

Wind, Solar, and Other Renewable Generation Models



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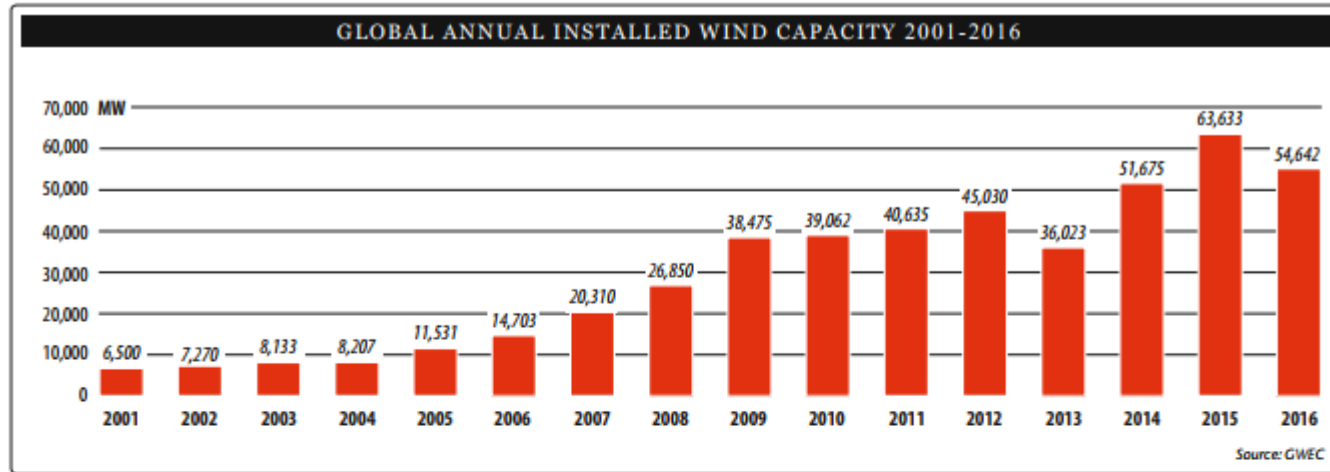
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Renewable Resource Modeling

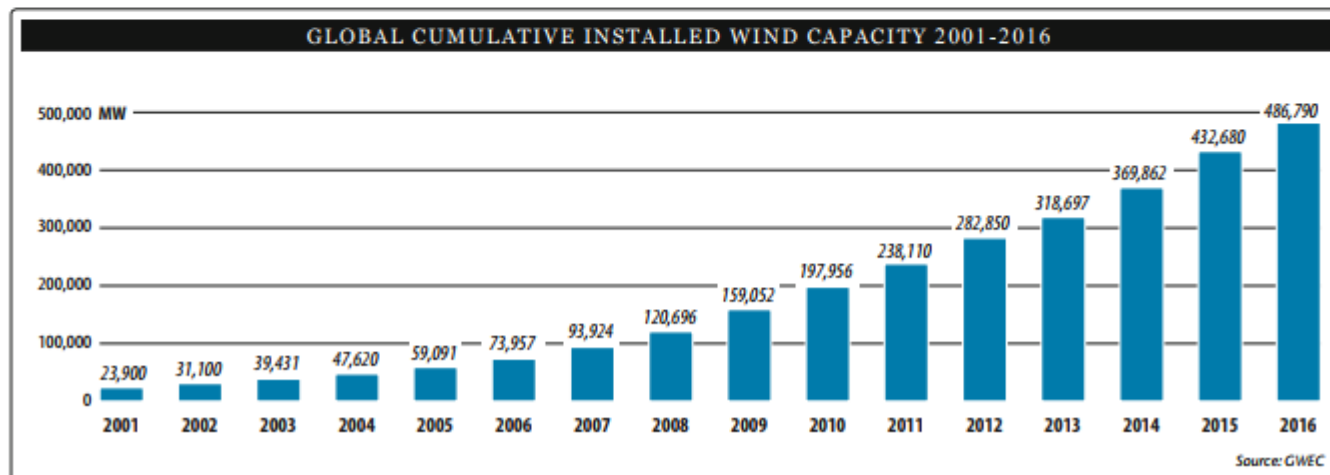


- With the advent of more renewable generation in power systems worldwide it is important to have correct models
- Hydro systems have already been covered
- Solar thermal and geothermal are modeled similar to existing stream generation, so they are not covered here
- Coverage will focus on transient stability level models for wind and solar PV for integrated system studies
 - More detailed EMTP-level models may be needed for individual plant issues, like subsynchronous resonance
 - Models are evolving, with a desire by many to have as generic as possible models

Growth in Wind Worldwide



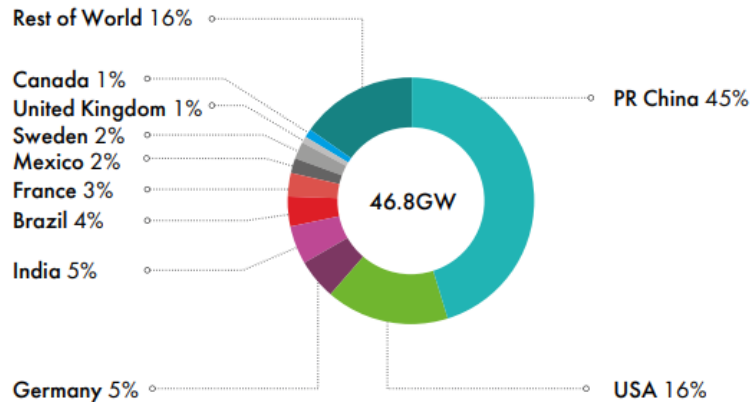
Source: Global Wind 2016 Report, Global Wind Energy Council



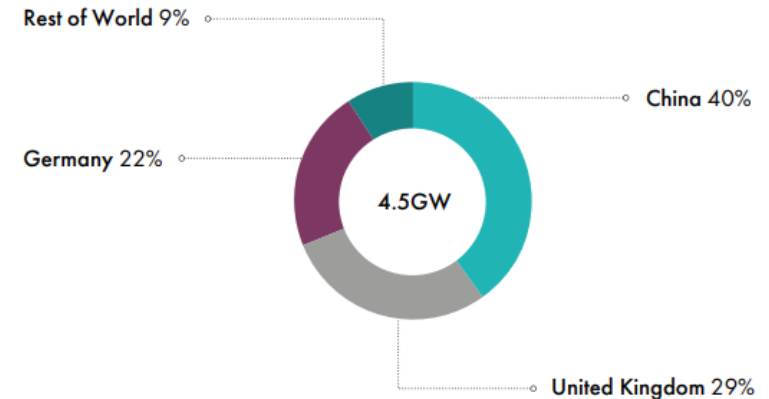
Growth in Wind Worldwide



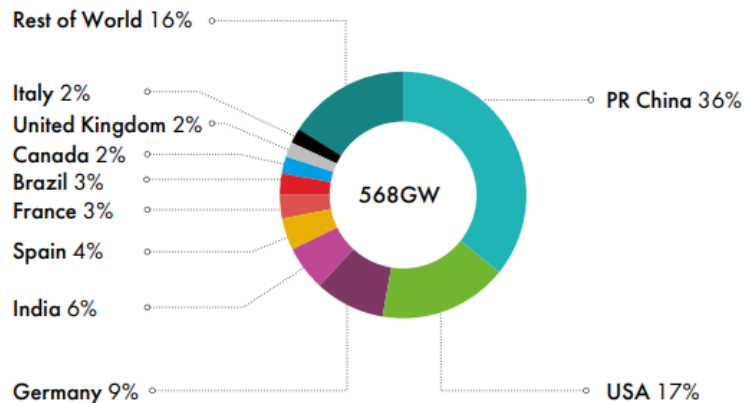
New installations onshore



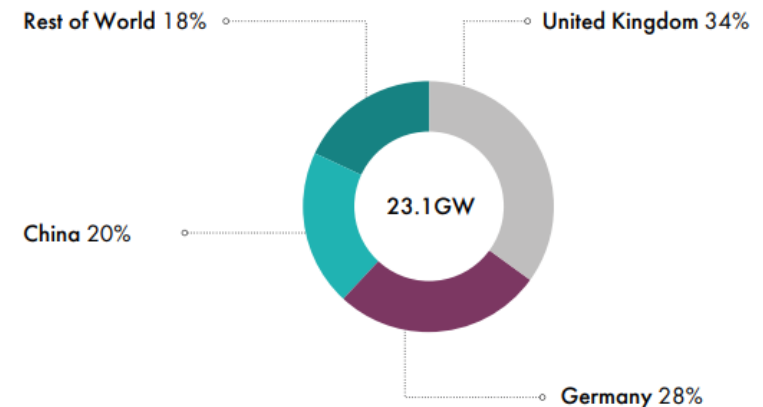
New installations offshore



Total installations onshore



Total installations offshore



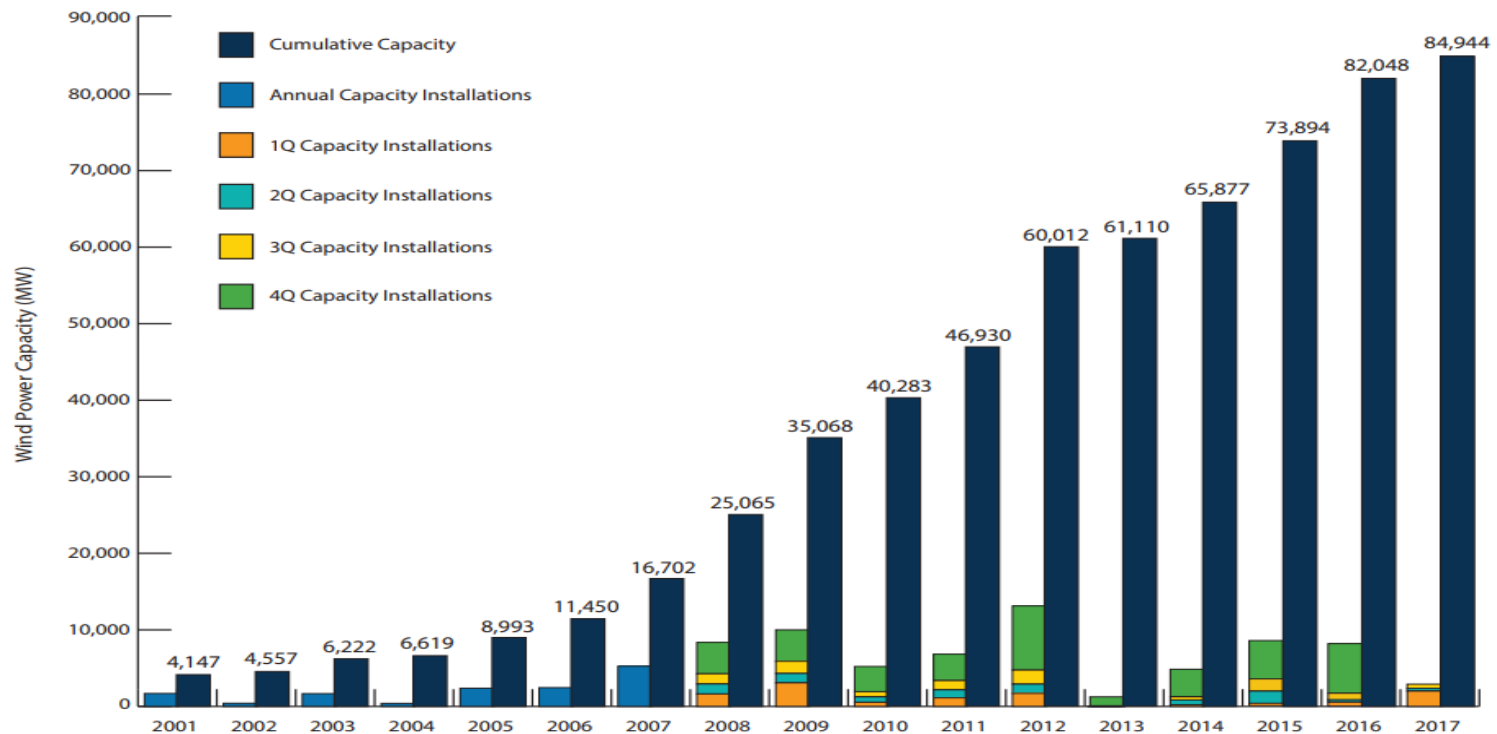
Source: Global Wind 2018 Report, Global Wind Energy Council

Growth in US Wind



- Production tax credit of \$24/MWh being phased out
 - 100% in 2016, 80% in 2017, 60% in 2018, 40% in 2019

U.S. Annual and Cumulative Wind Power Capacity Growth

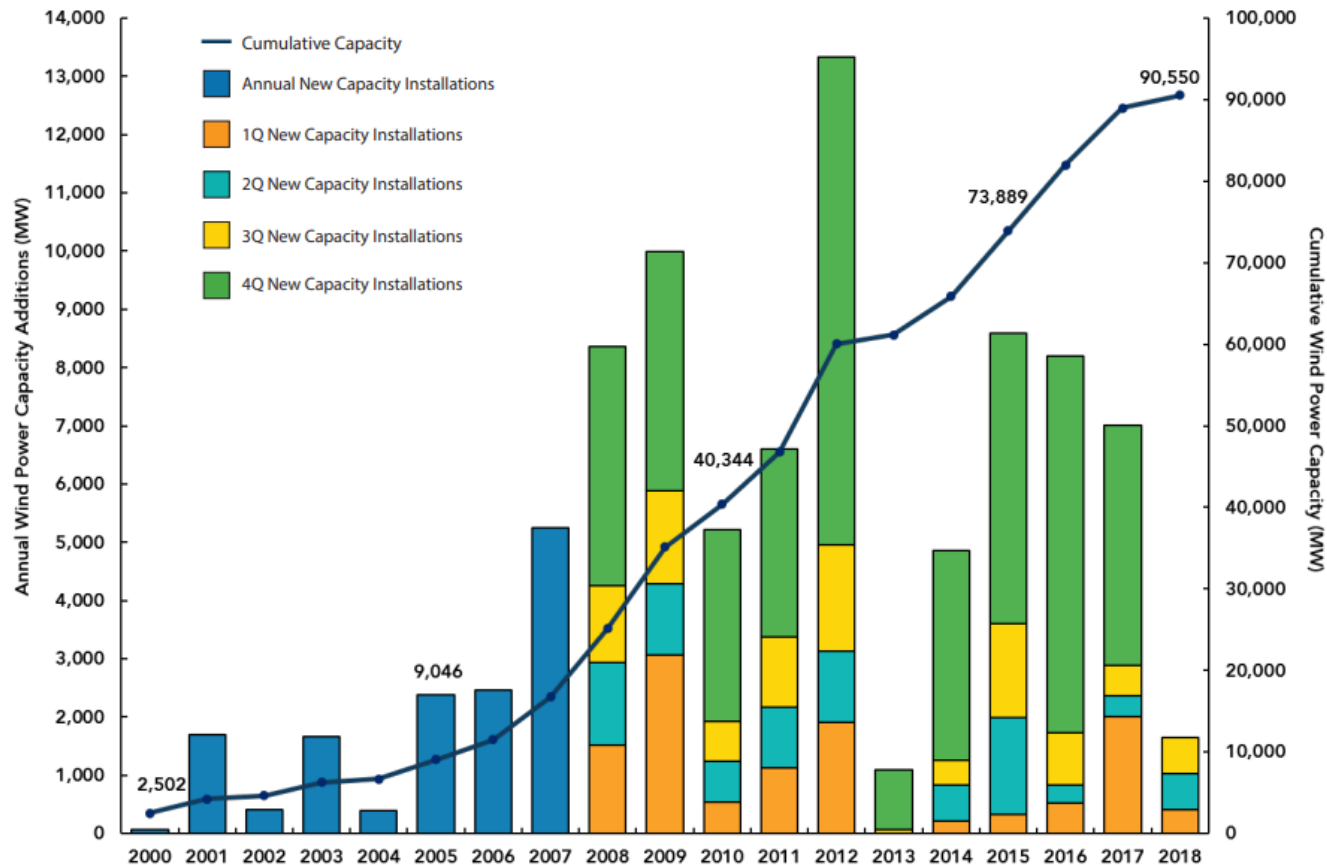


Source: American Wind Energy Association 2017 Third Quarter Market Report

US Annual and Cumulative Wind Power Capacity Growth



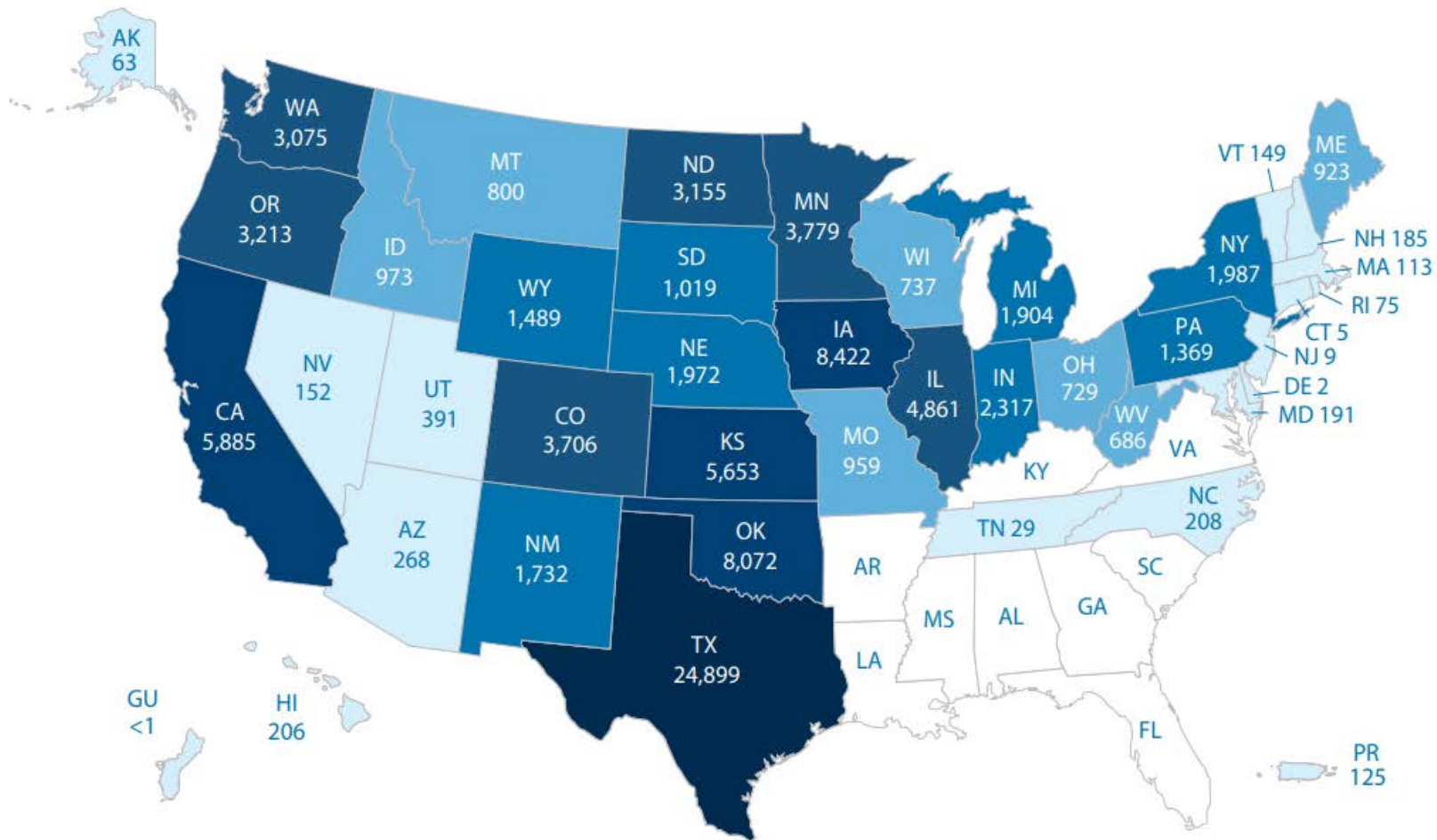
U.S. Annual and Cumulative Wind Power Capacity Growth



Note: Utility-scale wind capacity includes installations of wind turbines larger than 100-kW for the purpose of the AWEA U.S. Wind Industry Quarterly Market Reports. Annual capacity additions and cumulative capacity may not always add up due to decommissioned and repowered wind capacity. Wind capacity data for each year is continuously updated as information changes. AWEA did not track quarterly activity prior to 2008.

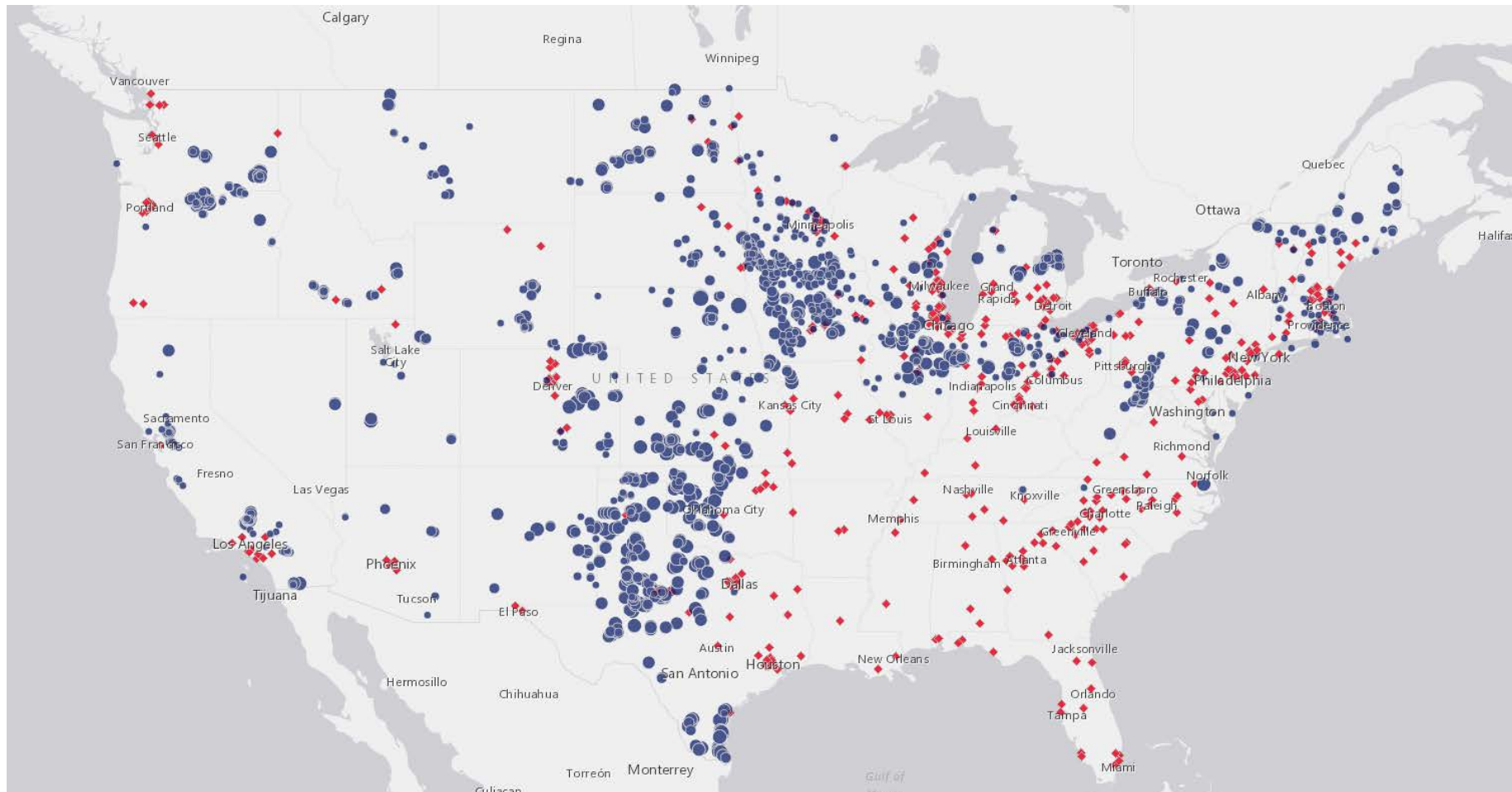
American Wind Energy Association | U.S. Wind Industry Third Quarter 2018 Market Report | Public Version

2018 Installed Capacity by State



■ 0 to 500 MW
 ■ >500 to 1,000 MW
 ■ >1,000 to 2,500 MW
 ■ >2,500 to 5,000 MW
 ■ >5,000 to 10,000 MW
 ■ >10,000 MW

