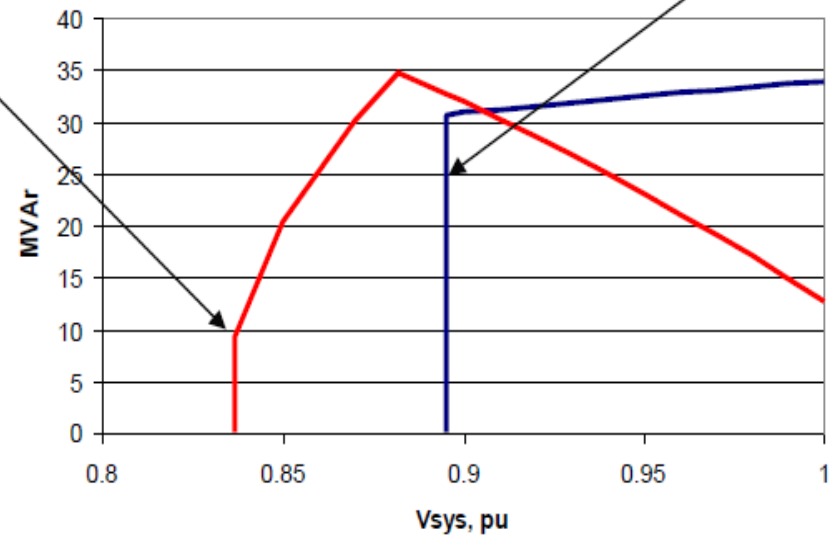
Solution 1):

Continuous Lagging Reactive Capability, Full Real Power Output

- Synch Gen
- Full-converter WP

WTs terminal voltage drops below 0.90 pu limit; go into low-voltage ride-through.

Sync Gen term voltage drops below 0.95 pu limit



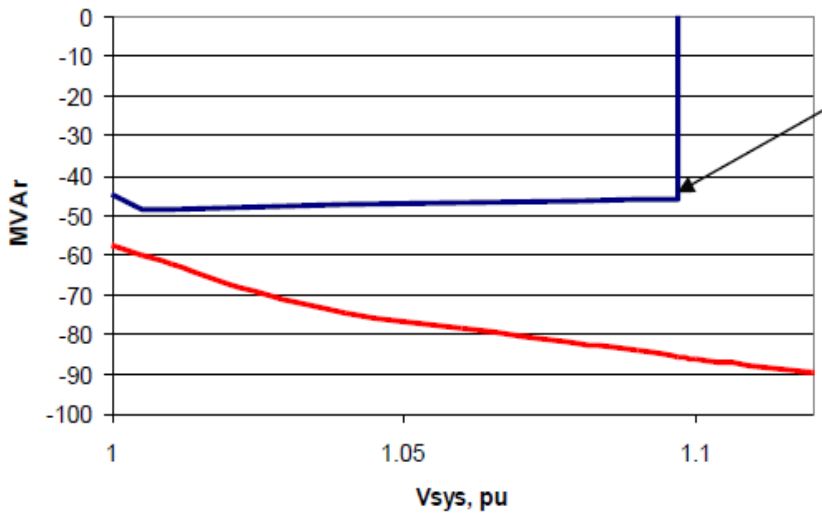
Note: neglects WP charging.

Similar max capabilities, but

- **The synchronous generator has a narrower operating voltage range and significantly greater capability near nominal voltage**
- **The WP has a wider control voltage range and is superior for very low transmission voltages (significantly below 0.90 pu, where the synchronous generator cannot provide continuous voltage support)**

Solution 2):

Continuous Leading Reactive Capability, Full Real Power Output



Synch gen terminal voltage goes above 1.05 pu limit

Synch Gen

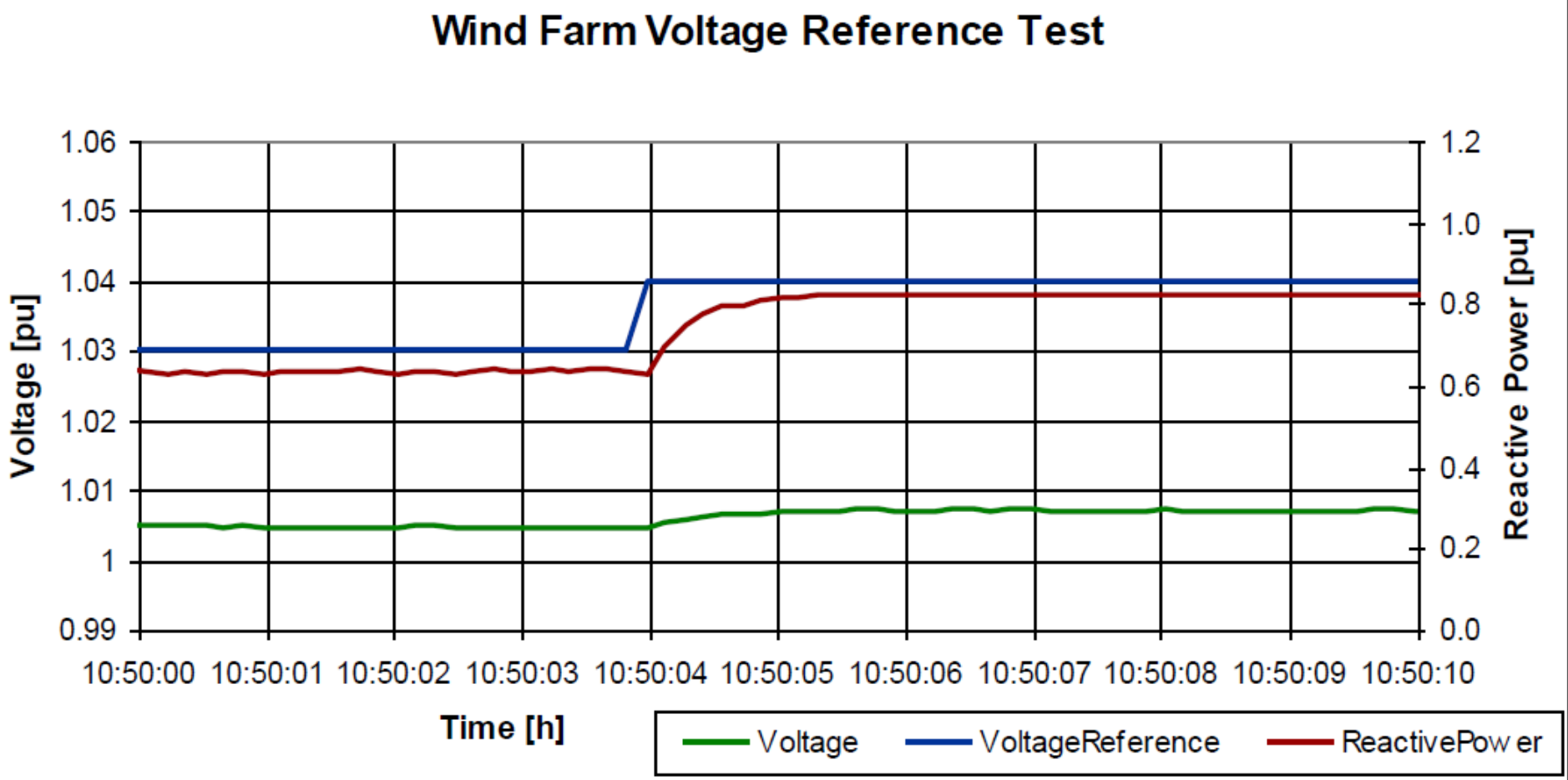
Full-converter WP

Note: neglects WP charging.

Similar capabilities near rated voltage, but

- **The synchronous generator has a narrower operating voltage range and less capability above 100% system voltage.**
- **The WP has a wider control voltage range and is superior for very high transmission voltages (above 1.0 pu, and particularly above 1.1 pu, where the synchronous generator is incapable of providing voltage support).**

Voltage control: Fast response to change in reference



Wind plant response very comparable to synchronous generator response.
WTG response very similar to excitation system response.

Summary – How Full-Converter WTGs provide Reactive Power Control

Capability	*Now*	*Possible*
Voltage Regulation with reactive droop	Y	
Medium Voltage	Y	
Transmission Voltage	Y	
Reactive Power Control	Y	
Power Factor Control	Y	
Voltage Reg without Active Power Production	Y	

What Are Common Active Power Control Requirements

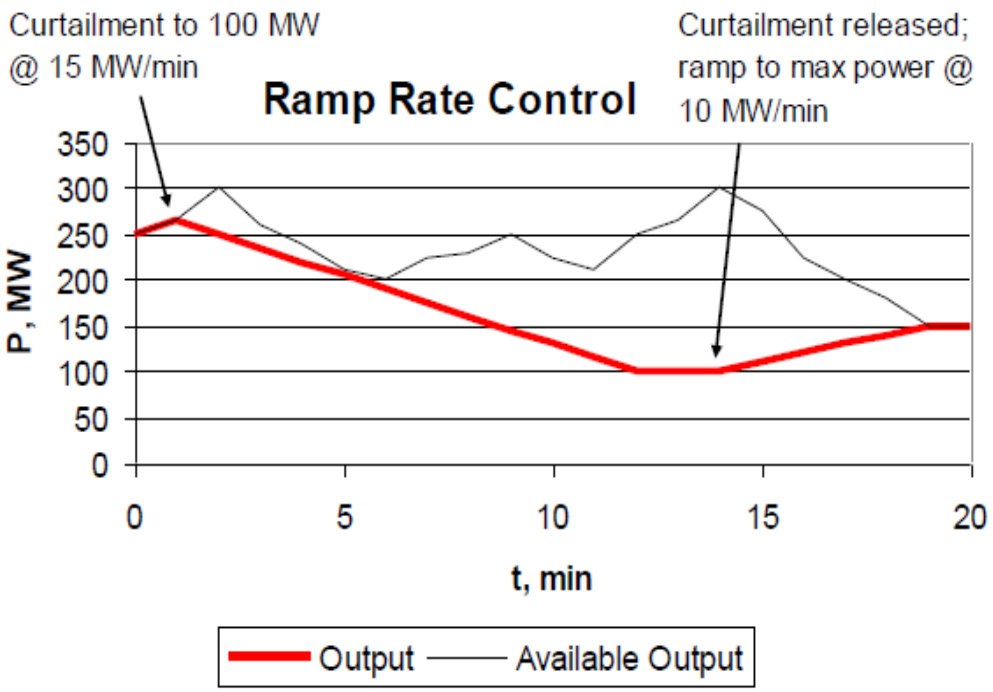
Existing:

- Power Output (Curtailment) Control
- Ramp Rate Control
- Curtailments
- Start-up
- Regulation Up for Underfrequency
- Adjustable Droop
- Regulation Down for Overfrequency
- Adjustable Droop
- Low Voltage Ride Through
- High Wind Ride-Through
- Rate Variation Control

Ramp rate control - smooth, controlled transition from one output level to another

Some system operators require ramp rate control to smoothly transition from one output level to another during curtailments.

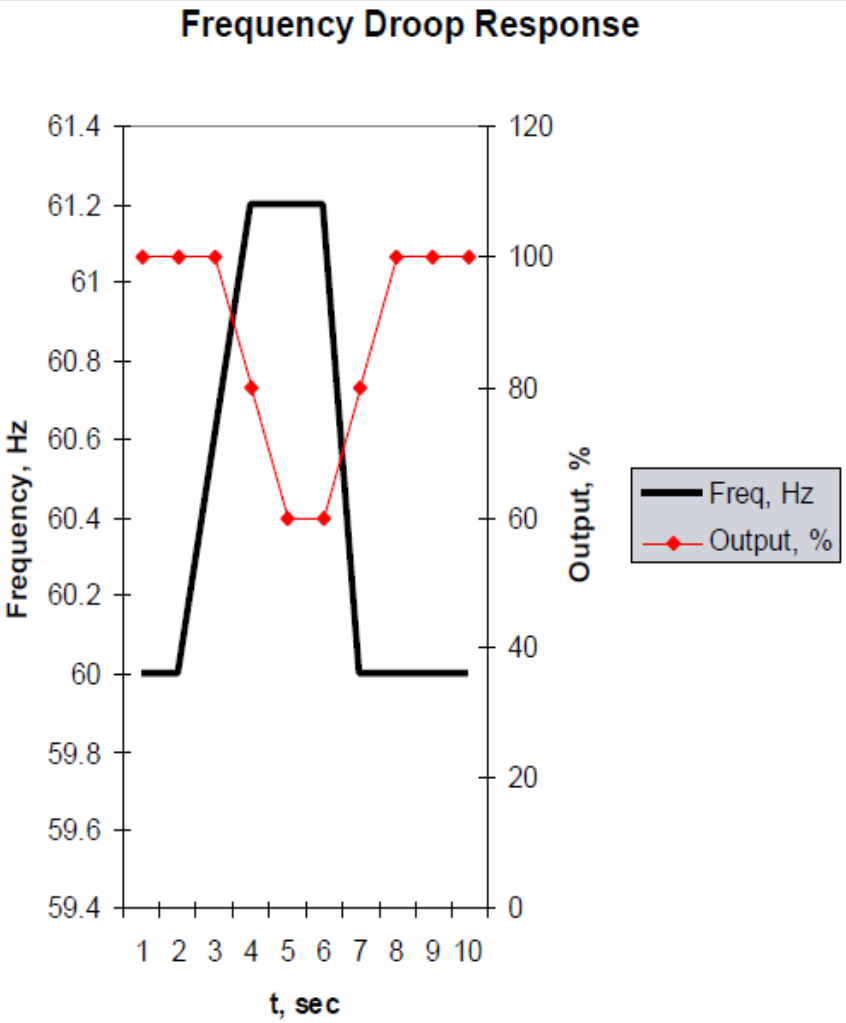
- Ramp-rate control is available in wind plants at rates of 10%/sec and slower.
- Can select any ramp rate (%/min MW/min, MW/sec, etc.), in range, assuming availability of adequate wind power



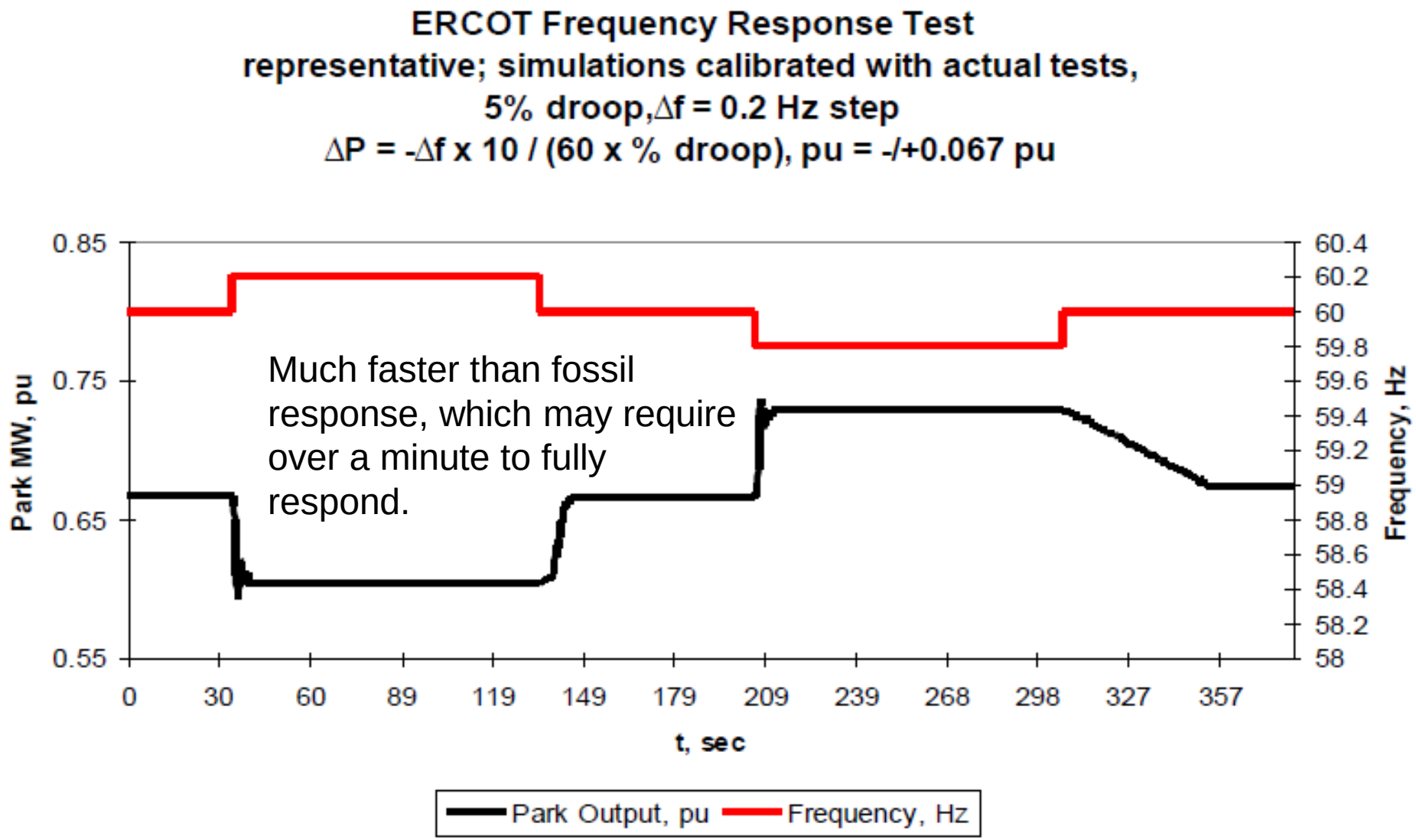
Frequency Droop Control - Primary Frequency Response

Some system operators require the use of frequency droop response from wind parks

- Normally constant (5%) frequency droop (5% change in freq → 100% change in output), but variable droop sometimes required (e.g., larger droop for small frequency excursions, smaller droop for larger excursions).
- Both reg up (underfreq), assuming curtailed state, and reg down (overfrequency) required.
- Sometimes conflicts w/ curtailments, Special Protection System operations.

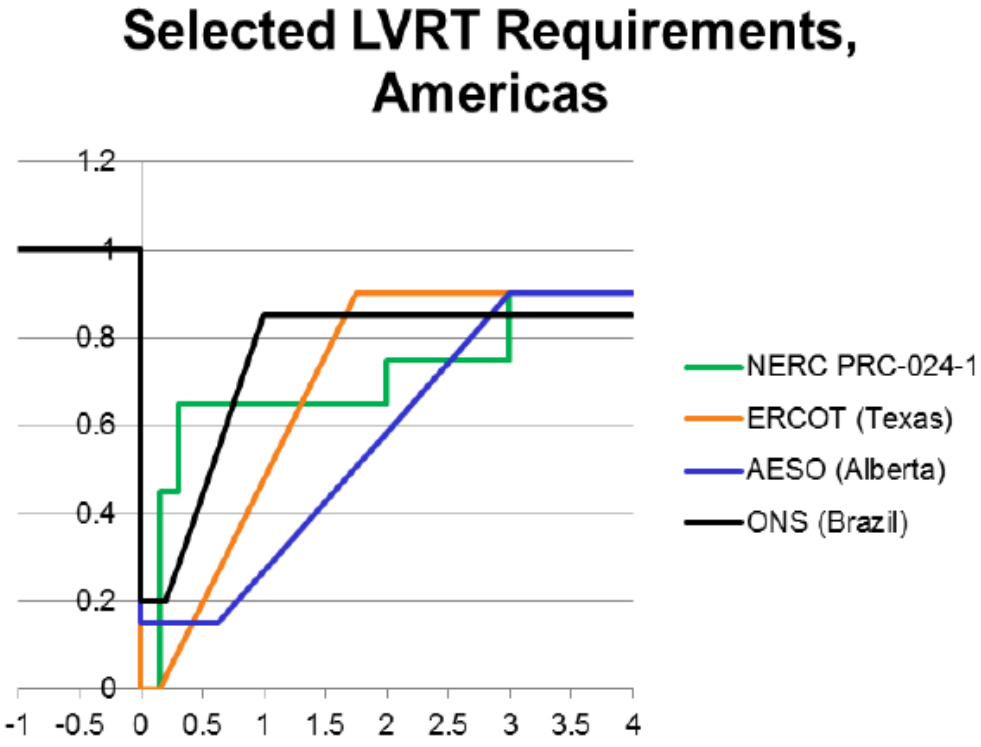


Frequency response – Simulations calibrated with test in Electric Reliability Council of Texas (ERCOT)



Low-voltage ride-through (LVRT)

- Requirements vary, but typically impose need for turbine to withstand extended (several second) low-voltage event (see below for most severe known requirements in North and South America)
- Wind turbine generators must conform to major LVRT requirements in Americas (e.g., ERCOT, proposed NERC PRC-024-1, most Canadian provinces, Brazilian ONS, Mexican CFE, etc).
- NERC PRC-024-1, recently passed, will apply to all large generation plants (wind, fossil, PV, etc).



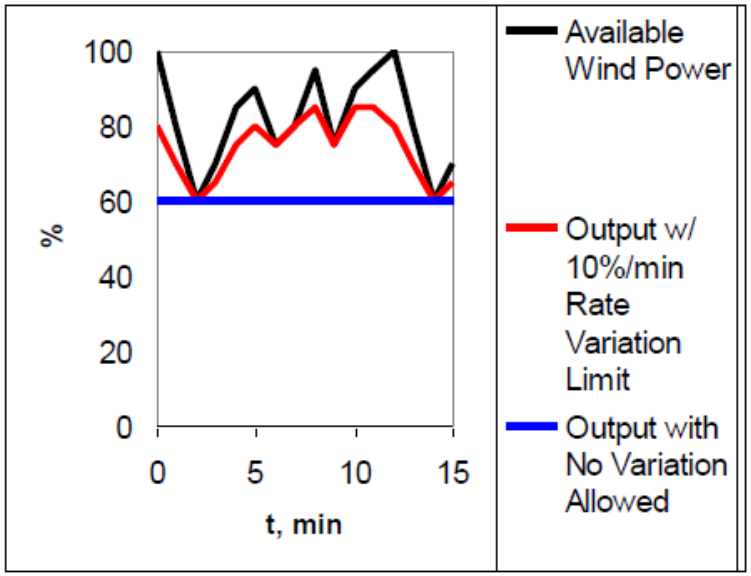
Rate Variation Control

Control of output power change, e.g., “no more than 10% change per minute”

Since electric power varies as cube of wind speed, rate variation control requires operation at reduced output power levels during conditions when wind speed varies or use of energy storage.

Controls typically assume persistence and use recent history to set output.

