Transient Stability Analysis with PowerWorld Simulator

T12: Wind Turbine Modeling

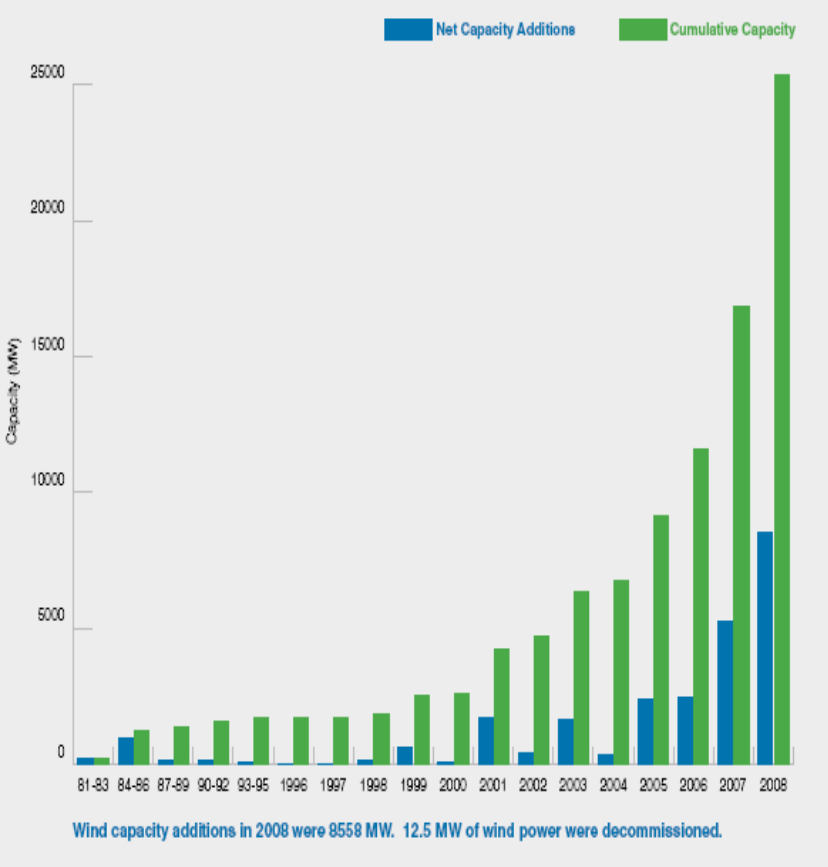
2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

support@powerworld.com
http://www.powerworld.com

Need for Wind Turbine Models

- Over the last decade wind turbine capacity has grown to the point where they need to be explicitly considered in system-wide transient stability studies

Growth in US Wind Capacity



http://www.awea.org/publications/reports/AWEA-Annual-Wind-Report-2009.pdf

Wind Turbine Modeling

- A wind farm usually consists of many small turbines in a collector system
- Each turbine's voltage is usually less than 1 kV (usually 600 V) with a step-up transformer (usually to 34.5 kV)
- Usually, the wind farm is modeled in aggregate, but how accurate such aggregate models are is an open question
- PowerWorld Simulator provides support of each of the four major types of wind turbine models used in transient stability studies
  - Type 1: Induction generator with fixed rotor resistance
  - Type 2: Induction generators with variable rotor resistance
  - Type 3: Doubly-fed induction generators
  - Type 4: Full converter generators
- New wind turbines are either Type 3 or Type 4

Wind Turbine Modeling: Power Flow Solution

- Wind turbines are represented as generators in the power flow
  - Type 1 and 2 units operate at fixed real/reactive power with the unit supplying real power and consuming reactive power; usually there are compensating capacitors
  - Type 3 and 4 are treated as regular PV buses

Wind Generator Models

- Wind Turbines do not have an “exciter”, “governor”, or “stabilizer”
- However, modeling is very analogous
  - Wind Machine Model = Machine Model
  - Wind Electrical Model = Exciter
  - Wind Mechanical Model = Governor
  - Wind Pitch Control = Stabilizer
  - Wind Aerodynamic Model = Stabilizer
- Simulator will show wind models listed as though they are Exciters, Governors, and Stabilizers
  - Obviously you should not use a synchronous machine exciter in combination with a wind machine model and wind governor!

Generic Wind Turbine Models

	Type 1		Type 2		Type 3		Type 4	
	GE DYD	PSS/E DYR	GE DYD	PSS/E DYR	GE DYD	PSS/E DYR	GE DYD	PSS/E DYR
Machine	WT1G	WT1G1	WT2G	WT2G1	WT3G	WT3G1, WT3G2	WT4G	WT4G1
"Exciter"			WT2E	WT2E1	WT3E	WT3E1	WT4E	WT4E1
"Governor"	WT1T	WT12T1	WT1T	WT12T1	WT3T	WT3T1	WT4T	
"Stabilizer"	*WT1P*	*W12A1*	*WT1P*	*WT12A1*	WT3P	WT3P1		

- Old Type 1 models as induction machine
  - MOTOR1, GENIND
  - CIMTR1, CIMTR2, CIMTR3, CIMTR4
- GE-specific Type 2 wind turbine model
  - GENWRI, EXWTG1, WNDTRB
- GE-specific Type 3 wind turbine model
  - GEWTG, EXWTGE, WNDTGE
  - Detailed model for GE 1.5, 1.6 and 3.5 MW turbines

Wind Turbine Voltage Control

- Voltage control of wind turbines depends on the type
- Type 1 squirrel cage induction machines- no direct voltage control
- Type 2- wound rotor induction machines with variable external resistance, no direct voltage control, but external resistance system usually modeled as an exciter
- Type 3 and Type 4- have the ability to perform voltage or reactive power control, similar to synchronous machines. Common control modes are constant power factor control, coordinated control across a wind farm to maintain a constant interconnection point voltage, and constant reactive power control

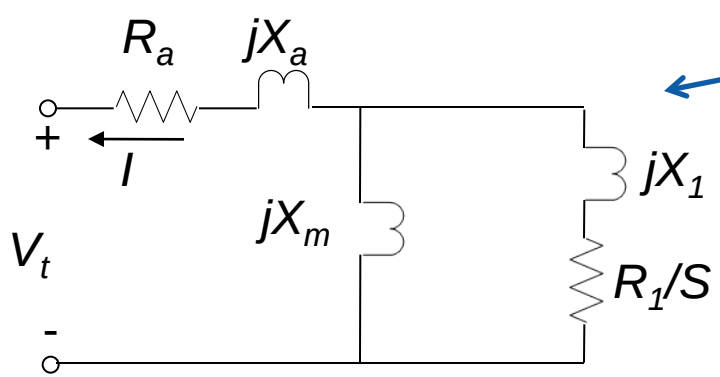
Glover, Sarma, Overbye, *Power System Analysis and Design*