Wind Farm and Wind-Related Plant Locations

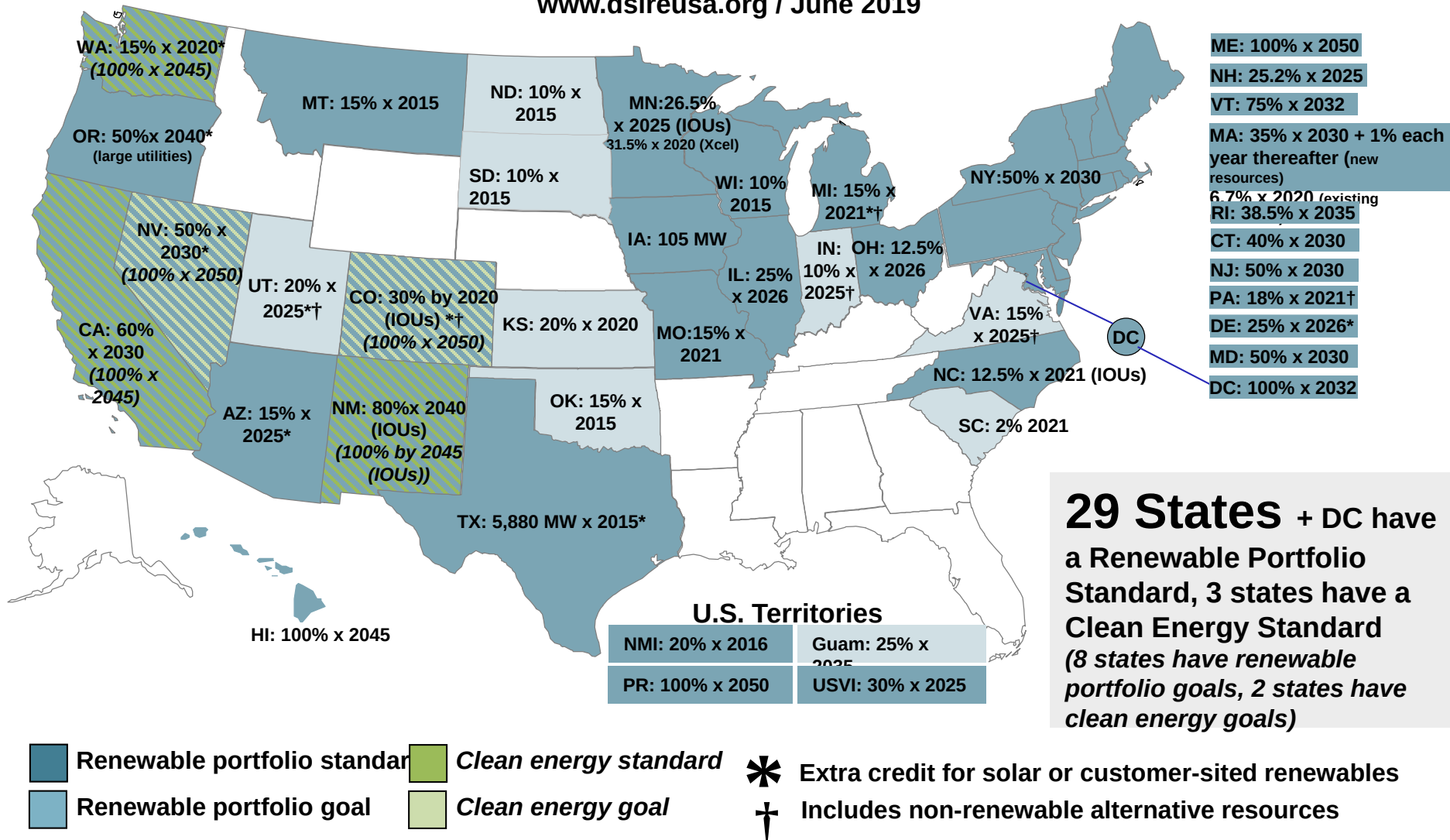


<http://gis.awea.org/arcgisportal/apps/webappviewer/index.html?id=eed1ec3b624742f8b18280e6aa73e>

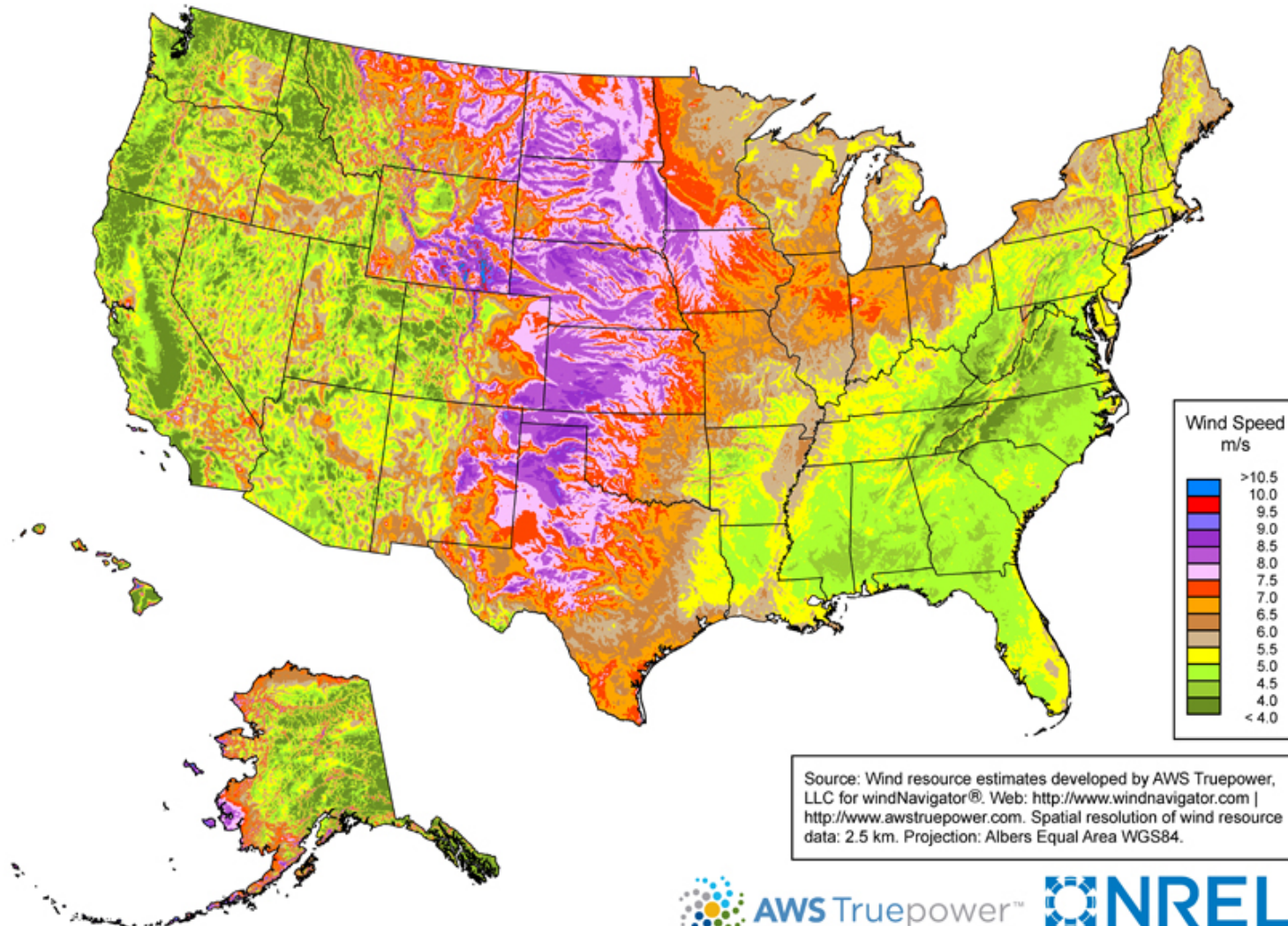
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Renewable & Clean Energy Standards

www.dsireusa.org / June 2019

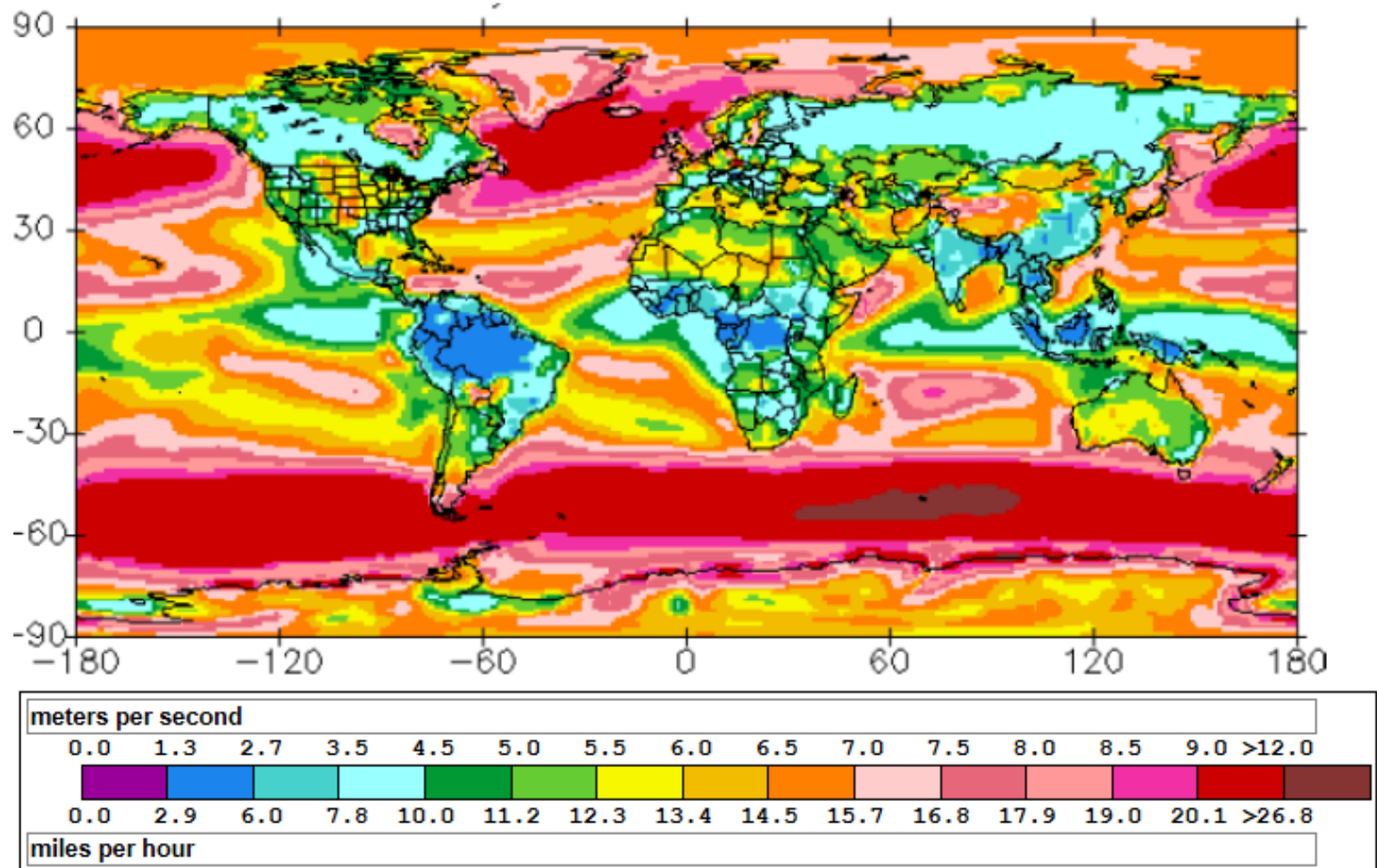


US Wind Resources



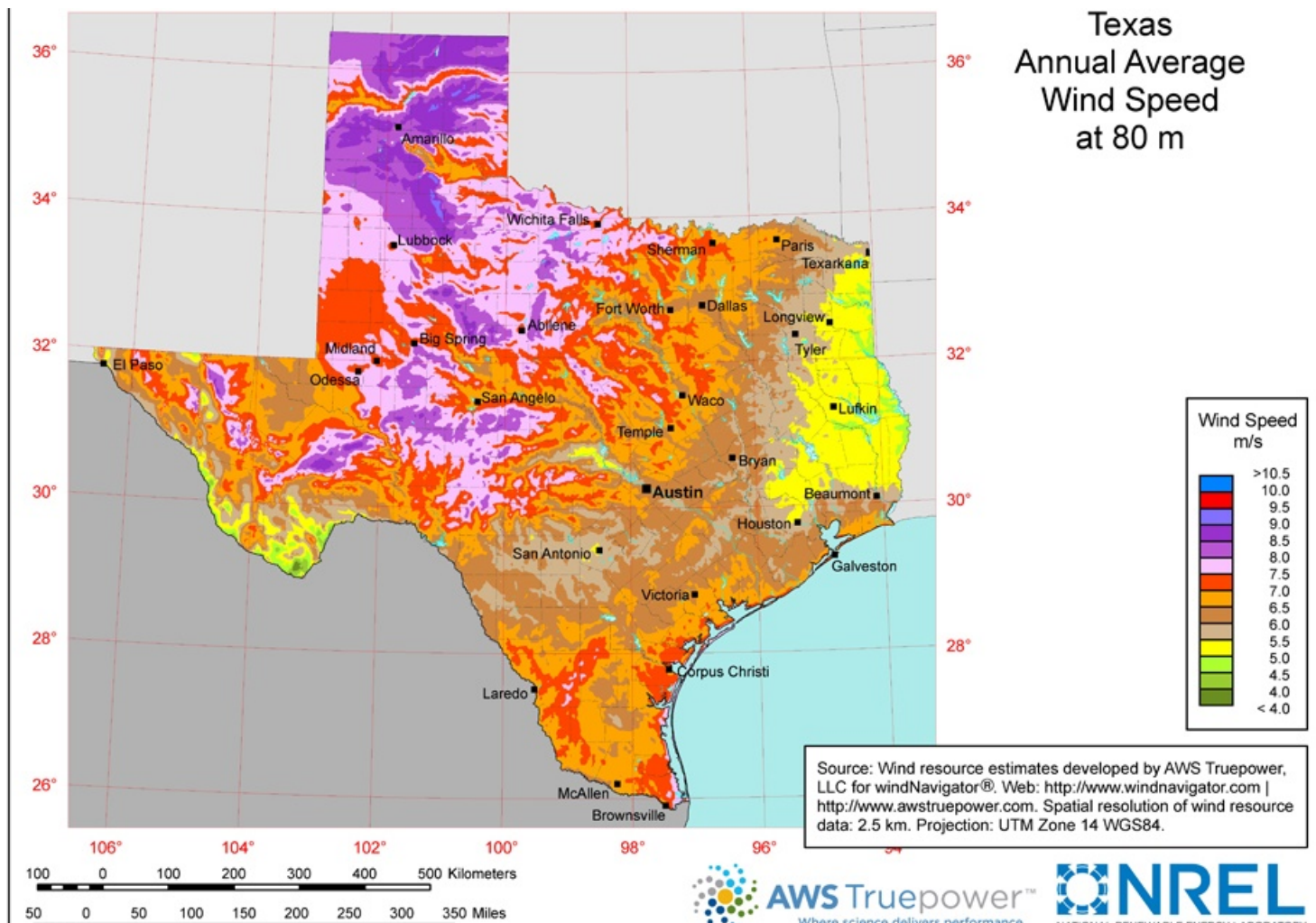
Source: http://www.windpoweringamerica.gov/wind_maps.asp

Global Wind Speed 50m Map



<http://www.climate-charts.com/World-Climate-Maps.html#wind-speed>

Wind Map Texas– 80m Height

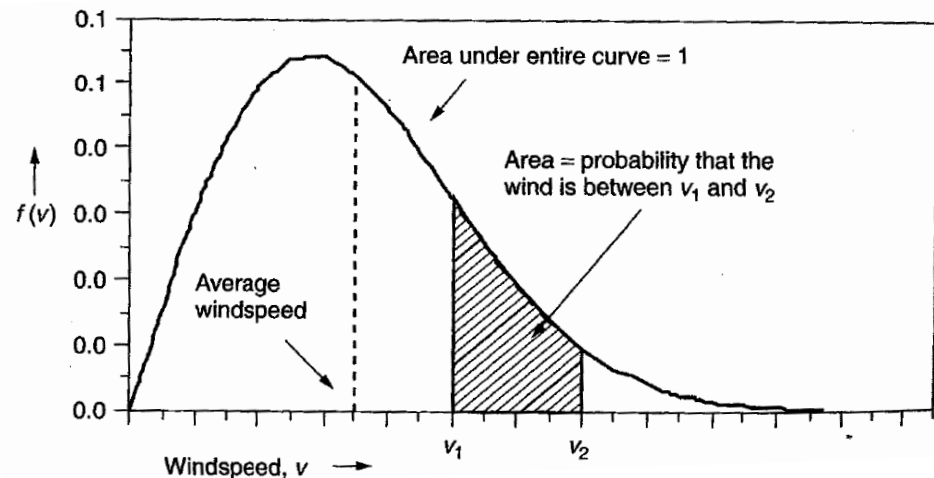


https://windexchange.energy.gov/files/u/visualization/image/tx_80m.jpg

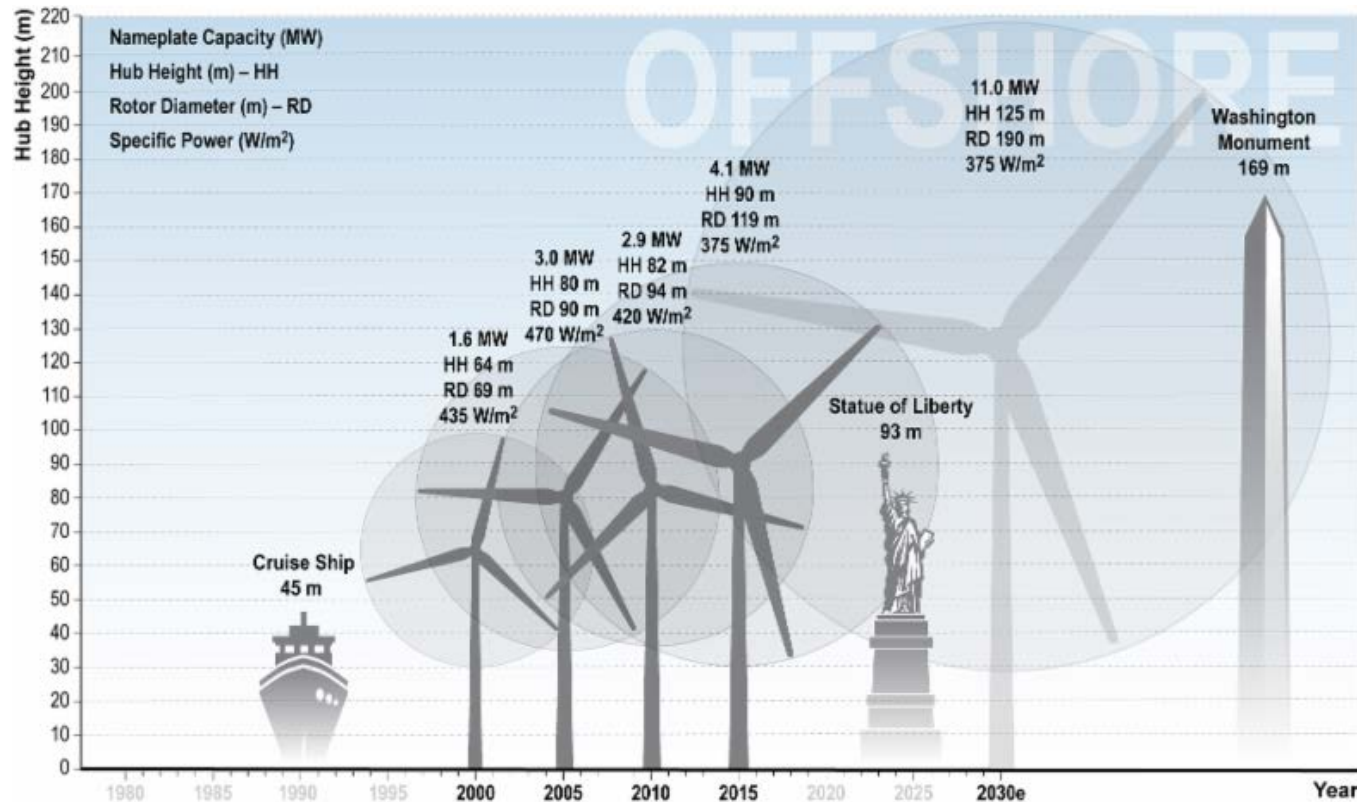
Power in the Wind



- The power in the wind is proportional to the cube of the wind speed
 - Velocity increases with height, with more increase over rougher terrain (doubling at 100m compared to 10m for a small town, but only increasing by 60% over crops or 30% over calm water)
- Maximum rotor efficiency is 59.3%, from Betz' law
- Expected available energy depends on the wind speed probability density function (pdf)



Wind Turbine Height and Size

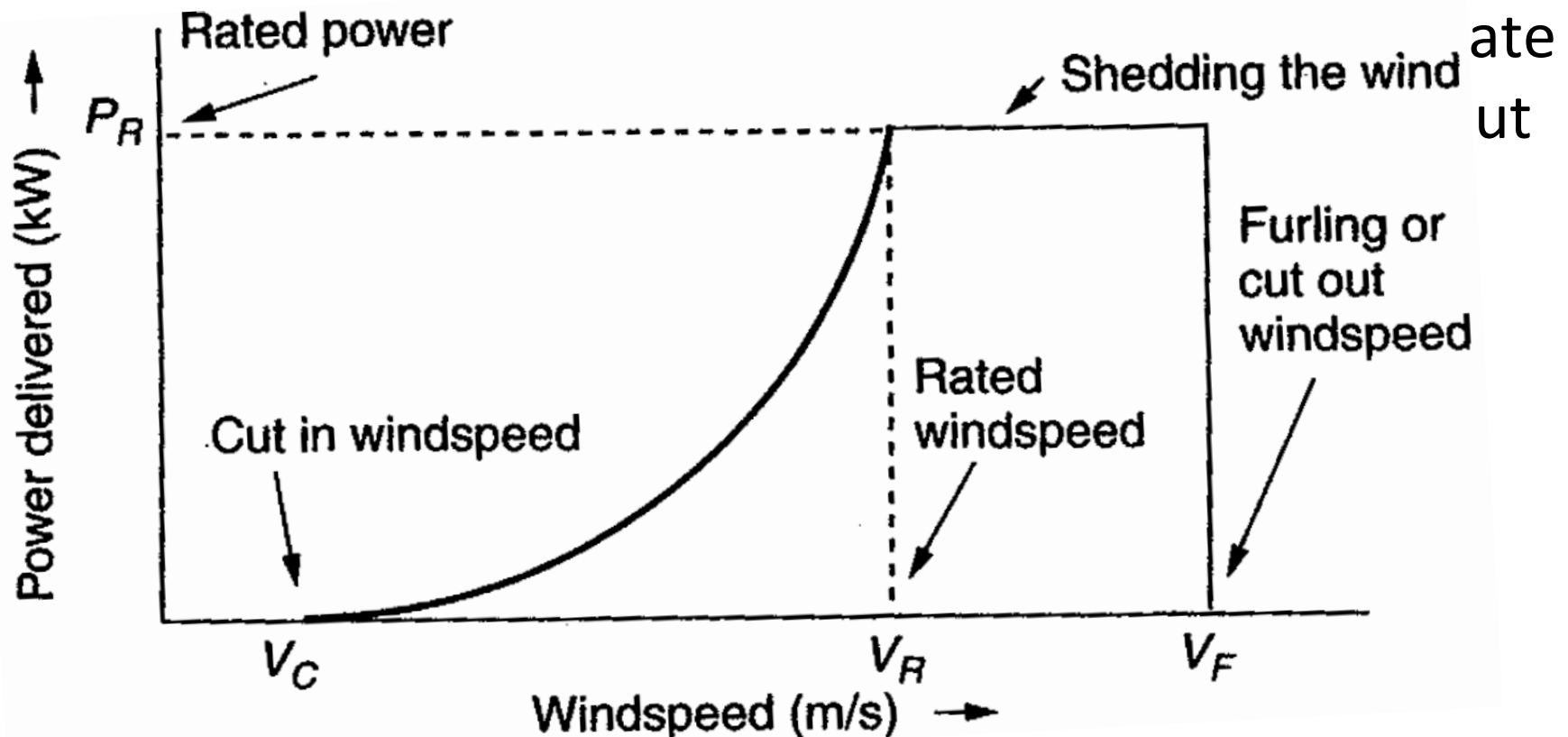


The current largest wind turbine by capacity is the Vestas V164 which has a capacity of 8 MW, a height of 220 m, and diameter of 164 m.

