

Line and Transformer Relay Models in PowerWorld Simulator



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Overview



- Line and Transformer Relay Models in PowerWorld Simulator Transient Stability tools
 - Distance/Impedance
 - Time Inverse Overcurrent
 - New Relay Model TIOCRS
- Treatment of Transient Stability Models in Power Flow Contingencies

Line Relay Models in PowerWorld

Transient Stability



- Nothing existed prior to Summer 2012
 - Including these in stability is something that transient stability software users were not clamoring for until the WECC MSRATF started
- August 2012
 - TLIN1 properly functioning and reporting events
- October 2012
 - Added support for Impedance/Distance Relays
- December 2012
 - Added Time-Inverse Overcurrent Relays
- March 2012
 - Added new Time-Inverse Overcurrent Relay TIOCRS to specify input parameters using standard curves (IEEE C37.112, IEC 255-4, IAC)
- Last Week
 - PowerWorld Simulator automatically utilizes **transient stability** relays inside the **power flow** contingency analysis tool

Transient Stability Relay Models



- PowerWorld Simulator Version 17 includes the following models
 - Under Voltage and Frequency Relays
 - TLIN1
 - Impedance/Distance Relays
 - DISTR1, ZLIN1, ZQLIN1, ZPOTT, ZDCB
 - Out-of-Step Impedance Relays
 - OOSLEN, OOSLNQ
 - Time Inverse Over-Current Relays
 - LOCTI, TIOCR1
 - TIOCRS (added in March 14, 2013 patch)

Transient Stability Relay Models



- Line Relay Data Structure Considerations
 - Model is assigned to specified end of a Branch. Handled by field in case information displays called **Device Location** which is *From* or *To*
 - Multiple relays can be assigned to each end of a branch
 - Distance Relay, Time-Inverse Over-Current, Voltage, etc...
 - For some types multiple relays of same type are allowed (introduced extra key field of **Device ID**)
- User Interface Considerations
 - Stability tab is available on the branch dialog
 - Line relay models listed

Transient Stability Relay Models User Interface



The screenshot displays the 'Model Explorer: Line Relay Models' window. The left sidebar shows a tree view with 'Line Relay Models (5)' highlighted. The main area shows a table of relay models and a 'Branch Information Dialog' for a selected line.

Line Relay Model Table:

Line	Fully Supported	From Number	To Number	Circuit	From Name_Nominal kV	To Name_Nominal kV
1	YES	5	4	1	Bus	Bus
2	YES	5	4	1	Bus	Bus
3	YES	5	4	1	Bus	Bus
4	YES	6	4	1	Bus	Bus
5	YES	8	9	1	Bus	Bus

Branch Information Dialog:

Line: 5 (From Bus) to 4 (To Bus), Circuit: 1

Name: Bus 5 (From Bus) to Bus 4 (To Bus)

Area: 1 (1) (From Bus) to 1 (1) (To Bus)

Nominal kV: 230.0 (From Bus) to 230.0 (To Bus)

Voltage/Angle: 1.00053 / -18.8976 (From Bus) to 1.02862 / -15.8669 (To Bus)

Labels: no labels

Parameters: OFF, Fault Info, Area, Zone, Owner, Sub, PTDF, Custom, **Stability**, SIC

Line Relay Model: ZQLIN1 (To End)

Type: ZQLIN1 (To End) Active

Device is at From End of Line (otherwise at To End)

Parameters:

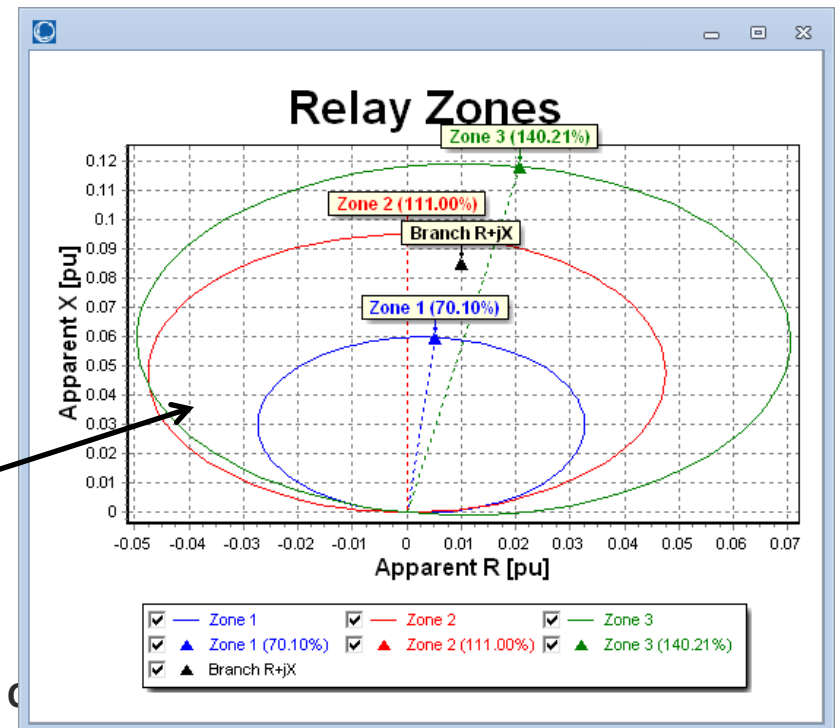
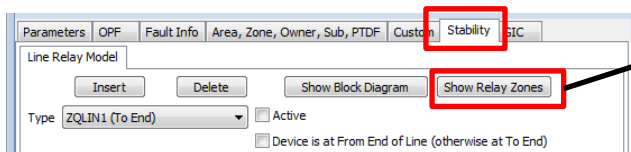
Nfar	none	Choose...			
No Trip	0	Wt1	0.5000	T2	0.00000
Shape1	1	Wr1	0.2500	Ang3	45.0000
Shape2	0	T1	0.00000	Rf3	0.2000
Shape3	0	Ang2	45.0000	Rr3	-0.05000
Tcb	0.00000	Rf2	0.2000	Wt3	0.06250
Ang1	45.0000	Rr2	-0.05000	Wr3	0.00000
Rf1	0.2000	Wt2	0.5000	T3	0.00000
Rr1	-0.05000	Wr2	0.1000		

Visualization for Distance/Impedance Relays



	To Number	Circuit	From Name_Nominal kV	To Name_Nominal kV	Device Location	Device ID	From Name	To Name	Type	Device Status	Sub-Inst	Zone 1 Reach %	Zone 2 Reach %	Zone 3 Reach %
1	4	1	Bus 5_230.00	Bus 4_230.00	From		Bus 5	Bus 4	ZLIN1	Active		58.42	233.68	116.84
2	4	1	Bus 5_230.00	Bus 4_230.00	To		Bus 5	Bus 4	ZQLIN1	Not active		233.68	233.68	233.68
3	4	1	Bus 5_230.00	Bus 4_230.00	From		Bus 5	Bus 4	DISTR1	Active		70.1	111	140.21
4	4	1	Bus 6_230.00	Bus 4_230.00	From		Bus 6	Bus 4	ZLIN1	Not active		106.89	0	0
5	9	1	Bus 8_230.00	Bus 9_230.00	From		Bus 8	Bus 9	TLIN1	Not active				