Wind Turbine Modeling

- Types 1 and 2- Induction machine models, stator windings are connected to the rest of the network, rotor currents are induced by the relative motion between the rotating magnetic field due to the stator currents and the rotor
- Slip is the difference between the synchronous speed and the rotor speed, defined using motor convention as

$$S = \frac{n_s - n_r}{n_s}$$

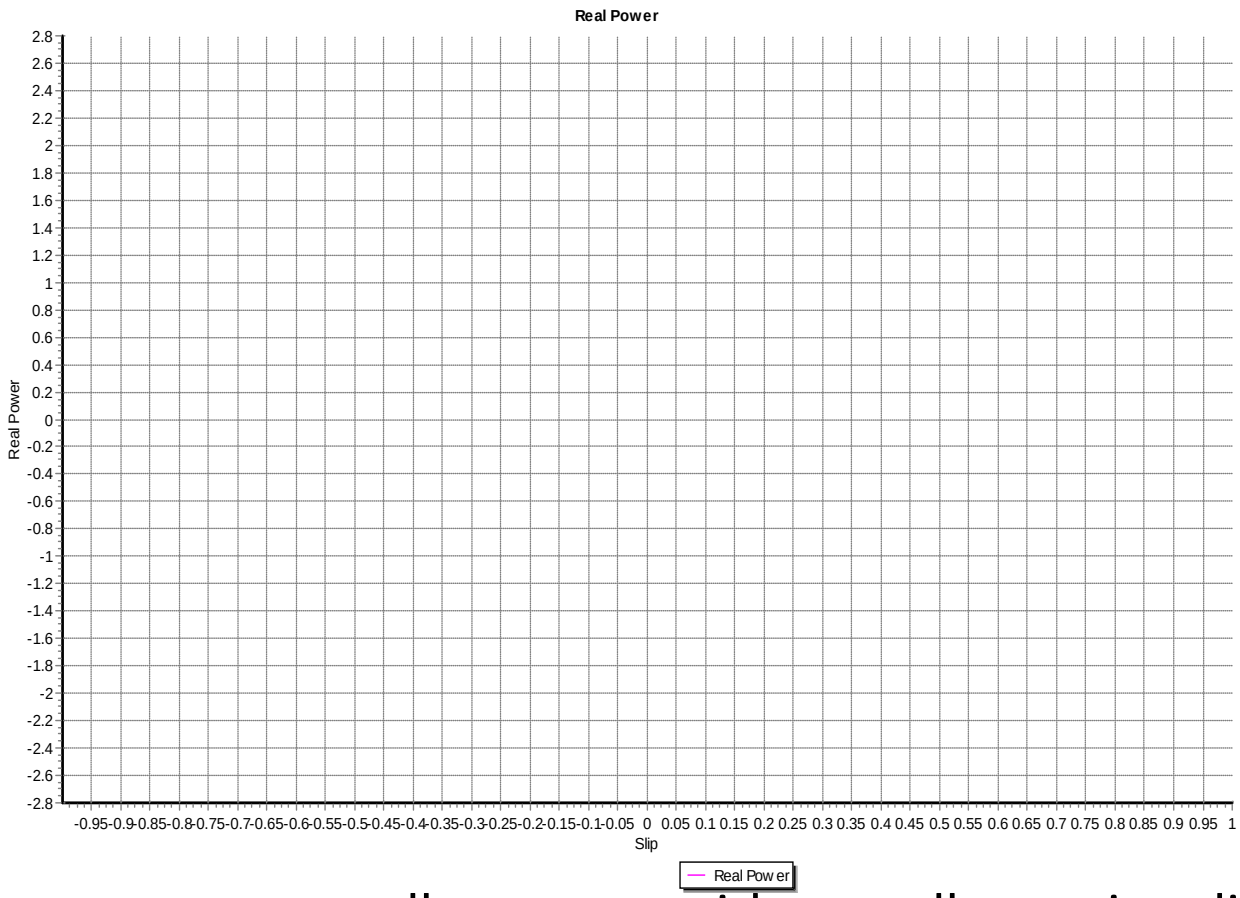
- Synchronous speed is n_s an rotor speed is n_r, per unit



