Transient Stability Analysis with PowerWorld Simulator

T12: Wind, Solar, and Other Renewable Generation Models in PowerWorld Simulator

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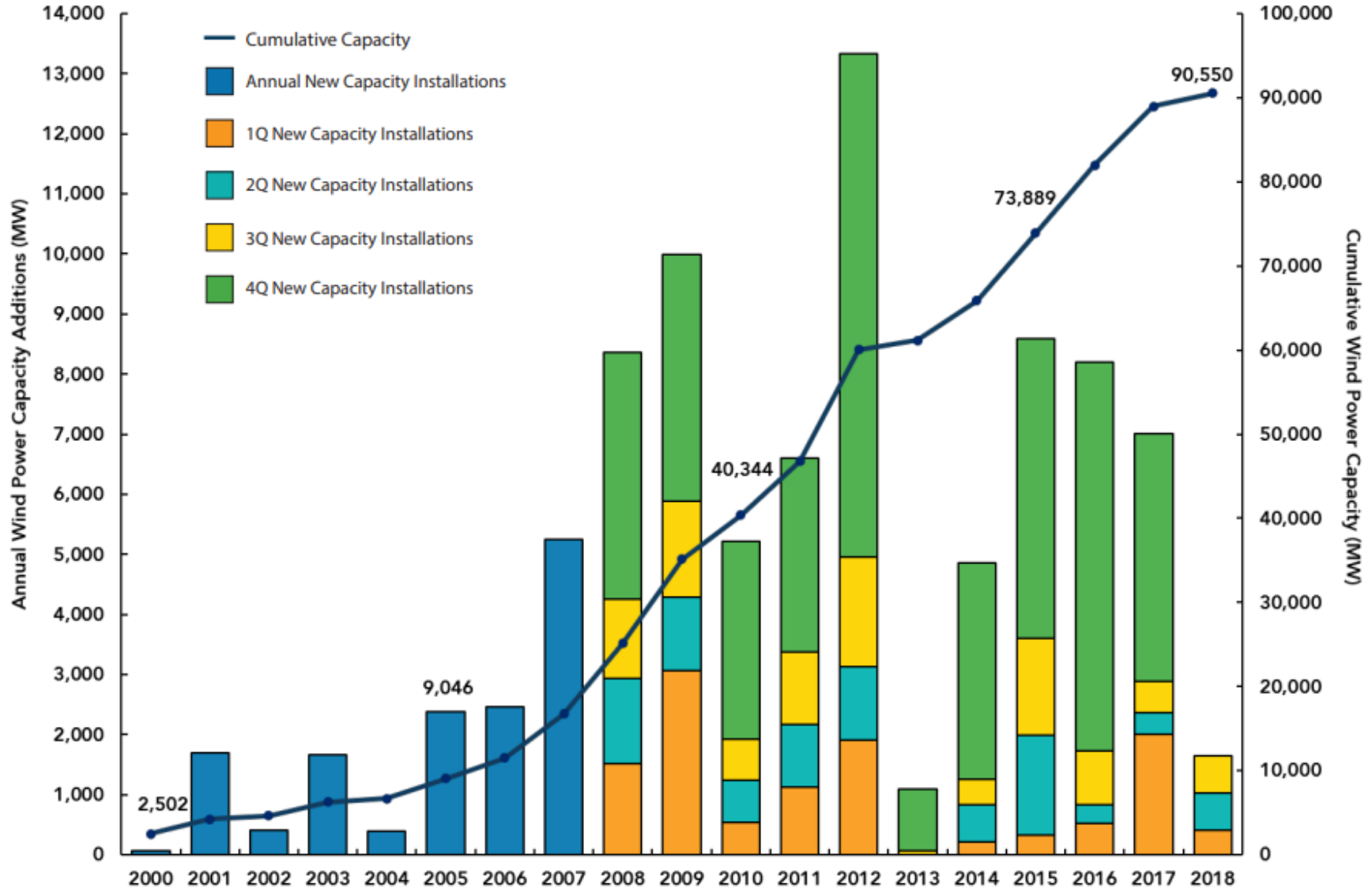
U.S. Annual and Cumulative Wind Power Capacity Growth

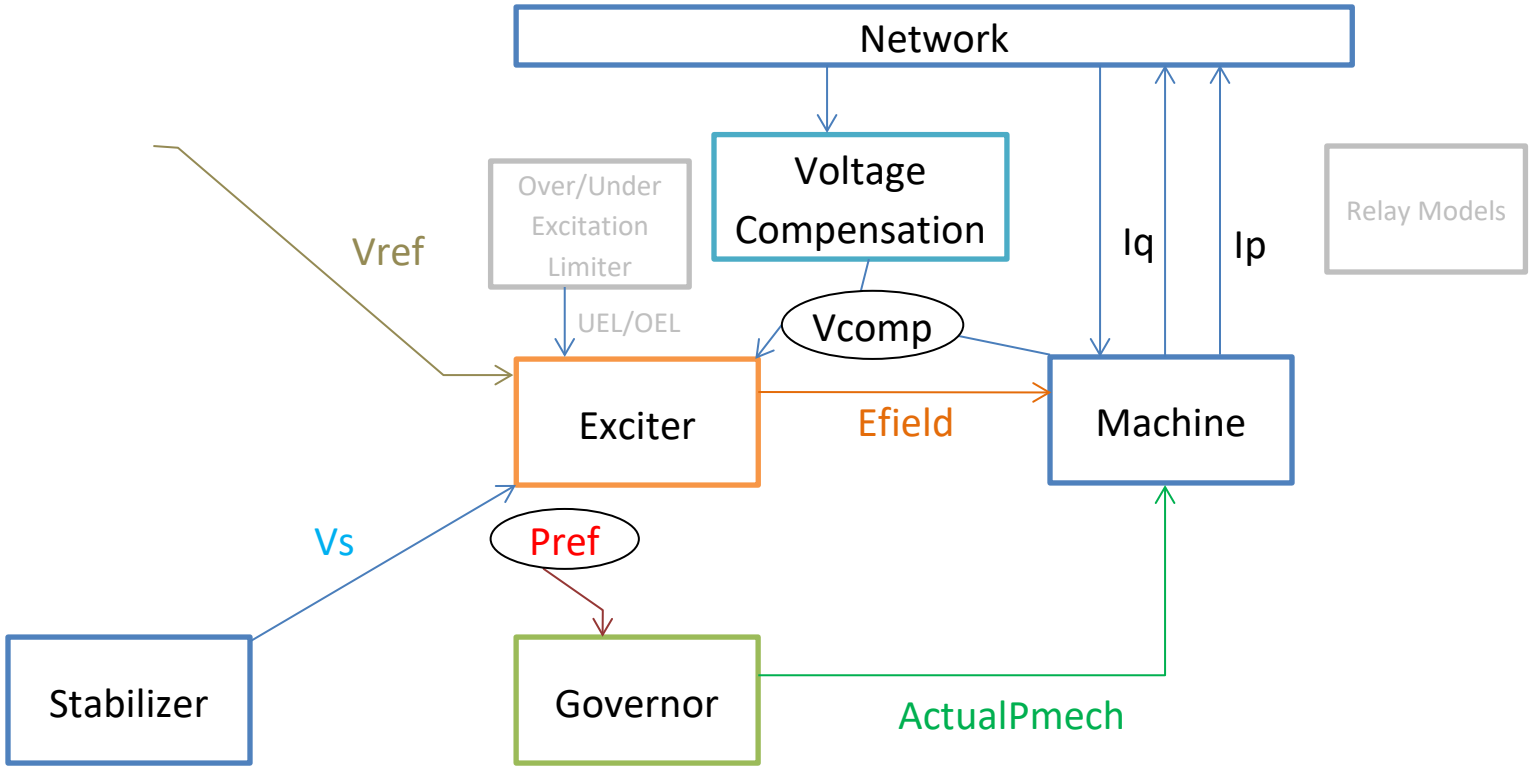


Note: Utility-scale wind capacity includes installations of wind turbines larger than 100-kW for the purpose of the AWEA U.S. Wind Industry Quarterly Market Reports. Annual capacity additions and cumulative capacity may not always add up due to decommissioned and repowered wind capacity. Wind capacity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

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

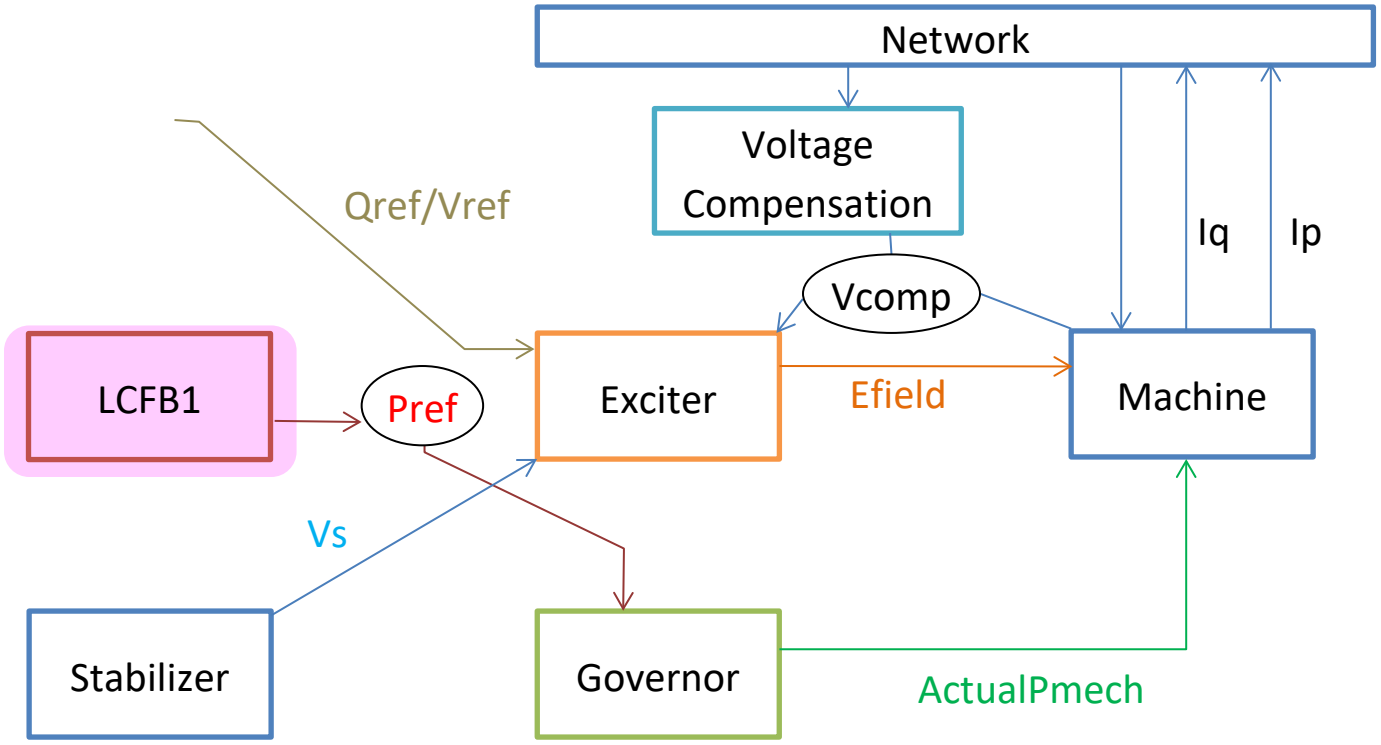
“Traditional” Synchronous Machine Modules



Modular Approach to Generator Modeling

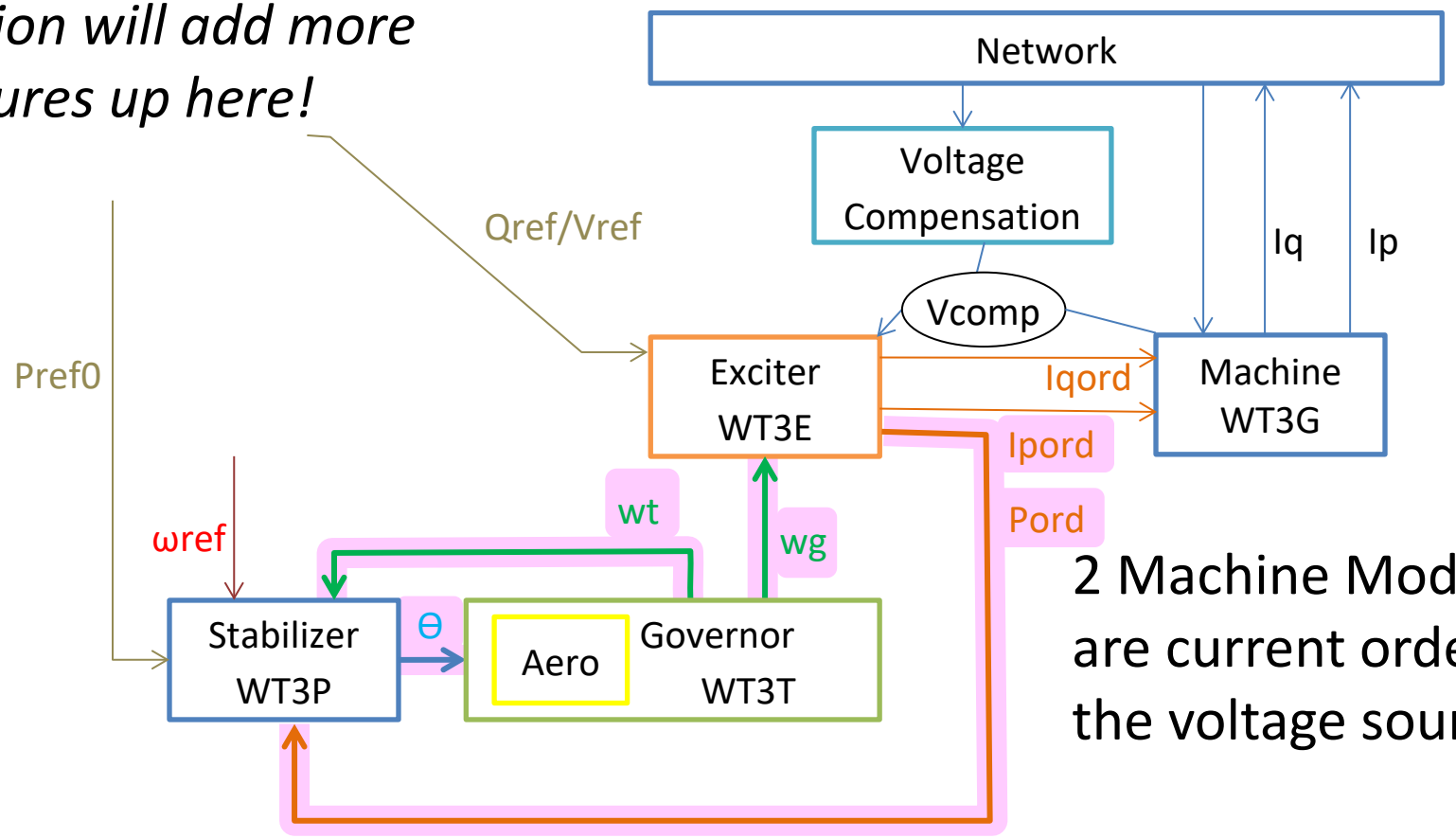
- First generation wind turbine models stuck with this structure
  - Added additional signals to pass between modules
  - Don’t get hung up on nomenclature “Exciter” just means the electrical control
- Unrelated to wind turbine modeling, another module was added for better modeling of large steam plants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