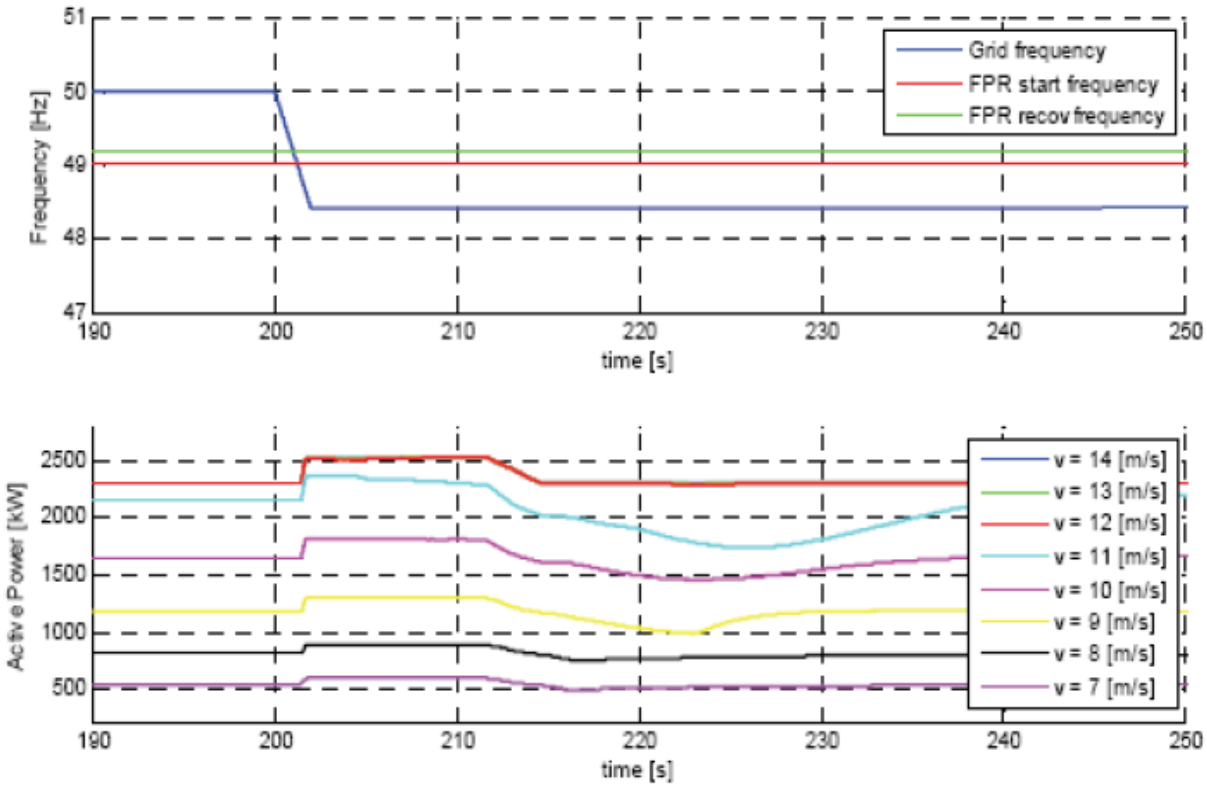
Seldom used.



Transient underfrequency response (“inertial response”)

Rapid response required after sudden frequency drop – necessary to forestall load shedding, especially on island systems

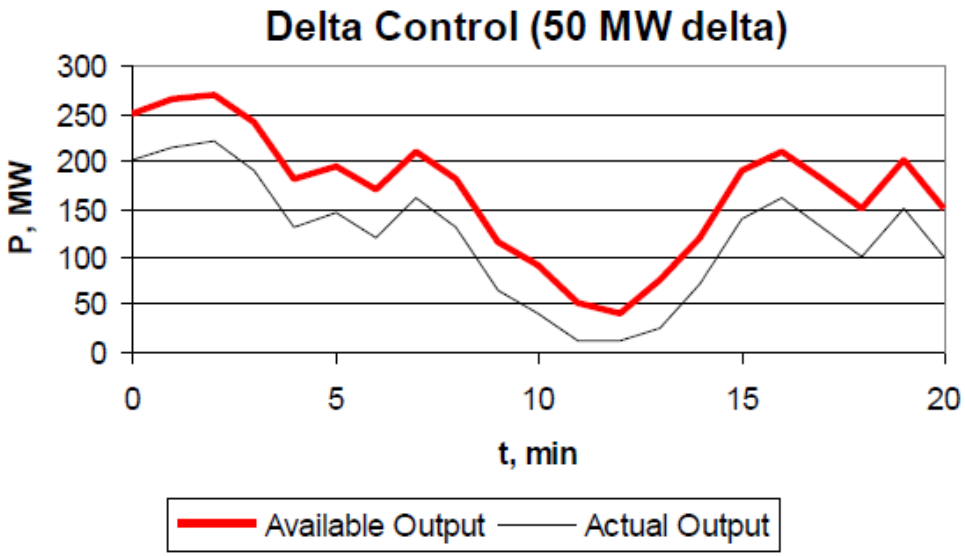
Industry is developing new controls to address this need



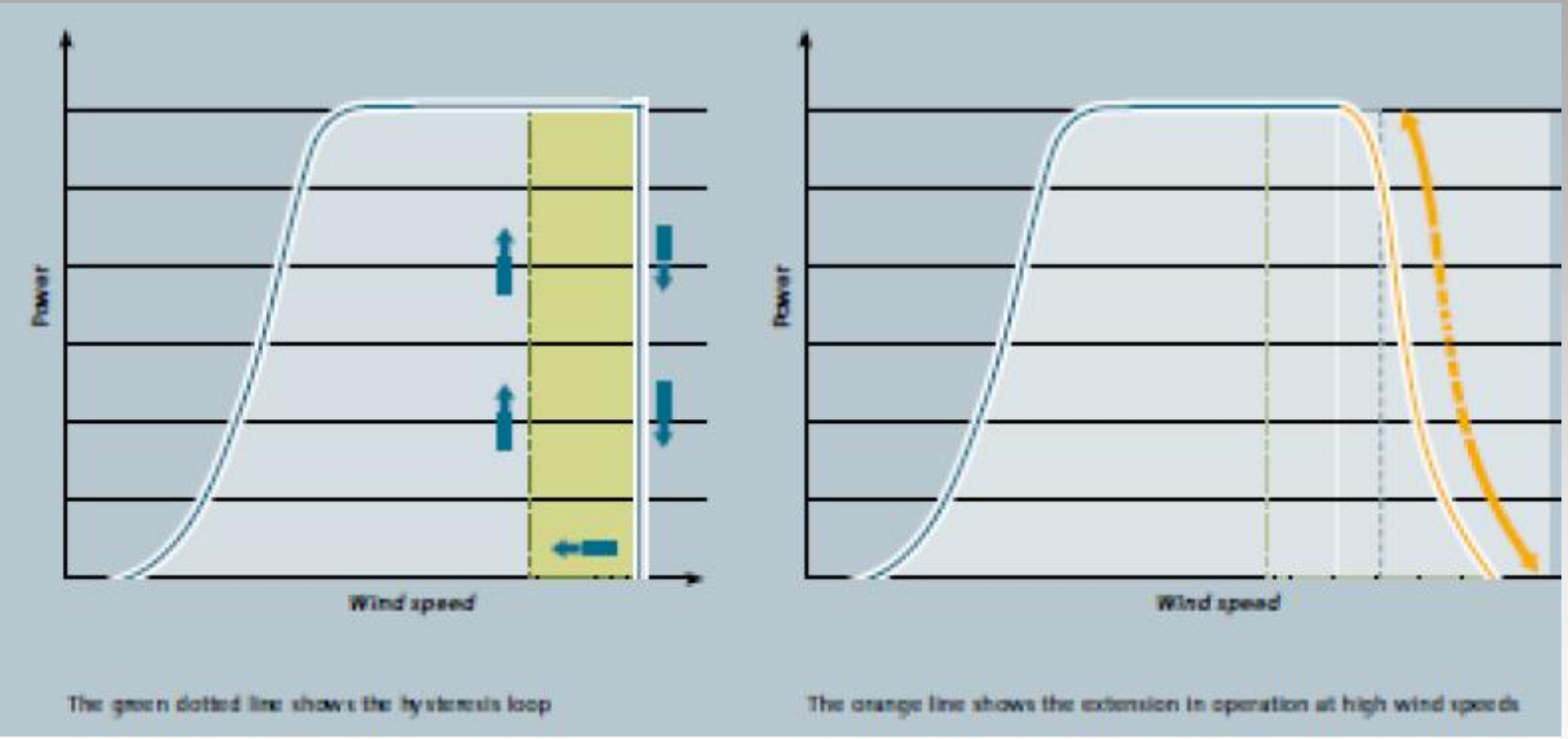
Delta control – operate with a constant delta below maximum output

Some Transmission Operators are considering the use of wind for regulation up and spinning reserve duty at some times of the day to release fossil capacity.

- Requires "spilling wind," but may be the least expensive way to provide capability
- Can select any delta (MW) assuming availability of adequate wind power
- Similar in concept to spinning reserve function for fossil units



High Wind Ride Through (HWRT)



High wind speeds (above 25 m/s) caused widespread tripping in the past;

Summary – How FC WTGs provide Power Control (existing and anticipated)

Capability	*Now*	*Soon*
Power Output (Curtailment) Control		
Ramp-Rate Control (ref change and startup)		
Frequency Droop Regulation Up		
Frequency Droop Regulation Down		
Frequency-Dependent Droop		
Spinning reserve ("delta control") capability		
Transient underfrequency ("inertial") response		
High wind ride-through		
AGC Response (from Park RTU)		
Rate Variation Control		

Modeling for power system analysis

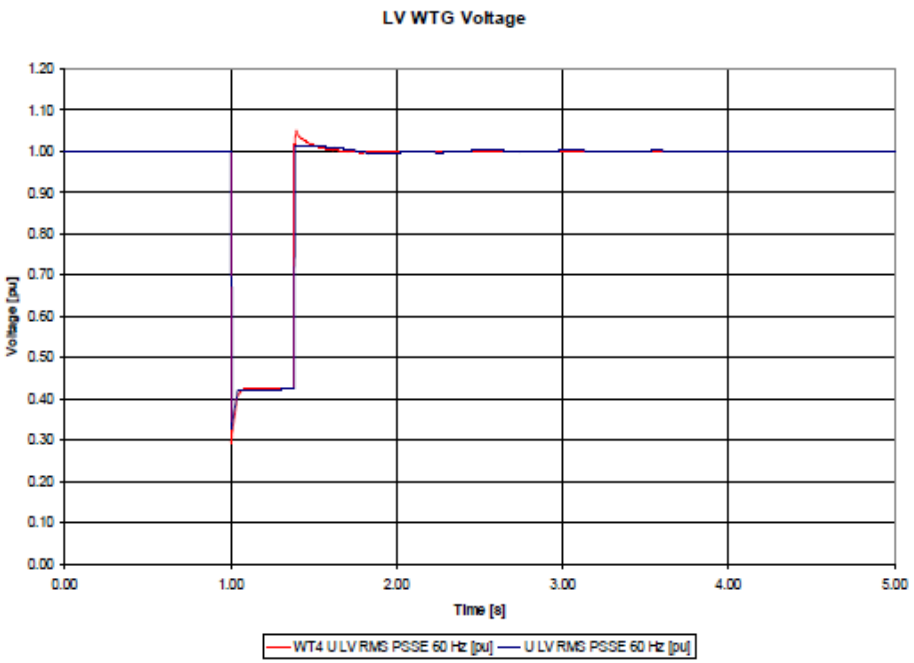
Dynamics models available in major simulation platforms

- Generic (library) – simple models for interconnection studies, contingency assessments, etc. (PSS/E, PSLF, ETAP, etc.)
- User-defined – more detailed models for optimization, in-house studies, etc. (usually selected packages that are widely used, like PSS/E, DigSilent)

Transient models

Detailed equipment specific time domain – for protection coordination, insulation coordination, subsynchronous resonance assessments, special protection schemes, etc. – now available in selected packages (e.g., PSCAD, NETOMAC).

PSS/E LVRT Benchmark Simulation



Type 3 WTG Fault Performance

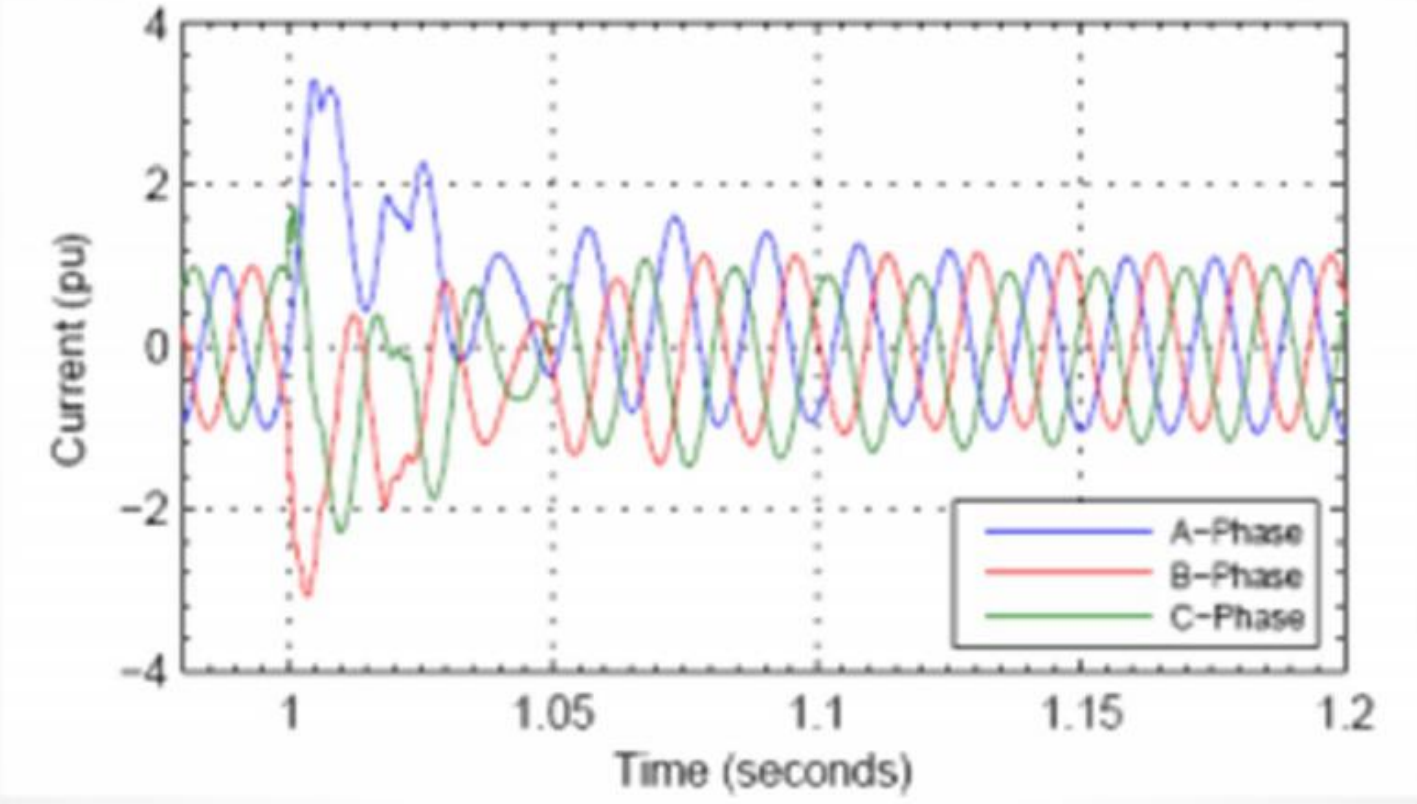
- Fault current in stator “feeds back” to overdrive the converter
  - Dc link voltage would be driven to excessive value unless mitigating action taken
- Type 3 WTGs have some sort of “crowbar” functionality to protect the converter; in the form of:
  - A shorting device on the rotor terminals – may be thyristor switched and may have some added impedance
  - Bypassing (shorting) of the rotor using the rotor-side converter bridge
  - Thyristor-switched chopper circuit resistor on the dc bus
- Crowbar is activated during faults exceeding a severity threshold – faults in, or very near wind plant for some designs
- Crowbar may be remain activated until fault clears, or may be removed during the course of a moderate fault
- Severity thresholds vary substantially with design

Type 3 WTG Performance During Crowbar Activation

- A doubly-fed generator effectively becomes an ordinary induction generator (i.e., like Type 1) when crowbar is on
- Performance defined by machine's flux equations
- But, with differences:
  - Type 1 and 2 induction generators operated with a few percent slip
  - Slip may be large with a DFG
  - Consequently, fault current may be at a substantially different frequency than grid frequency (~ 80 Hz for a DFG operating at +30% speed before fault; 40 Hz for one operating at -30% speed)
  - Inserted crowbar resistance (if used) can make fault current ac decrement much faster than dc decrement; resulting in no current zeroes for a number of cycles for close-in faults

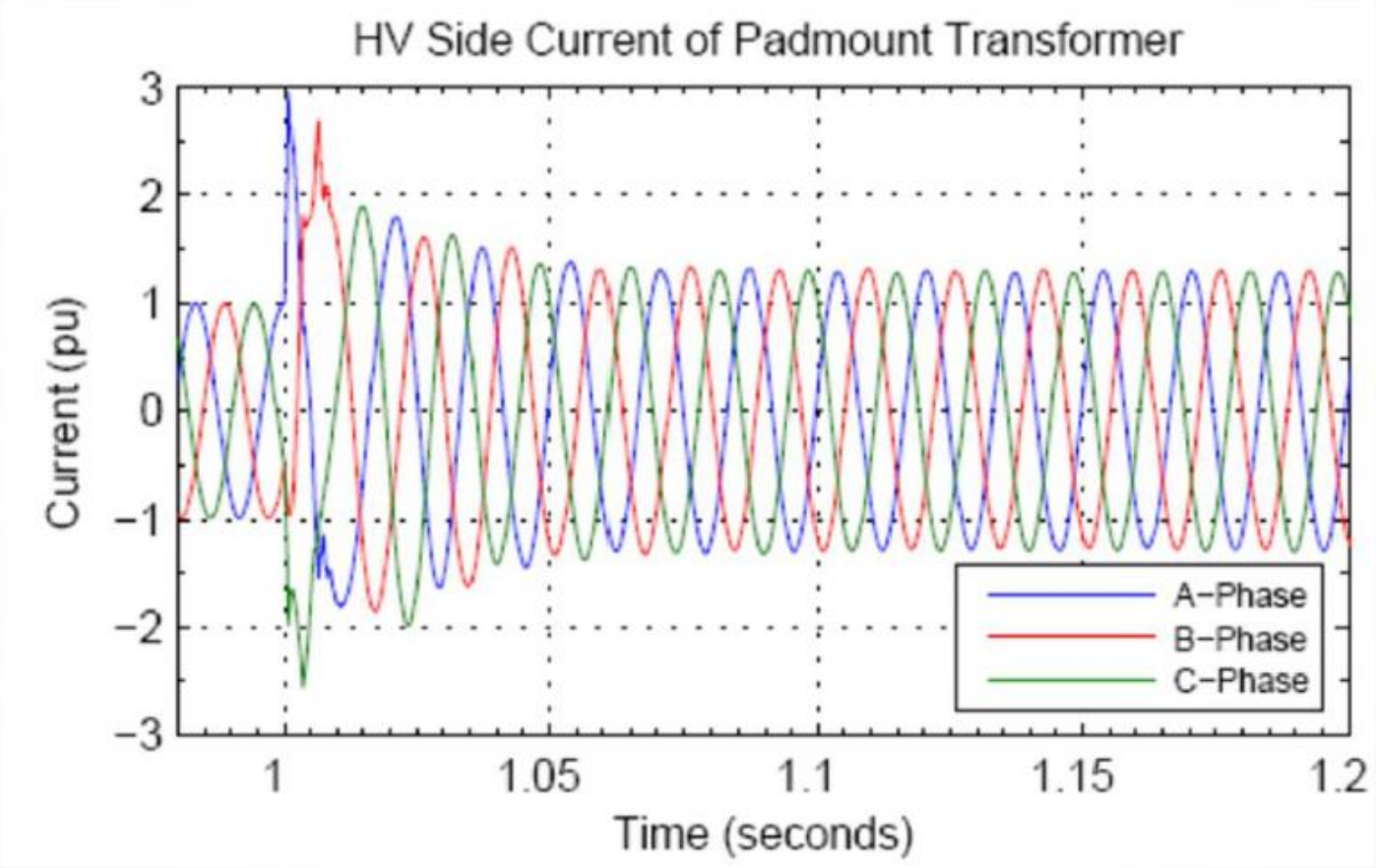
Example Type 3 Performance

- Three-phase long-duration fault to 20% residual voltage at WTG MV terminals



Crowbar on only for first 2-3 cycles of fault

Typical Type 4 WTG Short-Circuit Current Collector 3-Phase Fault



Model Limitations

- A wind plant may have any number of WTGs on line at any instant
  - Short-circuit current contribution variable from near zero (one WTG) to N times per-turbine maximum contribution
- Worst-case current for a Type 3 wind plant is the state with solid crowbarring
  - This condition can be sufficiently modeled using conventional voltage behind reactance (typically ~0.2 p.u. on WTG base + xfmr Z)
  - Does not factor in the off-nominal frequency of the contribution
- Type 4 max current is reasonably well defined
  - Use software with current-limited source capability, or
  - Iterate source impedance to bring current to the max value
  - Use infinite negative sequence impedance if design blocks negative sequence current
  - Consider defined current output vs. residual voltage specified by applicable grid code fault ride-through performance (not in North America, except where WTG is designed for compliance to overseas grid codes)

Comparison of FC WTG with Synchronous Generation to Comply with Interconnection Requirements

	Variable Speed Full Converter (FC)	Turbine-driven synchronous generator (SG)	Comments
Fault Ride-Through (Zero- and Low-Voltage)	YYY	Y	SGs may have fault clearing times as short as 6 cycles (0.1 sec) before instability. FCs can withstand for extended periods – theoretically forever.
Fast Dynamic Voltage Regulation	YY	YYY	SG is still the "gold standard". FCs are very comparable, but generally have more impedance to system. FCs can have issues in very weak (low sc strength) systems.
Fast Active Power Regulation and Frequency Response	YYY	YY	FC has fast, precise converter response. Can change output power at 10%/sec or more. SGs are limited by turbine ramp rates – generally an order of magnitude slower – 10% per minute or slower.
Short Circuit Current	YYY	X	FC sc contributions are roughly 1-2 pu after 3 cycles. SGs can have sc over 6 pu, with large dc offsets.
Ability to operate in series capacitor-compensated system	YYY	X	Sub-Synchronous Resonance (SSR) is a major problem for synchronous machines; FCs generally immune to SSR concerns.
Abnormal Frequency Operation	YYY	Y	SGs generally have +/-2% continuous range; some have far less. FCs have much wider continuous range.
Generic Model Availability	YY	YYY	Wind Turbine models are new, still have some bugs. SG models are well-established by long usage.