Equivalent circuit for a single cage induction machine

Glover, Sarma, Overbye, *Power System Analysis and Design*

Type 1 Wind Model- WT1G Power Speed Curve

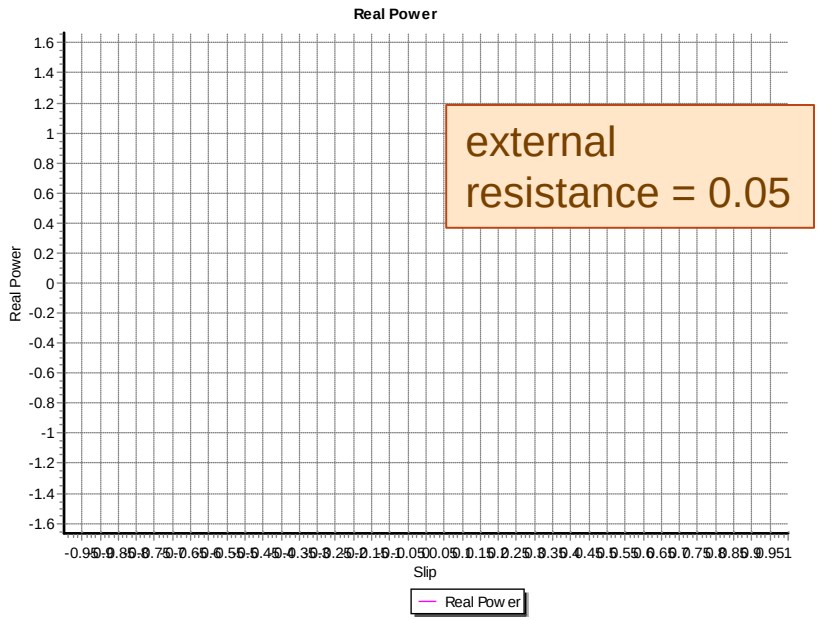


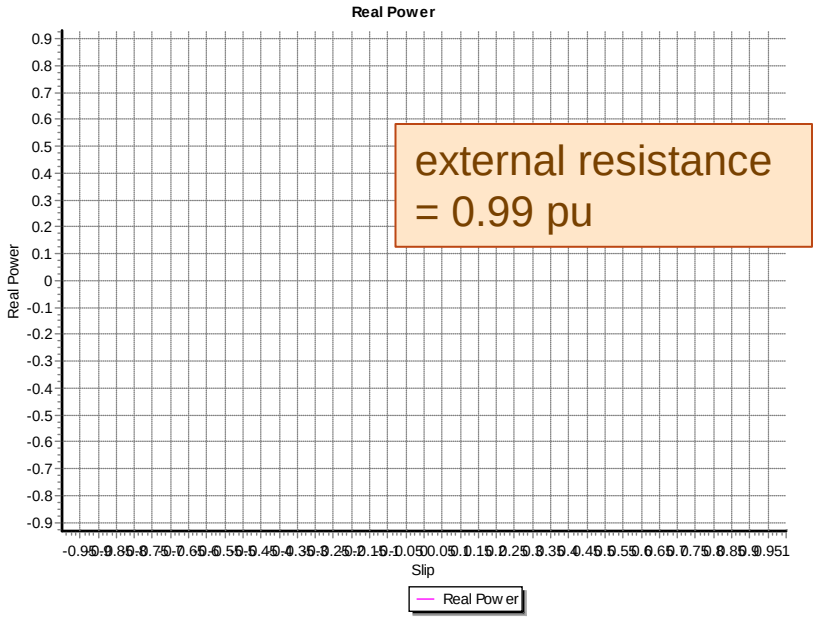
Values are calculated between a Slip of -1 and 1

Type 1 generators usually operate with a small negative slip since the wind turbine causes the machine to spin slightly faster than synchronous speed

Type 2 Wind Models

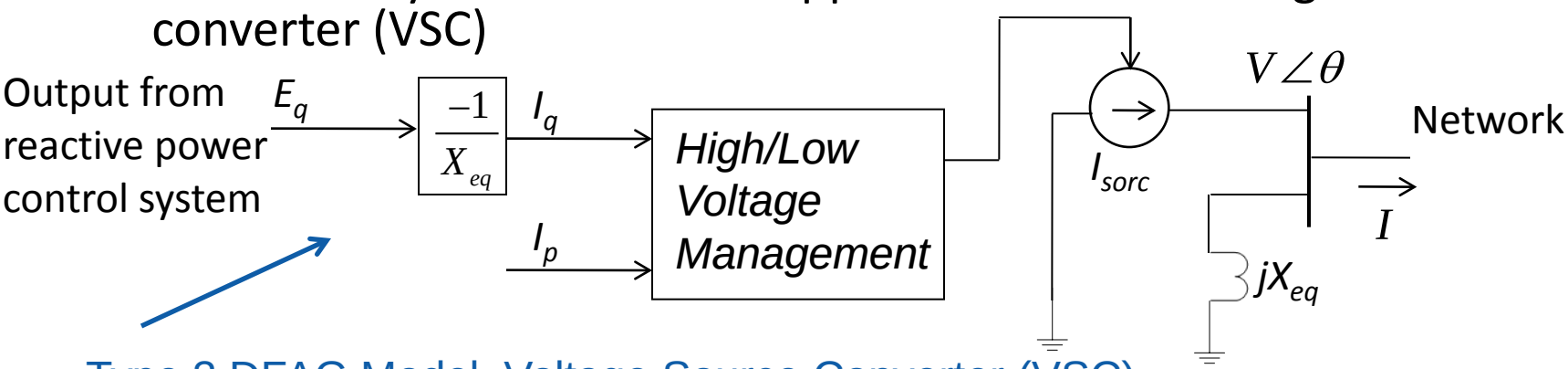
- Type 2 models augment Type 1 by allowing for variable rotor resistance control in the wound rotor induction generator
- By using turbine speed and electrical power output as inputs to the control system, the wind turbine can provide a more steady power output during wind variation





Type 3 Wind Models

- Models Doubly-Fed Asynchronous Generators (DFAGs) or Doubly-Fed Induction Generators (DFIGs)
- In addition to the stator windings, rotor windings are connected to the AC network through a converter
- Allows separate control of both real and reactive power
- Allows a much wider speed range
- No electrical coupling with the turbine dynamics
- The DFAG dynamics are well approximated as a voltage-source converter (VSC)



Type 3 DFAG Model, Voltage Source Converter (VSC)

Glover, Sarma, Overbye, *Power System Analysis and Design*

Type 3 Wind Models

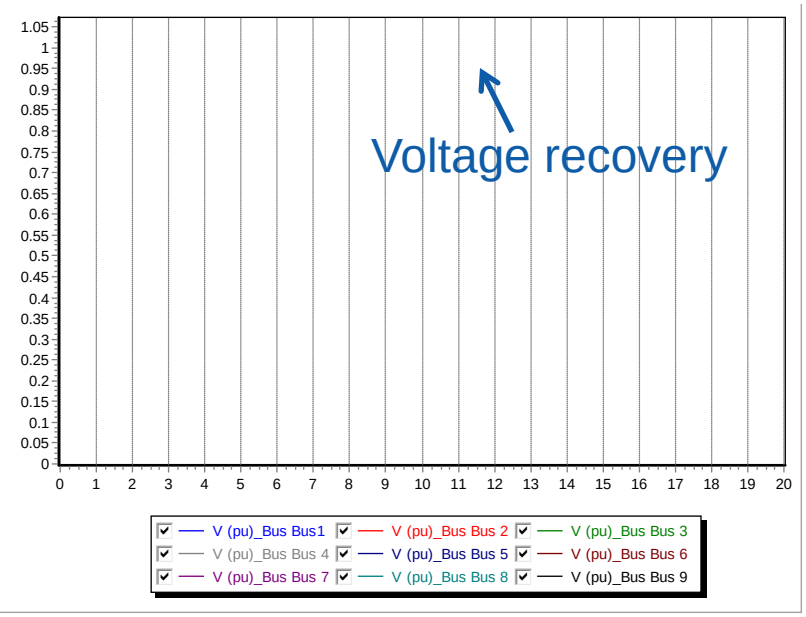
- Physically, these models usually consist of a wound rotor induction machine coupled with a voltage-source converter AC excitation system
- Electrical performance is dominated by the converter which acts on a much faster time scale than transient stability level dynamics
  - Machine model consists of a synthesized voltage behind a reactance
  - Rotor dynamics are not important electrically
- Modeling
  - Represents the generator by a machine model
  - Reactive power control by an exciter model
  - Mechanical control by a governor model
  - Blade pitch control by a stabilizer model

