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APPENDIX A – ABB REM543 POLE-SLIP LOGICS

Explanation of function blocks

ABS:	The output of the ABS function block is equal to the absolute value of the input.
ACOS:	The output of the ACOS function block is equal to arc-cos of the input.
ADD:	The output of the ADD function block is equal to the sum of the inputs.
AND:	The output of the AND function block is true if all the inputs are true.
ATAN:	The output of the ATAN function block is equal to arc-tan of the input.
DIV:	The DIV function block divides the top input by the bottom input.
GE:	The output of the GE function block is true if the top input is greater or equal to the bottom input.
LT:	The output of the LT function block is true if the top input is less than the bottom input.
MOVE:	The output of the MOVE function block is equal to the input.
MUL:	The MUL function block multiplies the inputs with each other.
OR:	The output of the OR function block is true if at least one input is true.
SEL:	If the input of the SEL function block is true, the output has the value of IN1. If the input is false, the output has the value IN0.
SUB:	The output of the SUB function block is equal to the top input minus the bottom input.

APPENDIX B – PSCAD POLE-SLIP LOGICS

APPENDIX C – PSCAD SIMULATION RESULTS

APPENDIX D – PSCAD ALGORITHM SOURCE FILE CD

Contents of CD:

New Pole-slip protection function logics for:

- PSCAD source file as well as **PDF version** of a Round Rotor Generator (590MVA example)
- PSCAD source file as well as **PDF version** of a Salient Pole Generator (158MVA example)

System requirements:

A licensed version of PSCAD (or a 30 day trial) is required to compile the simulations. The PSCAD models contain more nodes than the maximum number of nodes that the PSCAD demo version can simulate. The PSCAD software can be downloaded at www.pscad.com

Hints on using the pole-slip algorithm model:

Setting the fault duration

A fault is applied on one of the transmission lines. It is assumed that the faulted transmission line protection will clear the fault (which will leave only one transmission line in service after the fault is cleared). For example, if the fault is chosen to occur at 15 s for a duration of 200 ms, the timer that opens CB2s and CB2r must be set at 15.2 s.

Waiting for steady state before applying fault

It is important to wait for the simulation to reach steady state before applying a fault. It is recommended to apply the fault no earlier than 15 s after the simulation started. After the simulation is started while steady state is being approached, the controls switches must be set as follows:

RESET = 1

STEADY = 0

Toggle the switches about 2 seconds before the fault occurs to the following state:

RESET = 0

STEADY = 1

Viewing the graphs (results)

The graphs are located under the module named "Page2"

Changing generator active power output

The active power outputs of the four generators in the model can be independently changed by sliding the “ T_{primover} ”- sliders up and down. It is not recommended to change generator powers during the simulation to ensure that steady state is obtained before the fault occurs.

Changing shunt loads at Generator 1

The shunt load active- and reactive power magnitudes can be changed to verify the pole-slip function works accurately regardless of the shunt load at the generator terminals.

Changing Generator, Transformer and Transmission Line Parameters

If the user wishes to change any parameters on the Generators, Transformers or Transmission lines, the parameters must be modified in the PSCAD three-line diagram as well on the pole-slip algorithm inputs. The pole-slip algorithm inputs are located in the top-left corner of the model. For example, if the transmission line length is changed, the effective per unit value of the transmission line reactance and resistance must be calculated by the user and entered into the “Xline” and “Rline” parameters of the pole-slip algorithm.

NOTE: The MVA base is chosen to be the same as the MVA rating of Generator 1. If the MVA rating of generator 1 is changed, the following needs to be modified:

- Change the MVA base on all the Power Meters (this includes the power meters at the generator terminals, at the transformer HV terminals, at the generator shunt load, at the transmission line feeders, and at the infinite bus transmission line sections)
- Change the MVA base in the transmission line models
- Change the MVA base in the infinite bus source
- Change the MVA base in the pole-slip algorithm variable “ S_{base} ”

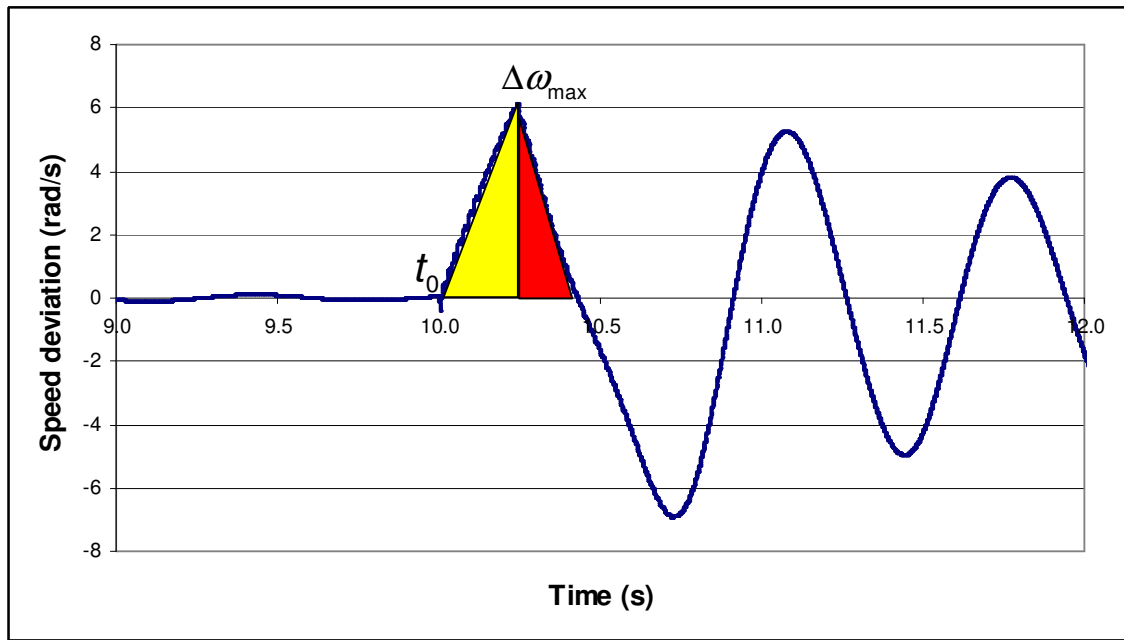
Adjusting Generator 2 overshoot factor

The pole-slip function is designed to predict the time that the rotor will remain above synchronous speed after the fault is cleared. This is, however, only calculated for Generator 1 in the PSCAD model. In a real power system, Generator 2 will have its own pole-slip relay, which will communicate the rotor angle to the pole-slip relay on Generator 1.

If the graph below is considered, the yellow area indicates the area during which the fault occurred, while the red area indicates the period after the fault is cleared until the rotor speed deviation reached 0 rad/s.

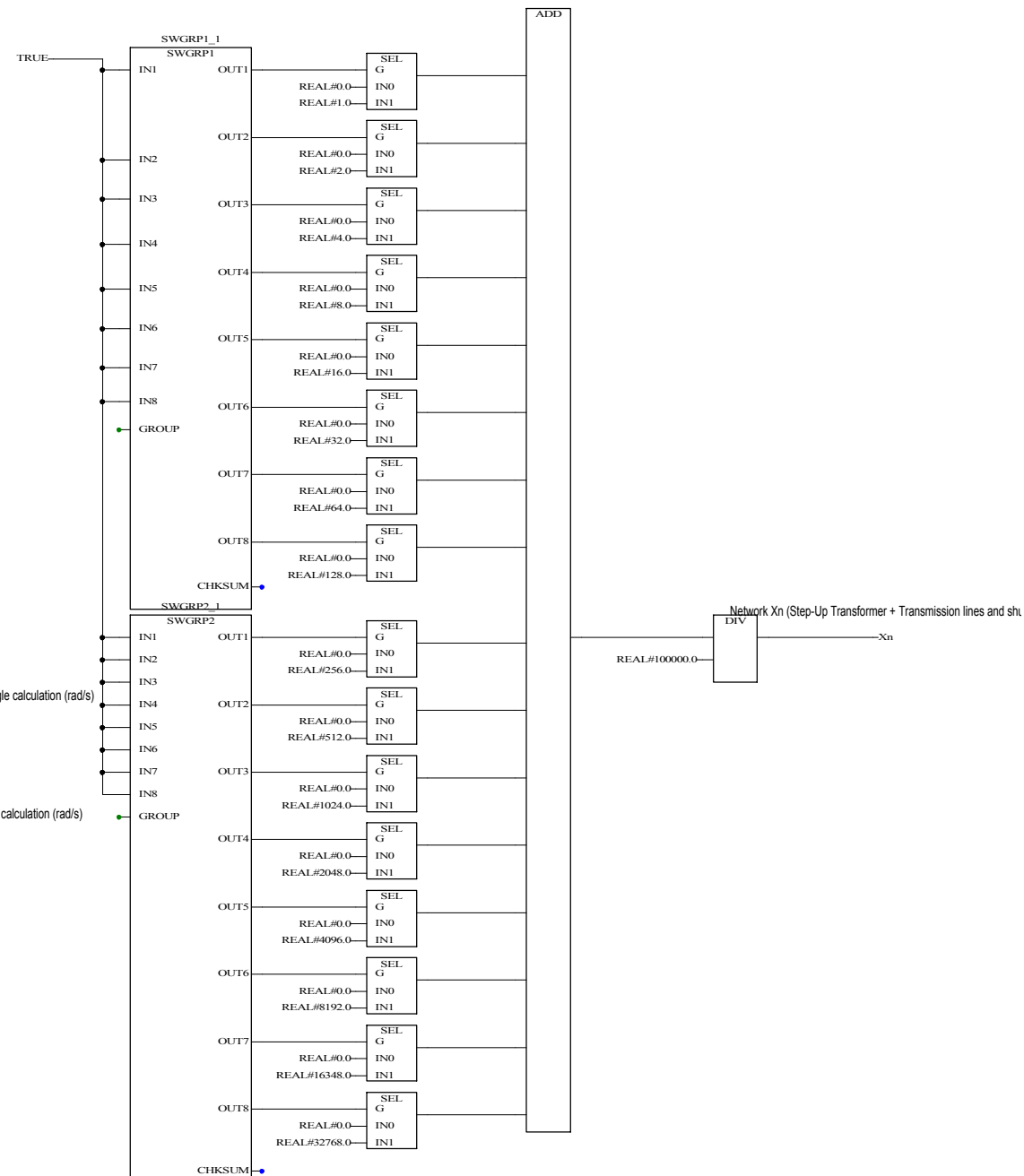
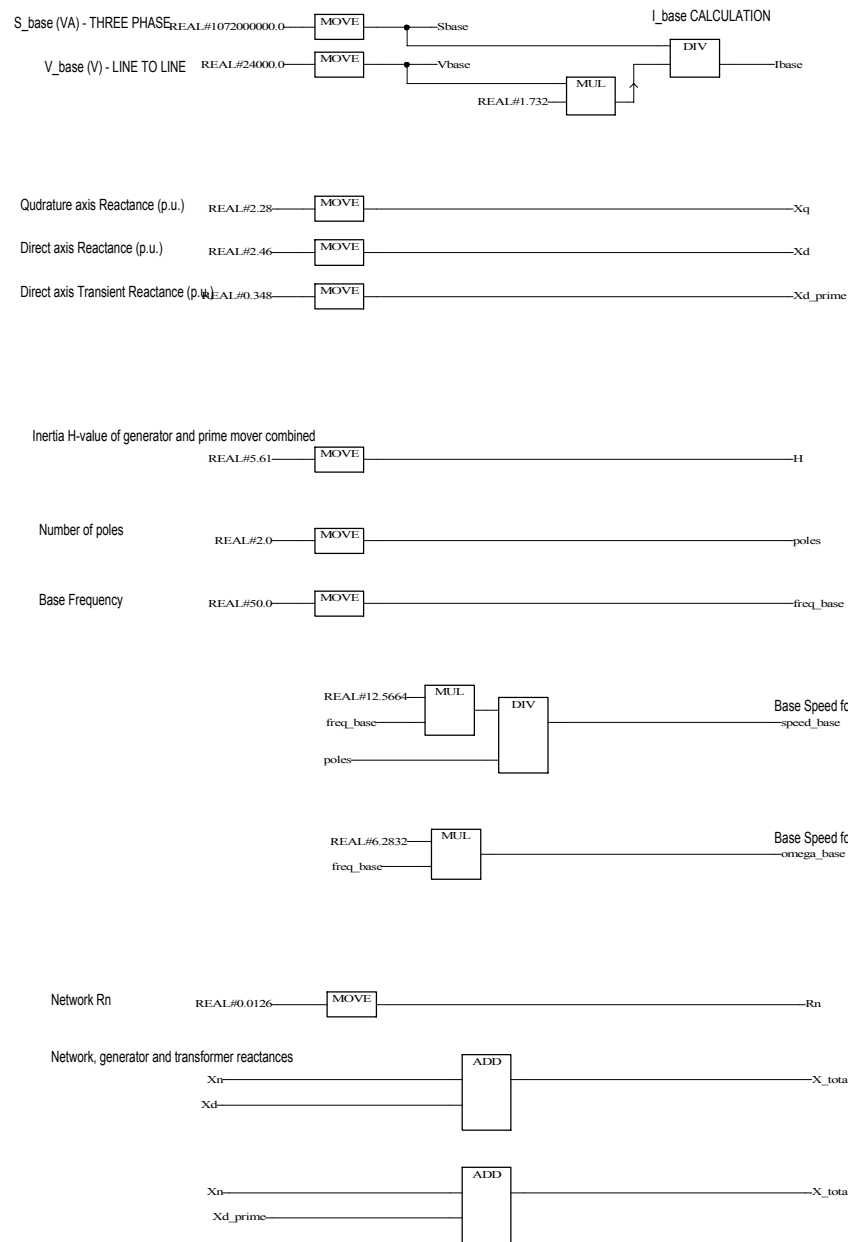
The “Gen2_rotor_overspeed” variable in the model must be calculated by the user as follows:

$$Gen2_rotorspeed_overshoot = \frac{\text{Red Area}}{\text{Yellow Area}} \quad (a)$$



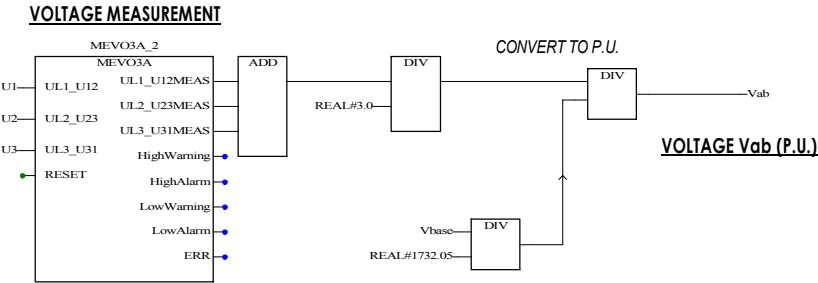
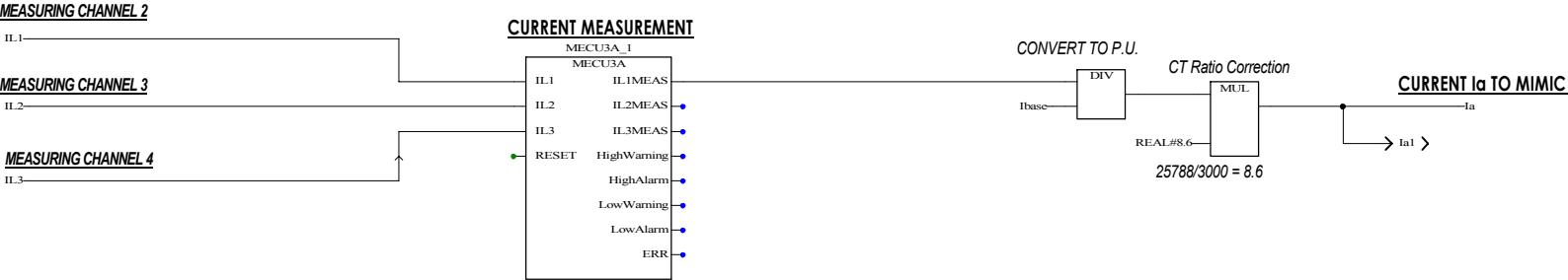
Generator speed deviation due to an electrical fault

Note that the calculation in equation (a) must be done after a simulation was run during which Generator 1 did not loose stability. Only after this calculation was performed, the simulation must be re-compiled with the correct variable “Gen2_rotorspeed_overshoot” entered into the pole-slip algorithm.



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MEASUREMENTS PAGE (CYCLE TIME 20ms)



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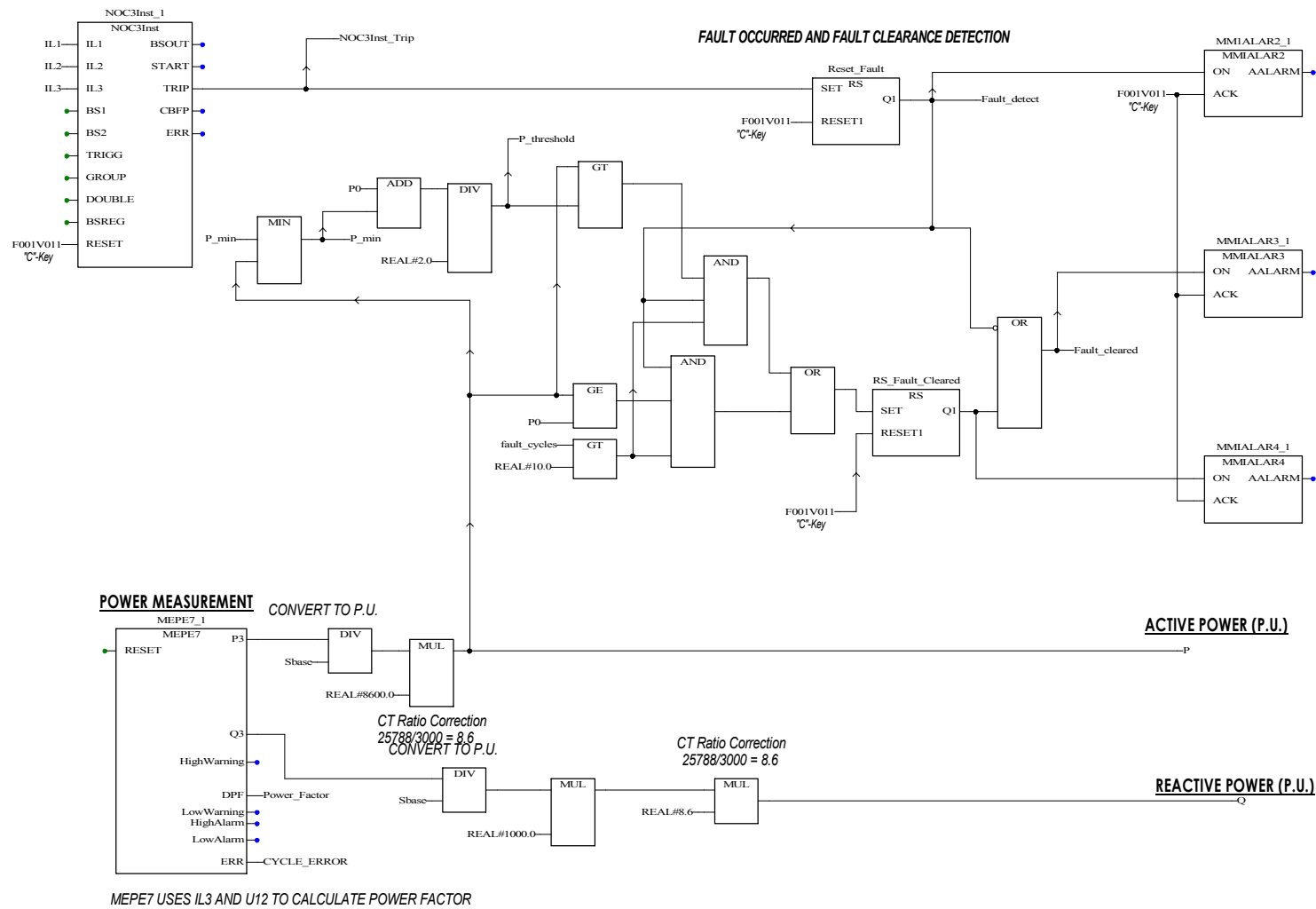
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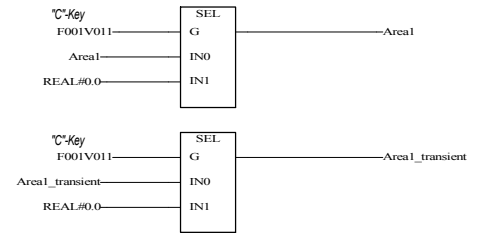
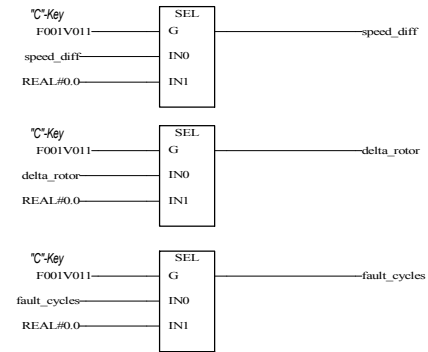
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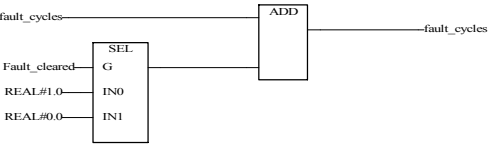
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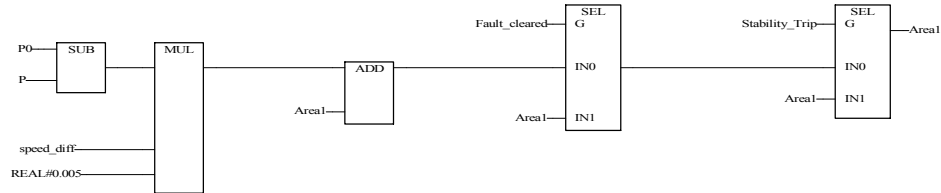
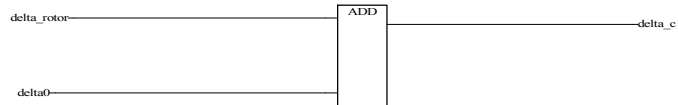
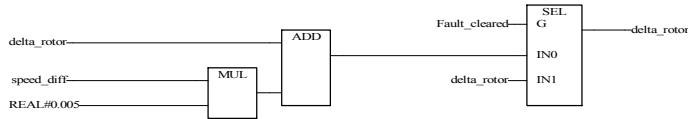
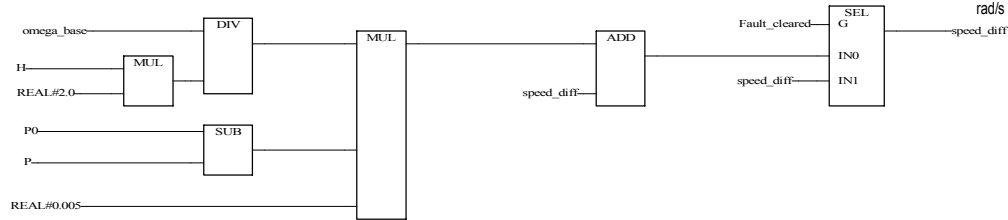
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SPEED DEVIATION CALCULATION FOR ELECTRICAL ROTOR ANGLE CALCULATION

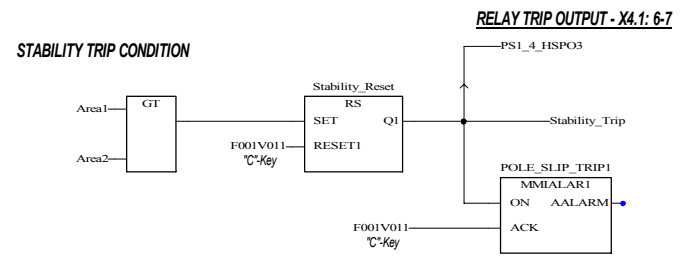
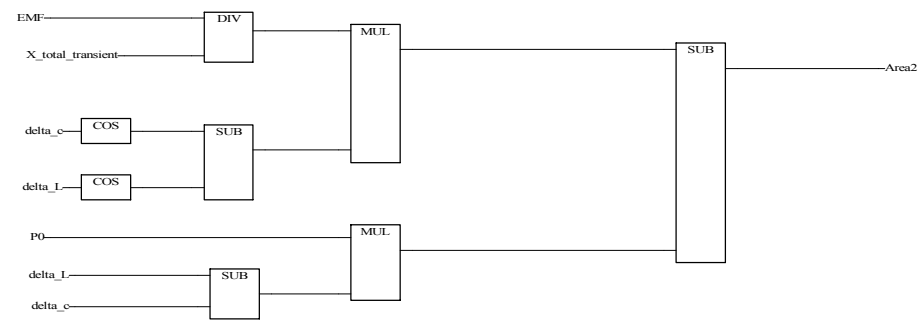


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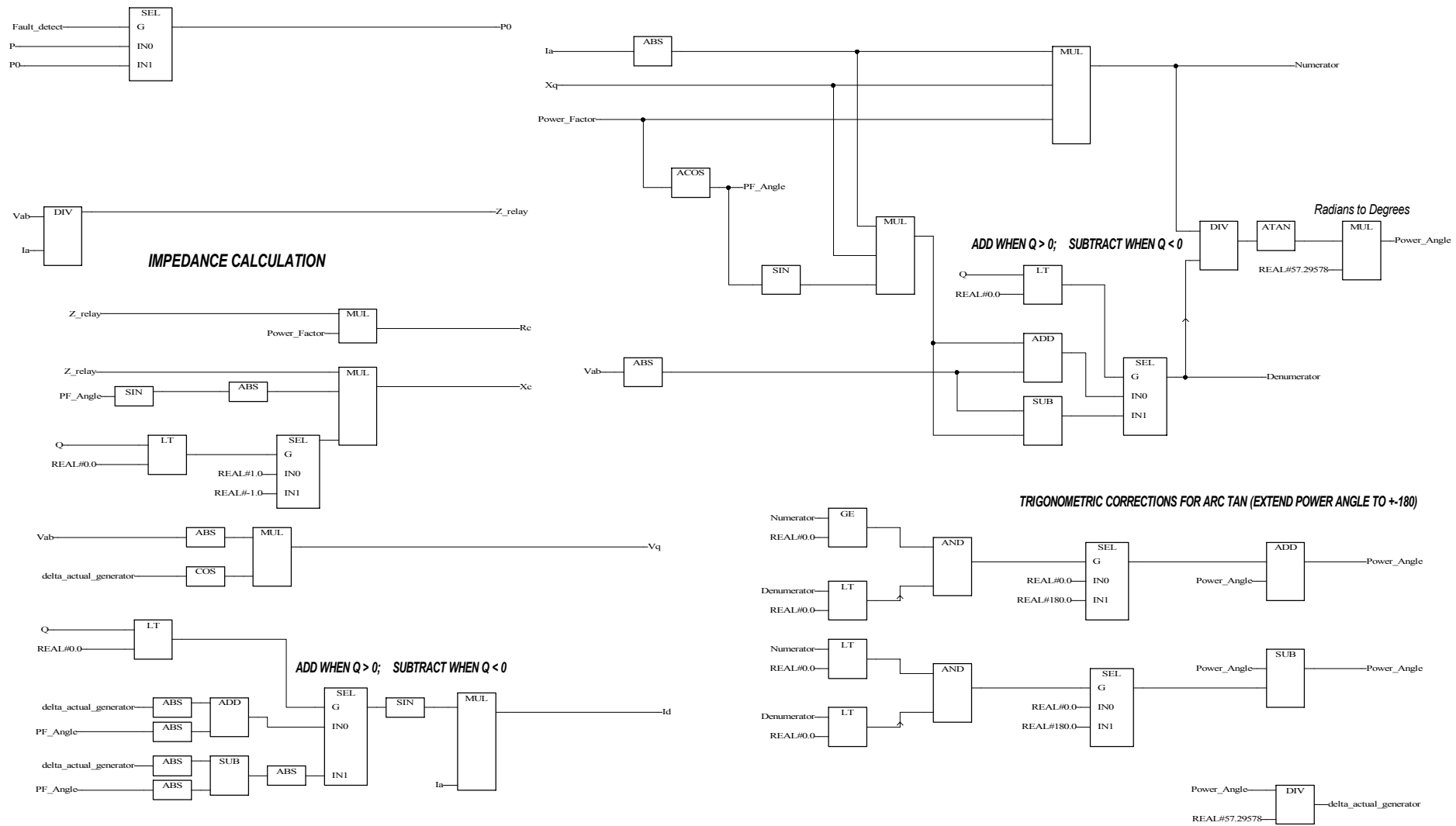
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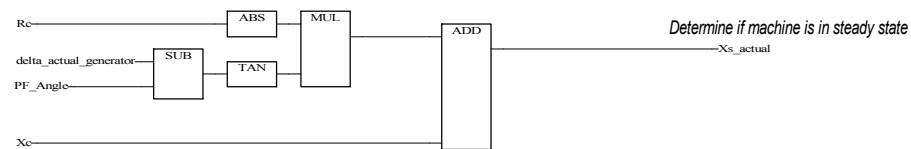
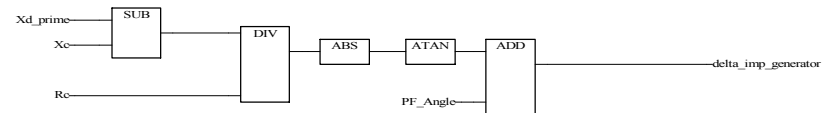
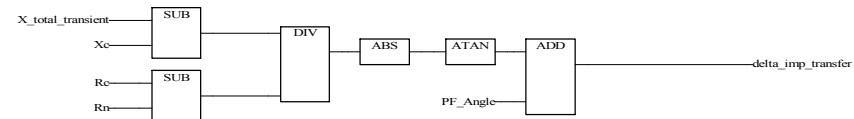
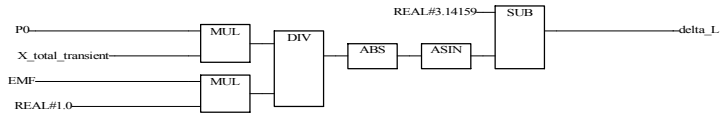
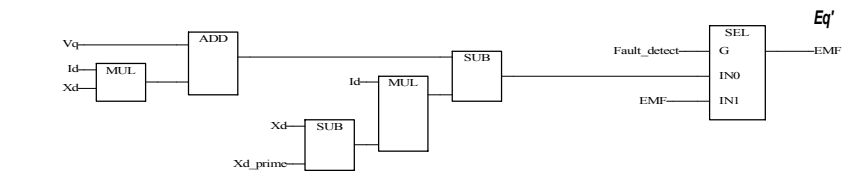