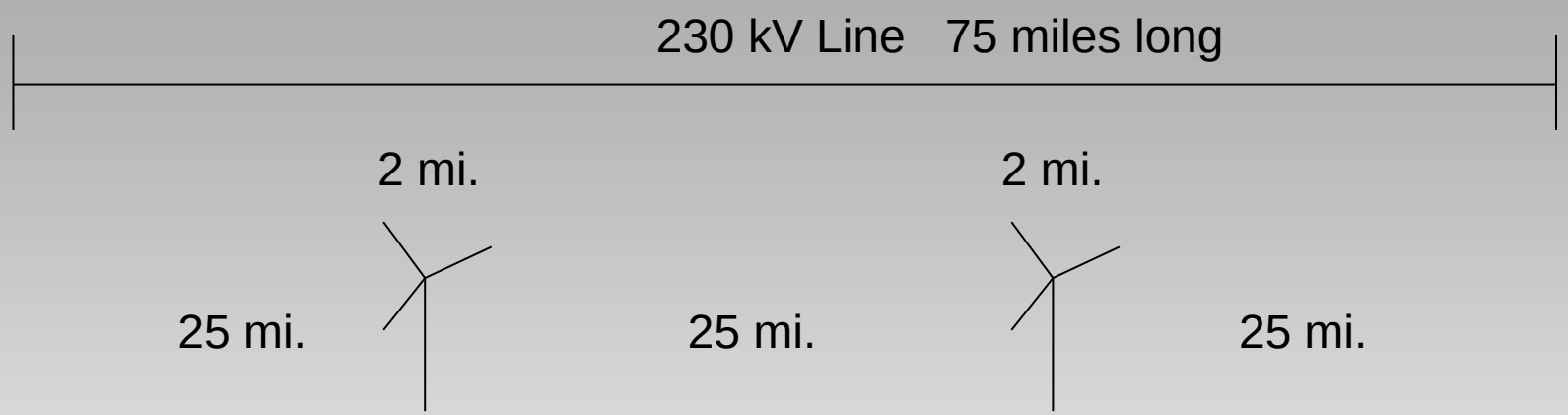
X = Capability generally not available w/o supplemental equipment

Y = Generally OK, but shortfalls in some apps YY = Generally acceptable YYY = Excellent

Future Developments (Present Weaknessess)

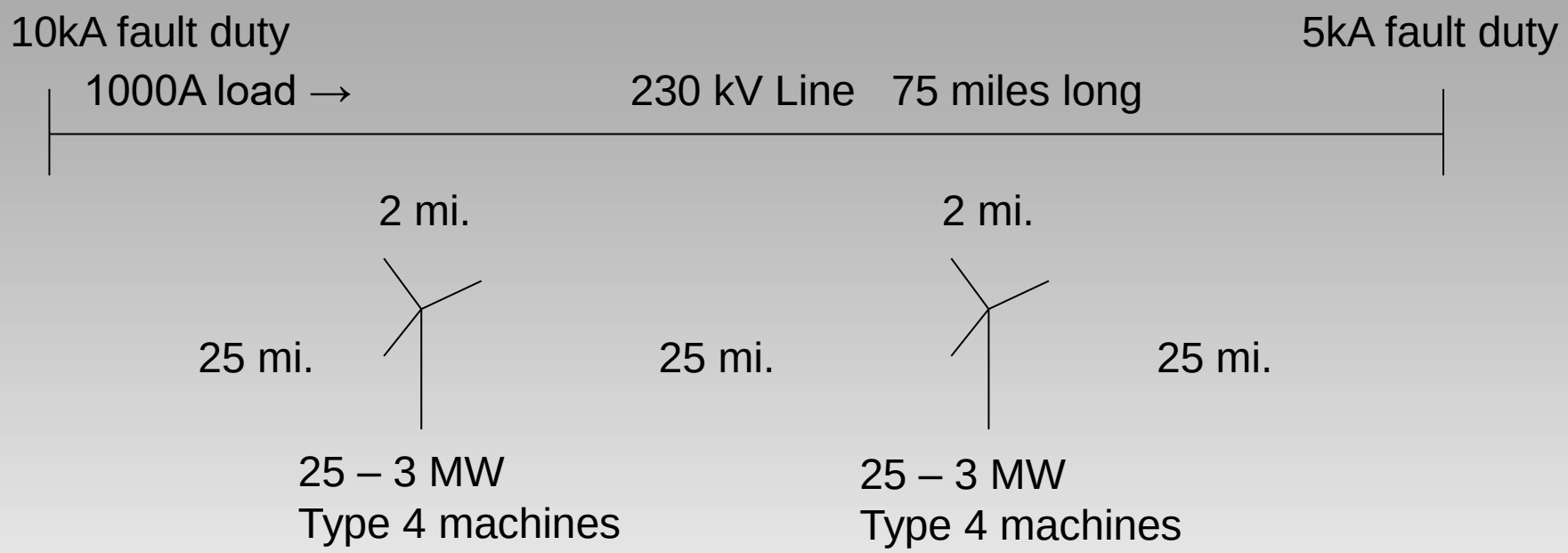
- Weak grid controls for sustained stable operation in systems with SCR < 3 (SCR = 3-phase short circuit MVA at regulation point / aggregate turbine MW)
- Power oscillation damping for inter-area power oscillations.
- Sub-synchronous resonance damping for series compensated systems
- Isochronous operation – standalone operation These are capabilities that can presently be provided by synchronous generators.

Protection Design Excercise

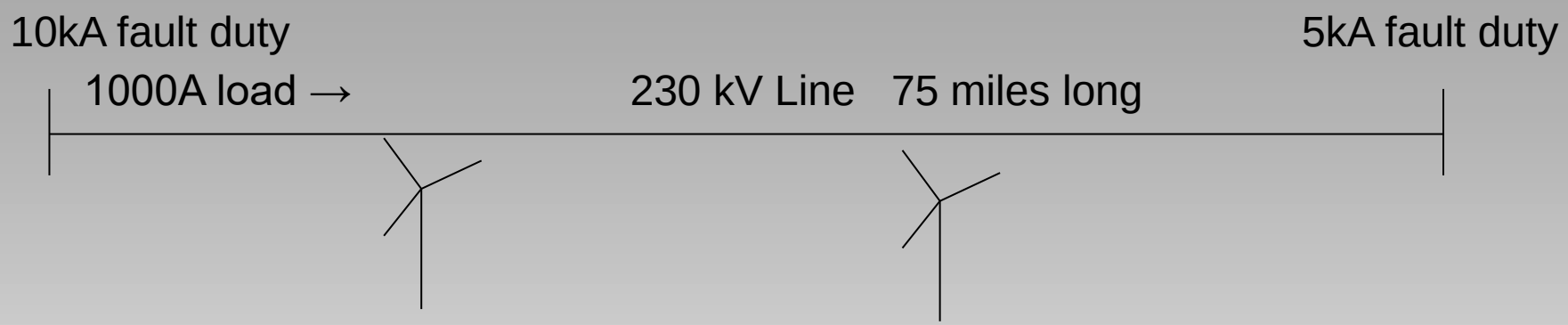


Assumptions:
$200,000 per installed 230 kV breaker
$100,000 + $10,000/MVA for installed transformer
$25,000 per installed 34.5 kV breaker
$150,000 per mile 34.5 kV line
$10,000 per mile for fiber
$50,000 per microwave link
$20,000 per installed relay

Protection Design Excercise



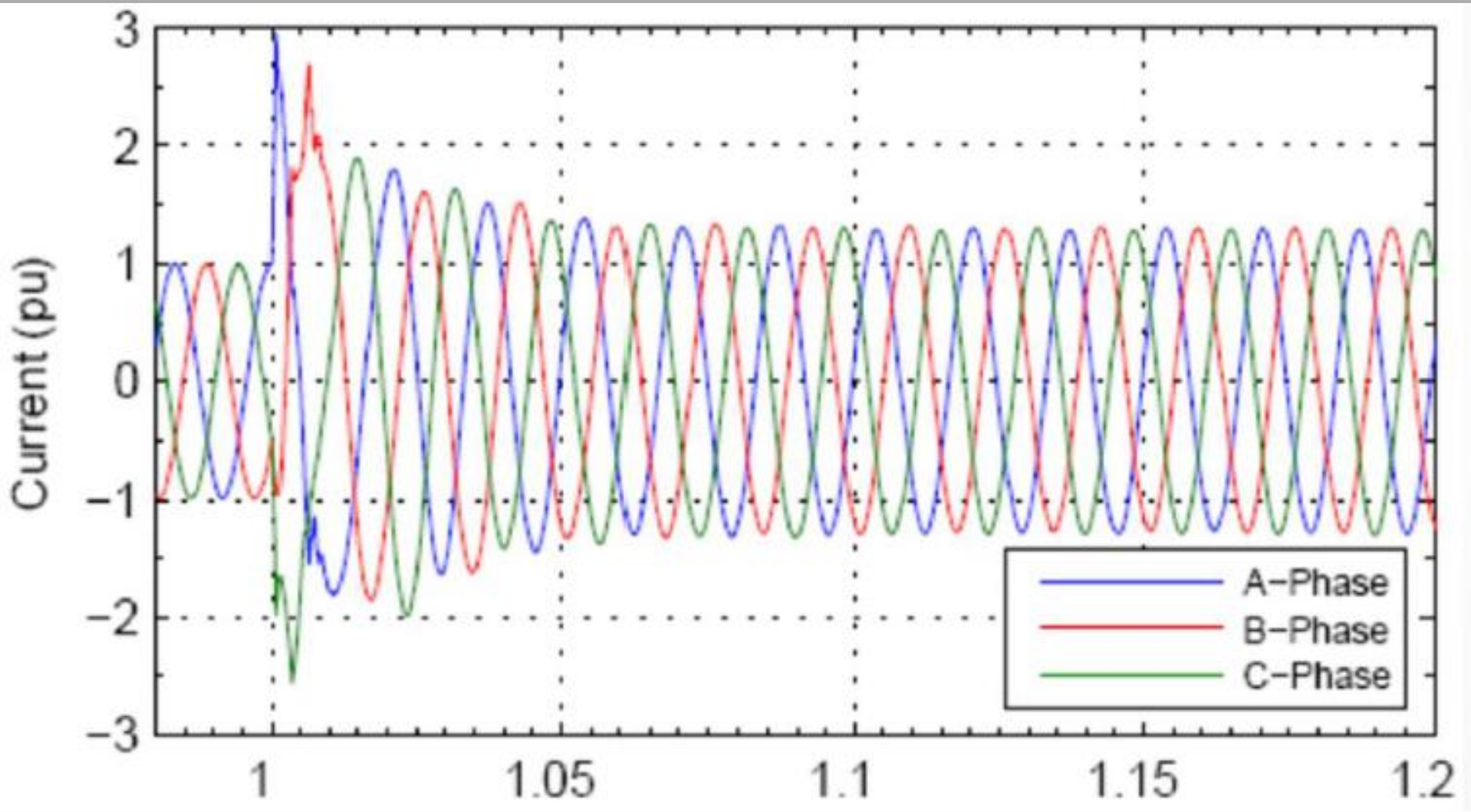
Considerations



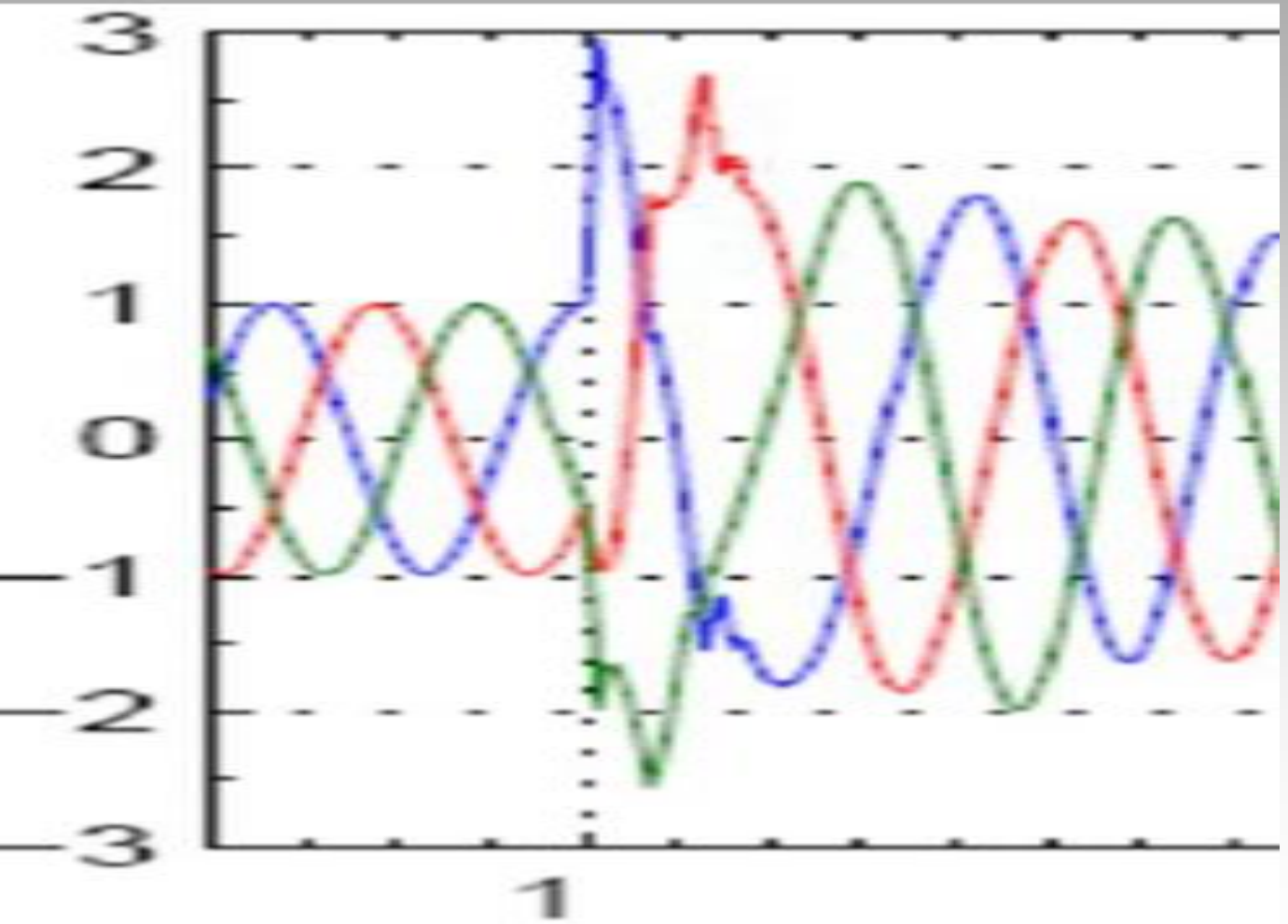
- Distance Relays have been shown to have unreliable reach if wind machines are radial due to SubSynchronous factors
- Line Current Differential can go up to 6 terminals
- Infeed is unreliable from wind farms (overcurrent complications, distance reach trouble)
- How much added fault “exposure” is being added, compared to the total line length?

Each generator has its advantages and disadvantages, but Full Converter WTGs generally have many advantages and few major disadvantages. If we could only control the wind…

Protection Considerations



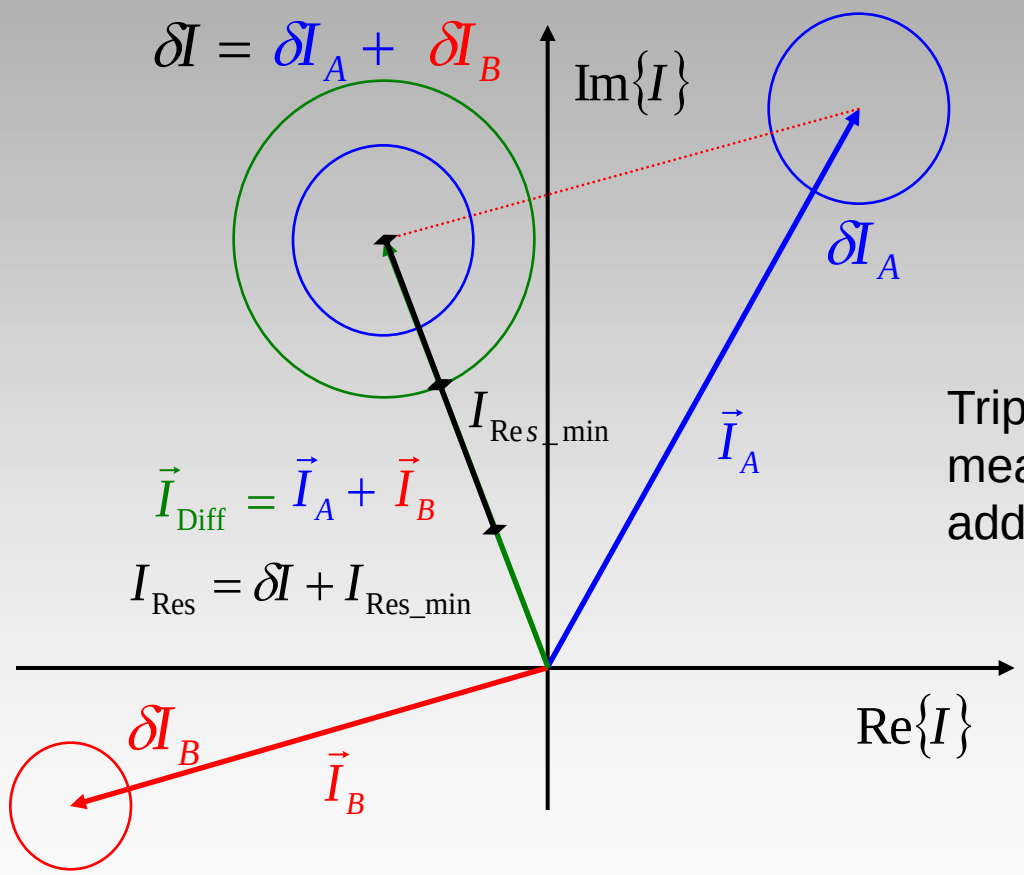
Distance Relay with Inverter Current



IZ-V_{op}

V_{pol}

Current Differential

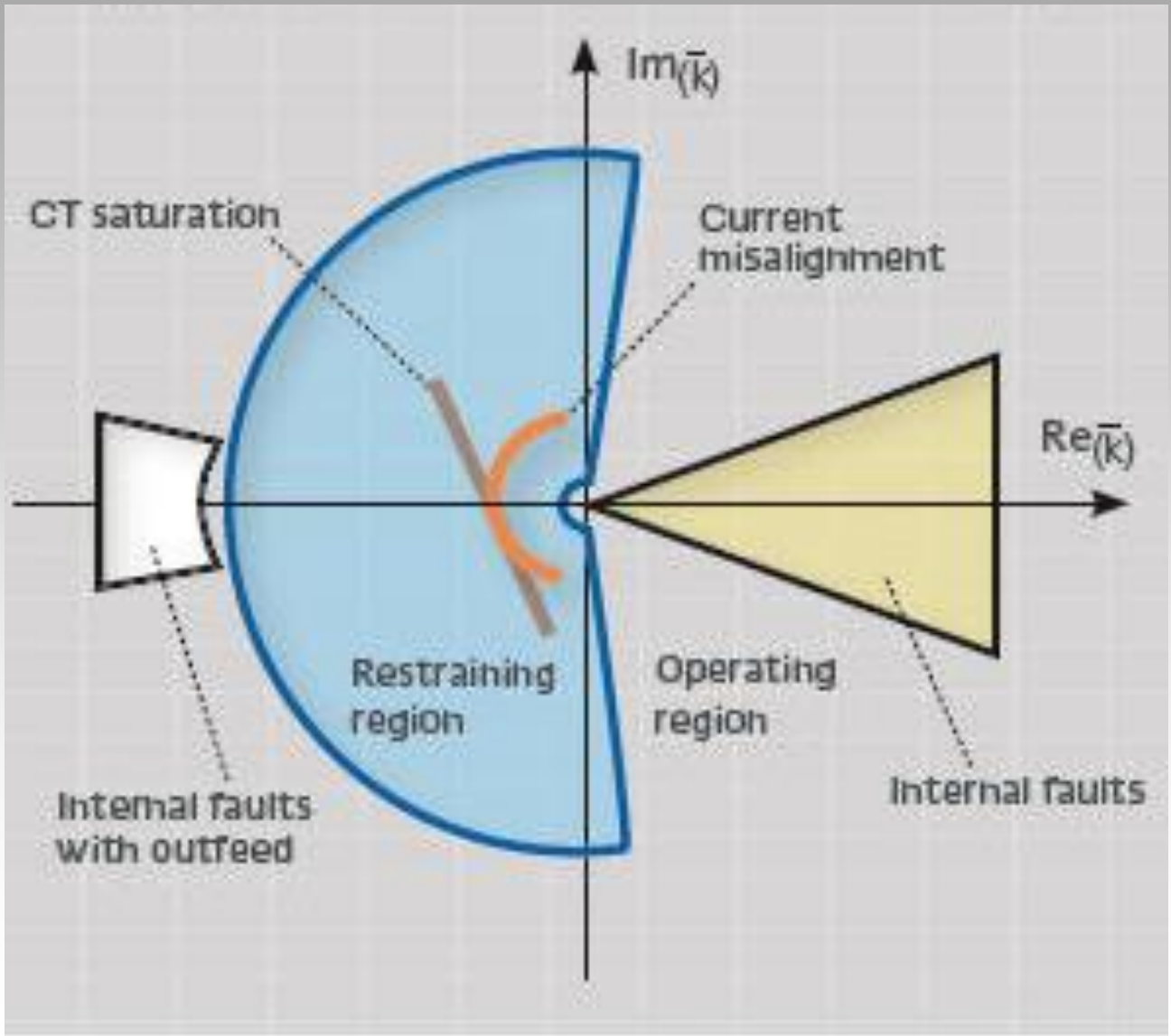


each δI is the summation of:

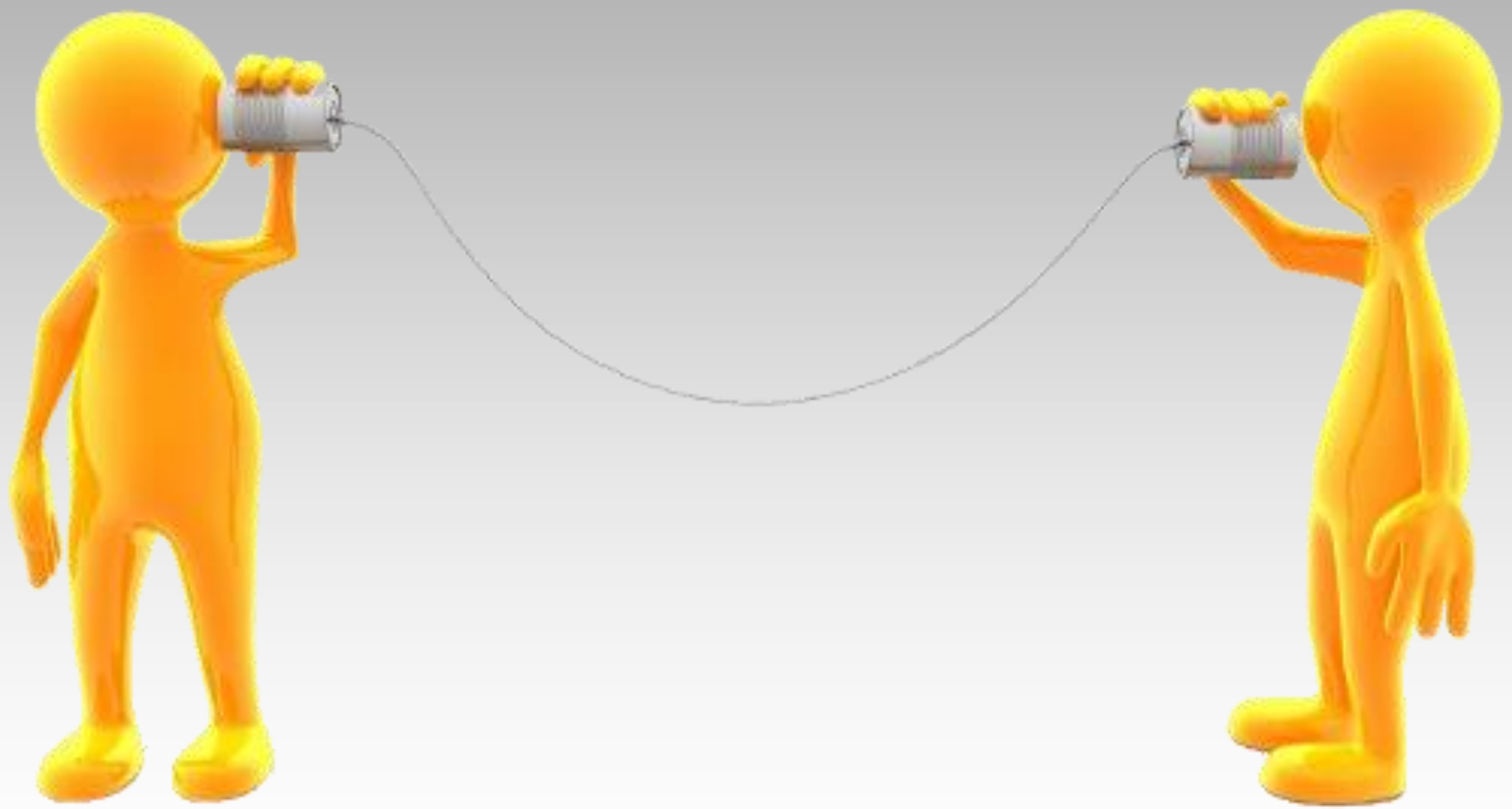
$\delta I_i = \delta I_{CT\text{-}Err.} + \delta I_{Signal\text{-}Err.} + \delta I_{Sync\text{-}Err.}$