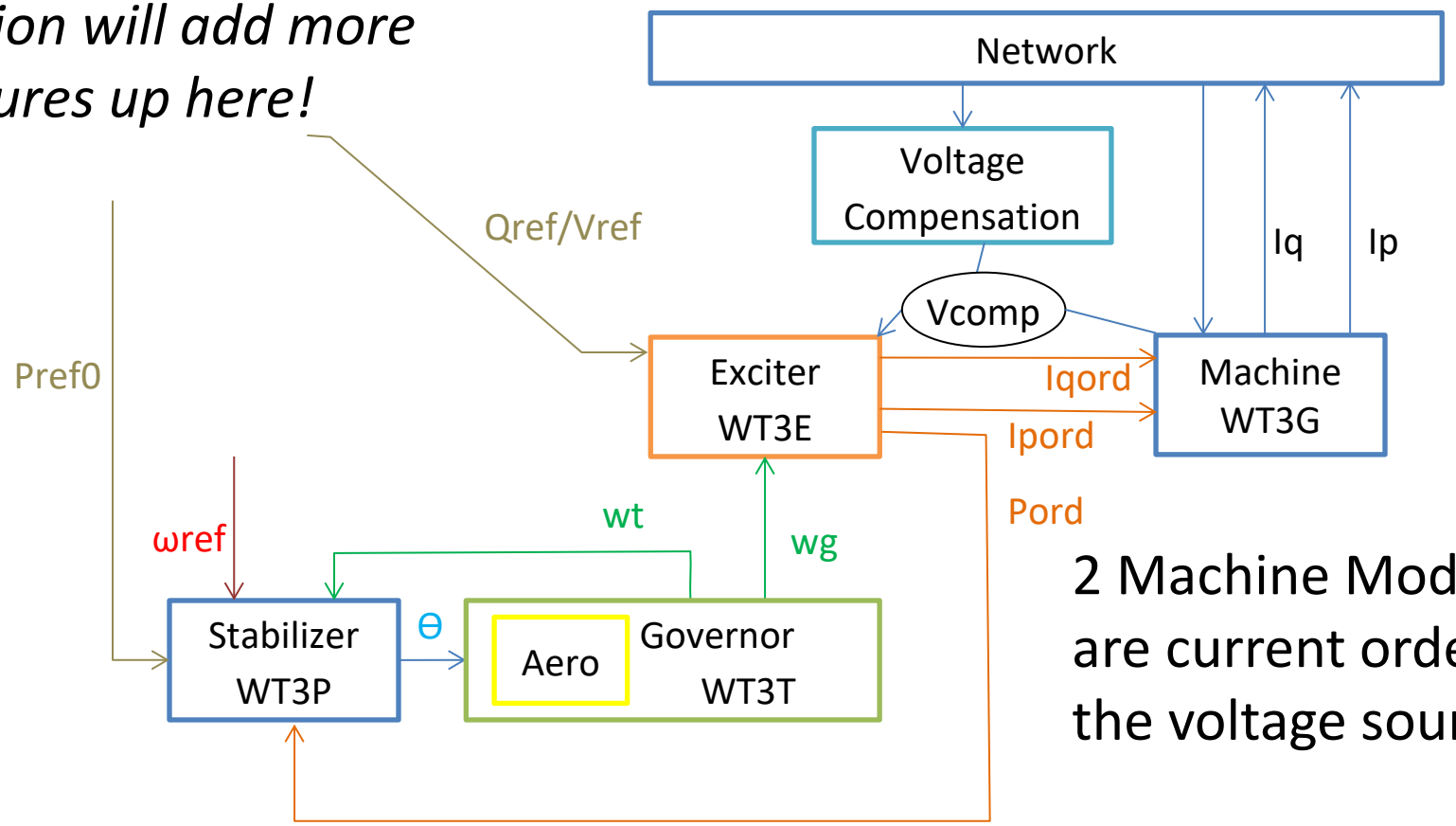
- First Generation model had few mechanisms to provide control features of
  - Real Power or Torque Control
  - Reactive Power
  - Voltage Control
  - For First Generation models, the wind turbine basically tried to bring values back to the initial condition
    - Pref bring power back to initial Power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



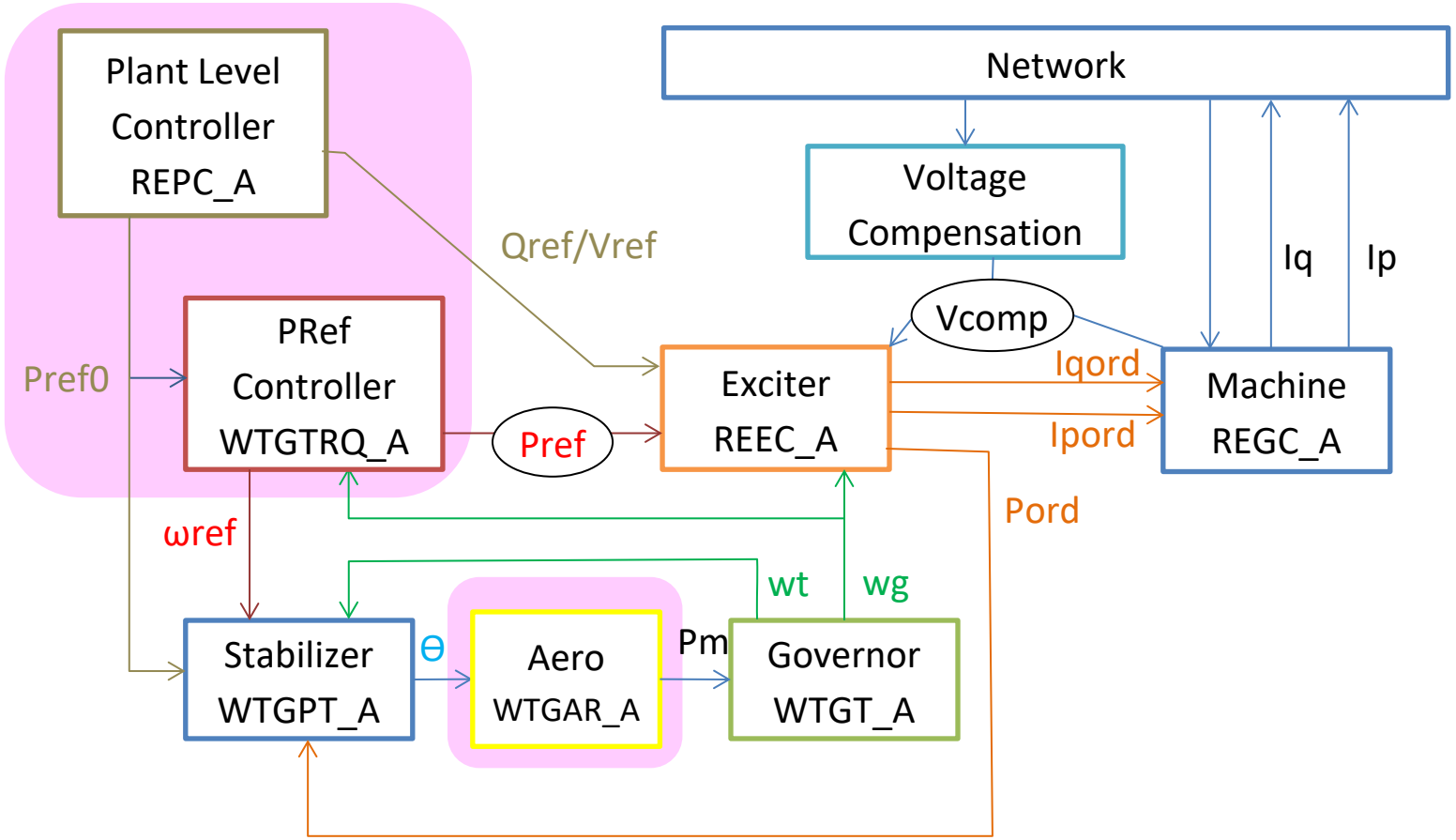
2 Machine Model inputs now. They are current orders requested of the voltage source converter

Several new signals passing around

2nd Generation Type 3 Wind Turbine

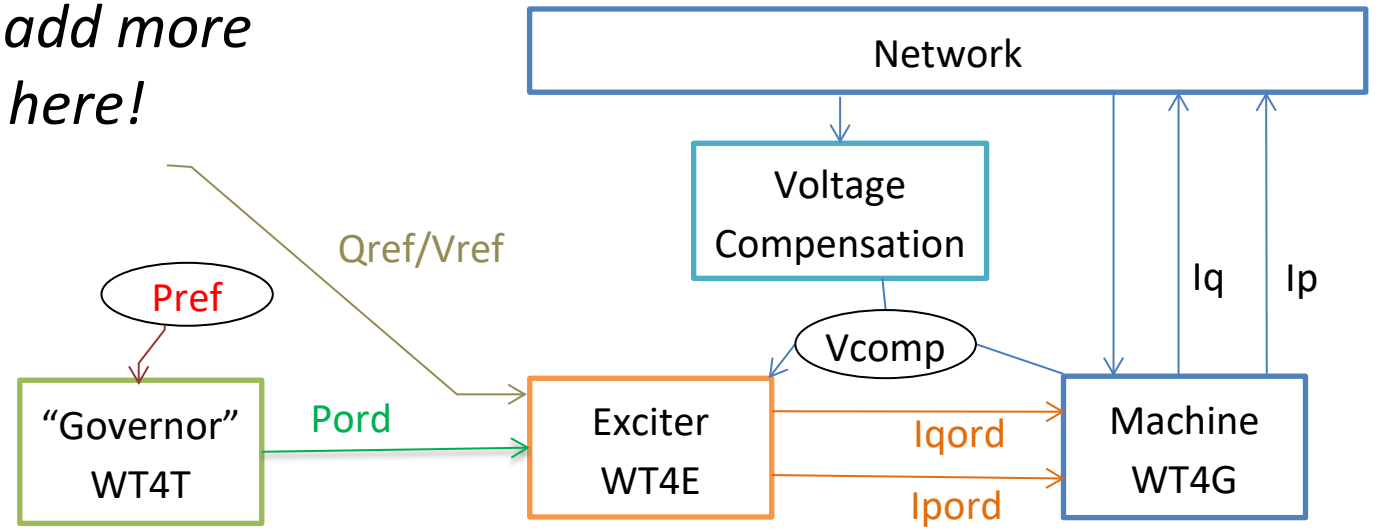
(REGC_A, REEC_A, WTGT_A, WTGAR_A, WTGPT_A, WTGTRQ_A, REPC_A)

2nd Generation adds the Aero, PRef and Plant Controllers



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

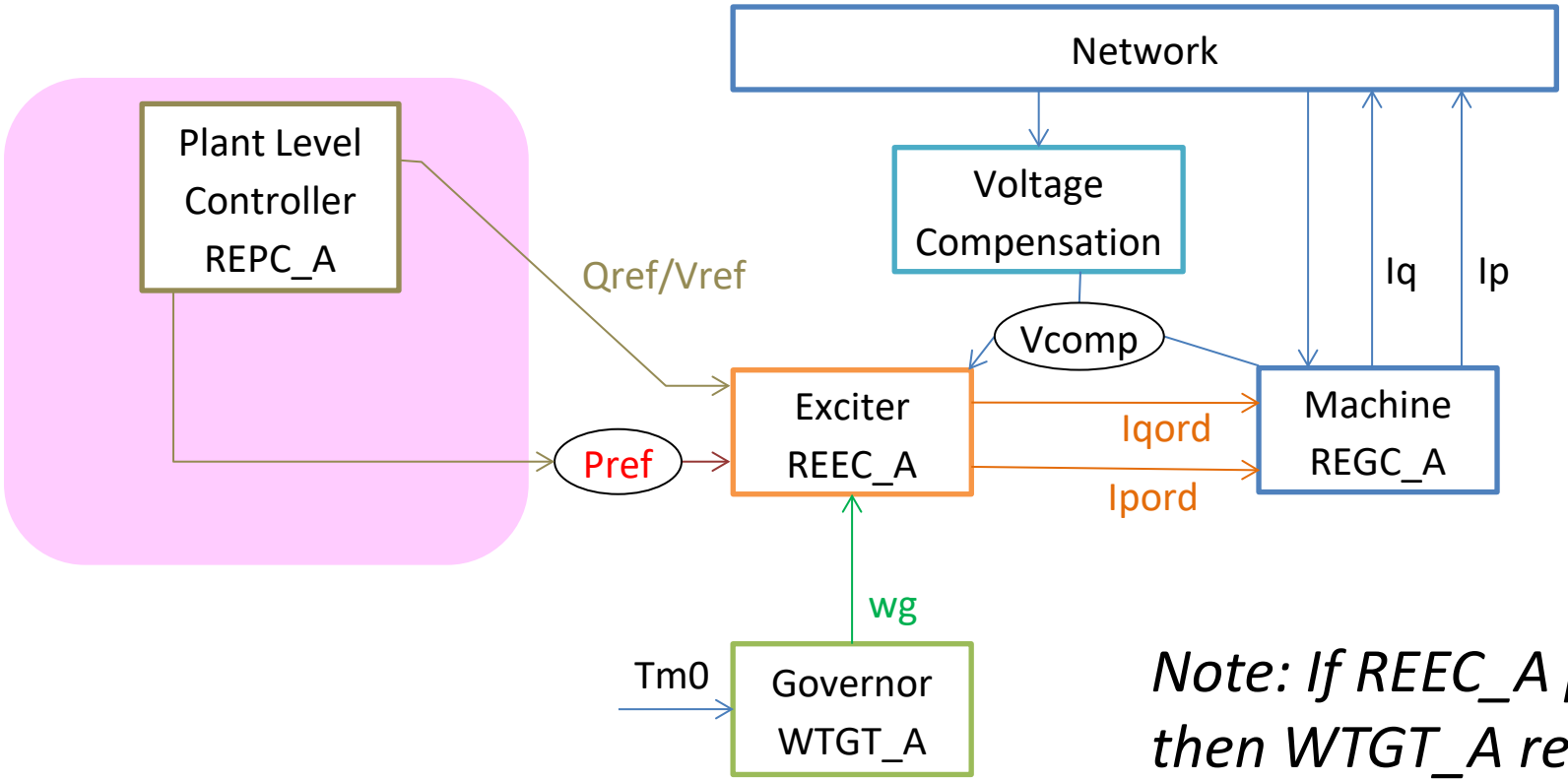
2nd Generation will add more control features up here!