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SLOW CYCLE PAGE - STEADY STATE CALCULATIONS (CYCLE TIME 1000ms)



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Pre-fault Actual Transfer Angle



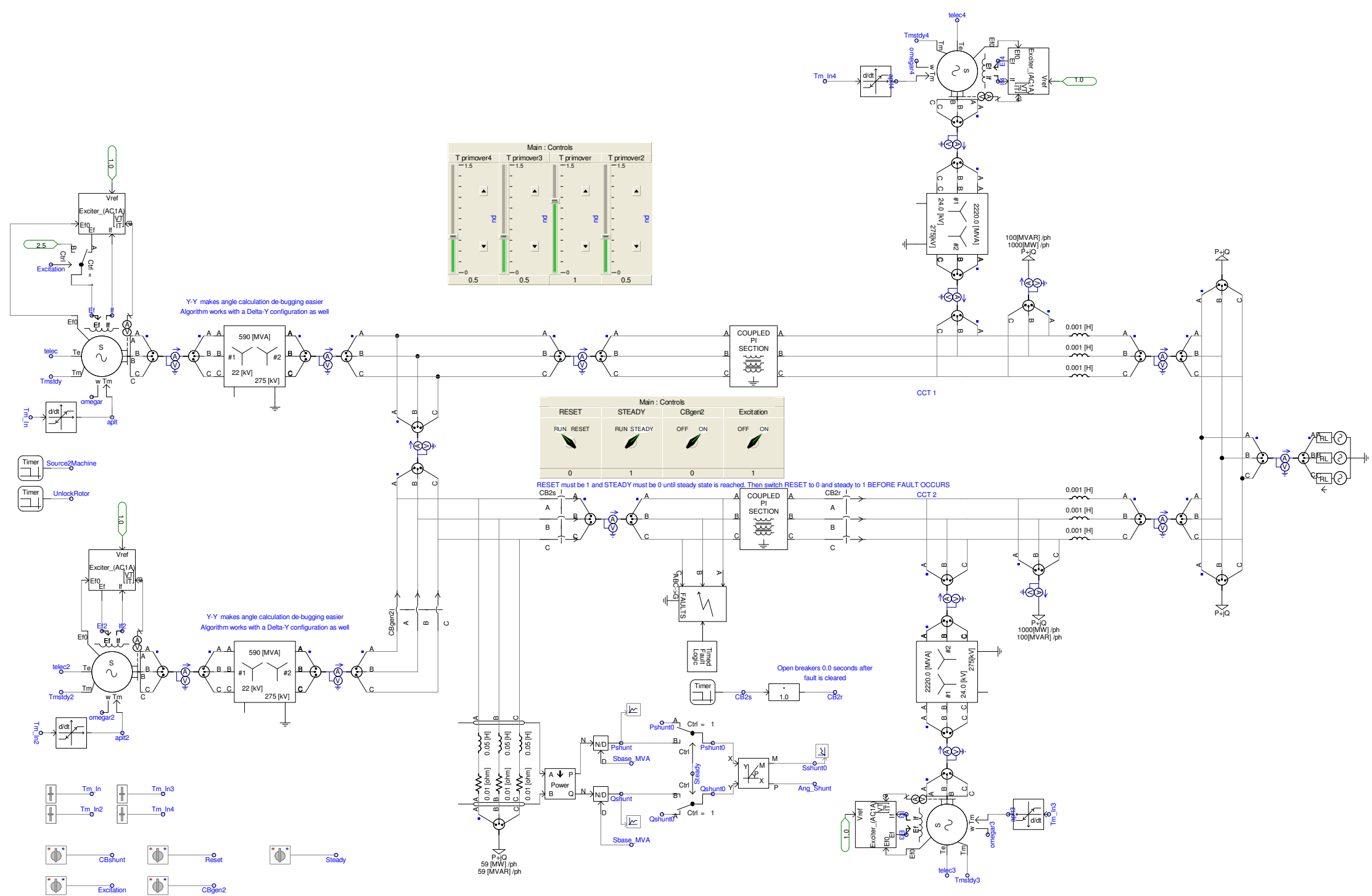
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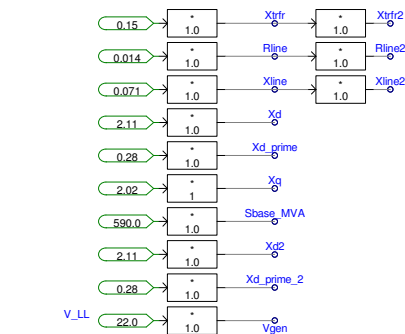
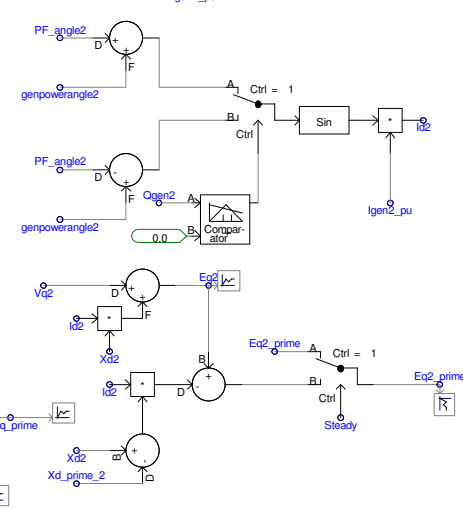
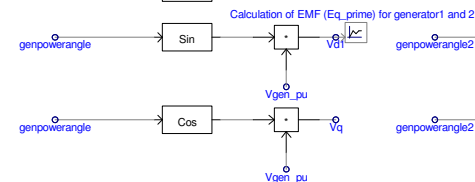
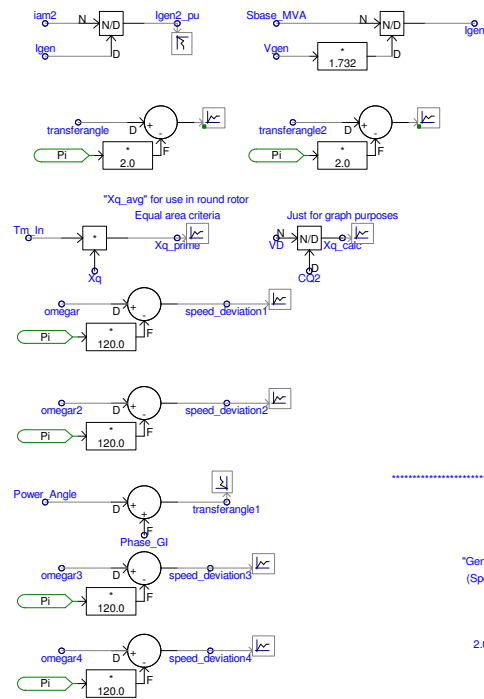
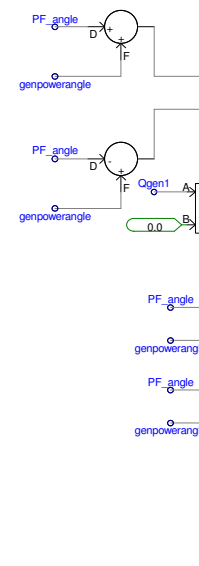
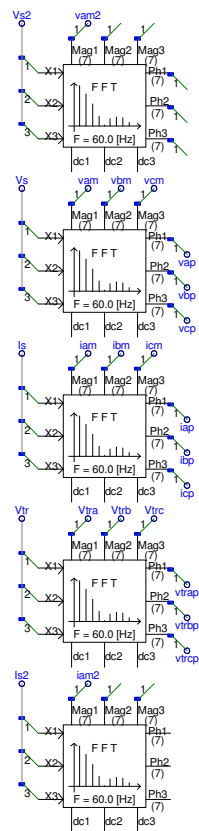
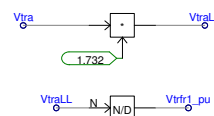
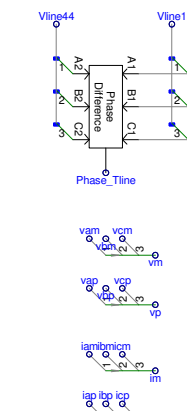
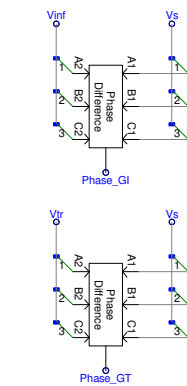
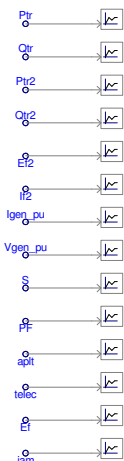
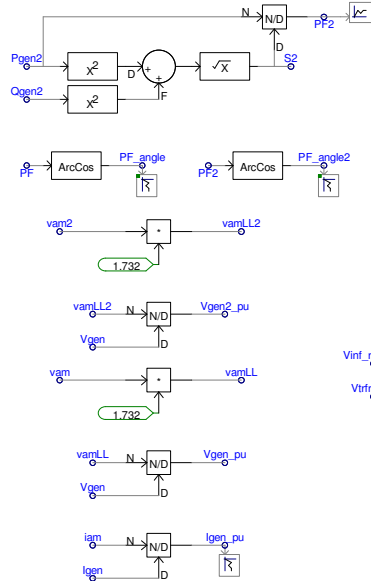
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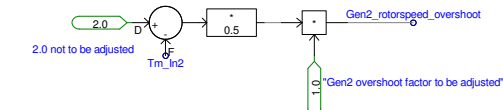
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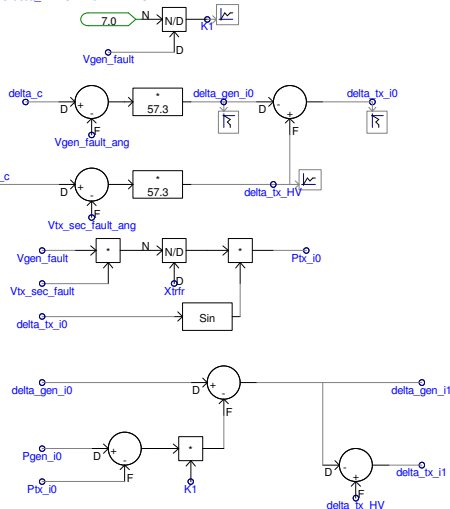
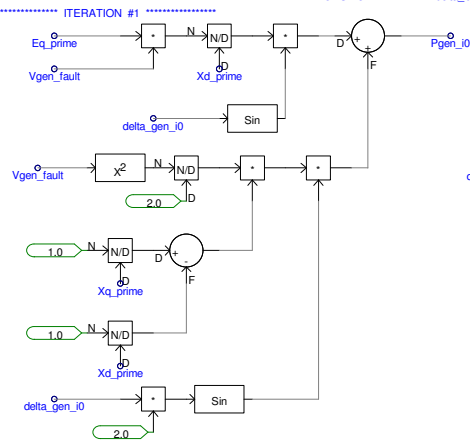
SELF-TUNING CORRECTION CONSTANT C1
Only applicable for round rotor machines. Salient rotors uses C1 = 1

The rotor speed overshoot (area under rad/s curve) after fault is cleared for Gen 2:
NOTE: This value is determined by the pole-slip relay on Gen2 and must be communicated automatically to the relay on Gen1.
The Pole-slip Relay on Gen2 is not included in this PSCAD simulation.
"Gen2_rotorspeed_overshoot" must therefore be manually updated by the user as follows;
(Speed Area after fault clearance until speed reaches 0 rad/s) / (Speed Area during fault)

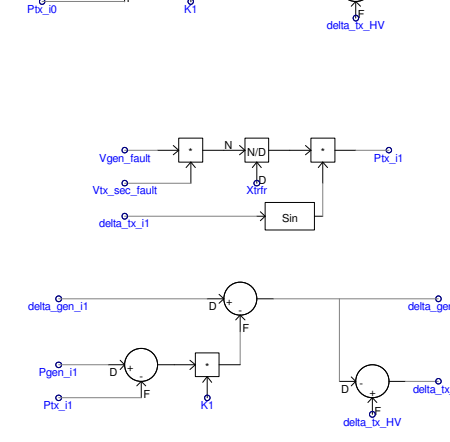
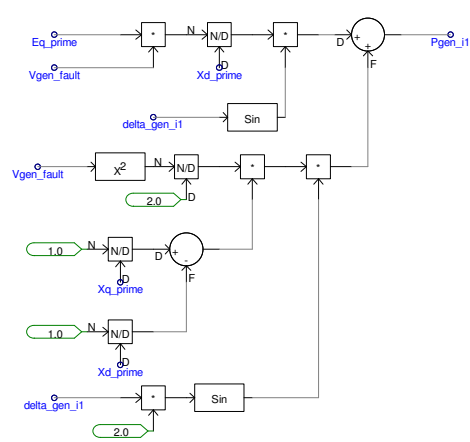


ITERATIONS TO DETERMINE delta_Gen1 & delta_Tx DURING THE FAULT

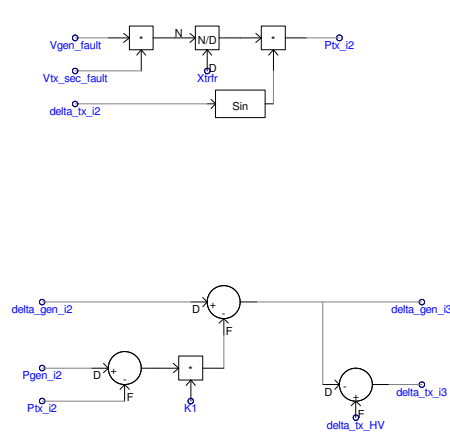
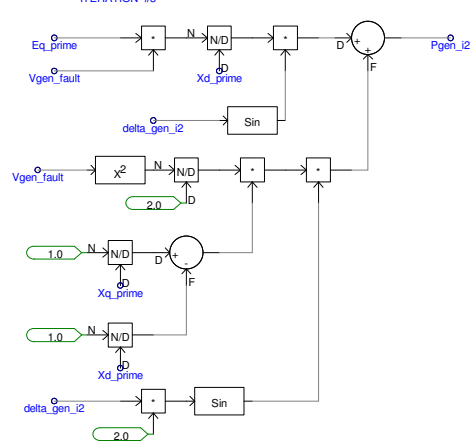
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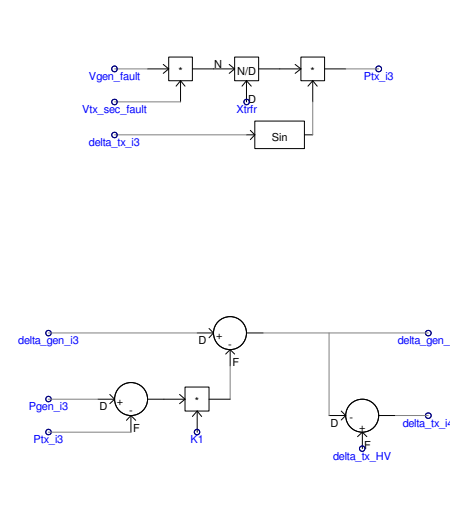
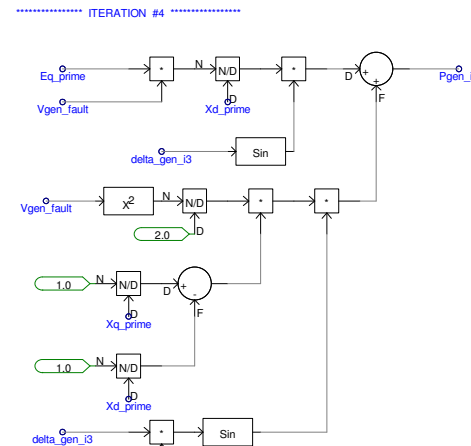
***** ITERATION #2 *****



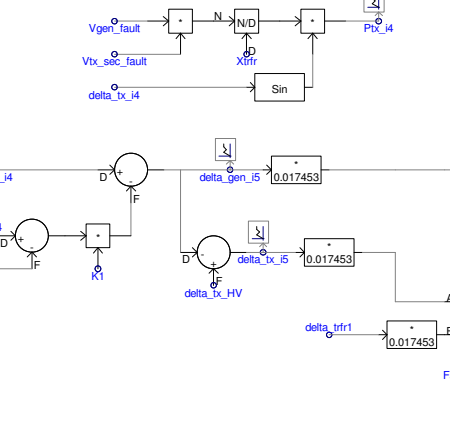
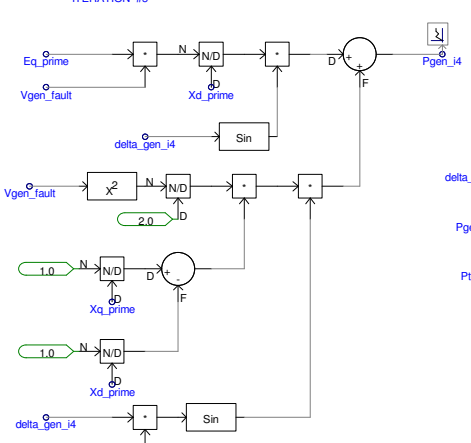
***** ITERATION #3 *****



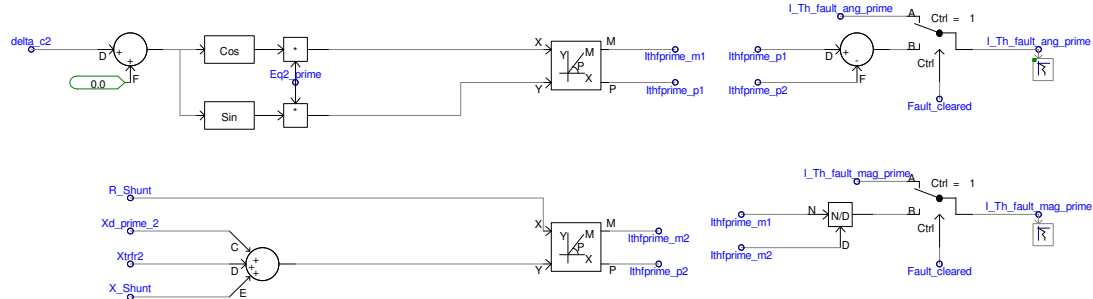
***** ITERATION #4 *****



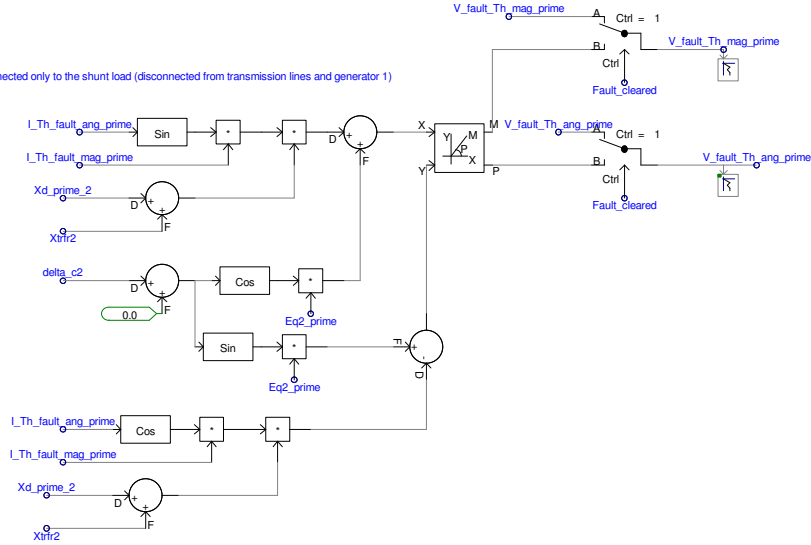
***** ITERATION #5 *****



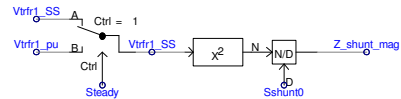
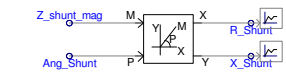
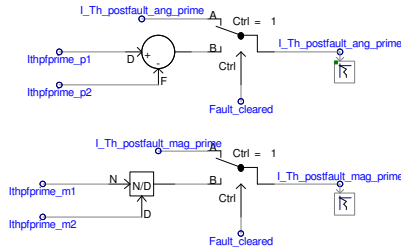
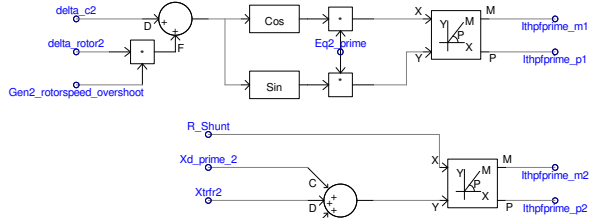
I_Thevenin_prime (fault) is the generator 2 current connected only to the shunt load (disconnected from transmission lines and generator 1)



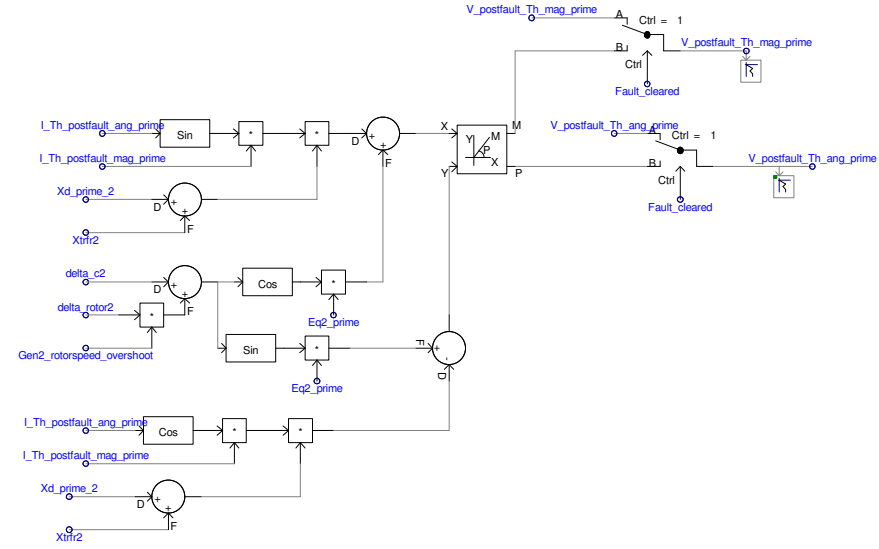
V_Thevenin_prime (fault) is the Transformer 2 HV Voltage connected only to the shunt load (disconnected from transmission lines and generator 1)



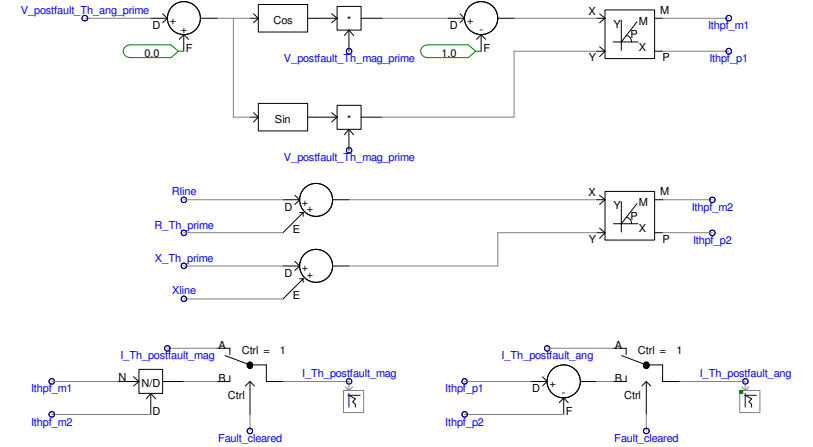
I_Thevenin_prime (postfault) is the generator 2 current connected only to the shunt load (disconnected from transmission lines and generator 1)



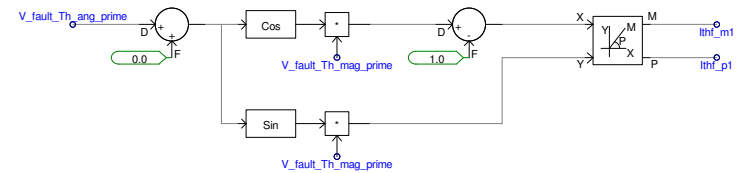
V_Thevenin_prime (postfault) is the Transformer 2 HV Voltage connected only to the shunt load (disconnected from transmission lines and generator 1)



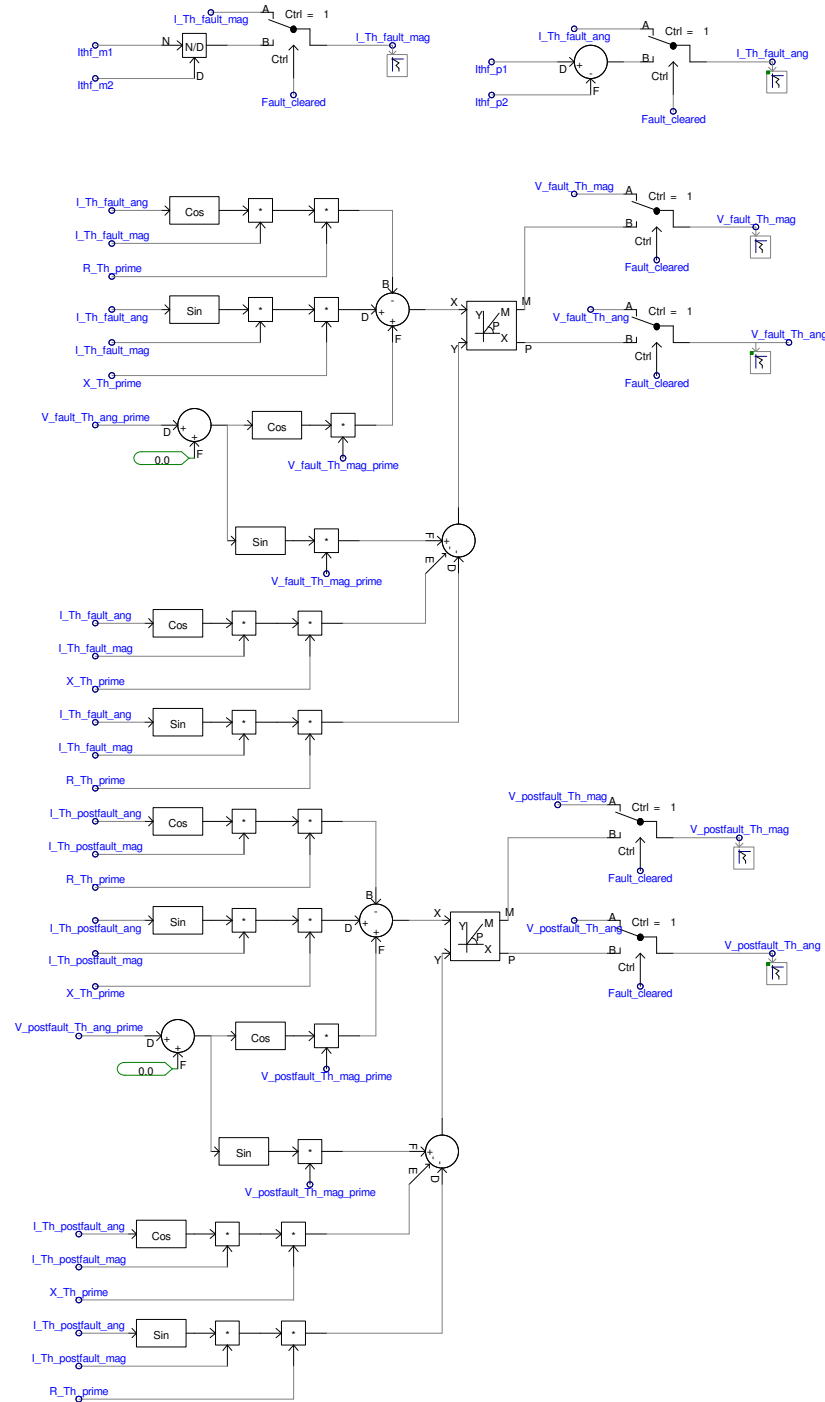
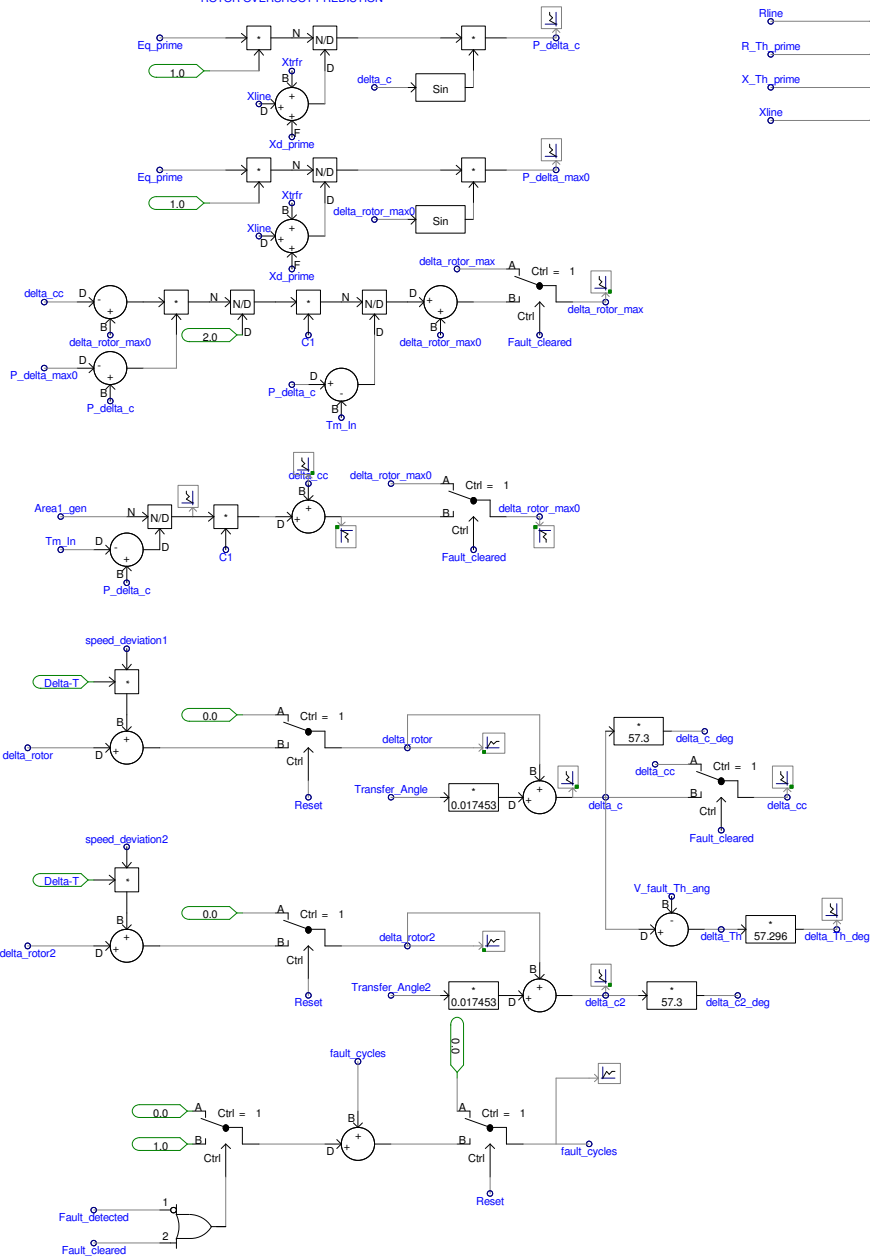
I_Thevenin (postfault) is the generator 2 current (without generator 1)

