Grid Interconnection for DGWind

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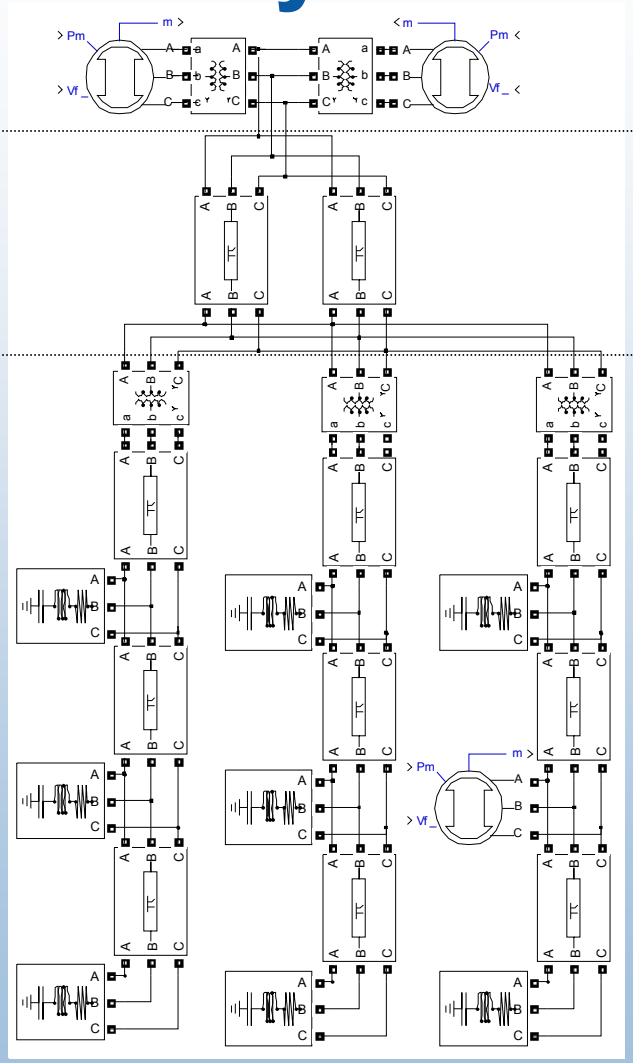
The Outline

- Intro
- Motivation
- Basics
- Engineering Information/Issues
- Business Information/Issues

The Electrical Power System

"The Grid"

- Generation
  - Large size ~ 1GW
  - Voltage ~ 20kV
- Transmission
  - Network (Parallel)
  - Voltage ~ 100kV – 1000kV
- Distribution
  - Radial (Series)
  - Voltage ~ 5kV– 40kV



EWEA's ROT's

Table E.1: Rule of Thumb Limits for Embedded Capacity

Connection Point	Typical Maximum Generation Capacity Which May be Connected
Low voltage	A few kW of embedded generation capacity
Lower levels of the distribution system (typically 10 or 11 kV)	Up to 2 MW, or possibly more than 2 MW close to the transformer feeding the network
Upper levels of the distribution system (20 – 35 kV): existing overhead line or cable	Can take 10 to 15 MW
Upper levels of the distribution system (20 – 35 kV): existing busbar in a substation	Is likely to accept up to the rating of the transformers, which could be 60 MW or more.
'Subtransmission' system (70 – 150 kV): existing overhead line or cable	A typical limit is 100 MW
'Subtransmission' system (70 – 150 kV): existing busbar in a substation	A typical limit would be several hundred MW
Transmission systems	Generalisations not possible

Source: Wind Energy the Facts

Primary Indicator

- Ratio of system short circuit power at point of interconnection (PCC) to nominal power of wind project
- Short circuit power: amount of power that will flow to ground immediately after a three phase fault.
- How “strong” is the PCC vs. how big the wind project is
- 25 and up is a “strong” PCC but even 5 is do-able

Motivation1: Benefits and Challenges

- Use local production as part of support
  - Energy—long term
  - Power & Voltage—short term
- Free up large generators

- Power system not designed for DG
- DG isn't always designed for power system

Motivation2: Primary Areas of Concern for DGWind

- Normal Operation
  - Voltage Regulation
  - Harmonics
  - Flicker
- Contingency Operation
  - Fault behavior
    - Short circuit current
    - Disconnection/reconnection behavior
      - Protective equipment coordination
      - Islanding behavior

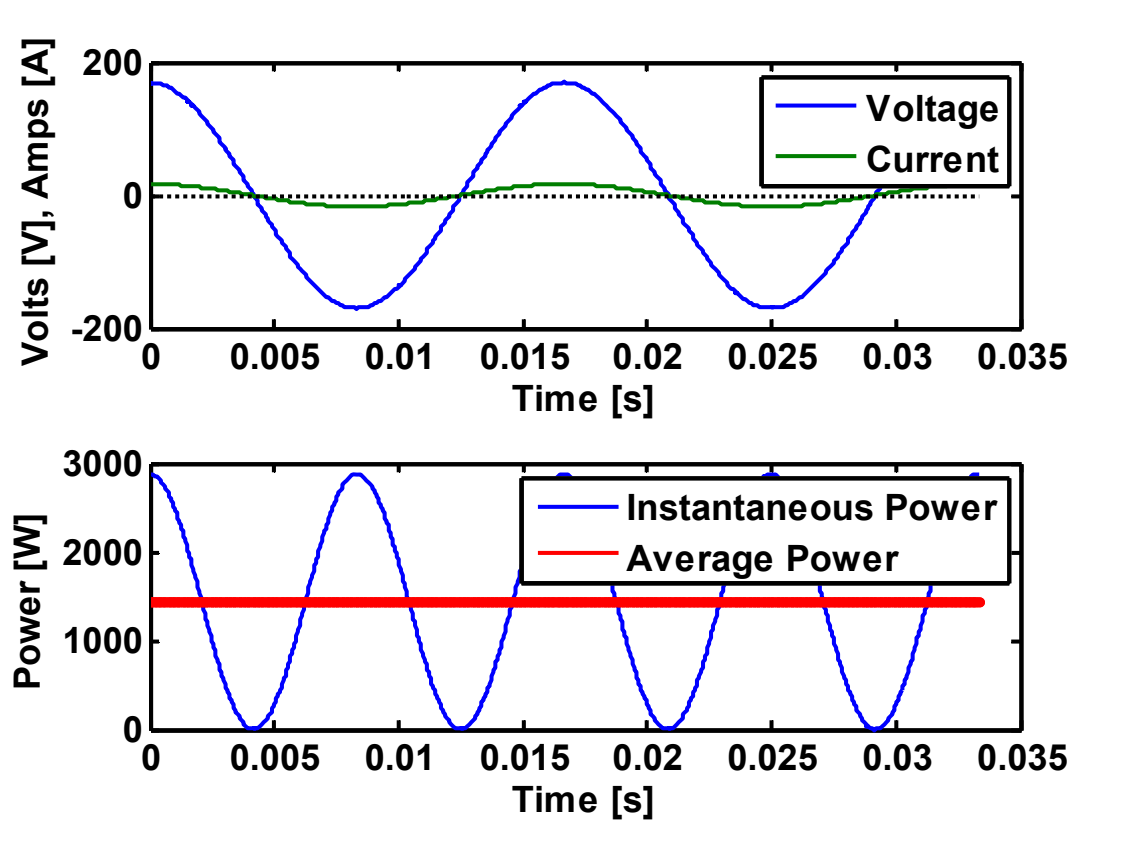
DGWind ~= DG

- Distributed generation renewable energy projects are almost like non-renewable DG but…
- No fuel requirement
- Not dispatchable (or semi-dispatchable)
- Variable output
  - Good: designed to cope well with variability
  - Bad: variable output can cause headaches

Water flowing in a pipe

- Direct Current (DC)
  - Pressure (psi) : voltage (volts)
  - Flow (gpm): current (amps)
  - Power (W) : psi X gpm, volts X amps
  - Work (J or kWh): power X time
  - $V=IR \rightarrow P_{loss}=I^2 \times R$
  - Higher voltage means much lower losses
- Alternating Current (AC) is similar but…
  - Now voltage and current can be out of phase
  - New quantity (besides power): reactive power (VAr)