Trip if differential current exceeds sum of measurement errors
added by safety margin I_{Res_min}

Alpha Plane Current Differential



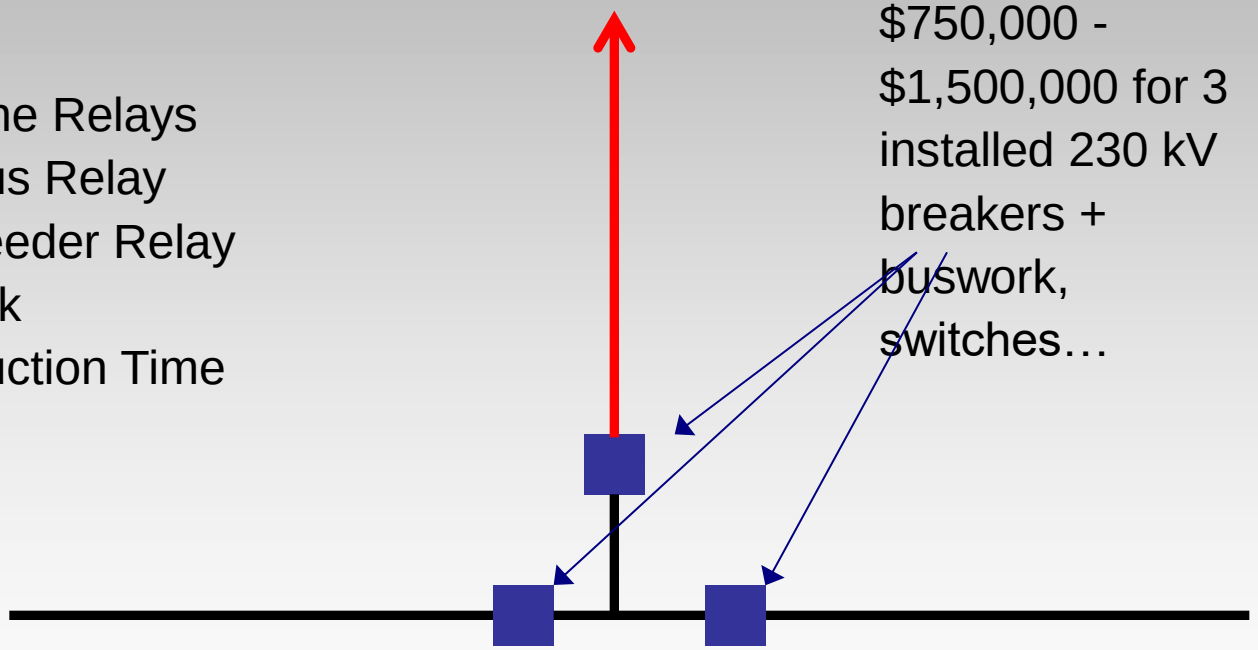
Differential More Secure but Adds Communications



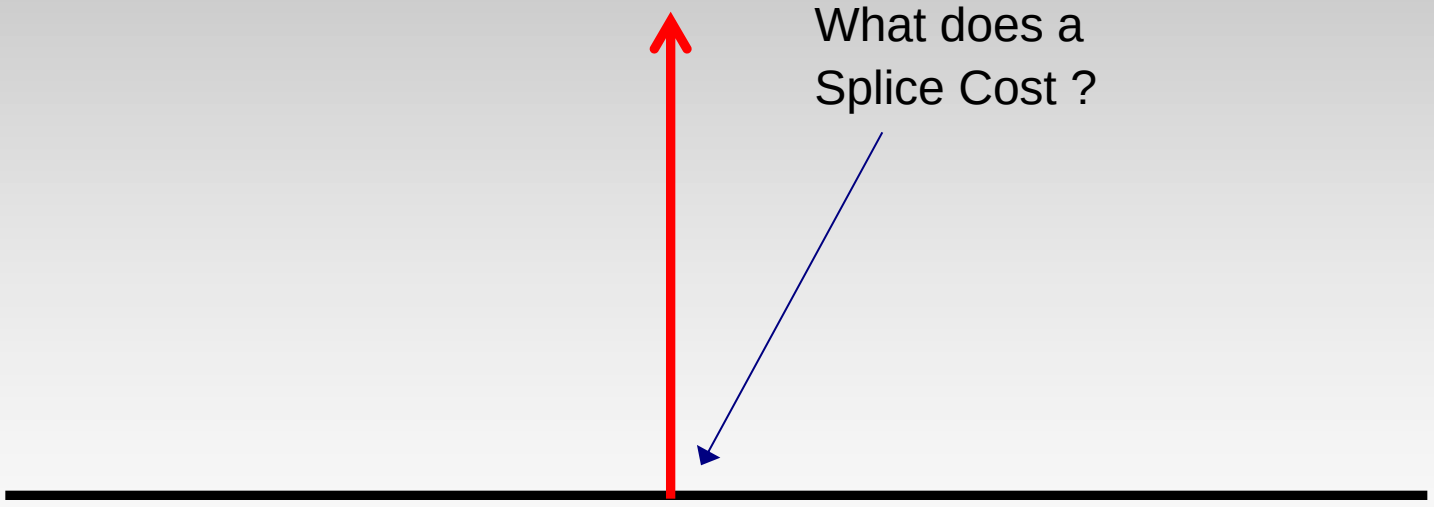
Let’s Calculate the Business Case of Tap versus Substation

Plus –

- New Line Relays
- New Bus Relay
- New Feeder Relay
- Buswork
- Construction Time

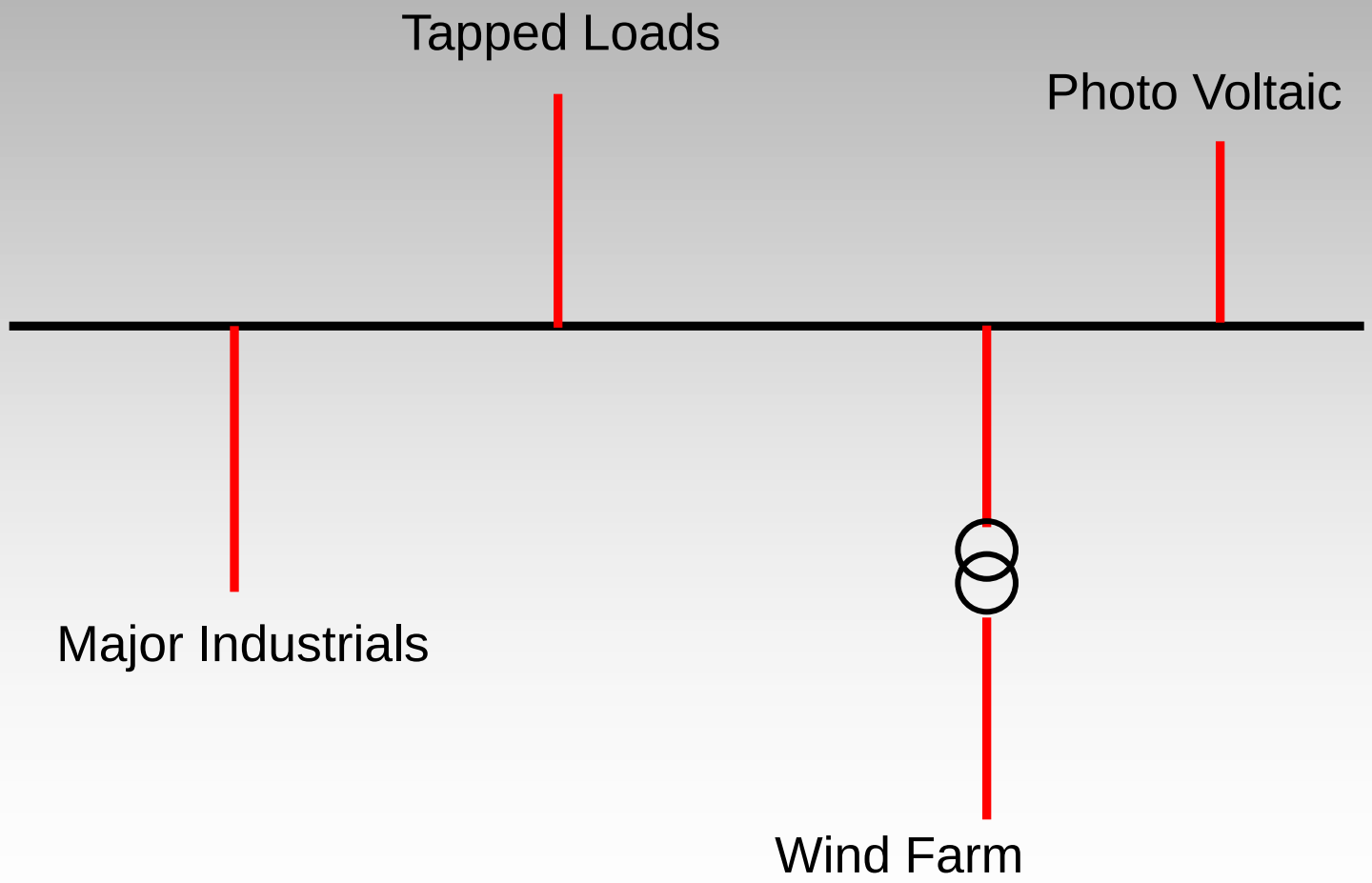


Look at Business Case of Tap –vs- Substation

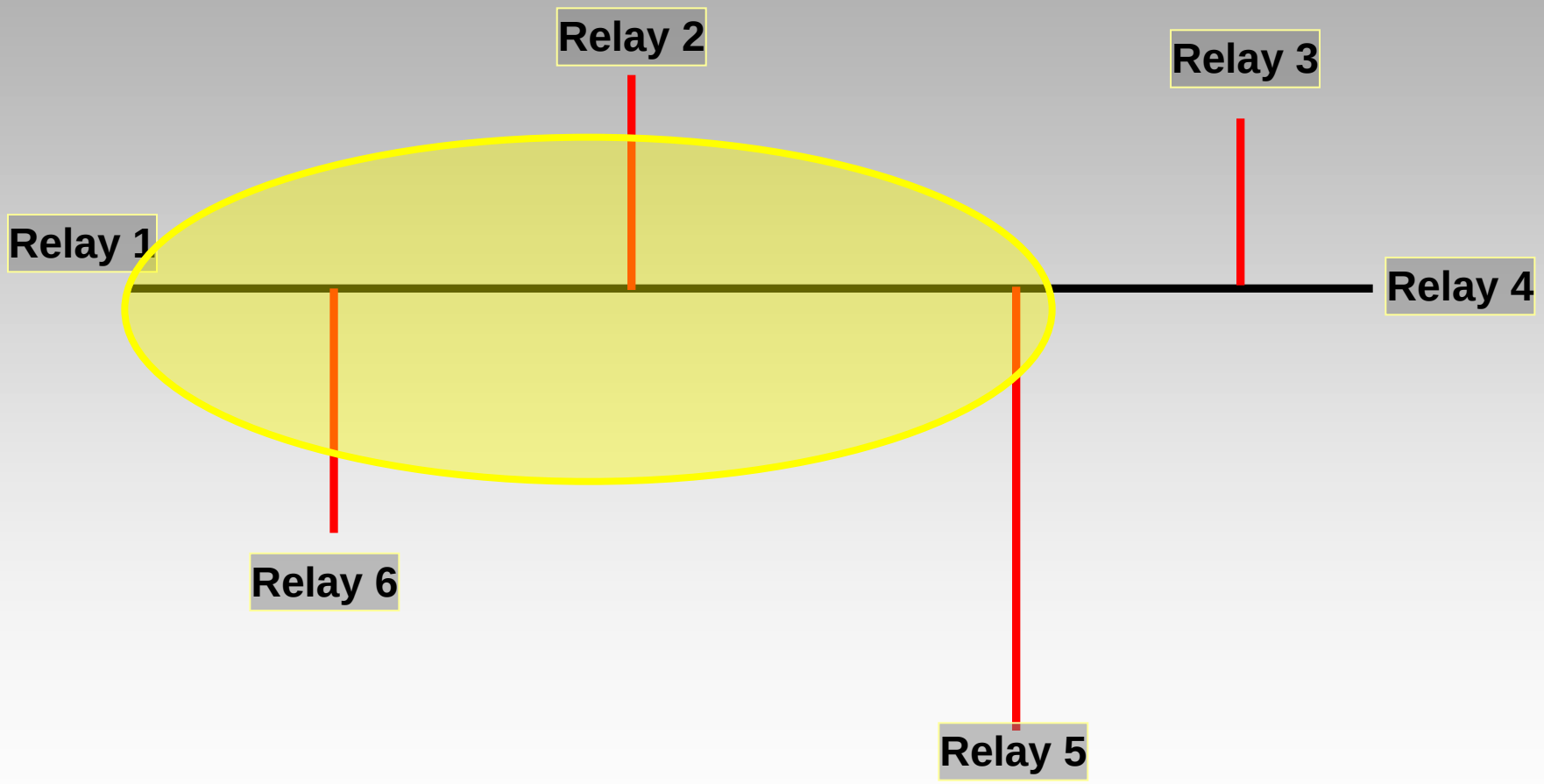


Provisos, Limitations, Exclusions…

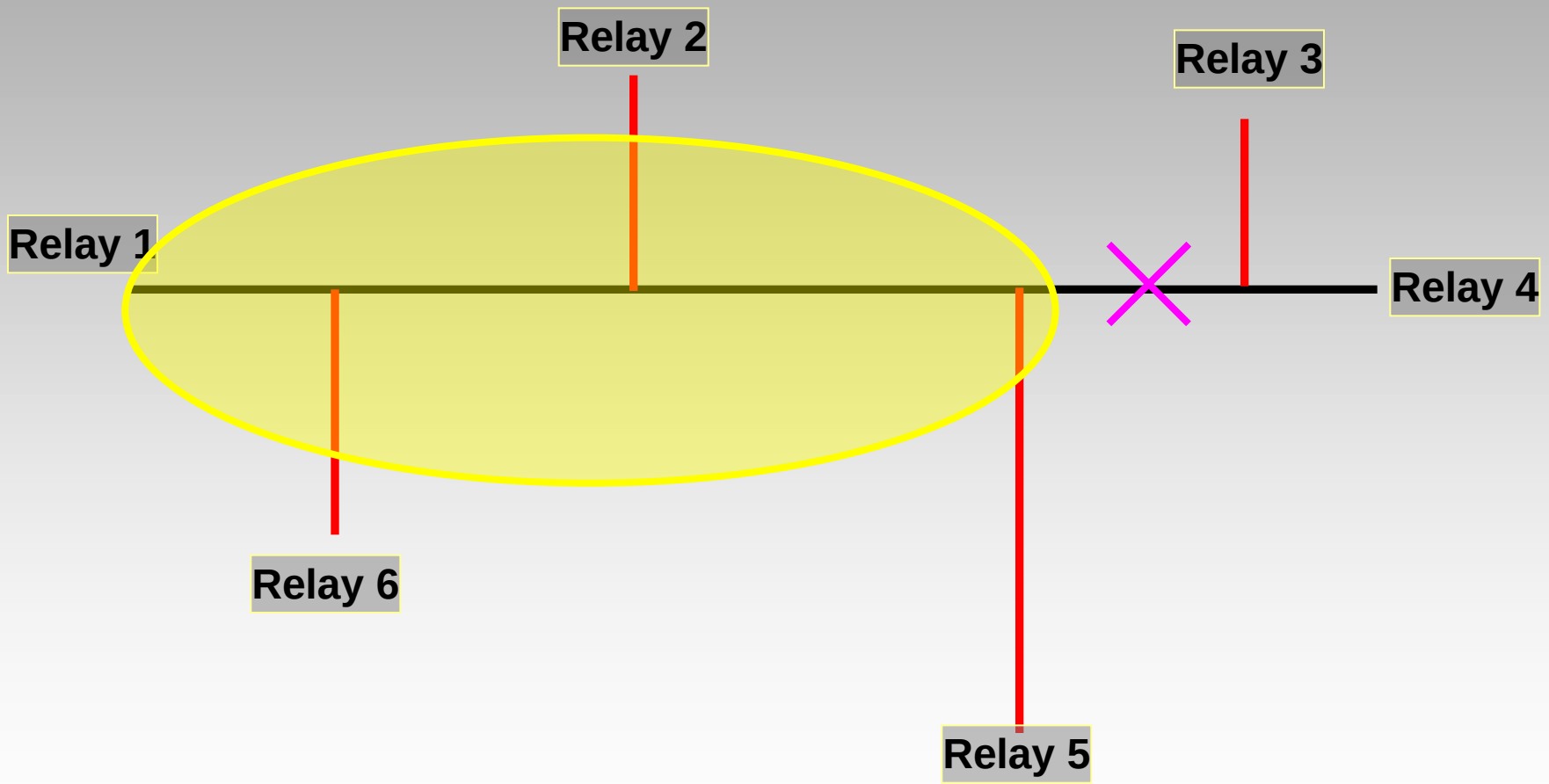
Up to 6 Terminals, 64kbps Channels to Each Relay



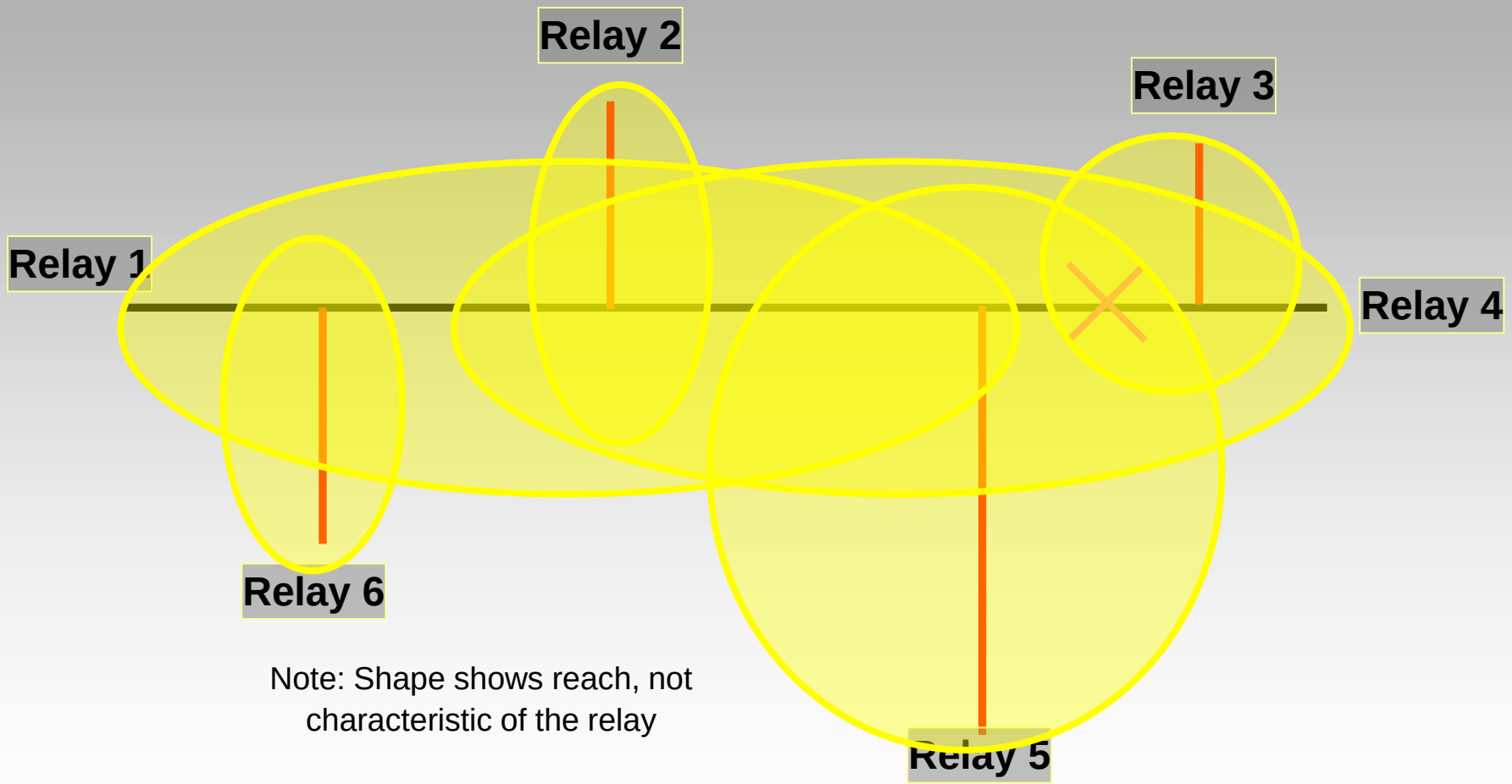
Apply Built-in Distance for Backup



Set Reach to Inside Line With Maximum Infeed – But What About Faults Beyond That ?