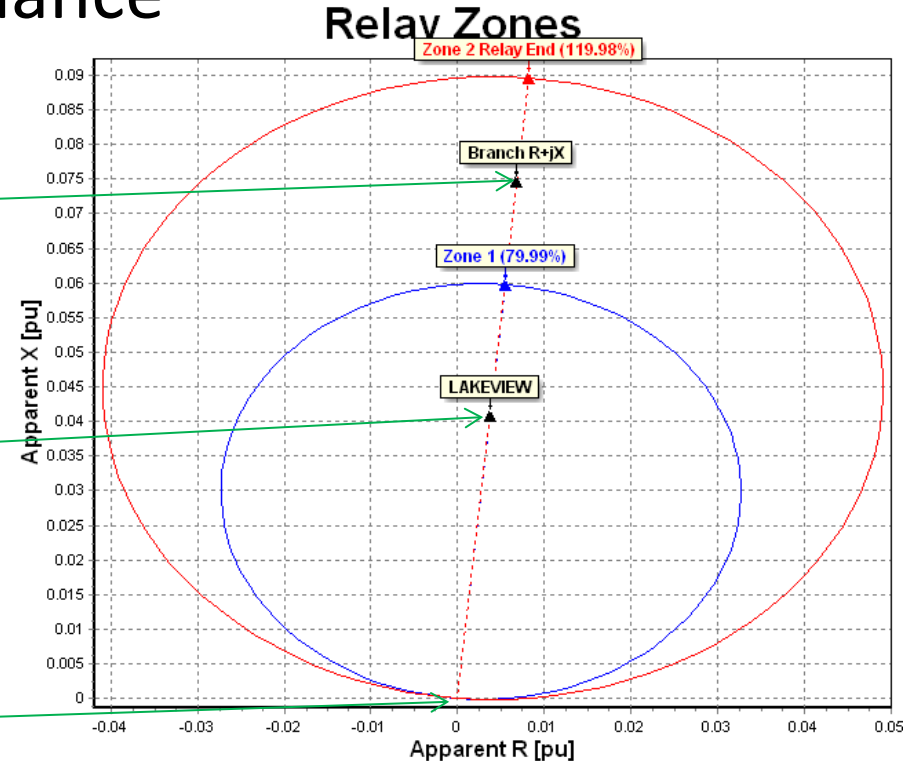
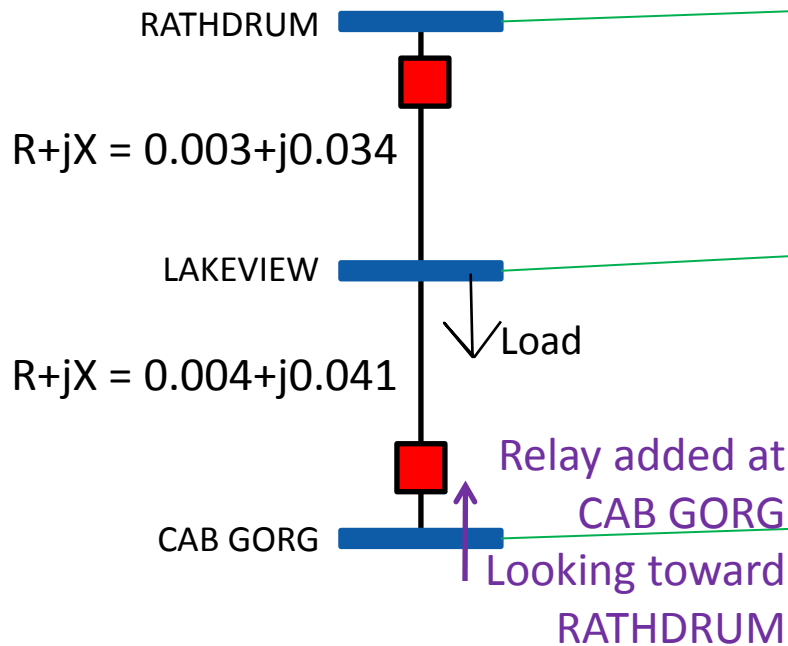
- Columns on Impedance Relays show Forward Reach %
- Click Button **Show Relay Zones** for Visualization