The Magic of AC—reactive power



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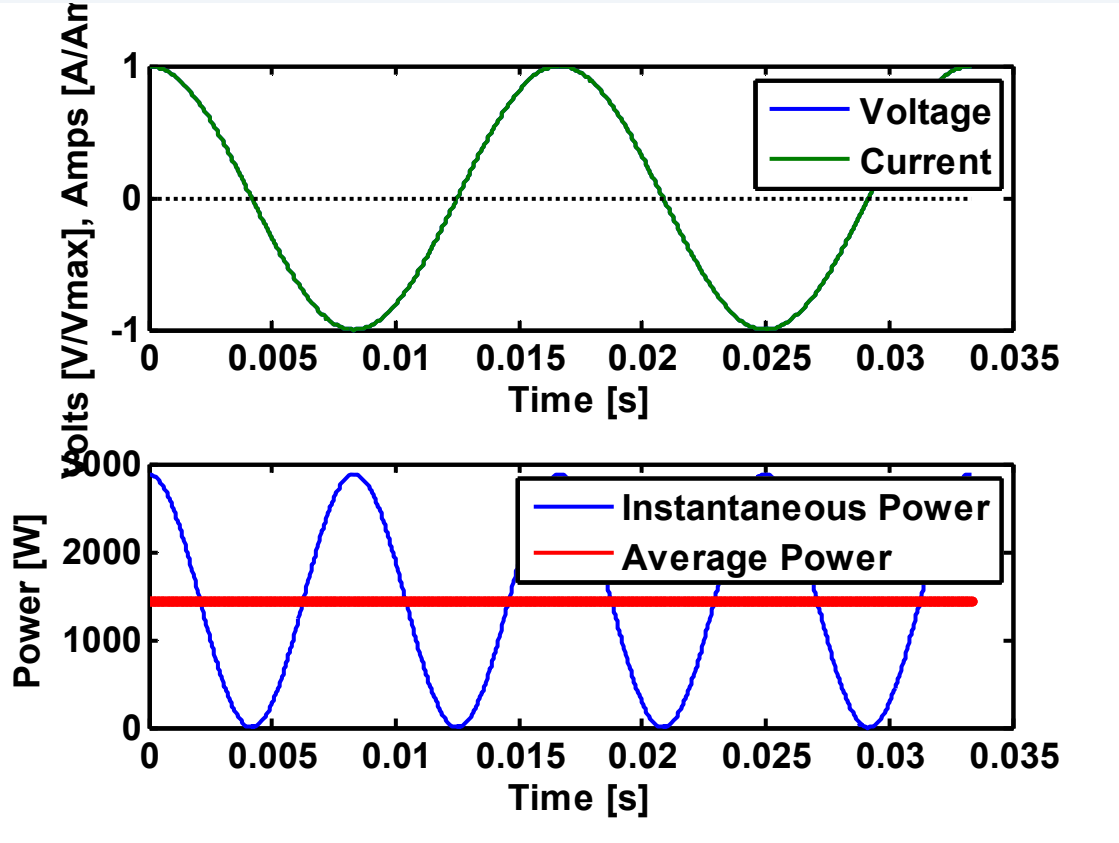

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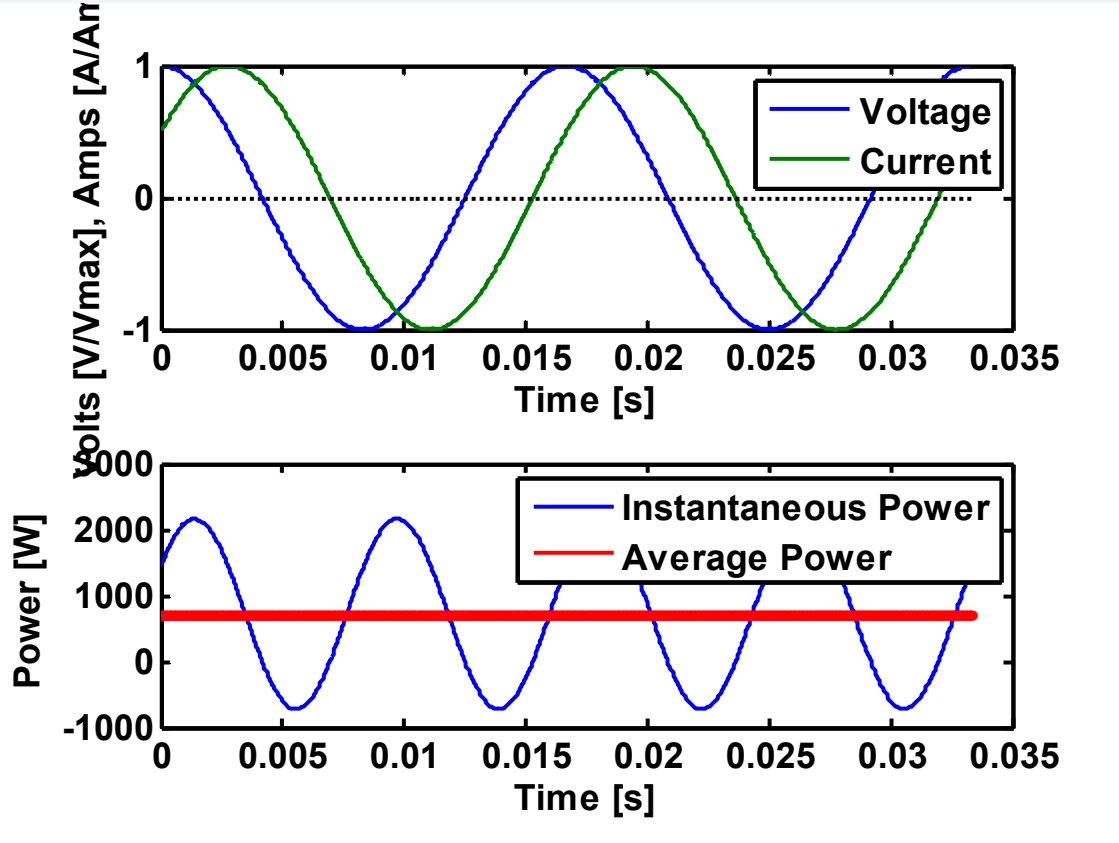

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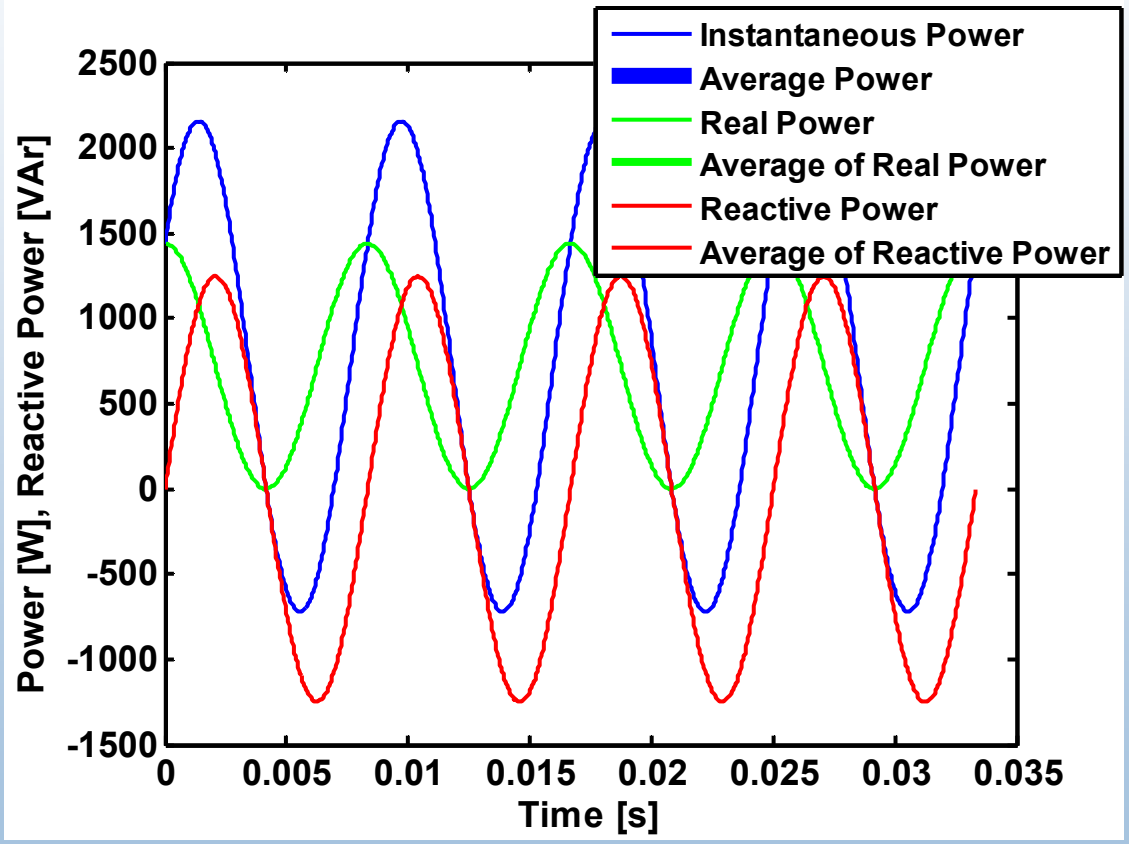