Legacy "Governor" WT4T
This really acts like the new PRef controller

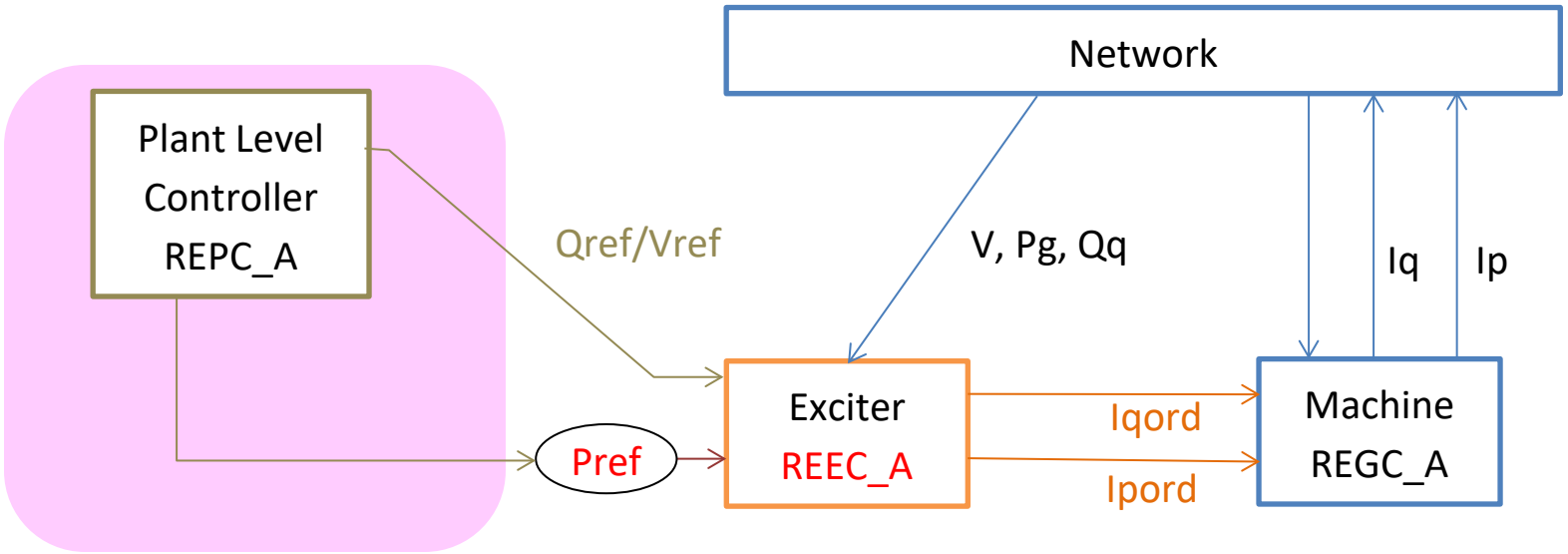
We will leave it in the toolbox as a "Governor" anyway

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

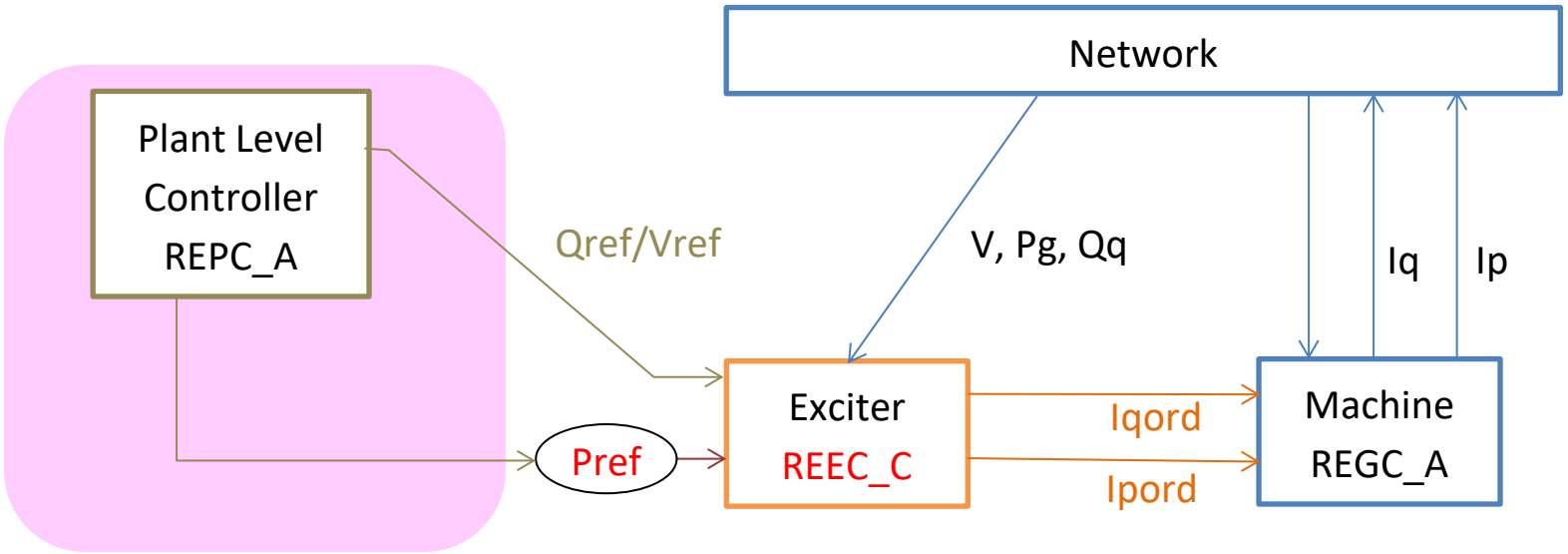
2nd Generation Solar Plant



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

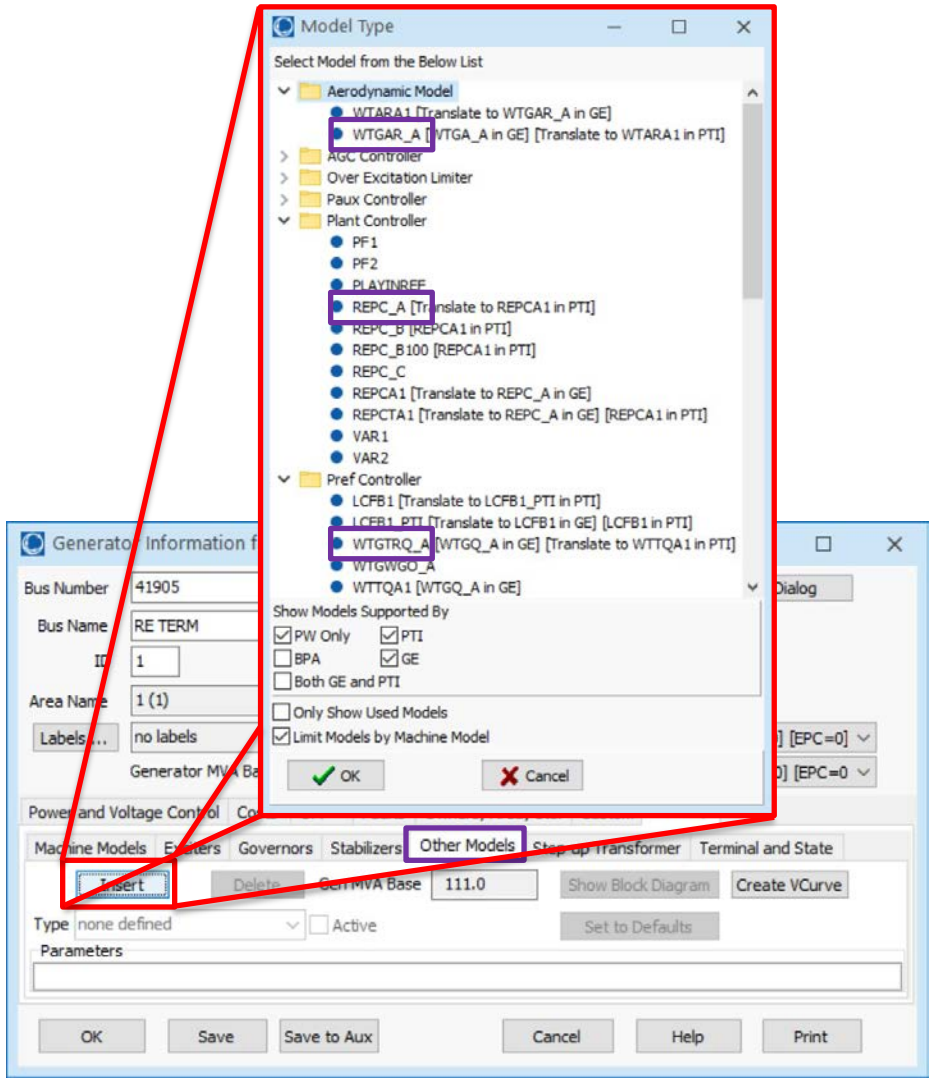
- Error checking is performed when validation is done
  - Ensure there is only 1 Pref controller defined
  - Ensure there is only 1 Plant controller defined
  - Ensure there is only 1 Aerodynamic model
    - Also note, if an aerodynamic model is required between the stabilizer and the governor (WTGPT_A and WTGT_A), but one is not defined, Simulator assumes a WTGAR_A exists with Ka = 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

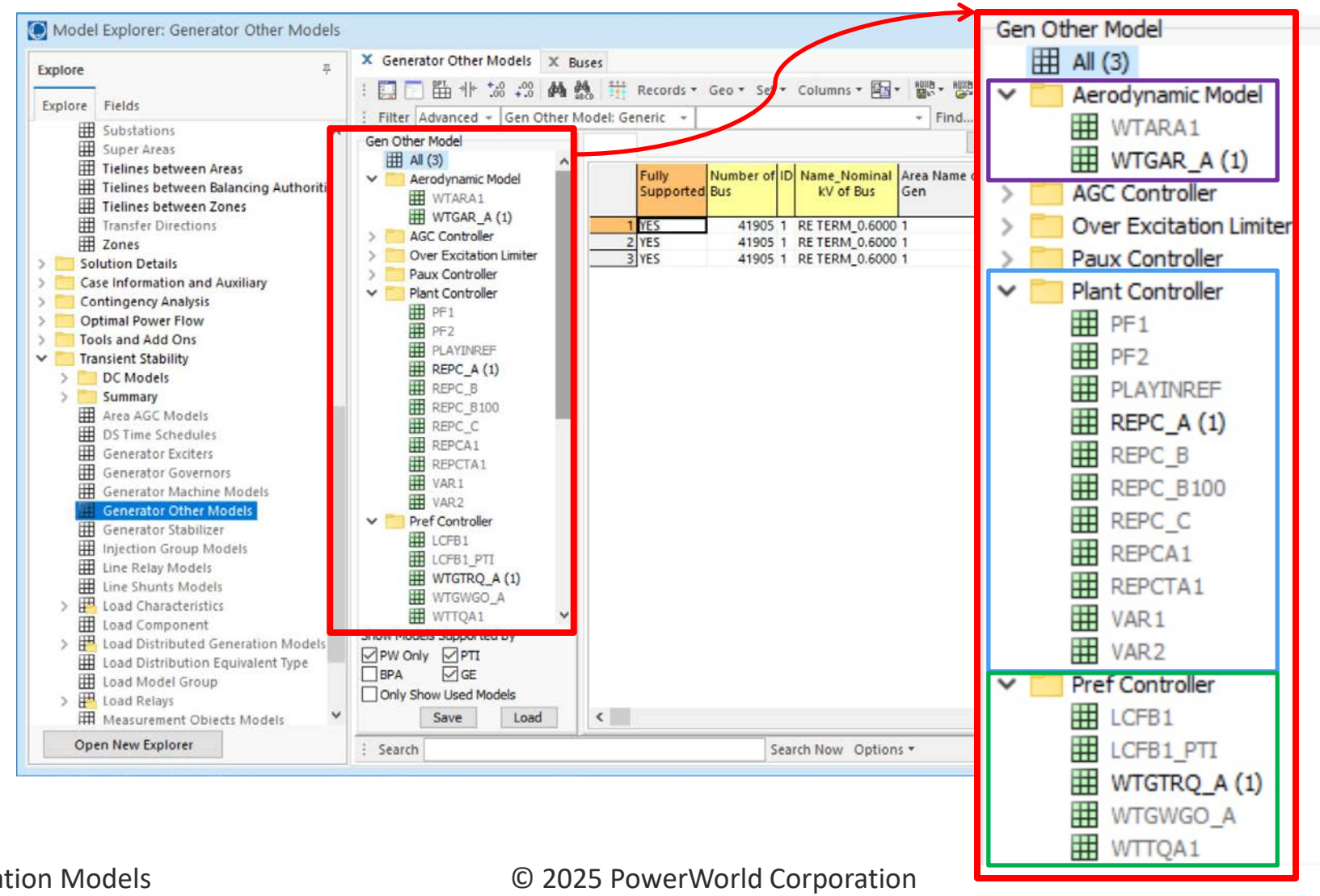
- Because of the way these various blocks connect together, the initialization order of the blocks important
  - Example: the “initial speed” of the wind turbine is calculated in different places
    - For 1st Gen Type 3 → WT3E *(Exciter)*
    - For 2nd Gen Type 3 → WTGTRQ_A *(PRef controller)*
    - 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

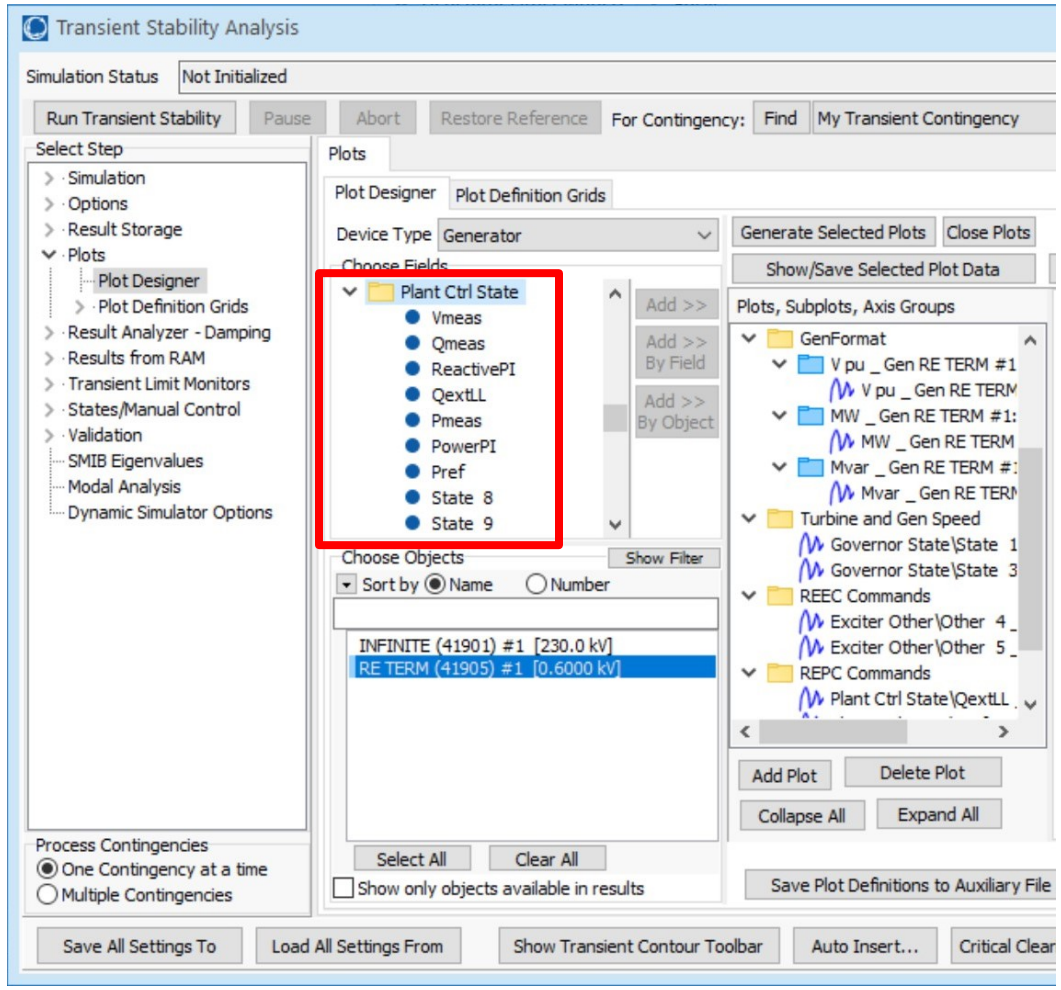
- Machine, Exciter, Governor, and Stabilizer remain prominent
- *Other Models* contain the other categories of modules
- You see it in the Model Explorer
- When inserting a new *Other Model* from the generator dialog
- Plot Designer in Transient Stability Dialog