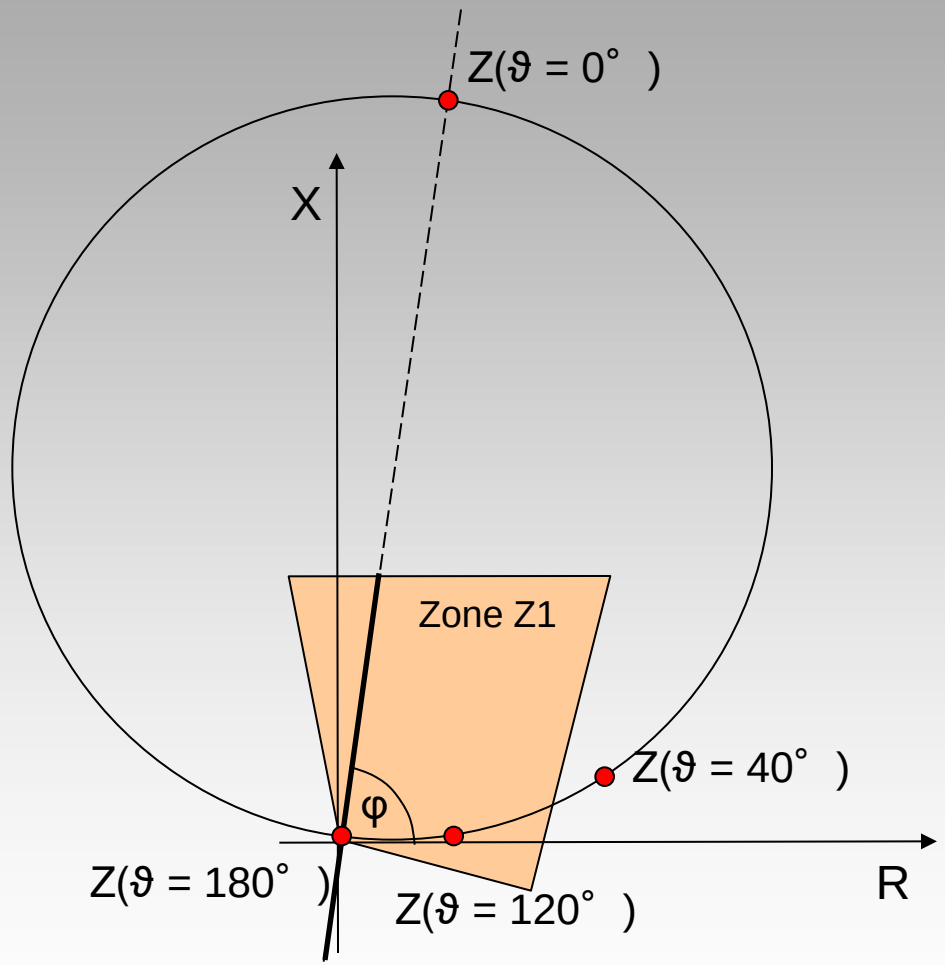


Sequential Tripping Clears Strongest Source First – Best Stability Response



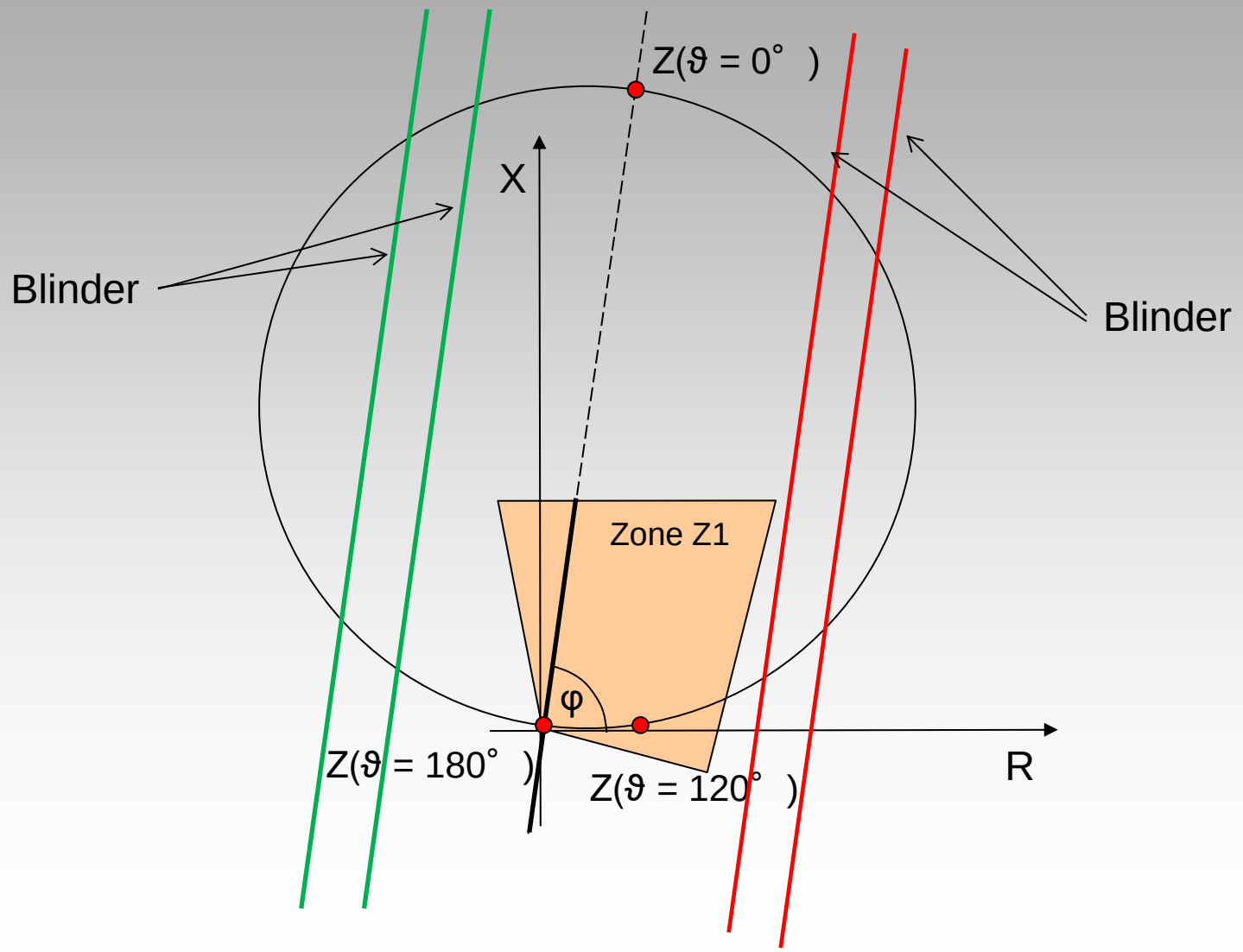
Note: Shape shows reach, not characteristic of the relay

Power Swing Detection
Typical impedance trajectory

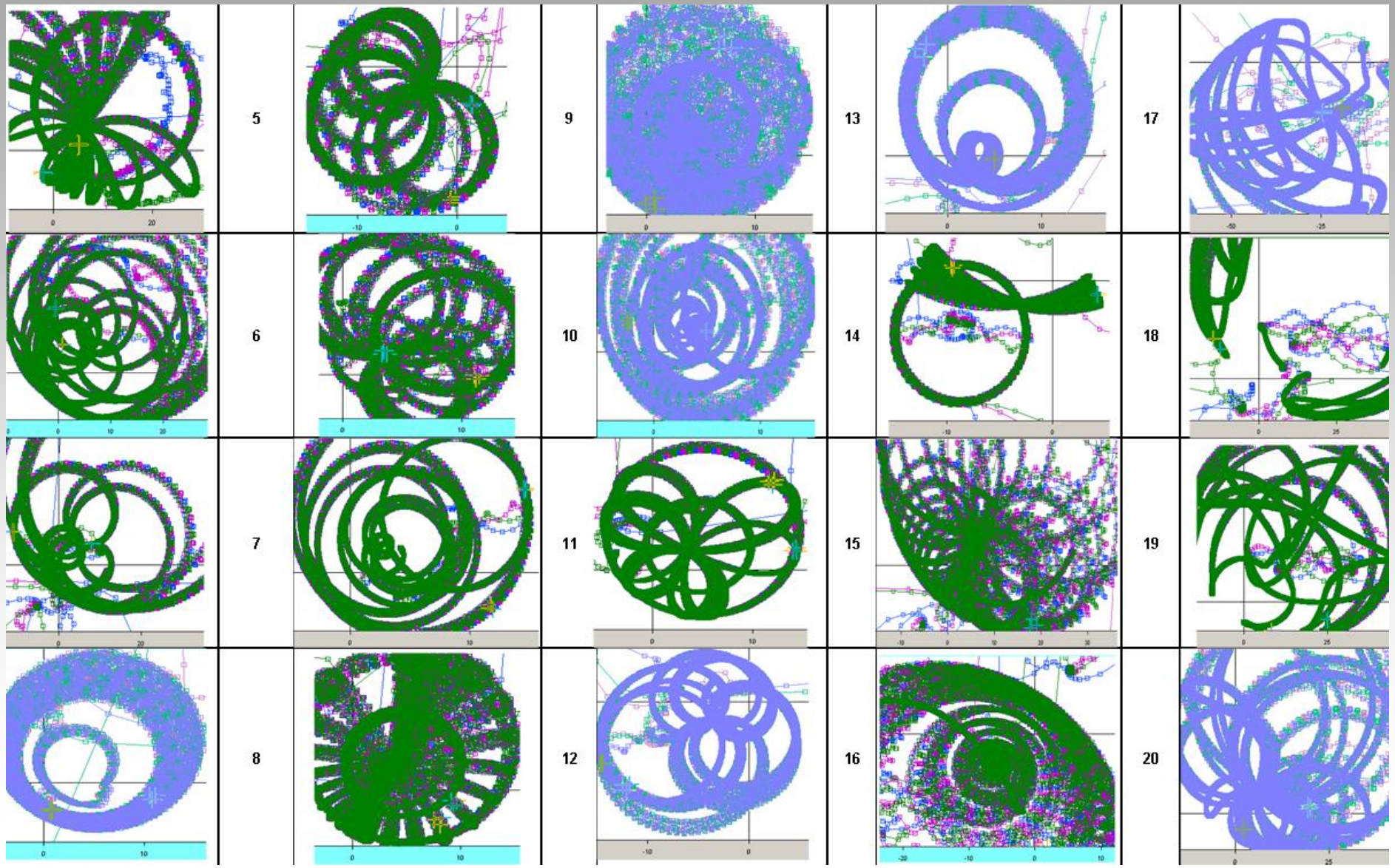


- ϑ = 40°
  normal load condition
- ϑ = 120°
  dangerous for distance protection
- ϑ = 180°
  unstable power swing
  → out of step tripping

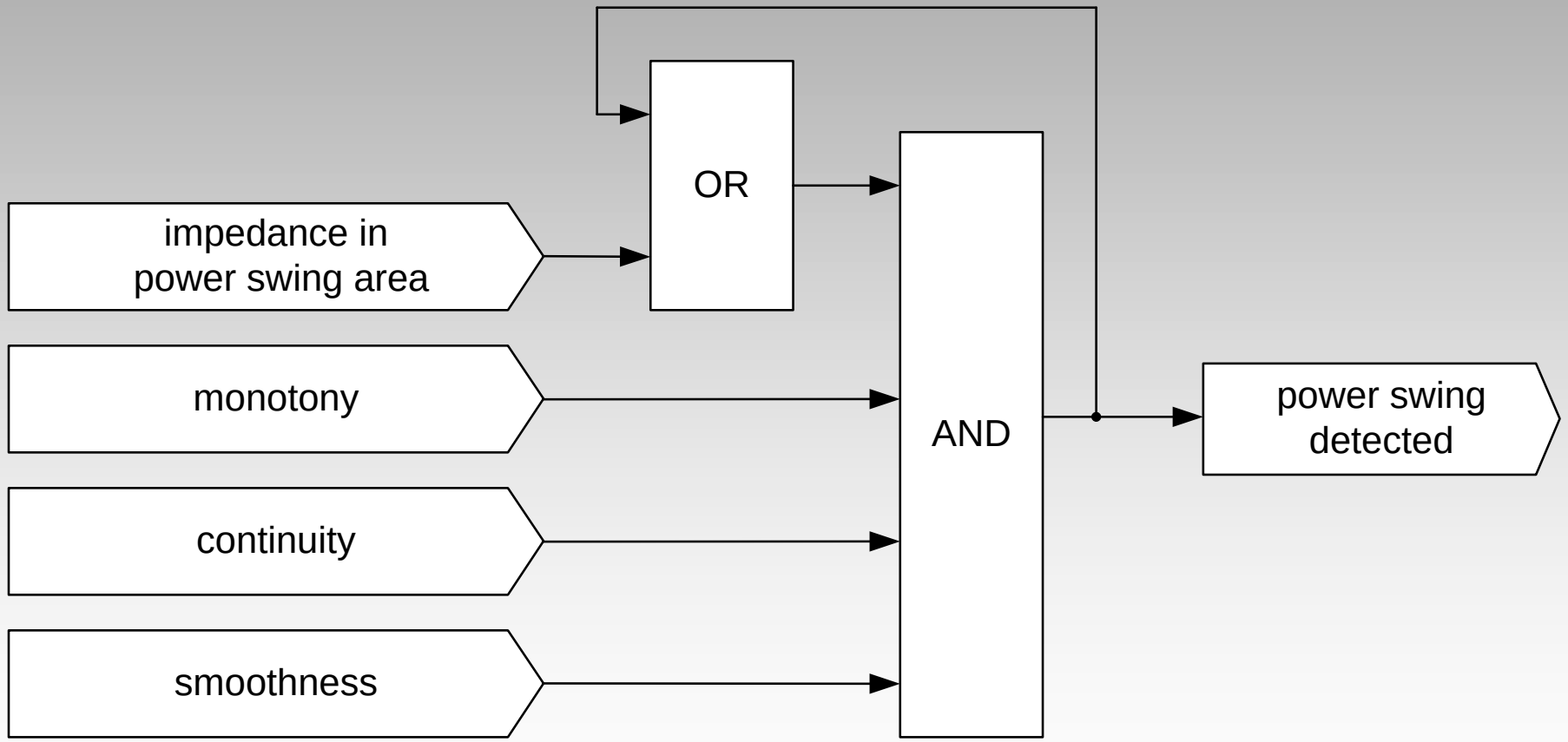
Traditional Power Swing Blocking and Tripping



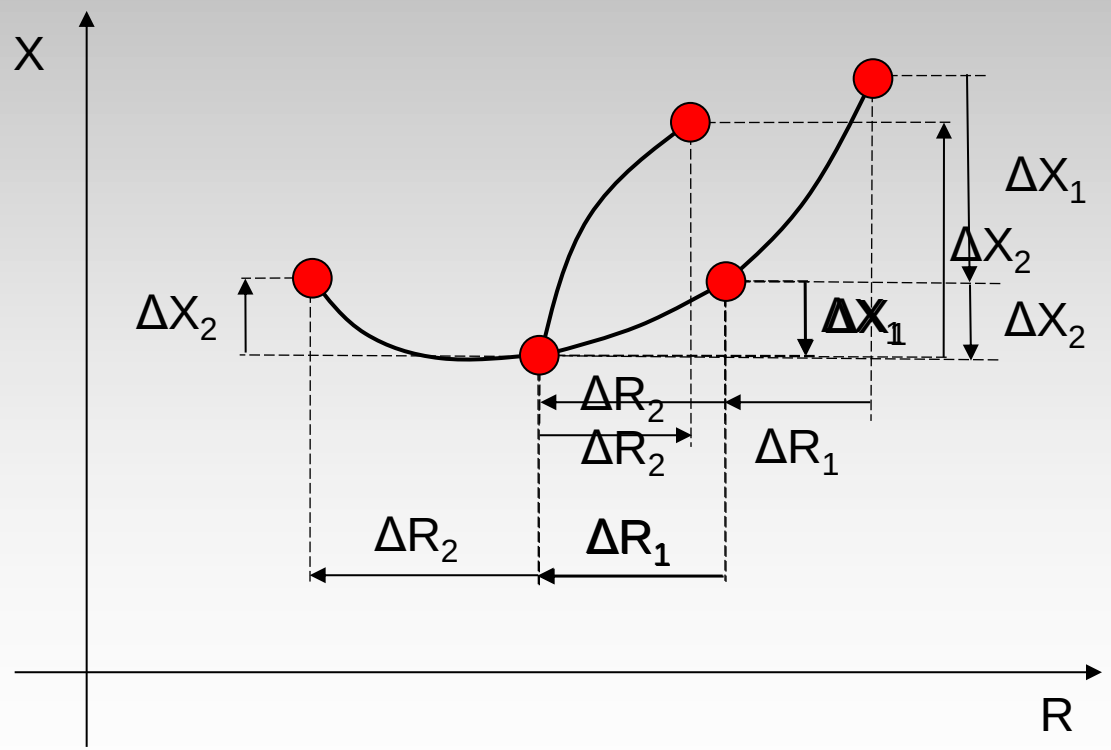
Impedance trajectories of 3-machine power-swings



Zero Setting Power Swing Detection

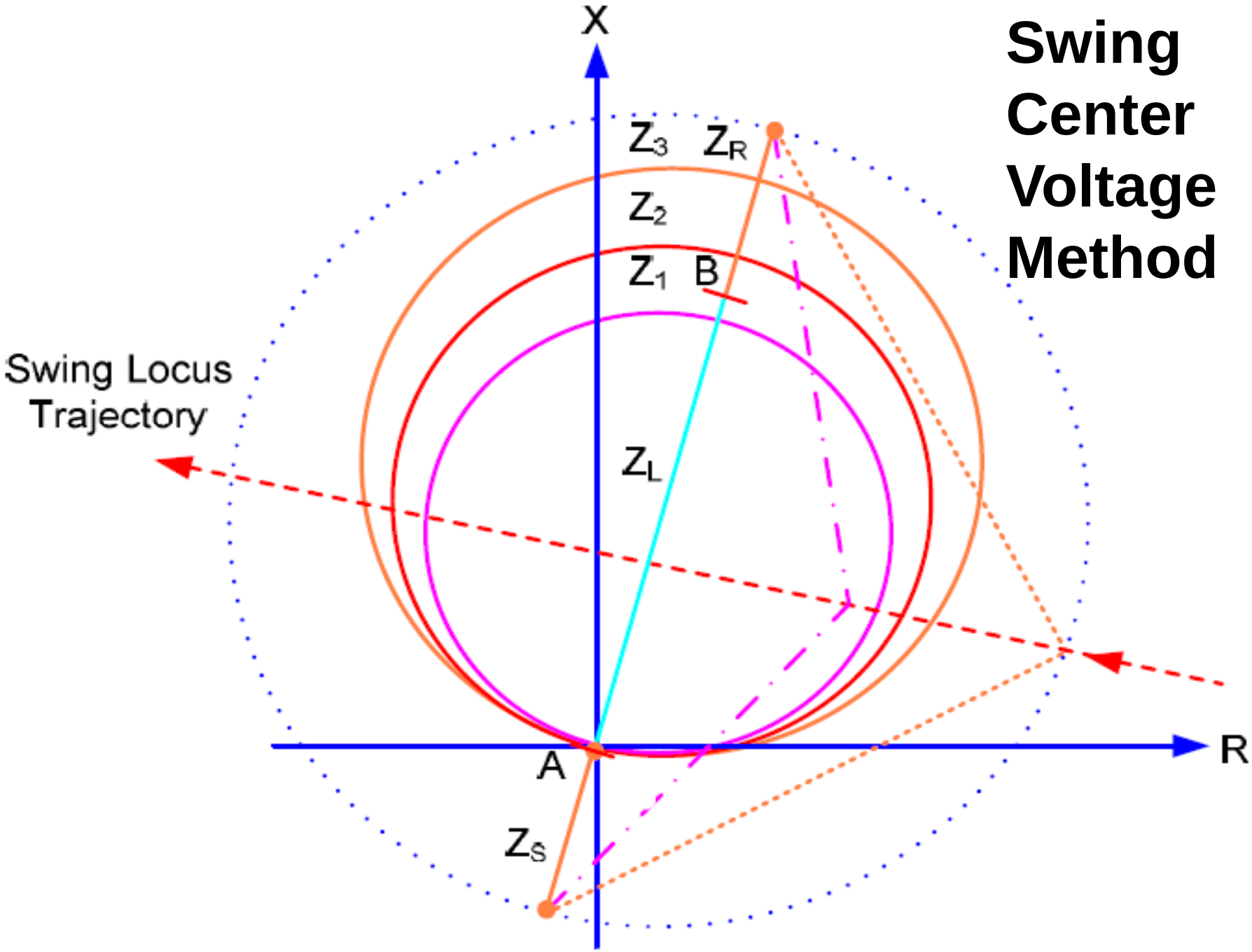


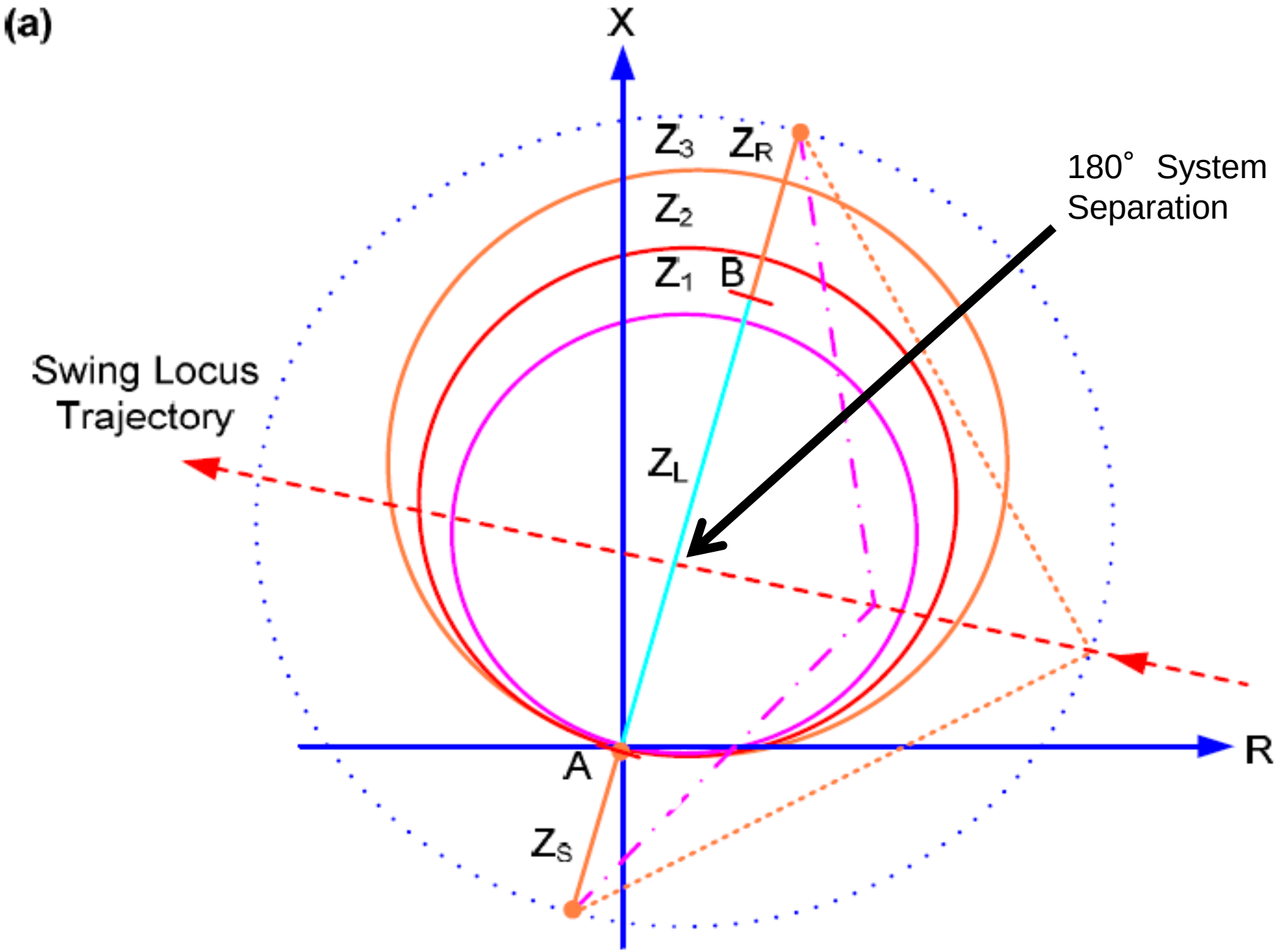
Measure Power Swings Like a Human Would



- power swing if ΔR1 and ΔR2 and ΔX1 and ΔX2 have same direction
- power swing if ΔR1 and ΔR2 or ΔX1 and ΔX2 have same directions
- no power swing if ΔR1 and ΔR2 and ΔX1 and ΔX2 have different directions