Extracted Power



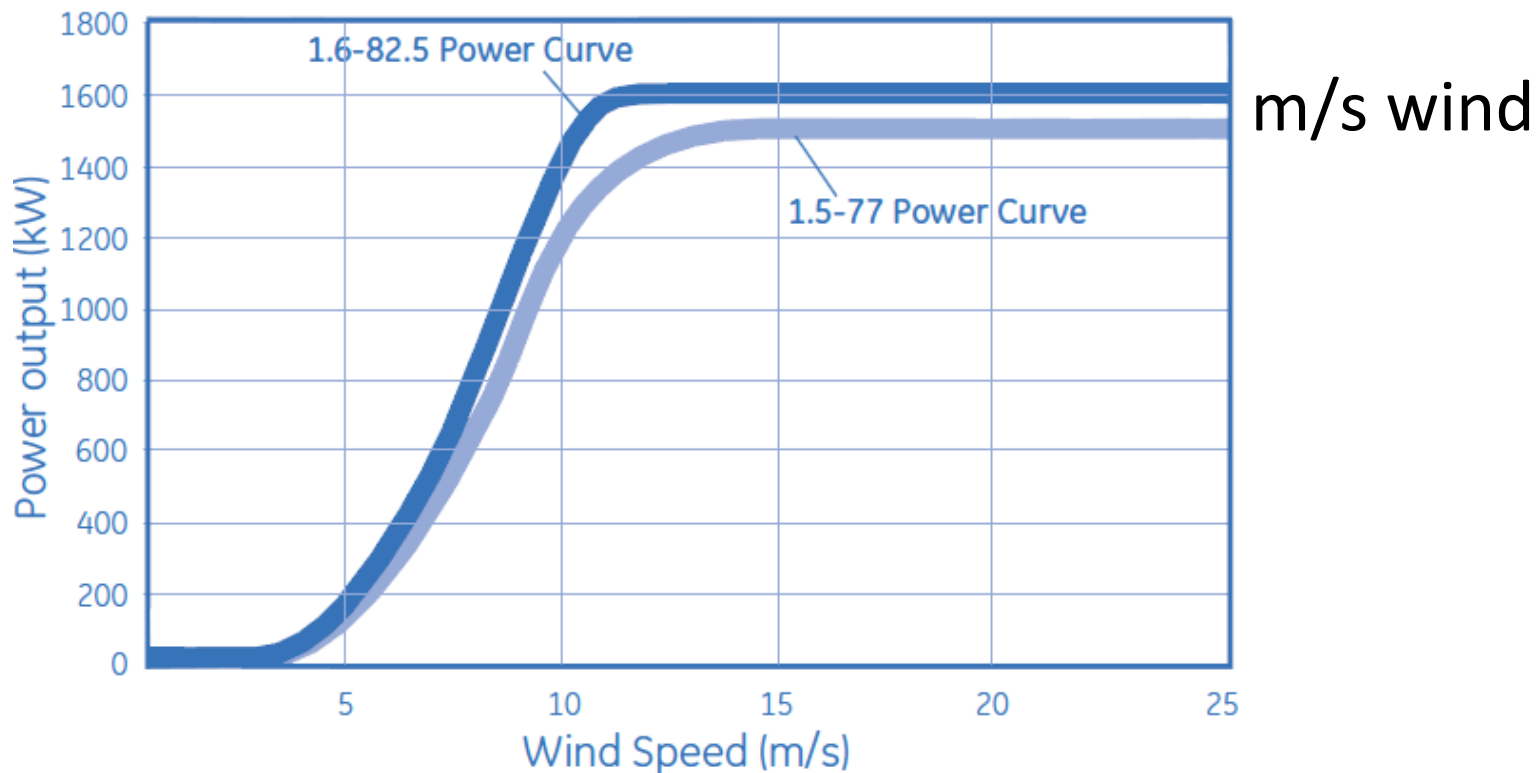
- WTGs are designed for rated power and windspeed



Example: GE 1.5 and 1.6 MW Turbines



- Power speed curves for the GE 1.5 and 1.6 MW



Source: http://site.ge-energy.com/prod_serv/products/wind_turbines/en/15mw/index.htm

Wind Farms (or Parks)



- Usually wind farm is modeled in aggregate for grid studies; wind farm can consist of many small (1 to 3 MW) wind turbine-generators (WTGs) operating at low voltage (e.g. 0.6kV)

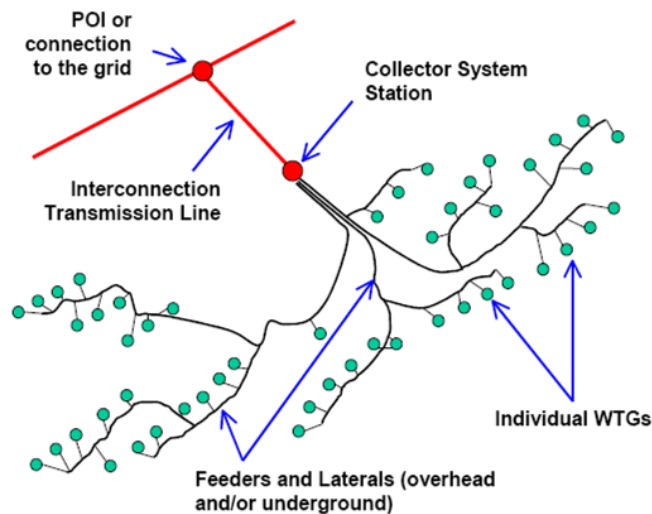


Photo Source:

www.energyindustryphotos.com/photos_of_wind_farm_turbines.htm

Economies of Scale

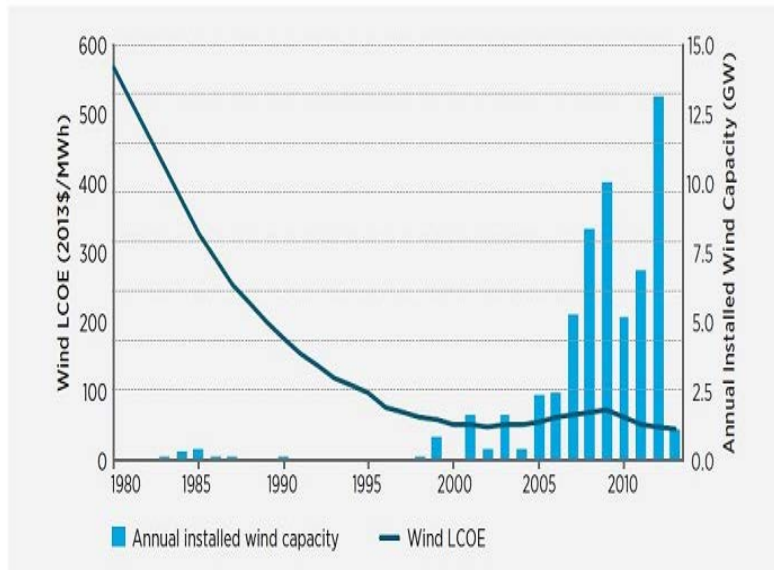


- Presently large wind farms produce electricity more economically than small operations
- Factors that contribute to lower costs are
 - Wind power is proportional to the area covered by the blade (square of diameter) while tower costs vary with a value less than the square of the diameter
 - Larger blades are higher, permitting access to faster winds, but size limited by transportation for most land wind farms
 - Fixed costs associated with construction (permitting, management) are spread over more MWs of capacity
 - Efficiencies in managing larger wind farms typically result in lower O&M costs (on-site staff reduces travel costs)

Wind Energy Economics

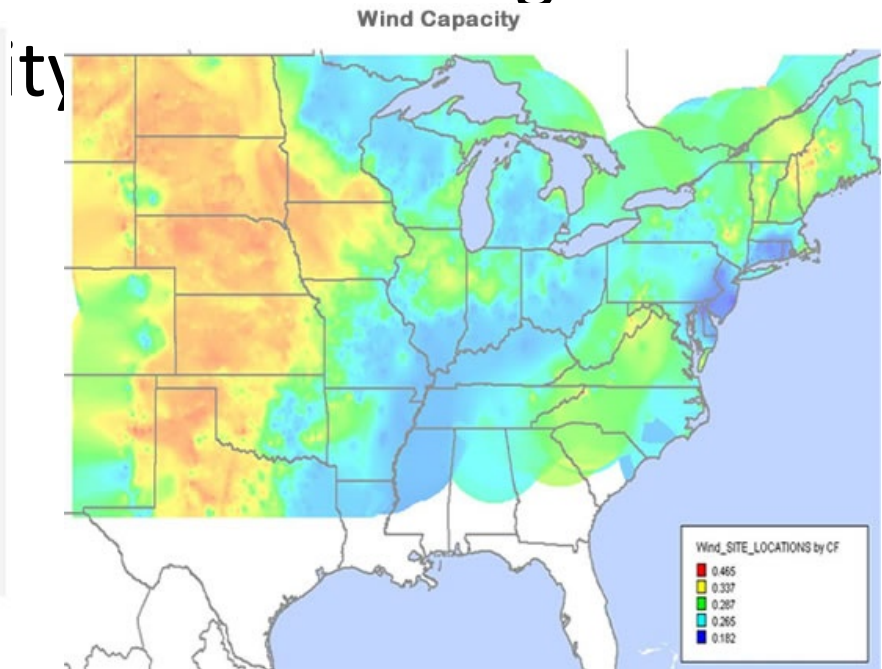


- Most of the cost is in the initial purchase and construction (capital costs); current estimate is about \$1690/kW; how much wind is generated



Note: In the Wind Vision, 'good to excellent sites' are those with average wind speeds of 7.5 meters per second (m/s) or higher at hub height. LCOE estimates exclude the PTC.

Source: Adapted from Lawrence Berkeley National Laboratory 2014 data [23]



Offshore Wind



- Offshore wind turbines currently need to be in relatively shallow water, so maximum distance from shore d
- Capacity factors tend to increase as turbines move further off-shore

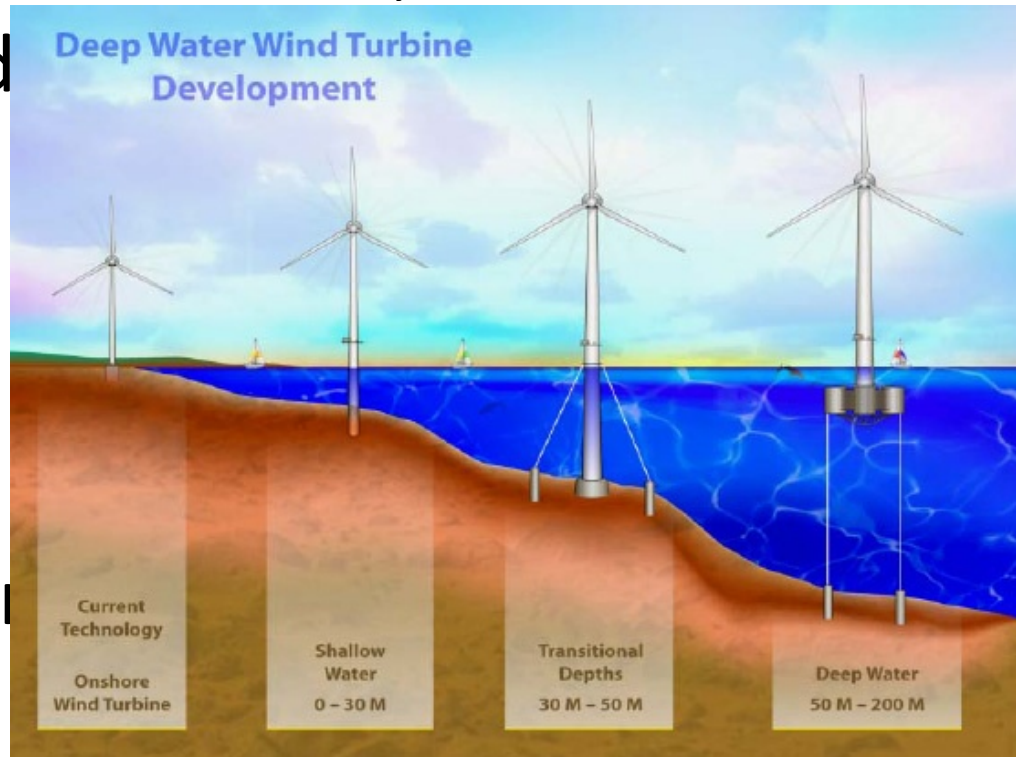
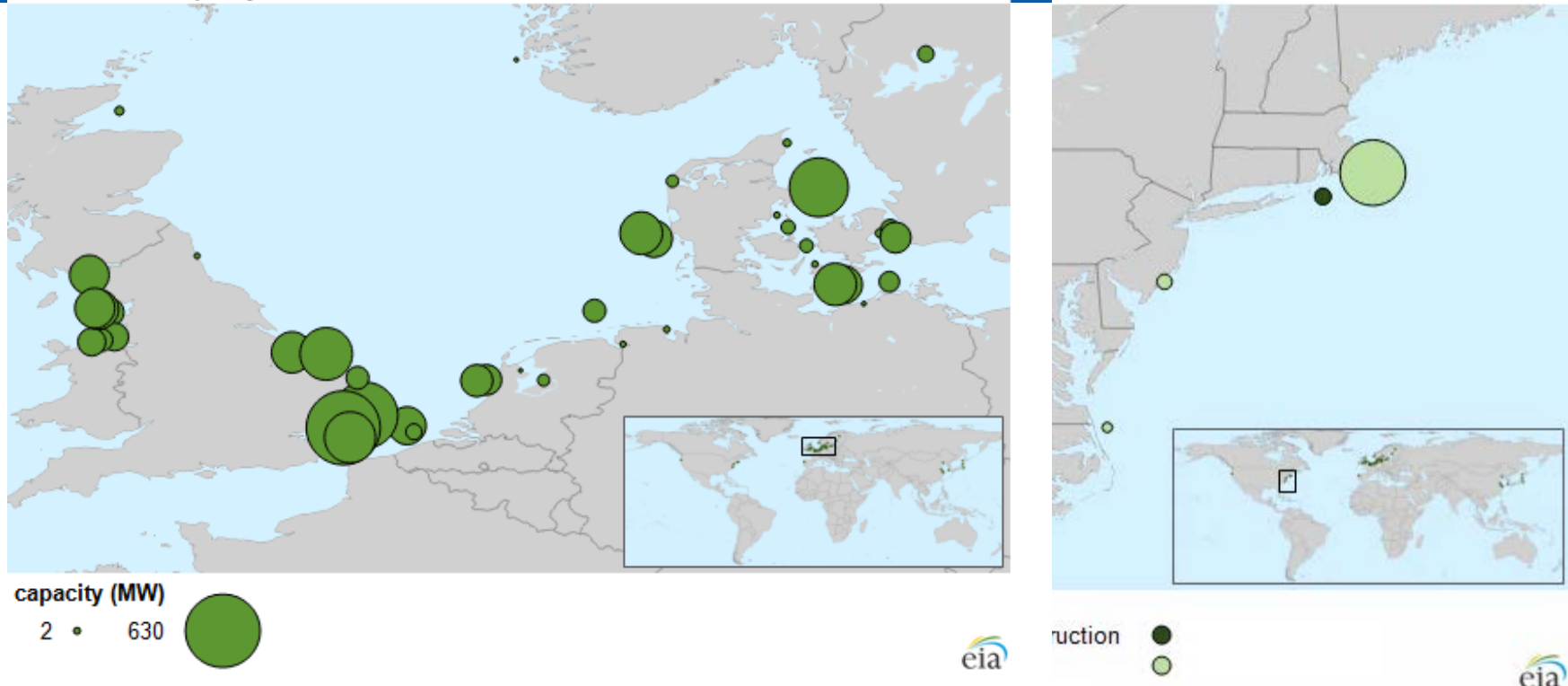


Image Source: National Renewable Energy Laboratory

Offshore Wind Installations

Offshore wind capacity



The first US offshore wind, Block Island (Rhode Island) with 30 MW, became operational in December 2016

Source: EIA August 14, 2015 and dwwind.com/project/block-island-wind-farm/

Offshore: Advantages and Disadvantages



- All advantages/disadvantages are somewhat site specific
- Advantages
 - Can usually be sited much closer to the load (often by coast)
 - Offshore wind speeds are higher and steadier
 - Easier to transport large wind turbines by ship
 - Minimal sound impacts and visual impacts (if far enough offshore), no land usage issues
- Disadvantages
 - High construction costs, particularly since they are in windy (and hence wavy) locations
 - Higher maintenance costs
 - Some environmental issues (e.g., seabed disturbance)

Types of Wind Turbines for Power Flow and Transient Stability



- Several different approaches to aggregate modeling of wind farms in power flow and transient stability
 - Wind turbine manufacturers provide detailed, public models of their WTGs; these models are incorporated into software packages; example is GE 1.5, 1.6 and 3.6 MW WTGs (see Modeling of GE Wind Turbine-Generators for Grid Studies, version 4.6, March 2013, GE Energy)
 - Proprietary models are included as user defined models; covered under NDAs to maintain confidentiality
 - Generic models are developed to cover the range of WTGs, with parameters set based on the individual turbine types
 - Concern by some manufacturers that the generic models do not capture their WTGs' behavior, such as during low voltage ride through (LVRT)

Types of Wind Turbines for Power Flow and Transient Stability



- Electrically there are four main generic types of wind turbines
 - Type 1: Induction machine; treated as PQ bus with negative P load; dynamically modeled as an induction motor
 - Type 2: Induction machine with varying rotor resistance; treated as PQ bus in power flow; induction motor model with dynamic slip adjustment
 - Type 3: Doubly Fed Asynchronous Generator (DFAG) (or DFIG); treated as PV bus in power flow
 - Type 4: Full Asynchronous Generator; treated as PV bus in power flow
- New wind farms (or parks) are all of Type 3 or 4

Generic Modeling Approach



- The generic modeling approach is to divide the wind farm models by functionality
 - Generator model: either an induction machine for Type 1 and 2's or a voltage source converter for Type 3 and 4
 - Reactive power control (exciter): none for Type 1, rotor resistance control for Type 2, commanded reactive current for Type 3 and 4
 - Drive train models: Type 1 and 2 in which the inertia appears in the transient stability
 - Aerodynamics and Pitch Models: Model impact of changing blade angles (pitch) on power output

Wind Turbine Issues



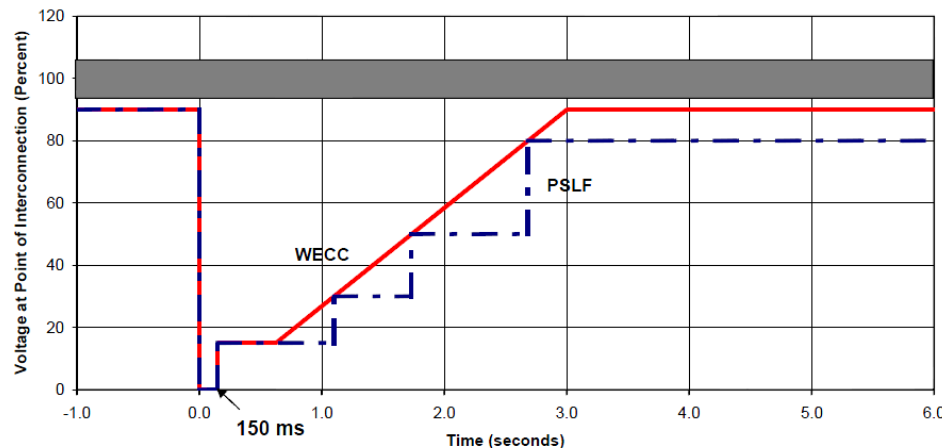
- Models are designed to represent the system level impacts of the aggregate wind turbines during disturbances such as low voltages (nearby faults) and frequency deviations
- Low voltage ride through (LVRT) is a key issue, in which the wind turbines need to stay connected to the grid during nearby faults
- Active and reactive power control is also an issue

Low Voltage Ride Through (LVRT)



- The concern is if during low voltages, such as during faults, the WTGs trip, it could quickly setup a cascading situation particularly in areas with lots of Type 3 WTGs
 - Tripping had been a strategy to protect the DFAG from high rotor currents and over voltages in the dc capacitor.
 - When there were acceptable
- Standards now require performance

Image from California ISO presentation



Type 3: Doubly Fed Asynchronous Generators (DFAG)



- Doubly fed asynchronous generators (DFAG) are usually a conventional wound rotor induction generator with an ac-dc-ac power converter in the rotor circuit
 - Power that would have been lost in external rotor resistance is now used
- Electrical dynamics are dominated by the voltage-source inverter, which has dynamics much faster than the transient stability time frame

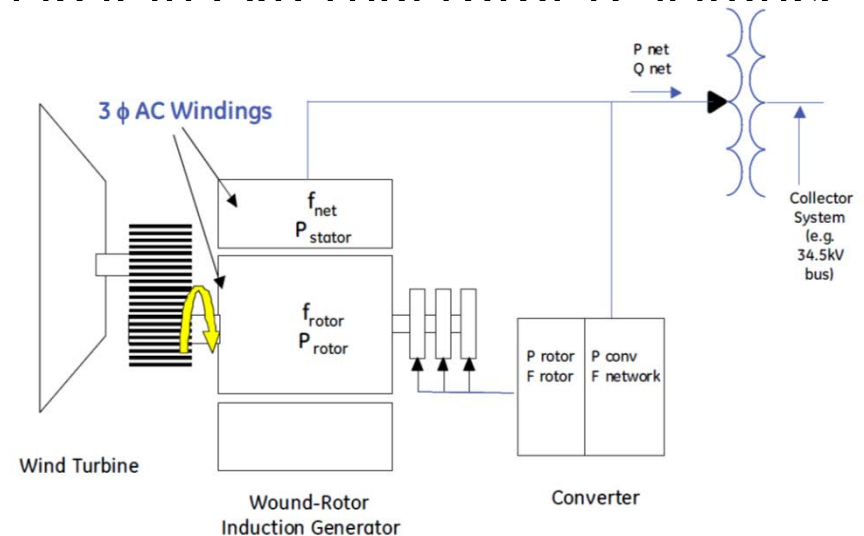


Figure 2-1. GE Doubly Fed Asynchronous WTG Major Components.

Image Source: Figure 2.1 from Modeling of GE Wind Turbine-Generators for Grid Studies, version 4.6, March 2013, GE Energy

Type 3 Converters



- A voltage source converter (VSC) takes a dc voltage, usually held constant by a capacitor, and produces a controlled ac output
- A phase locked loop (PLL) is used to synchronize the phase of the wind turbine with that of the ac connection voltage
 - Operates much faster than the transient stability time step, so is often assumed to be in constant synchronism
- Under normal conditions the WTG has a controllable real power current and reactive power current
- WTG voltages are not particularly high, say 600V

Type 3 Converters



- Type 3 machines can operate at a potentially widely varying slip
 - Example, rated speed might be 120% (72 Hz for a 60 Hz system) with a slip of -0.2, but with a control range of +/- 30%
- Control systems are used to limit the real power during faults (low voltage)
 - Current ramp rate limits are used to prevent system stress during current recovery
- Reactive current limits are used during high voltage conditions

Aerodynamics



- Type 3 and 4 models have more detailed models that directly incorporate the blade angle, so a brief coverage of the associated aerodynamics is useful
- The power in the wind is given by

$$P = \frac{\rho}{2} A v_w^3 C_p(\lambda, \theta)$$

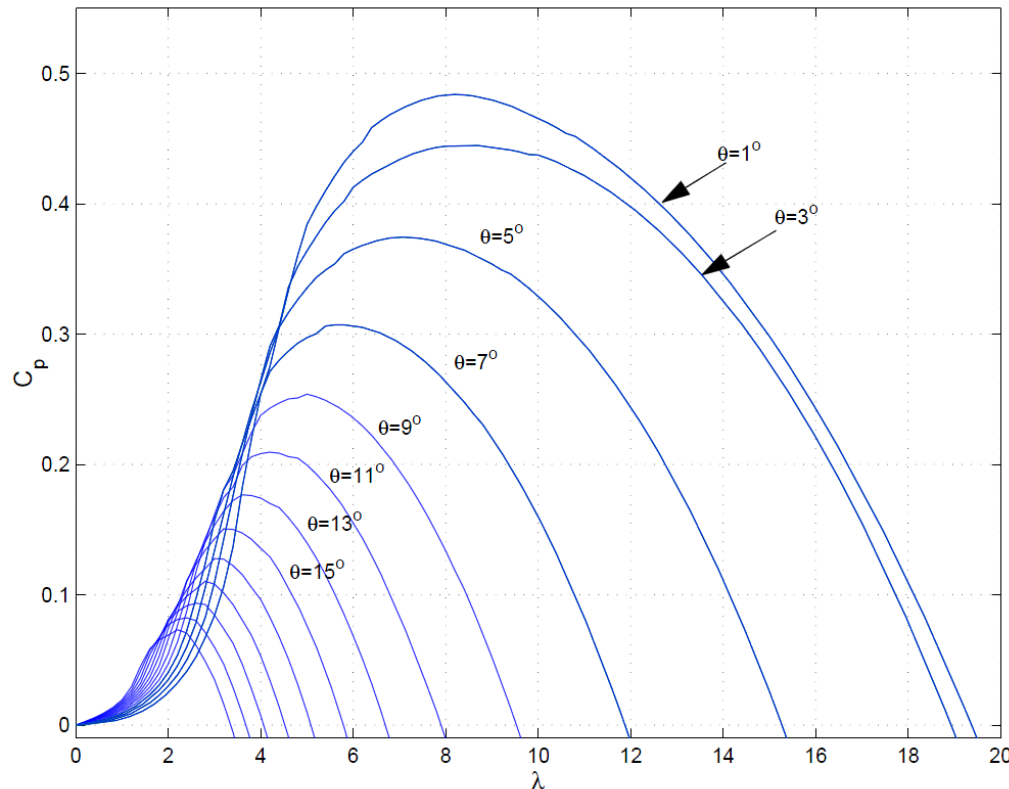
where ρ is the density of air, A is the area swept by the blades, v_w is the wind velocity, λ is the tip to wind speed ratio.