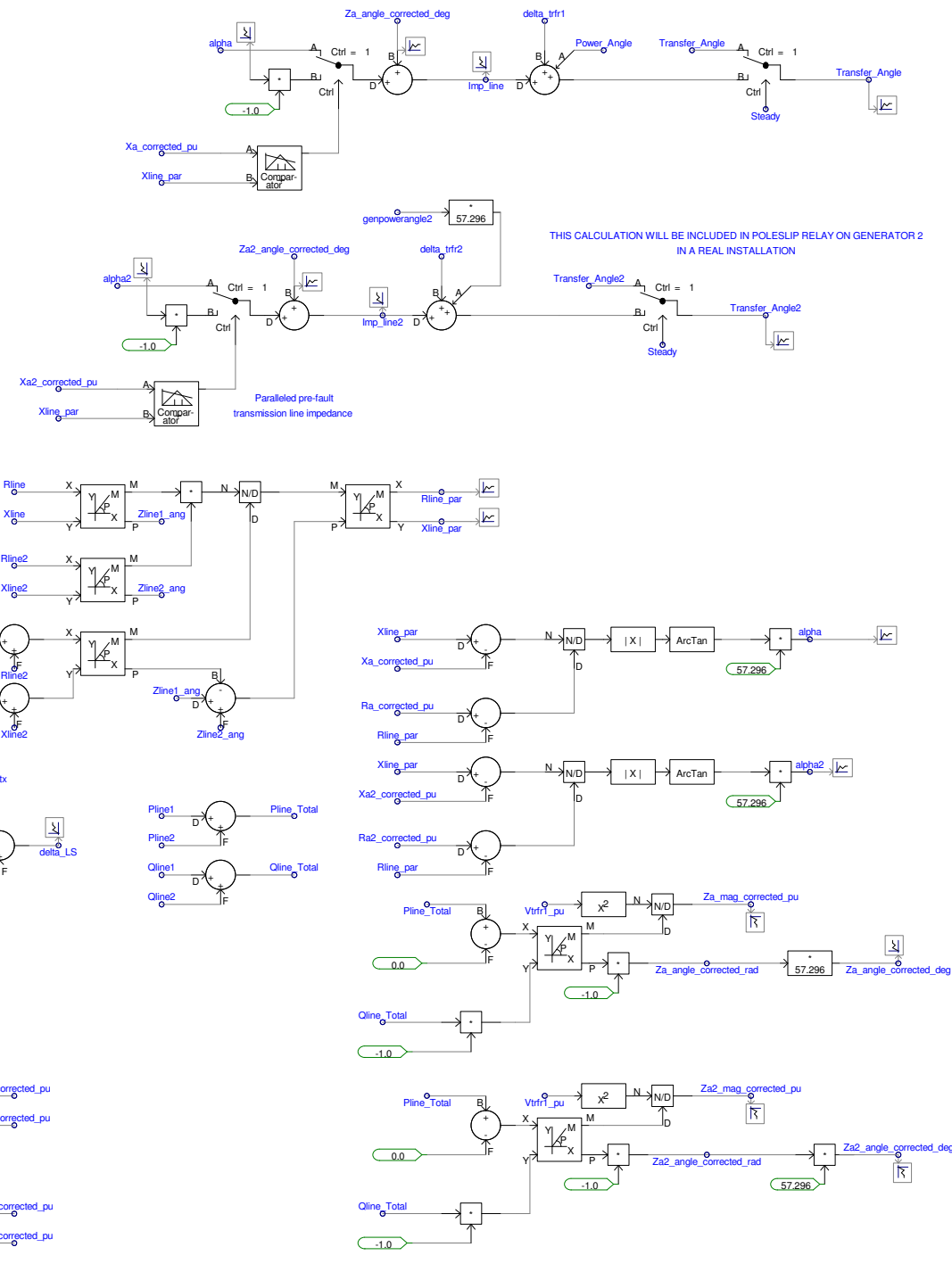


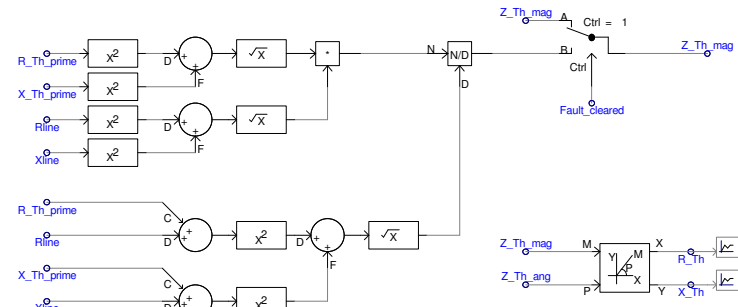
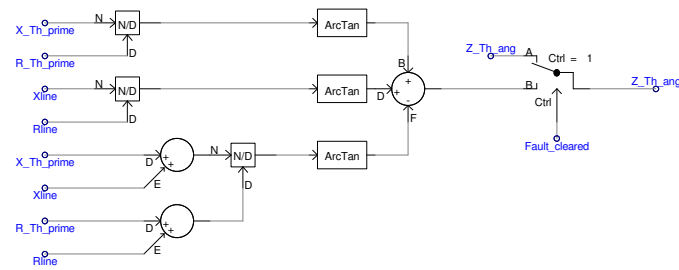
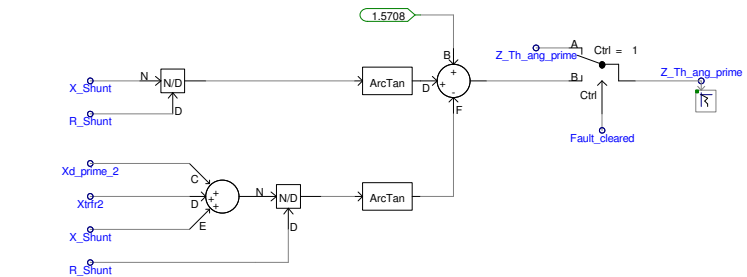
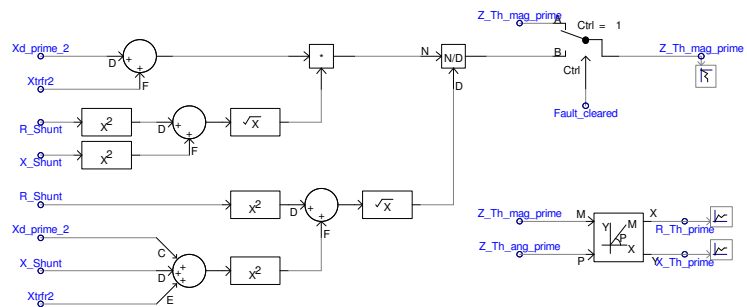
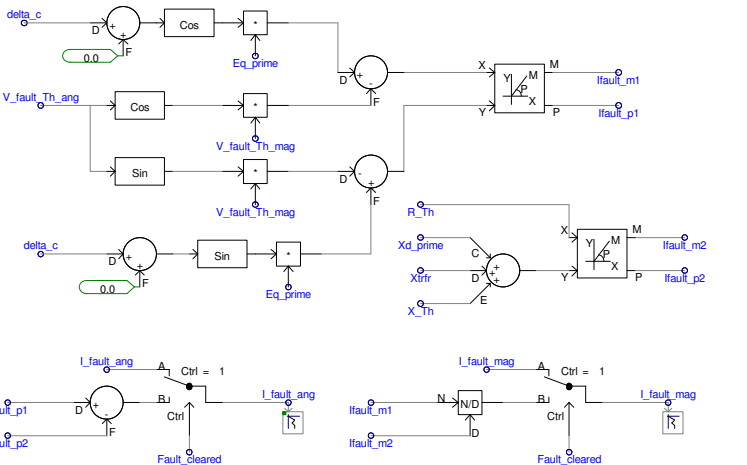
I_Thevenin (fault) is the generator 2 current (without generator 1)

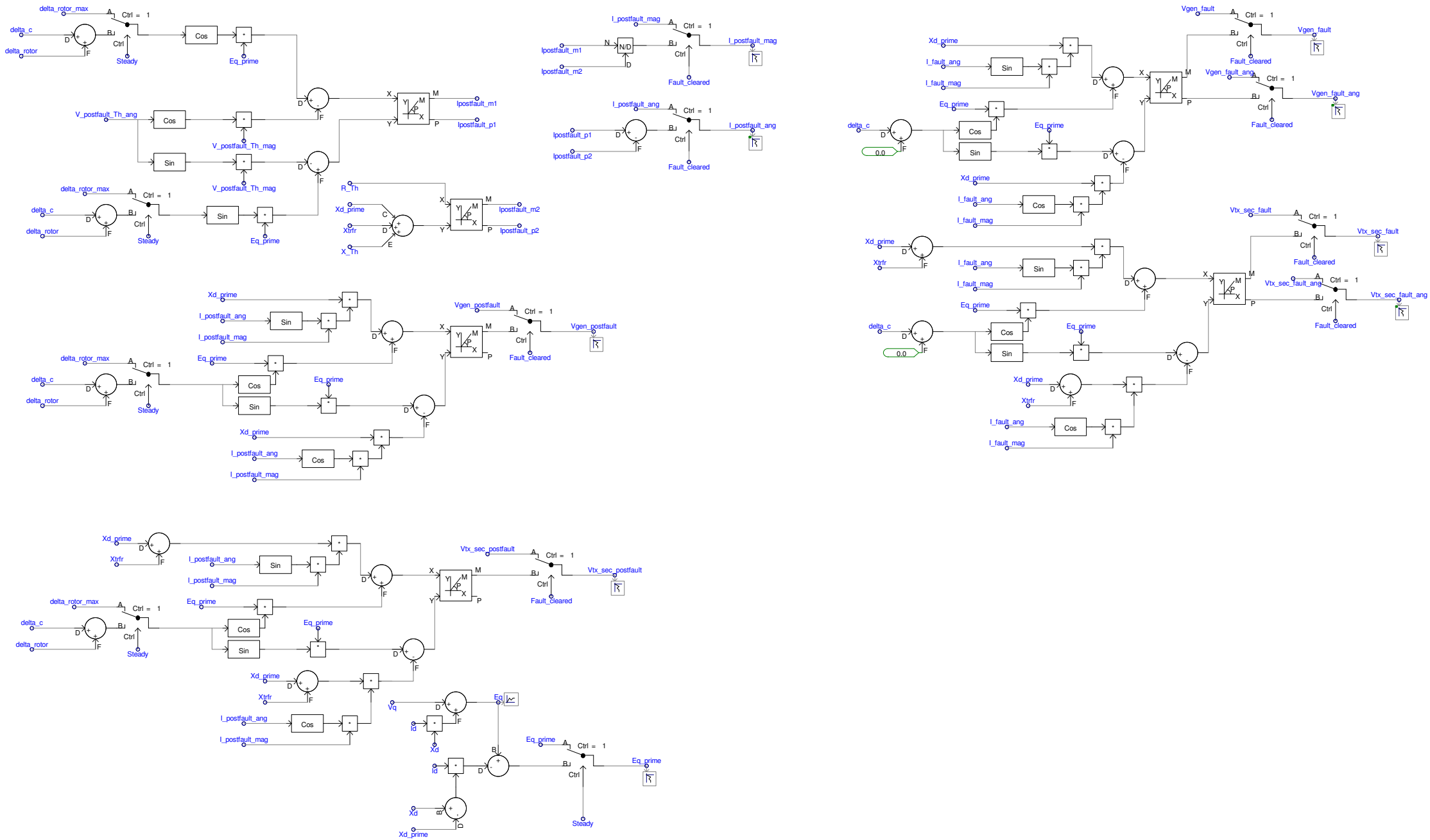


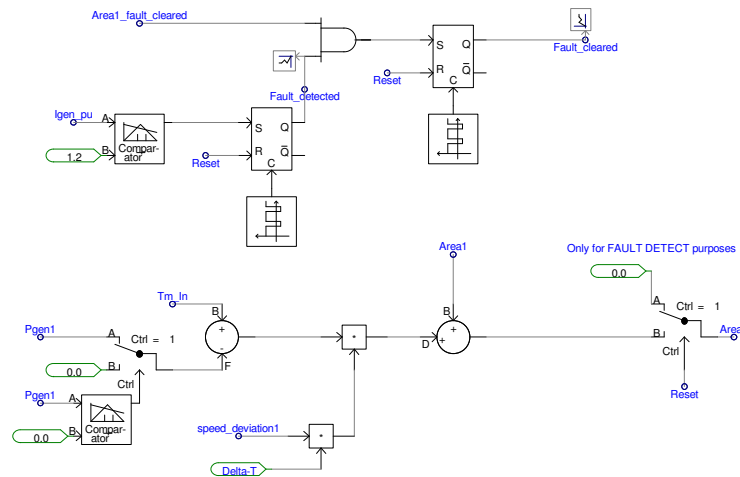
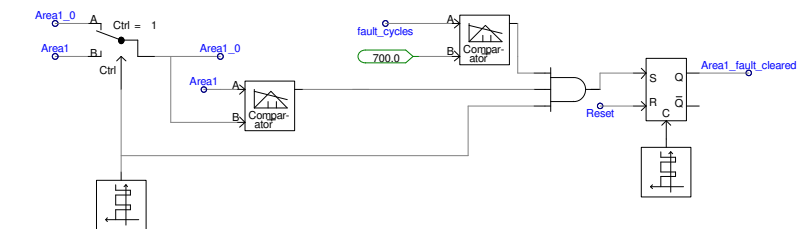
*****ROTOR OVERTSHOT PREDICTION*****



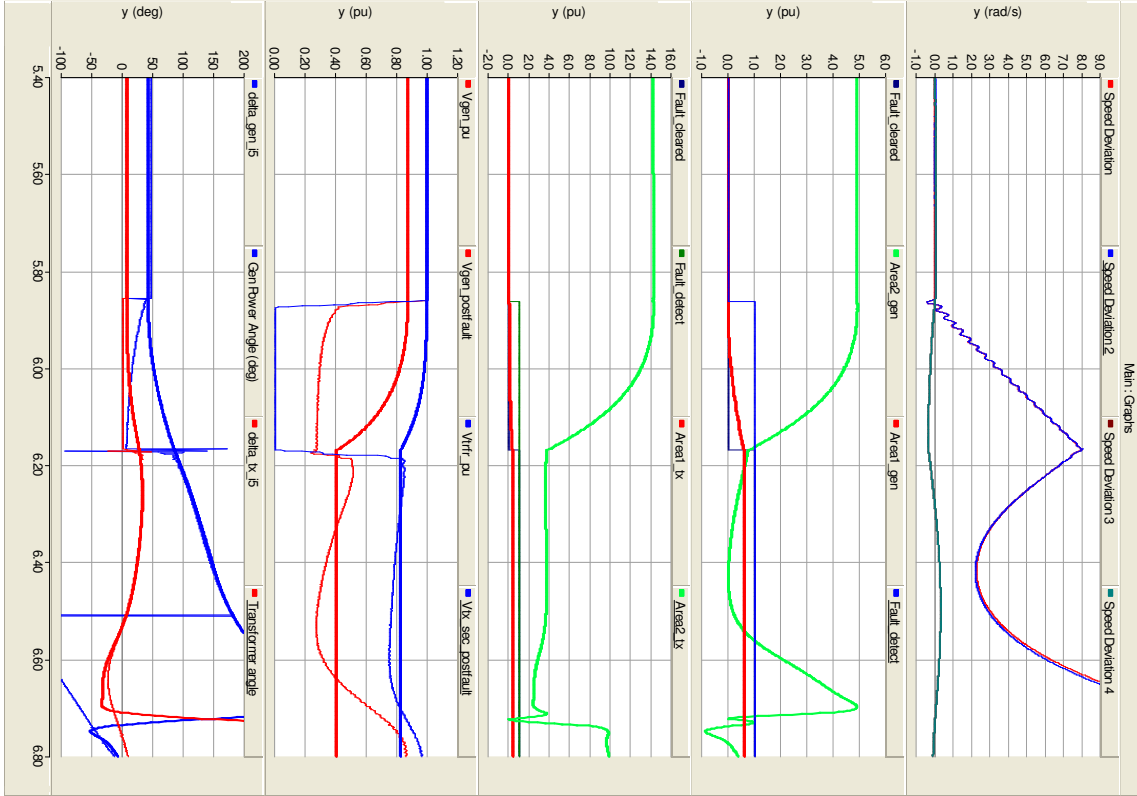




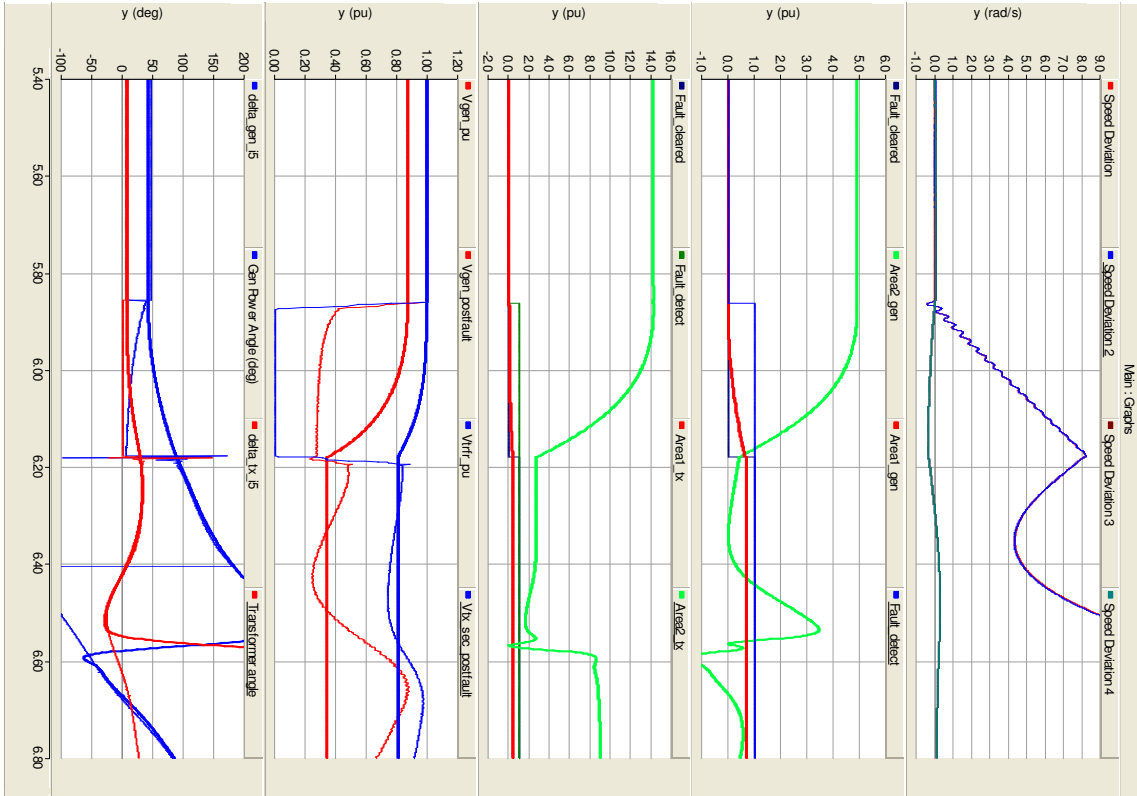




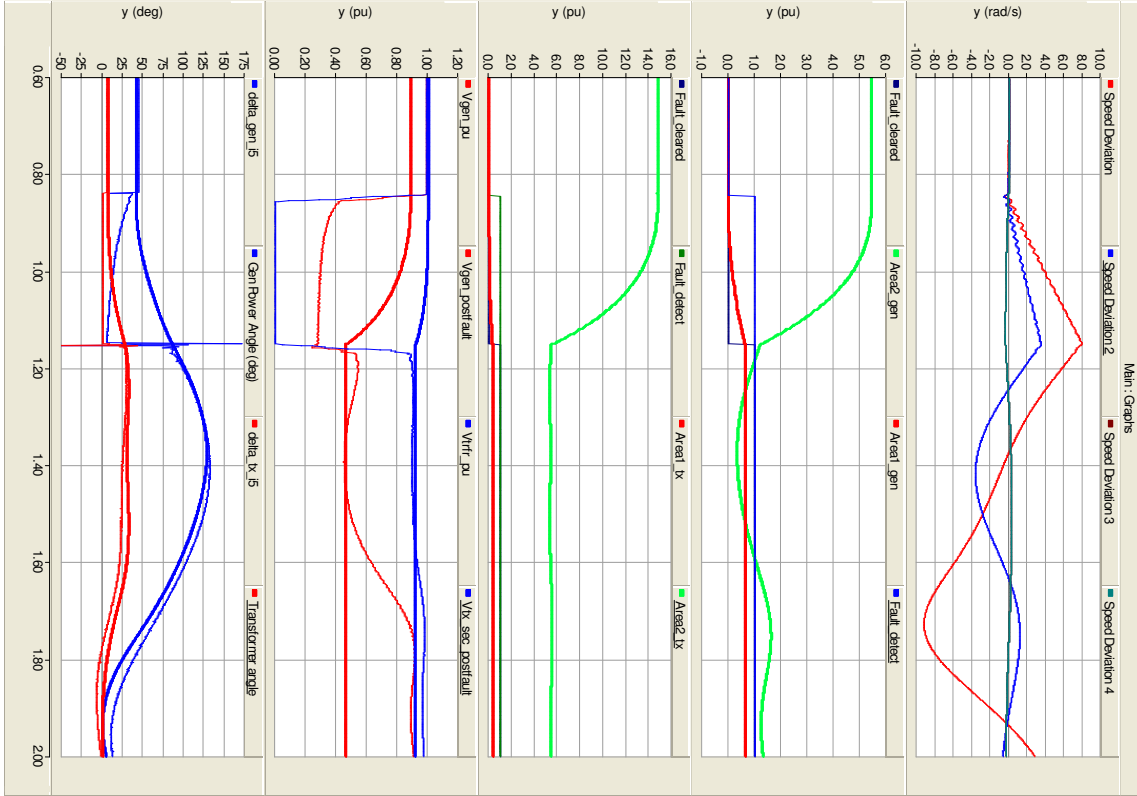
PSCAD Results: Generator A, Scenario 1, $t_{\text{fault}} = 310\text{ms}$ (stable)



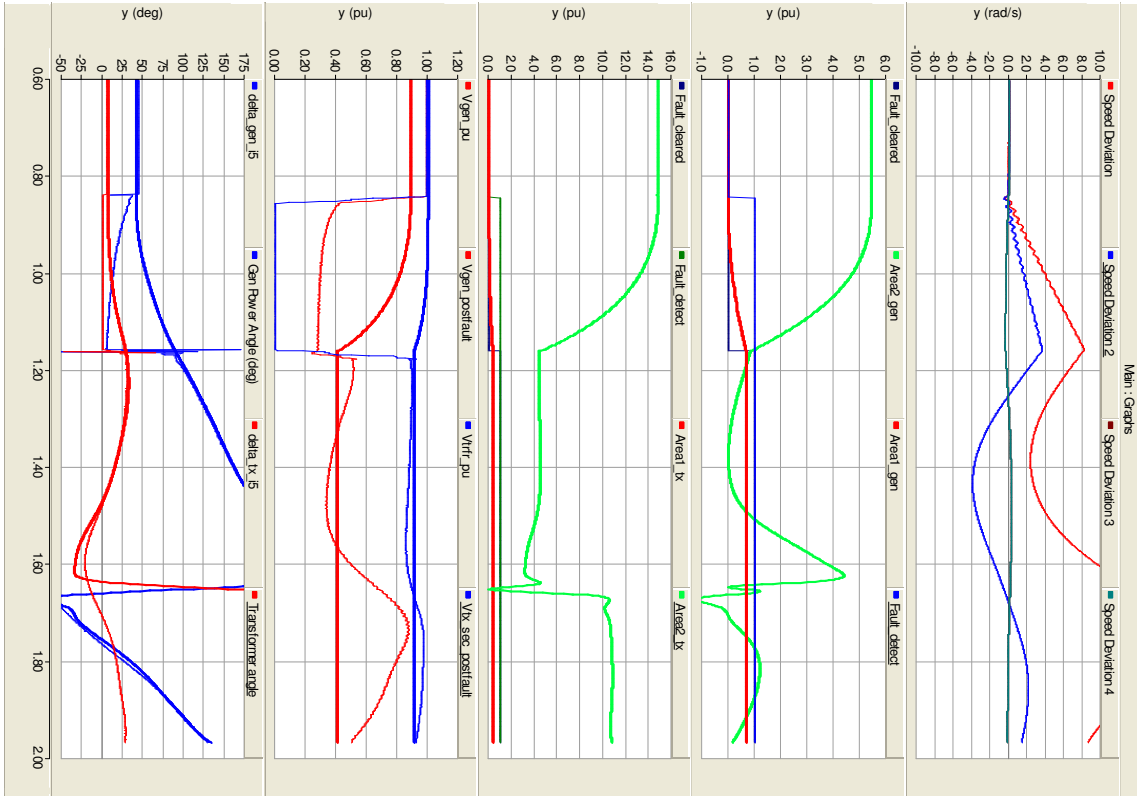
PSCAD Results: Generator A, Scenario 1, $t_{\text{fault}} = 320\text{ms}$ (unstable)



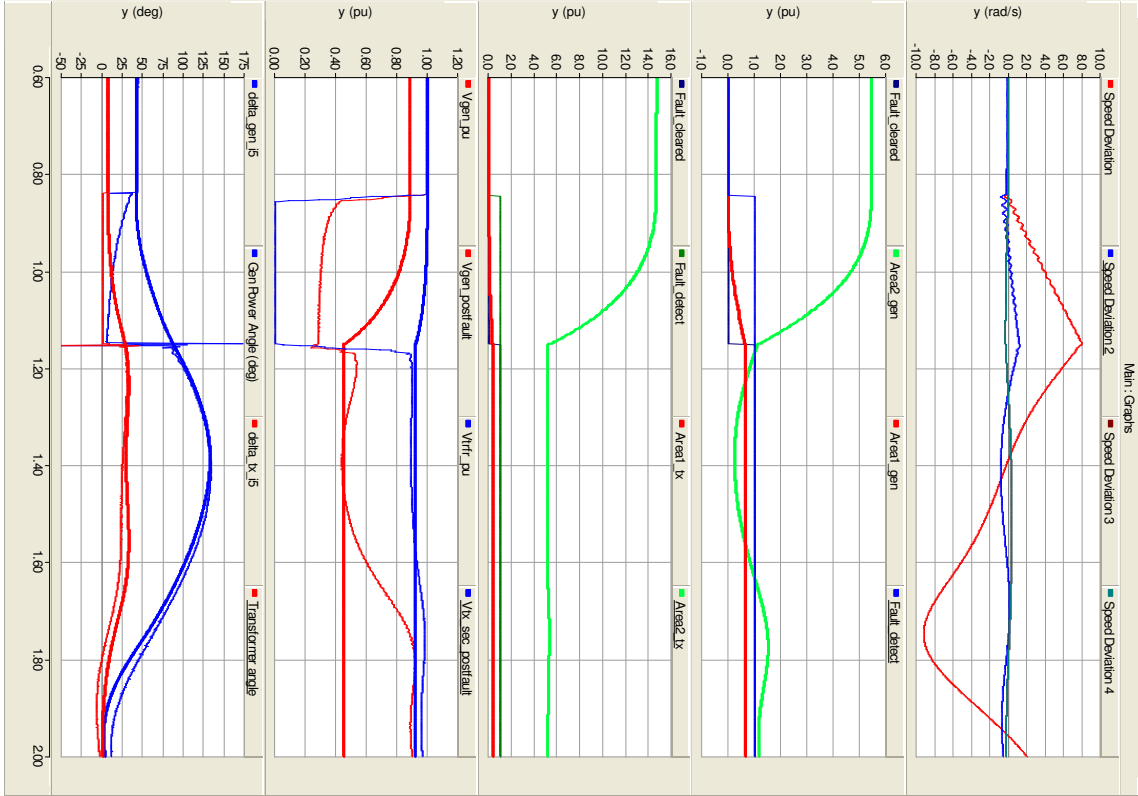
PSCAD Results: Generator A, Scenario 2, $t_{\text{fault}} = 310\text{ms}$ (stable)