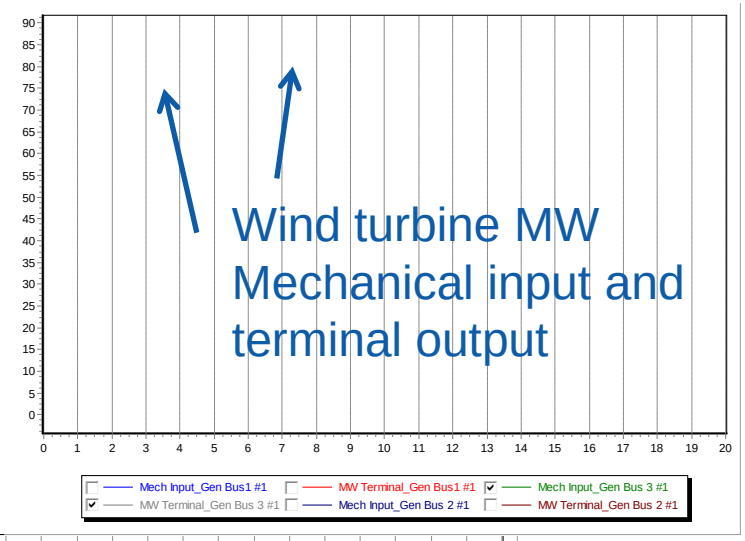
Type 3 Wind Model Example

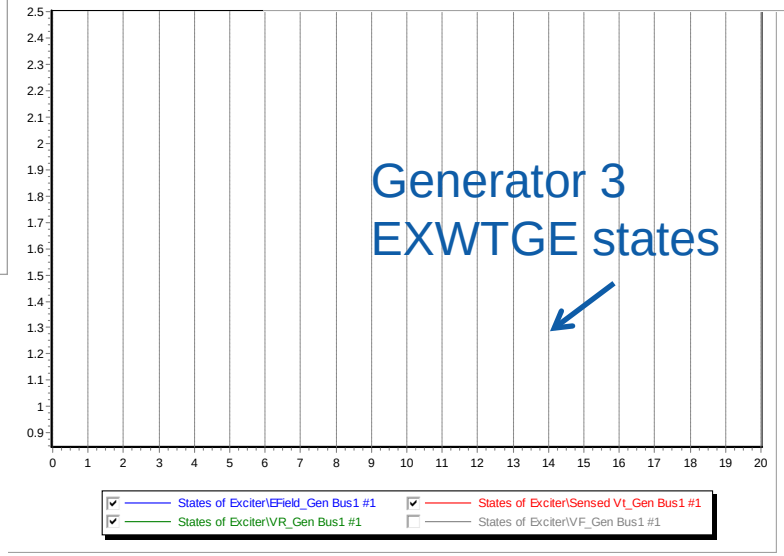
- Generator 3 will be modeled using a GEWTG machine, which models a 85 MW aggregation of GE 1.5 MW DFIGs
- Exciter model EXWTGE will be used to model the reactive power control of the wind turbine
- Governor model WNTDGE will be used to model the inertia of the wind turbine and its pitch control
- Generators 1 and 2 remain unchanged
- Open the case which has these settings, wscc_9bus_Type3WTG.pwb

Type 3 Wind Model Example

- Set up Plot Definitions as desired
- Click “Run transient Stability”



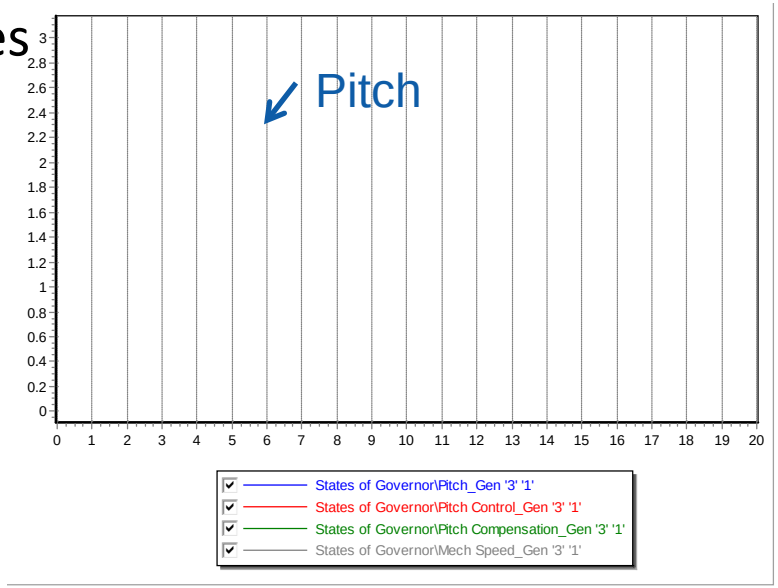


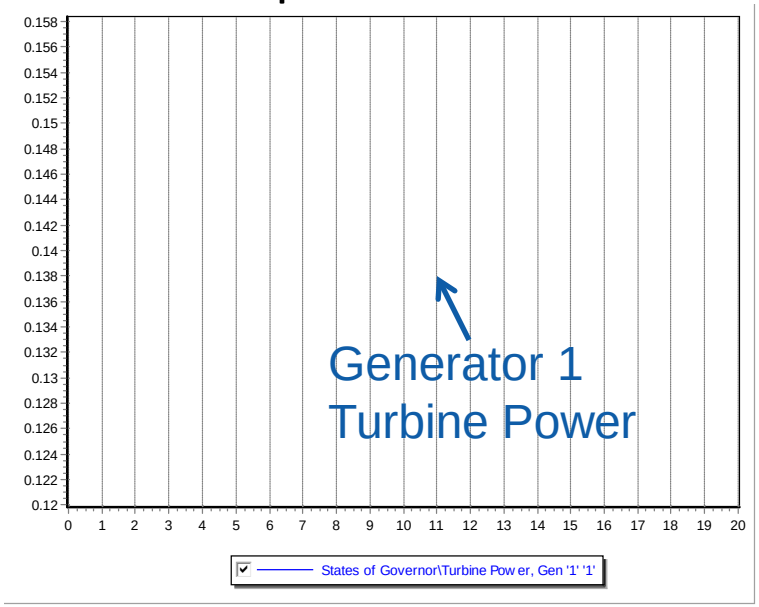


wscc_9bus_Type3WTG

Type 3 Wind Model Example

- During the fault the wind turbine terminal bus voltage will be quite low. This will cause the turbine's Low Voltage Power Logic (LVPL) to reduce the real power current to zero.
- This will cause the wind turbine pitch control system to begin to pitch the blades to reduce the mechanical power into the rotor. This pitch control occurs slowly.