For a given turbine with a fixed blade length, $\lambda = K_b (\omega / v_w)$

Aerodynamics



- The $C_p(q,l)$ function can be quite complex, with the GE 1.5 curves given below



If such a detailed curve is used, the initialization is from the power flow P . There are potentially three independent variables, v_w , θ and ω . One approach is to fix ω at rated (e.g., 1.2) and θ at $\theta_{\min}$

Source: Modeling of GE Wind Turbine-Generators for Grid Studies, version 4.6, March 2013, GE Energy

Type 4 Converters

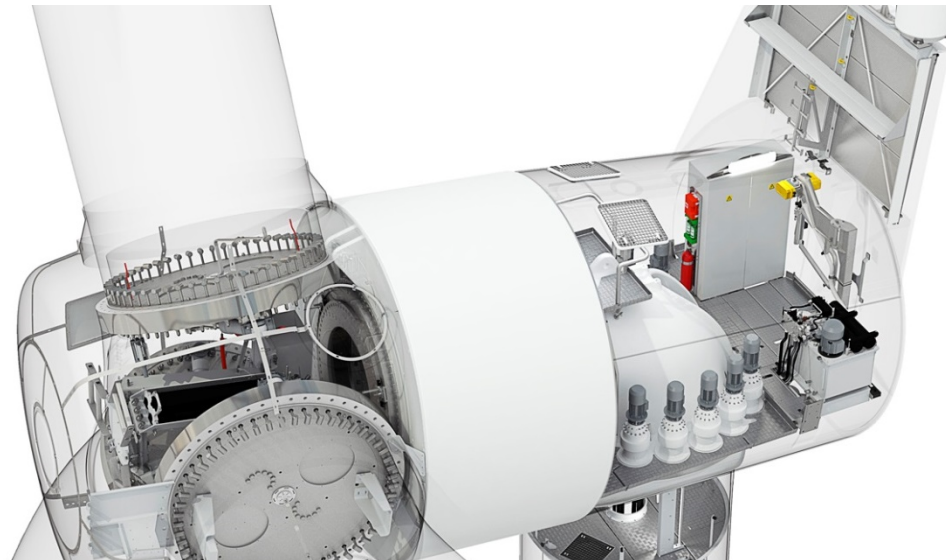


- Type 4 WTGs pass the entire output of the WTG through the ac-dc-ac converter
- Hence the system characteristics are essentially independent of the type of generator
 - Because of this decoupling, the generator speed can be as variable as needed
 - This allows for different generator technologies, such as permanent magnet synchronous generators (PMSGs)
 - Traditionally gearboxes have been used to change the slow wind turbine speed (e.g., 15 rpm) to a more standard generator speed (e.g., 1800 rpm); with Type 4 direct drive technologies can also be used

Example: Siemens SWT-2.3-113



- The Siemens-2.3-113 is a 2.3 MW WTG that has a rotor diameter of 113m. It is a gearless design based on a compact permanent magnet generator
 - No excitation power, slip rings or excitation control system



Solar Photovoltaic (PV)



- **Photovoltaic definition-** a material or device that is capable of converting the energy contained in photons of light into an electrical voltage and current
- Solar cells are diodes, creating dc power, which in grid applications is converted to ac by an inverter
- For terrestrial applications, the capacity factor is limited by night, relative movement of the sun, the atmosphere, clouds, shading, etc
 - A ballpark figure for Illinois is 18%
 - "One sun" is defined as 1 kW/m^2 , which is the maximum insolation that reaches the surface of the earth (sun right overhead)

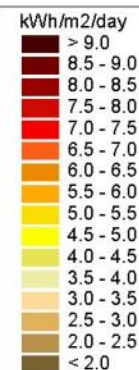
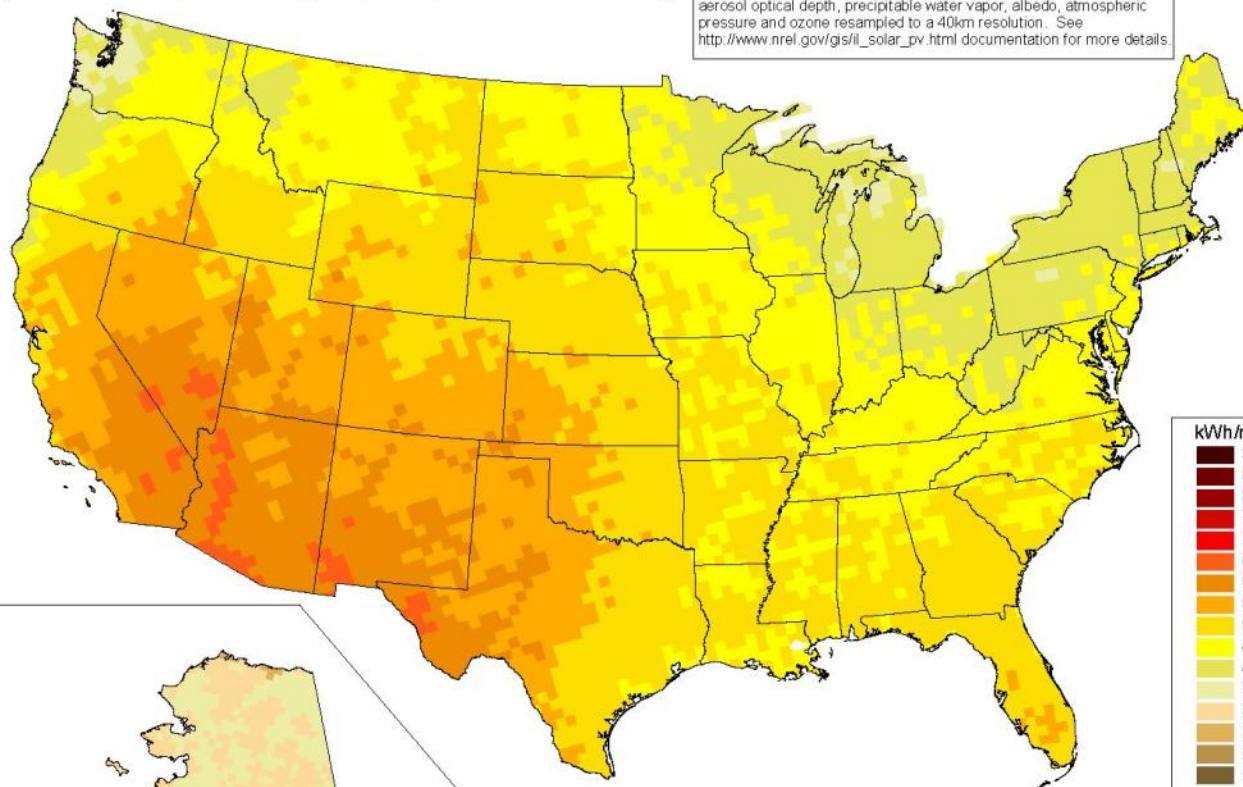
US Annual Insolation



PV Solar Radiation (Flat Plate, Facing South, Latitude Tilt)

Annual

Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html documentation for more details.

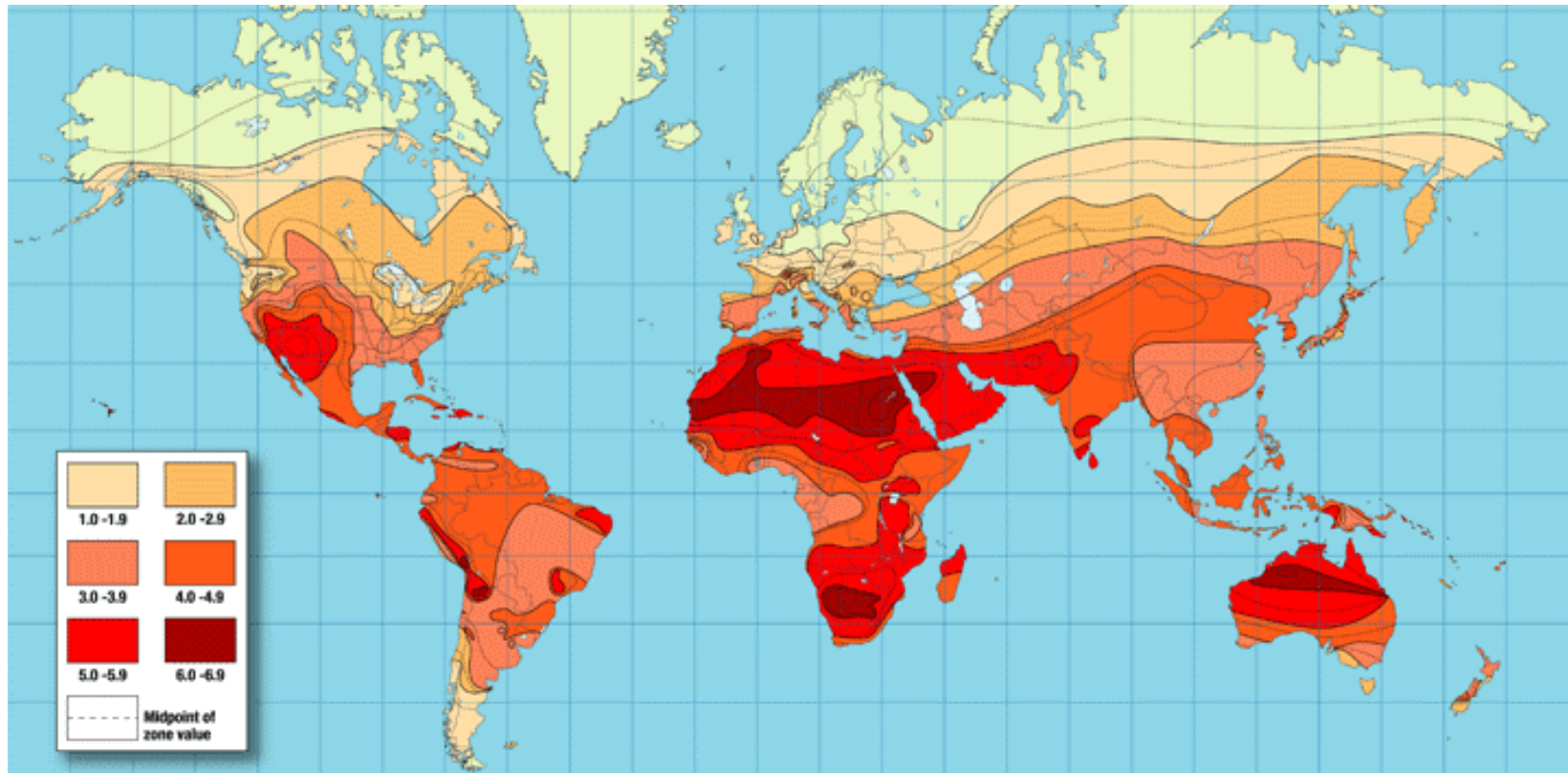


The capacity factor is roughly this number divided by 24 hours per day



Produced by the Electric & Hydrogen
Technologies & Systems Center - May 2004

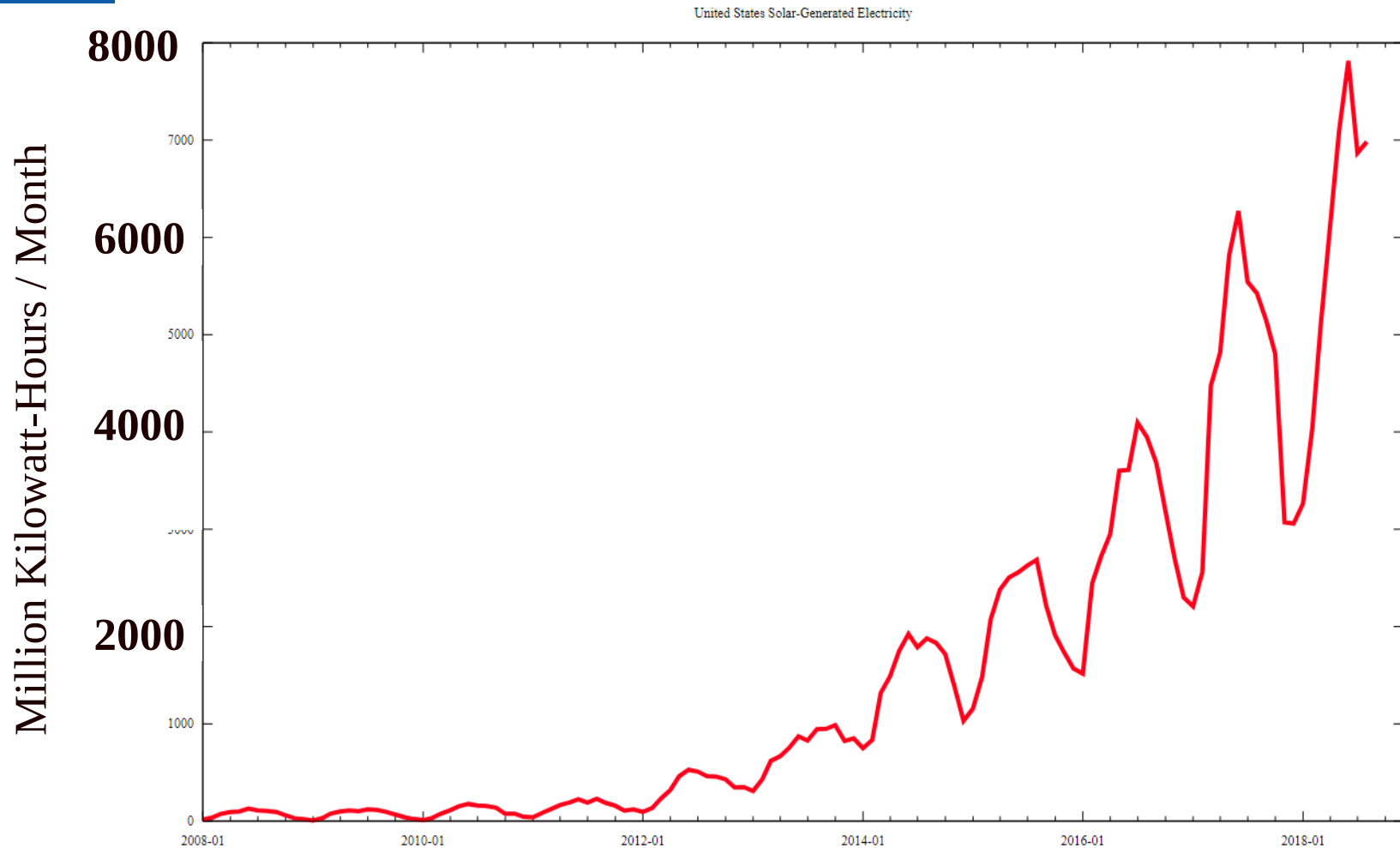
Worldwide Annual Insolation



In 2016 the top countries for total solar capacity are China (78.1 GW), Japan (42.8 GW), Germany (41.2 GW), US (40.3), Italy (19.3);

In just 2016 China added 34.5 GW, US 14.7, Japan 8.6, Indian 4 GW

US Solar Generated Electricity

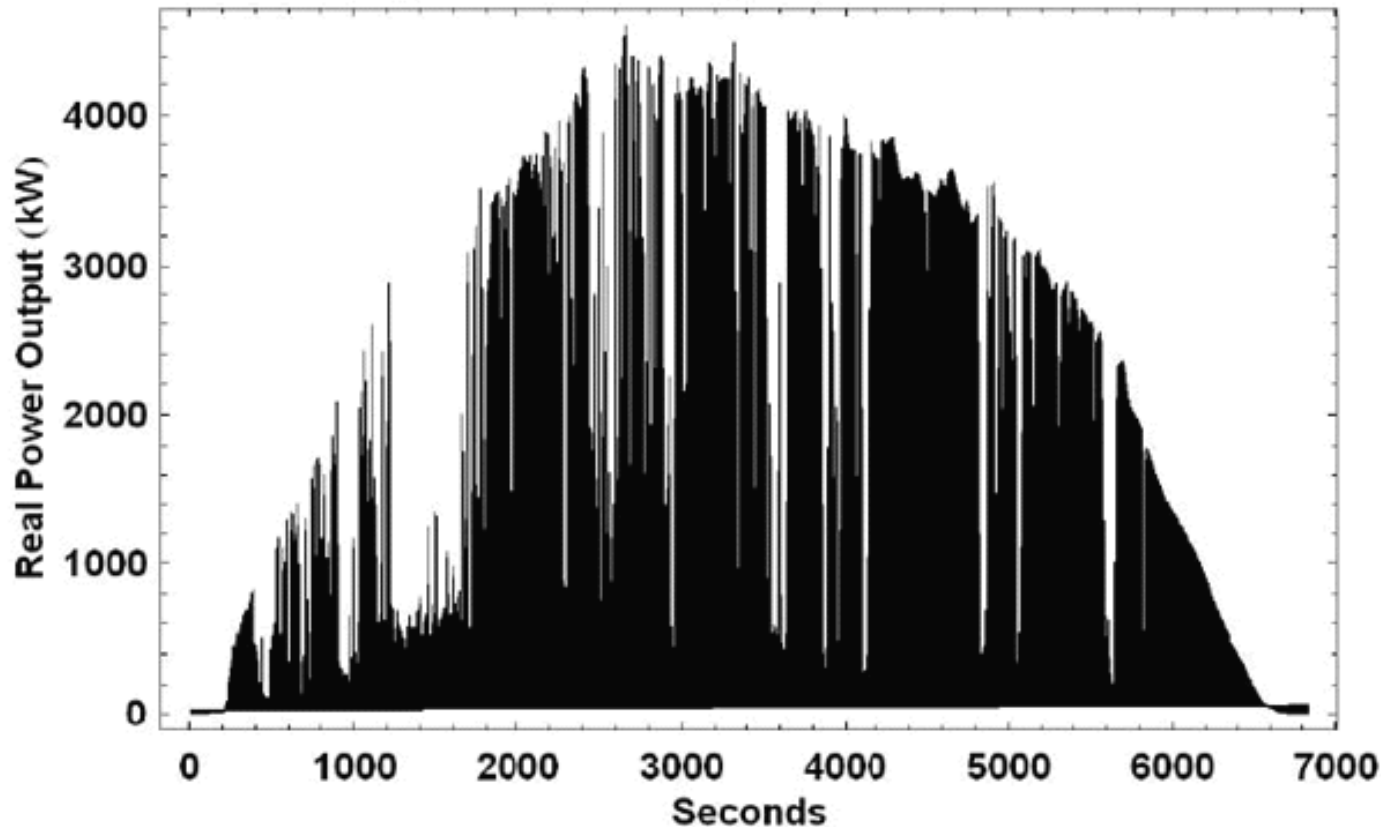


https://upload.wikimedia.org/wikipedia/commons/4/4e/US_Monthly_Solar_Power_Generation.svg

Solar PV can be Quite Intermittent Because of Clouds



Springerville AZ, One Day at 10 Second Resolution



Intermittency can be reduced some when PV is distributed over a larger region; key issue is correlation across an area

Image: <http://www.megawattsf.com/gridstorage/gridstorage.htm>

Modeling Solar PV



- Since a large portion of the solar PV is distributed in small installations in the distribution system (e.g., residential rooftop), solar PV modeling is divided into two categories
 - Central station, which is considered a single generation plant
 - As part of the load model

Distributed PV System Modeling



- PV in the distribution system is usually operated at unity power factor
 - There is research investigating the benefits of changing this
 - IEEE Std 1547 now allows both non-unity power factor and voltage regulation
 - A simple model is just as negative constant power load
- An issue is tripping on abnormal frequency or voltage conditions
 - IEEE Std 1547 says, "The DR unit shall cease to energize the Area EPS for faults on the Area EPS circuit to which it is connected." (note EPS is electric power system)

Distributed PV System Modeling



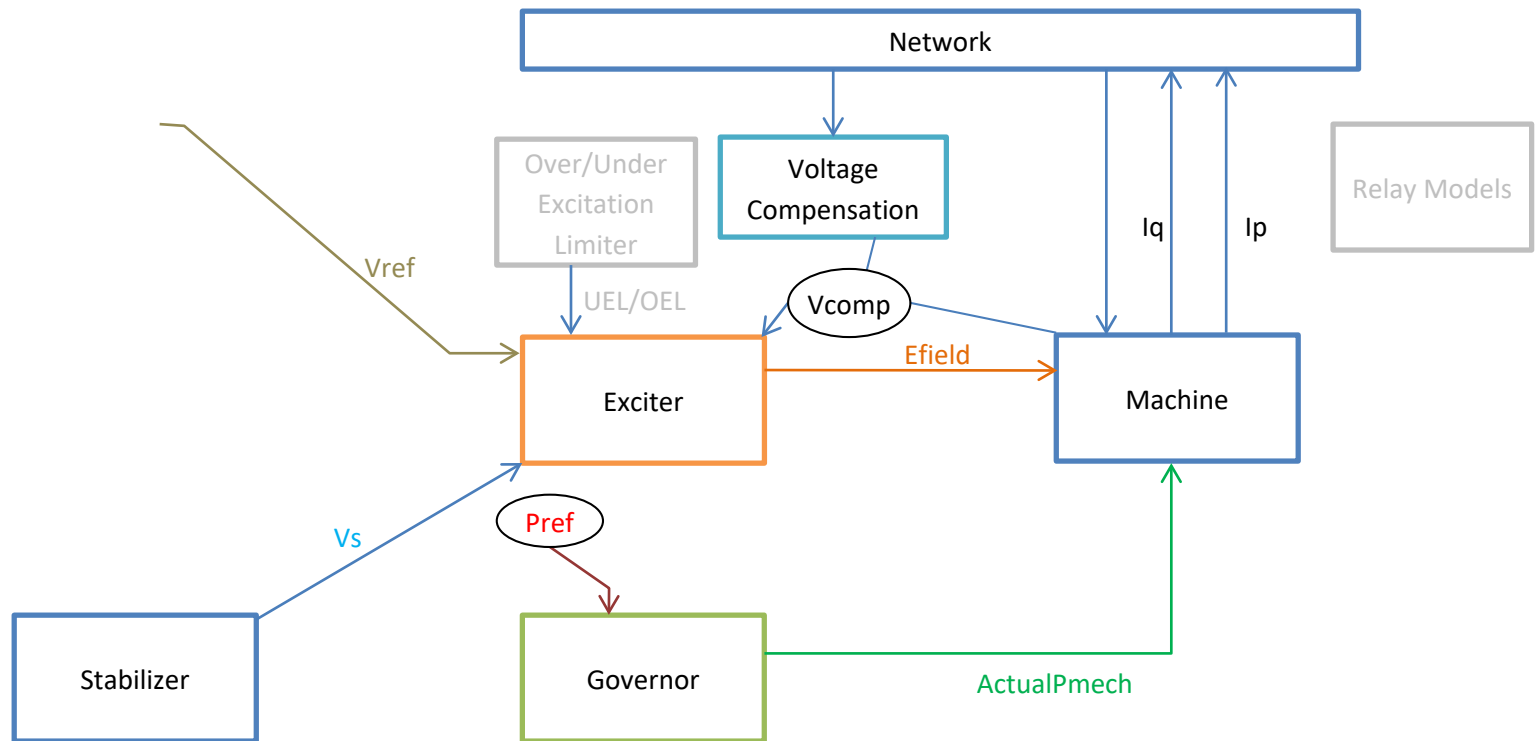
- An issue is tripping on abnormal frequency or voltage conditions (from IEEE 1547-2003, 2014 amendment)
 - This is a key safety requirement!
 - Units need to disconnect if the voltage is < 0.45 pu in 0.16 seconds, in 1 second between 0.45 and 0.6 pu, in 2 seconds if between 0.6 and 0.88 pu; also in 1 second if between 1.1 and 1.2, and in 0.16 seconds if higher
 - Units need to disconnect in 0.16 seconds if the frequency is > 62 or less than 57 Hz; in 2 seconds if > 60.5 or < 59.5
 - Reconnection is after minutes
 - Values are defaults; different values can be used through mutual agreement between EPS and DR operator

Modular Approach to Generator Modeling



- Industry has always used a modular approach for generator models
 - Machine
 - Exciter
 - Governor
 - Stabilizer
 - Under Excitation Limiter
 - Over Excitation Limiter
 - Relay Model
 - GP1, LHFRT, LHVRT
 - Compensator Model
 - Often is part of the machine model, but can also be a separate model
 - The old BPA IPF program models included this in the Exciter model

“Traditional” Synchronous Machine Modules

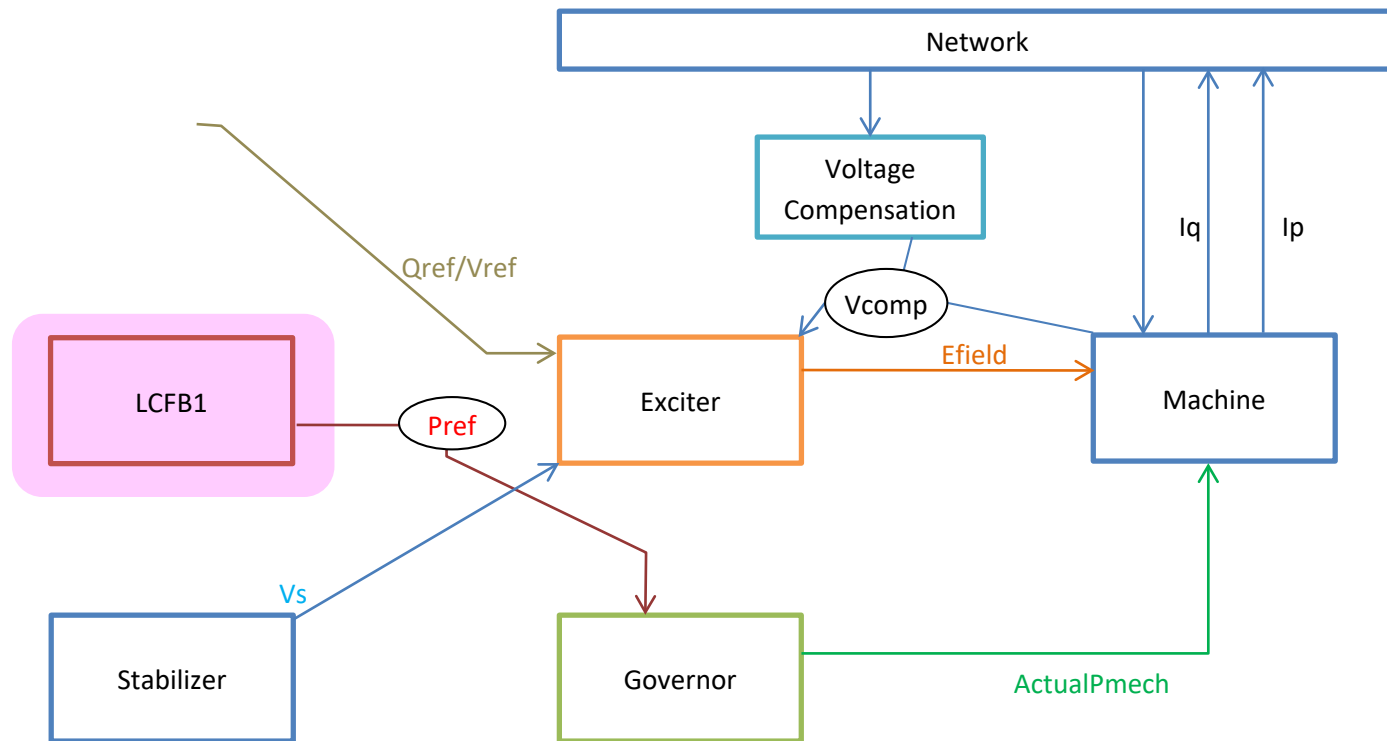


Modular Approach to Generator Modeling



- First generation wind turbine models stuck with this structure
 - Added additional signals to pass between modules
 - Don't get hung up on nomenclature “Exciter” just means the electrical control
- Unrelated to wind turbine modeling, another module was added for better modeling of large steam plants
 - LCFB1 – extra controller feeding the governor allowing control of Pref