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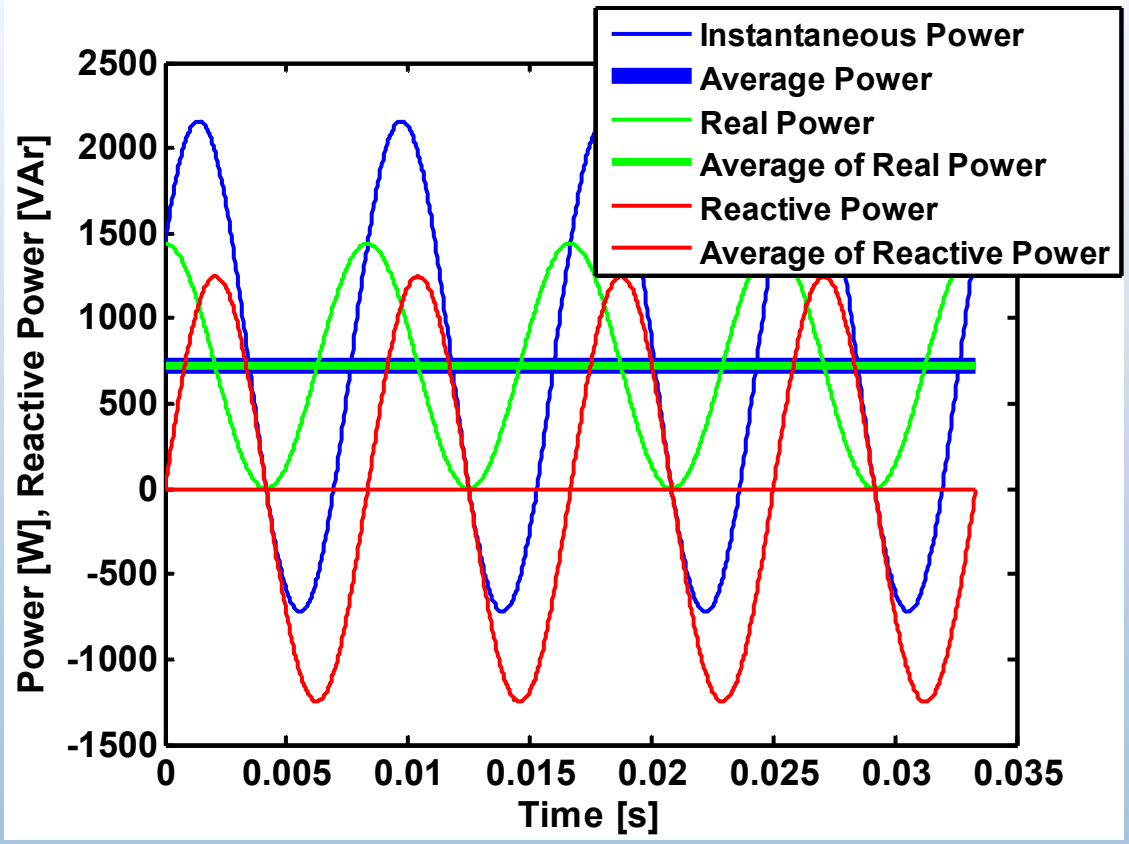

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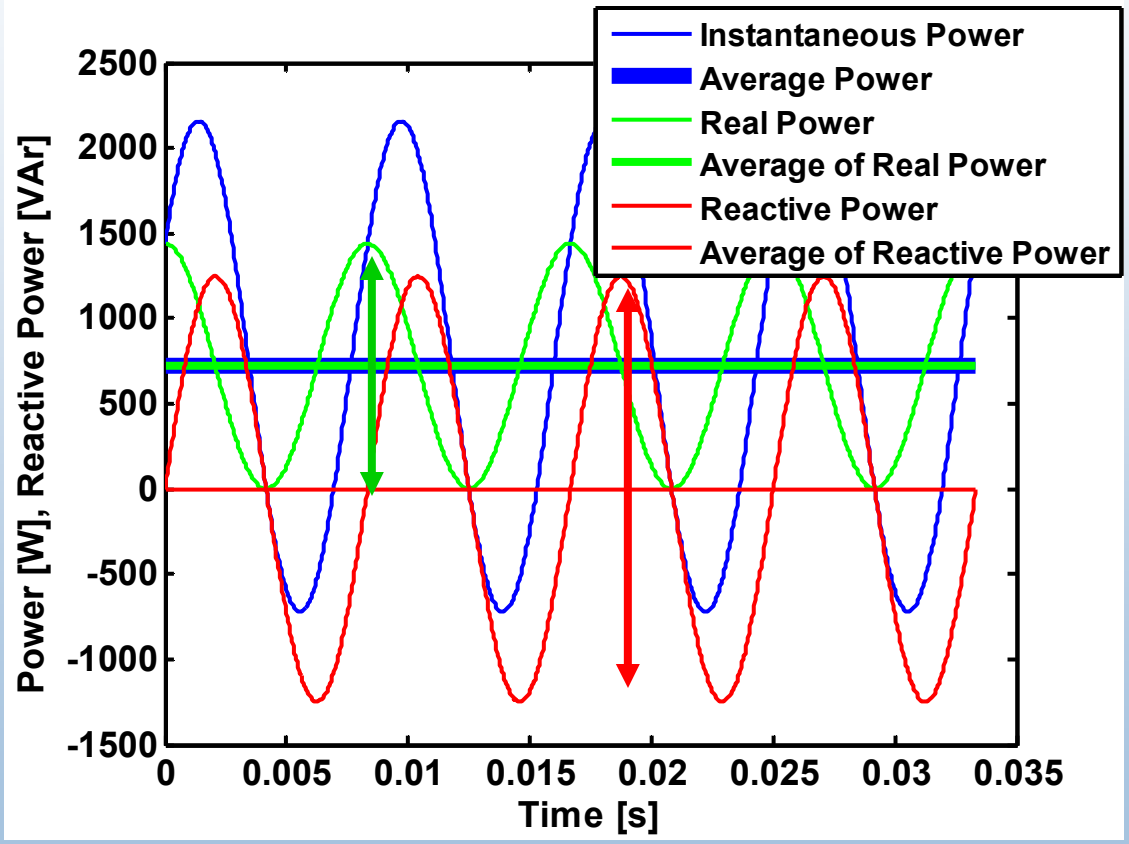


More on Real and Reactive Power

- Real power is power to do work
  - Mechanical
  - Thermal
  - Losses
- Reactive power doesn't really do anything, but…
  - Takes up current capacity in line
  - Can** be used for regulating voltage
  - 'Foam' in the beer flowing in pipe analogy
  - No actual losses

Power Factor and VA

- Cosine of the phase lag between voltage and current
  - Can vary from 0 to 1 and lagging to leading
  - Previous e.g. cos(60°)=0.5 lagging
- Lagging: current is lagging the voltage
- Pf=1: voltage and current are in phase
- Convention:
  - lagging load is consuming VArs
  - leading generator is consuming VArs
  - Both depress the voltage to some degree!
- VA: how most electrical equip is rated