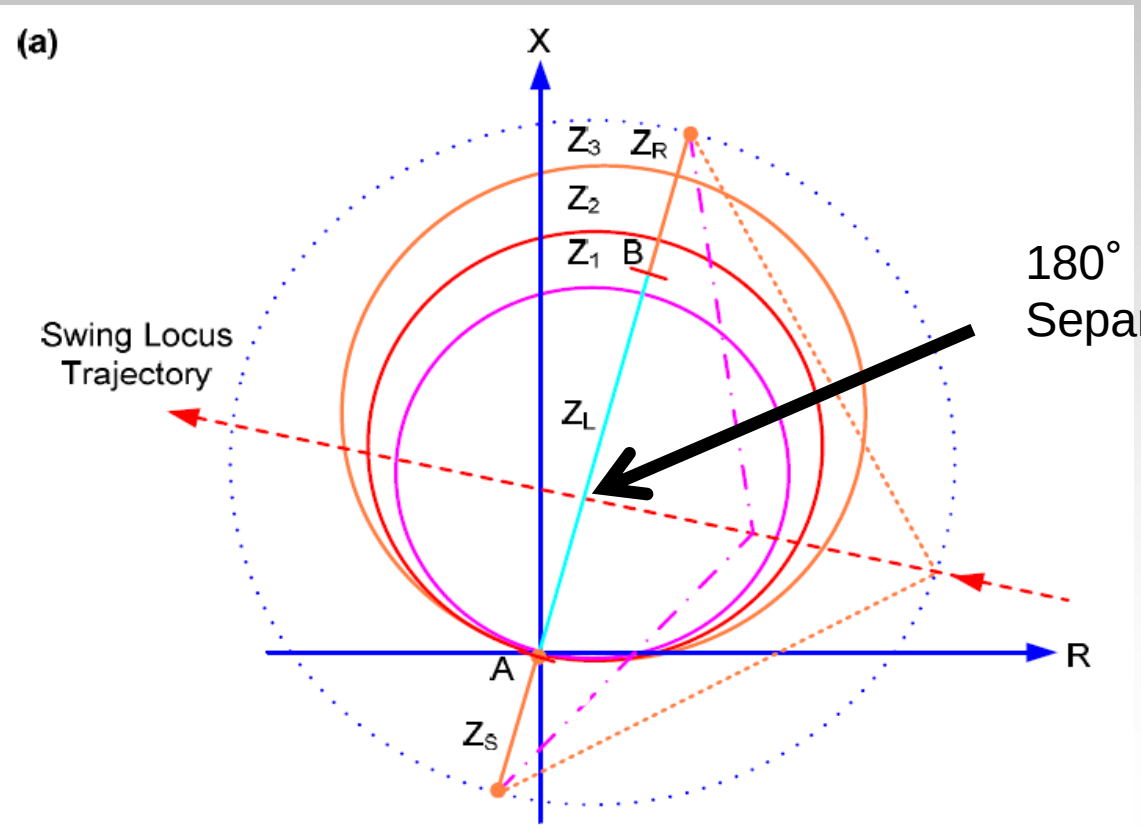
Swing Center Voltage Method




(a)
X
R
Z_3
Z_R
Z_2
Z_1
B
Z_L
A
Z_S
180° System Separation
Swing Locus Trajectory

Quick Quiz

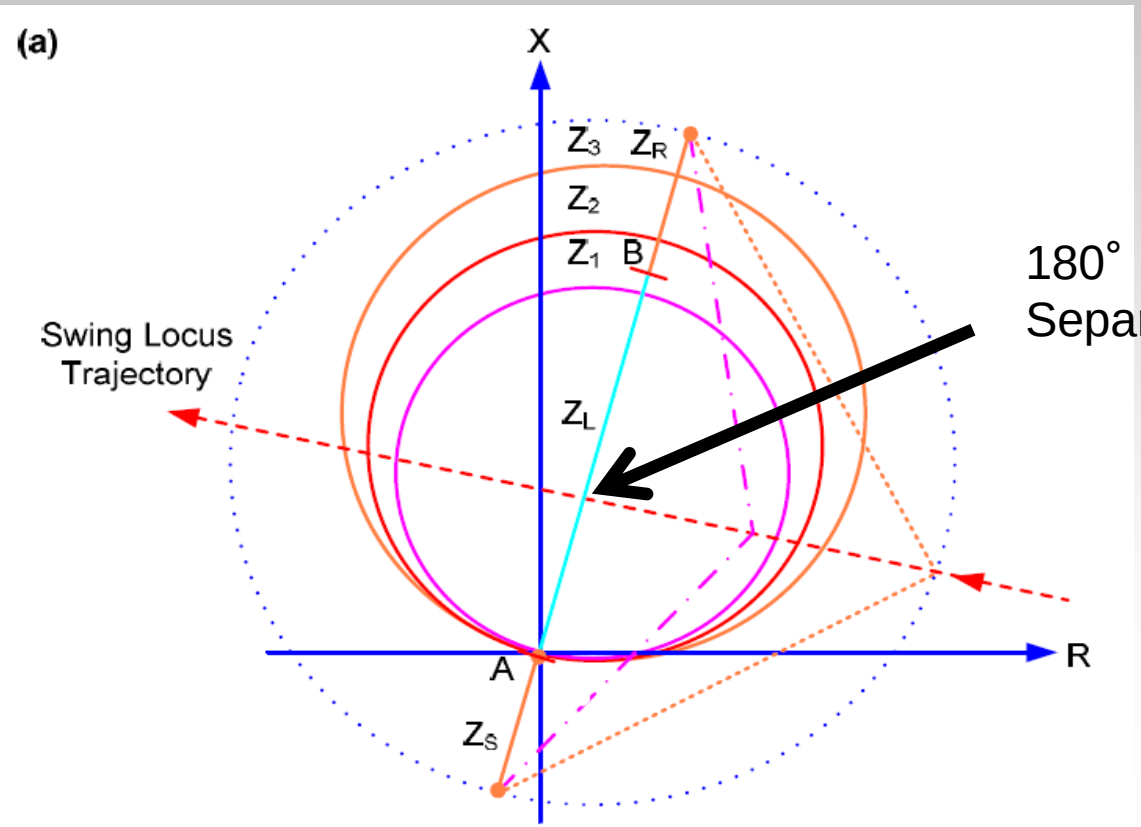
What will the voltage across the breaker contacts be if tripped on the line between ZS and ZR ?



Quick Quiz

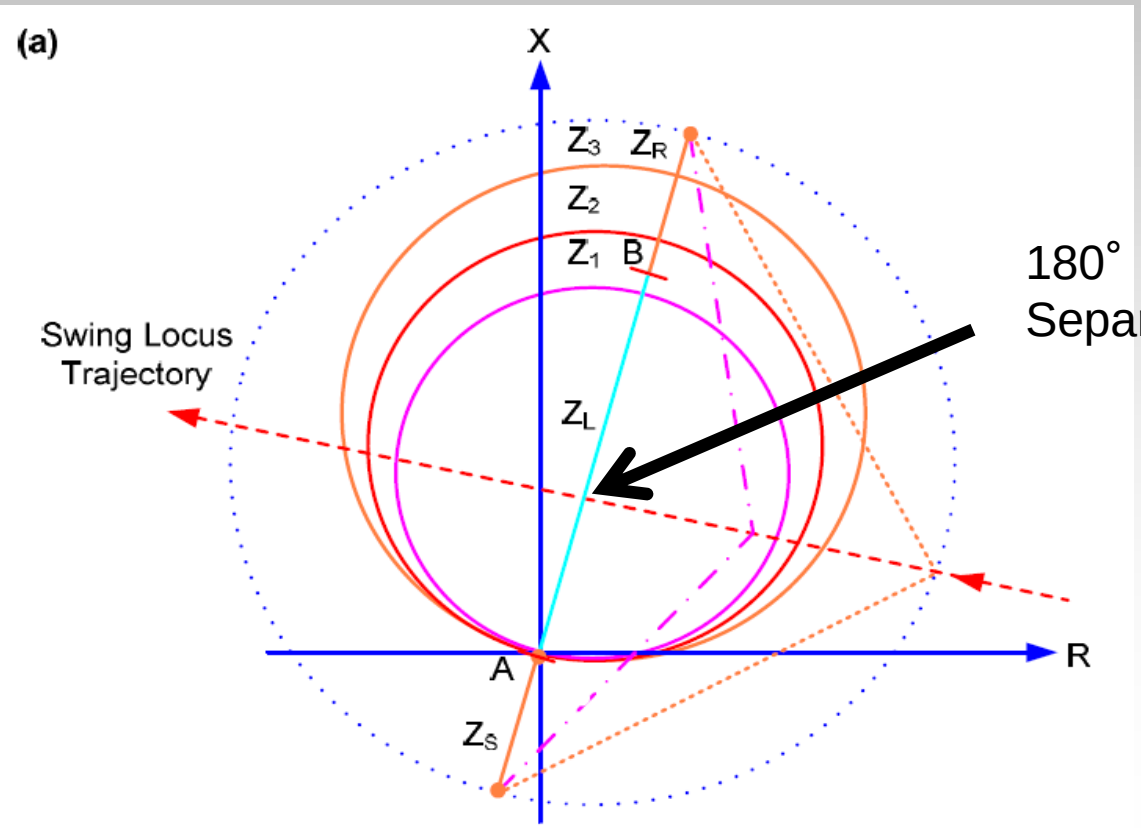
What will the voltage across the breaker contacts be if tripped on the line between ZS and ZR ?

A. 2 X L-L Voltage



Quick Quiz pt 2

What would you expect to happen when the breaker tries to open at 2 X L-L Voltage?



Quick Quiz pt 2

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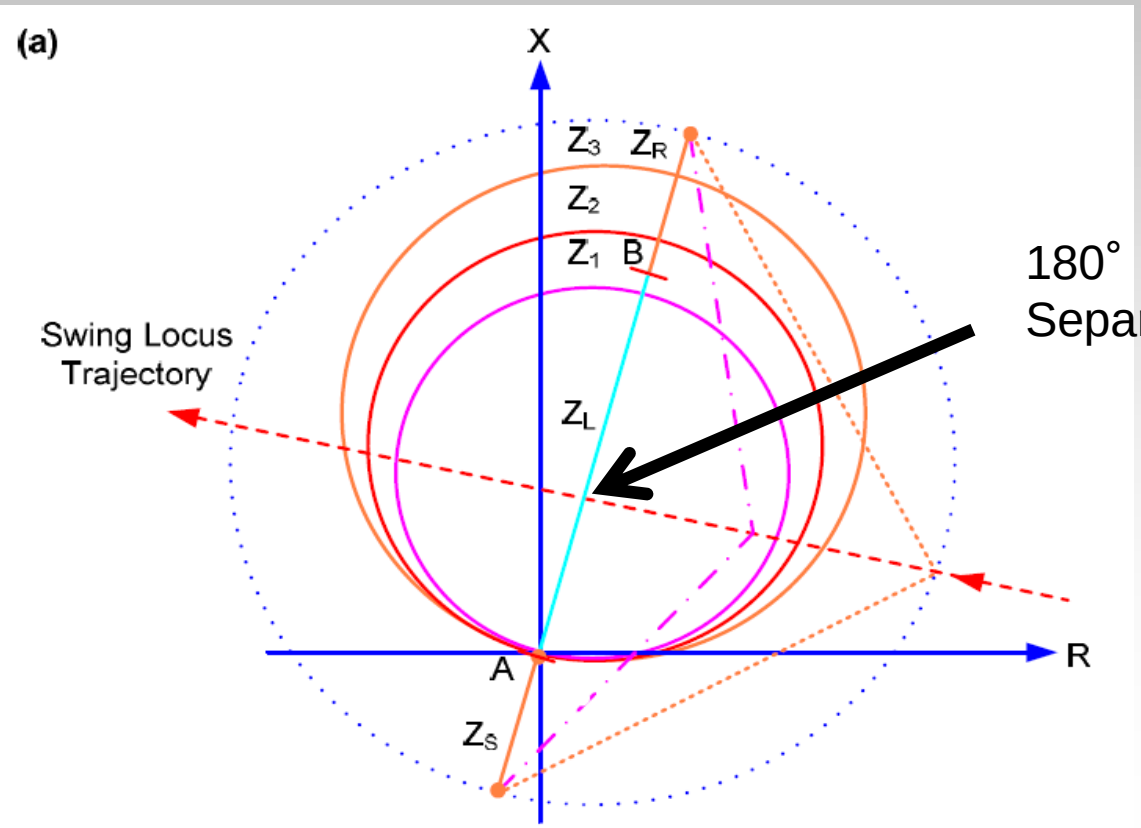
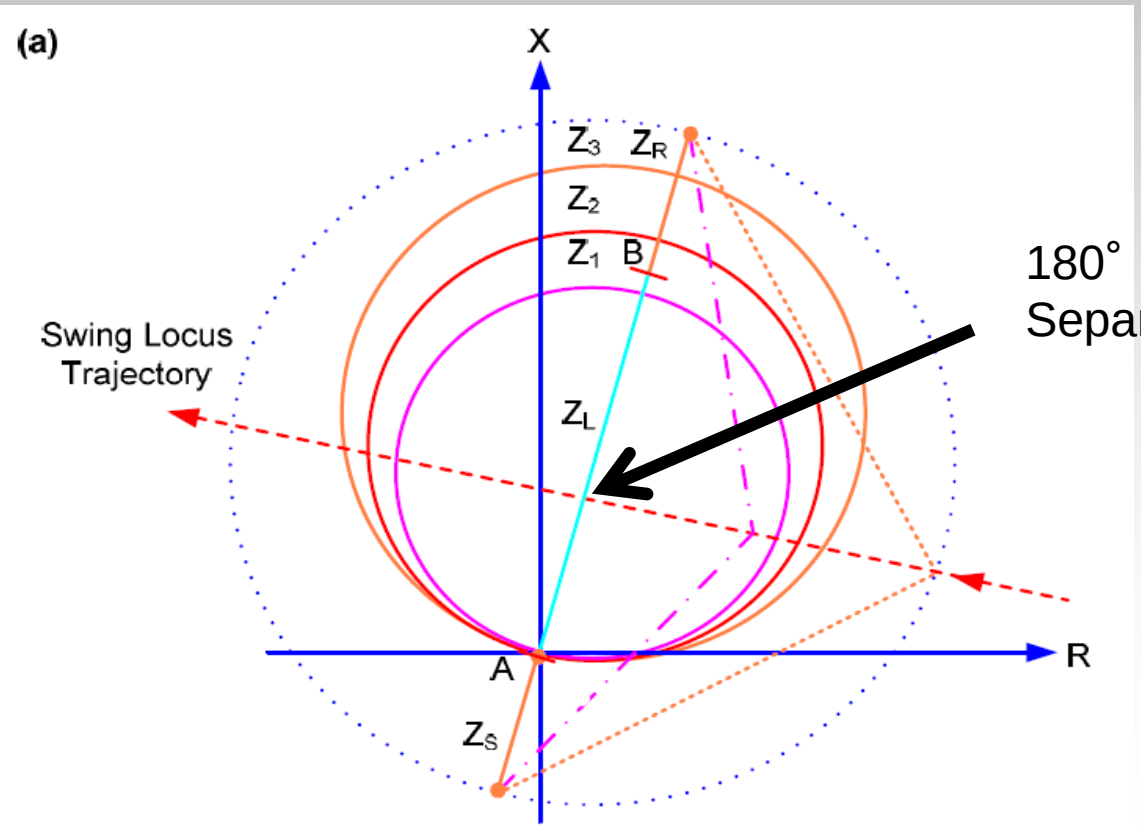


A. Restrike !!

Quick Quiz pt 3

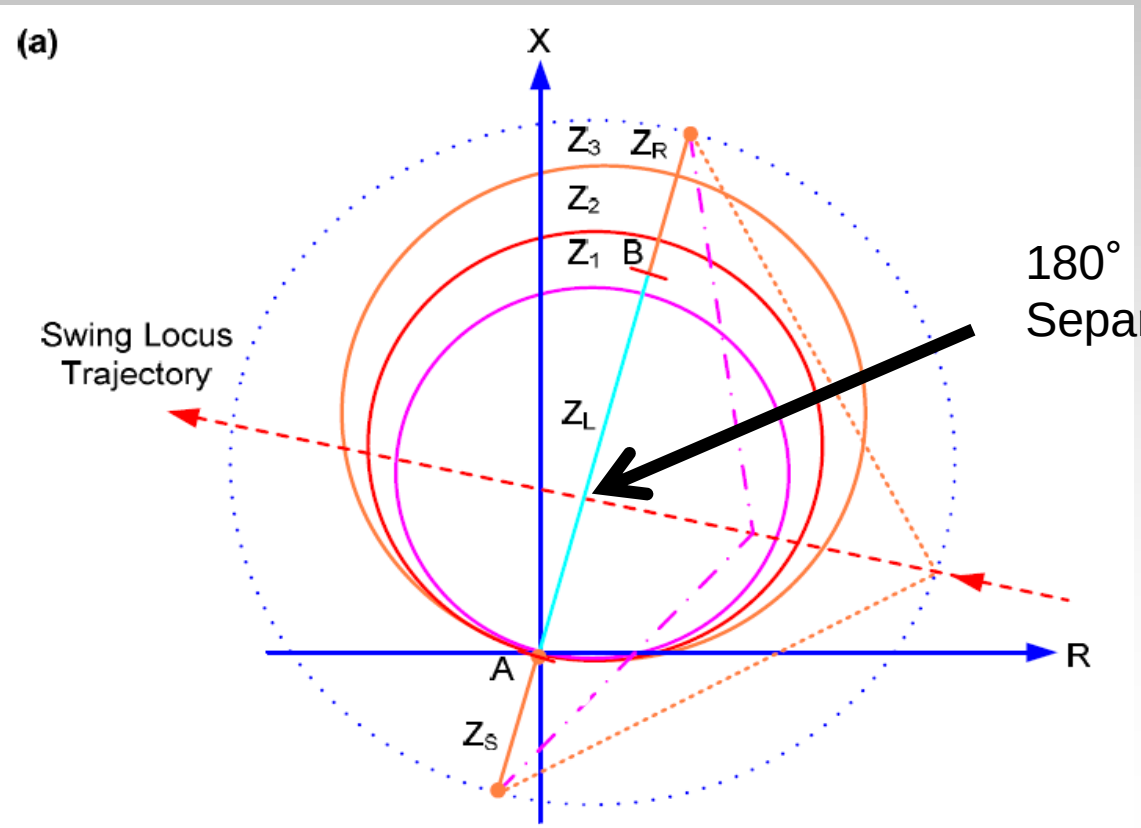
What would Generators (type 1 or 2 wind machines) during a restrike ?



Quick Quiz pt 3

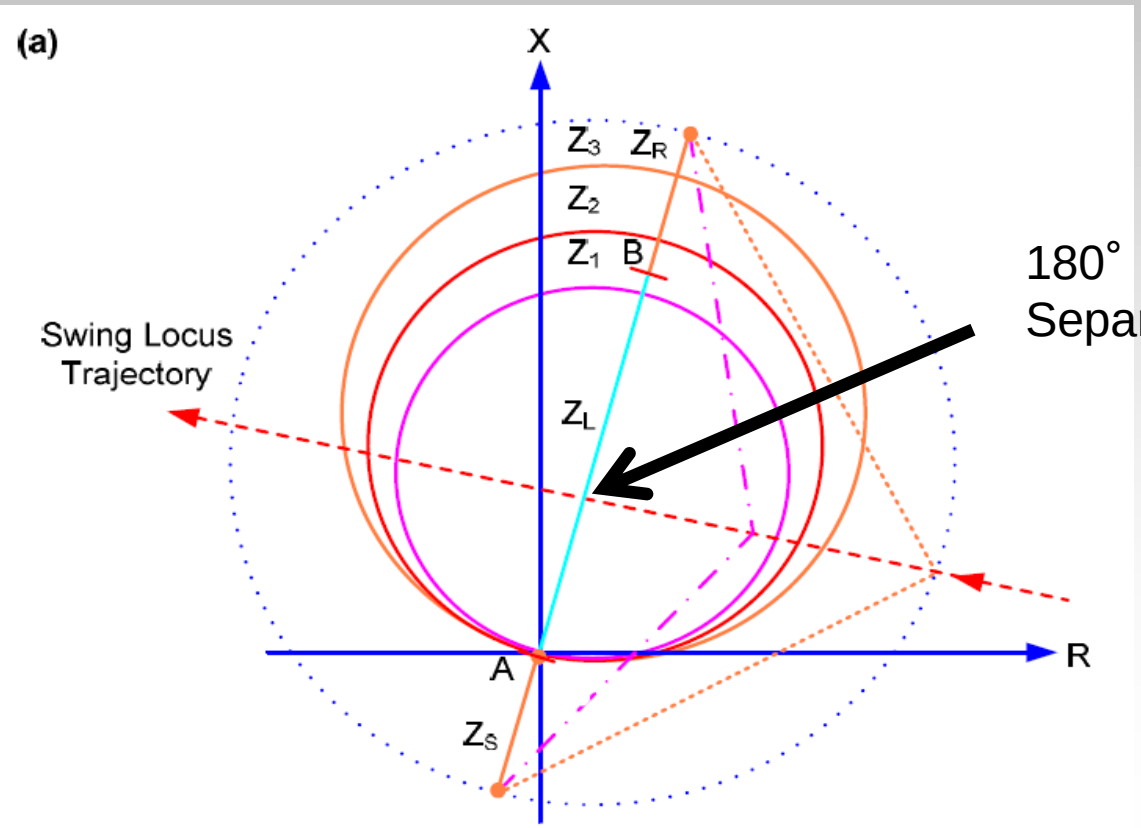
What would Generators (type 1 or 2 wind machines) during a restrike ?

A. Serious Damage Possible



Quick Quiz pt 4

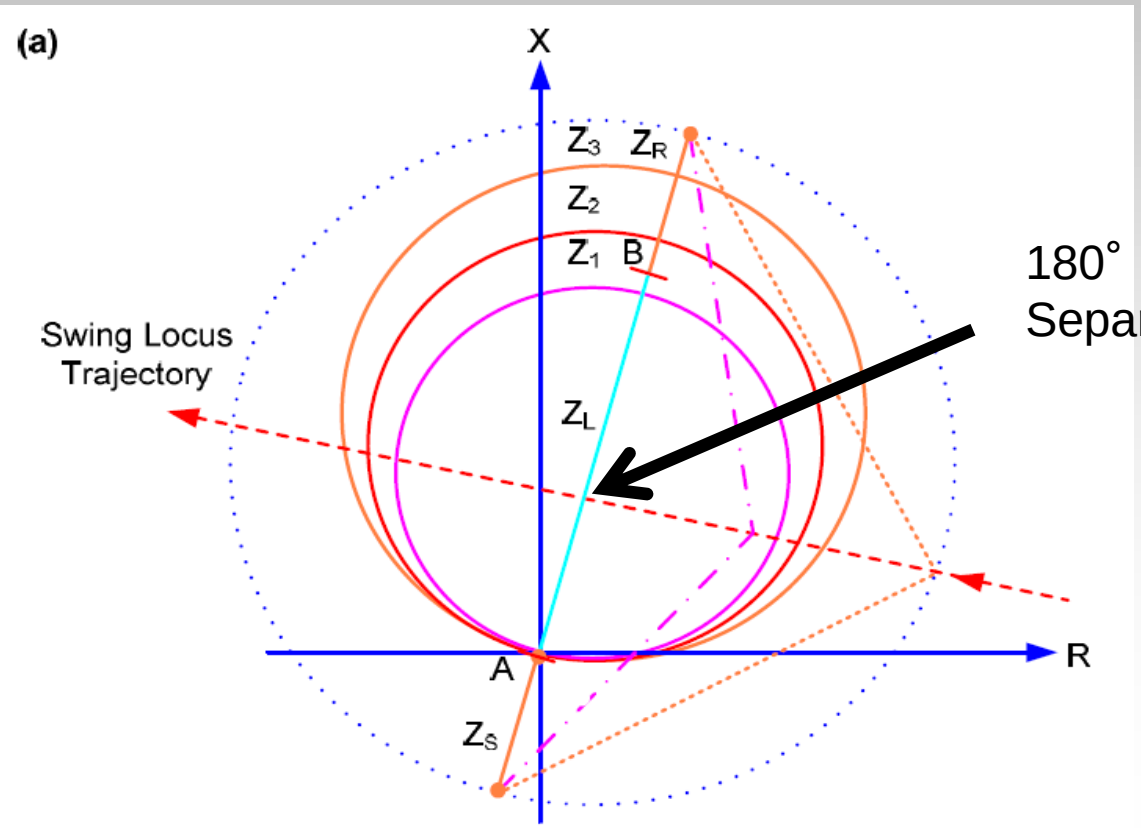
What would happen to capacitor banks energized by a restriking breaker ?



Quick Quiz pt 4

What would happen to capacitor banks energized by a restriking breaker ?