Visualization for Distance/Impedance Relays

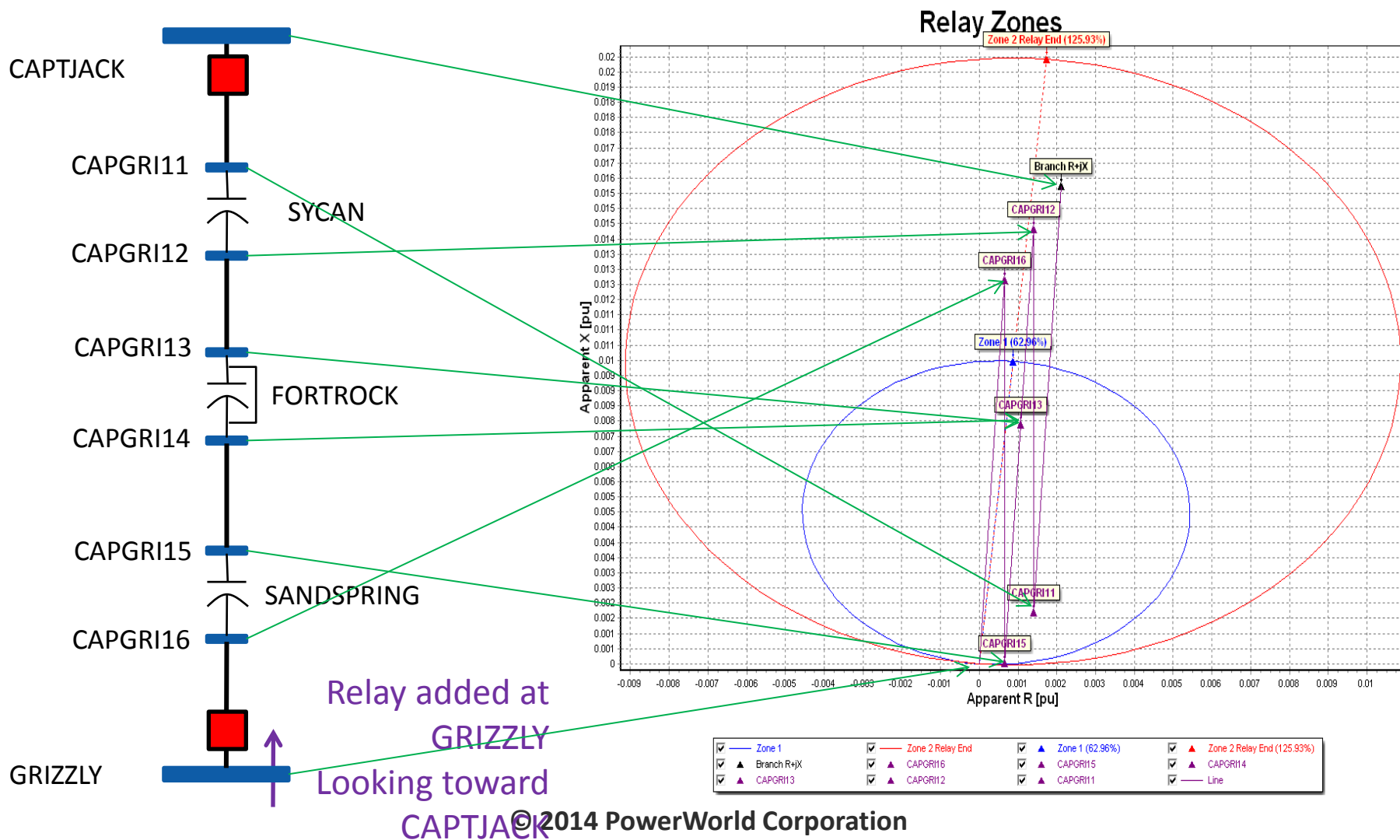


- If relay specifies a “far end”, visualization will show intermediate buses and percentage based on series impedance



<input checked="" type="checkbox"/> Zone 1	<input checked="" type="checkbox"/> Zone 2 Relay End
<input checked="" type="checkbox"/> Zone 1 (79.99%)	<input checked="" type="checkbox"/> Zone 2 Relay End (119.98%)
<input checked="" type="checkbox"/> Branch R+jX	<input checked="" type="checkbox"/> LAKEVIEW