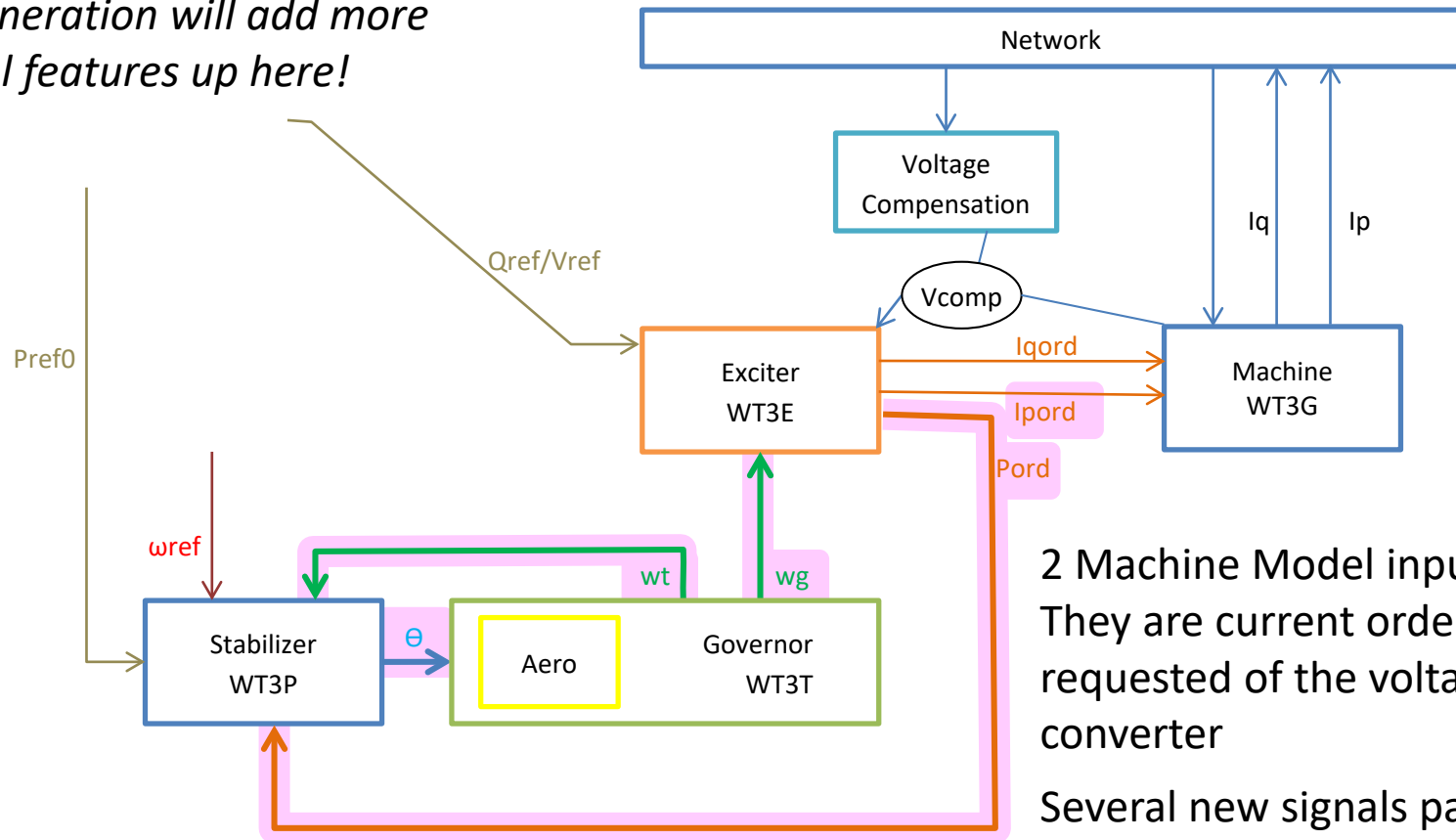
LCFB1 model: Controller for Pref



First Generation Type 3 Wind Turbine (WT3G, WT3E, WT3T, WT3P)



2nd Generation will add more control features up here!



2 Machine Model inputs now.
They are current orders
requested of the voltage source
converter

Several new signals passing
around

Limitations of First Generation Wind Models



- First Generation model had few mechanisms to provide control features of
 - Real Power or Torque Control
 - Reactive Power
 - Voltage Control
 - For First Generation models, the wind turbine basically tried to bring values back to the initial condition
 - Pref bring power back to initial Power
 - Qref or Vref or PowerFactorRec

Comparing First and Second Generation Models

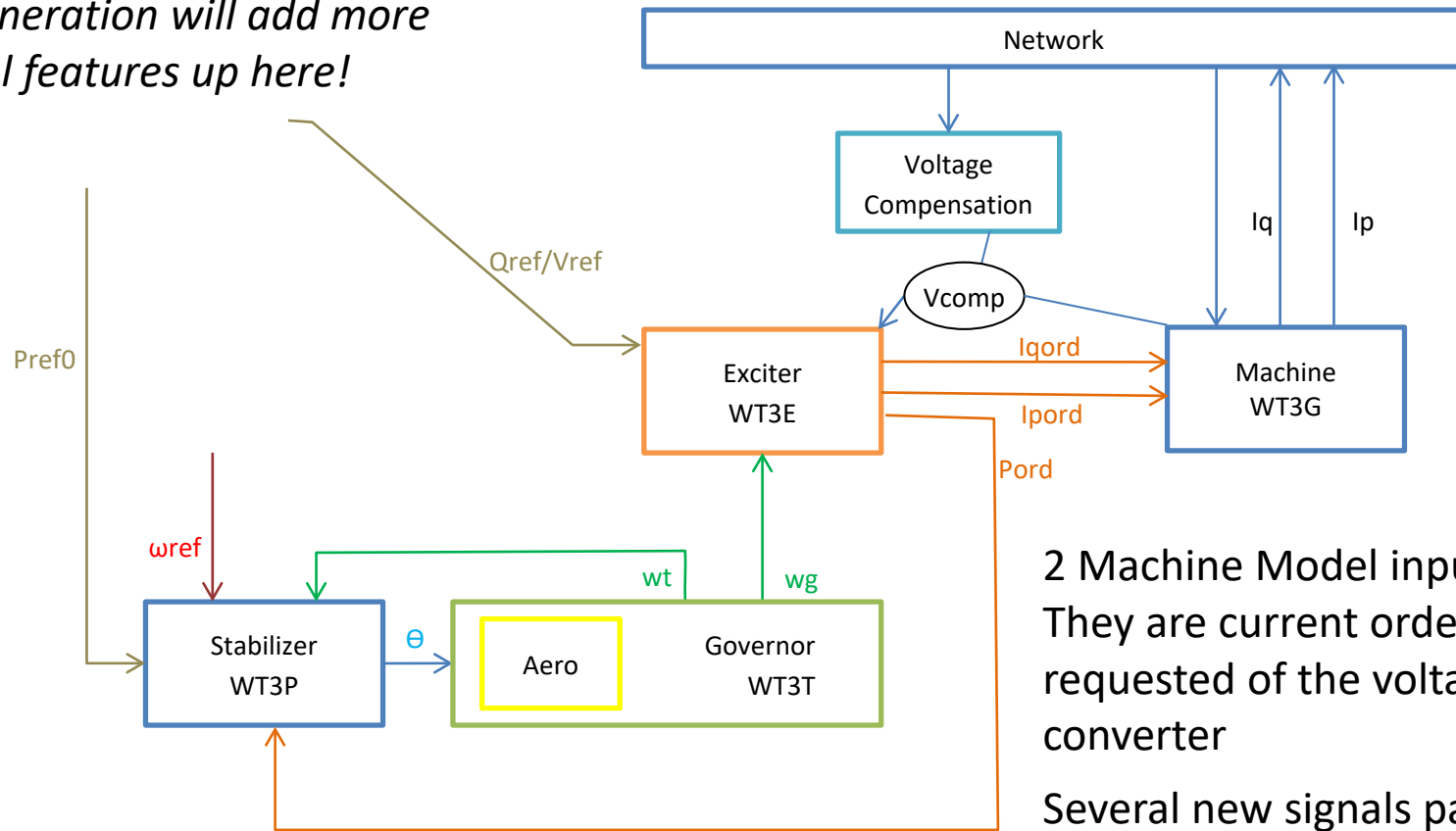


- Many parts actually change very little
 - “Machine”: Voltage Source Converter model of the generator is nearly identical
 - WT3G/WT4G is pretty much same as REGC_A
 - “Governor”: Mechanical Model of wind turbine is identical
 - Combination of WTGT_A and WTGAR_A is identical to WT3T
 - “Stabilizer”: Pitch Control model has only a small addition
 - WT3P is pretty much same as WTGPT_A
- What’s Different – Control System Models
 - The WT3E and WT4E models essentially embedded voltage control and power control inside the model
 - This is now split into separate models
 - REEC_A: models only control with setpoints are as inputs to this model. Control features a little more flexible than the WT3E and WT4E models
 - WTGTRQ_A: control system resulting in the output of PRef
 - REPC_A : control system resulting in output of both a P and V/Q signal

First Generation Type 3 Wind Turbine (WT3G, WT3E, WT3T, WT3P)



2nd Generation will add more control features up here!



2 Machine Model inputs now.
They are current orders
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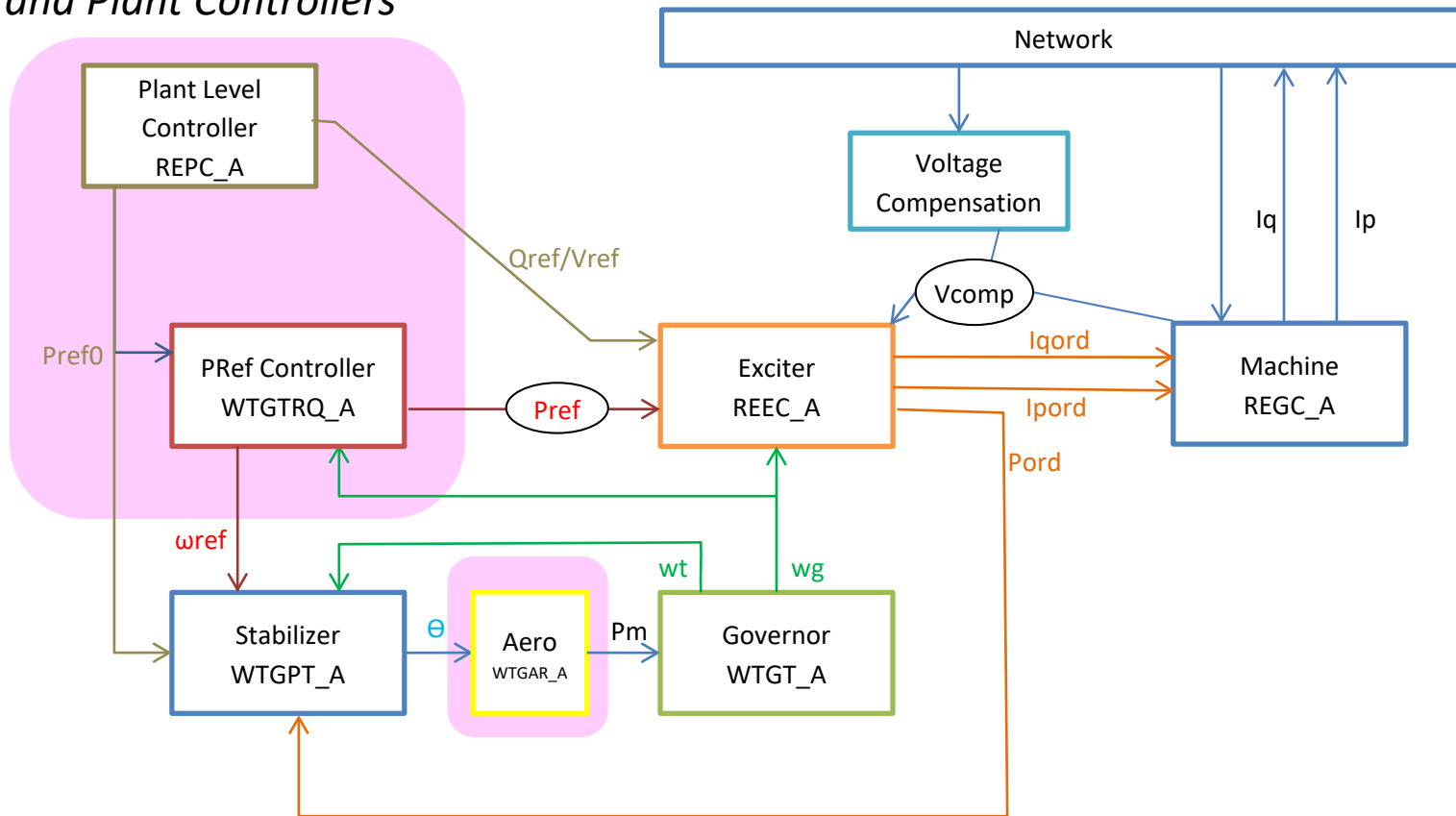
Several new signals passing
around

2nd Generation Type 3 Wind Turbine

(REGC_A, REEC_A, WTGT_A, WTGAR_A, WTGPT_A, WTGTRQ_A, REPC_A)



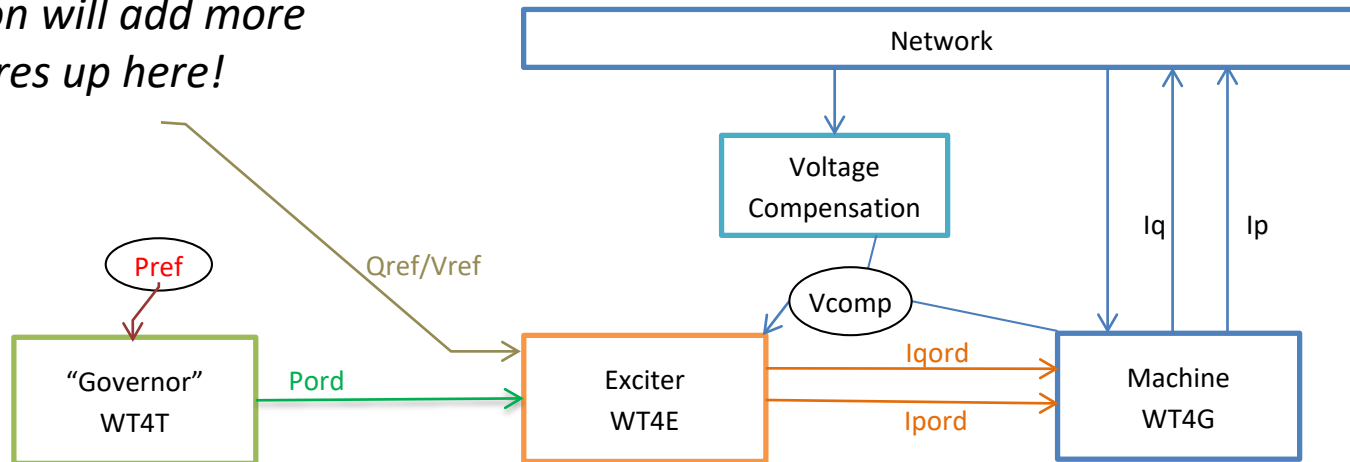
2nd Generation adds the Aero, PRef and Plant Controllers



First Generation Type 4 Wind Turbine (WT4G, WT4E, WT4T)



2nd Generation will add more control features up here!

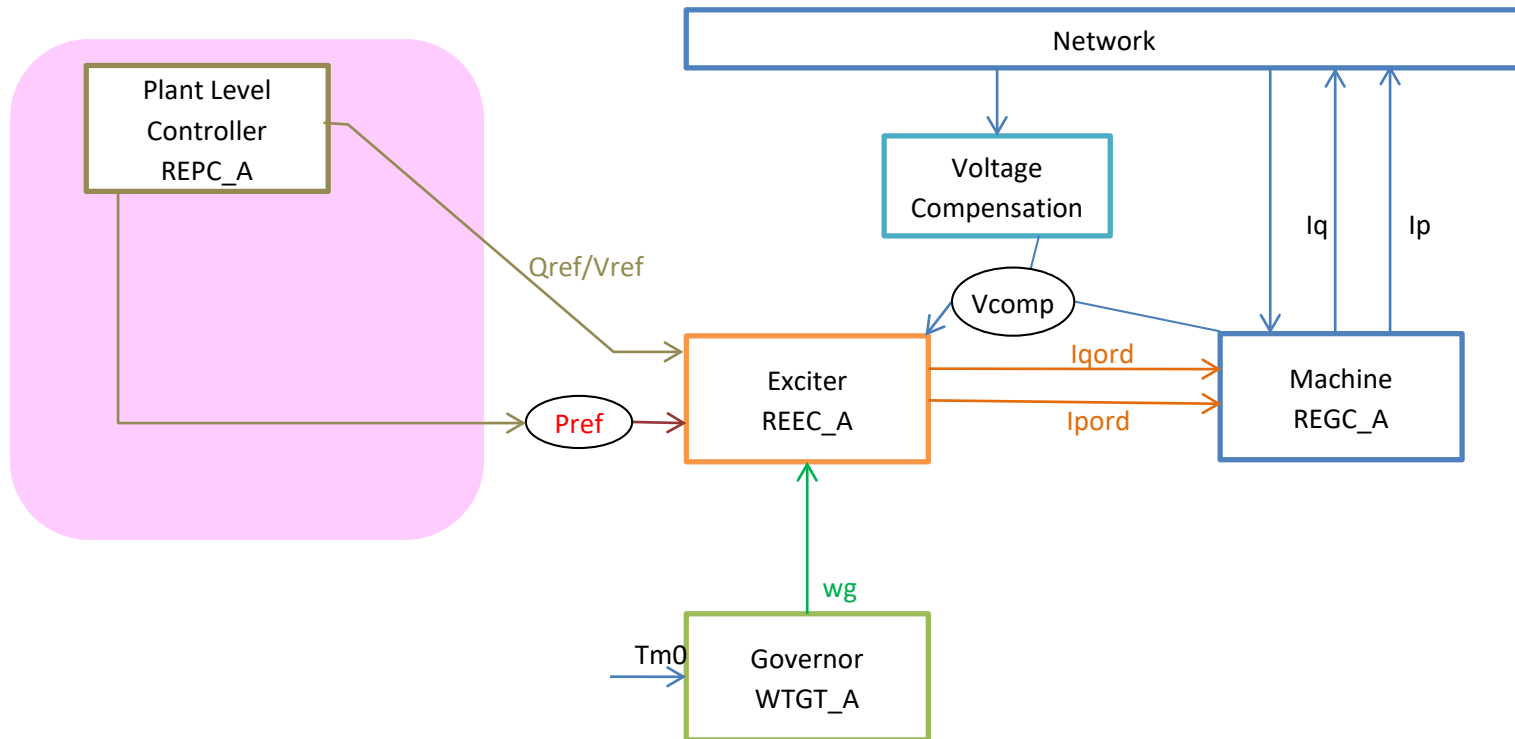


Legacy "Governor" WT4T

This really acts like the new PRef controller

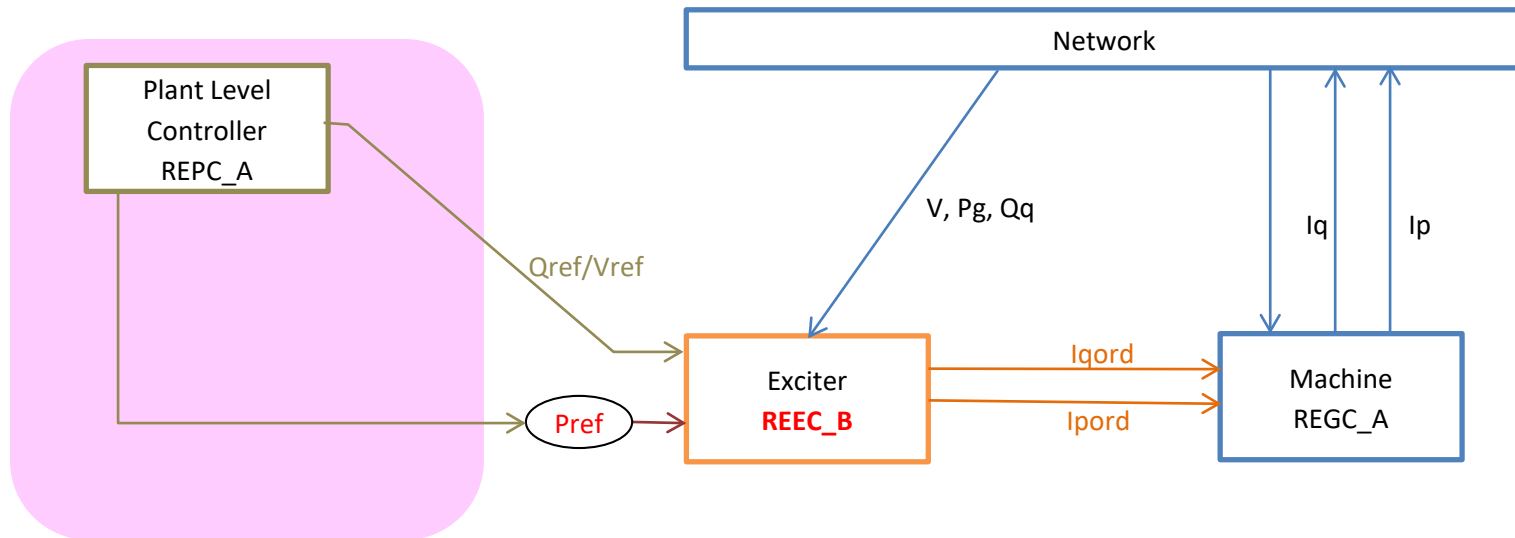
We will leave it in the toolbox as a "Governor" anyway

2nd Generation Type 4 Wind Turbine (REGC_A, REEC_A, WTGT_A, REPC_A)



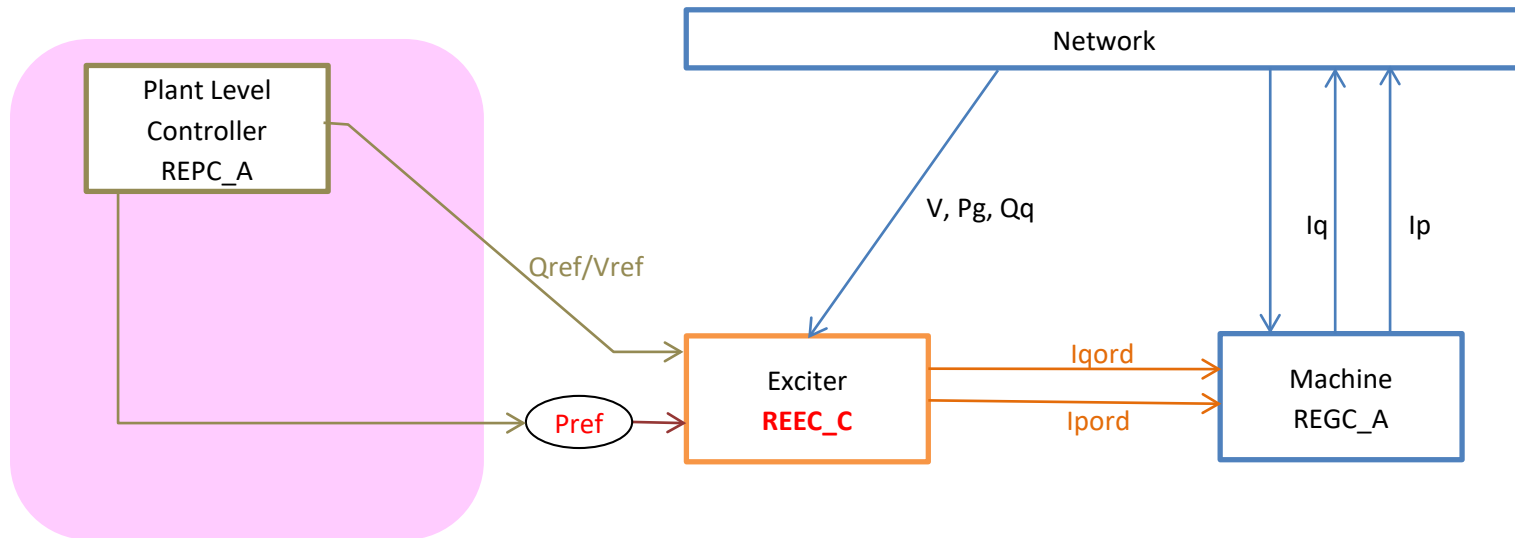
Note: If REEC_A parameter Pflag = 0, then WTGT_A really doesn't do anything so it can be omitted completely

2nd Generation Solar Plant



**Used REEC_B Initially,
But actually don't anymore!
Go back to REEC_A**

2nd Generation Energy Storage



Use REEC_C

Software Implementation



- PowerWorld has kept the existing general classes of generator models
 - Machine (Generator/Converter Model)
 - Exciter (P and Q controller)
 - Governor (Drive Train)
 - Stabilizer (Pitch Control)
 - Relay Model
 - Under Excitation Limiter
 - Over Excitation Limiter
 - Compensator Model
- Added 3 new types of generator modules
 - Aerodynamic Model
 - Pref Controller
 - Plant Controller

Scope of new Modules



- Aerodynamic Model
 - Can only be used with Type 3 wind turbine
- Pref Controller
 - Can be used with any type of generator
 - Existing model LCFB1 is now a Pref Controller
 - Pref Signal Output
 - Feeds into Governor if governor accepts Pref
 - Else feeds into Exciter if exciter accepts Pref
- Plant Controller
 - Can be used with any type of generator
 - Existing model PLAYINREF is now a Plant Controller
 - Vref/Qref Signal Output
 - Vref/Qref signal will feed into Exciter if the exciter accepts it
 - Pref Signal Output
 - Pref feeds into Pref Controller if it exists
 - Else feeds into Governor if governor accepts Pref
 - Else feeds into Exciter if exciter accepts Pref