A. Failure…Explosion …Fire…



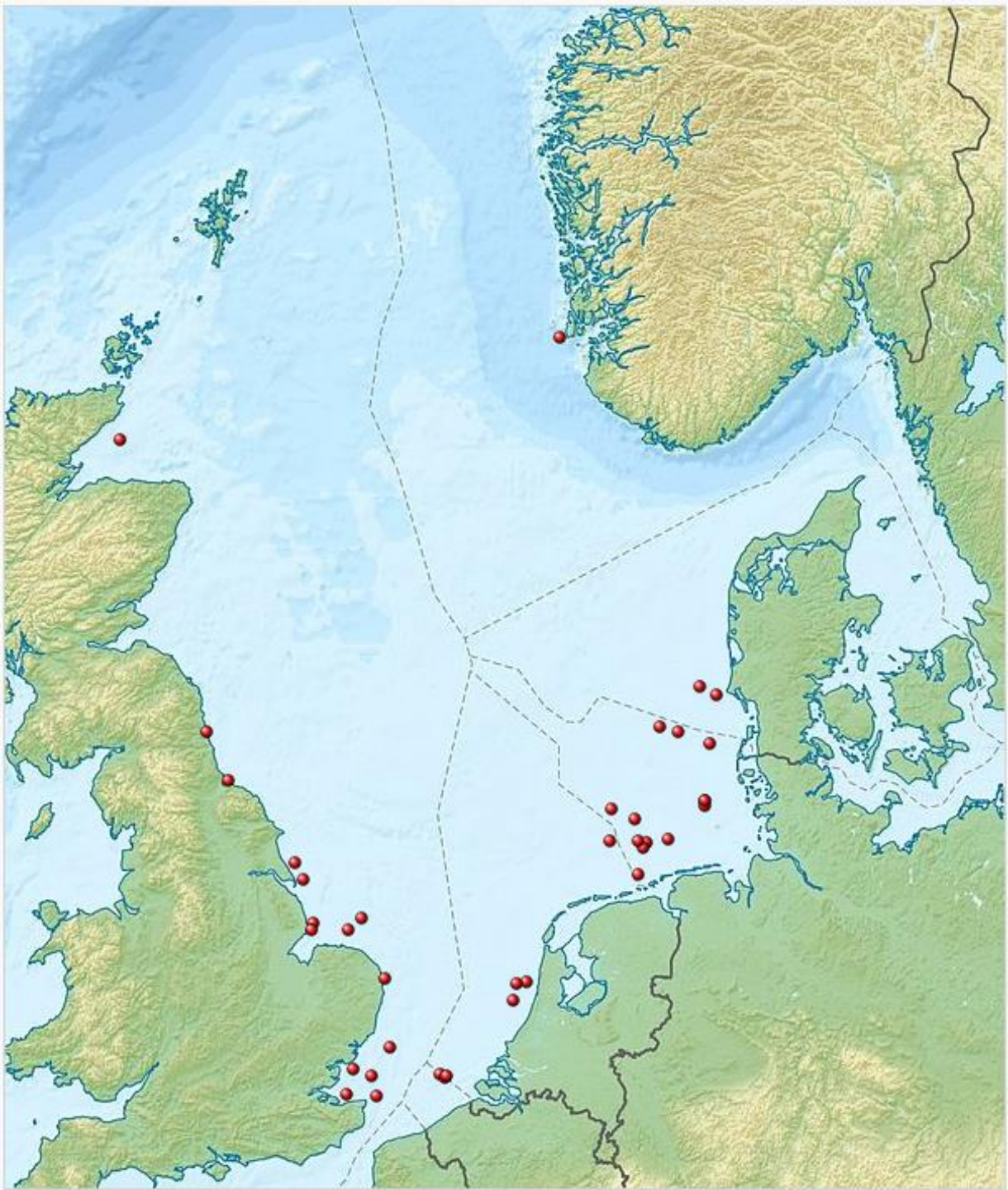
Replacing Nuclear with Wind

High Availability
High Inertia
Dynamic Voltage Support
Significant Fault Contribution

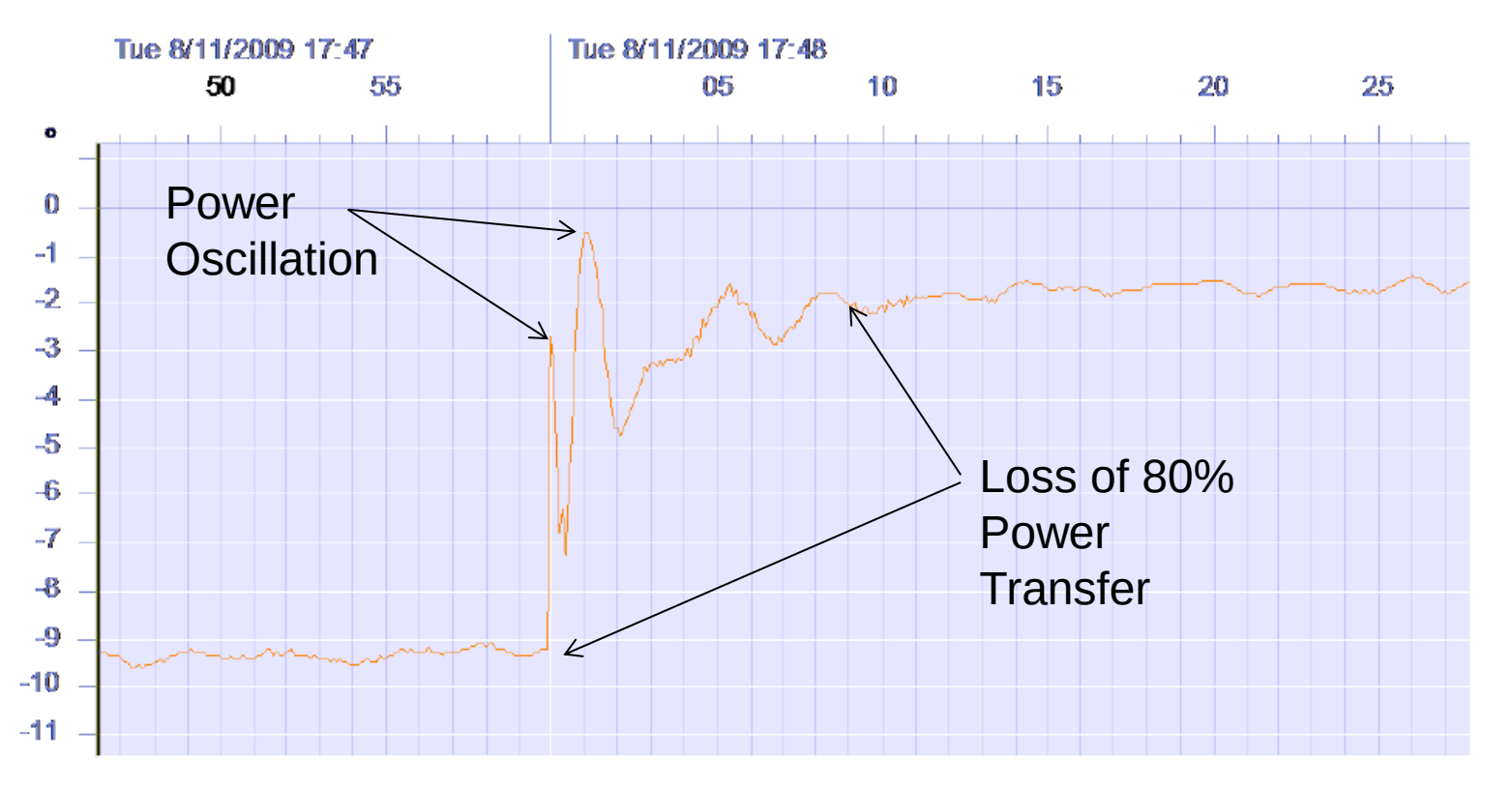
Non-Dispatchable
Low Inertia
No Dynamic Voltage Support
Minimal Fault Contribution

Massive Wind Farms Installed and Planned for the North Sea

8 GW Installed and 2.9 Awaiting Installation

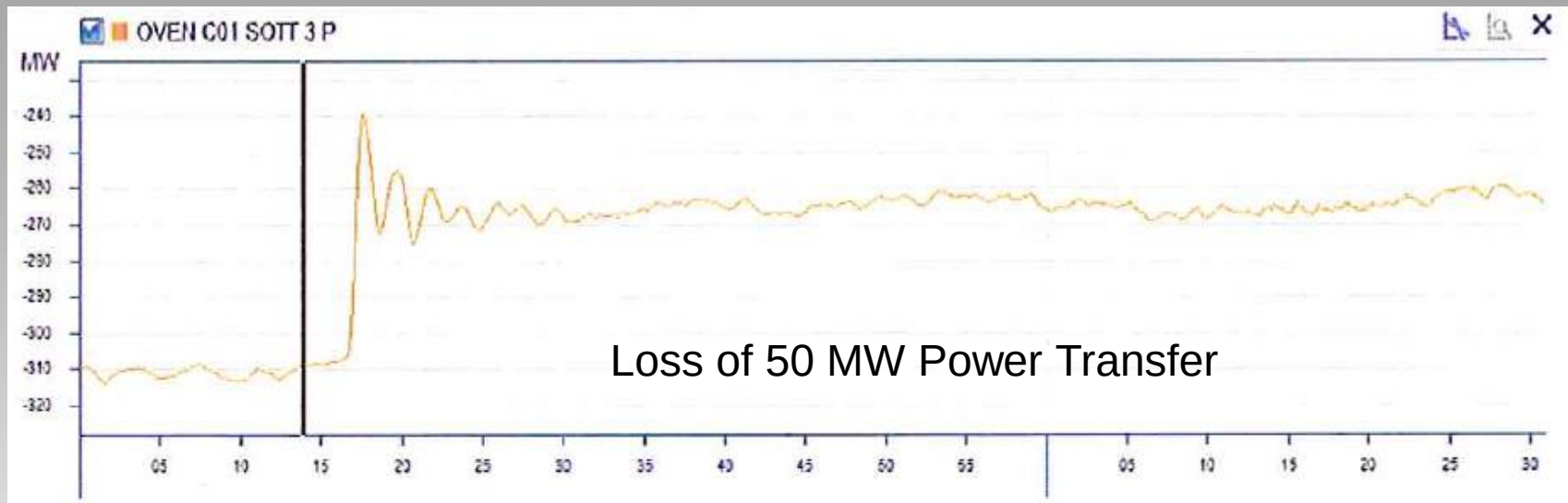


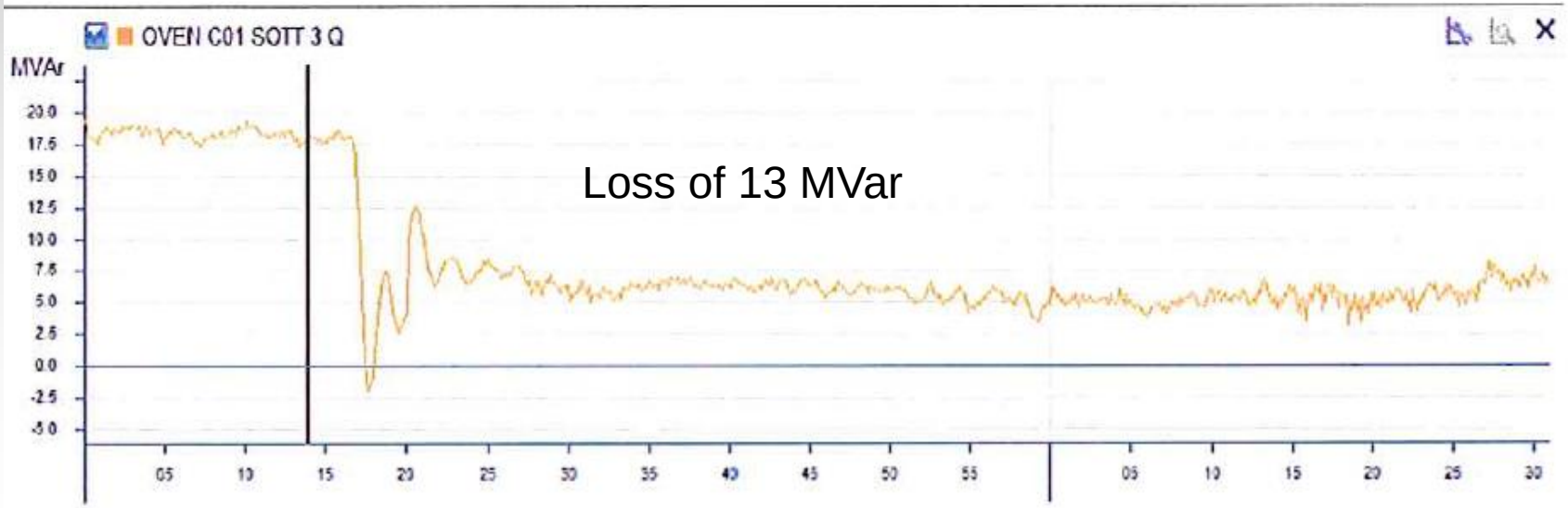
Loss of Northern Power Plant



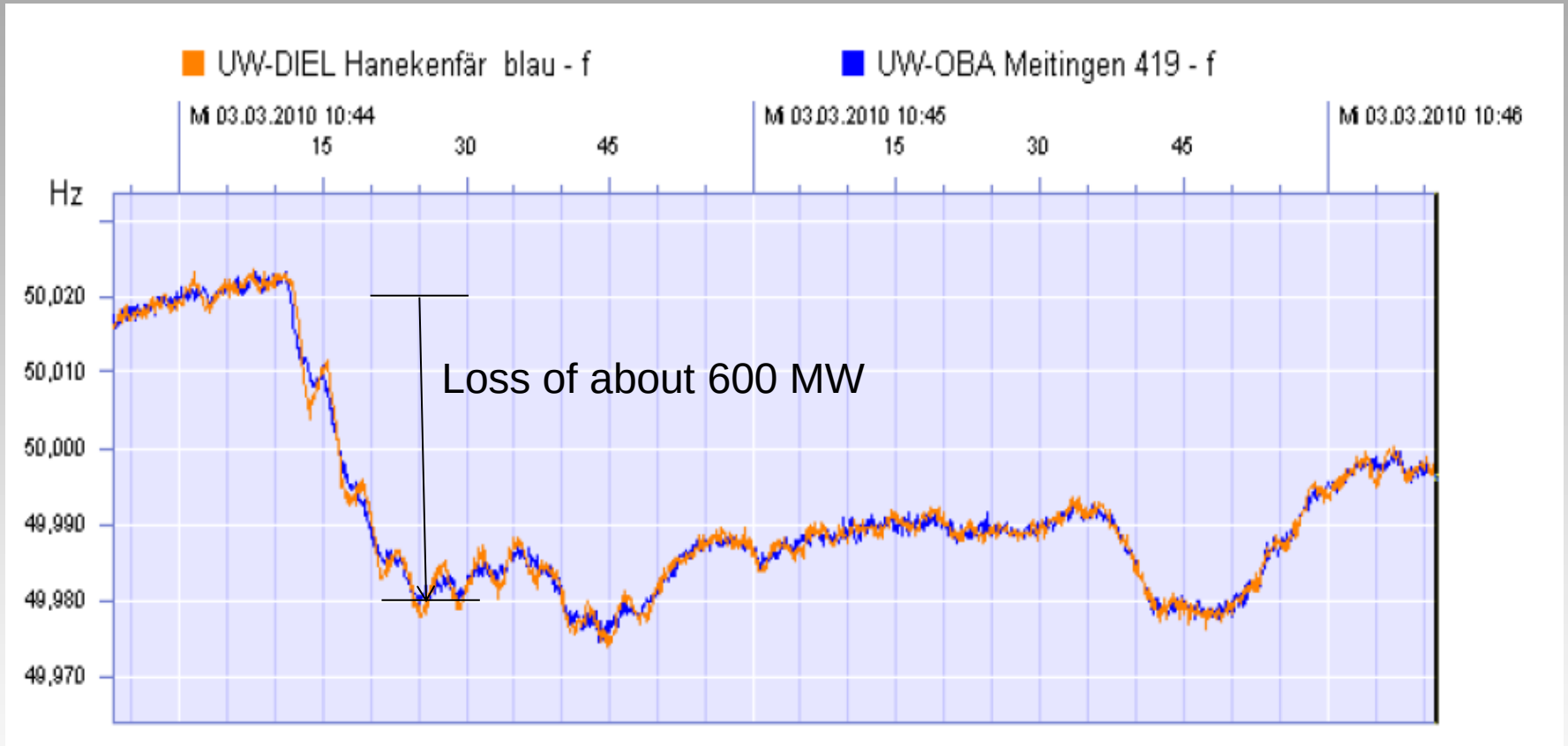
$$P=V_1V_2\sin\Theta/X$$

System Impact of a Line Trip





Power Plant Trip in Southern Area



Impact of System Changes On Protection Settings

Fault Duty – Overcurrent Pickup

Critical Clearing Time, Breaker Failure

Load Changes – Load Encroachment

Overcurrent Coordination

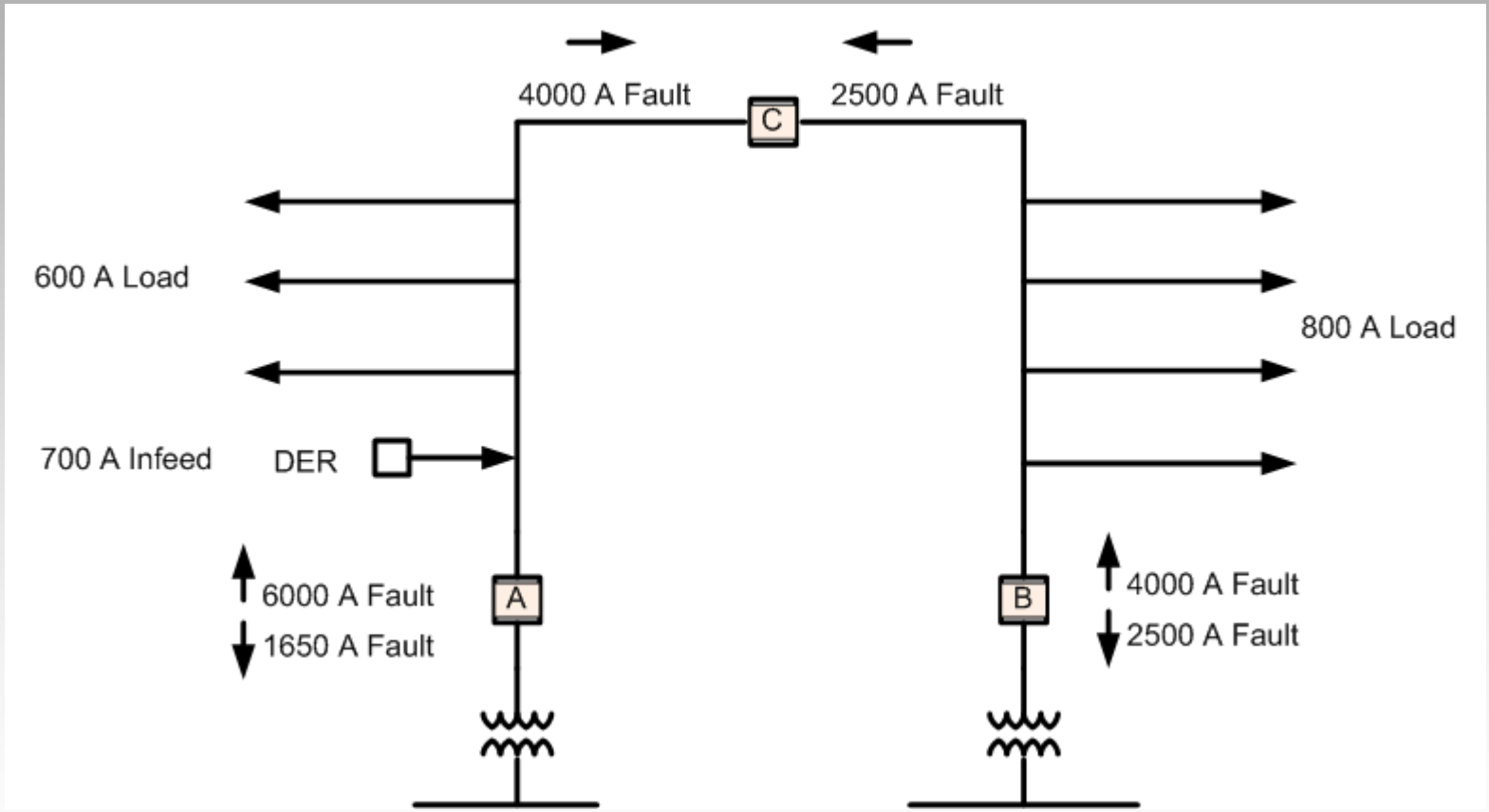
Load Balance – Islanding Considerations

Power Swing Settings

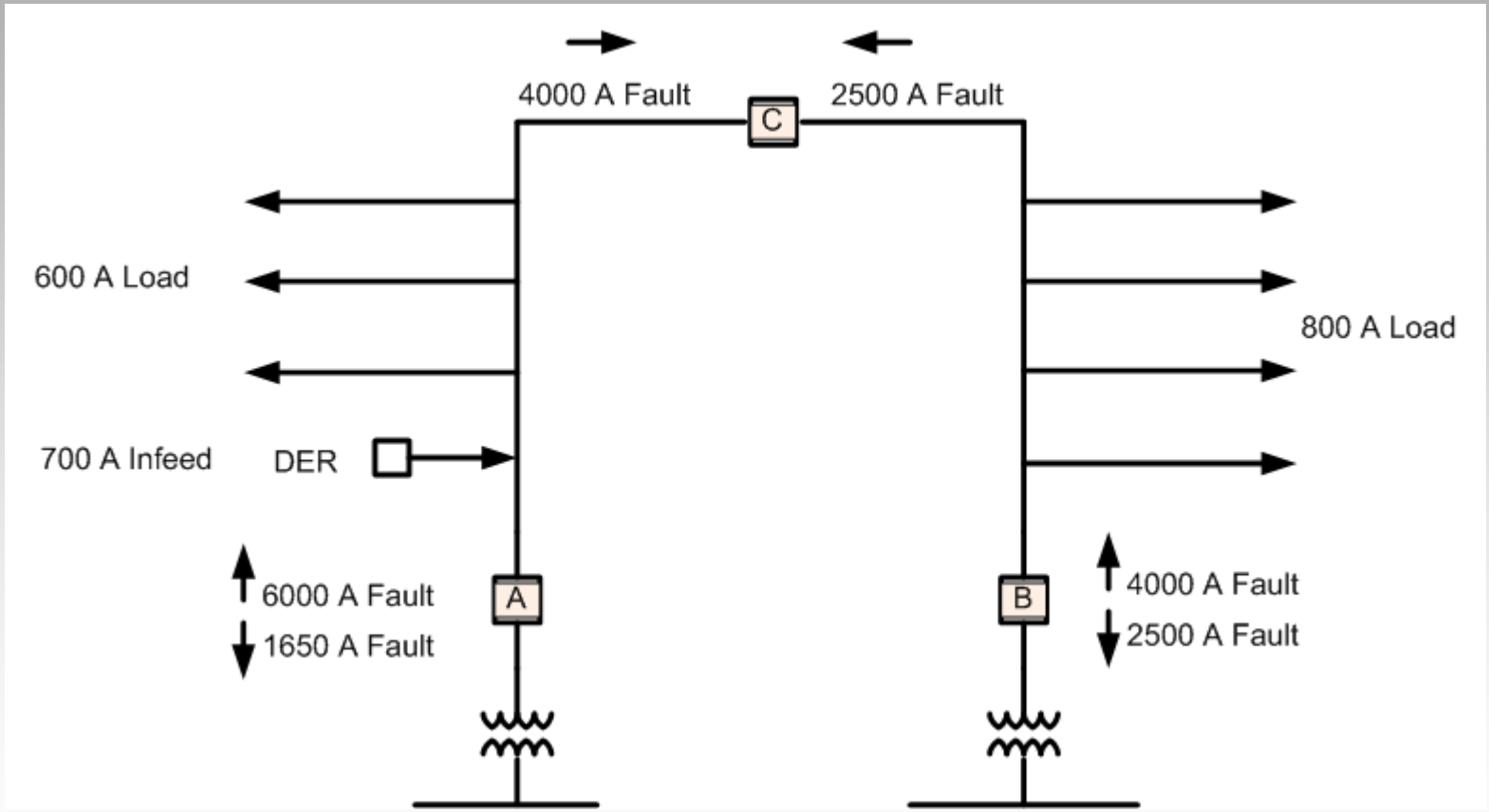
Adaptive Protection ?