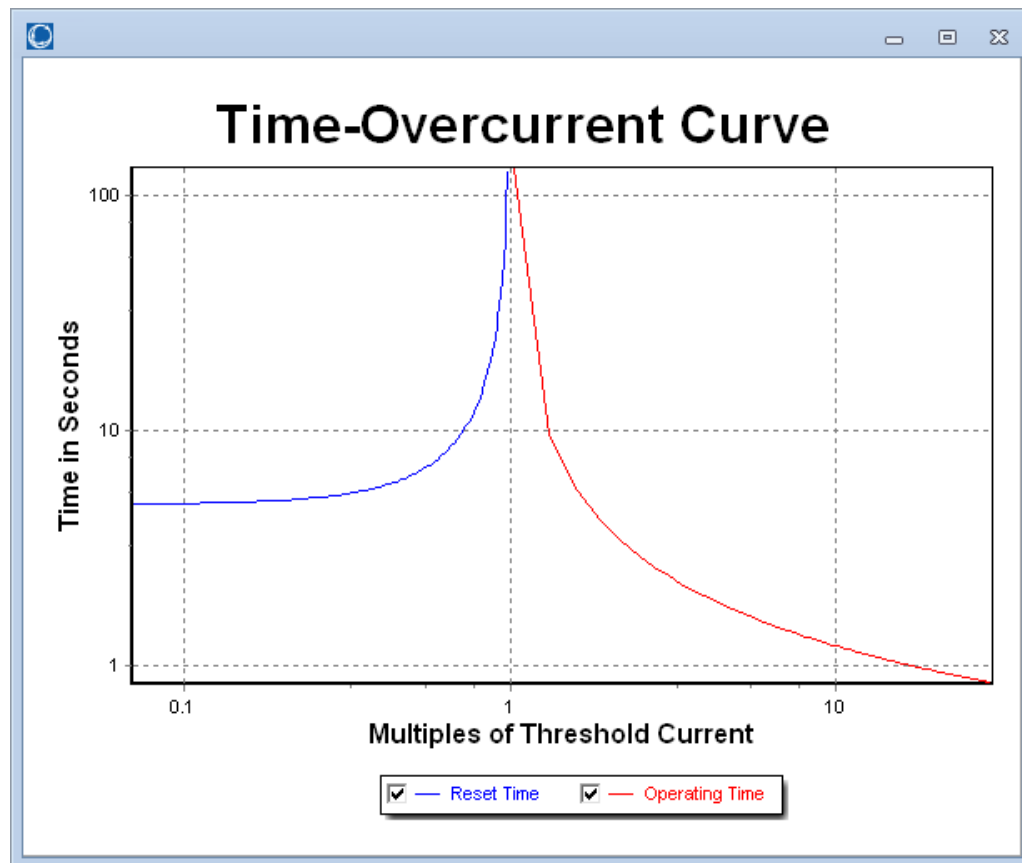
Visualization with Series Caps (CAPTJACK – GRIZZLY)



Visualization of Time-Overcurrent Curves



- For Time-Inverse Overcurrent relays, clicking button **Show Relay Zones** gives



New Line/Transformer Relay Model: TIOCRS



- TIOCRS: Time Inverse Overcurrent “Standard”
 - Very similar to TIOCRS and LOCTI
- Difference – specification of the curve which describes the time-inverse overcurrent characteristic is set based on commonly used standards
 - IEEE C37.112-1996 Standard (North America)
 - IEC 255-4 or British BS142 (Europe)
 - IAC GE Curves (GE electromechanical)

Specification of Time To Close



- LOCTI and TIOCR1 include specification of a piecewise linear curve to describe the Time-To-Close

- IEEE C37.112-1996 Standard

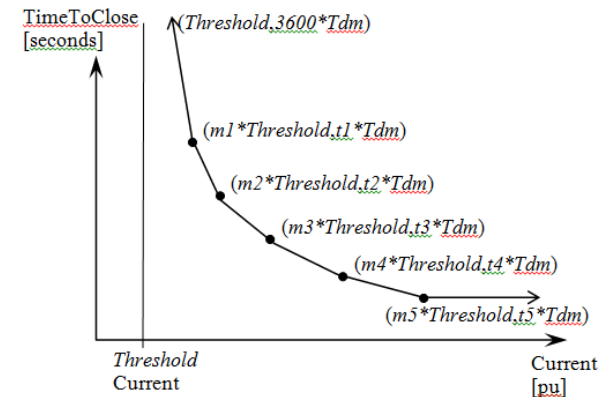
$$- \text{TimeToClose} = T_{dm} \left(B + \frac{A}{\left(\frac{I_{current}}{\text{Threshold}} \right)^p - 1} \right)$$

- IEC 255-4 or British BS142

$$- \text{TimeToClose} = T_{dm} \left(\frac{A}{\left(\frac{I_{current}}{\text{Threshold}} \right)^p - 1} \right)$$