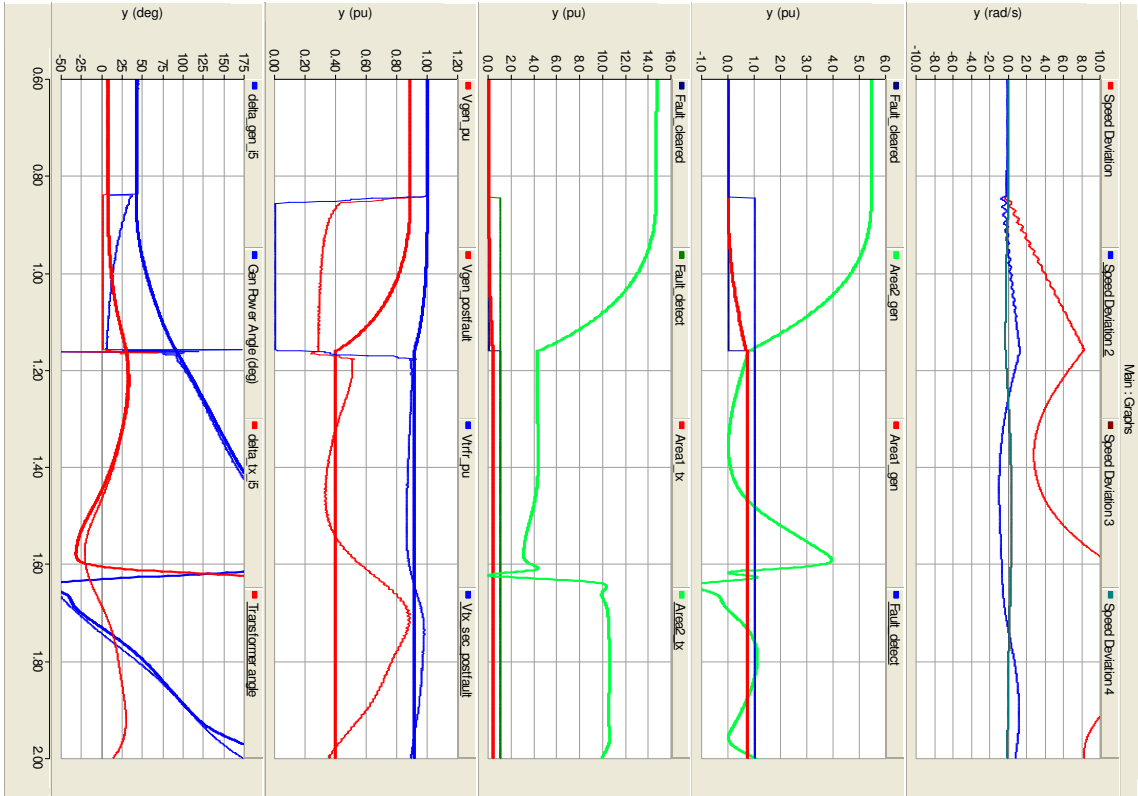
PSCAD Results: Generator A, Scenario 2, $t_{\text{fault}} = 320\text{ms}$ (unstable)



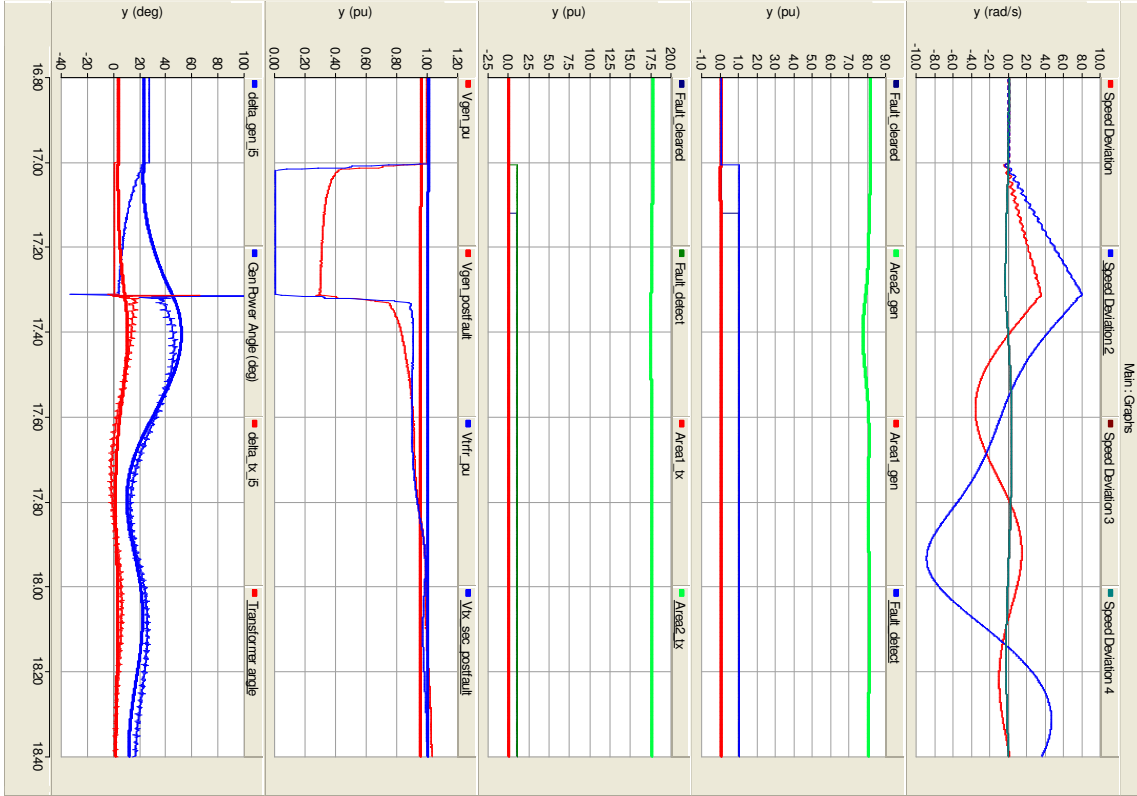
PSCAD Results: Generator A, Scenario 3, $t_{\text{fault}} = 310\text{ms}$ (stable)



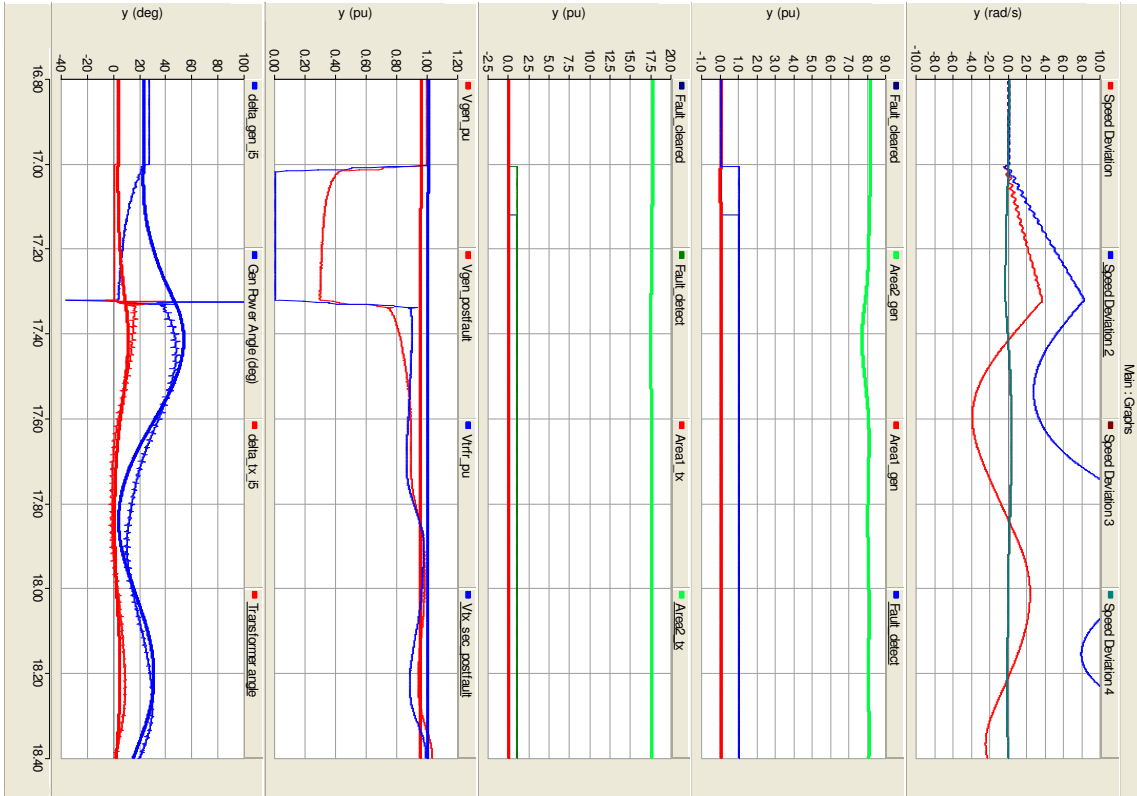
PSCAD Results: Generator A, Scenario 3, $t_{\text{fault}} = 320\text{ms}$ (unstable)



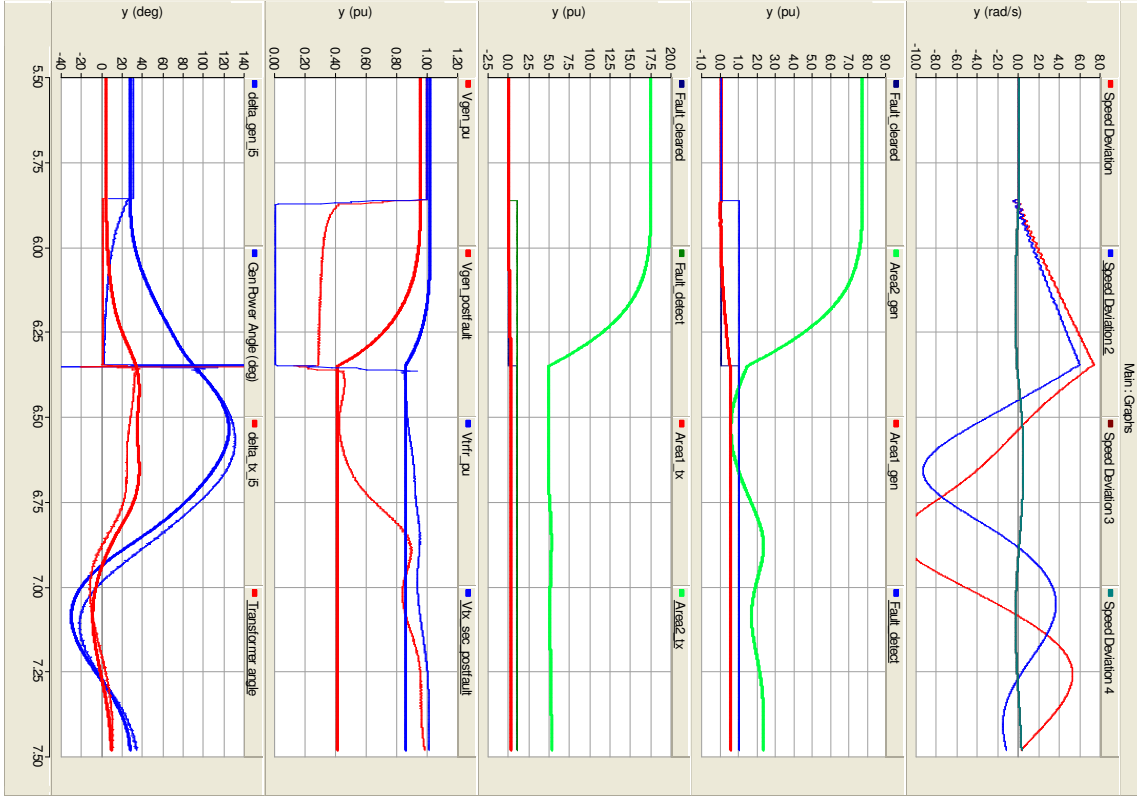
PSCAD Results: Generator A, Scenario 4, $t_{\text{fault}} = 310\text{ms}$ (stable)



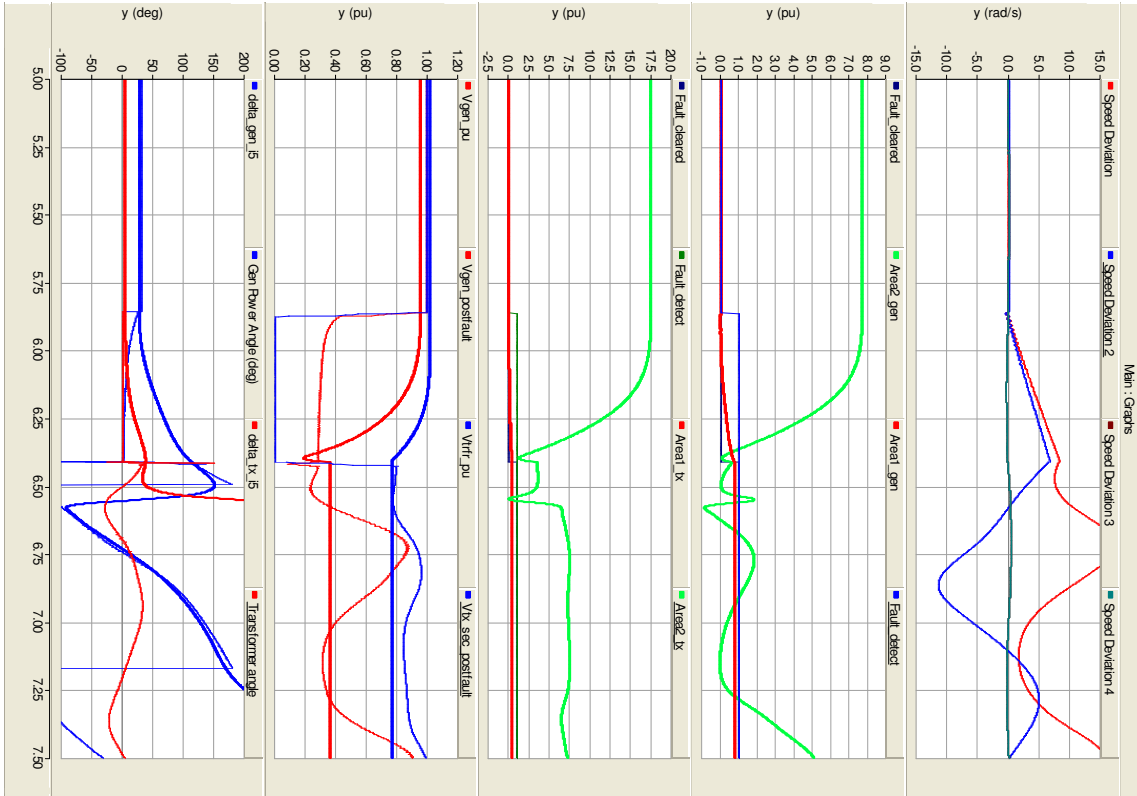
PSCAD Results: Generator A, Scenario 4, $t_{\text{fault}} = 320\text{ms}$ (**Gen 1 STABLE**)



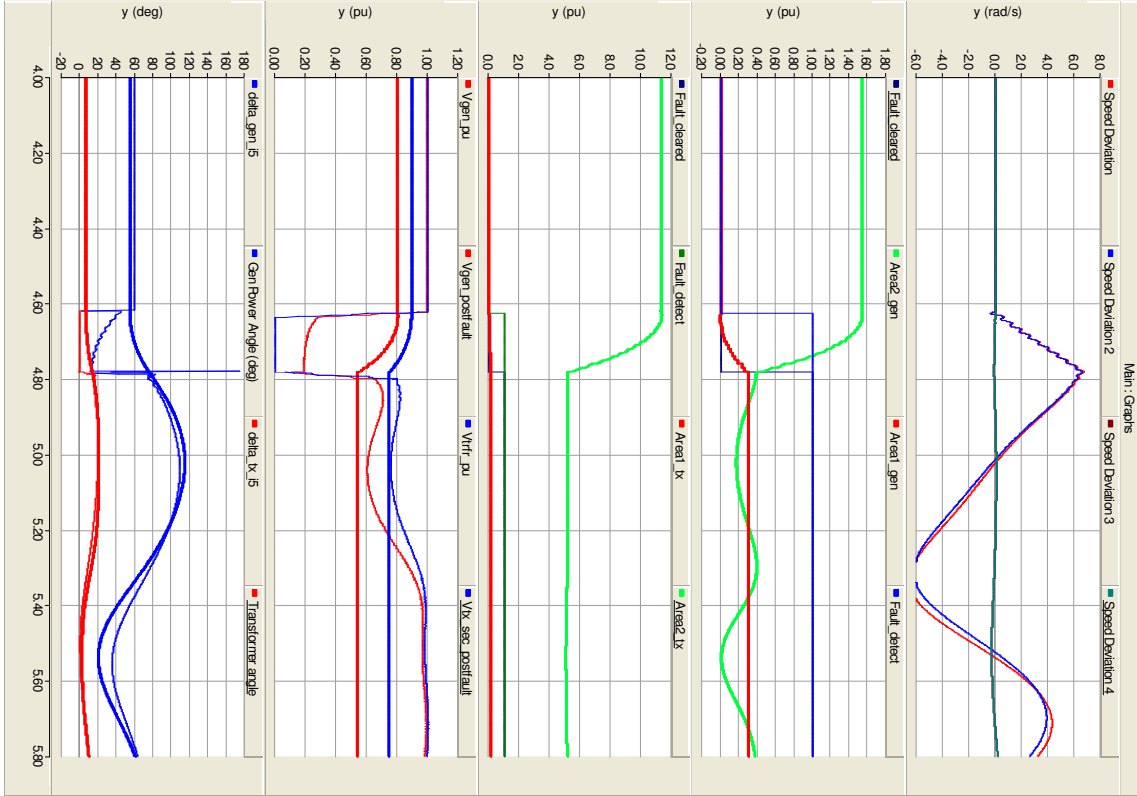
PSCAD Results: Generator A, Scenario 5, $t_{\text{fault}} = 490\text{ms}$ (stable)



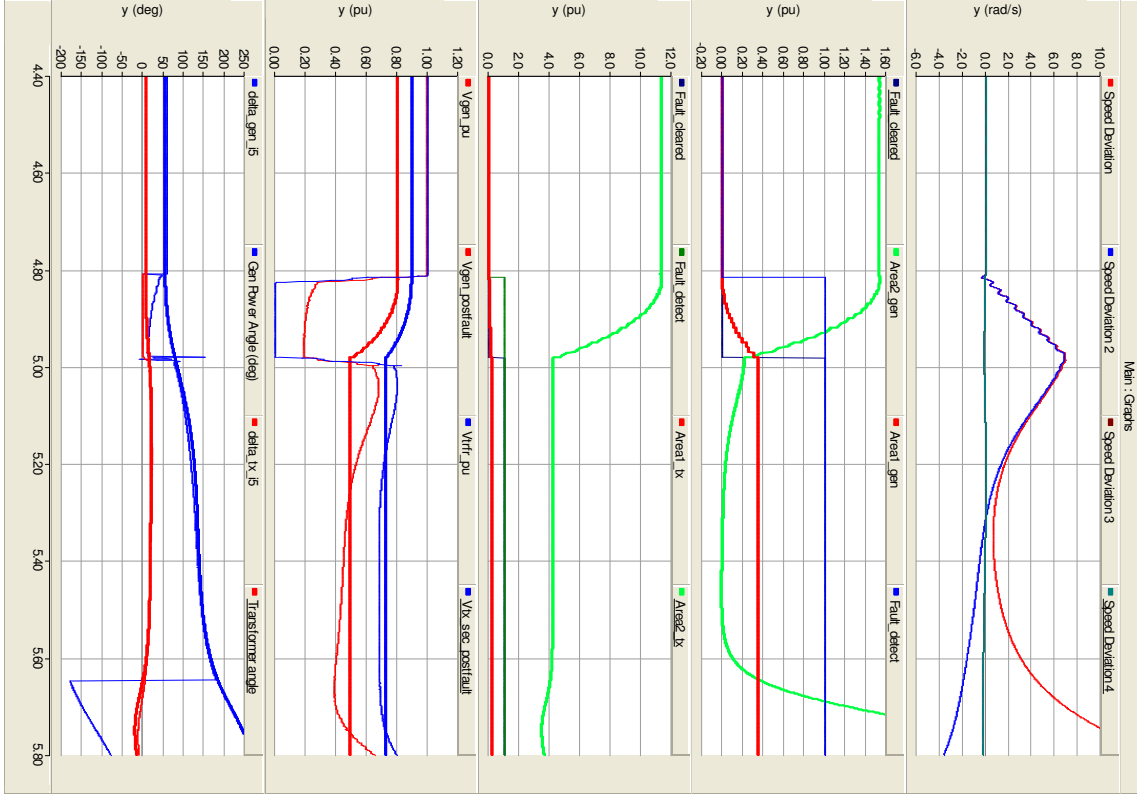
PSCAD Results: Generator A, Scenario 5, $t_{\text{fault}} = 500\text{ms}$ (unstable)



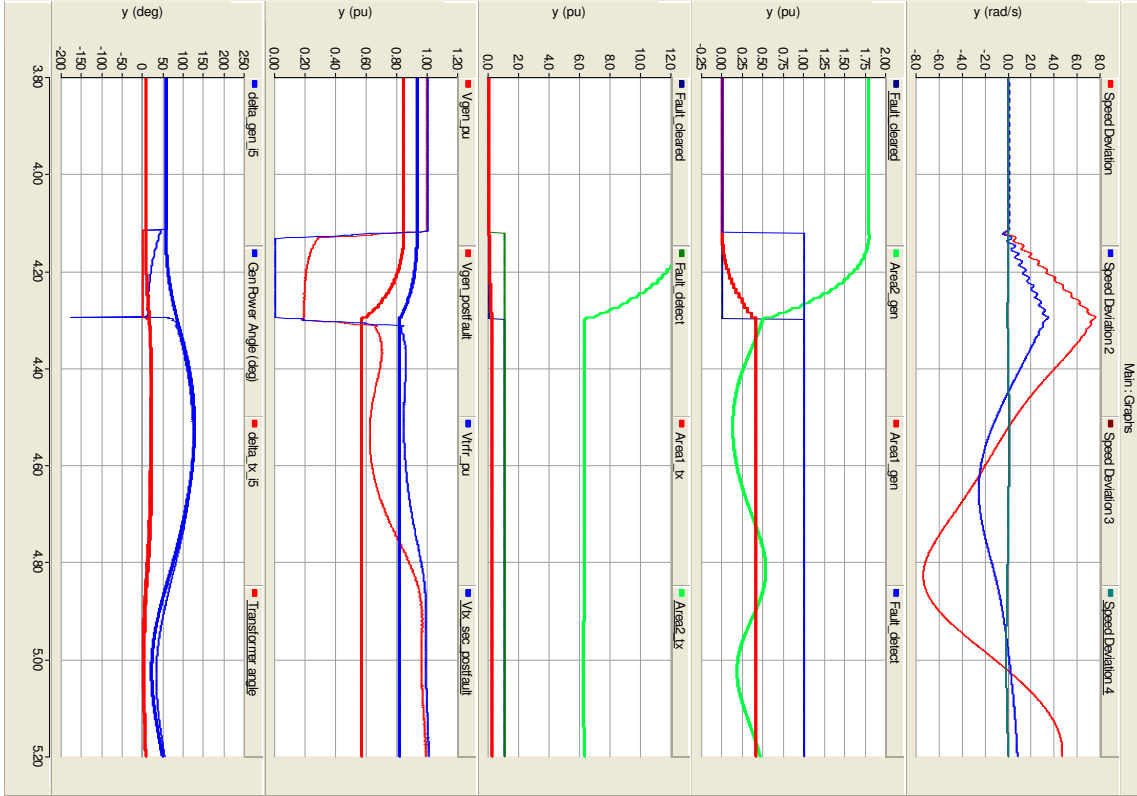
PSCAD Results: Generator B, Scenario 1, $t_{\text{fault}} = 160\text{ms}$ (stable)



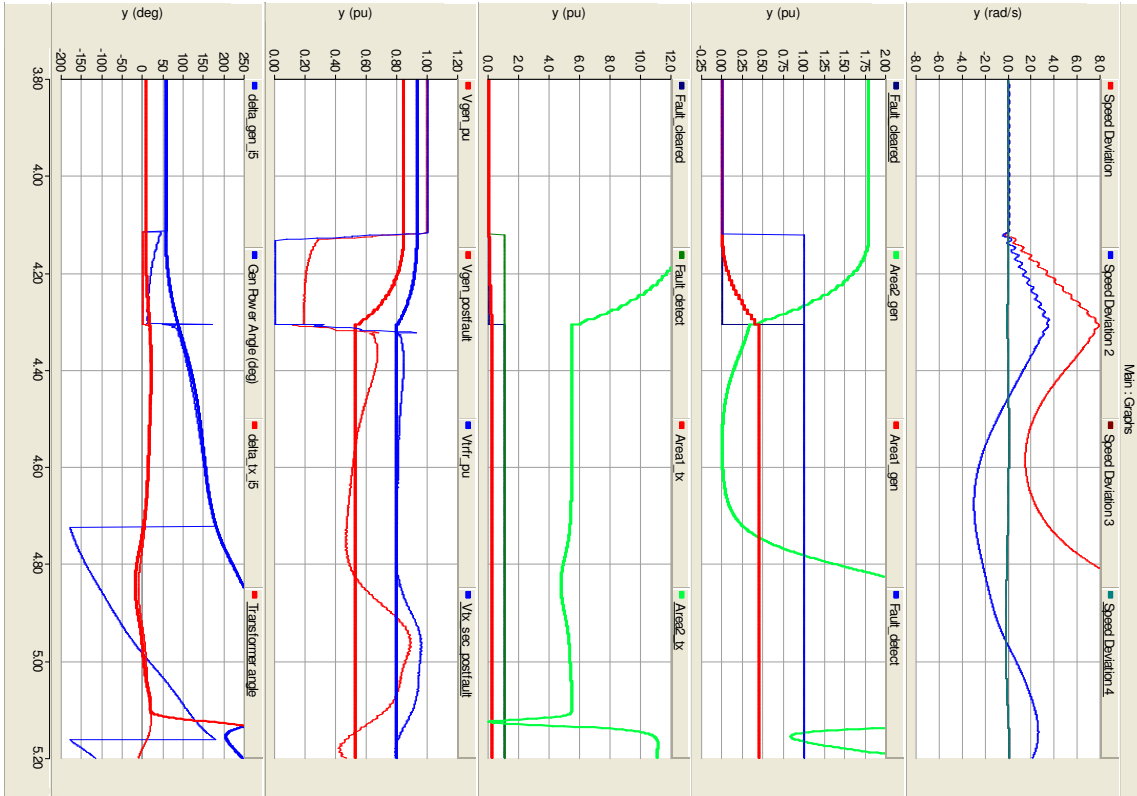
PSCAD Results: Generator B, Scenario 1, $t_{\text{fault}} = 170\text{ms}$ (stable)



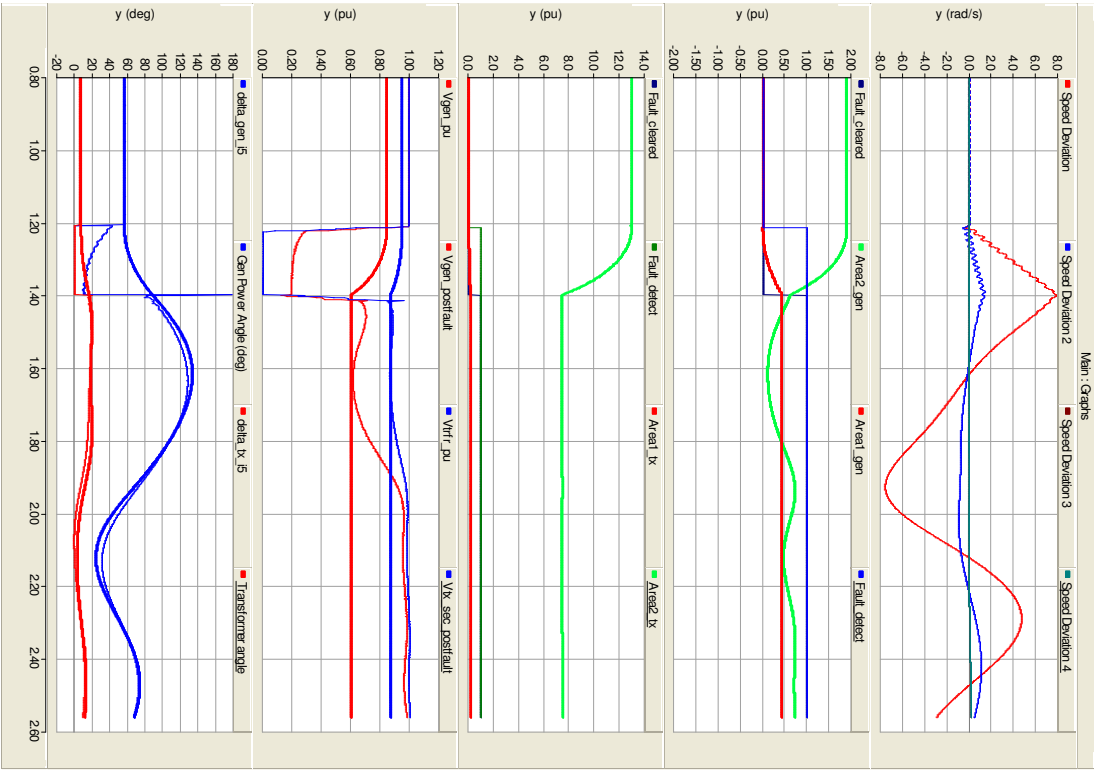
PSCAD Results: Generator B, Scenario 2, $t_{\text{fault}} = 180\text{ms}$ (stable)