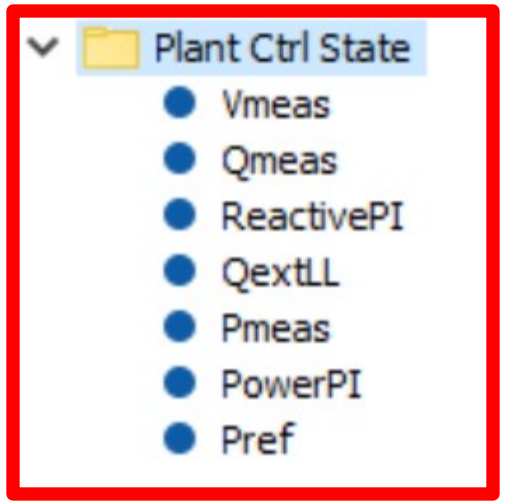


Model Explorer



Plot Designer





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_B, REPC_A
    - REEC_B is 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

Additional Uses

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	REGC_A
Electrical Model		WT2E WT2E1	REEC_A	REEC_A	REEC_B		REEC_C
Mechanical	WT1T WT12T1	WT2T WT12T1	WTGT_A	WTGT_A			
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

REPC_B = Plant controller for up to 50 machines and SVCs

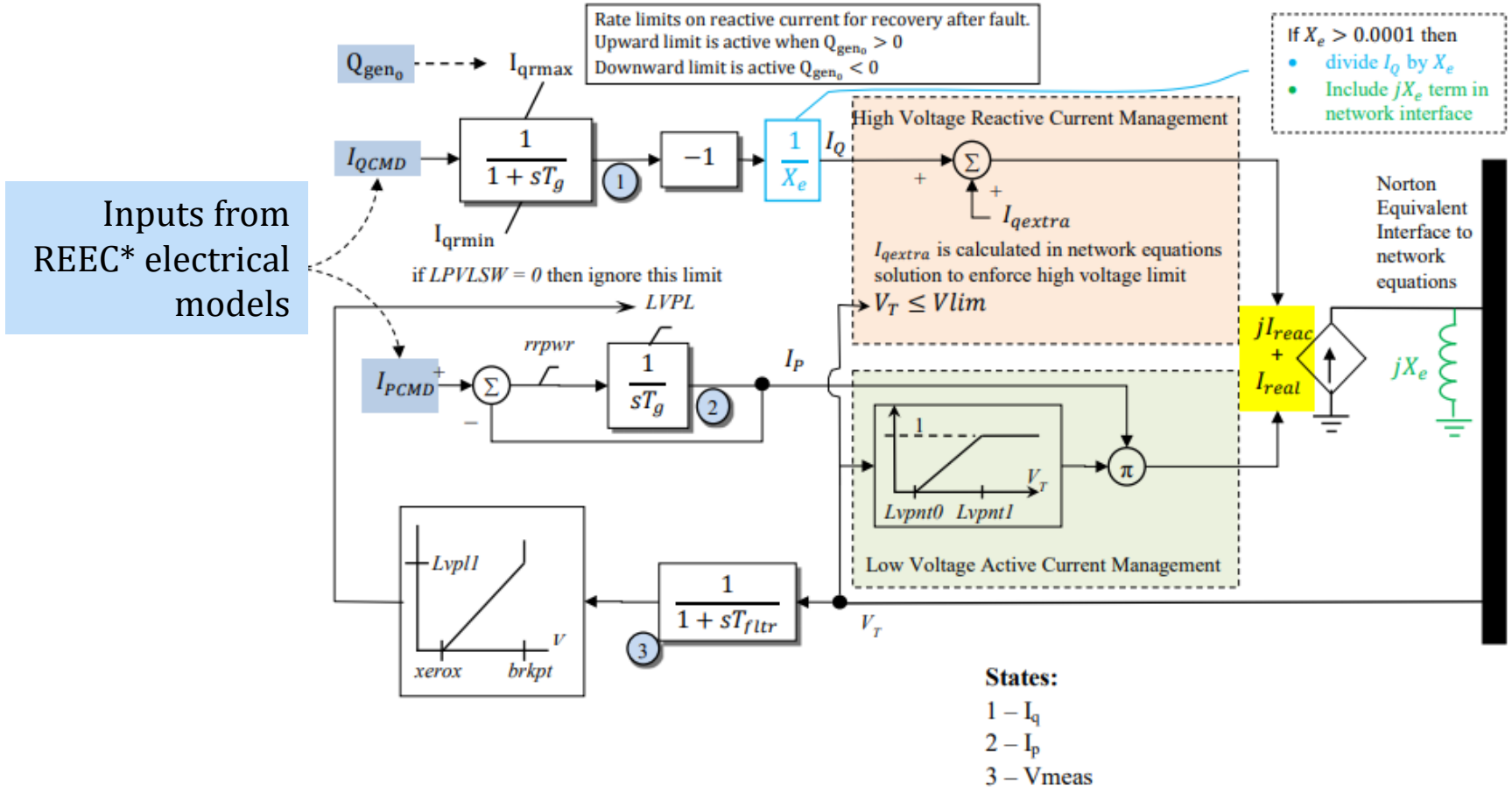
Detailed Documentation on the “Second Generation” From WECC

- 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

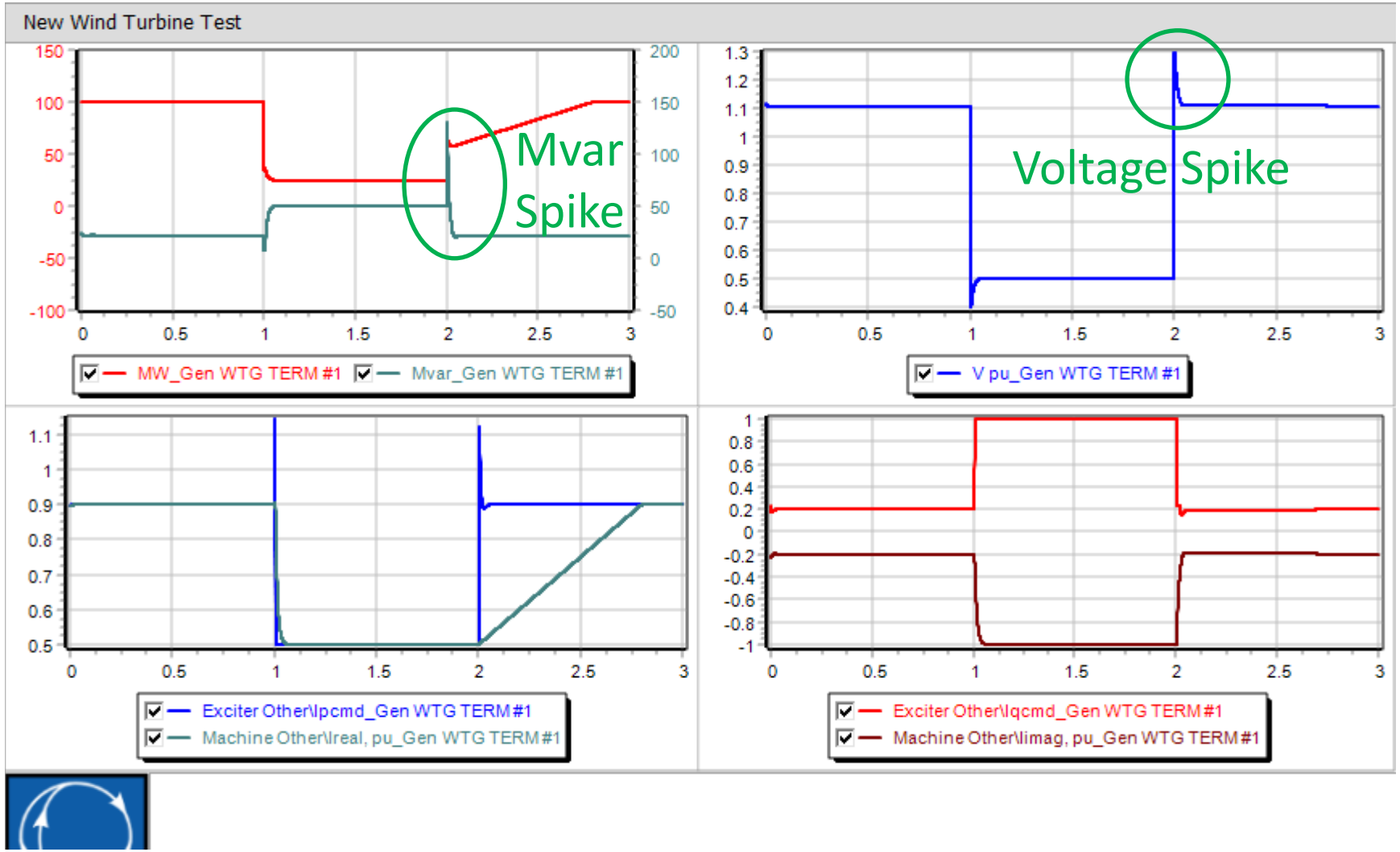
- "Machine Model": Really a network interface



REGC_A Description

- This model is doing very little actually
  - Time delay Tg 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



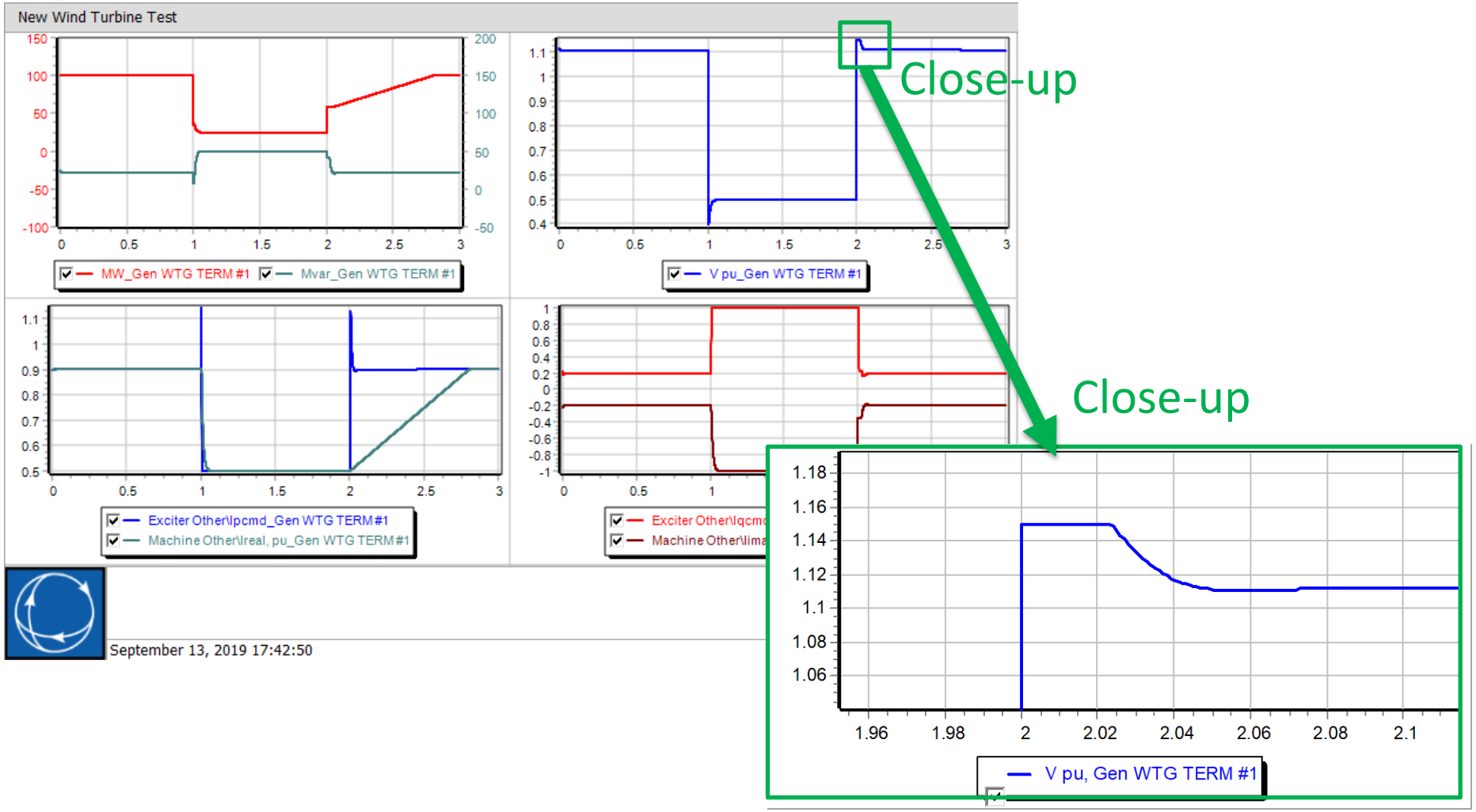
High Voltage Reactive Current Management

- 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 Tg (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

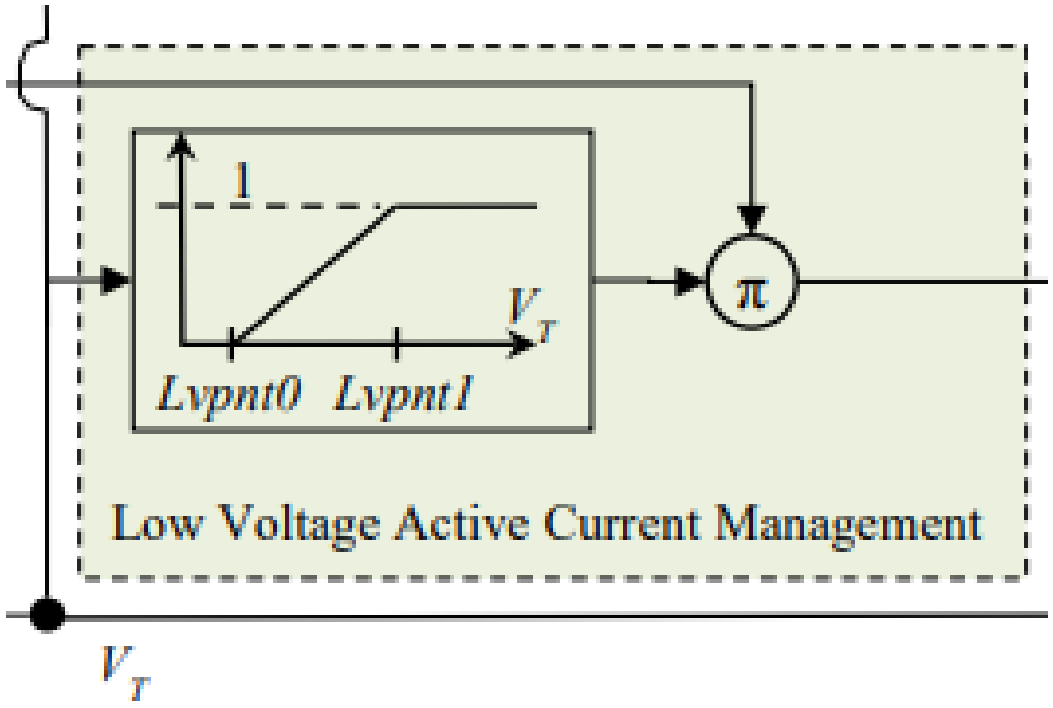
- Power electronics are going to protect the equipment
  - If a high voltage (parameter Vlim) is detected then the reactive current will drop (and go negative) nearly instantaneously to prevent damage
  - This must be handled in the network boundary equations actually
    - If voltage goes above this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