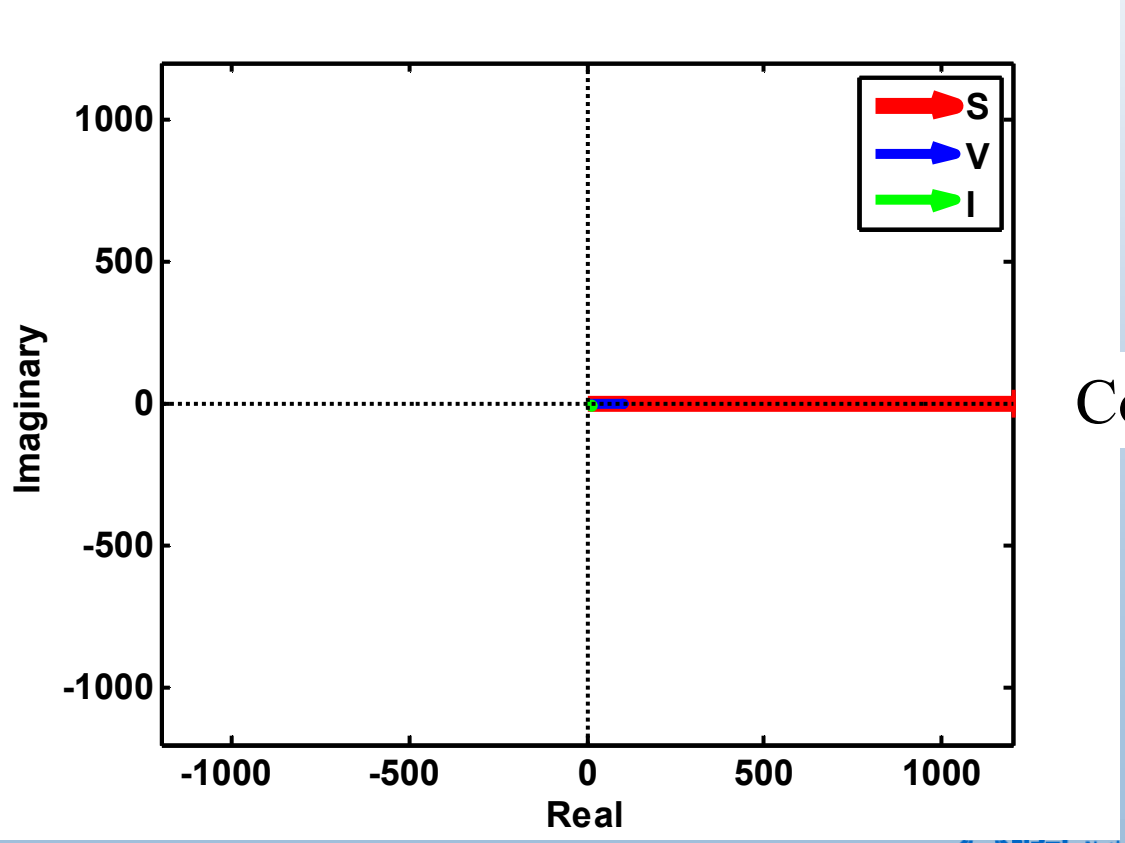
Phasors

- Not particularly useful on Romulans
- “removes” the sinusoidal component of a waveform
- Uses Euler's identity
  - $e^{jx}=\cos(x)+j*\sin(x)$
- $v(t)=V*\cos(2*\pi*f*t)=V*\mathrm{Real}(e^{j(2*\pi*f*t)})$
- $v(t)= V*\mathrm{Real}(e^{j(2*\pi*f*t)})$
- if $i(t)=I*\cos(2*\pi*f*t+\delta)=I*\mathrm{Real}(e^{j(2*\pi*f*t)} *e^{j\delta})$
- Drop the $e^{j(2*\pi*f*t)}$ to see phase relationship
- $\underline{V}=V\angle 0°$, $\underline{I}=I\angle\delta$

Phasors Actually Make Life Easier

- $\underline{S} = V\angle 0° * I\angle -\delta$

Consume Q



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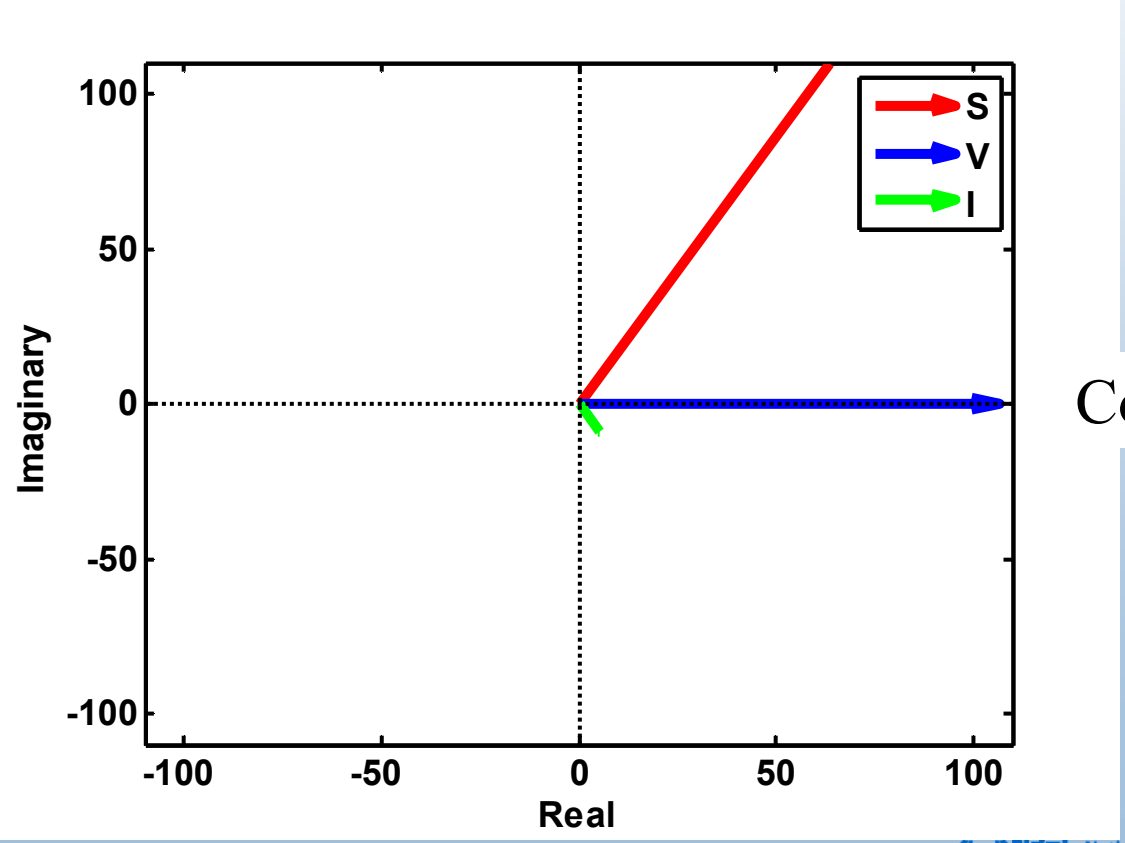