Error Checking



- Error checking is performed when validation is done
 - Ensure there is only 1 Pref controller defined
 - Ensure there is only 1 Plant controller defined
 - Ensure there is only 1 Aerodynamic model
 - Also note, if an aerodynamic model is required between the stabilizer and the governor (WTGPT_A and WTGT_A), but one is not defined, Simulator assumes a WTGAR_A exists with $K_a = 0.007$ and $\Theta = 0$
- General error checking is done to make sure the model mix makes sense
 - GENTPF can't have a REEC_A “exciter”

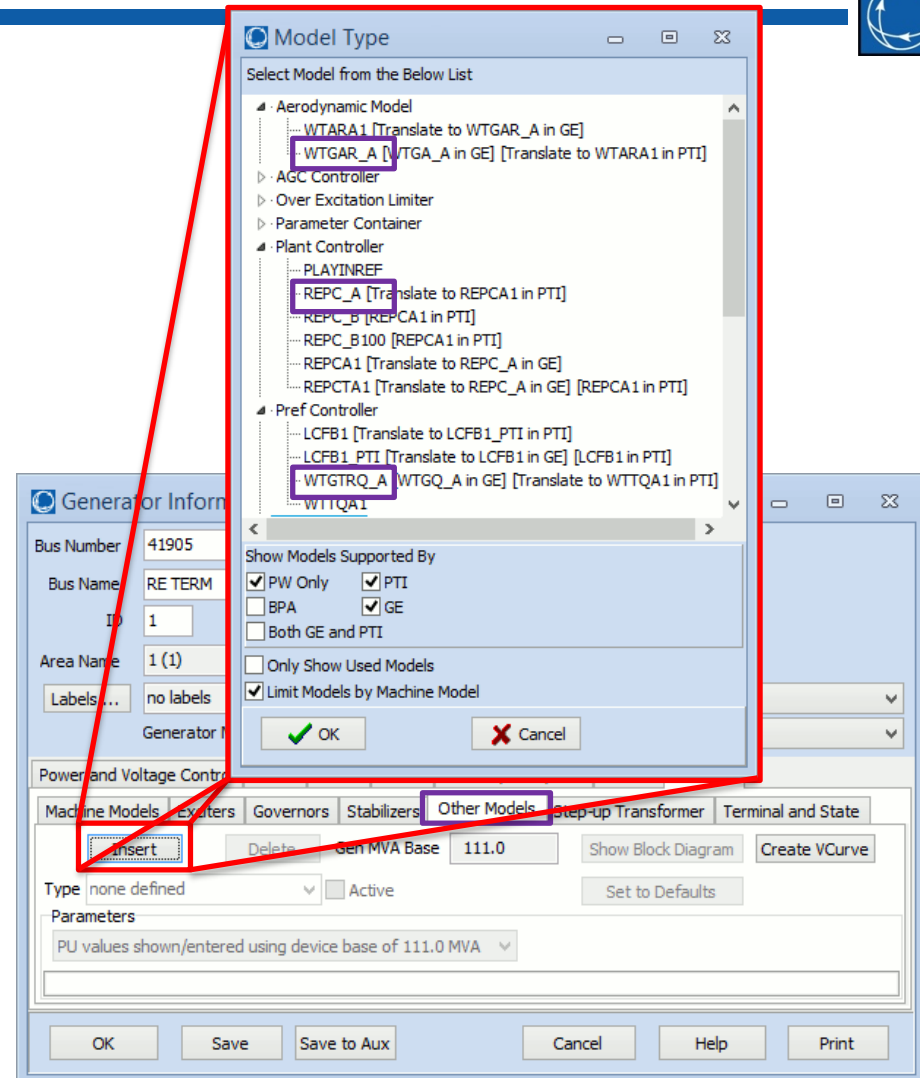
Initialization Notes



- Because of the way these various blocks connect together, the initialization order of the blocks is important
 - Example: the “initial speed” of the wind turbine is calculated in different places
 - For 1st Gen Type 3 → WT3E (Exciter)
 - For 2nd Gen Type 3 → WTGTRQ_A (PRef controller)
 - For 2nd Gen Type 4 → WTGT_A (Governor)
 - This is all handled internally by Simulator so the user does not need to be concerned with the order

Where does it appear in GUI

- Machine, Exciter, Governor, and Stabilizer remain prominent
- *Other Models* contain the other categories of modules
- You see it in the Model Explorer
- When inserting a new *Other Model* from the generator dialog
- Plot Designer in Transient Stability Dialog



Model Explorer



Model Explorer: Generator Other Models

Explore Fields

- Recent
- Network
- Aggregations
- Solution Details
- Case Information and Auxiliary
- Contingency Analysis
- Optimal Power Flow
- Tools and Add Ons
- Transient Stability
 - DC Models
 - Summary
 - Area AGC Models
 - DS Time Schedules
 - Generator Exciters
 - Generator Governors
 - Generator Machine Models
 - Generator Other Models**
 - Generator Stabilizer
 - Line Relay Models
 - Line Shunts Models
 - Load Characteristics
 - Load Component
 - Load Distributed Generation Model
 - Load Distribution Equivalent Type
 - Load Model Group
 - Load Relays
 - Measurement Objects Models
 - PlayIn Configuration
 - Switched Shunt Models

Filter Advanced Gen Other Model: Generic

Gen Other Model

All (3)

- Aerodynamic Model
 - WTARA1
 - WTGAR_A (1)
- AGC Controller
- Over Excitation Limiter
- Parameter Container
- Plant Controller
 - PLAYINREF
 - REPC_A (1)
 - REPC_B
 - REPC_B100
 - REPCA1
 - REPCA1
 - REPCA1
- Pref Controller
 - LCFB1
 - LCFB1_PTI
 - WTGTRQ_A (1)
 - WTTQA1
- Relay Model
- Under Excitation Limiter
- Voltage Compensator

Table:

	Fully Supported	Number of Bus
1	YES	41905 1
2	YES	41905 1
3	YES	41905 1

Show Models Supported By

☒ PW Only ☒ PTI

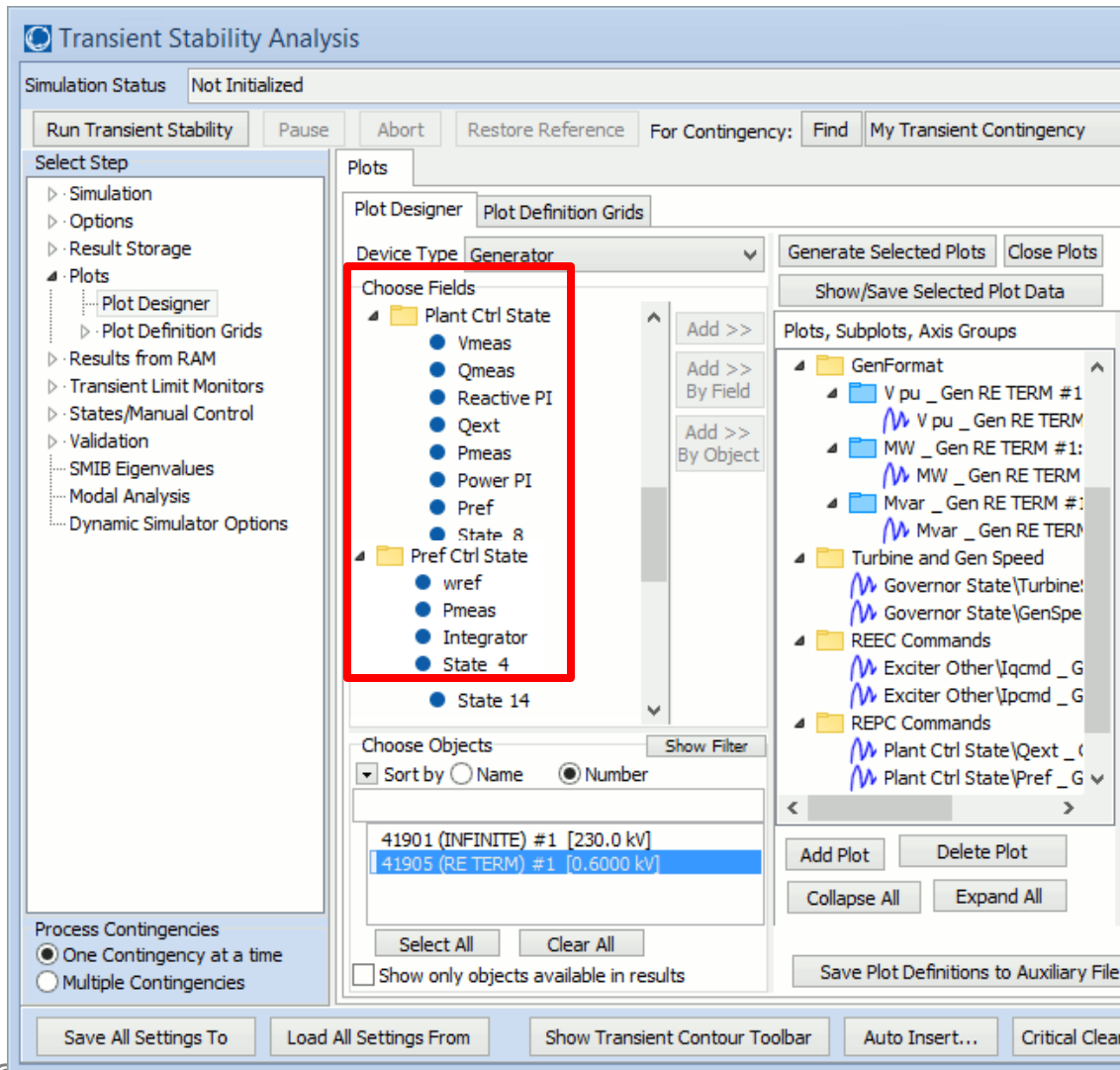
☐ BPA ☒ GE

☐ Only Show Used Models

Save Load

Search

Plot Designer



- Plant Ctrl State
 - Vmeas
 - Qmeas
 - Reactive PI
 - Qext
 - Pmeas
 - Power PI
 - Pref
- Pref Ctrl State
 - wref
 - Pmeas
 - Integrator
 - State 4

2nd Generation Models



- Type 3 Wind Turbine
 - REGC_A, REEC_A, WTGT_A, WTGPT_A, WTGAR_A, REPC_A, WTGTRQ_A
- Type 4 Wind Turbine
 - REGC_A, REEC_A, WTGT_A, REPC_A
- Solar PV Models
 - REGC_A, REEC_A, REPC_A
 - REEC_B was just a variation of REEC_A with less parameters and features
 - Has been determine that Solar should use REEC_A to model momentary cessation correctly (VDL curves)
- Energy Storage (Battery)
 - REGC_A, REEC_C, REPC_A
- New Pitch Control for Type 1 and 2 Wind Turbines
 - WT1P_B
- Plant Controller with up to 50 machines (and SVCs)
 - REPC_B (similar to REPC_A but has output to 50 devices)

Renewable Energy Models (Wind, Solar, Storage Models)



1st Generation Models

Class of Model Type	Wind Type 1	Wind Type 1	Wind Type 2	Wind Type 2	Wind Type 3	Wind Type 3	Wind Type 4	Wind Type 4	Solar PV
Machine	WT1G	WT1G1	WT2G	WT2G1	WT3G	WT3G1	WT4G	WT4G1	PV1G
Electrical Model			WT2E	WT2E1	WT3E	WT3E1	WT4E	WT4E1	PV1E
Mechanical	WT1T	WT12T1	WT2T	WT12T1	WT3T	WT3T1	WT4T		
Pitch Controller	WT1P	WT12A1	WT2P	WT12A1	WT3P	WT3P1			

2nd Generation Models

Class of Model Type	Wind Type 1	Wind Type 2	Wind Type 3	Wind Type 4	Solar PV	Distributed PV Model	Energy Storage
Machine	WT1G WT1G1	WT2G WT2G1	REGC_A	REGC_A	REGC_A	PVD1 DER_A	REGC_A
Electrical Model		WT2E WT2E1	REEC_A	REEC_A	REEC_B		REEC_C
Mechanical	WT1T WT12T1	WT2T WT12T1	WTGT_A	WTGT_A	Additional Uses		
Pitch Controller	WT1P_B	WT2P WT12A1	WTGPT_A				
Aerodynamic			WTGA_A				
Pref Controller			WTGTRQ_A				
Plant Controller			REPC_A or REPC_B	REPC_A or REPC_B	REPC_A or REPC_B		REPC_A or REPC_B

3 new classes of models

Detailed Documentation on the “Second Generation” From WECC



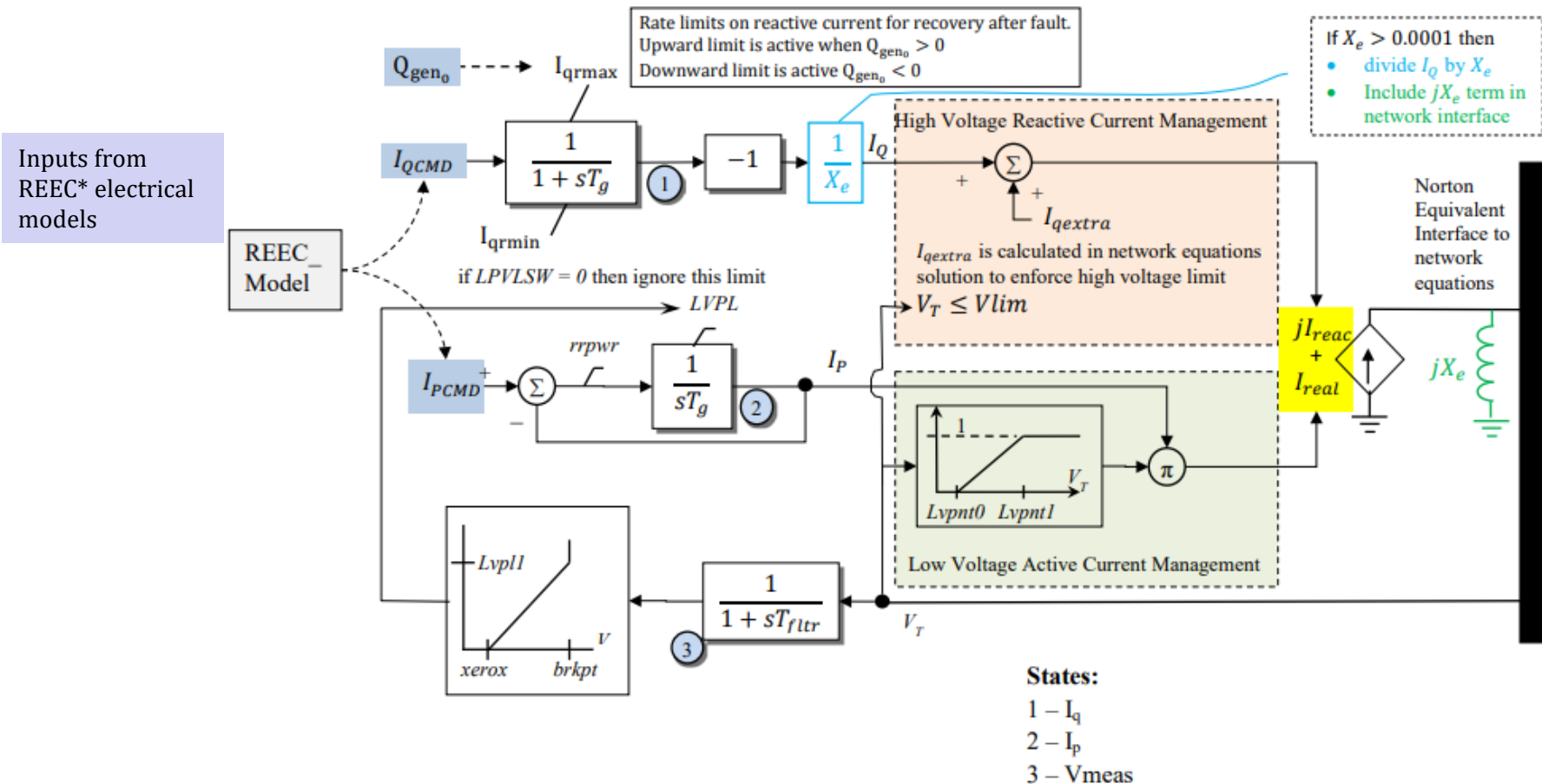
- Type 3 Wind-Turbine
 - https://www.powerworld.com/WebHelp/#Other_Documents/WECC-Type-3-Wind-Turbine-Generator-Model-Phase-II-012314.pdf
- Type 4 Wind-Turbine / (Same for Solar/Storage)
 - https://www.powerworld.com/WebHelp/#Other_Documents/WECC-Type-4-Wind-Turbine-Generator-Model-Phase-II-012313.pdf

REGC_A (or REGCA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Machine%20Model%20REGC_A.htm



- “Machine Model”: Really a network interface



REGC_A Description



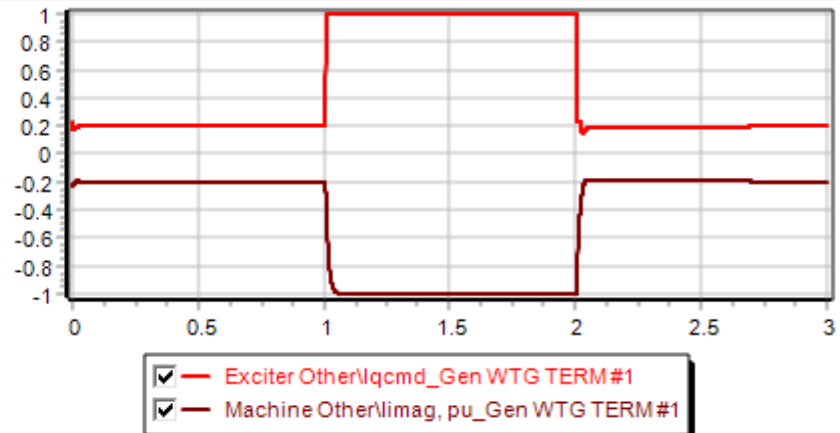
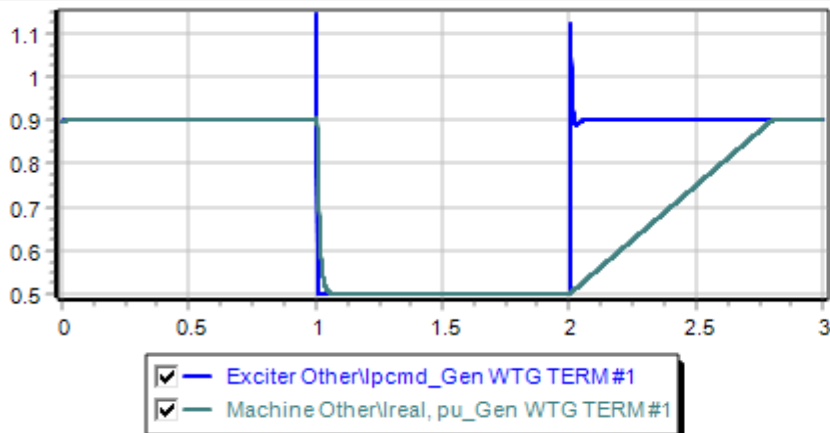
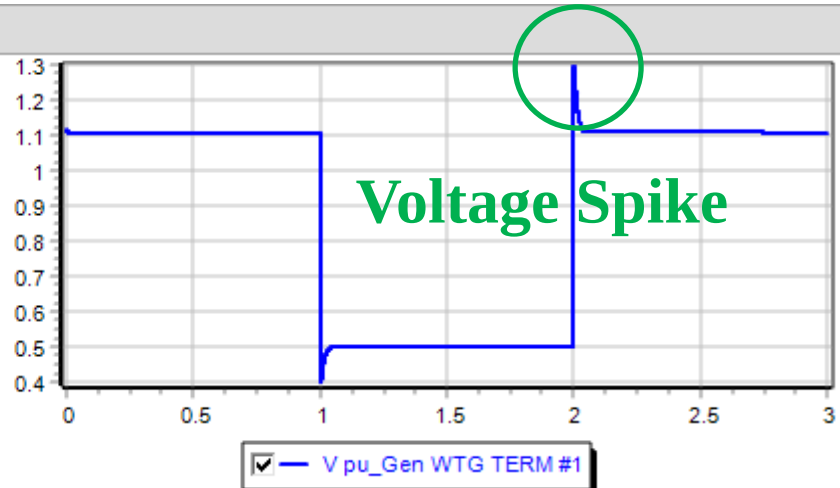
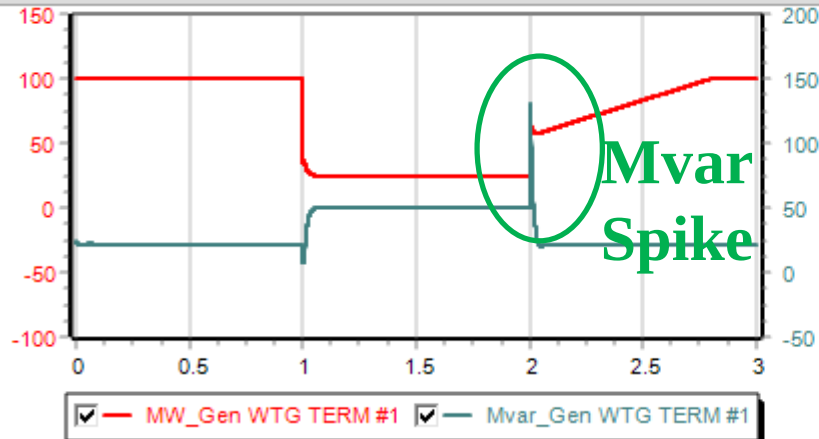
- This model is doing very little actually
 - Time delay T_g is the entirety of the converter model
 - Crudely, the model says
“Electrical Controller asks for a real and reactive current → 0.020 seconds later the converter creates this”
 - We are NOT modeling any of the power electronics at all
 - We are not modeling any phase-locked-loop (PLL)
 - Our assumption is all of that stuff is really fast
- “High Voltage Reactive Current Management” and “Low Voltage Active Current Management”
 - These are a dubious names because we aren’t modeling things in enough detail to really have “control” here
 - This control happens in the less than 1 cycle time-frame!

What is Happening?