Vlim = 1.15



Low Voltage Current Management

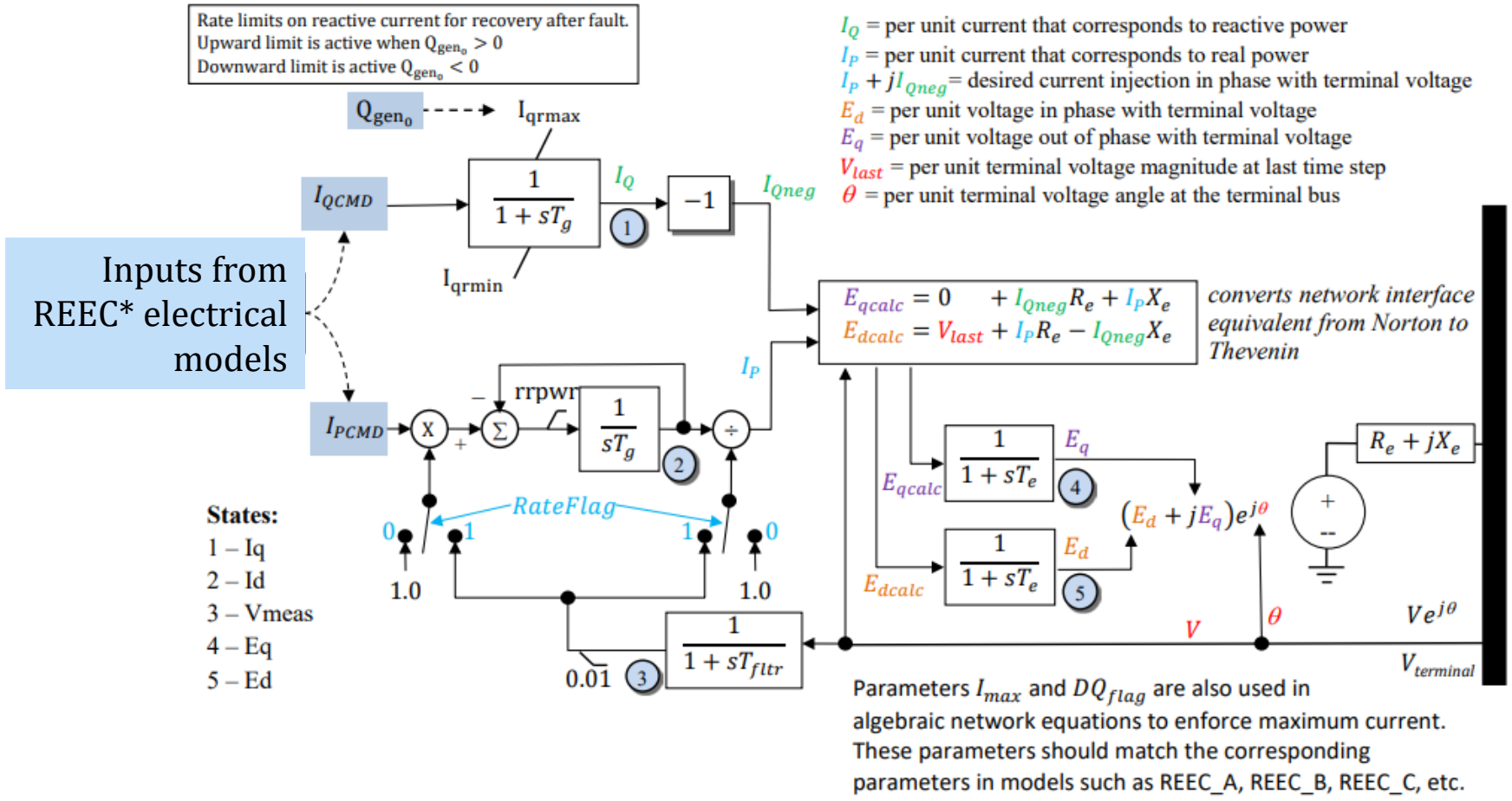
- Immediately after a fault occurs, the numerical simulation is going to be pushing current into a fault (0.0 voltage)
- That is both not possible AND will make the software fail to solve
- This is parameter are for
  - Lvpnt0 and Lvpnt1
  - Do NOT set these to 0.0!
  - (Simulator won't allow them lower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



REGC_B (Beta Model)

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

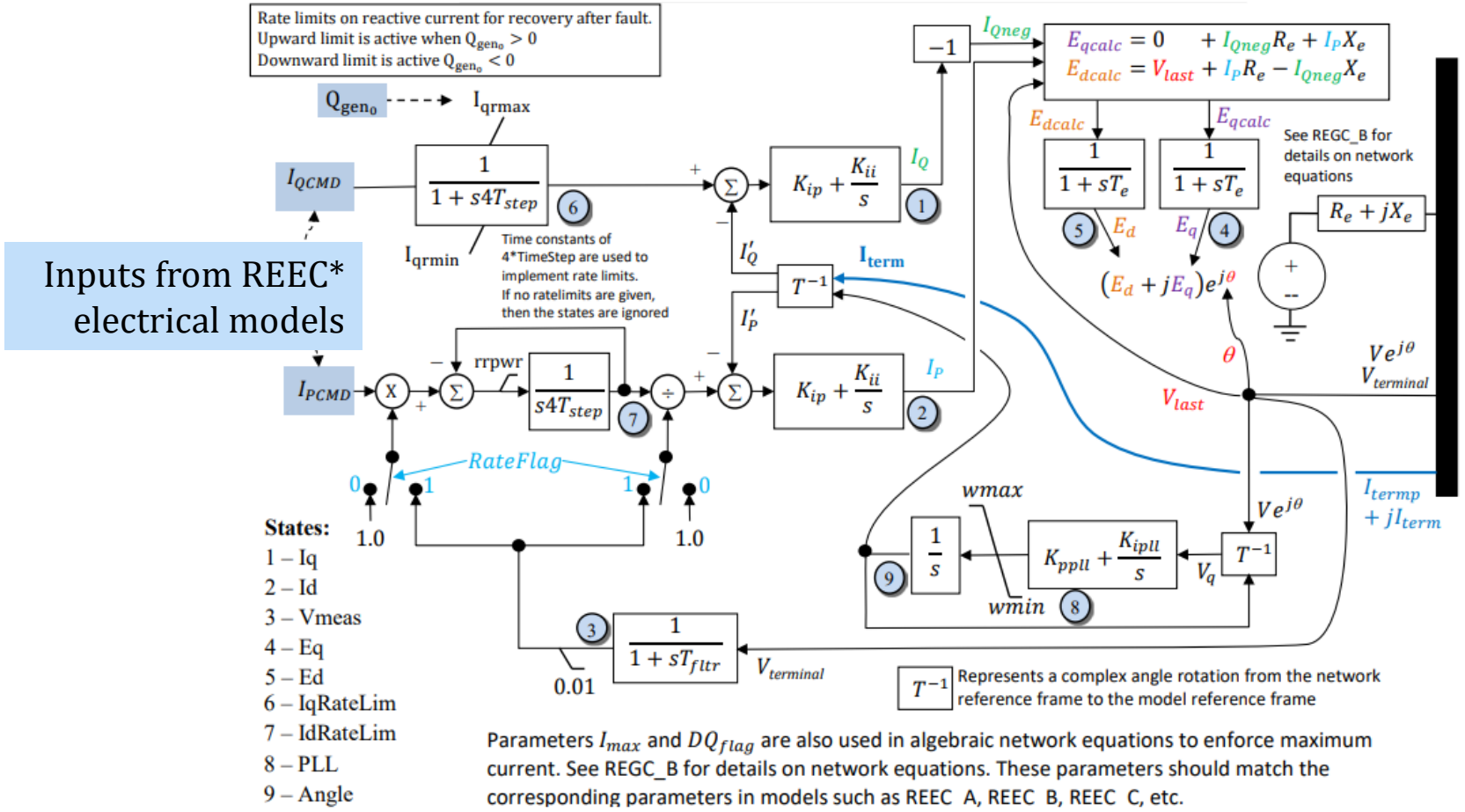
- "Machine Model": Really a network interface



REGC_C (Beta Model)

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

- "Machine Model": Really a network interface

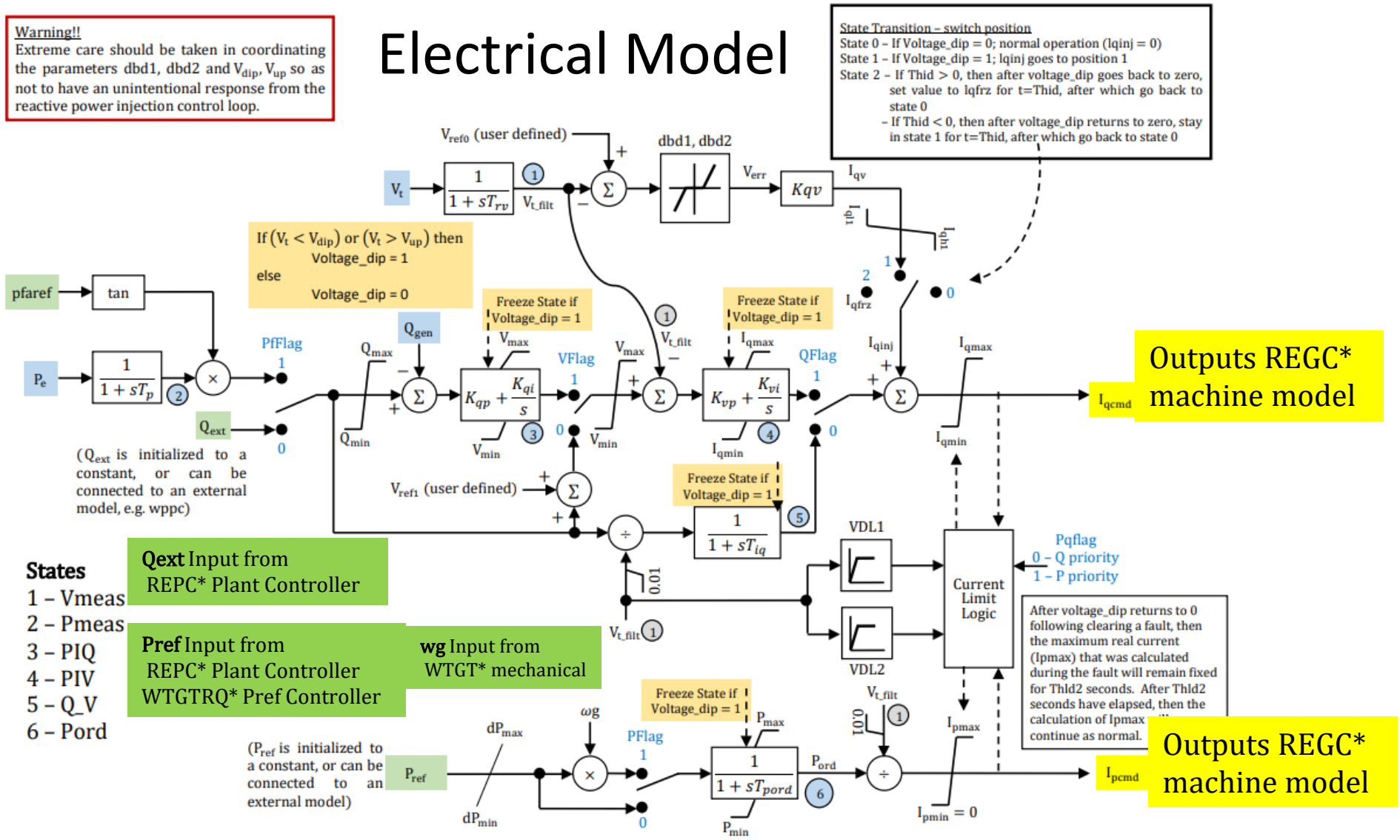


Parameters I_{max} and DQ_{flag} are also used in algebraic network equations to enforce maximum current. See REGC_B for details on network equations. These parameters should match the corresponding parameters in models such as REEC A, REEC B, REEC C, etc.

REEC_A (same as REECA1)

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

Electrical Model



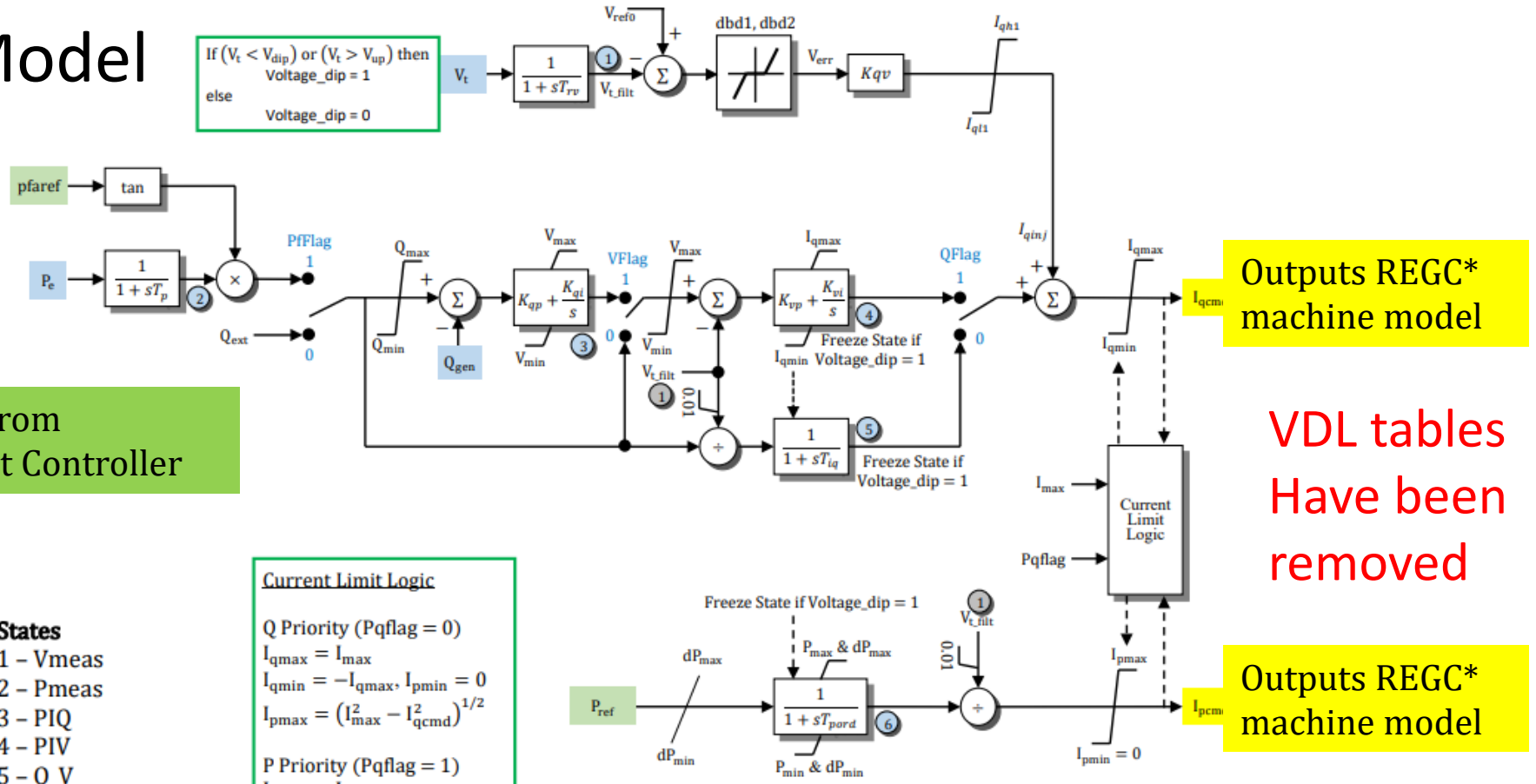
REEC_A Description

- First thing you must do is choose the control stategy
  - 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