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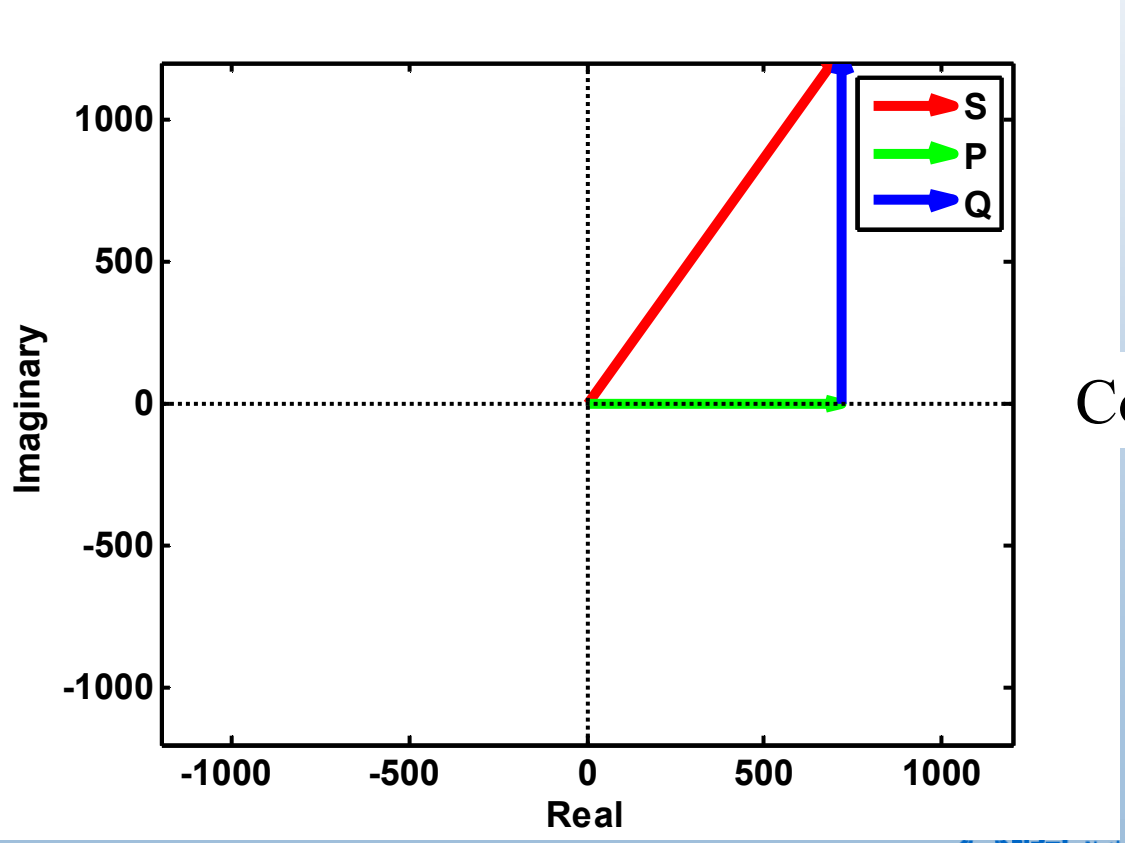
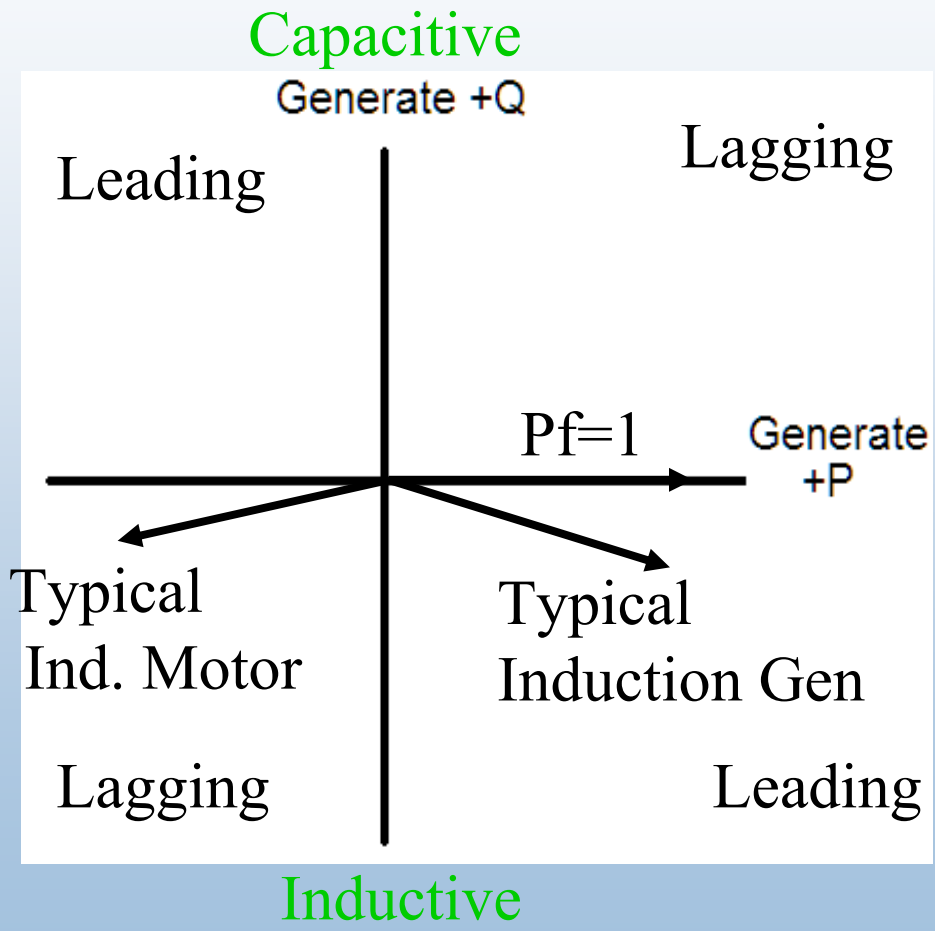


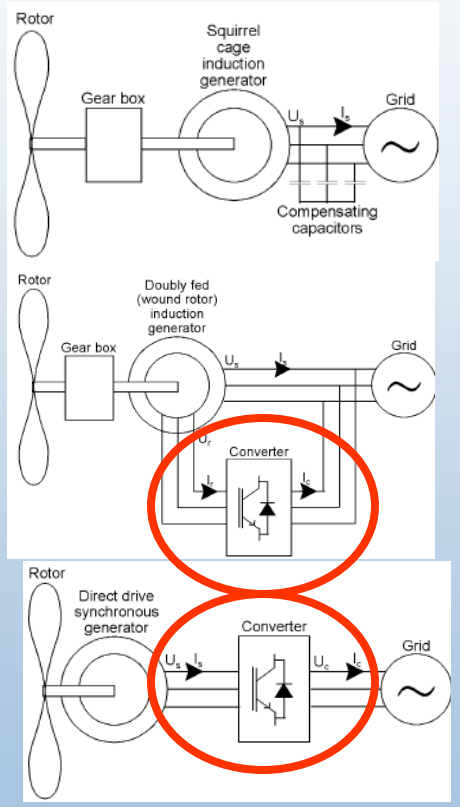
Consume P

A Helpful Graph



Wind Turbine Electrical Power System

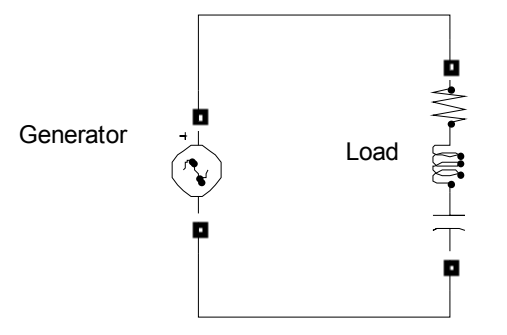
- Generators
  - Induction
  - Synchronous
- Power Electronics
  - None (SCIG)
  - Partially rated (DFIG)
  - Full Rated

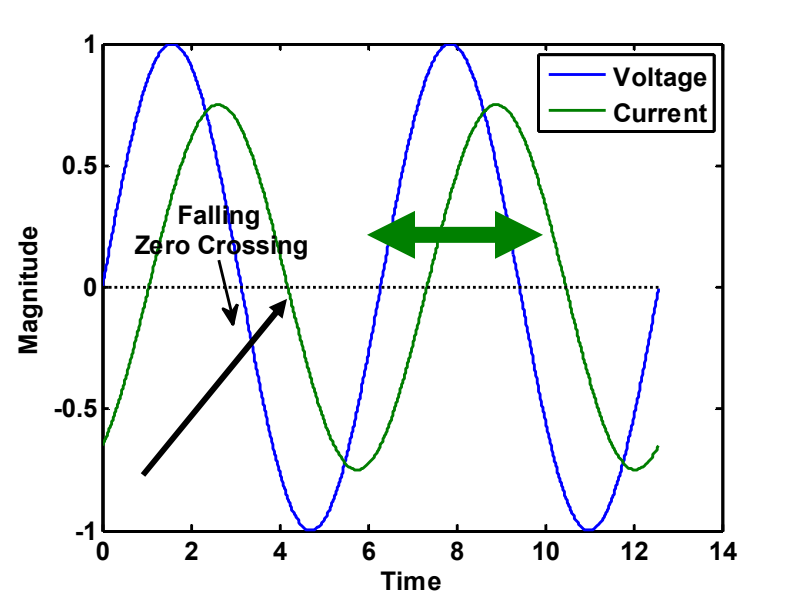


J Slootweg 2003

Power Electronics and Their Potential

- Decouple prime-mover (rotor) and “the grid”
- Originally: increase energy capture
- Then: load reduction
- Now: allow fine control of voltage and current
- Flexible AC Transmission System technology
- Expensive