- Once the fault is cleared, this current is ramped back up, subject to a rate limit.

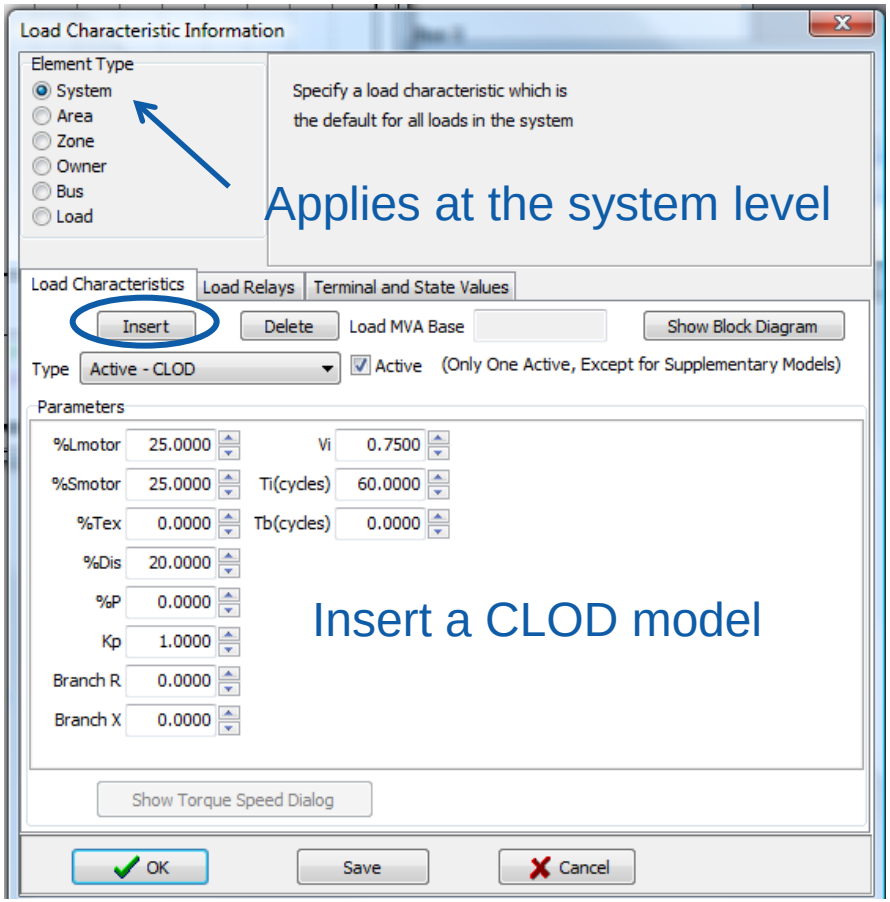
wscc_9bus_Type3WTG

Example: Impact of a Complex Load

- The way load dynamics are modeled often has a significant impact on the results of transient stability studies
- So far, we have mostly been looking at generator models, but many load models are also available in Simulator
- The default (global) models are specified on the Options, Power System Model page as constant impedance loads
  - Used when no other model is specified
  - Discussed in the Transient Stability Basics section
- Simulator makes it very easy to add complex load models
- More detailed models are added by selecting "Stability Case Info" from the ribbon, then Case Information, Load Characteristics Models.
- Models can be specified for the entire case (system), or individual areas, zones, owners, buses or loads.
- To insert a load model, right-click and select "Insert" to display the Load Characteristic Information dialog.

Complex Load Example

- Add a CLOD model to the system
  - Go to the Load Characteristic page in Model Explorer
  - Right-click and choose “insert” to open the Load Characteristic information dialog
- In the dialog, click “System” in the Element Type box to apply the load model to all buses in the system
- Click “Insert” to select the model type. Use CLOD (see [1]), which models the load as a combination of large and small induction motors, constant power and discharge lighting loads