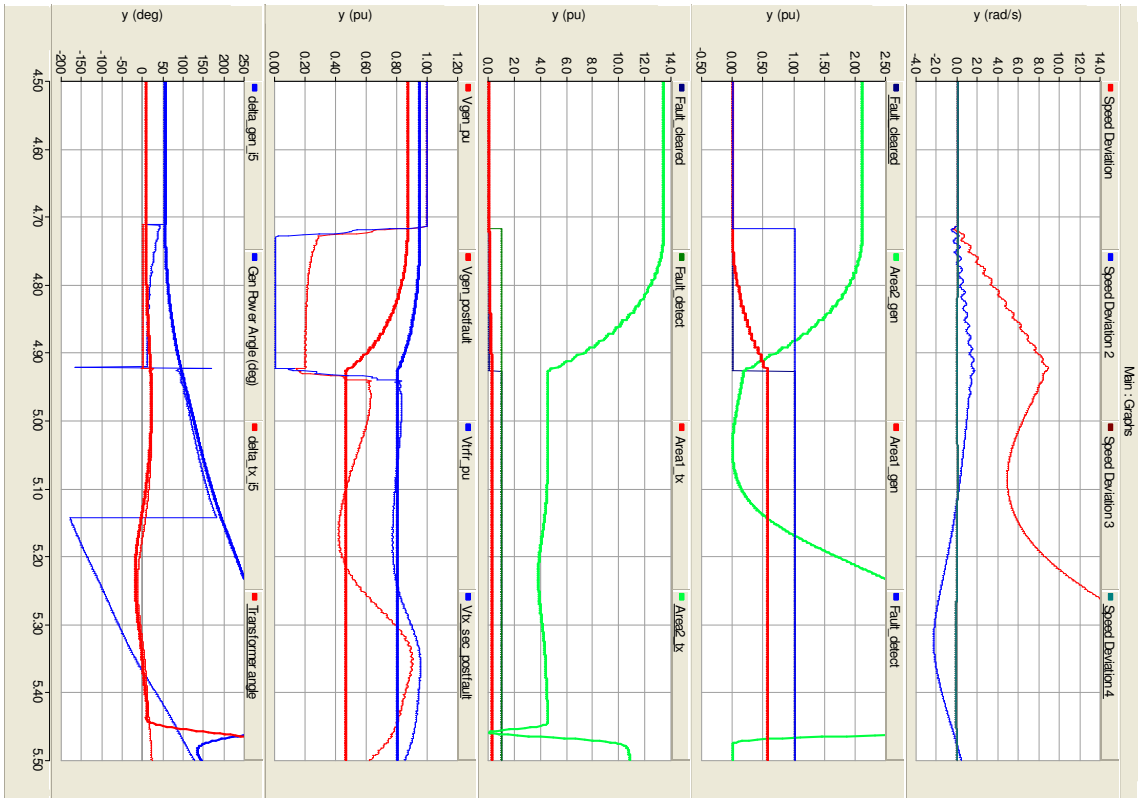
PSCAD Results: Generator B, Scenario 2, $t_{\text{fault}} = 190\text{ms}$ (unstable)



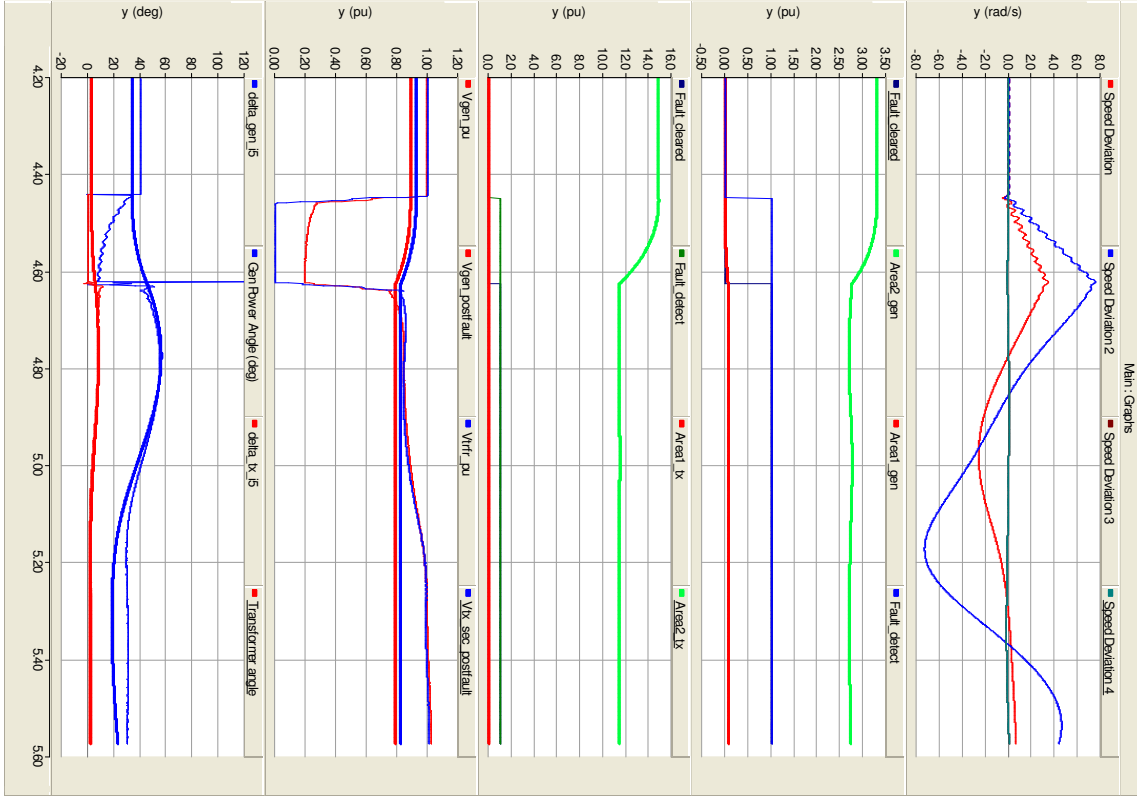
PSCAD Results: Generator B, Scenario 3, $t_{\text{fault}} = 200 \text{ ms}$ (stable)



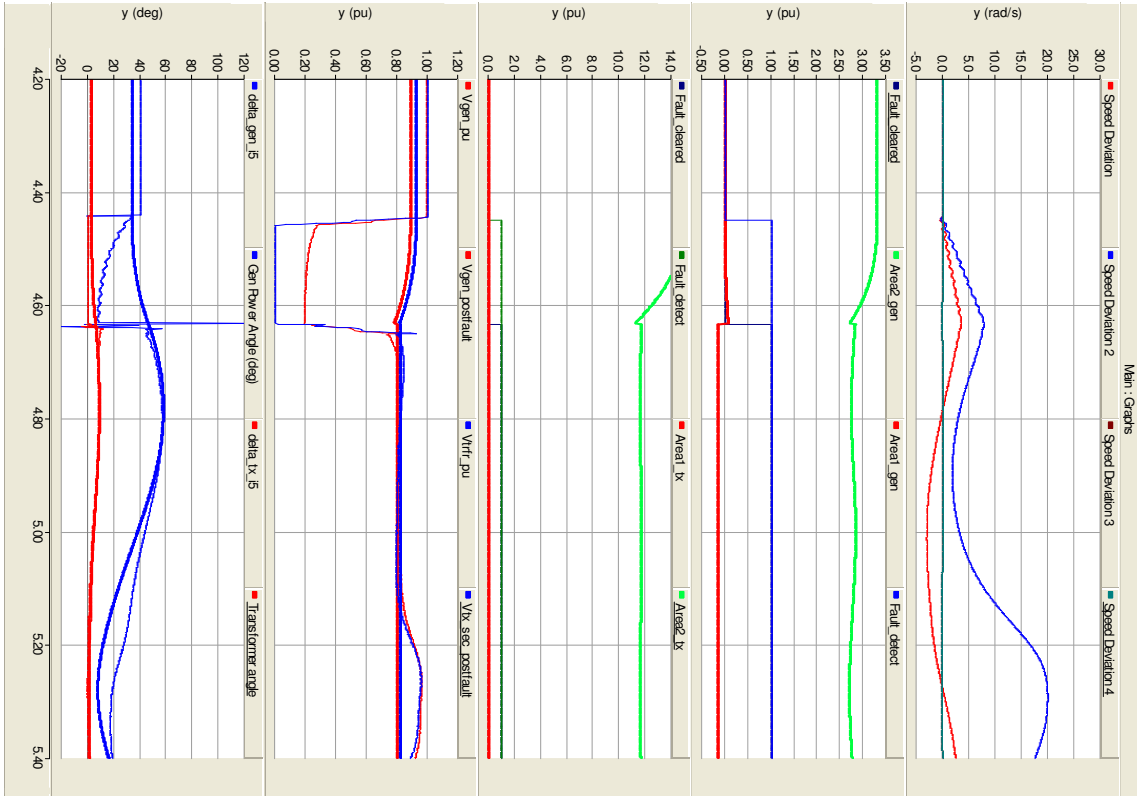
PSCAD Results: Generator B, Scenario 3, $t_{\text{fault}} = 210 \text{ ms}$ (unstable)



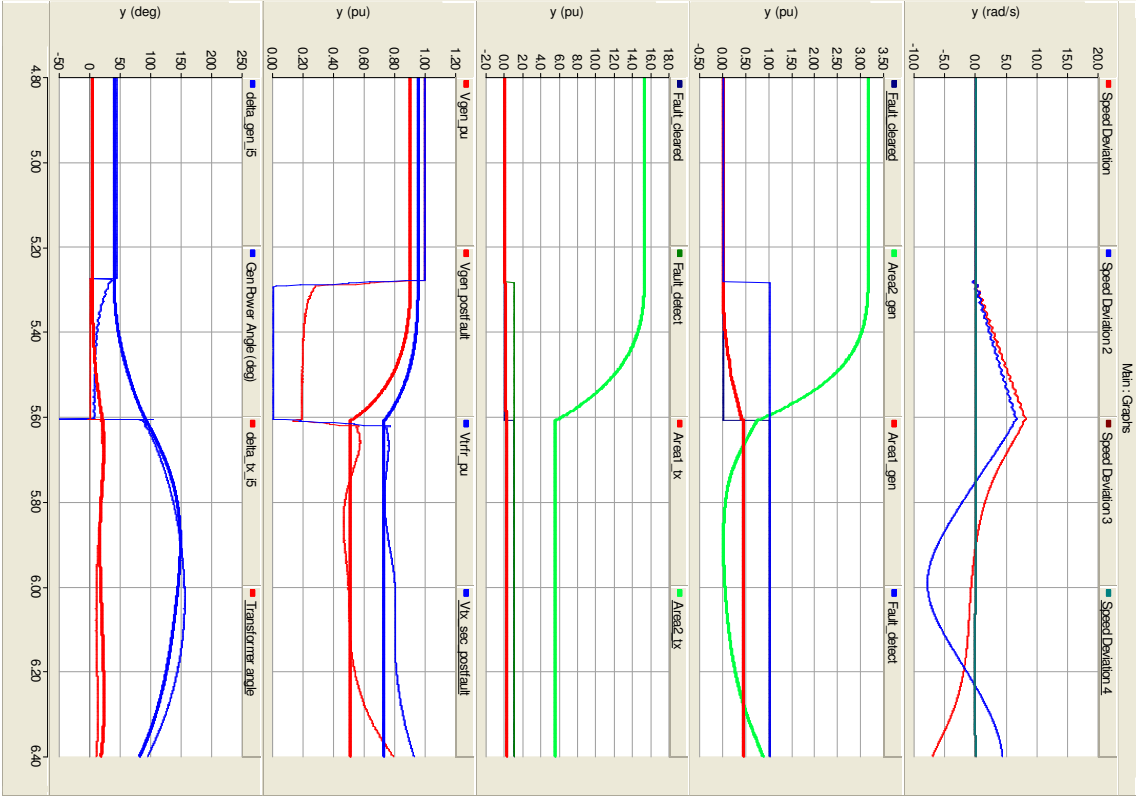
PSCAD Results: Generator B, Scenario 4, $t_{\text{fault}} = 180\text{ms}$ (stable)



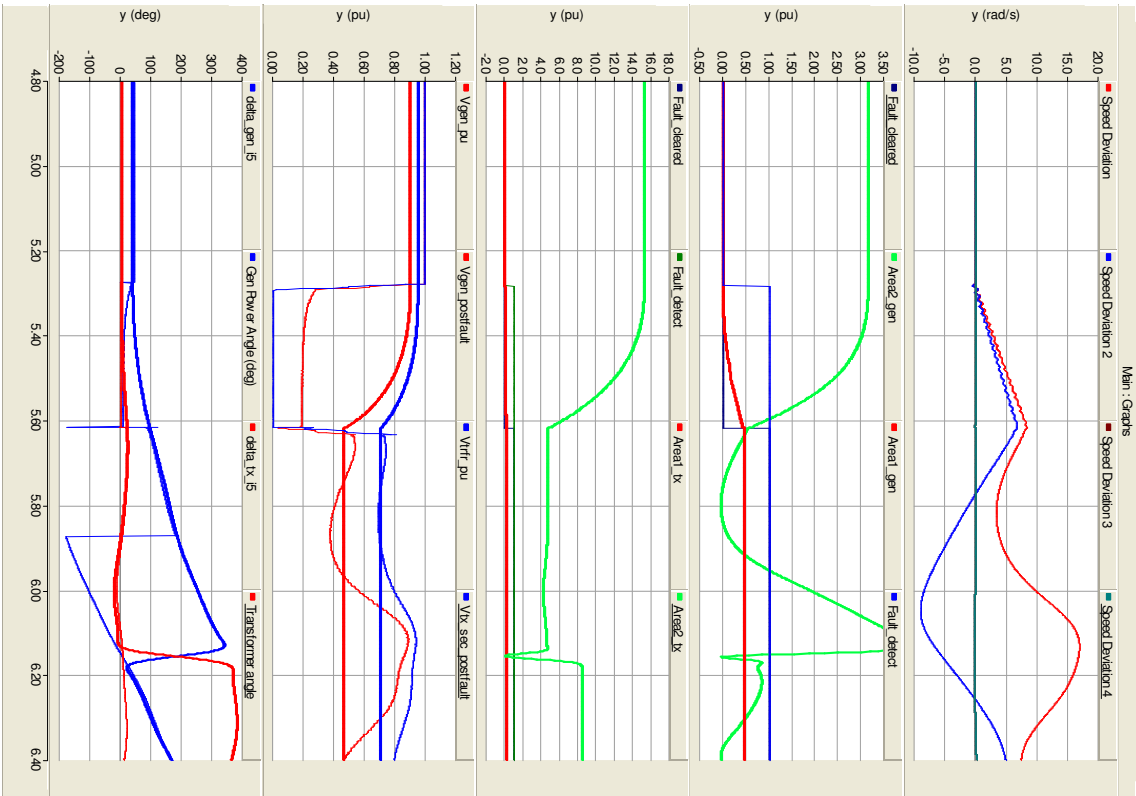
PSCAD Results: Generator B, Scenario 4, $t_{\text{fault}} = 190\text{ms}$ (*Gen 1 STABLE*)



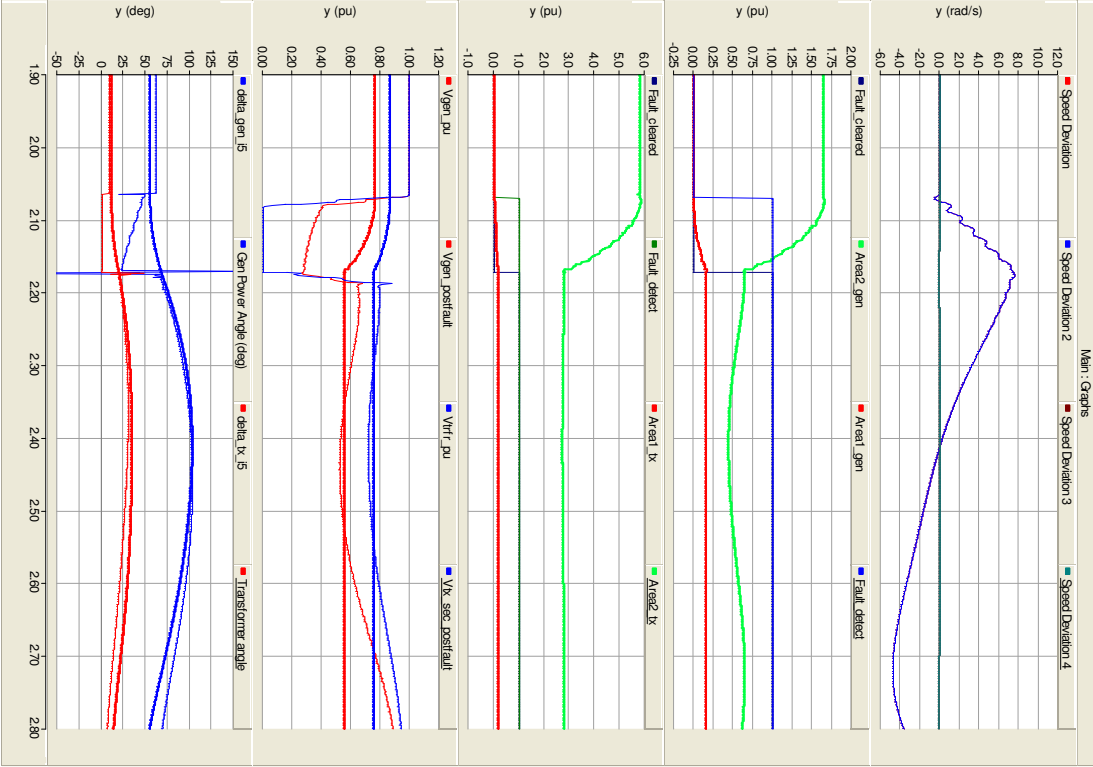
PSCAD Results: Generator B, Scenario 5, $t_{\text{fault}} = 330 \text{ ms}$ (stable)



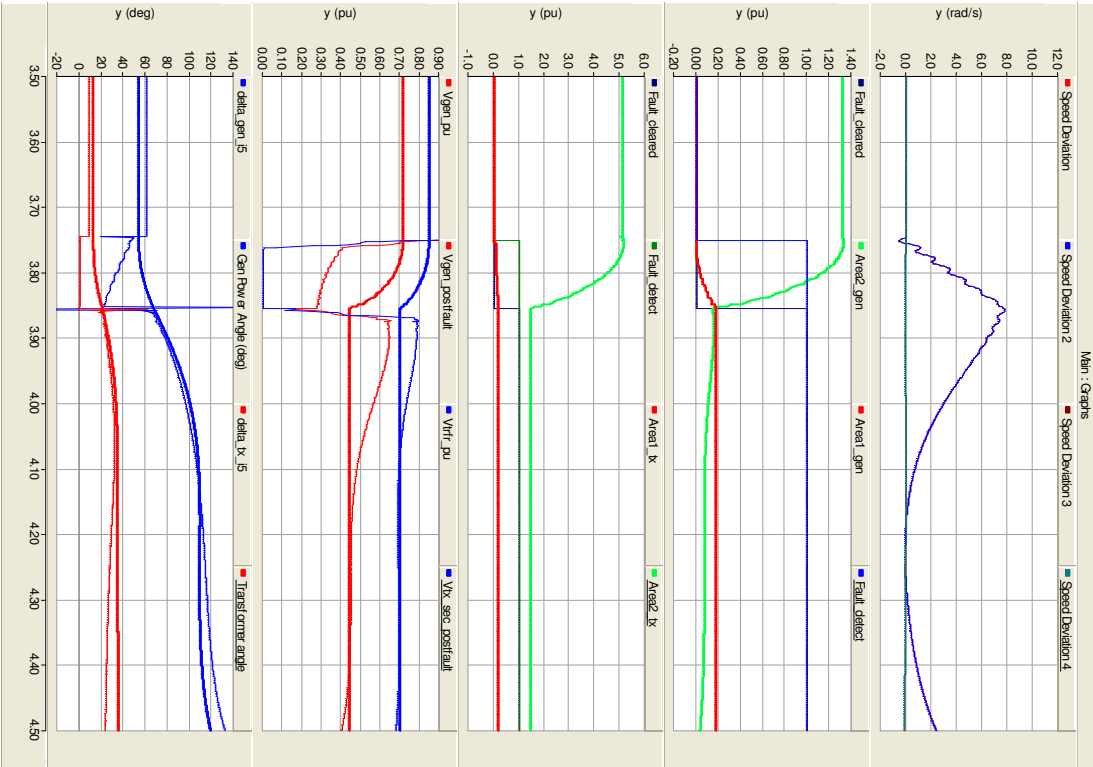
PSCAD Results: Generator B, Scenario 5, $t_{\text{fault}} = 340 \text{ ms}$ (unstable)



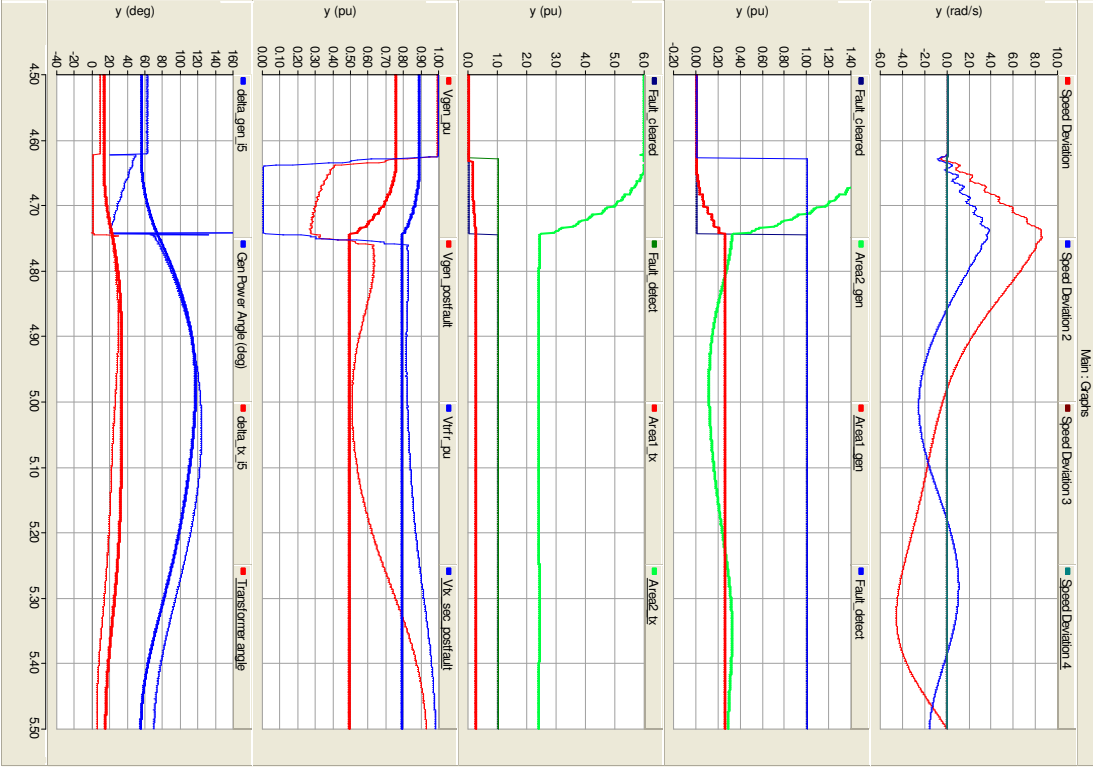
PSCAD Results: Generator C, Scenario 1, $t_{\text{fault}} = 106 \text{ ms}$ (stable)



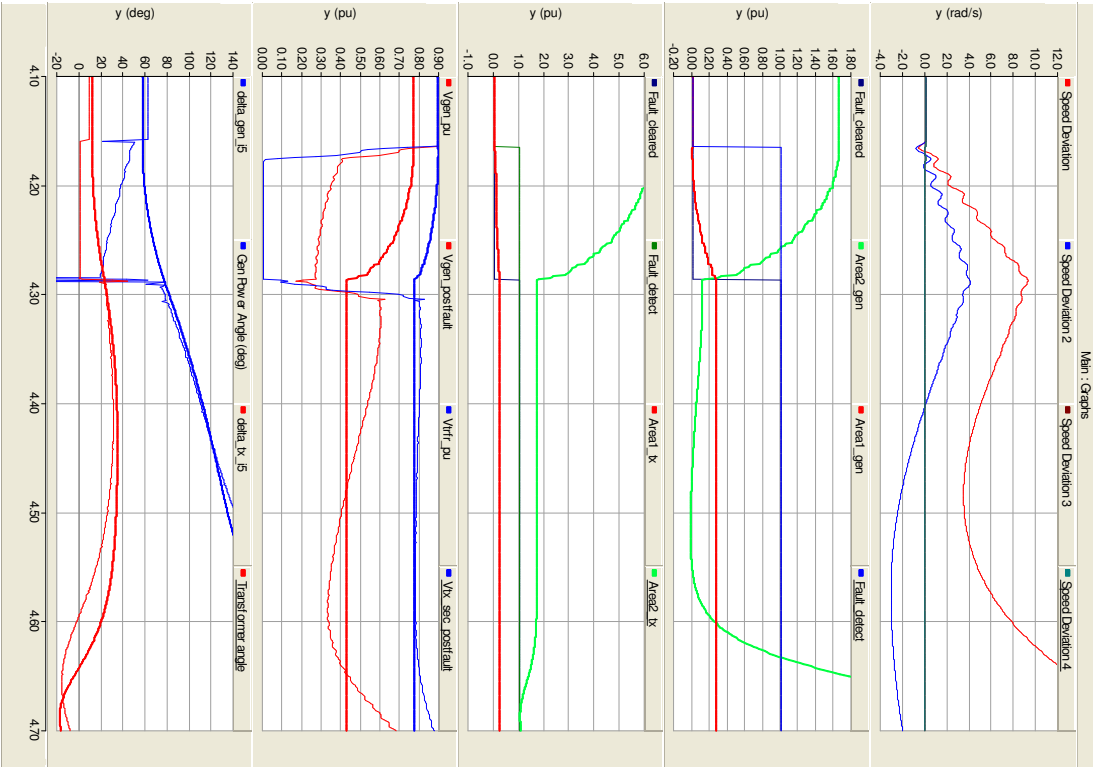
PSCAD Results: Generator C, Scenario 1, $t_{\text{fault}} = 116 \text{ ms}$ (unstable)



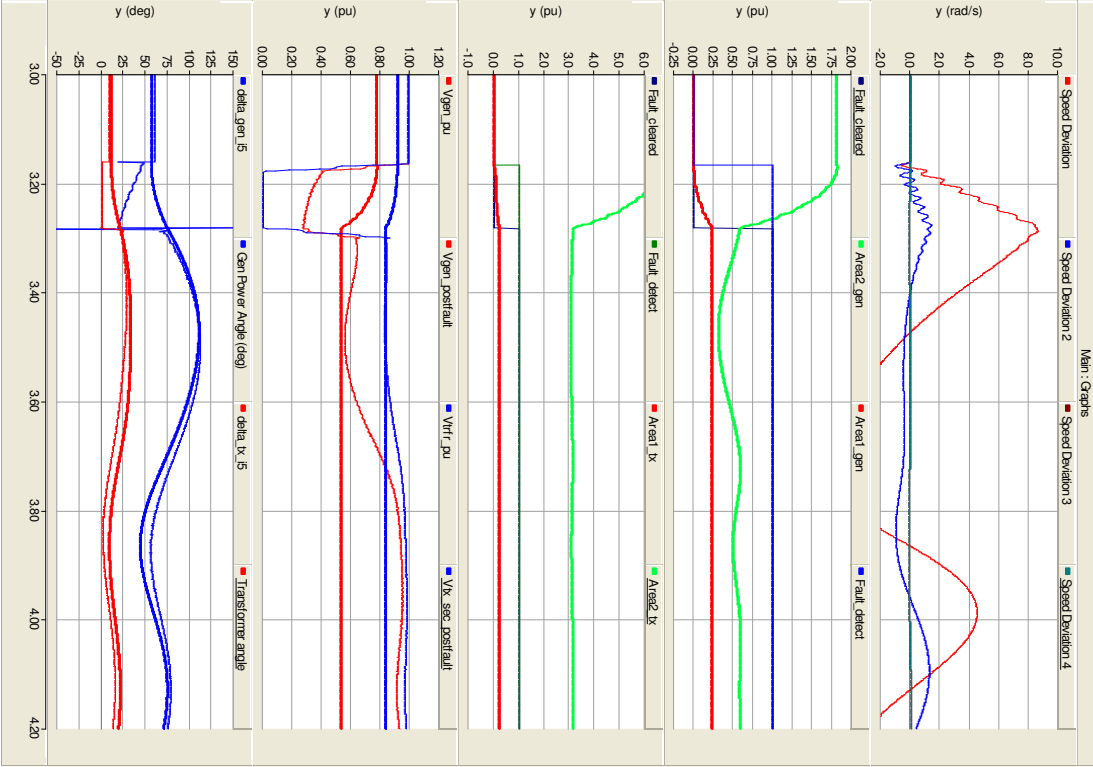
PSCAD Results: Generator C, Scenario 2, $t_{\text{fault}} = 108 \text{ ms}$ (stable)