Voltage Regulation

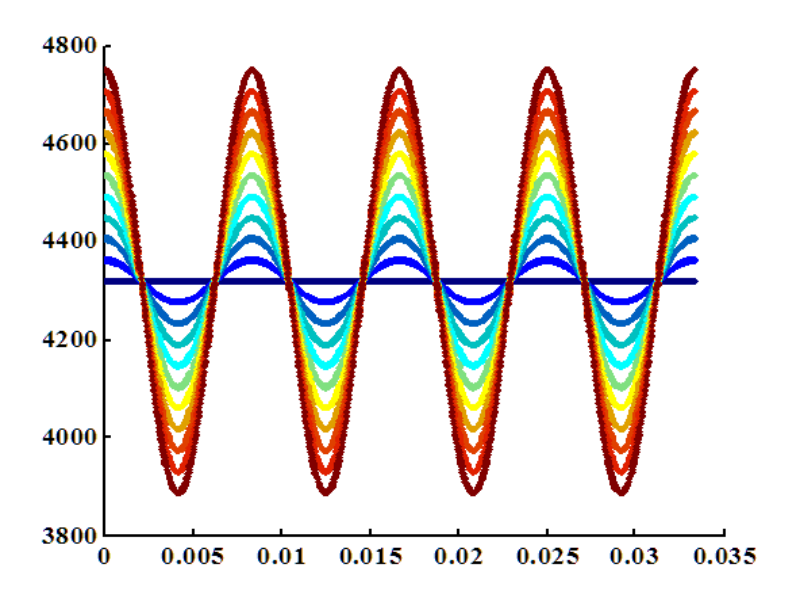
- Line voltage to remain within say +/- 5% (ANSI C84.1)
- During operation
  - Fluctuating power causes fluctuating voltage
- During start-up
  - Large inrush current can depress local voltage
- Power Electronics equipped turbines can do a lot to mitigate the fluctuations
  - By limiting inrush current
  - By manipulating voltage and current phase

Harmonics

- But…power electronics can be a source of harmonics (other sources, too)
- Ideal generator is a voltage source with pure 60Hz sine wave
- Harmonics are multiples of 60Hz e.g. 120Hz, 180Hz, even up to 3000+Hz
- Distort the shape of the waveform
- Harmonic voltage source →harmonic currents
- IEEE/ANSI 519 specifies tolerable limits
- THD is a measure of all of the harmonics combined

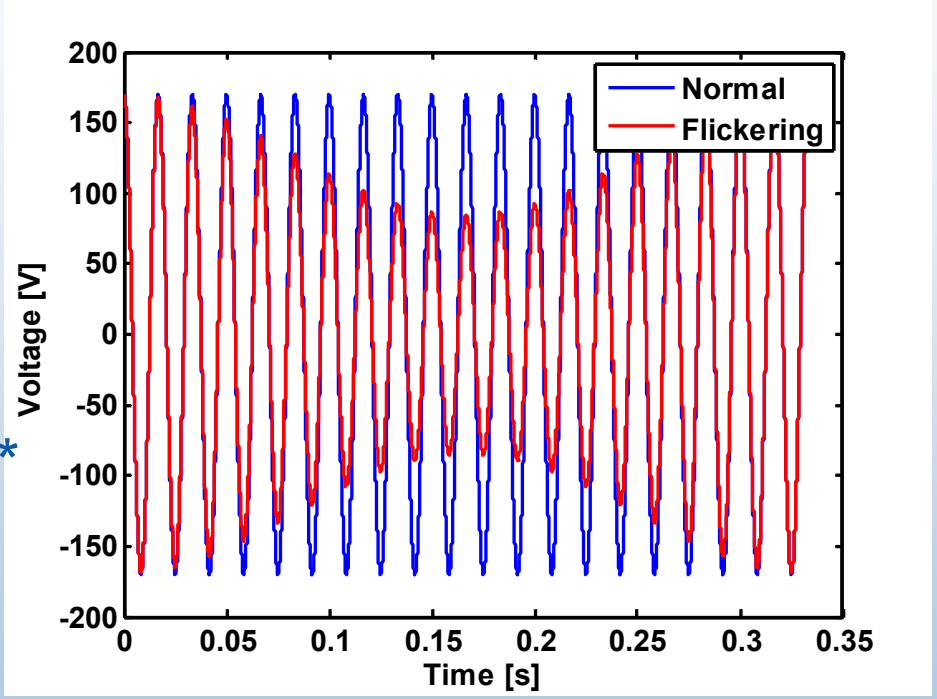
Why do we care?

- Harmonics cause problems
  - Electrical Interference
  - Additional heating of equipment
  - Torque ripple
  - Reduce power factor
  - Triplen (3,9,15…) harmonics end up in neutral wires of wye connected equipment



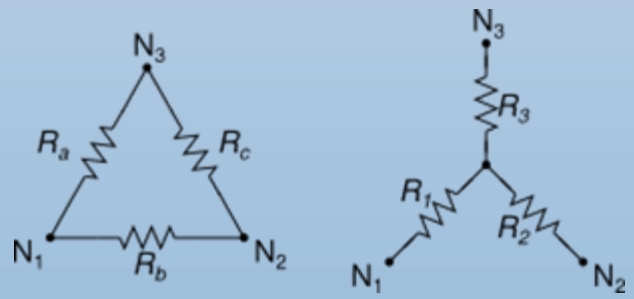
Flicker

- A modulation of the 60Hz voltage
- Often during starts, stops, switching ops
- Causes lights to flicker
- Power electronics can** essentially eliminate
- IEEE/ANSI 519 sets limits



3 Phase Power: An Additional Layer of Complexity

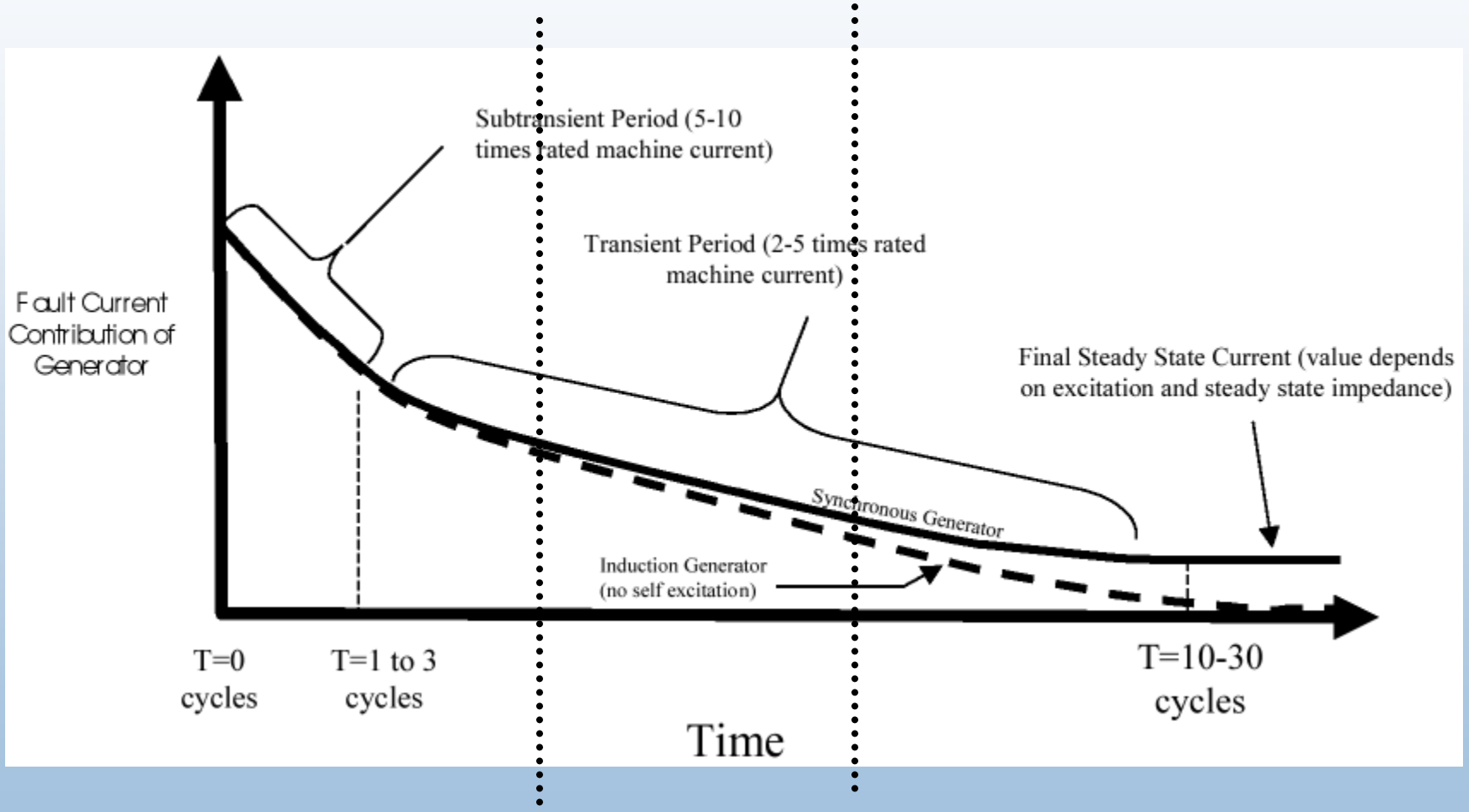
- 3ϕ brings enormous benefits
  - Balanced 3ϕ doesn't require** a neutral
  - No torque ripple for motors/generators
- But, it's more complicated than 1ϕ
- Most 3ϕ equipment is rated in terms of voltage between 2 of the phases: V_{L-L}
- $V_{L-L} = V_{L-N} * \text{sqrt}(3)\angle 30°$
- 3ϕ equipment can be connected in Wye (Star) or Delta