Qext Input from REPC* Plant Controller

VDL tables Have been removed

States
1 – Vmeas
2 – Pmeas
3 – PIQ
4 – PIV
5 – Q_V
6 – Pord

Current Limit Logic

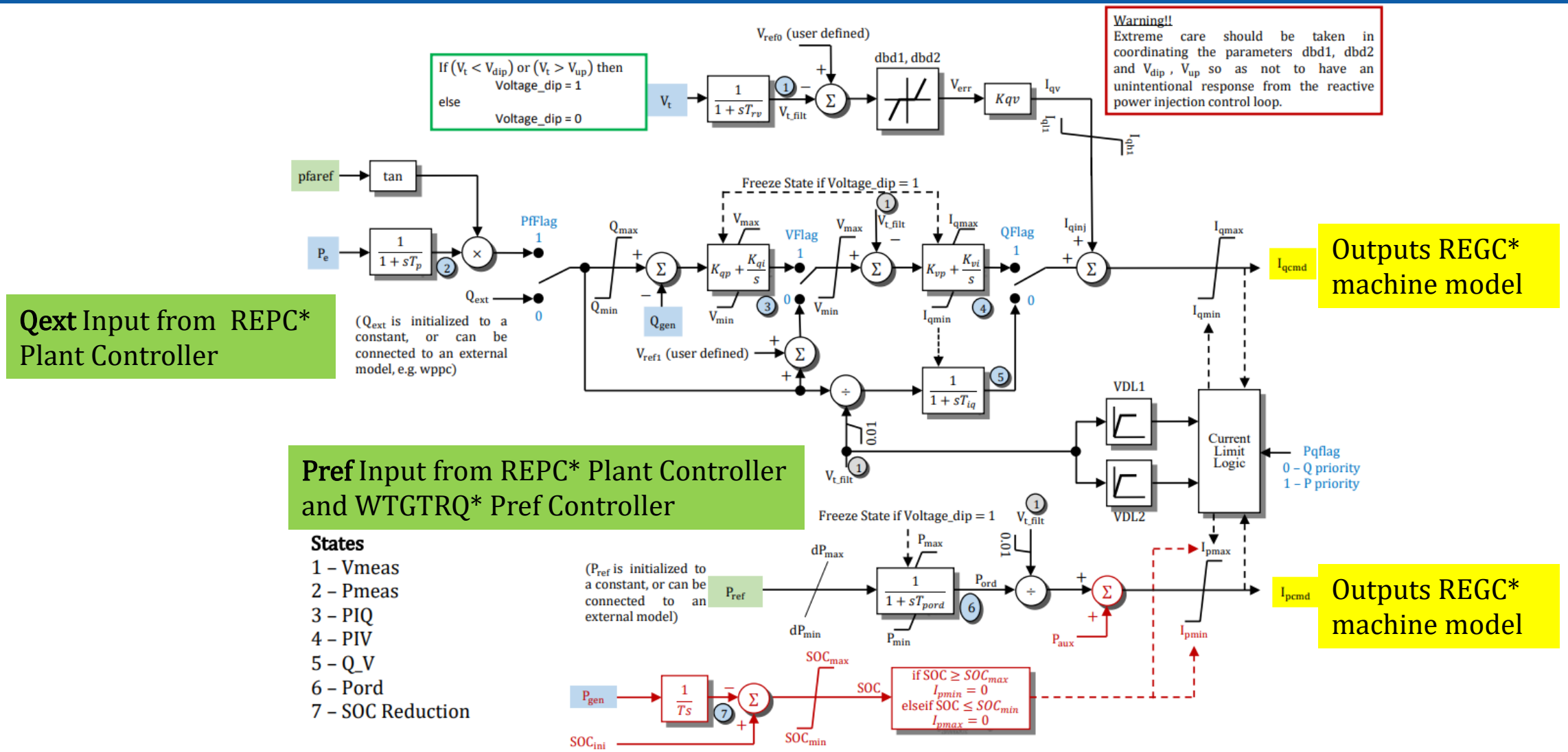
Q Priority (Pqflag = 0)
$I_{qmax} = I_{max}$
$I_{qmin} = -I_{qmax}$, $I_{pmin} = 0$
$I_{pmax} = (I_{max}^2 - I_{qcmd}^2)^{1/2}$

P Priority (Pqflag = 1)
$I_{pmax} = I_{max}$
$I_{qmin} = -I_{qmax}$, $I_{pmin} = 0$
$I_{qmax} = (I_{max}^2 - I_{pcmd}^2)^{1/2}$

Pref Input from REPC* Plant Controller and WTGTRQ* Pref Controller

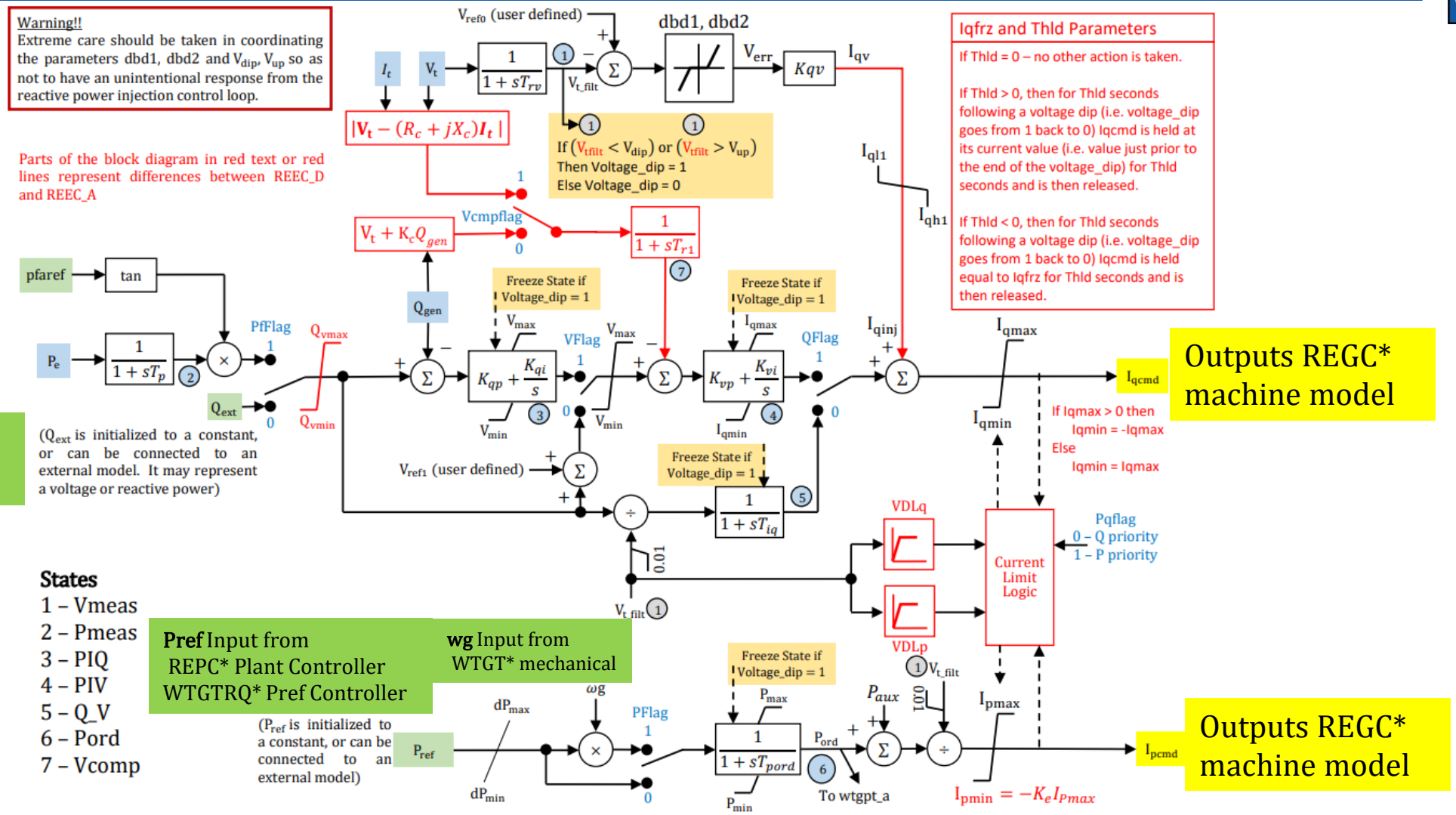
REEC_C (Model for Storage)

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



REEC_D (New Electrical Model)

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



Qext Input from REPC* Plant Controller

Outputs REGC* machine model

Outputs REGC* machine model

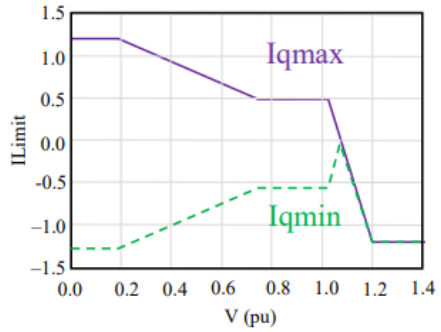
REEC_D

- Added voltage compensation
- Added charging support (Ke > 0)
- VDLp and VDLq tables have 10 points and treatment when Iqmax < 0 means Iqmax = Iqmax
  - 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 Iq5 value

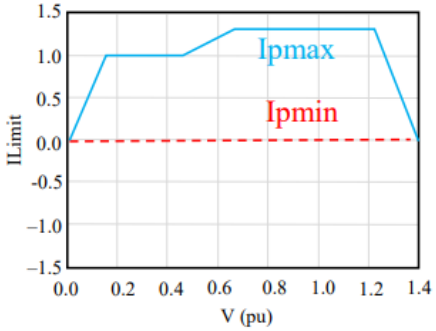
```
Vp1=0.00; Vp2=0.15; Vp3=0.46; Vp4=0.67; Vp5=1.21; Vp6=1.40
Ip1=0.00; Ip2=1.00; Ip3=1.00; Ip4=1.30; Ip5=1.30; Ip6=0.00

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
```

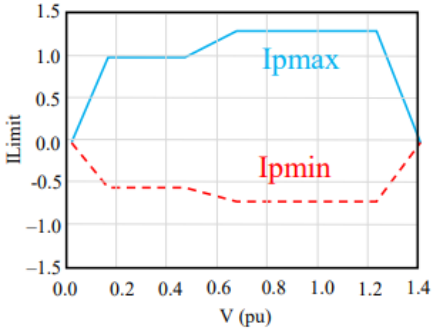


Figures at bottom show different values of Ke parameter.