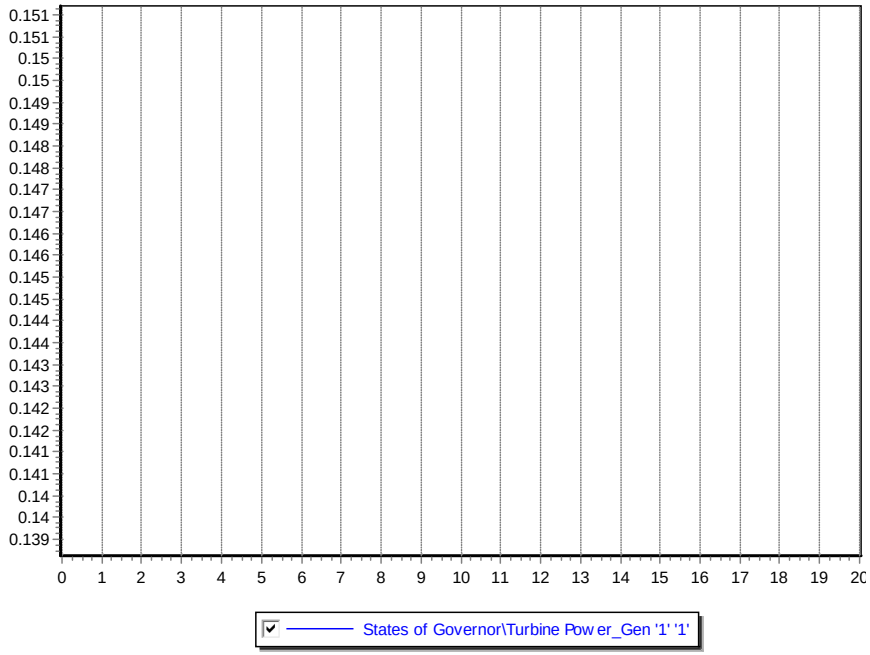


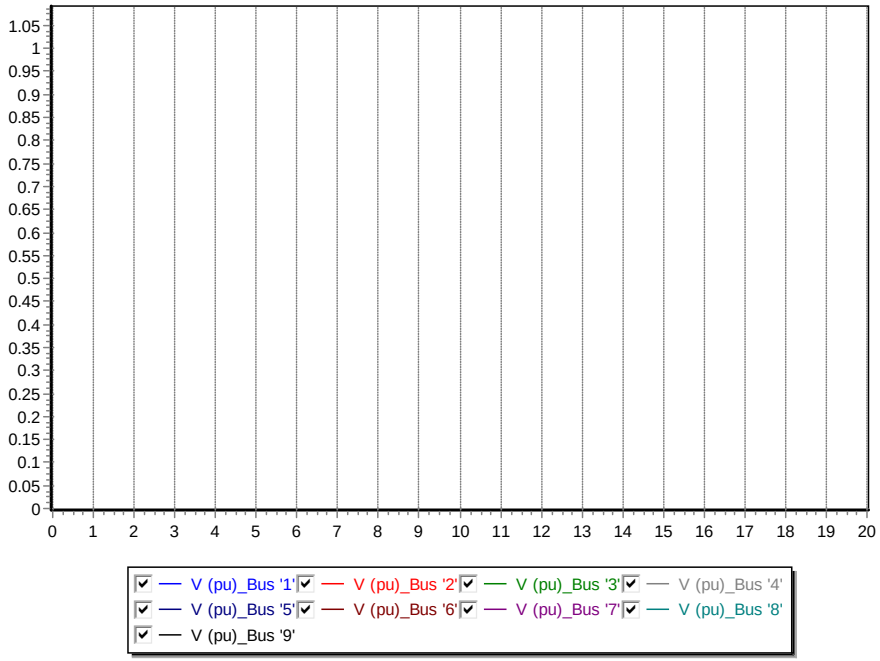
[1] J.A. Diaz de Leon II, B. Kehrli, “The Modeling Requirements for Short-Term Voltage Stability Studies,” Power Systems Conference and Exposition (PSCE), Atlanta, GA, October, 2006, pp. 582-588.

Complex Load Example

- The case with these settings is wscc_9bus_Type3WTG_CLOD
- Run the simulation
- Compare the plots obtained with and without the CLOD load model

Plots after inserting system-level CLOD model

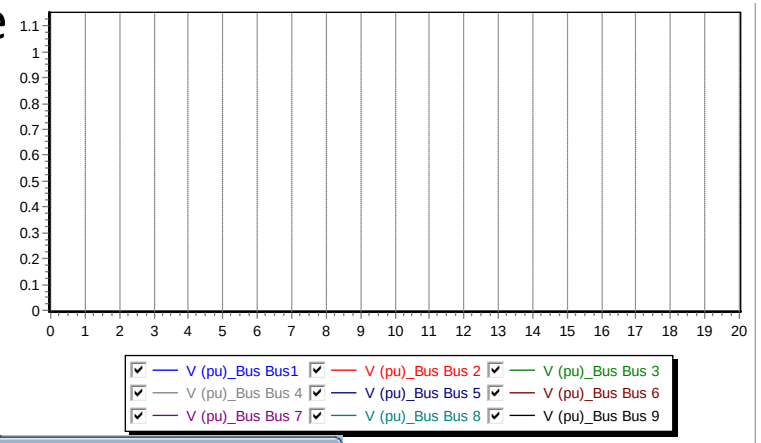


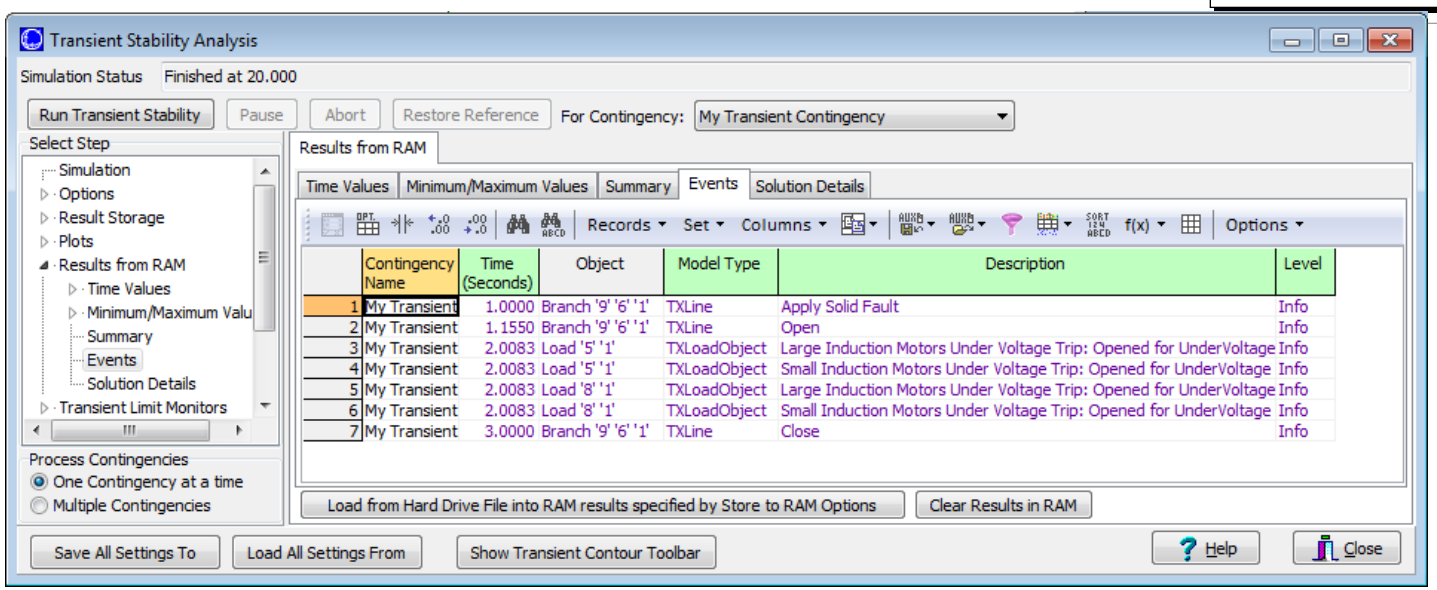


wscc_9bus_Type3WTG_CLOD

Complex Load Example

- On the Simulation page, increase the time for when the line is opened from 1.12 seconds to 1.155 seconds
- Open the Events tab on the Results page
- The Transient Contingency events are there, but there are also under voltage load trip events present