Why do we Care?: Faults

- Most 3ϕ distribution systems are either:
  - 4 wire multigrounded (i.e. wye based)
  - 3 wire ungrounded (i.e. delta based)
- 2 types of faults:
  - Short circuit: e.g. line falls on ground
  - Open circuit: e.g. fuse opens inadvertently
- Most faults on distribution systems are single phase short circuits
- 1ϕ & 2ϕ shorts can be hard on generators--imbalance
- 3ϕ shorts, though rare, have high currents

Fault Current



Source: EPRI 1004061 Integrating Distributed…

Transformer Grounding Compatibility

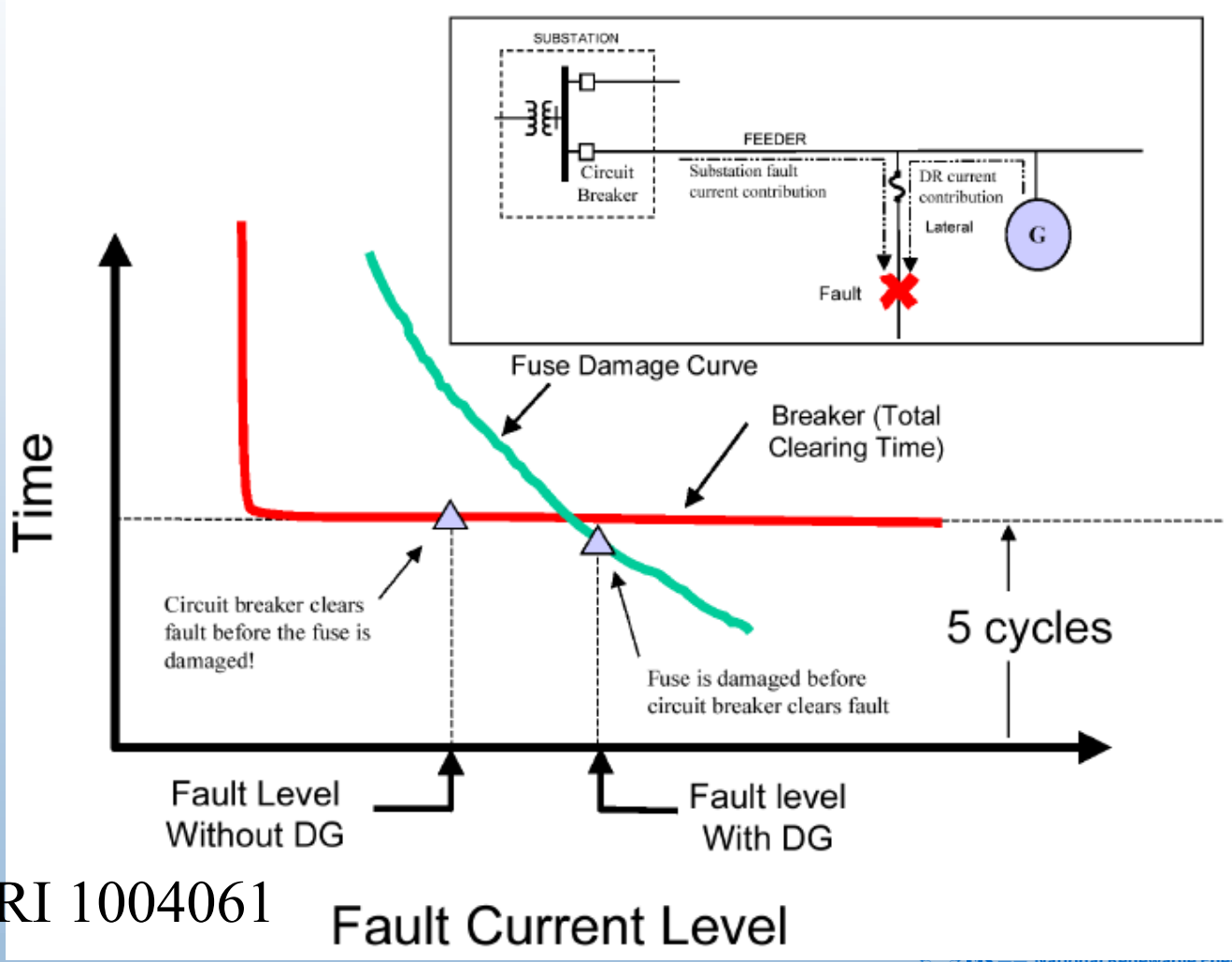
Winding Configuration Employed for Interface Between the Generator and Utility System		Is it a Grounded Generation Source with Respect to Utility System Primary?	Type of Distribution System to Which this Transformer Should Normally Be Applied
Utility Primary Side	Generator Side (Low voltage side)		
		Yes	Suitable for four-wire, multi-grounded neutral systems. It may need a neutral grounding impedance and three-pole switchgear on the primary of the transformer
		Only if the generator neutral is grounded	Suitable for most four-wire, multi-grounded neutral systems but the generator must be grounded. May expose the generator to severe fault forces—neutral grounding impedance may be needed.
		No	Not usually recommended for four-wire, multi-grounded systems. A good choice for three-wire, ungrounded distribution systems.
		No	Not usually recommended for four-wire, multi-grounded neutral systems. A possible choice for three-wire, ungrounded distribution systems.