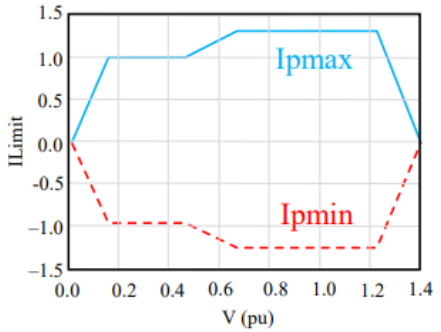
$I_{pmin} = -K_e I_{Pmax}$



VDLp Table when **Ke = 0.0**



VDLp Table when **Ke = 0.5**

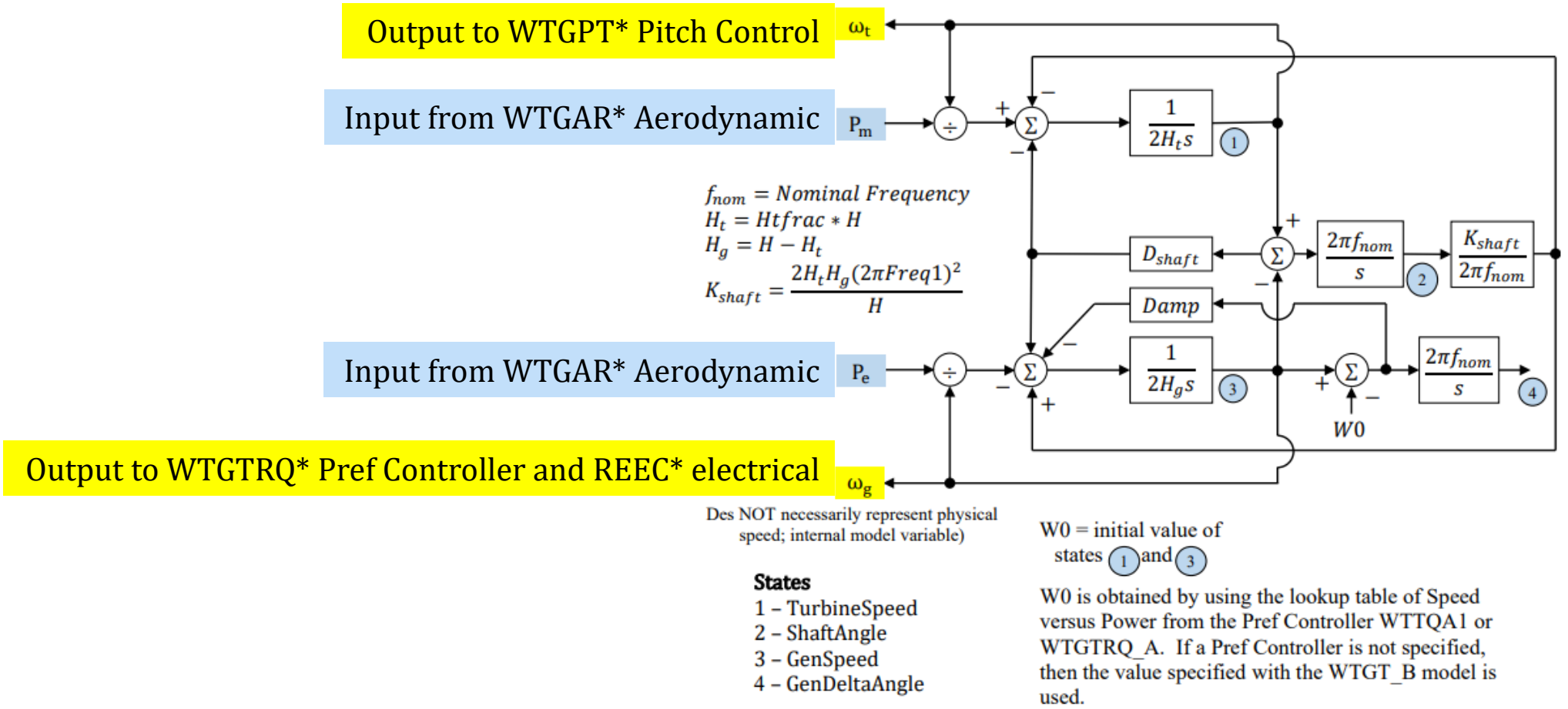


VDLp Table when **Ke = 1.0**

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

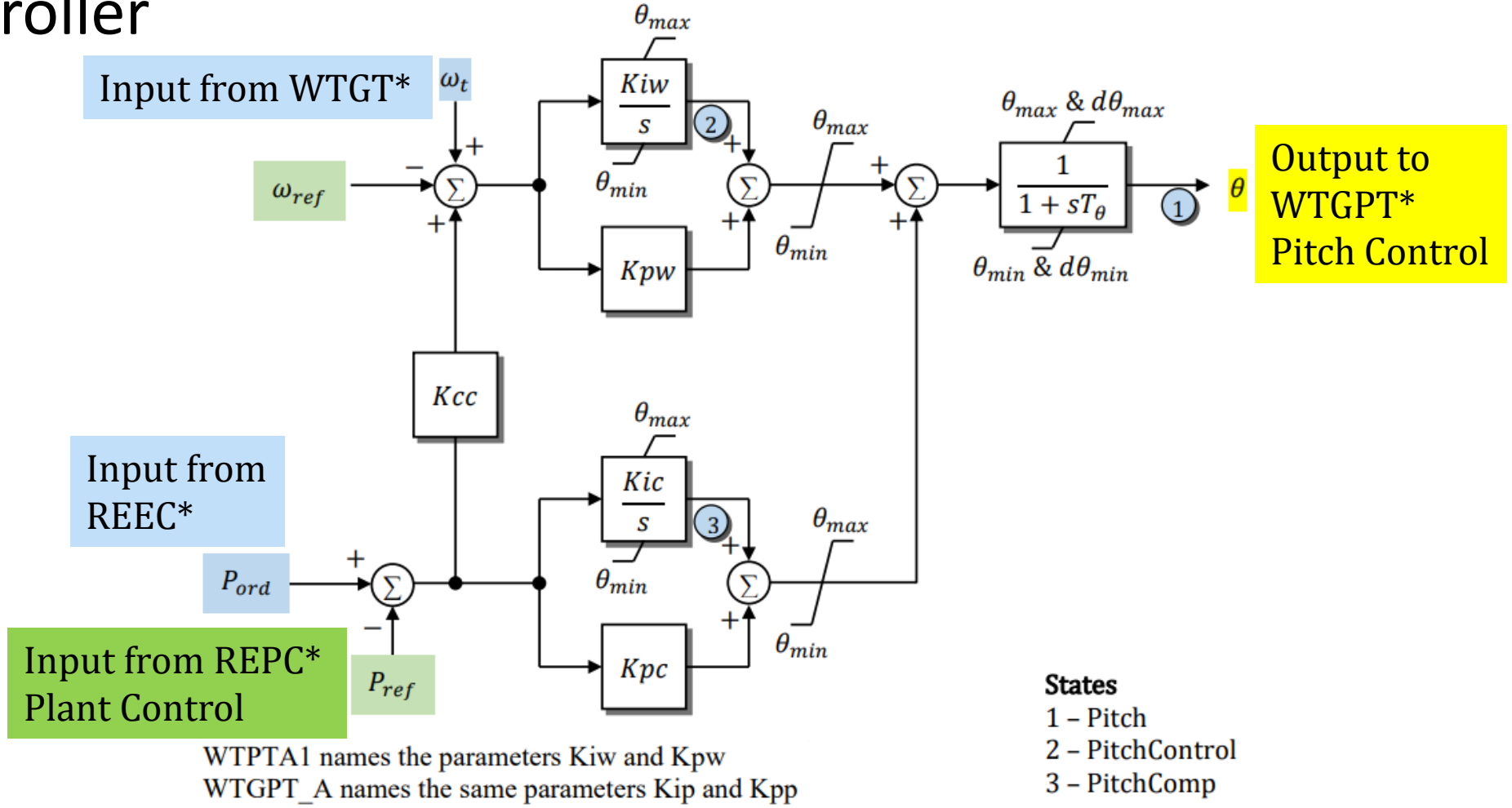
- Mechanical Model (models turbine blades and induction inertia)



WTGPT_A (WTGP_A or WTPTA1)

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

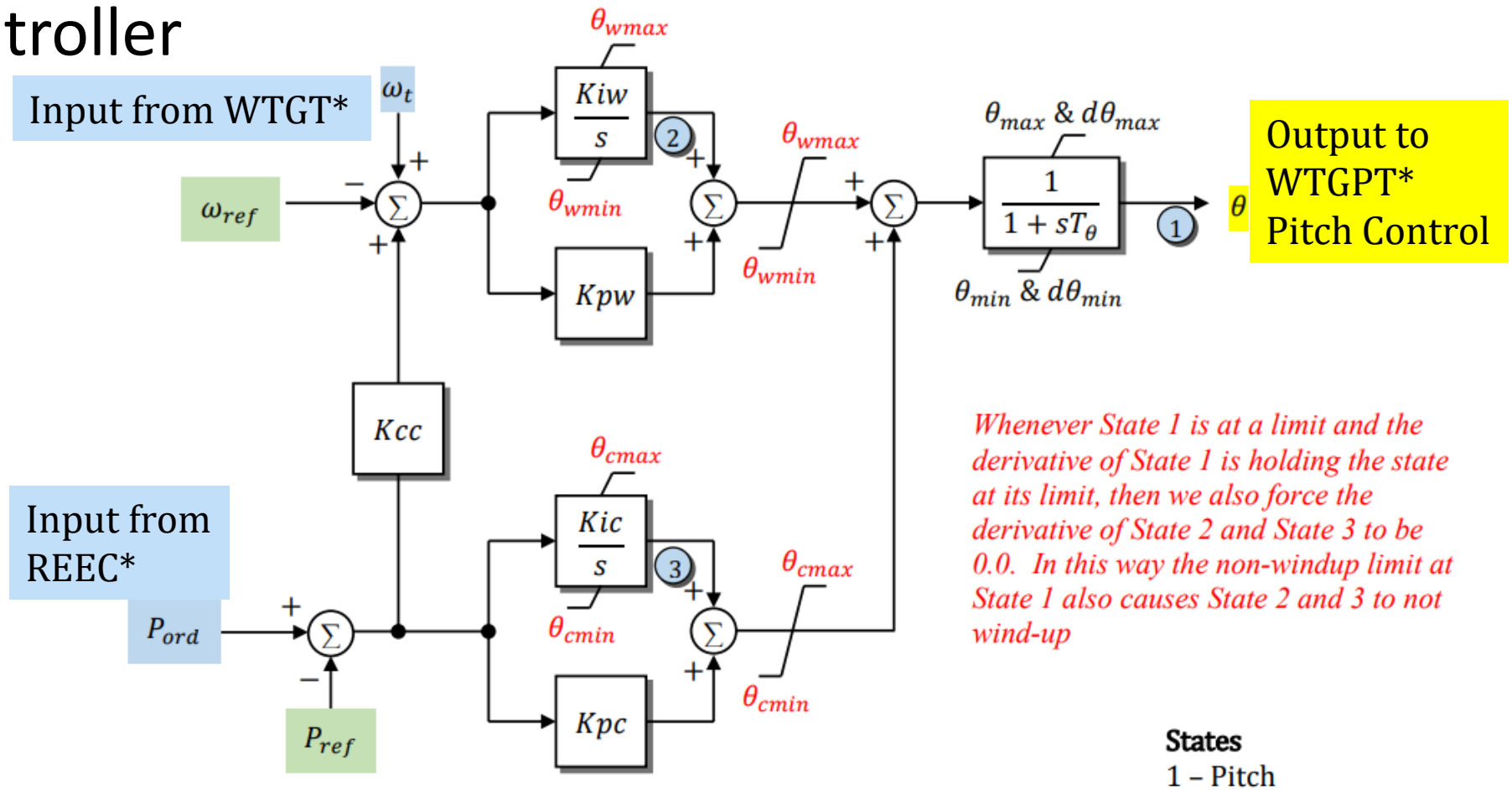
- Pitch Controller



WTGPT_B

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

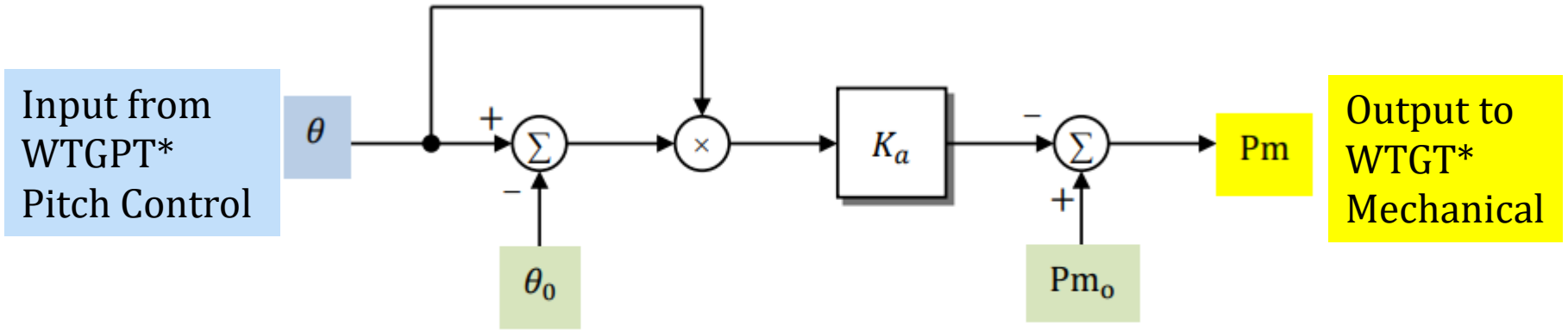
- Pitch Controller



WTGAR_A (WTGA_A and WTARA1)

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

- Aerodynamic Model

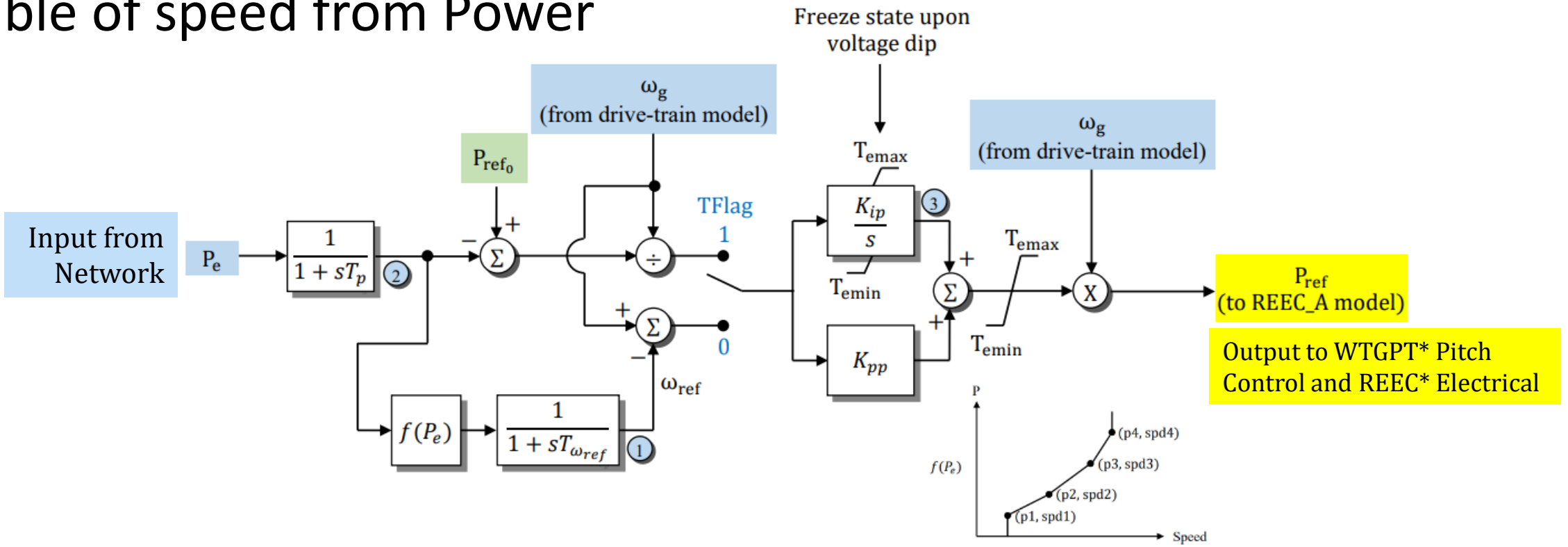


Model supported by PowerWorld
Named WTGA_A in PSLF
Named WTARA1 in PSS/E

WTGTRQ_A (WTTQA1)

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

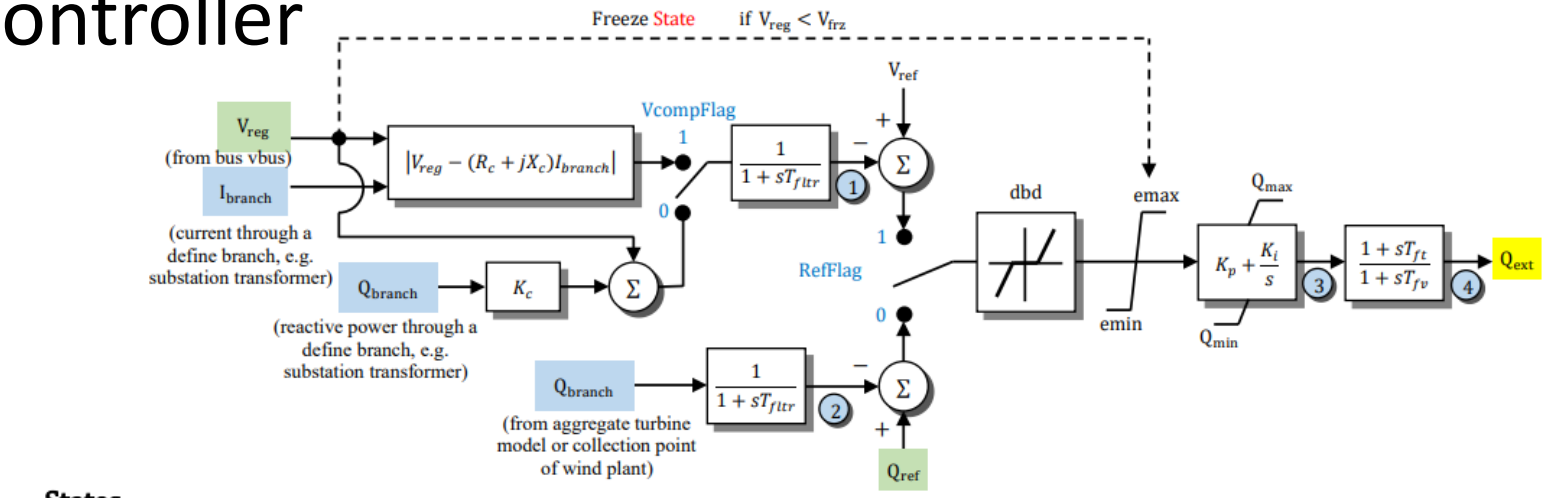
- Torque Controller for Wind Turbine
- Normal Recommendation is Tflag = 0 as this includes the lookup table of speed from Power



REPC_A (REPCA1, REPCTA1)