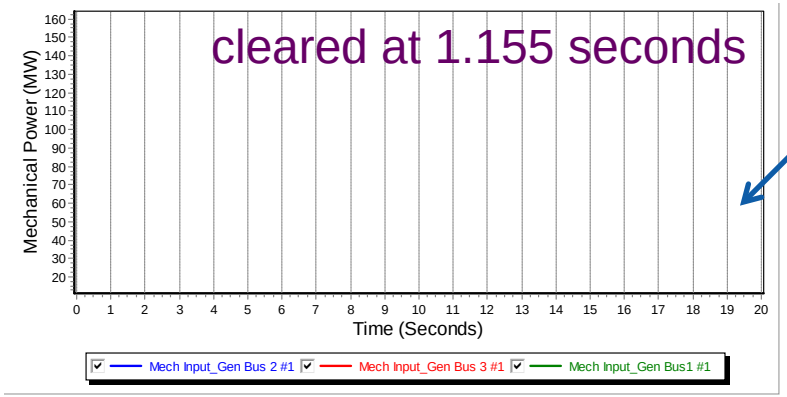




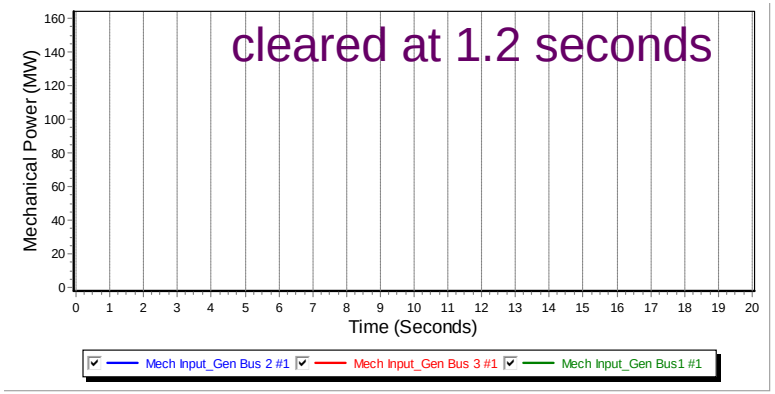
wscc_9bus_Type3WTG_CLOD

Complex Load Example

- In the PowerWorld CLOD model, under-voltage motor tripping may be set by the following parameters
  - Vi = voltage at which trip will occur (default = 0.75 pu)
  - Ti (cycles) = length of time voltage needs to be below Vi before trip will occur
- In the example, under voltage trips occurred at bus 5 and bus 8 when the fault clearing time was increased to 1.155
- Verify that increasing the clearing time further to 1.2 causes additional under-voltage trips of loads at buses 6, and an over-frequency trip of Generator 2



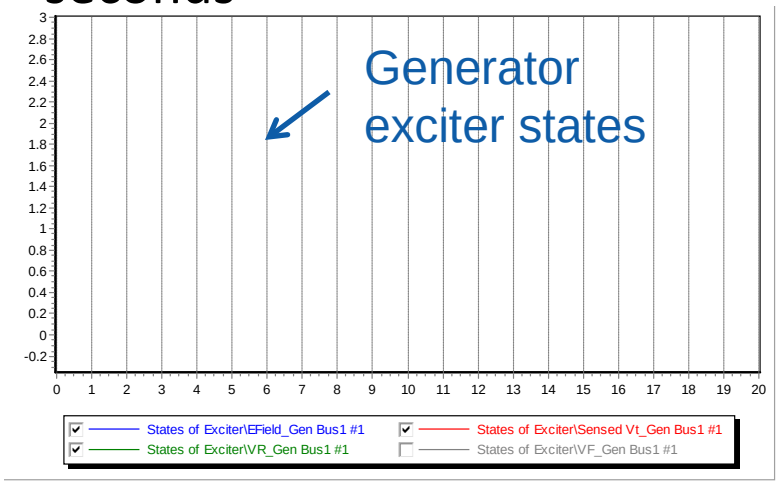
Generator Pmech



wscc_9bus_Type3WTG_CLOD

Complex Load Example

Plots when fault is cleared at 1.2 seconds



Large and Small Induction Motor Loads experience under voltage trips at buses 5,6, and 8 at about 2 seconds after the line opens

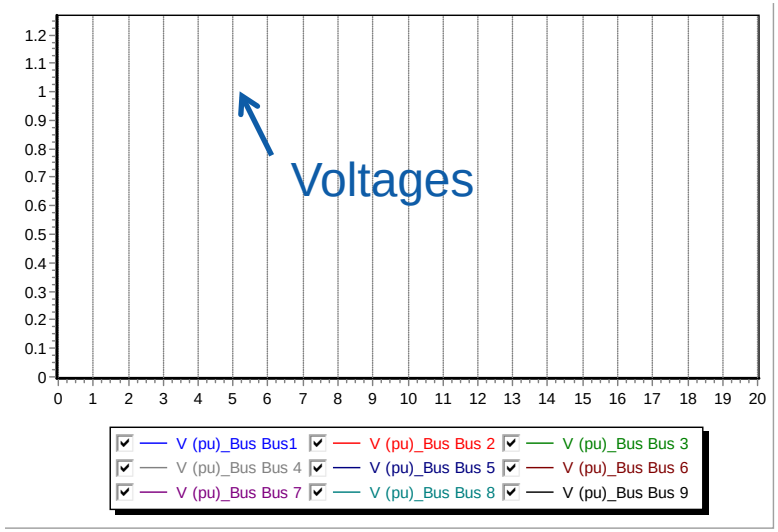
Generator 2 opens due to over frequency at 4.2 seconds after the line recloses