- IAC GE Curves

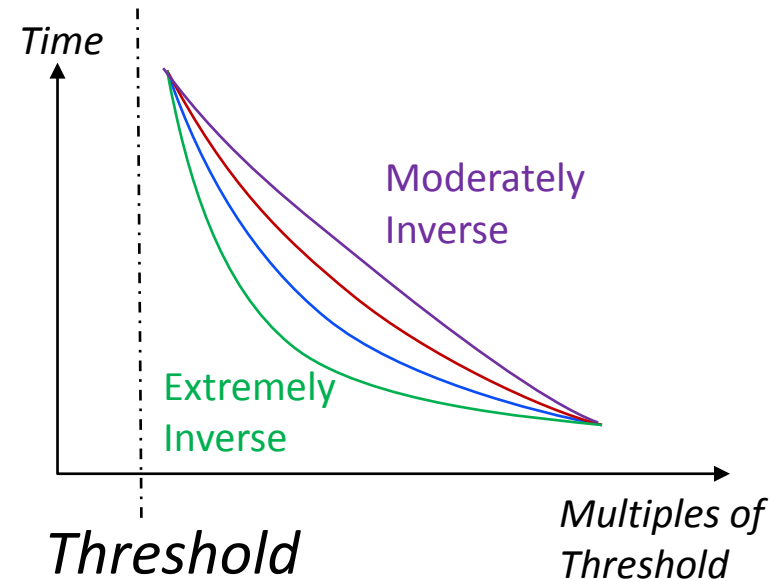
$$- \text{TimeToClose} = T_{dm} \left(A + \frac{B}{\left(\frac{I_{current}}{\text{Threshold}} - C \right)} + \frac{D}{\left(\frac{I_{current}}{\text{Threshold}} - C \right)^2} + \frac{E}{\left(\frac{I_{current}}{\text{Threshold}} - C \right)^3} \right)$$



Time Overcurrent: Standard Curve Shapes



- Curve provides the “Shape”
- Relay Engineers talk about
 - Moderately Inverse
 - Inverse
 - Very Inverse
 - Extremely Inverse
 - Short-Time Inverse



- Relays then have a Time Dial Multiplier (represented by input T_{dm}) which allows the relay engineer to tune the speed of response
 - Increase T_{dm} \rightarrow curve moves up \rightarrow slower
 - Decrease T_{dm} \rightarrow curves moves down \rightarrow faster

Standard Curves Available as Defaults



- Click on **Set To Defaults** button in PowerWorld for the TIOCRS relay and you get choices on right.

Line Relay Model

Insert Delete Show Block Diagram Show Relay Zones

Type: Active - TIOCRS (From End) Active Device is at From End of Line (otherwise at To End)

Set to Defaults Note: Multiple defaults available

Parameters

Tran Trip Line 1	none	Choose...
Tran Trip Line 2	none	Choose...
Tran Trip Line 3	none	Choose...

Relay Slot	1	Reset time	4.8500	E	0.00000
Monitor	1	p	0.02000	Load Shed %	1.0000
Curve Type	1	A	0.05150		
Threshold Current	1.0000	B	0.1140		
Breaker Time	0.00000	C	0.00000		
Tdm	1.0000	D	0.00000		

- IEEE C37.113 Moderately Inverse
- IEEE C37.113 Very Inverse
- IEEE C37.113 Extremely Inverse
- SEL US U1 (Moderately Inverse)
- SEL US U2 (Inverse)
- SEL US U3 (Very Inverse)
- SEL US U4 (Extremely Inverse)
- SEL US U5 (Short-Time Inverse)
- SEL IEC C1 (Standard Inverse)
- SEL IEC C2 (Very Inverse)
- SEL IEC C3 (Extremely Inverse)
- SEL IEC C4 (Long-Time Inverse)
- SEL IEC C5 (Short-Time Inverse)
- IEC 255-4 Curve A
- IEC 255-4 Curve B
- IEC 255-4 Curve C
- IEC 255-4 Short Inverse
- IAC Extreme Inverse
- IAC Very Inverse
- IAC Inverse
- IAC Short Inverse

Transient Stability Relay Models



- Basics of relay modeling in **transient stability** is not a software hurdle
 - At this point, all the software vendors have line relay models which are appropriate for use
 - More complex relays can certainly be created, but there doesn't seem to be an immediate need
- What's hard?
 - Staff time to collect and compile the input data
- Modeling of these features in the **power flow** simulations is another consideration