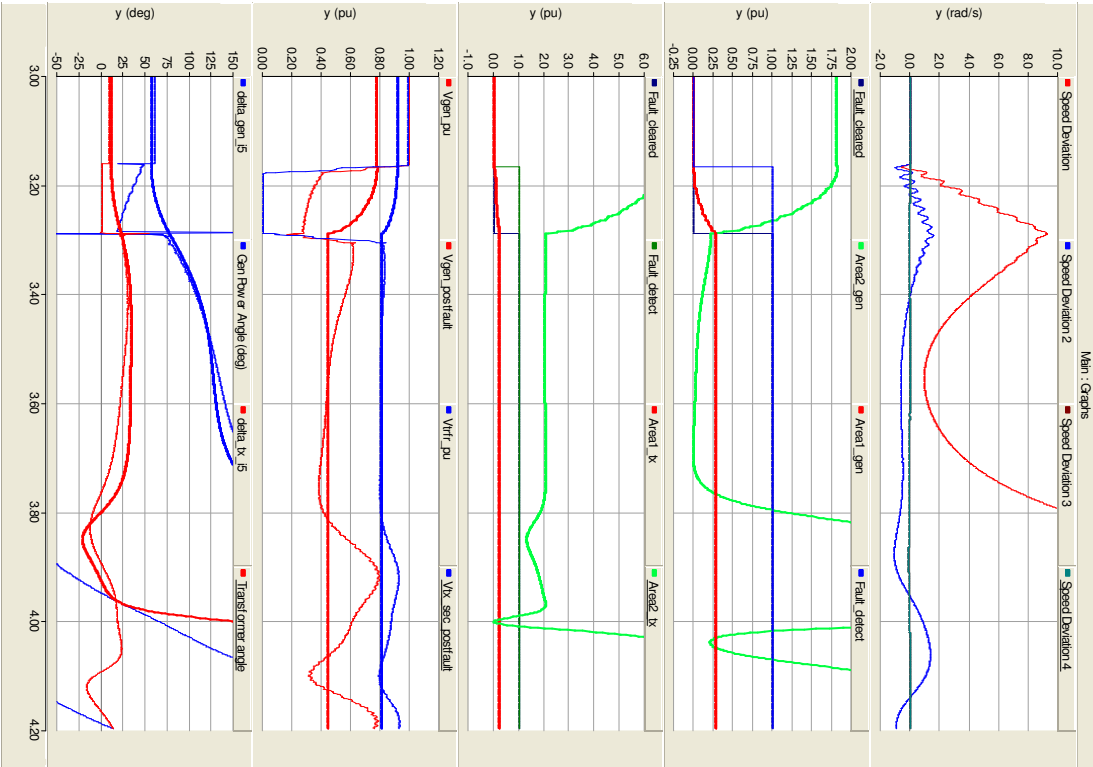
PSCAD Results: Generator C, Scenario 2, $t_{\text{fault}} = 114 \text{ ms}$ (unstable)



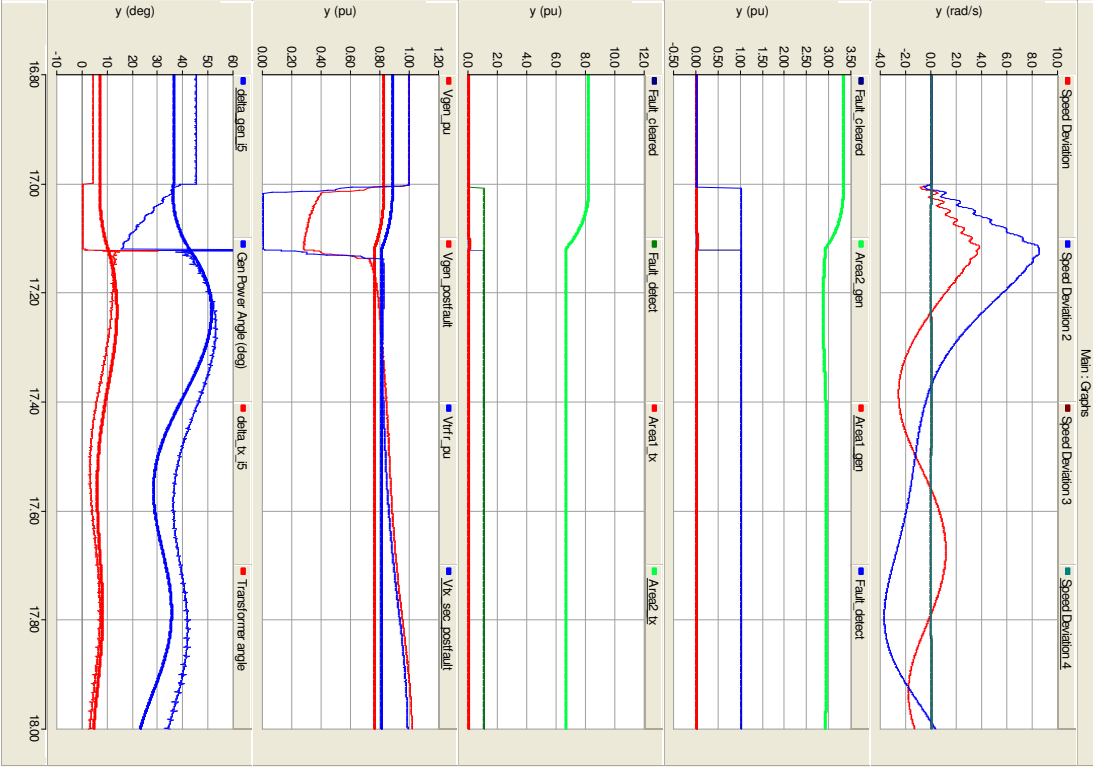
PSCAD Results: Generator C, Scenario 3, $t_{\text{fault}} = 121 \text{ ms}$ (stable)



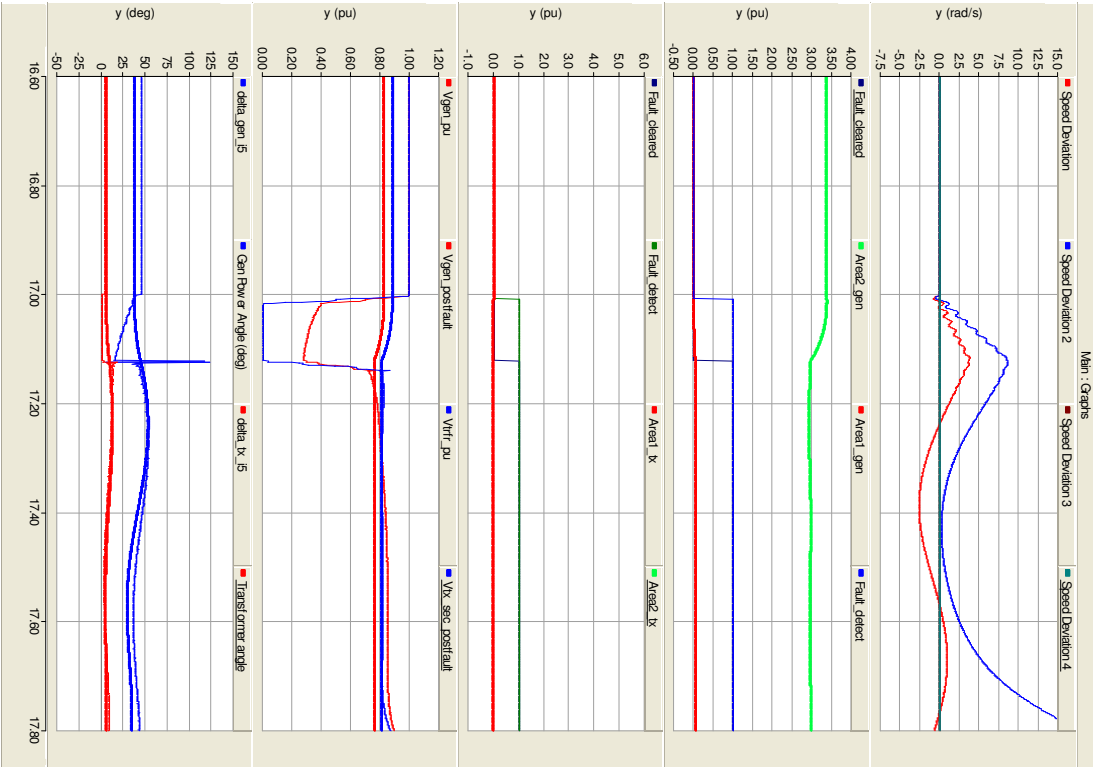
PSCAD Results: Generator C, Scenario 3, $t_{\text{fault}} = 126 \text{ ms}$ (unstable)



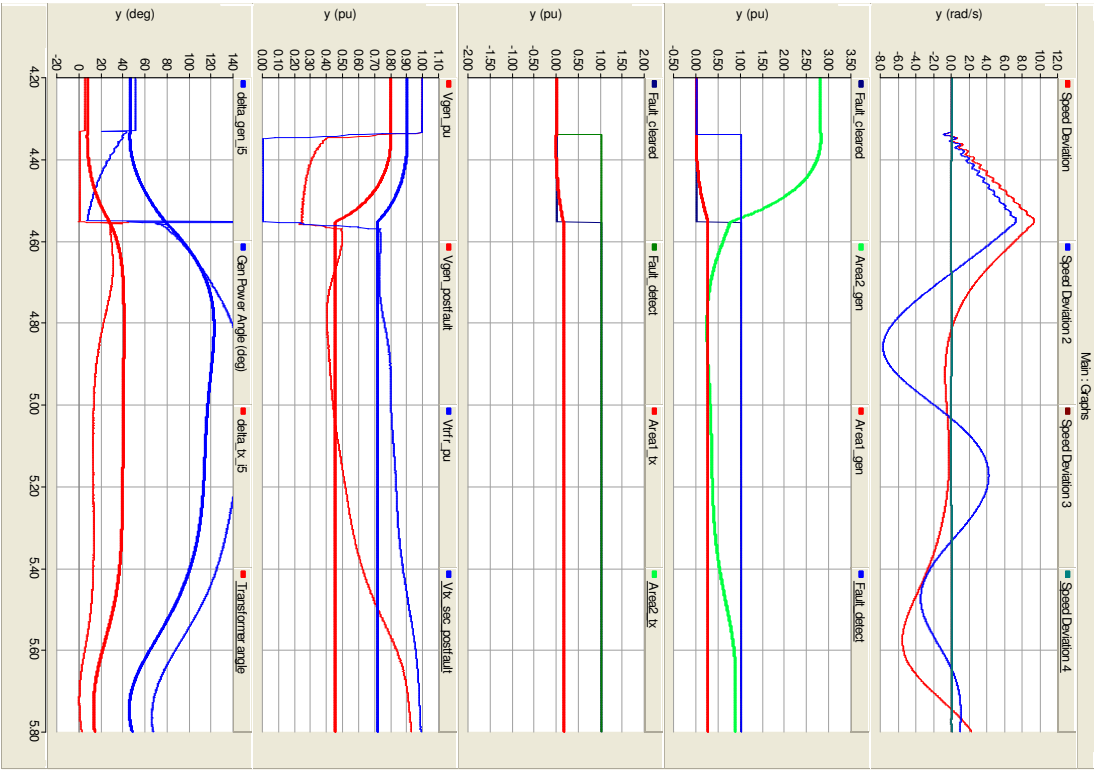
PSCAD Results: Generator C, Scenario 4, $t_{\text{fault}} = 120 \text{ ms}$ (stable)



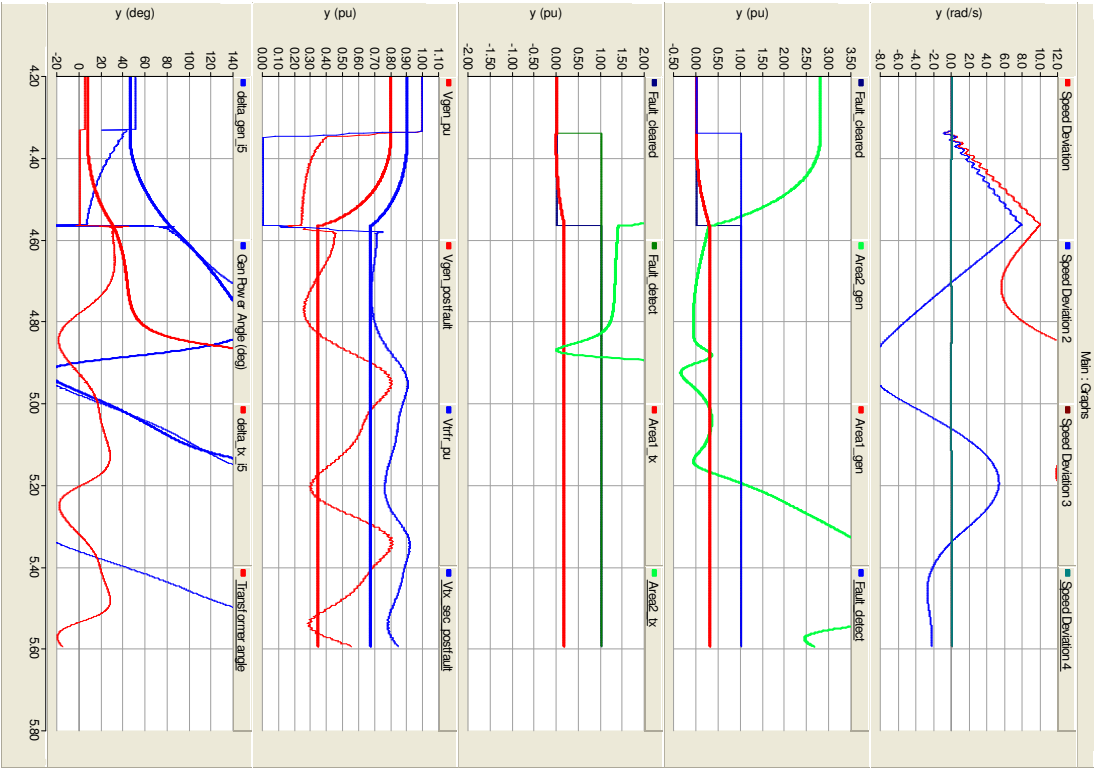
PSCAD Results: Generator C, Scenario 4, $t_{\text{fault}} = 130 \text{ ms}$ (**Gen 1 STABLE**)



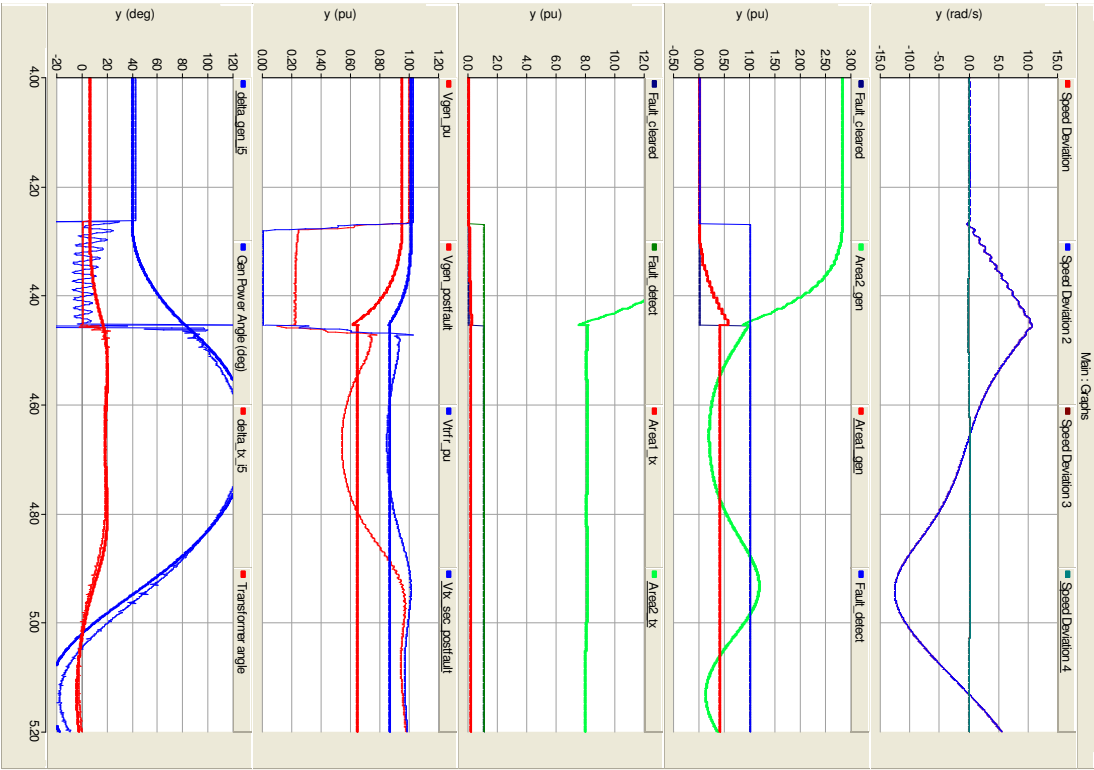
PSCAD Results: Generator C, Scenario 5, $t_{\text{fault}} = 220 \text{ ms}$ (stable)



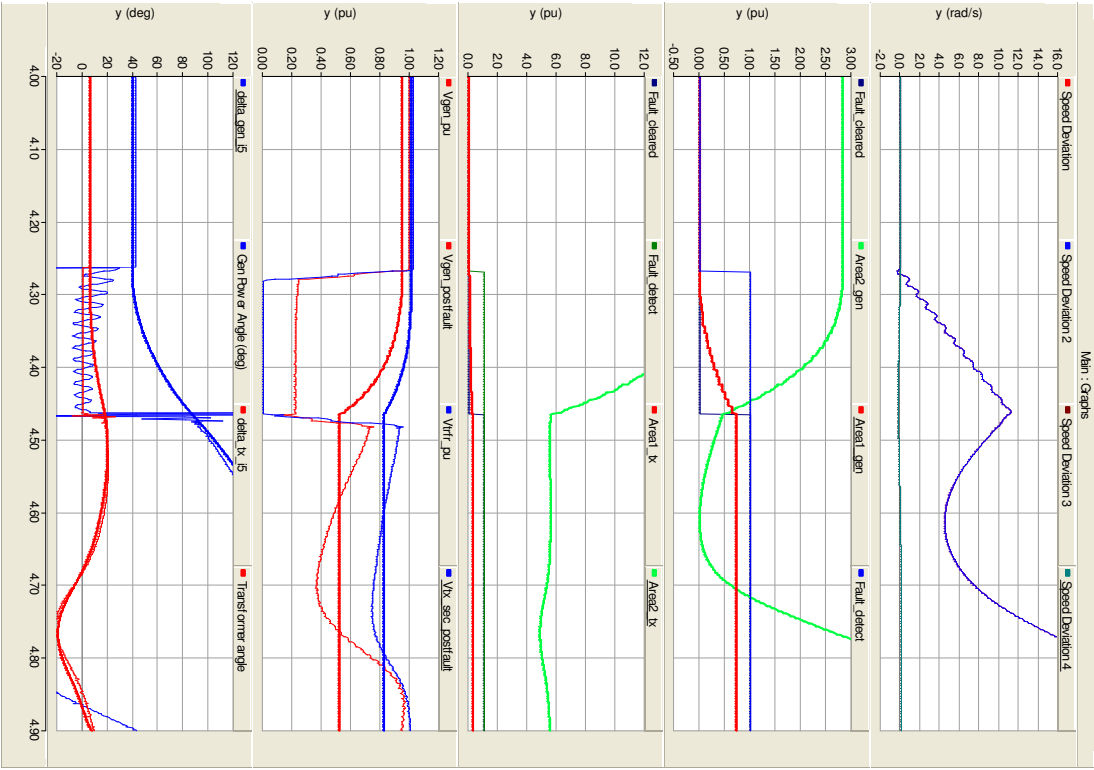
PSCAD Results: Generator C, Scenario 5, $t_{\text{fault}} = 232 \text{ ms}$ (unstable)



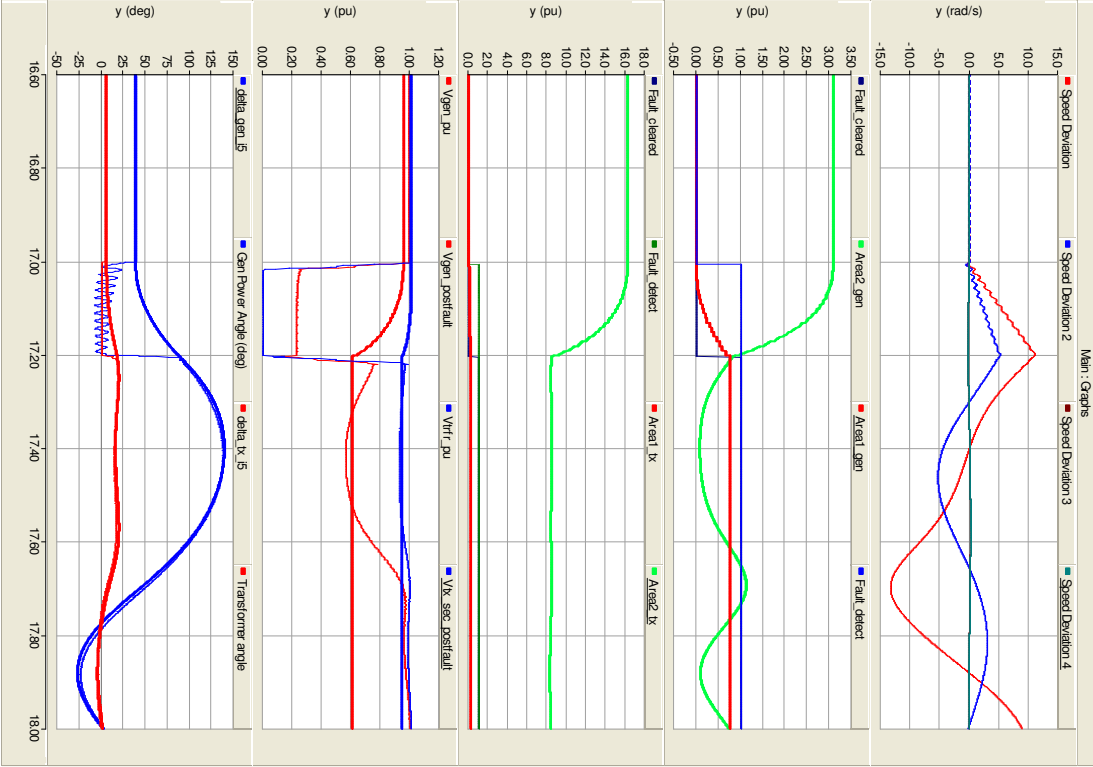
PSCAD Results: Generator D, Scenario 1, $t_{\text{fault}} = 190 \text{ ms}$ (stable)



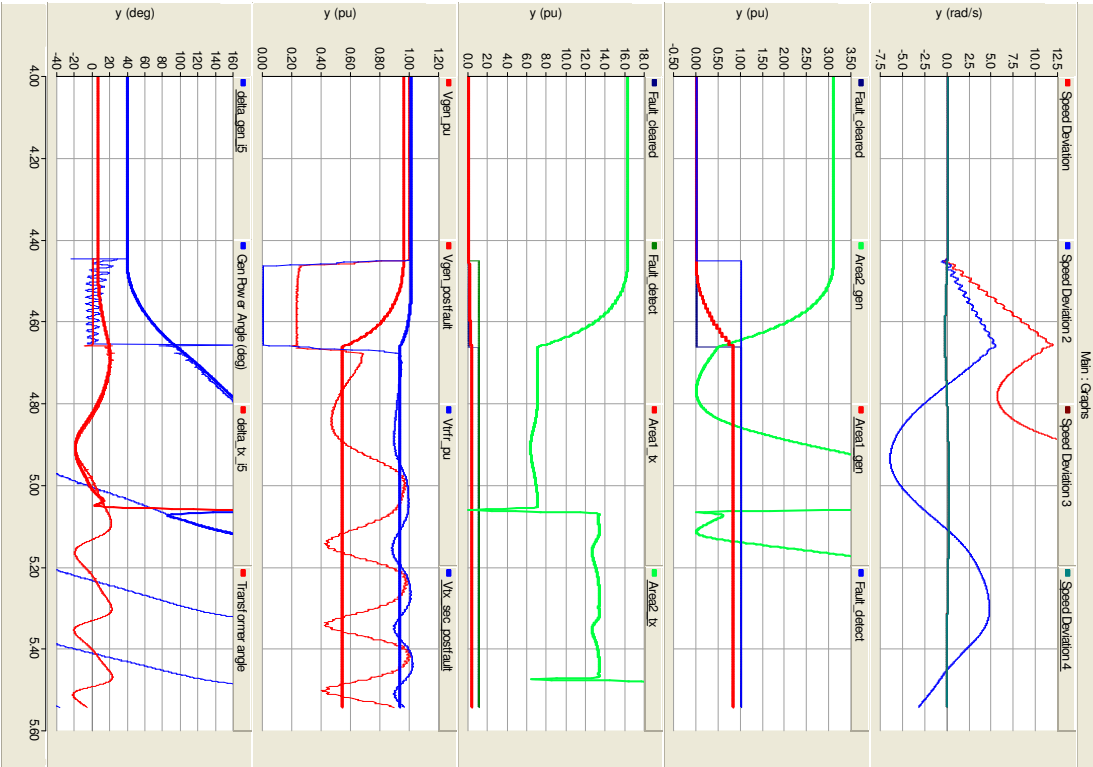
PSCAD Results: Generator D, Scenario 1, $t_{\text{fault}} = 200 \text{ ms}$ (unstable)



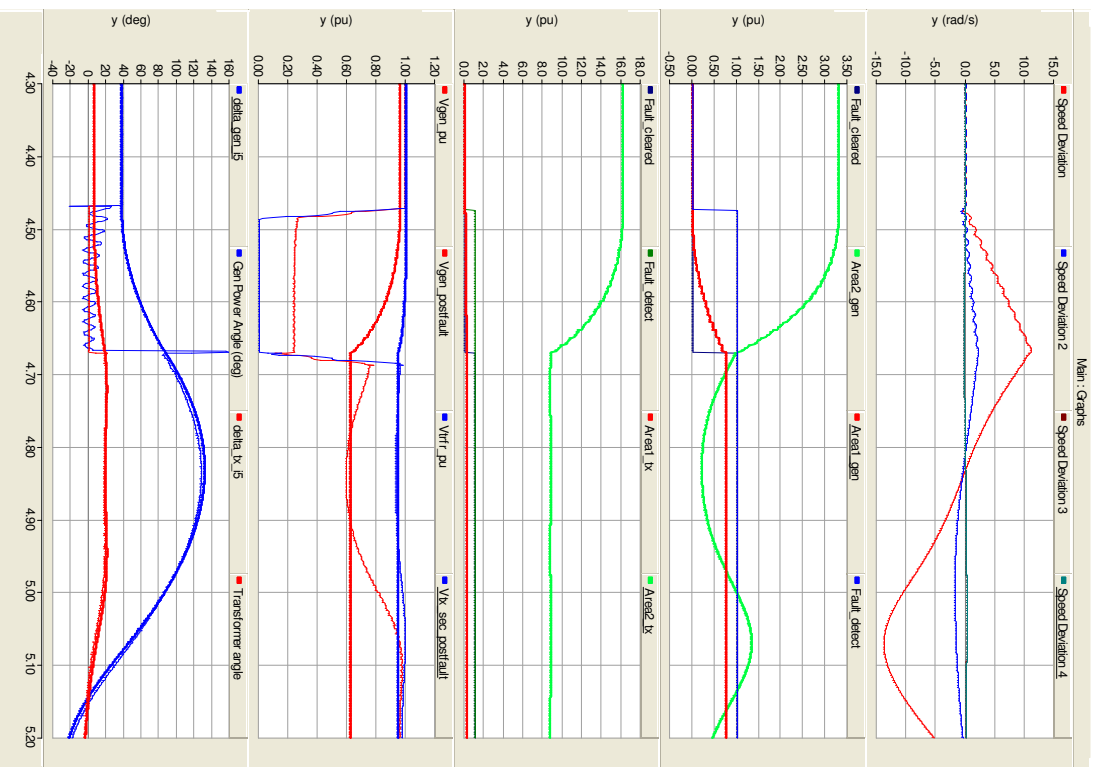
PSCAD Results: Generator D, Scenario 2, $\tau_{\text{fault}} = 200 \text{ ms}$ (stable)