Source: EPRI 1004061 Integrating Distributed…

Protective Device Coordination

- Radial nature of distribution system allows a simplified protection scheme
  - Power (Current) flows from the substation down to the end of the feeder
  - Protection is usually based on time and current
- Again, power electronics can** alleviate or mitigate problems—by immediately (~1 cycle) stopping the flow of current

One e.g. How DG can Interfere with Protection



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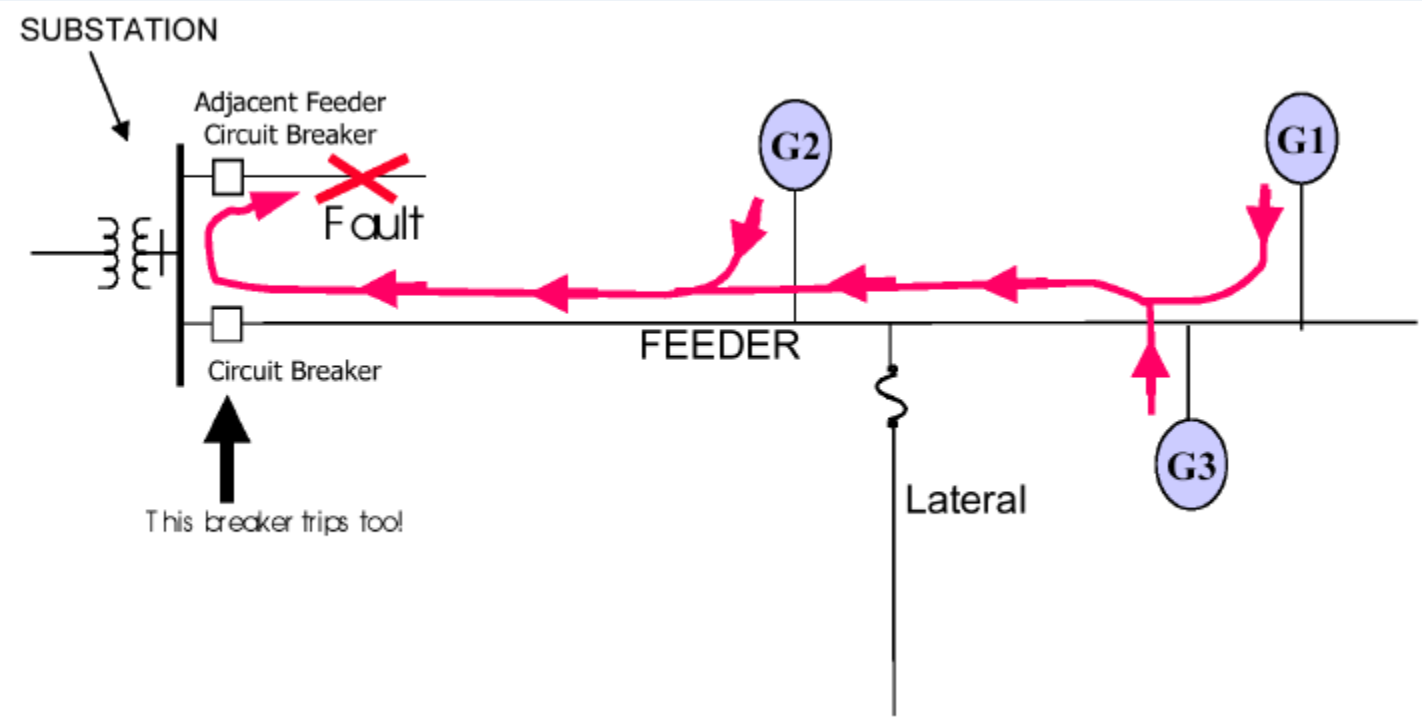
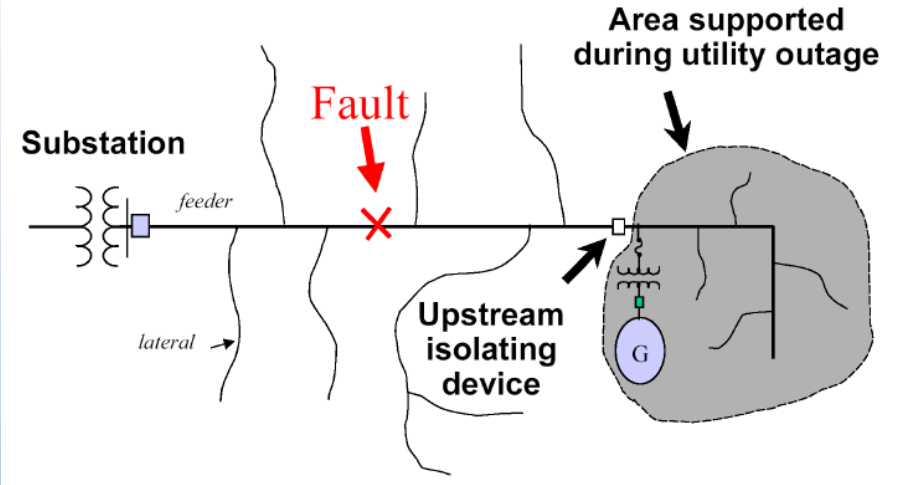
Nuisance Trips



Source: EPRI 1004061

Islanding

- Can be good
  - Island can have power supply
- Can be very bad
  - Voltage magnitude can fluctuate
  - Reconnection is tricky
- Still a tricky problem



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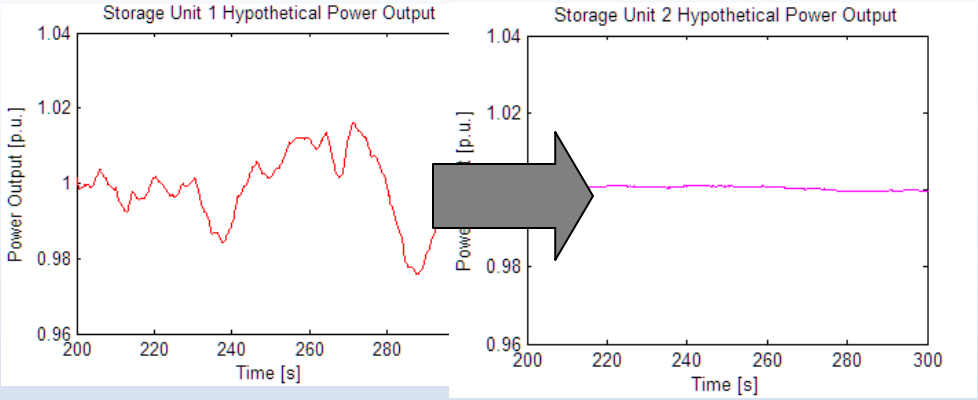
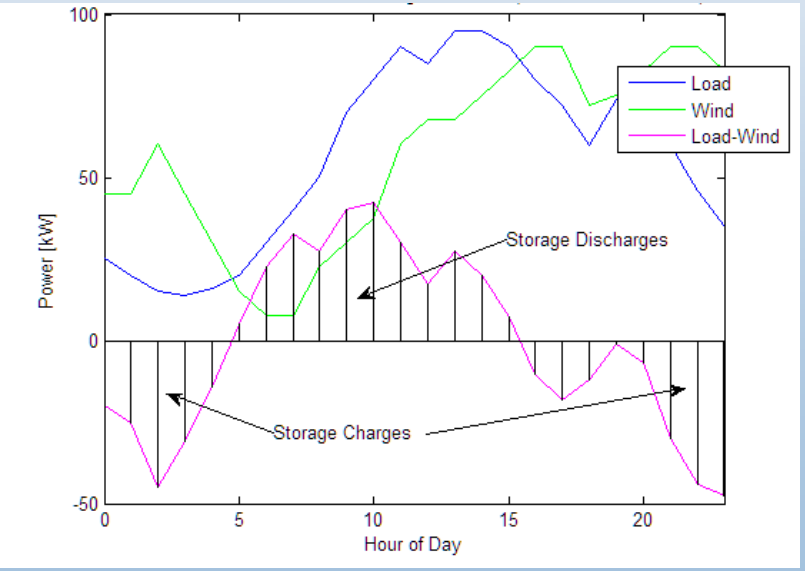
A Potential Game Changer

- Storage further decouples rotor and grid
- Allows:
  - Smoothing
    - Short-term
    - Long-term
  - Dispatching of renewable power
  - Better contingency operation





Some of the Business

- Behind the meter
  - DG never generates above your minimum load
  - Utility never sees your generator
- Net metering
  - Utility sums up all the energy you generate over say a month
  - You are billed only for the kWh you didn't generate
  - Usually for small (i.e. a few kW) projects
- Larger projects
  - All sorts of regulations and thresholds
    - Your utility, your ISO/RTO, your state

The Process

- Behind the meter probably doesn't require much
  - probably need a facility disconnect switch: safety
  - You will need to do the analysis for you system
- Net metering
  - Various levels: might have an expedited procedure
  - IEEE 1547
- Larger project
  - System impact studies, etc and etc…

The Technical Upshot

- I like power electronics, so do many utilities
- Can be done without power electronics
- Are available in a range of sizes
  - 3.6kW Skystream Southwest Windpower
  - 100kW Northwind Distributed Energy
  - 1.5MW GE
  - 2.5MW Liberty Clipper
  - others
- As time passes, more variants will appear
- A good website: www.dsireusa.org
- A good starting ref: EPRI 1004061

Questions?