Voltage and Mvar Spike



New Wind Turbine Test



High Voltage Reactive Current Management



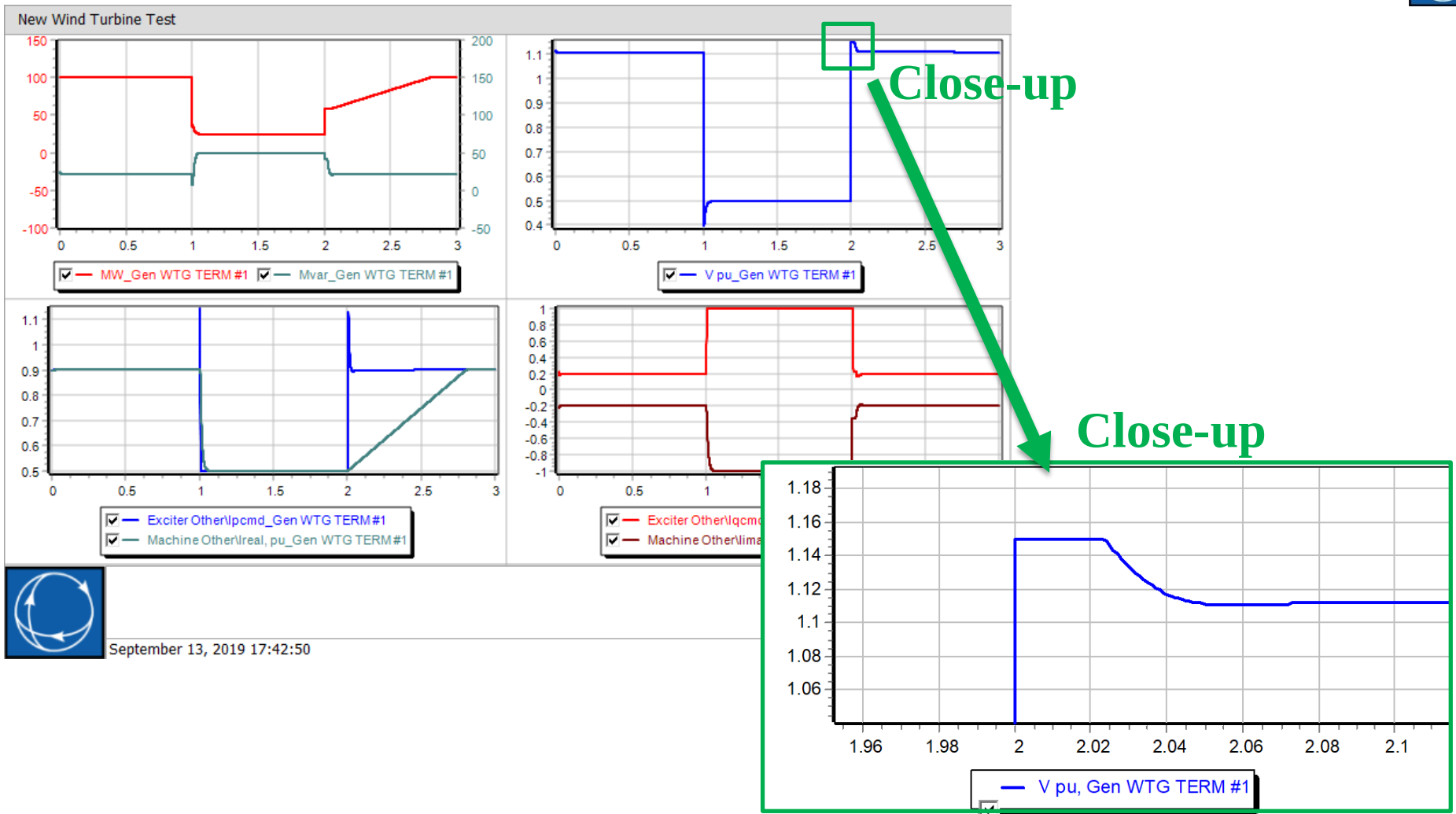
- What is Happening?
 - During the fault, the REEC* model control is going to push the reactive current command to a large value
 - It's trying to pull the voltage up as best it can!
 - Then the fault clears and the voltage pops back up
 - The current command is still high
 - The command goes through a time-delay of T_g (0.020 normally)
 - Thus higher voltage, High reactive current
 - → Giant Mvar output and a voltage spike!
- In an actual converter it would detect this extremely fast system changes and prevent this spike
 - I suspect you'd still see the spike, it just wouldn't last so long

High Voltage Reactive Current Management



- Power electronics are going to protect the equipment
 - If a high voltage (parameter V_{lim}) is detected then the reactive current will drop (and go negative) nearly instantaneously to prevent damage
 - This must be handled in the network boundary equations actually
 - If voltage goes above this threshold, then we model a reactive current that puts the voltage nearly exactly at this V_{lim} limit

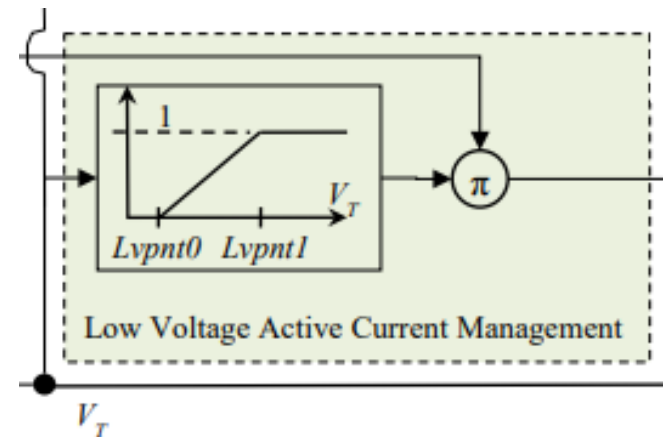
$$V_{lim} = 1.15$$



Low Voltage Current Management



- Immediately after a fault occurs, the numerical simulation is going to be pushing current into a fault (0.0 voltage)
- That is both not possible AND will make the software fail to solve
- This is parameter are for
 - Lvpnt0 and Lvpnt1
 - Do NOT set these to 0.0!
 - (Simulator won't allow them lower than 0.2 and 0.4)



REGC_B (Beta Model)

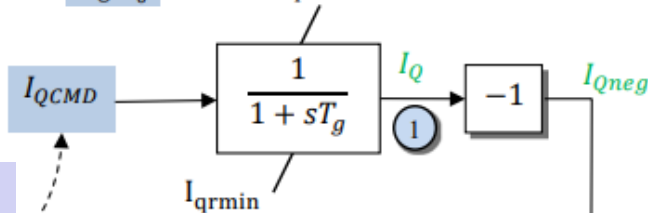
https://www.powerworld.com/WebHelp/#TransientModels_HTML/Machine%20Model%20REGC_B.htm



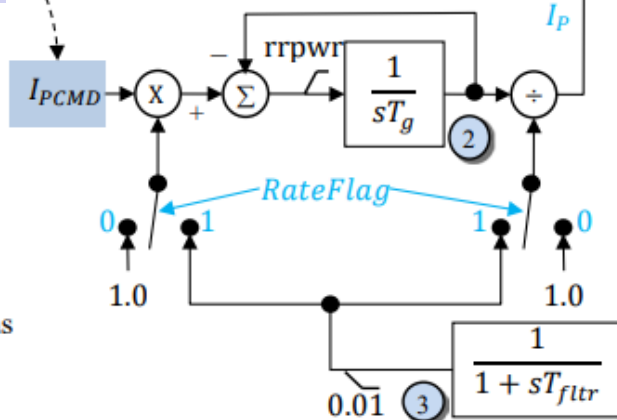
• “Machine Model”: Really a network interface

Rate limits on reactive current for recovery after fault.
Upward limit is active when $Q_{gen_0} > 0$
Downward limit is active $Q_{gen_0} < 0$

Q_{gen_0} → I_{qrmax}



Inputs from REEC* electrical models



States:

- 1 – I_q
- 2 – I_d
- 3 – V_{meas}
- 4 – E_q
- 5 – E_d

I_Q = per unit current that corresponds to reactive power

I_P = per unit current that corresponds to real power

$I_P + jI_{Qneg}$ = desired current injection in phase with terminal voltage

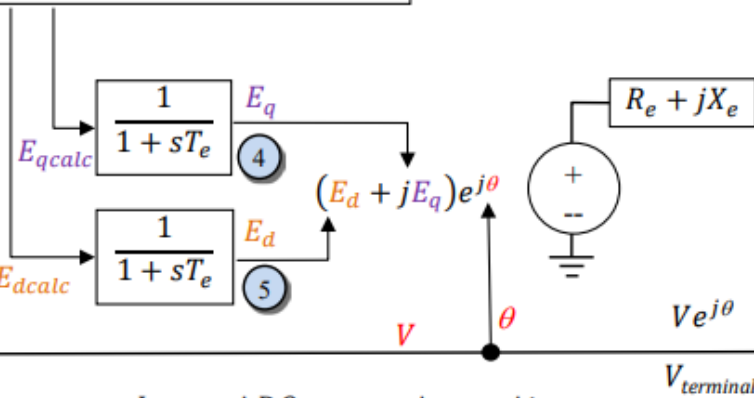
E_d = per unit voltage in phase with terminal voltage

E_q = per unit voltage out of phase with terminal voltage

V_{last} = per unit terminal voltage magnitude at last time step

θ = per unit terminal voltage angle at the terminal bus

$E_{qcalc} = 0 + I_{Qneg}R_e + I_PX_e$
 $E_{dcalc} = V_{last} + I_PR_e - I_{Qneg}X_e$
converts network interface equivalent from Norton to Thevenin



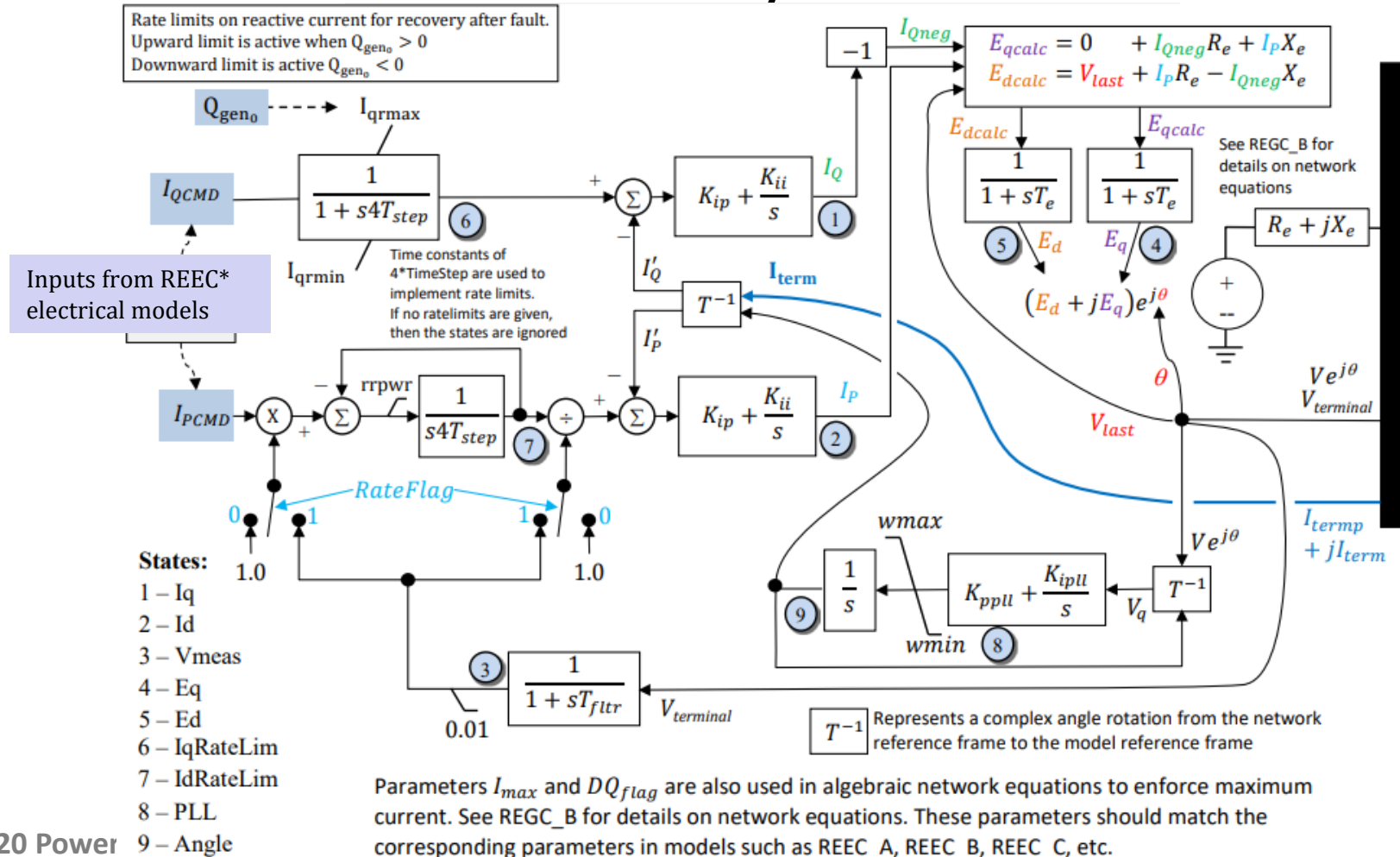
Parameters I_{max} and DQ_{flag} are also used in algebraic network equations to enforce maximum current. These parameters should match the corresponding parameters in models such as REEC_A, REEC_B, REEC_C, etc.

REGC_C (Beta Model)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Machine%20Model%20REGC_C.htm



- “Machine Model”: Really a network interface

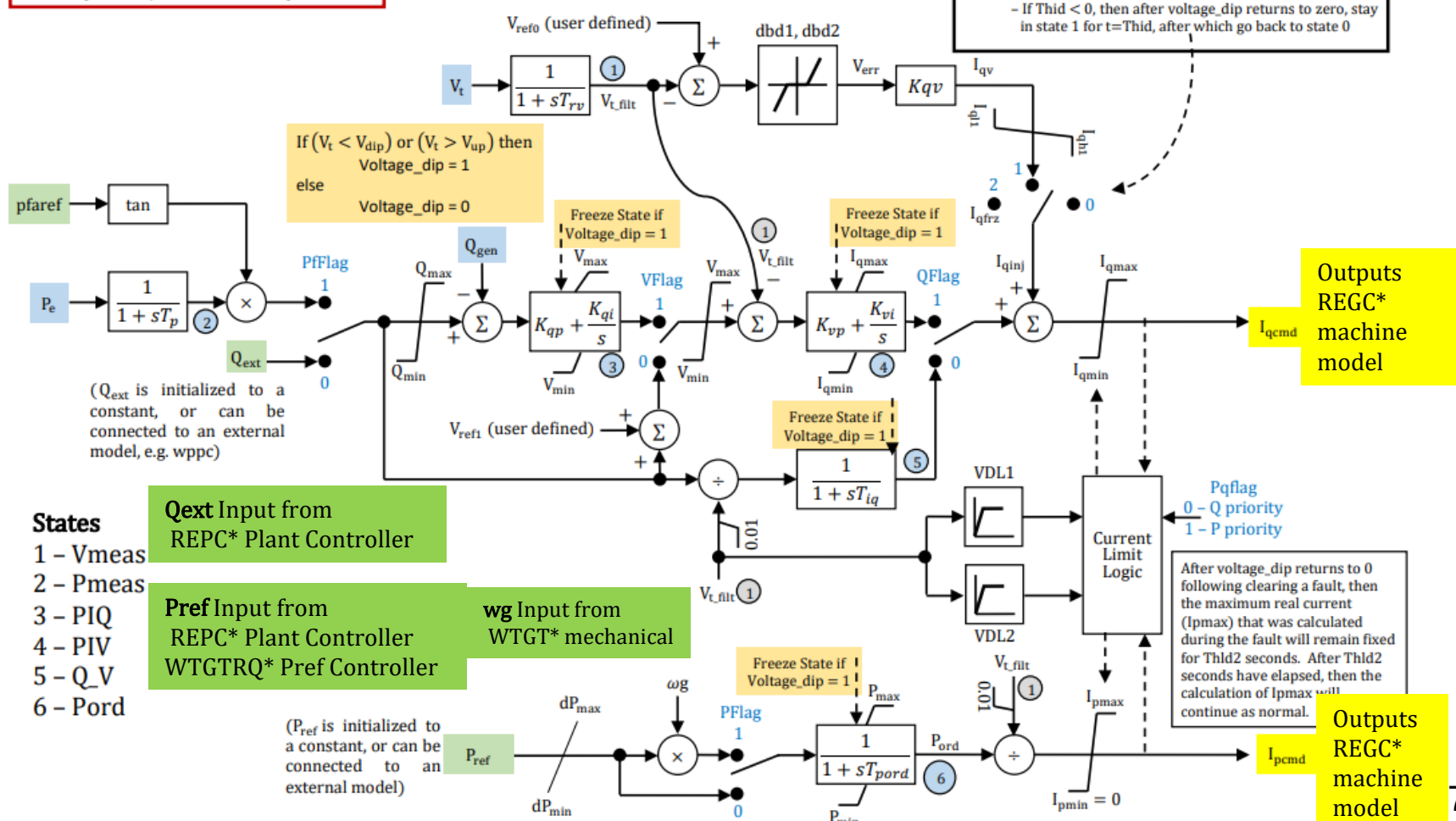


REEC_A (same as REECA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Exciter%20REEC_A.htm

Warning!!

Extreme care should be taken in coordinating the parameters dbd1, dbd2 and V_{dip} , V_{up} so as not to have an unintentional response from the reactive power injection control loop.



REEC_A Description



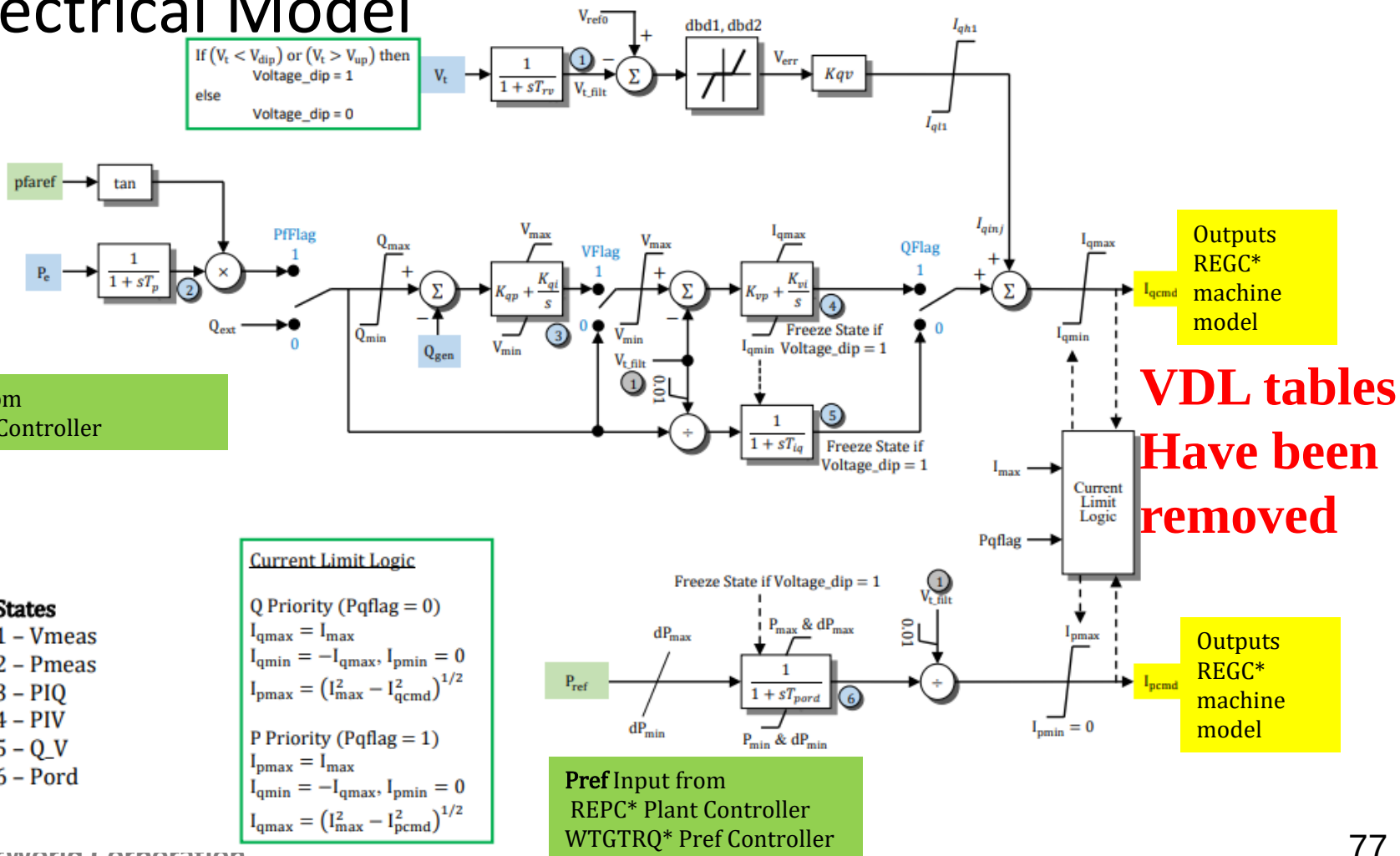
- First thing you must do is choose the control strategy
 - Voltage, Reactive Power, Constant Power Factor
 - When current limit is hit, do you have a preference to keep real power or reactive power up?
 - You can NOT “tune” these parameters!
- After than you set the PI controller parameters
 - Be careful not to set the K value too large. Large K means a very fast controller

REEC_B (same as REECB1)

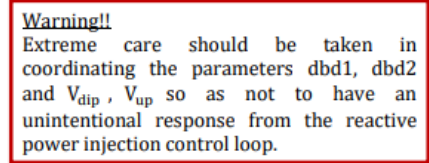
https://www.powerworld.com/WebHelp/#TransientModels_HTML/Exciter%20REEC_B.htm



Electrical Model



[/Exciter%20REEC C.htm](#)



Outputs
REGC*
machine
model

Outputs

REGC*

machine

model

[/Exciter%20REEC D.htm](#)

$$I_{pmin} = -K_e I_{Pmax}$$

REEC_D



- Added voltage compensation
- Added charging support ($K_e > 0$)
- VDLp and VDLq tables have 10 points and treatment when $I_{qmax} < 0$ means $I_{qmin} = I_{qmax}$

— Better support for momentary cessation modeling

— This is also why the REEC_B model is no longer recommended for Solar modeling

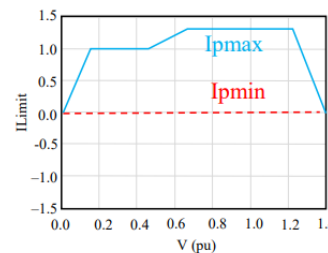
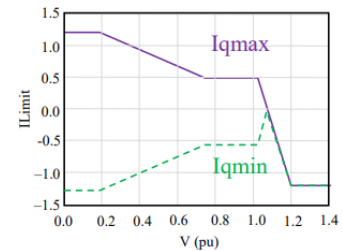
Example VDLp and VDLq tables showing negative I_{q5} value

Vp1=0.00; Vp2=0.15; Vp3=0.46; Vp4=0.67; Vp5=1.21; Vp6=1.40
Ip1=0.00; Ip2=1.00; Ip3=1.00; Ip4=1.30; Ip5=1.30; Ip6=0.00

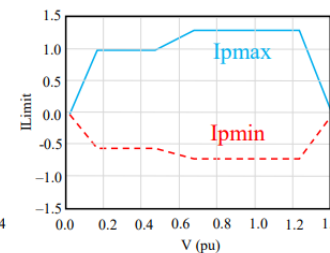
Vq1=0.00; Vq2=0.20; Vq3=0.72; Vq4=1.00; Vq5= 1.20; Vq6= 1.40
Iq1=1.20; Iq2=1.20; Iq3=0.50; Iq4=0.50; Iq5=-1.20; Iq6=-1.20

Figures at bottom show different values of K_e parameter.

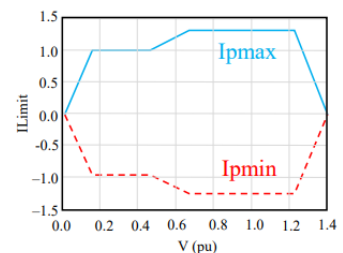
$$I_{pmin} = -K_e I_{pmax}$$



VDLp Table when $K_e = 0.0$



VDLp Table when $K_e = 0.5$



VDLp Table when $K_e = 1.0$

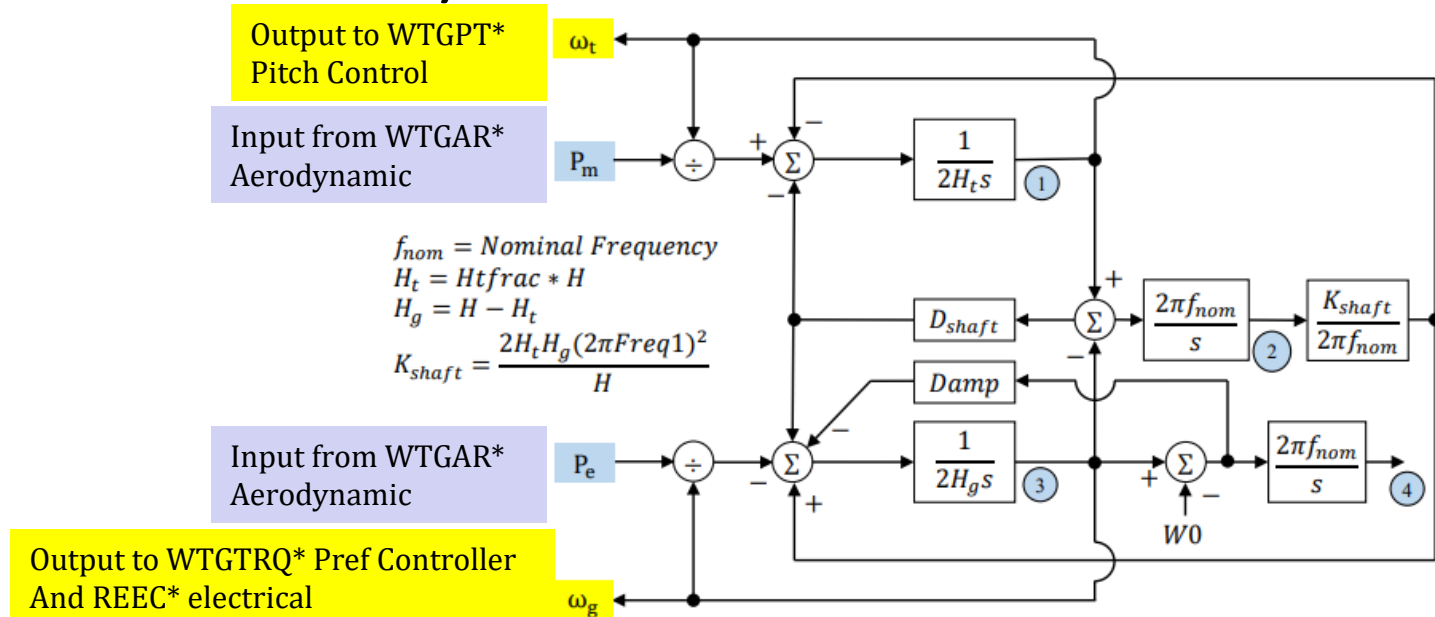
WTGT_A and WTDTA1

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Governor%20WTDTA1.htm

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Governor%20WTGT_A.htm



- Mechanical Model (models turbine blades and induction inertia)



Des NOT necessarily represent physical speed; internal model variable)

States

- 1 - TurbineSpeed
- 2 - ShaftAngle
- 3 - GenSpeed
- 4 - GenDeltaAngle

W0 = initial value of states ① and ③

W0 is obtained by using the lookup table of Speed versus Power from the Pref Controller WTTQA1 or WTGTRQ_A. If a Pref Controller is not specified, then the value specified with the WTGT_B model is used.