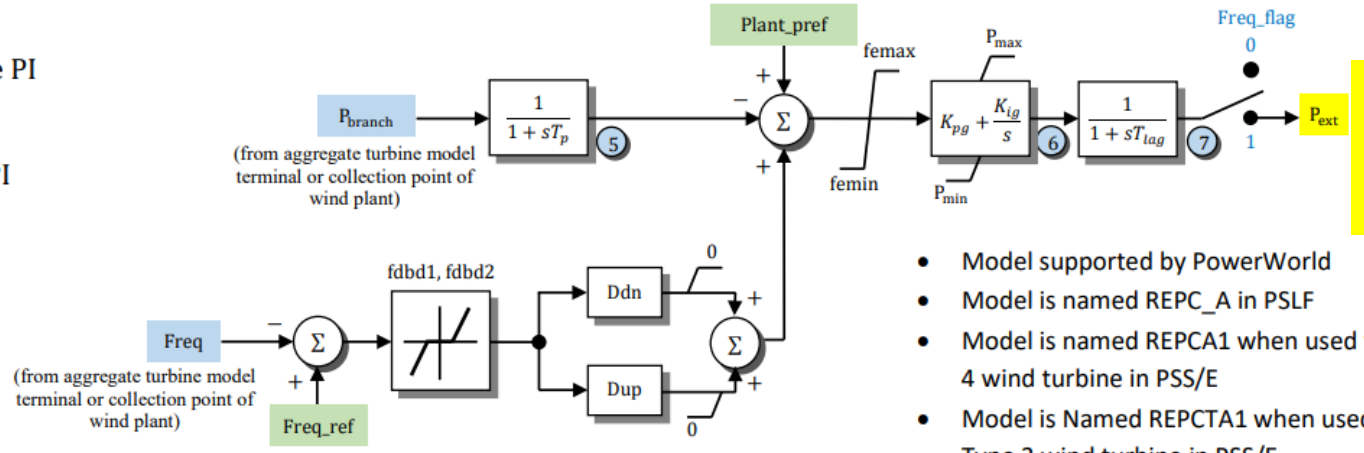
https://www.powerworld.com/WebHelp/#TransientModels_HTML/Plant%20Controller%20REPC_A.htm

- Plant Controller



Output to REEC_* electrical controller

States
1 – Vmeas
2 – Qmeas
3 – Reactive PI
4 – Qext
5 – Pmeas
6 – Power PI
7 – Pref

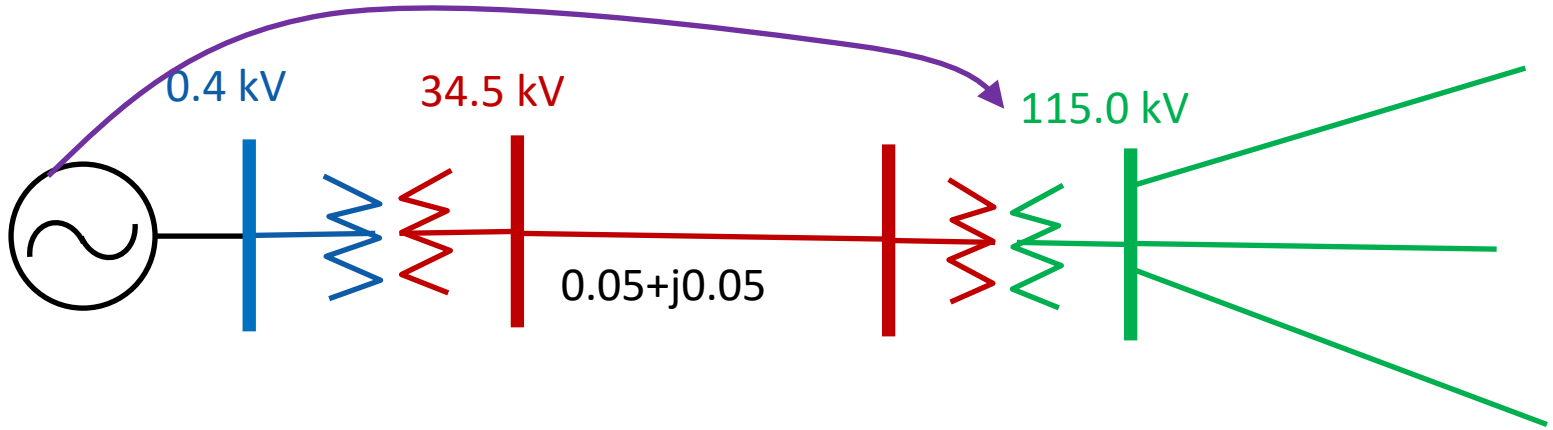


Output to WTGTRQ* torque controller or REEC_* electrical controller

- Model supported by PowerWorld
- Model is named REPC_A in PSLF
- Model is named REPCA1 when used with Type 4 wind turbine in PSS/E
- Model is Named REPCTA1 when used with a Type 3 wind turbine in PSS/E

Renewable Generator Questions started in 2013

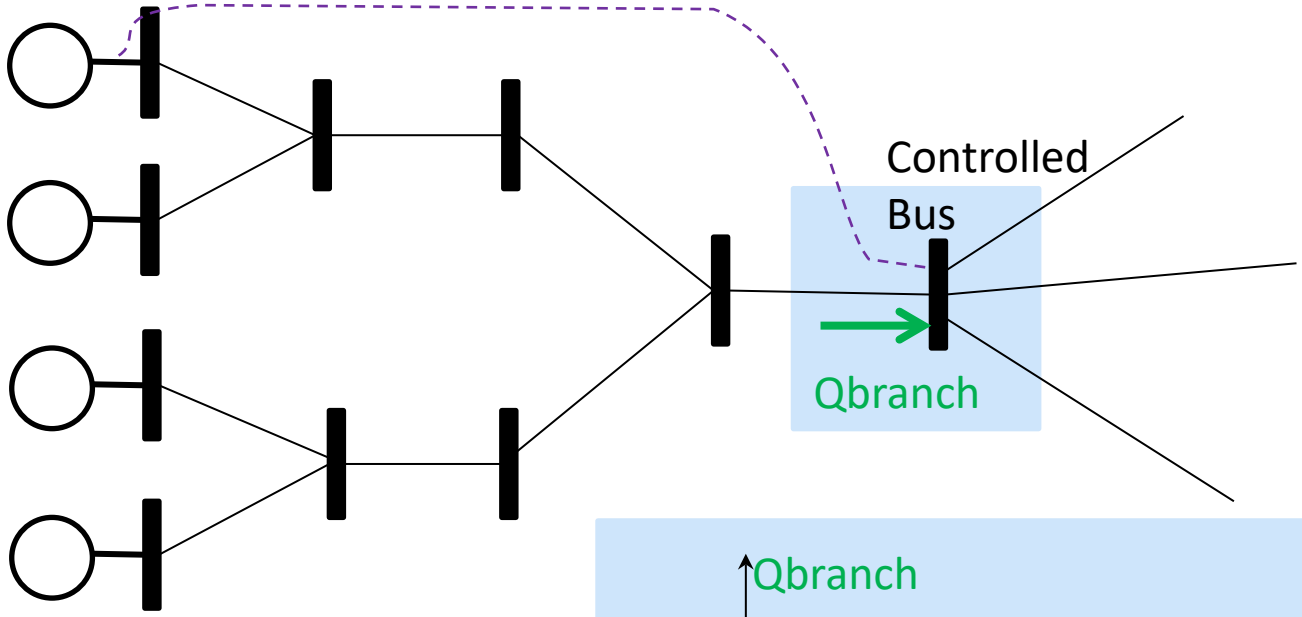
- Renewable generators regulate a point closer to the point of interconnection

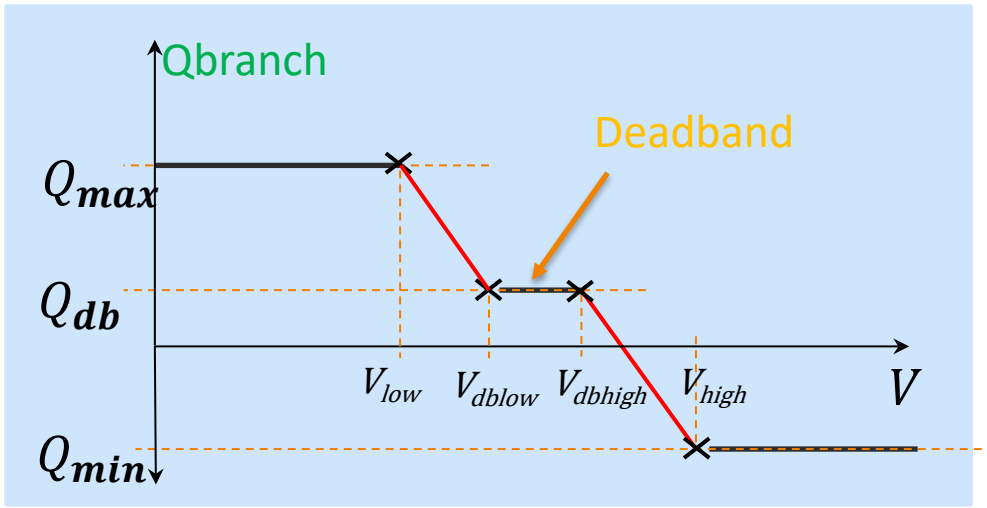


- They regulate the voltage at the POI (the 115 kV bus) against a QV characteristic curve
- Starting to get questions about Solar PV plant voltage control

Typical Configuration may have multiple Generators

Generators are all configured to regulate the Controlled Bus

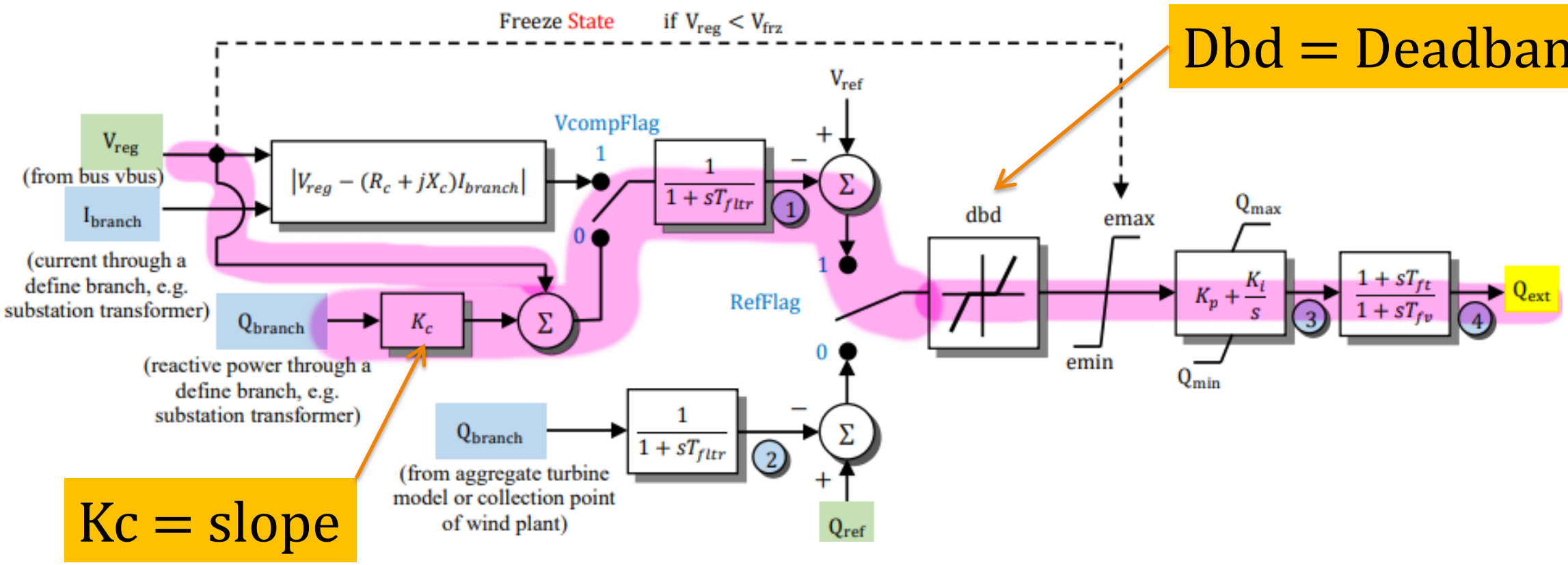




Slope Control with Deadband

- Getting questions about solar and sind 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

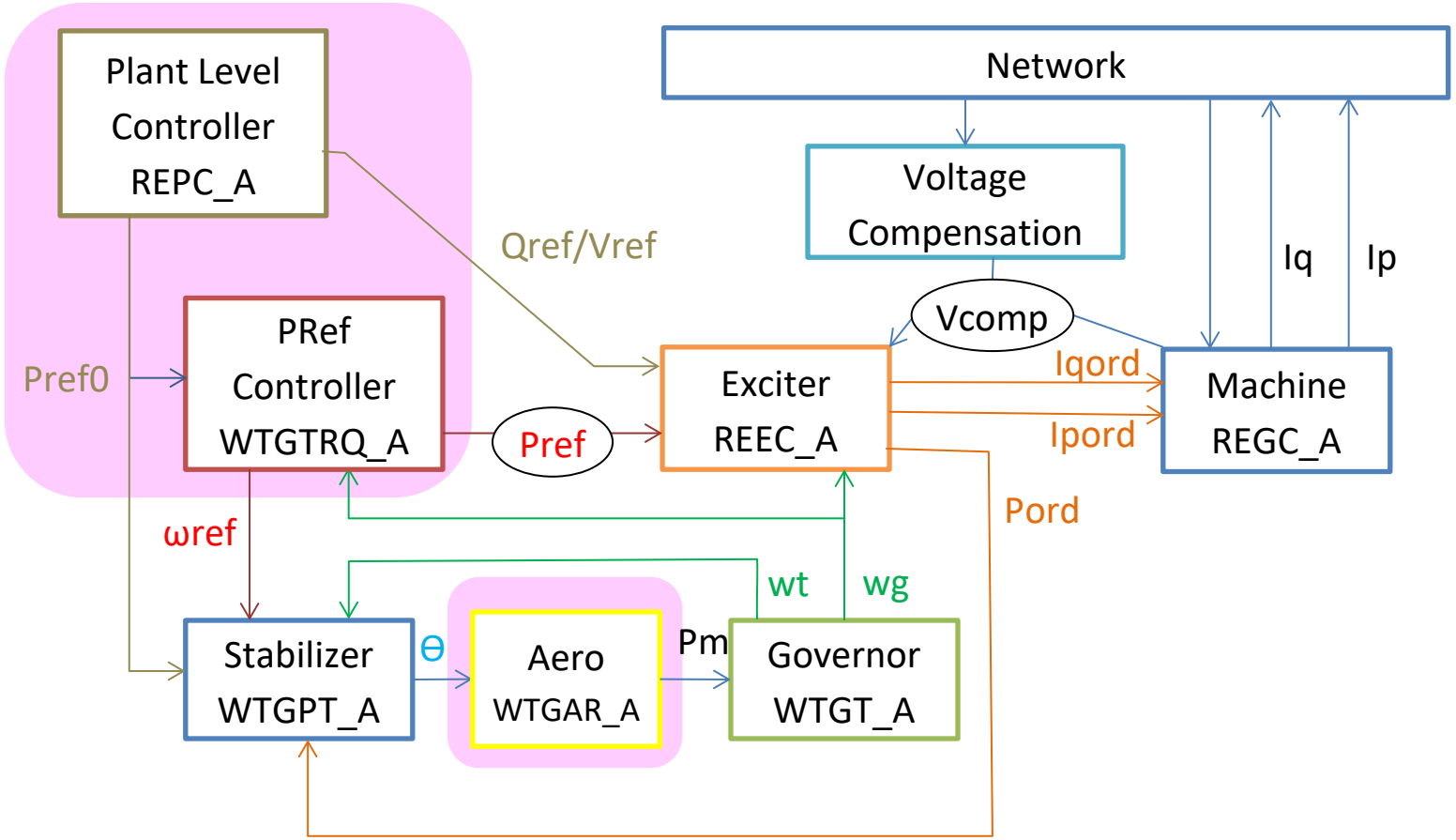
REPC_A has this Voltage Droop Control with Deadband!



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



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