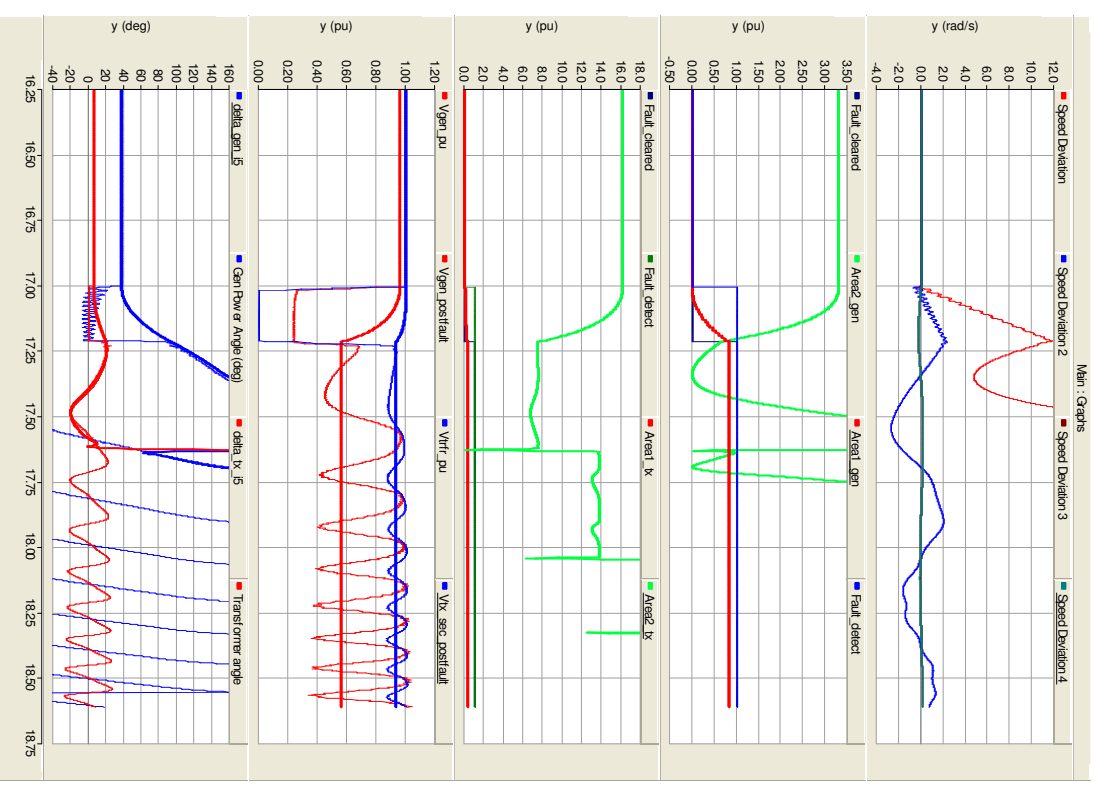
PSCAD Results: Generator D, Scenario 2, $\tau_{\text{fault}} = 212 \text{ ms}$ (unstable)



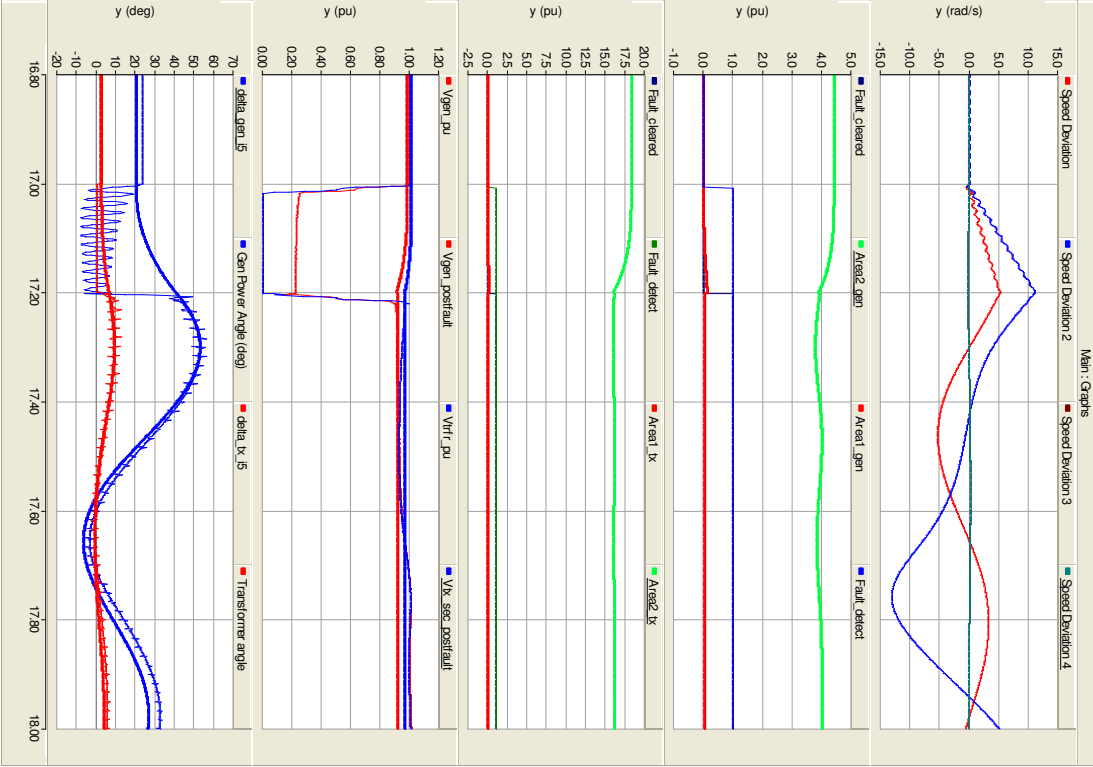
PSCAD Results: Generator D, Scenario 3, $t_{\text{fault}} = 200$ ms (stable)



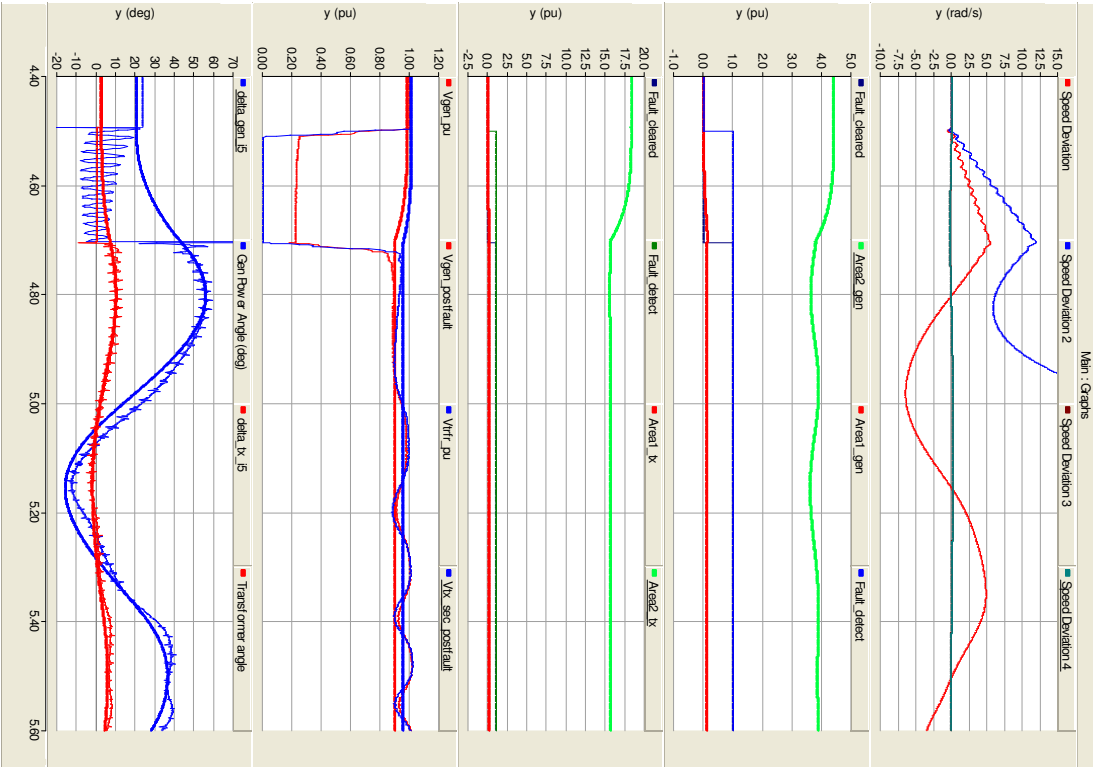
PSCAD Results: Generator D, Scenario 3, $t_{\text{fault}} = 210$ ms (unstable)



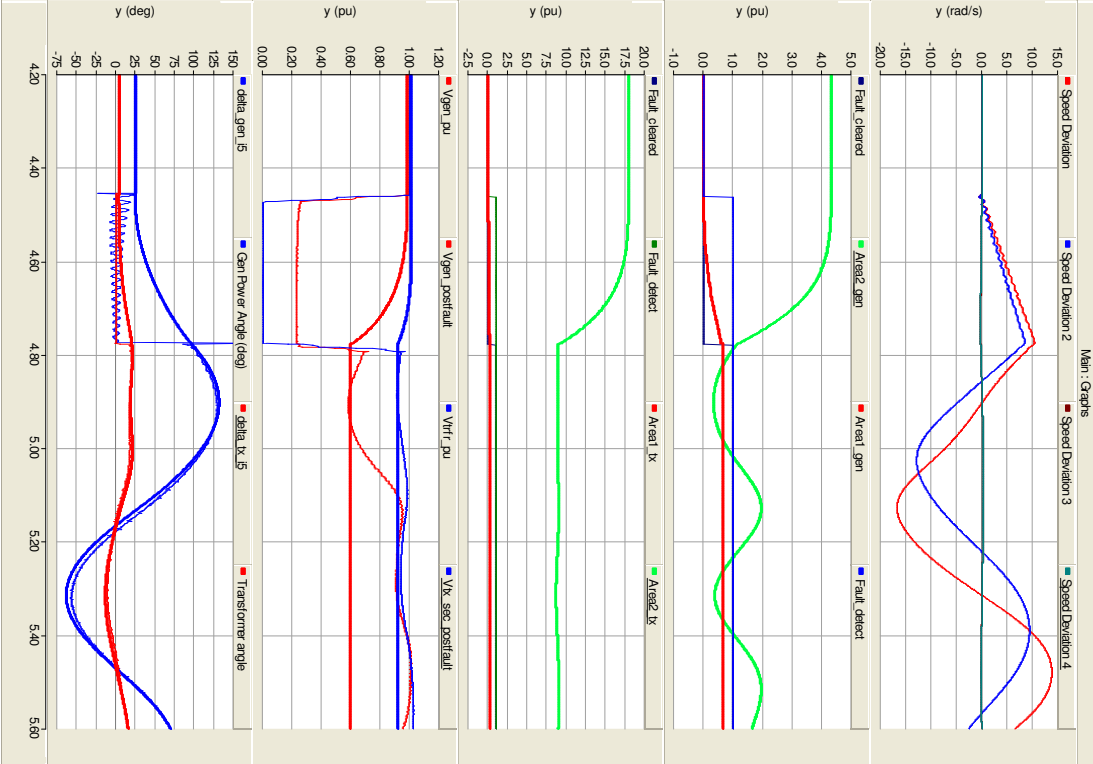
PSCAD Results: Generator D, Scenario 4, $t_{\text{fault}} = 200 \text{ ms}$ (stable)



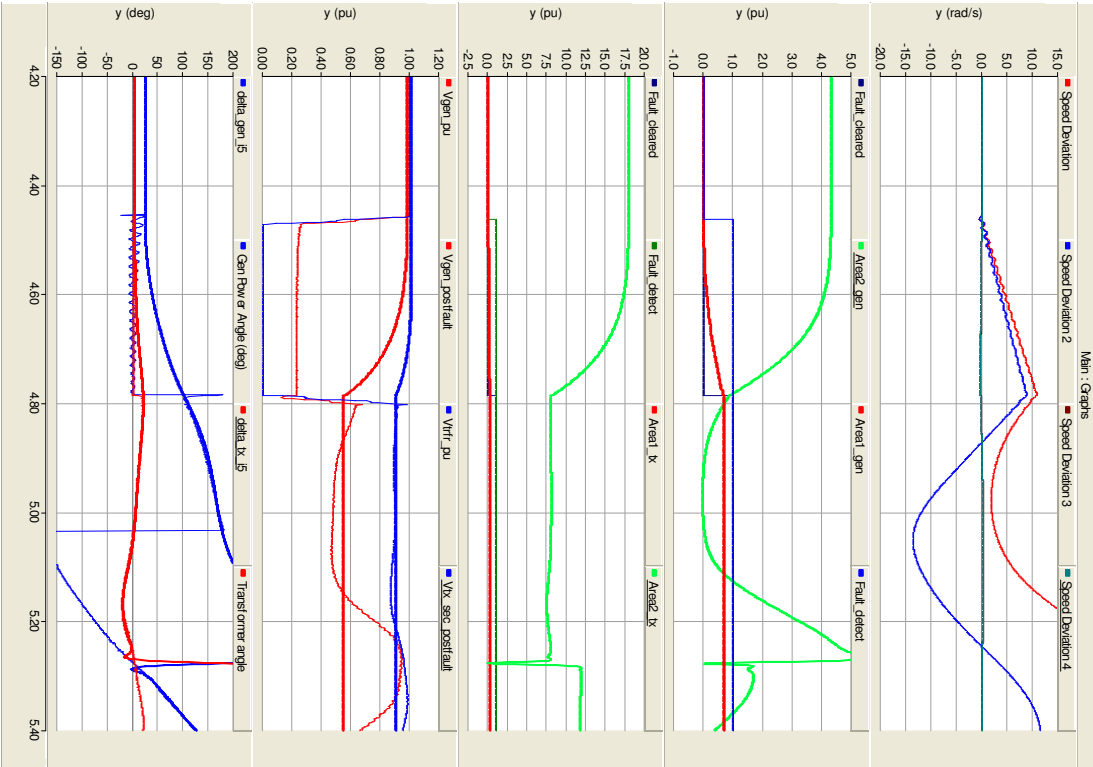
PSCAD Results: Generator D, Scenario 4, $t_{\text{fault}} = 210 \text{ ms}$ (Gen 1 STABLE)



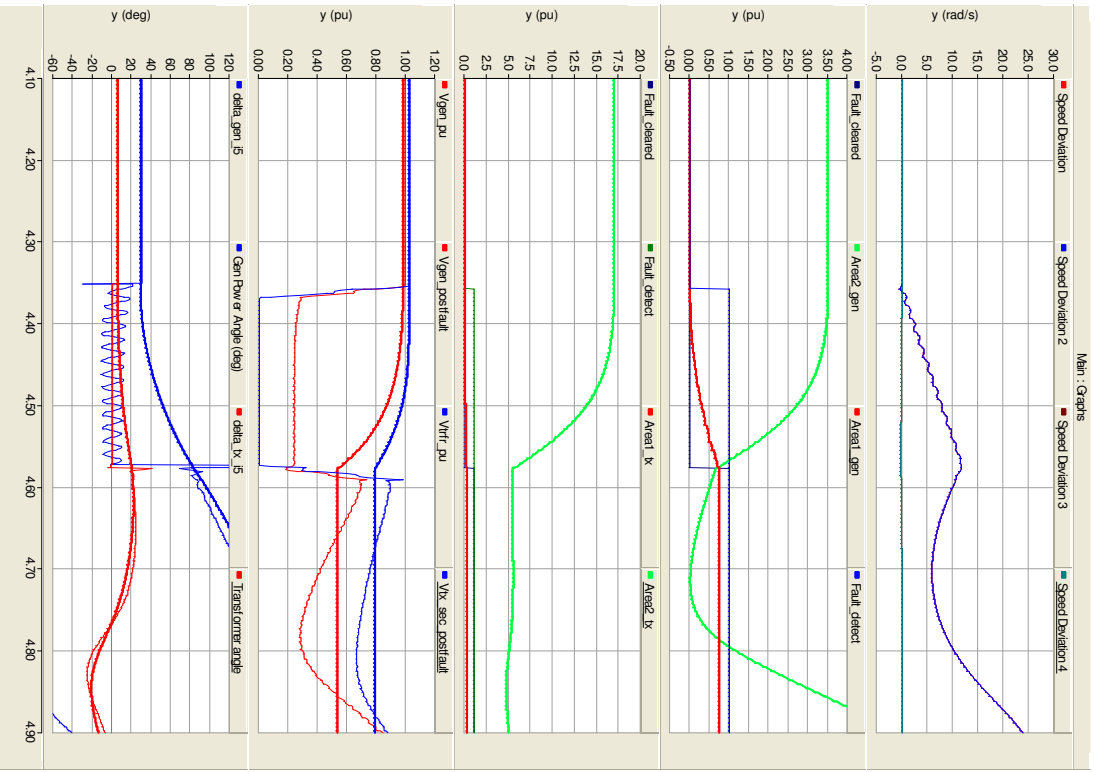
PSCAD Results: Generator D, Scenario 5, $t_{\text{fault}} = 320 \text{ ms}$ (stable)



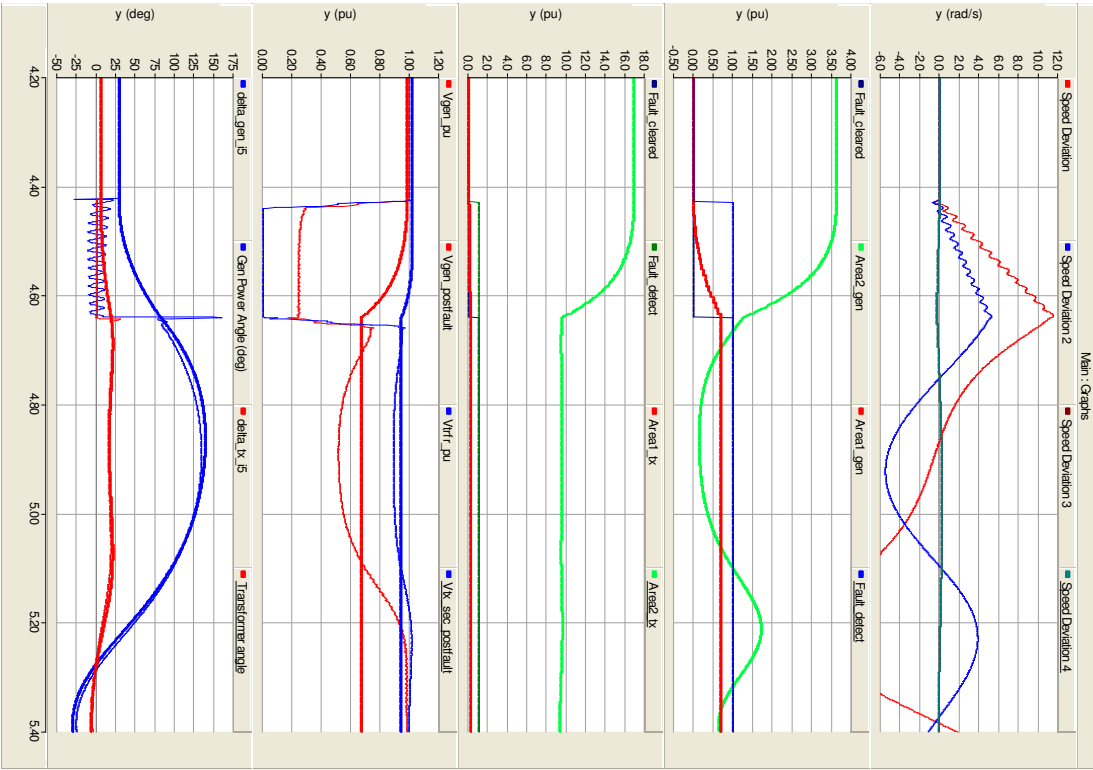
PSCAD Results: Generator D, Scenario 5, $t_{\text{fault}} = 330 \text{ ms}$ (unstable)



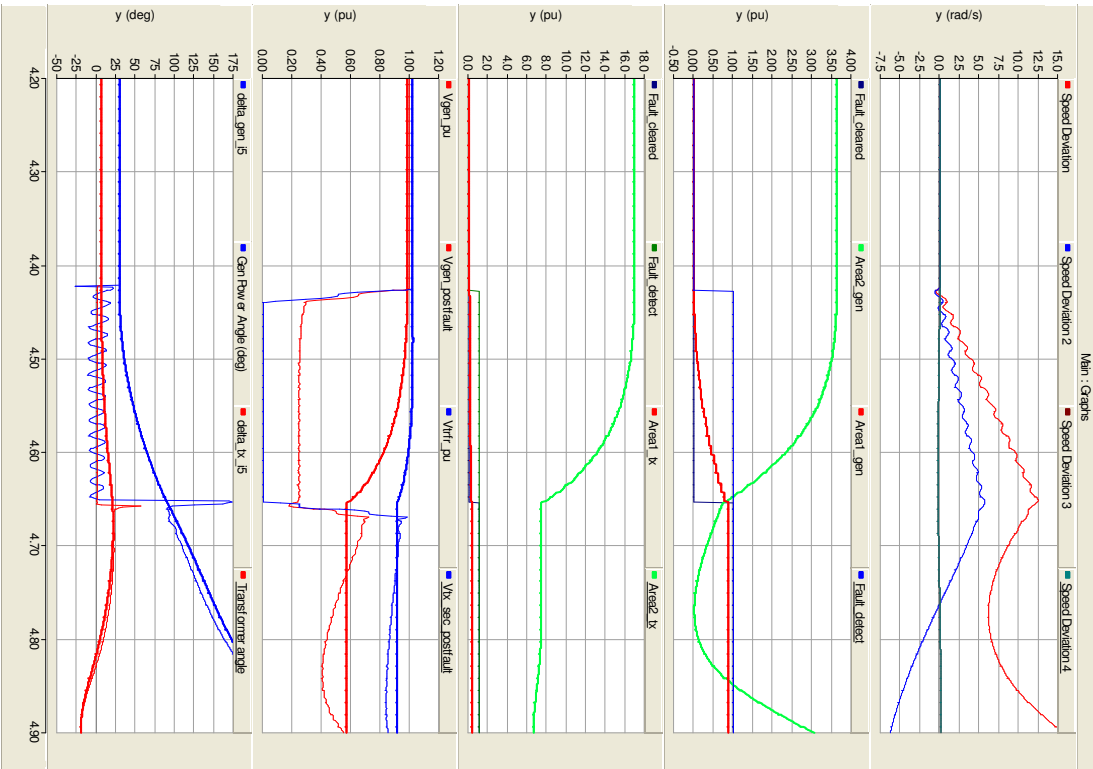
PSCAD Results: Generator E, Scenario 1, $t_{\text{fault}} = 222$ ms (unstable)



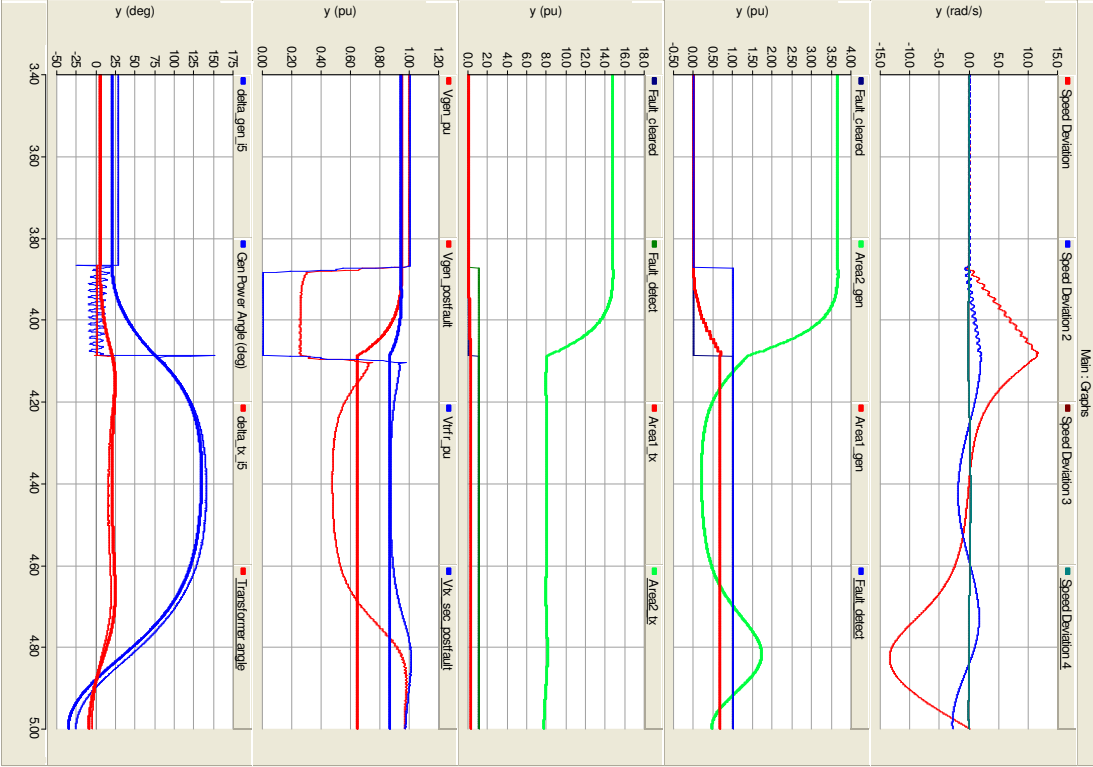
PSCAD Results: Generator E, Scenario 2, $t_{\text{fault}} = 217 \text{ ms}$ (stable)



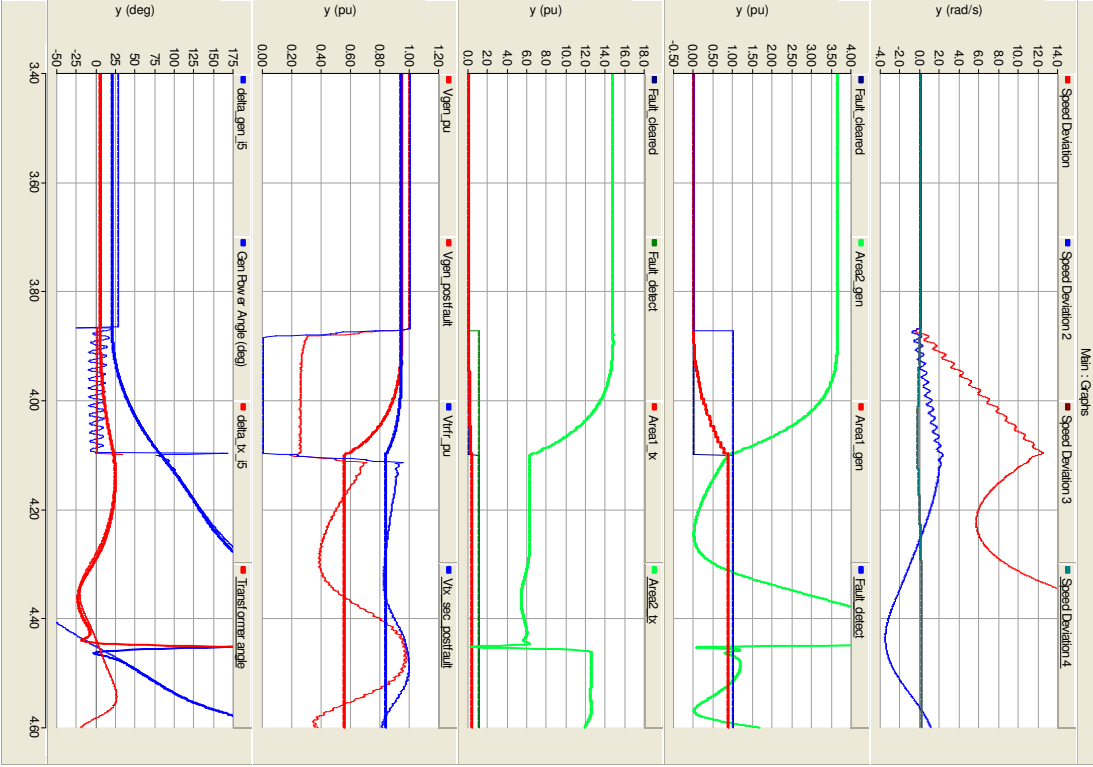
PSCAD Results: Generator E, Scenario 2, $t_{\text{fault}} = 228 \text{ ms}$ (unstable)



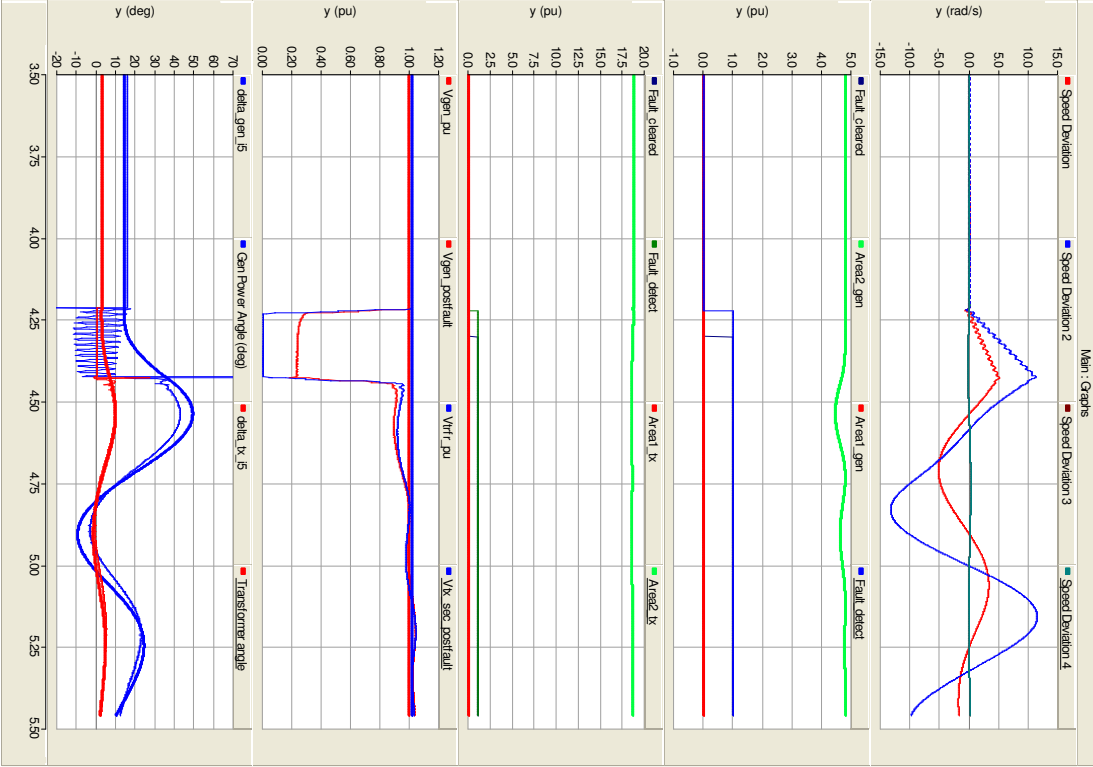
PSCAD Results: Generator E, Scenario 3, $t_{\text{fault}} = 220 \text{ ms}$ (stable)