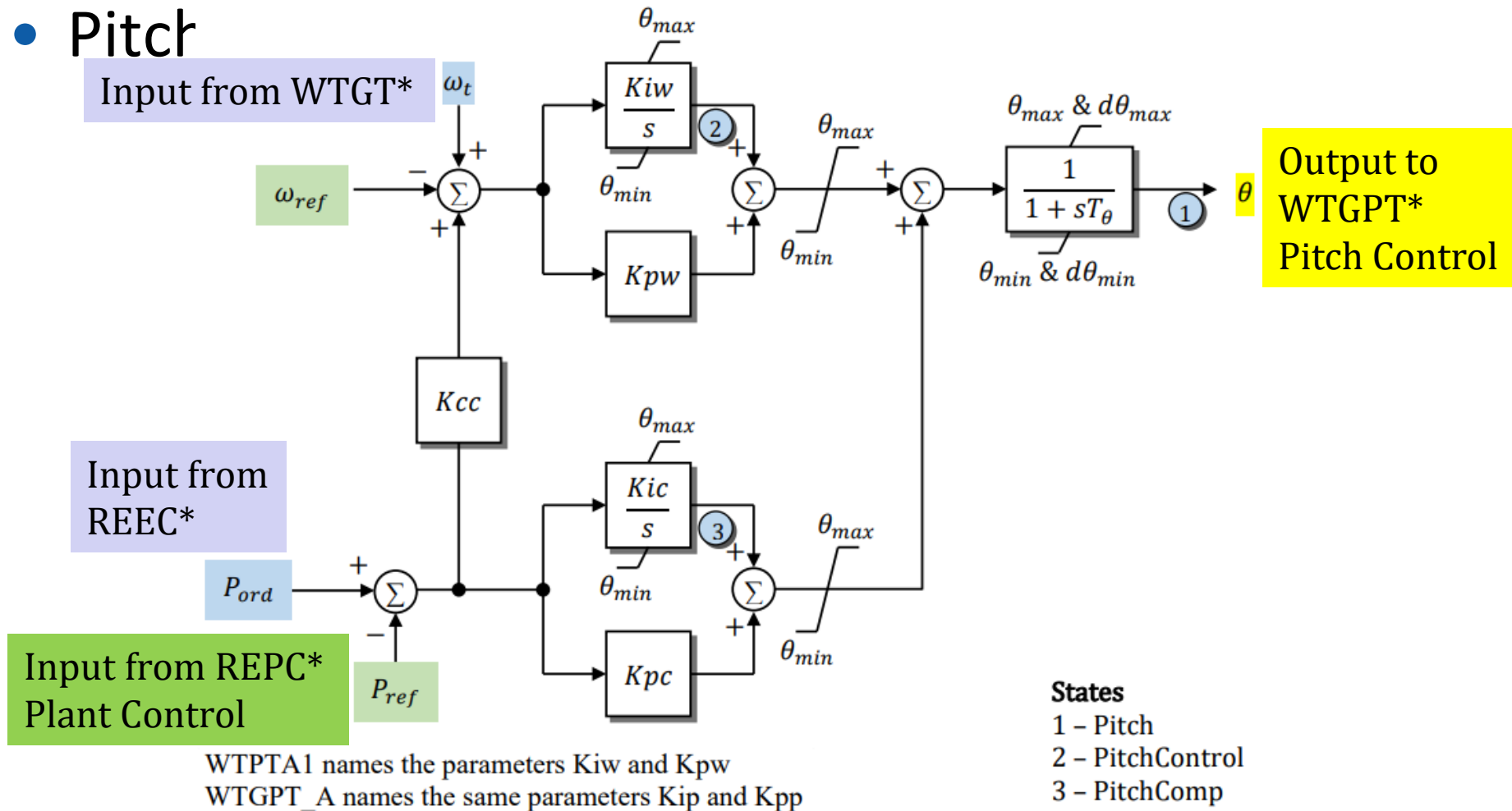
WTGPT_A (WTGP_A or WTPTA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Stabilizer%20WTGPT_A.htm



• Pitch

Input from WTGT*



WTGPT_B

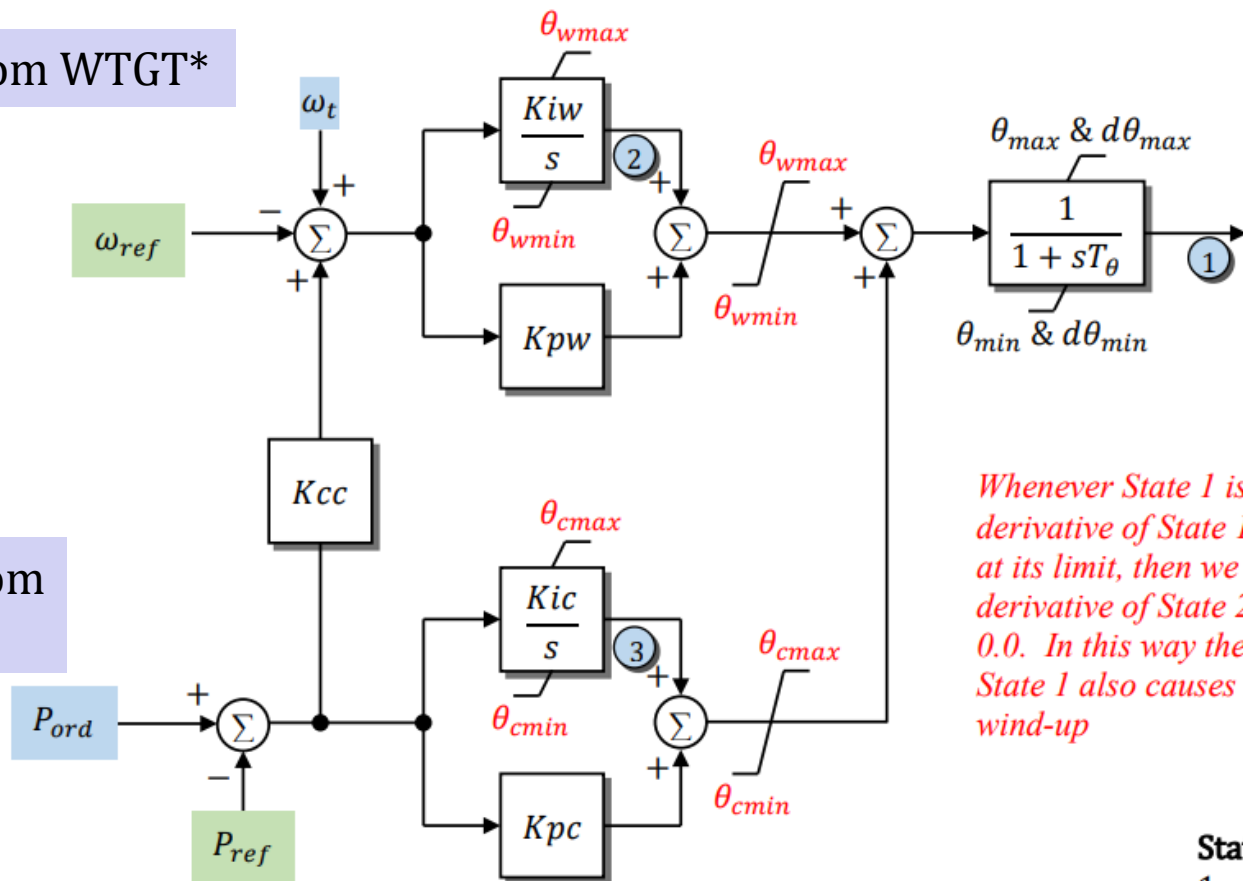
https://www.powerworld.com/WebHelp/#TransientModels_HTML/Stabilizer%20WTGPT_B.htm



• Pitch Controller

Input from WTGT*

Input from REEC*



Output to WTGPT*
Pitch Control

Whenever State 1 is at a limit and the derivative of State 1 is holding the state at its limit, then we also force the derivative of State 2 and State 3 to be 0.0. In this way the non-windup limit at State 1 also causes State 2 and 3 to not wind-up

States

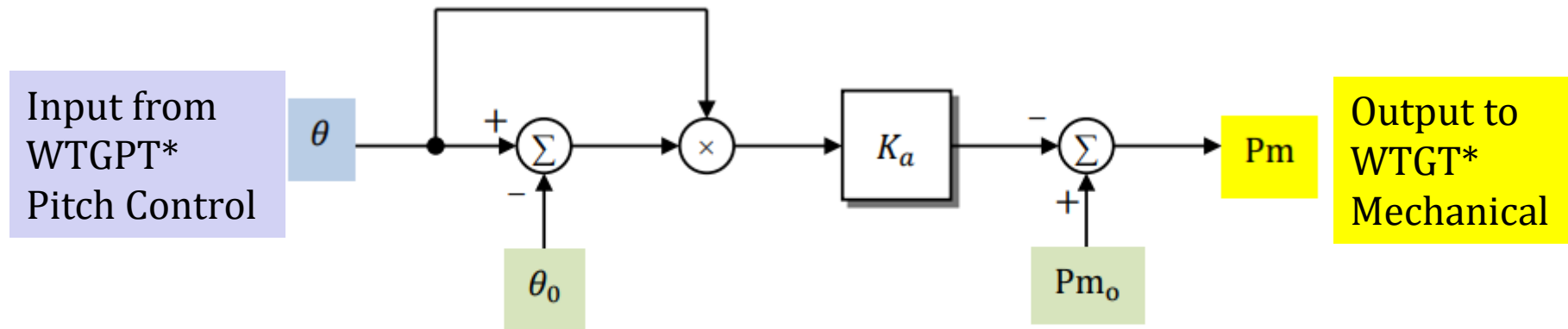
- 1 – Pitch
- 2 – PitchControl
- 3 – PitchComp

WTGAR_A (WTGA_A and WTARA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Aerodynamic%20Model%20WTGAR_A.htm



- Aerodynamic Model



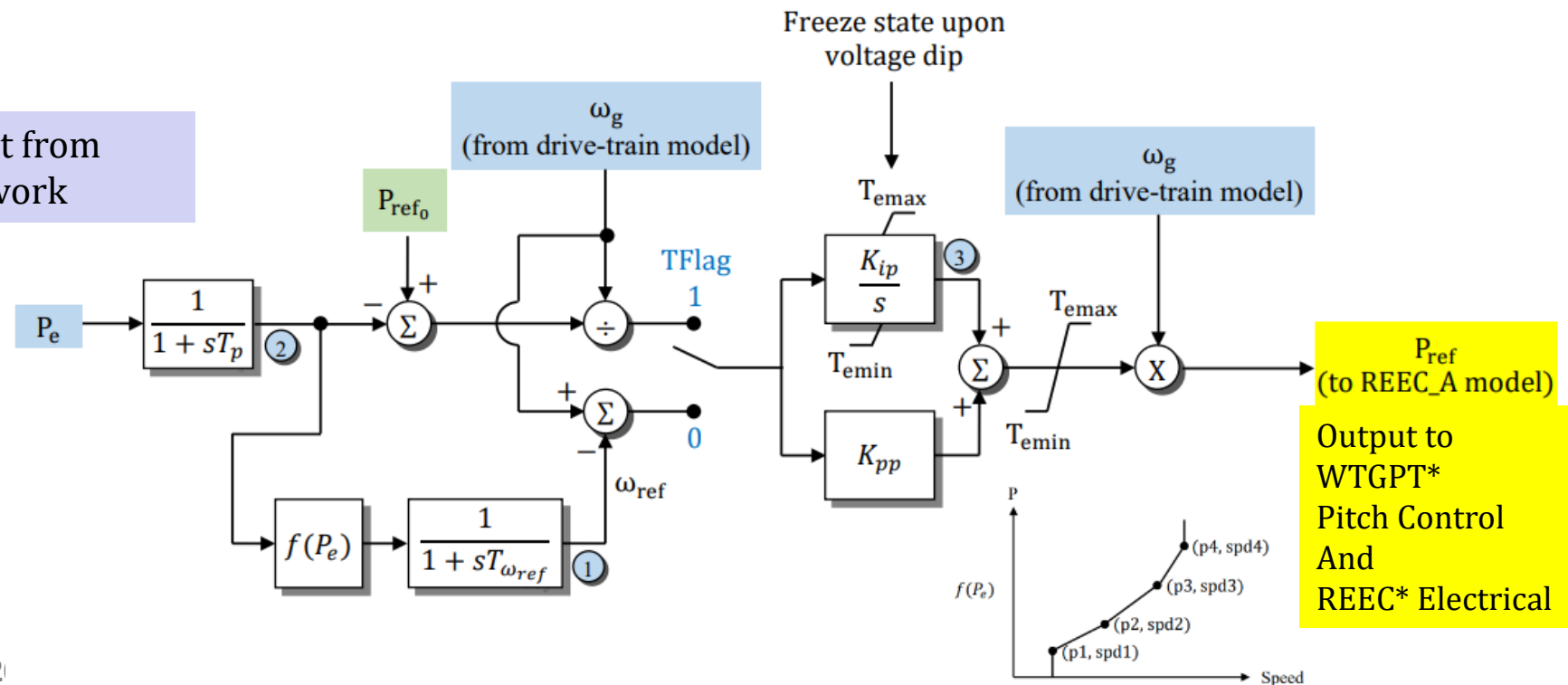
Model supported by PowerWorld
Named WTGA_A in PSLF
Named WTARA1 in PSS/E

WTGTRQ_A (WTTQA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Pref%20Controller%20WTGTRQ_A.htm



- Torque Controller for Wind Turbine
- Normal Recommendation is Tflag = 0 as this includes the lookup table of speed from Power

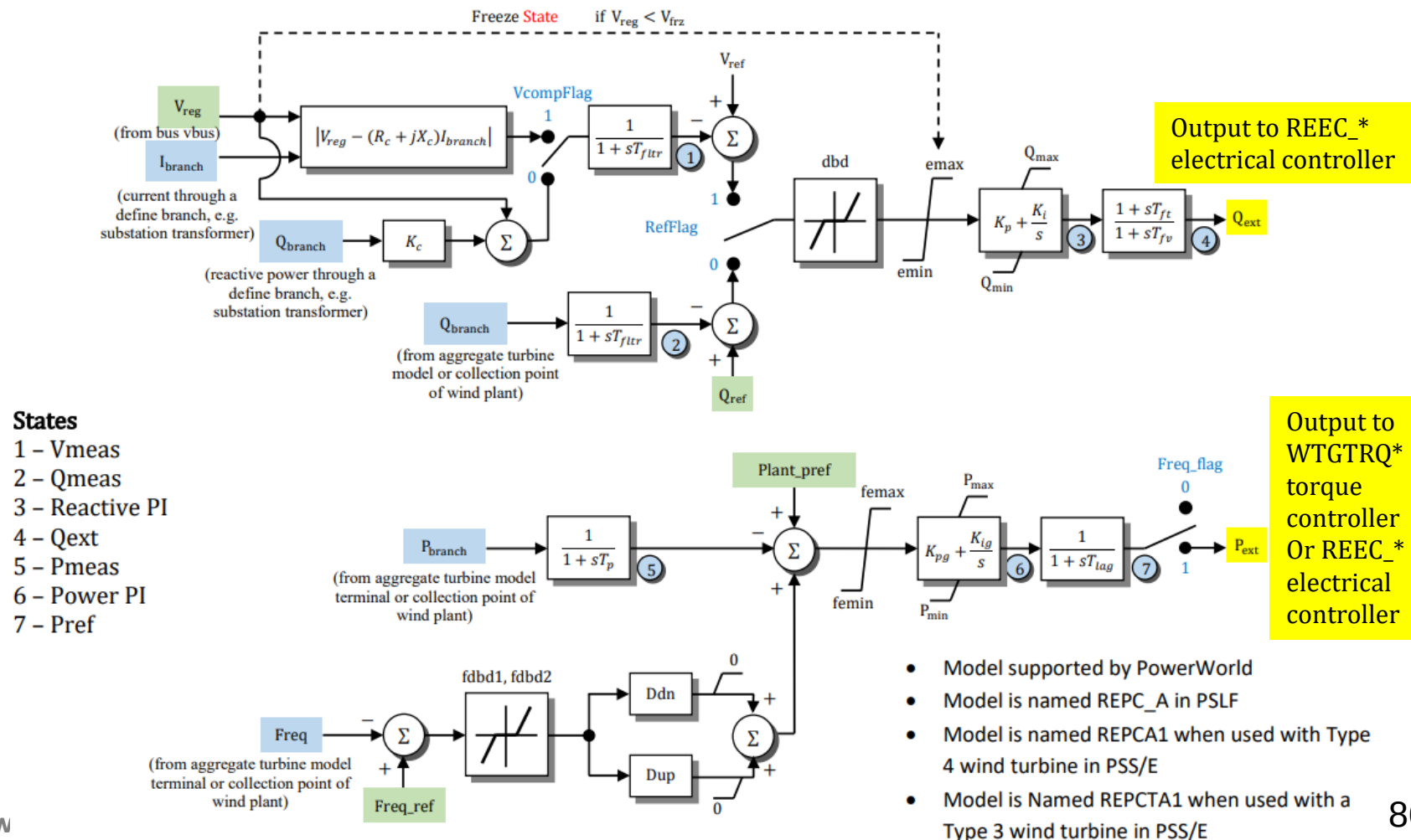


REPC_A (REPCA1, REPCTA1)

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Plant%20Controller%20REPC_A.htm



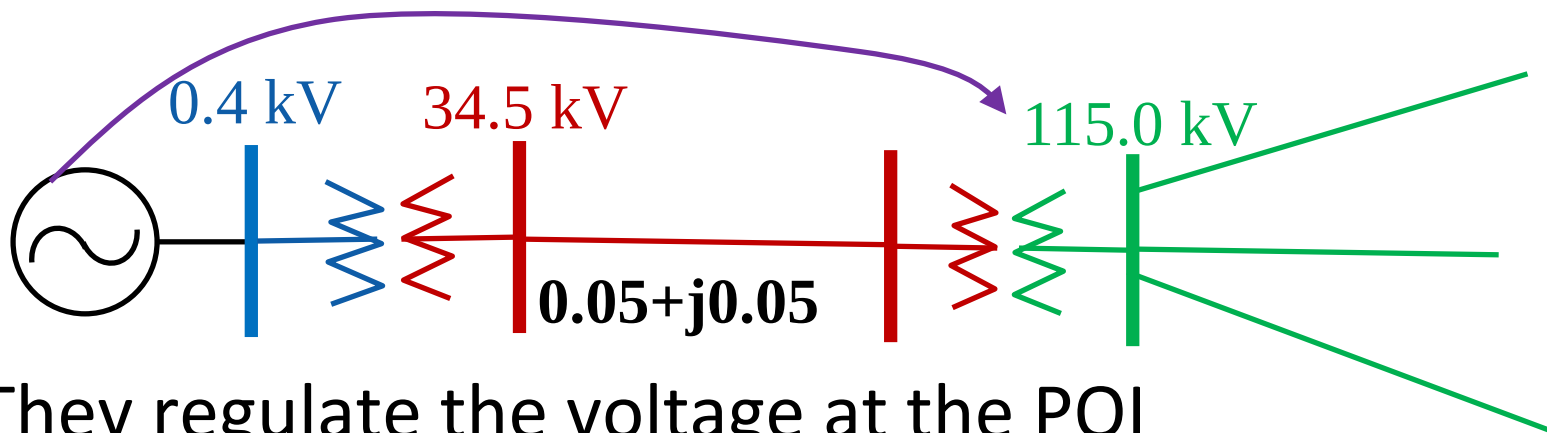
• Plant Controller



Renewable Generator Questions started in 2013



- Renewable generators regulate a point closer to the point of interconnection

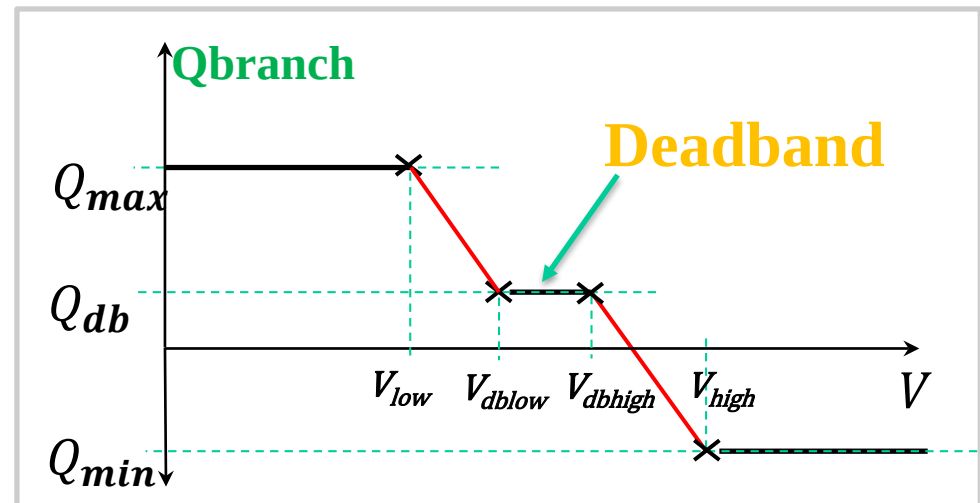
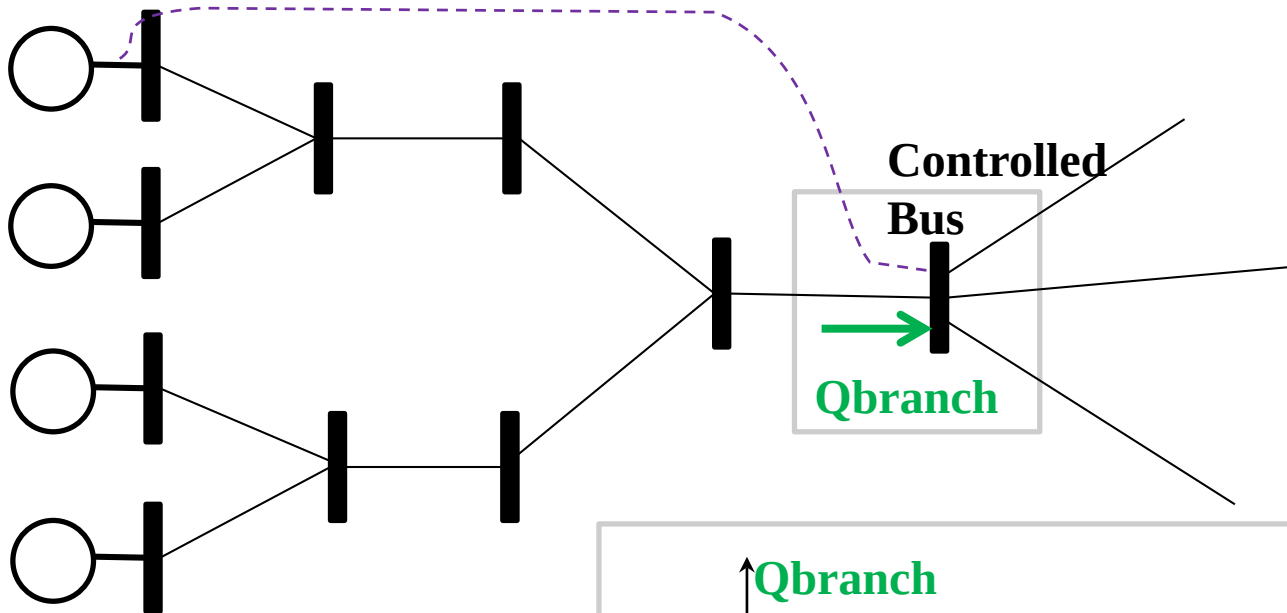


- They regulate the voltage at the POI (the 115 kV bus) against a QV characteristic curve
- Starting to get questions about Solar PV plant voltage control

Typical Configuration may have multiple Generators



Generators are all configured to regulate the Controlled Bus



Slope Control with Deadband

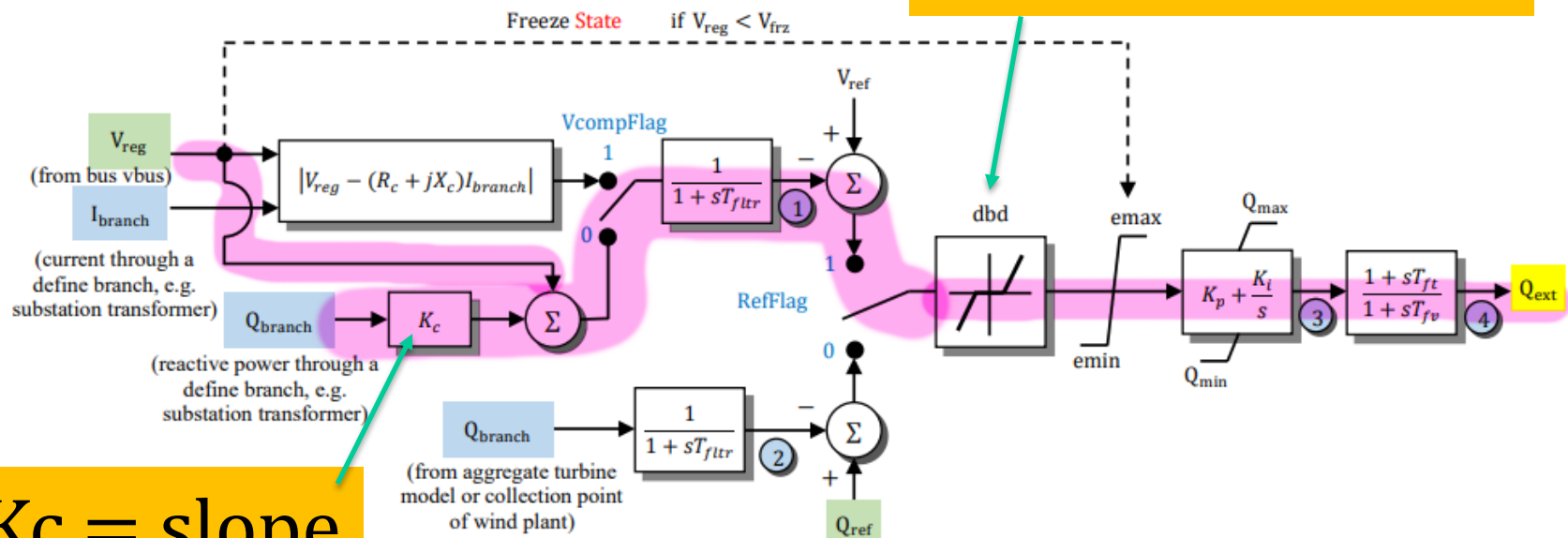


- Getting questions about solar and wind farms that have voltage control that is not a setpoint
- A deadband is given
 - 0.98 to 1.02 per unit voltage – provide zero Mvars (or a constant value)
- Once outside these deadband, a negative slope characteristic is followed
- Maximum and Minimum Mvar will be hit eventually

REPC_A has this Voltage Droop Control with Deadband!



Dbd = Deadband



$K_c = \text{slope}$

REPC_B and REPC_B100

https://www.powerworld.com/WebHelp/#TransientModels_HTML/Plant%20Controller%20REPC_B.htm



- Plant Controller (connect 50 or 100 gens/svcs)