Treatment of **Transient Stability**

Models in **Power Flow** Contingencies

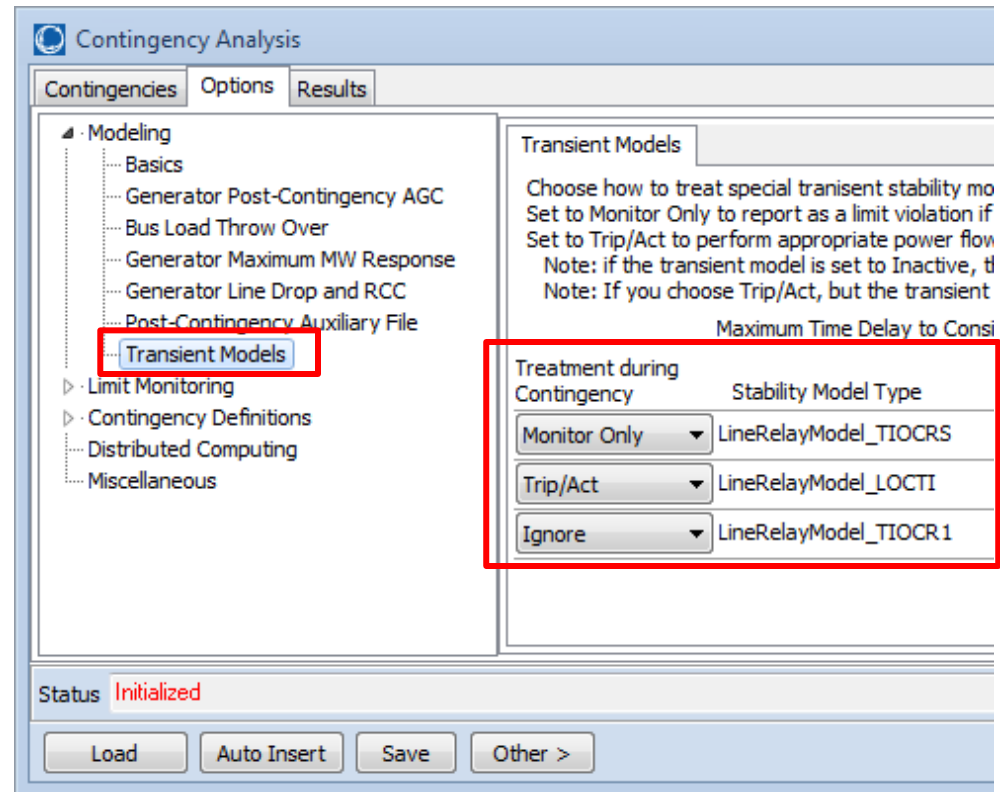


- Various transient relays can now be automatically handled in power flow contingency analysis
- Treatment is specified by model type
 - TIOCRS, LOCT1, and TIOCR1
 - Choices are Monitor, Trip, or Ignore
 - Default is to ignore
 - Also, if Transient Model **Status** = *Inactive* then ignore
- These have been implemented very generically inside PowerWorld Simulator
 - Future: Generator Relays, Load Relays, Load Model with embedded tripping, under voltage motor tripping
 - Other?

Options for Treatment in Power Flow Contingency Analysis



- Ignore
 - default setting
- Trip/Act
 - if conditions of model are met then actual actions will be taken (such as tripping a line for overcurrent)
 - If “monitor only” flag of stability model, then the specific model will instead just monitor
- Monitor Only
 - if conditions of model are met, then special contingency limit violations are reported
 - Similar to “Custom Monitors”, but they will show up as “Transient” monitors in the contingency analysis results



Effects on Results and Actions



- Trip/Act
 - Reported under “What Actually Occurred”
 - “Origin of Action” will indicate “Transient”
 - Available immediately
 - March 22 Patch of PowerWorld Simulator 17
- Monitoring results
 - Reported under “Violations”
 - “Category” will indicate “Transient”
 - Will be available in PowerWorld Simulator 18
 - Required modifications to PWB file format
 - Would work in 17, but when saving PWB you would lose these violations causing user confusion
 - Beta version available by request