Results from RAM

Time Values | Minimum/Maximum Values | Summary | Events | Solution Details

Records ▾ Set ▾ Columns ▾ f(x) ▾

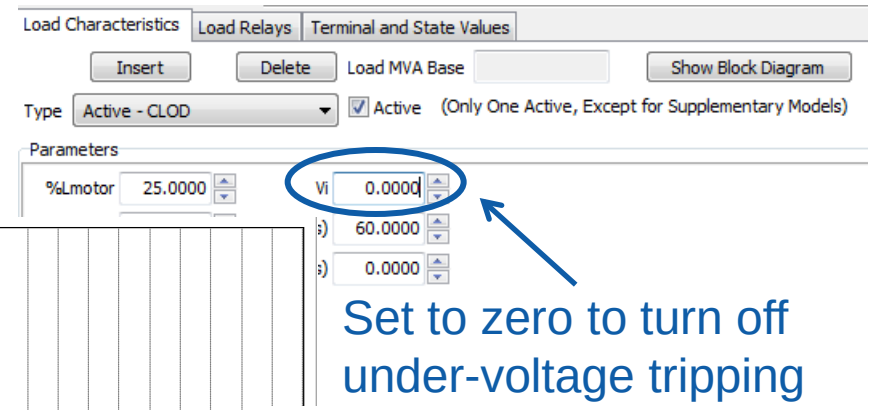
	Contingency Name	Time (Seconds)	Object	Model Type	Description	Level
1	My Transient	1.0000	Branch '9' '6' '1'	TXLine	Apply Solid Fault	Info
2	My Transient	1.2000	Branch '9' '6' '1'	TXLine	Open	Info
3	My Transient	2.0083	Load '5' '1'	TXLoadObject	Large Induction Motors Under Voltage Trip: Ope	Info
4	My Transient	2.0083	Load '5' '1'	TXLoadObject	Small Induction Motors Under Voltage Trip: Ope	Info
5	My Transient	2.0083	Load '6' '1'	TXLoadObject	Large Induction Motors Under Voltage Trip: Ope	Info
6	My Transient	2.0083	Load '6' '1'	TXLoadObject	Small Induction Motors Under Voltage Trip: Ope	Info
7	My Transient	2.0083	Load '8' '1'	TXLoadObject	Large Induction Motors Under Voltage Trip: Ope	Info
8	My Transient	2.0083	Load '8' '1'	TXLoadObject	Small Induction Motors Under Voltage Trip: Ope	Info
9	My Transient	3.0000	Branch '9' '6' '1'	TXLine	Close	Info
10	My Transient	4.2000	Gen '2' '1'	TXGenericGen	GENROU Over Frequency: Open	Info



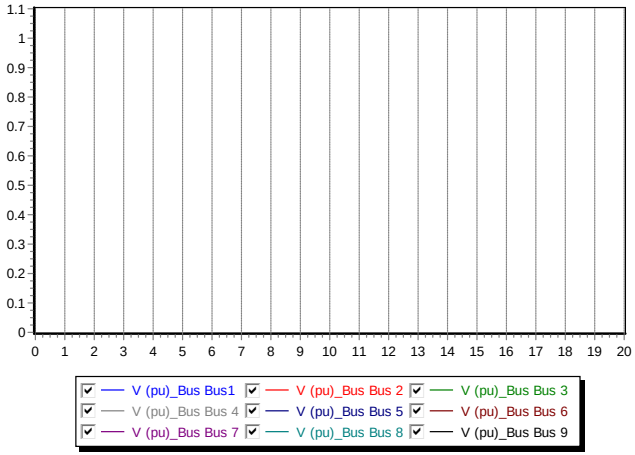
wscc_9bus_Type3WTG_CLOD

Complex Load Example

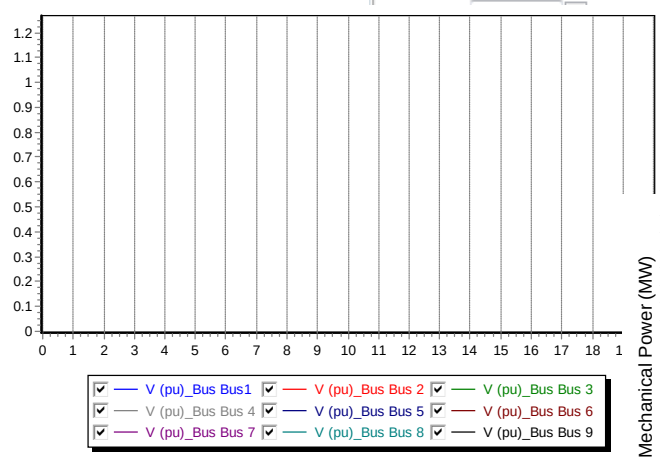
- CLOD model under-voltage tripping can be turned off by setting its parameter Vi to zero
- Re-open the CLOD dialog, and set Vi to zero
- Run the simulation, clearing the fault at 1.2 seconds
- Compare the plots



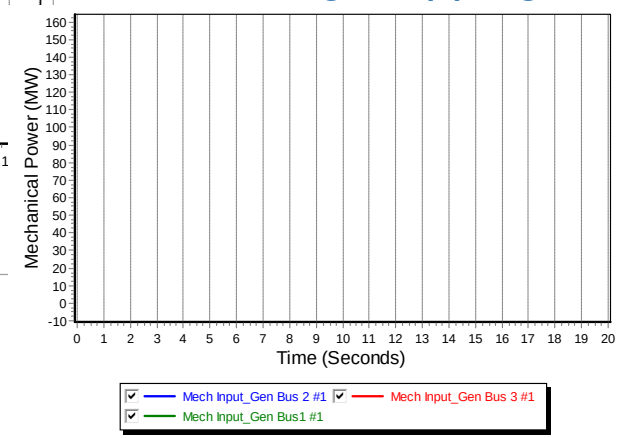
Set to zero to turn off under-voltage tripping



Voltages with under-voltage tripping turned OFF



Voltages with under-voltage tripping turned ON (default)



wscc_9bus_Type3WTG_CLOD

Type 4 Wind Models

- Completely asynchronous by design, called a "full converter model"
- The wind turbine's output is completely decoupled from the network using an AC-DC-AC converter
- This decoupling allows considerable freedom in selecting what type of electric machine is used
  - Machine could be a conventional synchronous generator, permanent magnet synchronous generator, or squirrel cage induction machine
  - No electrical coupling with the turbine dynamics
- Represented as a VSC, like Type 3, but with I_p and I_q as direct control variables and without effective reactance
- Modeled
  - Machine/Exciter combination WT4G1/WT4E1 (PSSE)
  - Machine/Exciter/Governor WT4G, WT4E, and WT4T (PSLF)