- How Are Settings Changed ?
- What is Protection Impact during setting changes?

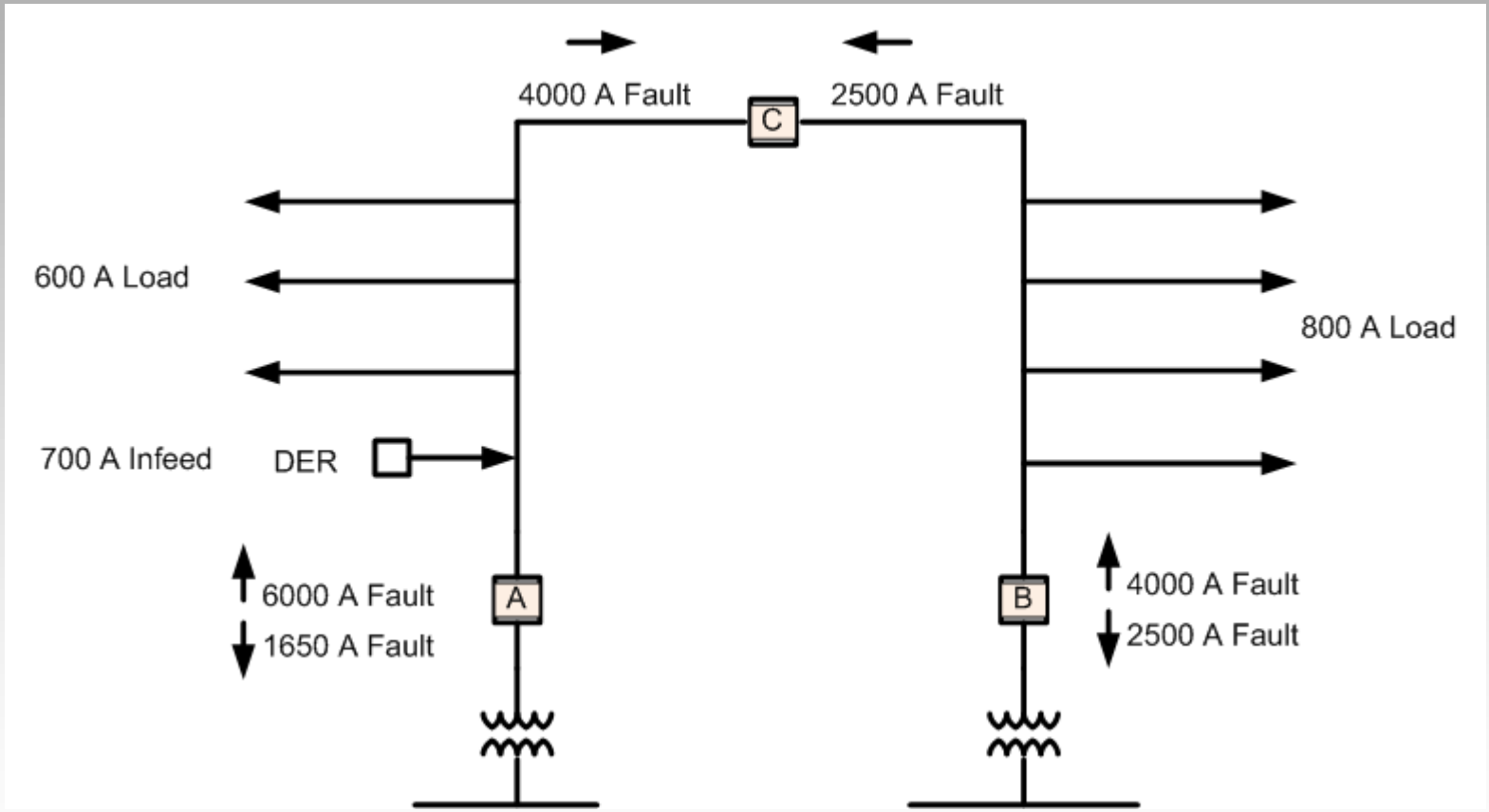
Real – World Distribution Example



Provide Overcurrent Settings for Breaker B

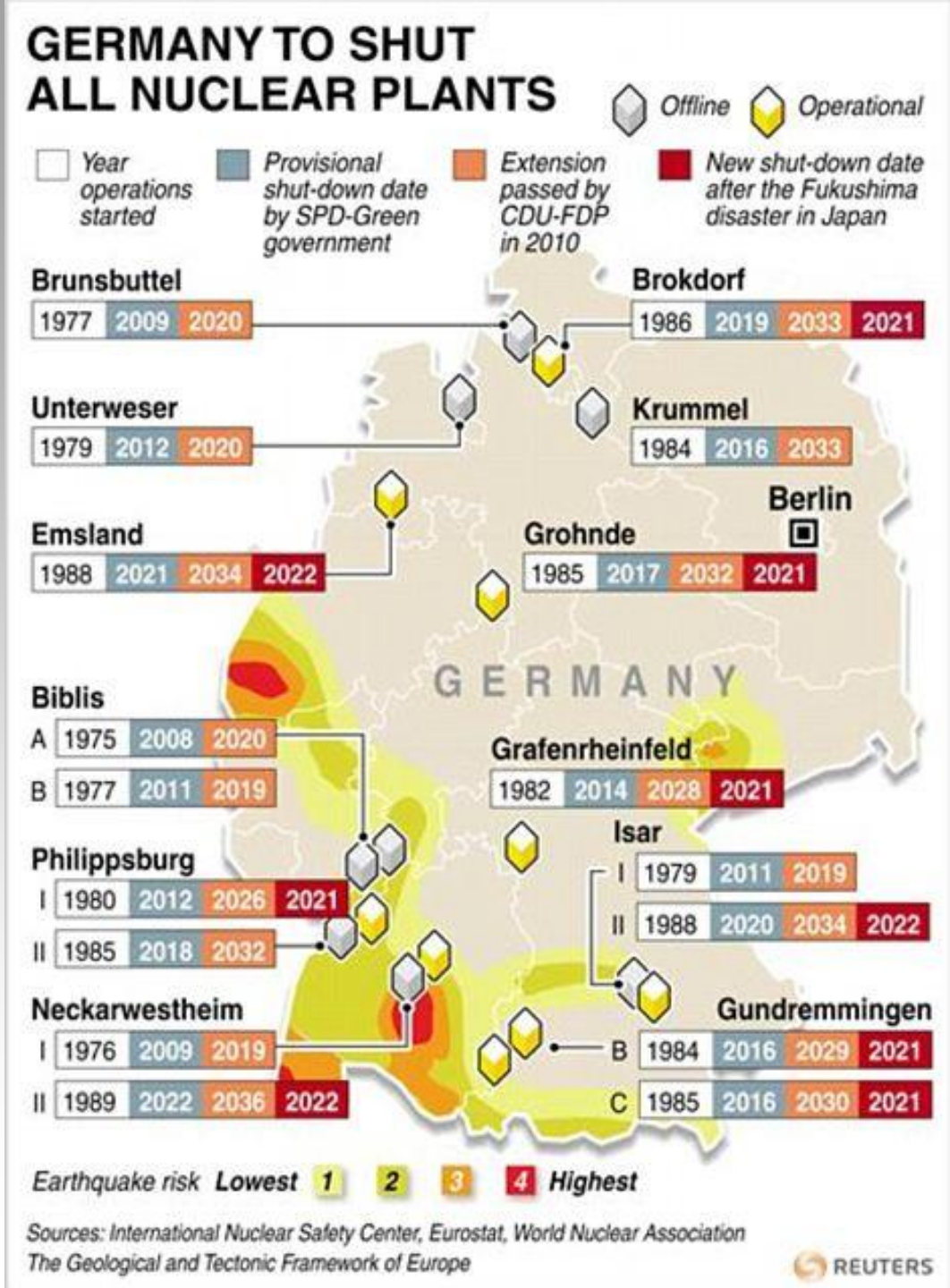


Settings if Breaker B knew Status of Breaker C ??



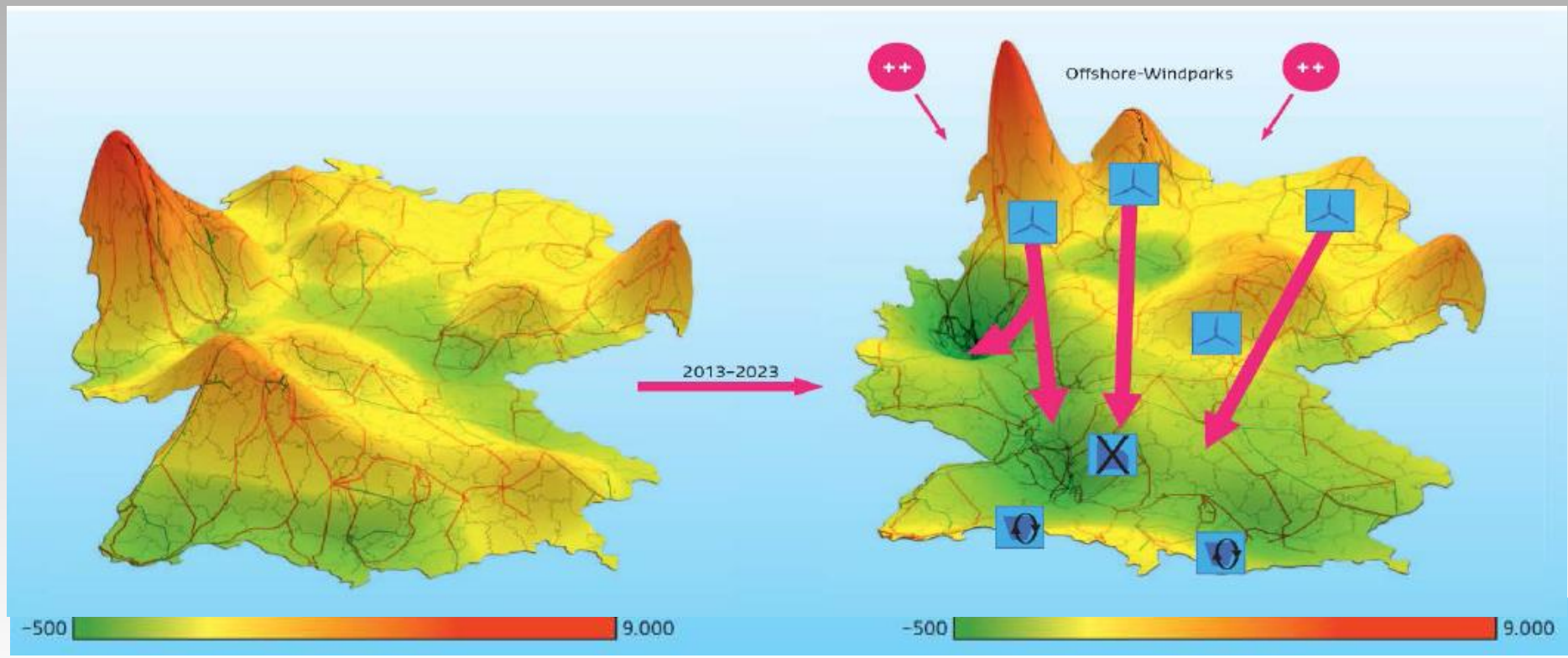
Headlines Impact System Stability

Note the Concentration of Nuclear Plants along the West Edge and the SouthWest

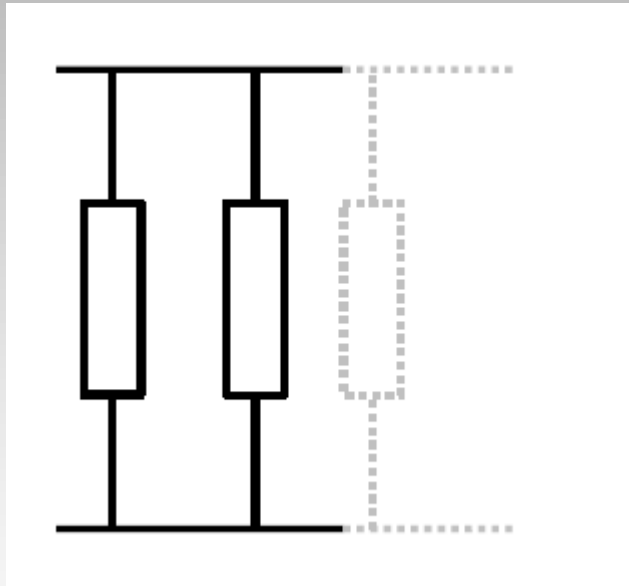


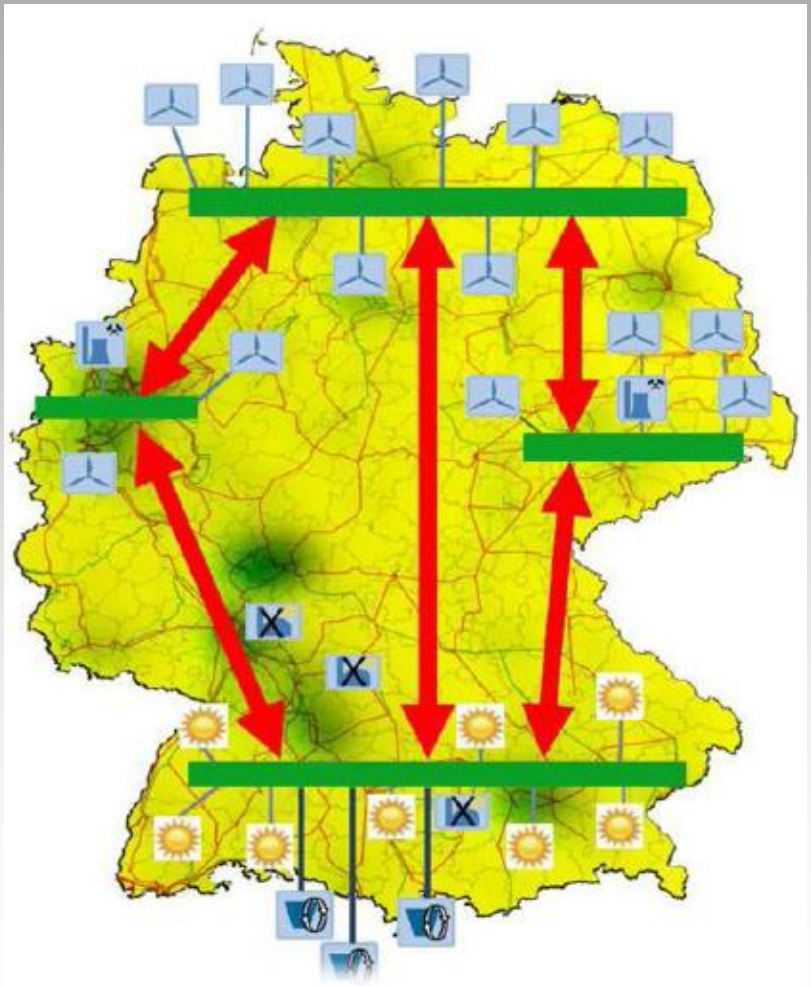
Current Account Balance

2013 2023

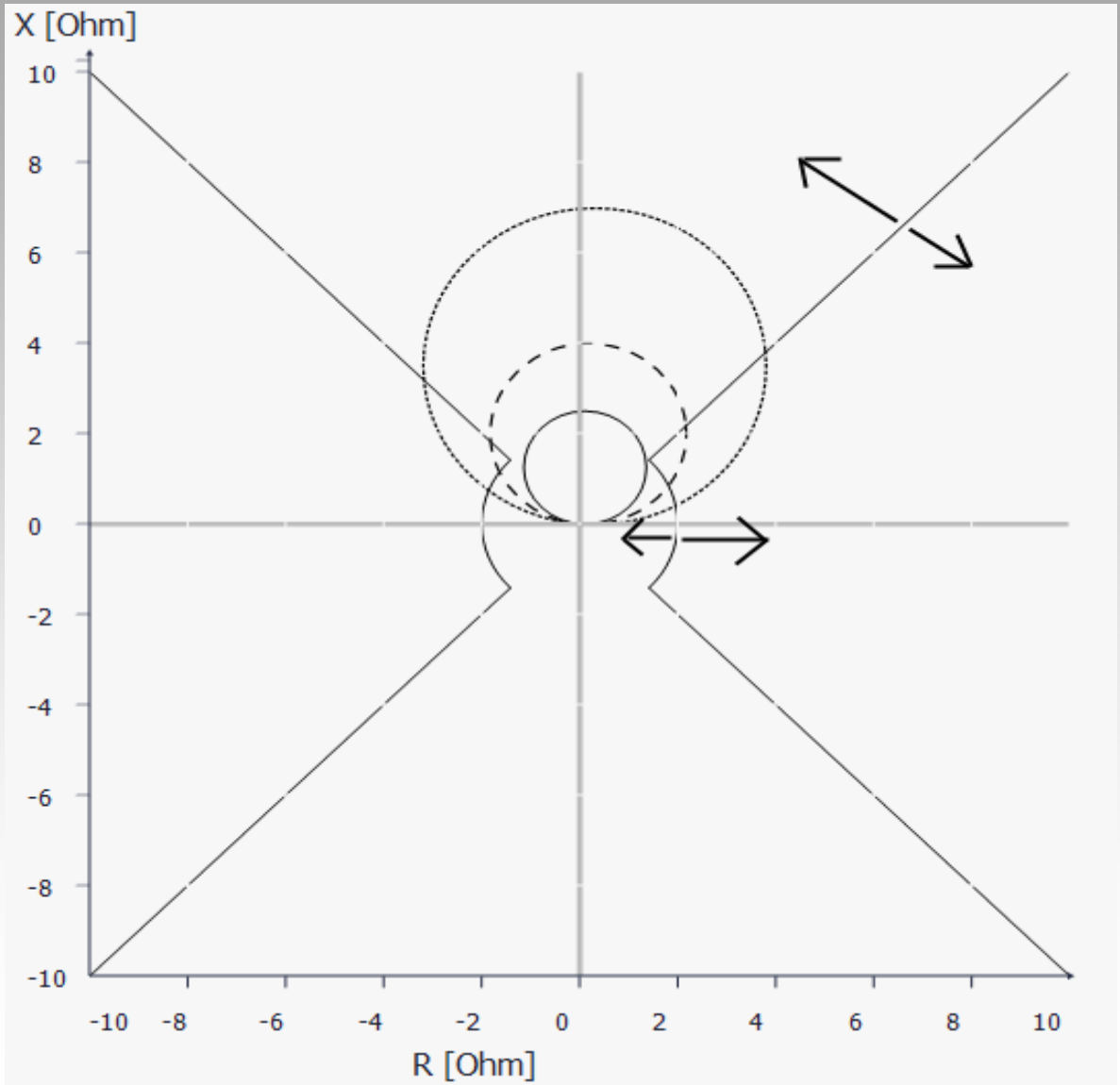


Bulk Power Flows

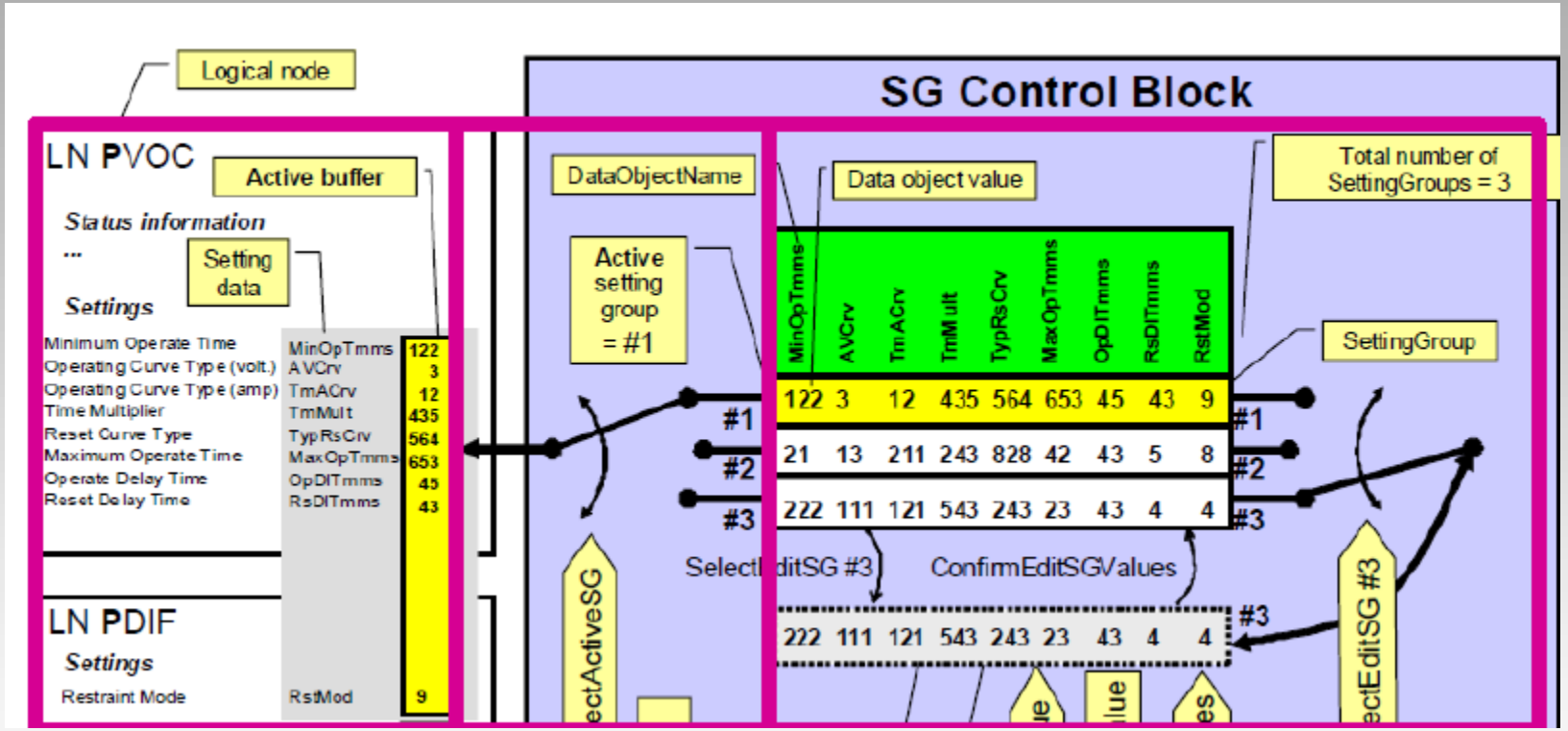




Adjusting to Dynamic Load Limits



Changing Setting Groups and Files



In Service Application Considerations

Setting Groups and Setting Files

- Loss of Protection during Group Change ?
- Time Required for Setting File Input ?
- Security of File Transfer

Time Required

- Control Center Calculations
- Data Transmission
- Time inside relay

In Service Results

- Setting Groups and Setting Files

No Loss of Protection during Group Change

Security of File Transfer

Time to Transfer and Implement New Settings File

10 Seconds for Control Center Calculations and transmission

1 second within the relay

Security

Encrypted files to Station and to Relay

Backup / Fallback Settings Always in Place

Wind is Here to Stay

Protection Considerations

- Fault Response
- System Response
- Out of Step Impacts
- Coordination Impacts
- Connection Costs

Questions ?