What Actually Occurred Reporting for Transient Models



- Transient Relay Model will cause actions

Contingency Analysis

Contingencies Options Results

Records Set Columns Options

	Label	Skip	Processed	Solved	Post-CTG AUX	Islanded Load	Islanded Gen	QV Autoplot?	Custom Monitor Violations	Violations	Max Branch %	Min Volt	Max Volt	Max Interface %
1	L_000001One-000002TwoC1	NO	YES	YES	none			NO	0	1	151.6			
2	L_000001One-000003ThreeC1	NO	YES	YES	none			NO	0	2	169.4	0.863		
3	L_000002Two-000003ThreeC1	NO	YES	YES	none			NO	2	2	233.3	0.772		
4	L_000002Two-000004FourC1	NO	YES	YES	none			NO	0	0				
5	L_000002Two-000005FiveC1	NO	YES	YES	none			NO	0	0				
6	L_000002Two-000006SixC1	NO	YES	YES	none			NO	0	0				
7	L_000003Three-000004FourC1	NO	YES	YES	none			NO	0	0				
8	L_000004Four-000005FiveC1	NO	YES	YES	none			NO	0	0				
9	L_000007Seven-000005FiveC1	NO	YES	YES	none			NO	0	1	106.6			
10	L_000006Six-000007SevenC1	NO	YES	YES	none			NO	0	0				
11	L_000006Six-000007SevenC2	NO	YES	YES	none			NO	0	0				

Violations What Actually Occurred

	Actions	Model Criteria	Status	Comment	Brief What Occurred	Origin of Action	
1	OPEN Line Two_138.0 (2) TO Three_138.0 (3) CKT 1		CHECK		Opened flow of 39.99 MVA	ELEMENT	OPEN Line
2	OPEN Load Seven_138.0 (7) #1	junk	CHECK			ELEMENT	OPEN Load
3	OPEN Three_138.0 (3) TO Four_138.0 (4) CKT 1	Branch Three_138.0 (3) T	POSTCHECK		Opened flow of 65.11 MVA	TRANSIENT	OPEN Three

Status Finished with 6 Violations and 0 Unsolveable Contingencies. Initial State Restored. Refresh Displays After Each Contingency

Load Auto Insert Save Other > Start Run Close Help

Limit Violation Reporting based on Transient Models

Category of Violation

- Branch Amp
- Bus Low Volts
- Custom
- **Transient**

The screenshot shows the 'Contingency Analysis' software interface. The main table lists various contingencies with columns for Label, Skip, Processed, Solved, Post-CTG AUX, Islanded Load, and Islanded Gen. Below this, a detailed violation report is shown with columns for Element, Value, Limit, Percent, Area Name Assoc., and Nom kV Assoc.

Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1 Branch Amp BAMP 13 13 FROMTO One (1) -> Three (3) CKT 1 at Three	634.45	271.94	233.31	Top-Top	138.00
2 Bus Low Volts VLOW 3 Three (3)	0.77	0.90		Top	138.0
3 Jamie CUSTOM 'Jamie' Branch '1' '3' '1' Line One (1) TO Three (3) CKT 1 LineLimitPercent:2	233.31	0.00			
4 Transient TRANSIENT LineRelayModel_LOCTI '1' '3' '1' 'From Branch One (1) TO Three (3) CKT 1, Line Relay Model: LOCTI at One (1)	625.34	543.88	114.98	Top-Top	138.00

Status: Finished with 6 Violations and 0 Unsolveable Contingencies. Initial State Restored.

Branch One (1) TO Three (3) CKT 1, Line Relay Model: LOCTI at One (1)

Relay Tripping Order: Time Delay Matters



- Handled at the end of POSTCHECK loop
 - Query all stability models that are enabled for Trip/Act
 - Obtain a list of models whose conditions are met
 - From this list, obtain list of models that will Trip/Act FIRST (based on time delays in transient model)
 - Models with zero time delay trip/act immediately
 - For inverse-time overcurrent relays, the “time delay” value is obtained based on the actual current
 - Apply action of models (relays trip devices)
 - Resolve power flow

How this is integrated with existing *CHECK* and *POSTCHECK* actions



- Contingency processing is as follows:
 1. Apply *ALWAYS* actions and true *CHECK* actions
 2. Update topology (branch, bus status)
 3. Apply true *TOPOLOGYCHECK* actions
 4. Solve power flow
 5. Apply true *POSTCHECK* and *TOPOLOGYCHECK* actions
 6. Repeat steps 2-5 until no more *POSTCHECK* and no *TOPOLOGYCHECK* actions are done
 7. Apply true *TRANSIENT* actions that will trip next based on the time delays in the transient model
 8. Repeat steps 2-7 until no more *TRANSIENT* actions are done

Summary



- Transient stability models of line relays
- Waiting for folks to use these features and provide feedback
- Looking for guidance on how the monitoring and action of certain transient models should be handled in the power flow
 - Relay models
 - Other models?
 - Under voltage tripping associated with certain load models