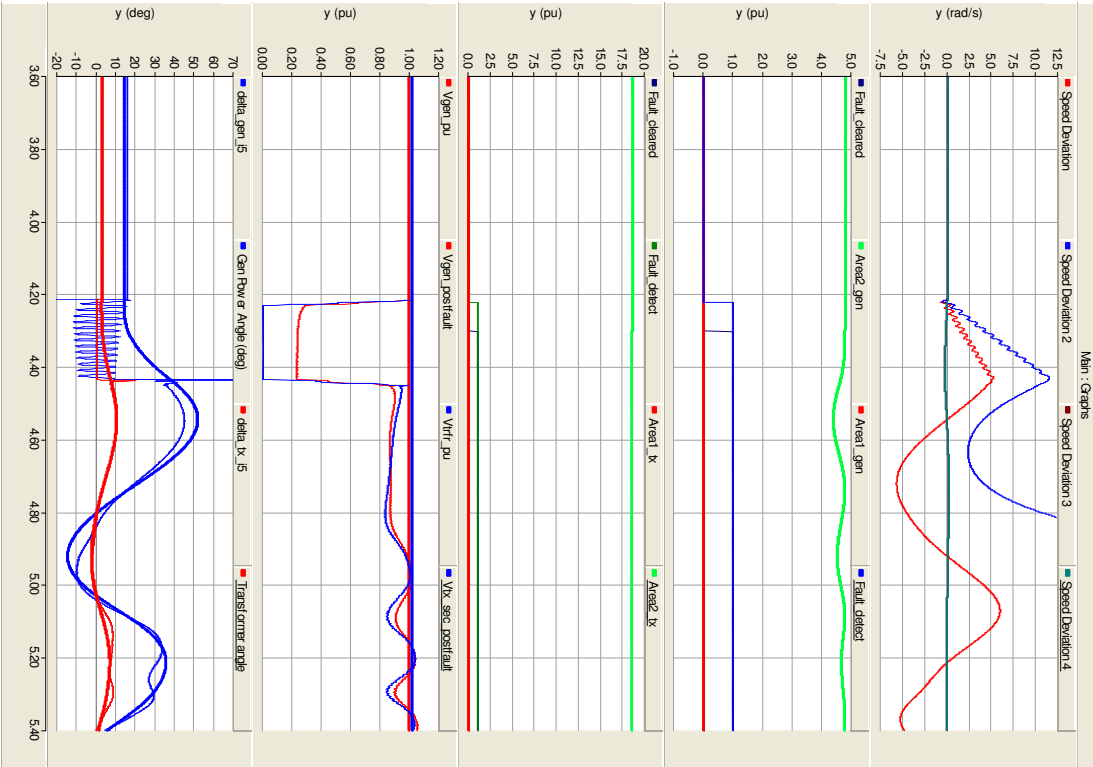
PSCAD Results: Generator E, Scenario 3, $t_{\text{fault}} = 229 \text{ ms}$ (unstable)



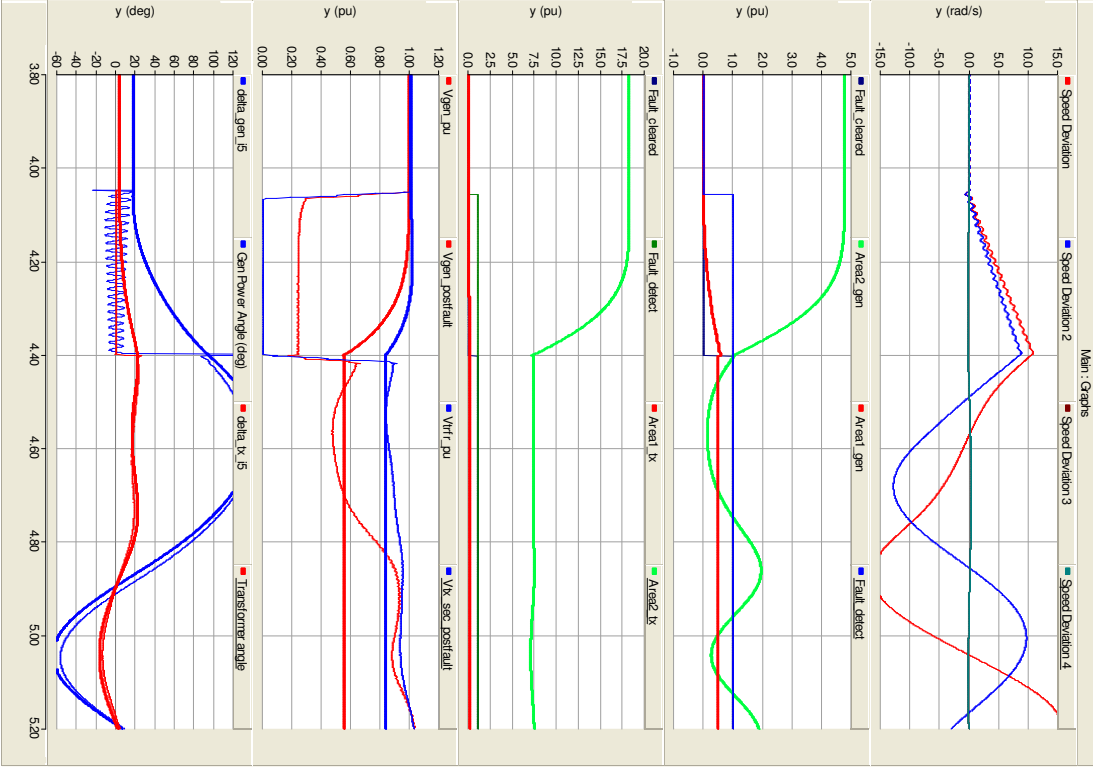
PSCAD Results: Generator E, Scenario 4, $t_{\text{fault}} = 210 \text{ ms}$ (stable)



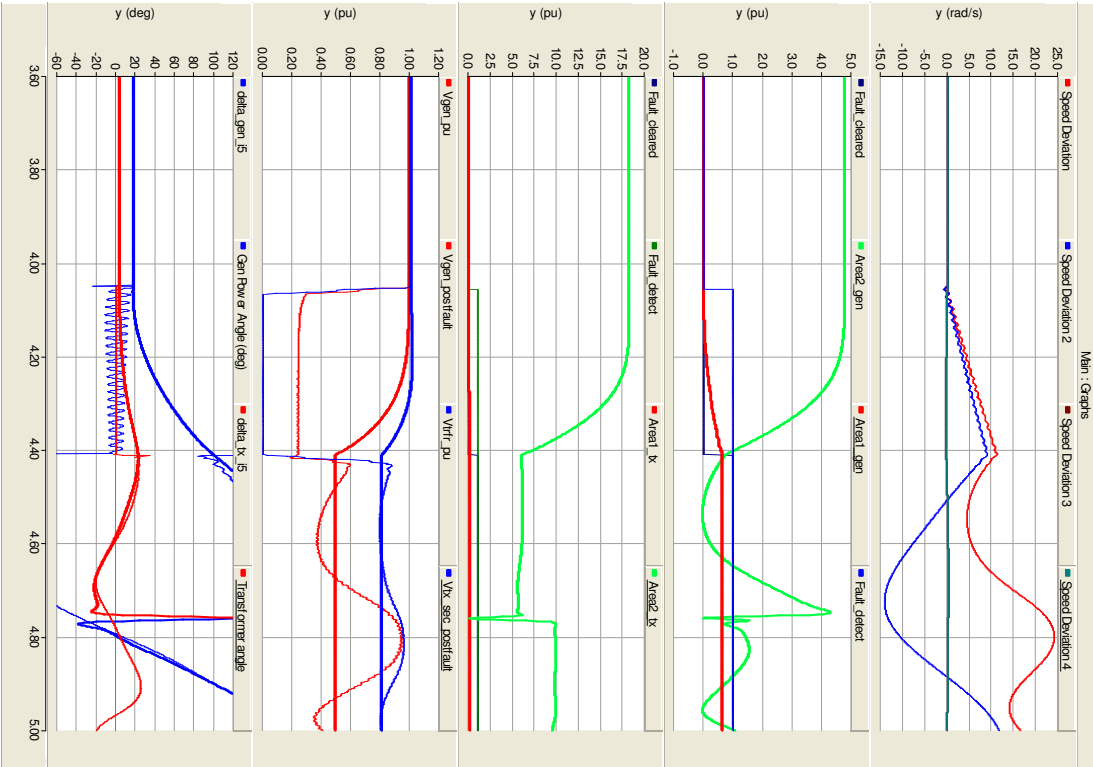
PSCAD Results: Generator E, Scenario 4, $t_{\text{fault}} = 220 \text{ ms}$ (Gen 1 STABLE)



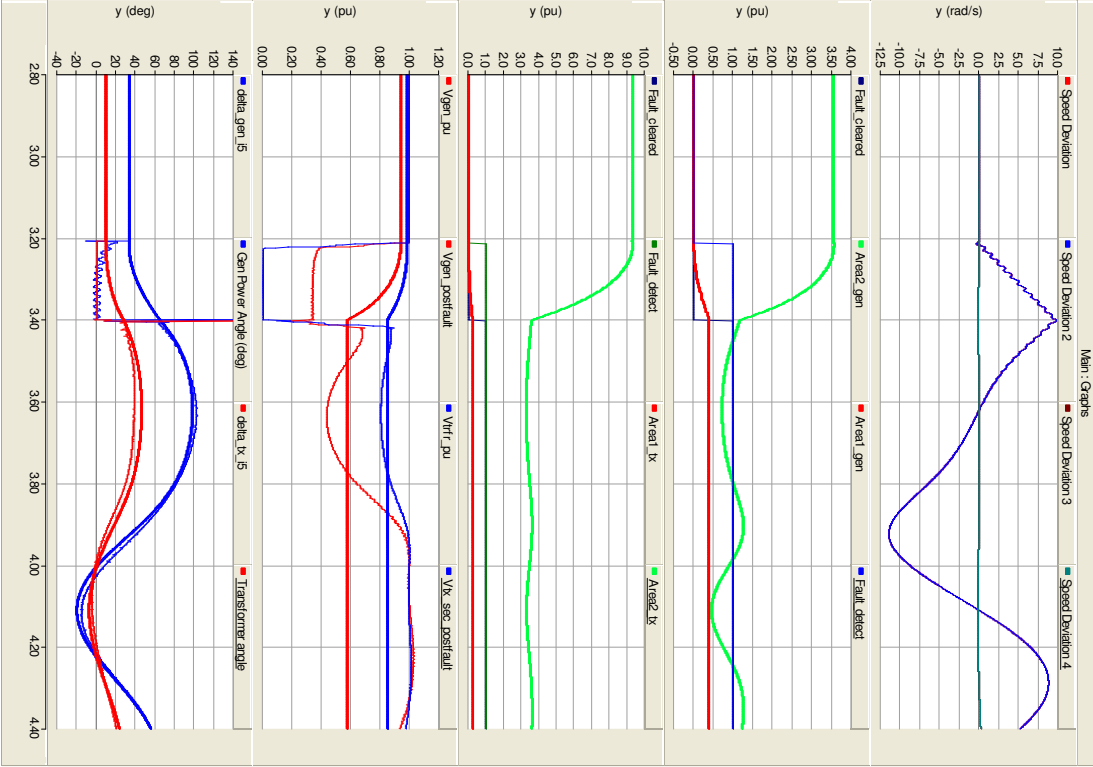
PSCAD Results: Generator E, Scenario 5, $t_{\text{fault}} = 350 \text{ ms}$ (stable)



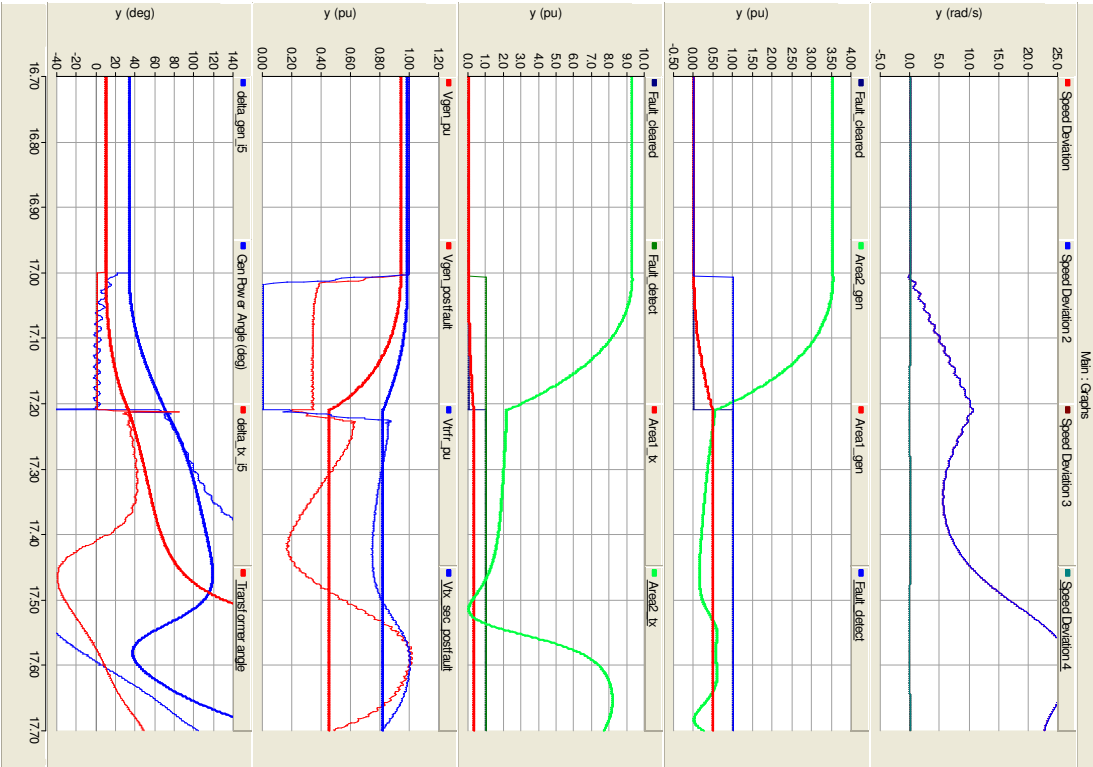
PSCAD Results: Generator E, Scenario 5, $t_{\text{fault}} = 360 \text{ ms}$ (unstable)



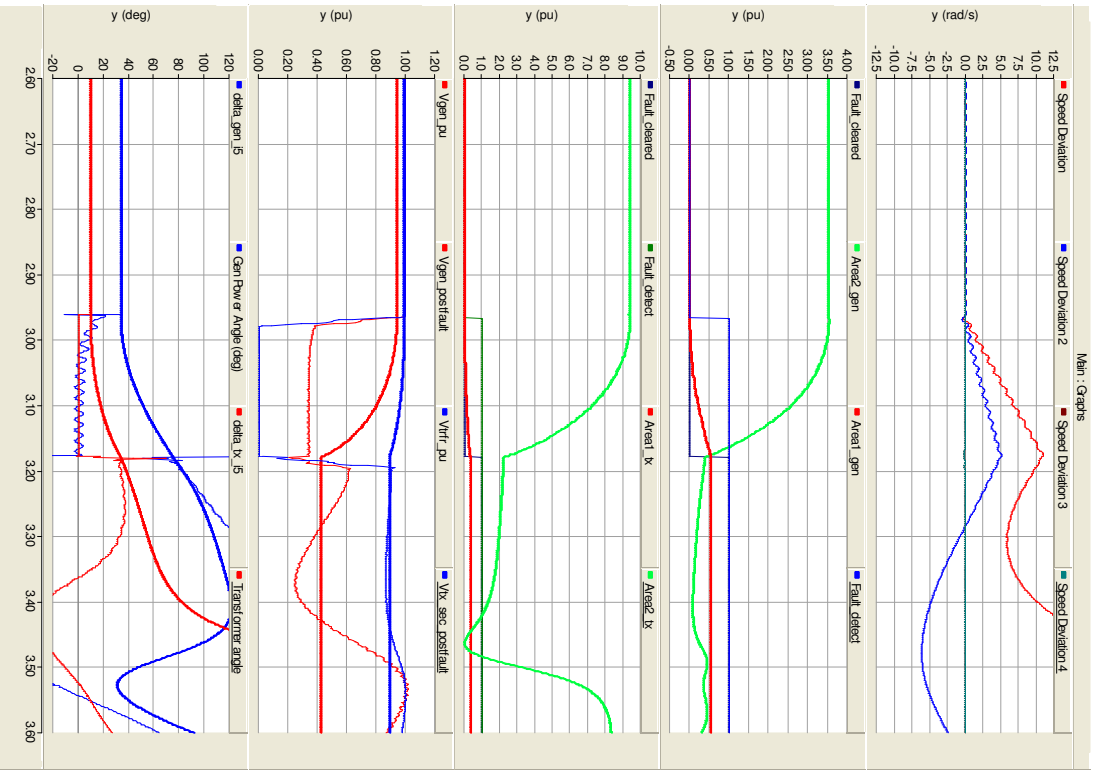
PSCAD Results: Generator F Scenario 1, $t_{\text{fault}} = 193 \text{ ms}$ (stable)



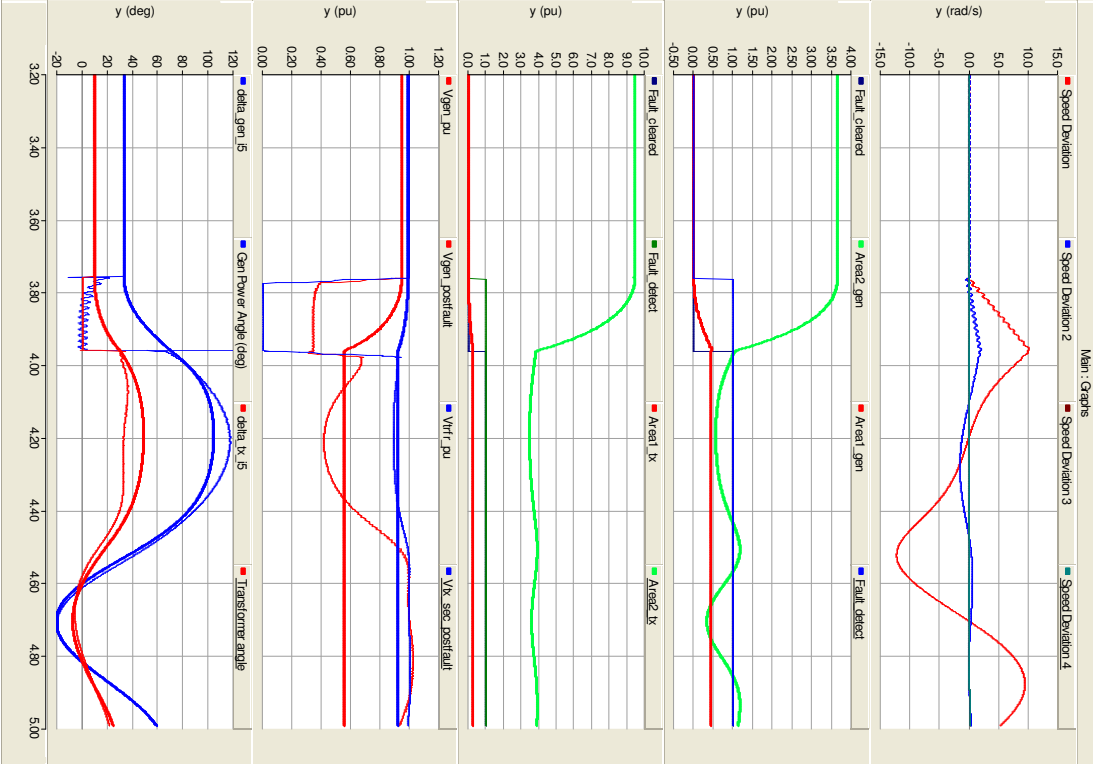
PSCAD Results: Generator F, Scenario 1, $t_{\text{fault}} = 208 \text{ ms}$ (unstable)



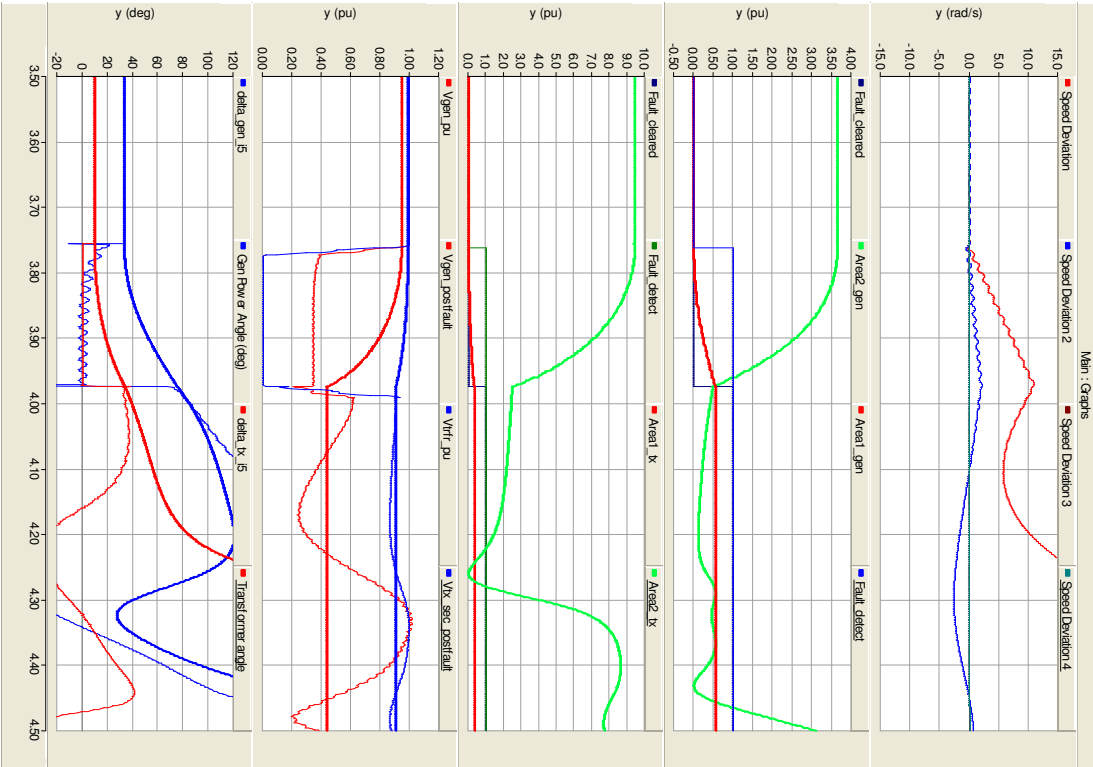
PSCAD Results: Generator F, Scenario 2, $t_{\text{fault}} = 213$ ms (unstable)



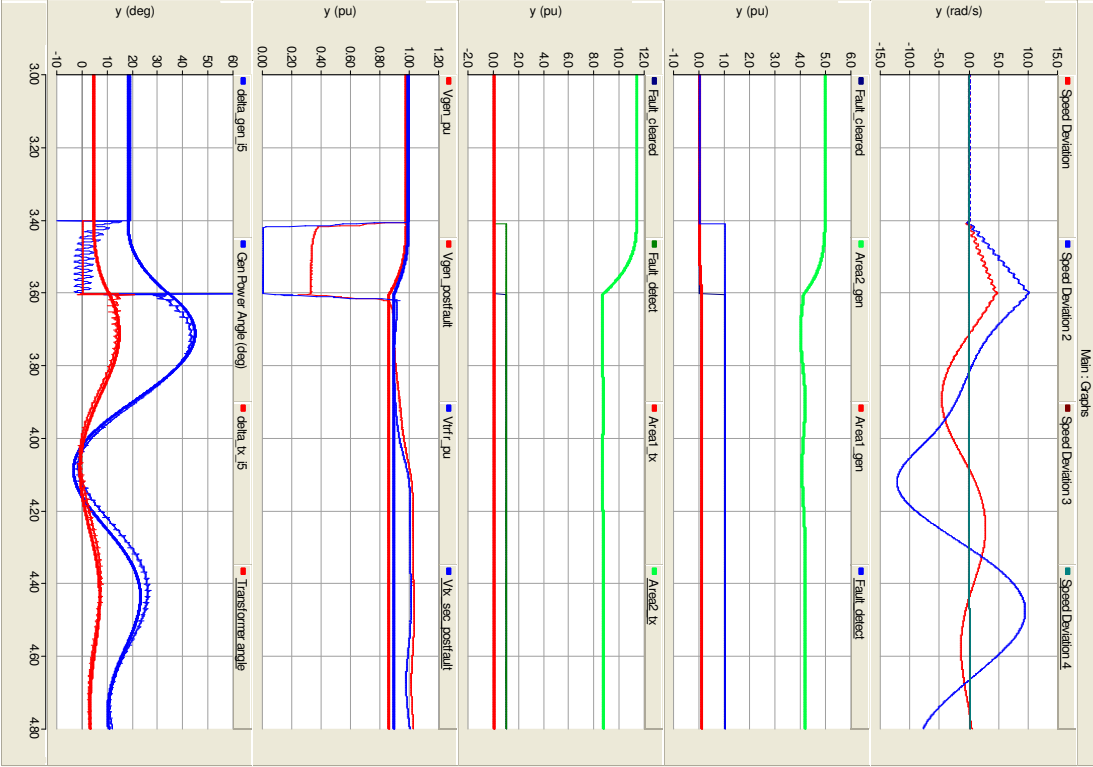
PSCAD Results: Generator F, Scenario 3, $t_{\text{fault}} = 204\text{ms}$ (stable)



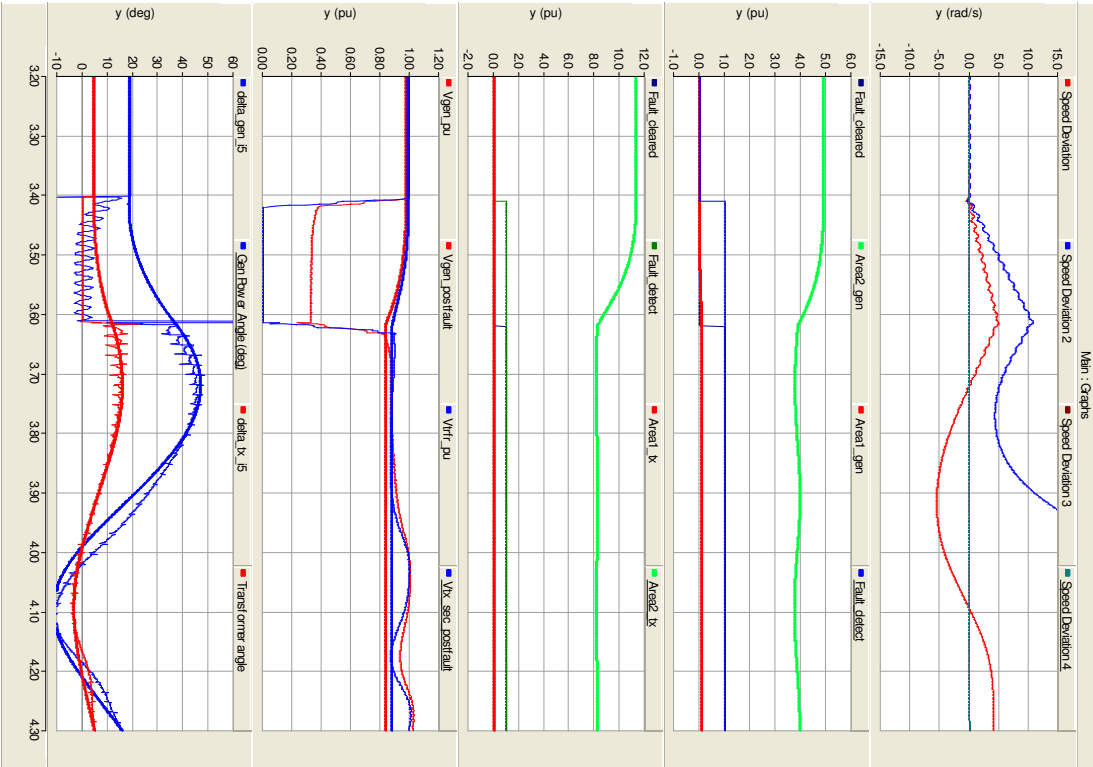
PSCAD Results: Generator F, Scenario 3, $t_{\text{fault}} = 216\text{ ms}$ (unstable)



PSCAD Results: Generator F, Scenario 4, $t_{\text{fault}} = 200 \text{ ms}$ (stable)



PSCAD Results: Generator F, Scenario 4, $t_{\text{fault}} = 210 \text{ ms}$ (Gen 1 STABLE)



PSCAD Results: Generator F, Scenario 5, $t_{\text{fault}} = 350$ ms (unstable)

