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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 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:

\[
\text{RESET} = 1 \\
\text{STEADY} = 0
\]

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

\[
\text{RESET} = 0 \\
\text{STEADY} = 1
\]

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 “Tprimover” 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 “Sbase”

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:

\[
Gen2\_rotorspeed\_overshoot = \frac{\text{Red Area}}{\text{Yellow Area}}
\]  

(a)

Note that the calculation in equation (a) must be done after a simulation was run during which Generator 1 did not lose 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.
S_base (VA) - THREE PHASE
V_base (V) - LINE TO LINE

Quadrature axis Reactance (p.u.)
Direct axis Reactance (p.u.)
Direct axis Transient Reactance (p.u.)

Inertia H-value of generator and prime mover combined
Number of poles
Base Frequency

Network Rn
Network, generator and transformer reactances

Base Speed for mechanical angle calculation (rads)
Base Speed for electrical angle calculation (rads)

Network, generator and transformer reactances

Xq
Xd
Xd_prime

X_total_steady
X_total_transient

H
poles
freq_base
speed_base

omega_base
SPEED DEVIATION CALCULATION FOR ELECTRICAL ROTOR ANGLE CALCULATION

```
speed_diff = delta_rotor 

Fault_cleared = 0.0
omega_base = 0.005

Stability_Trip = speed_diff 
```
STABILITY TRIP CONDITION

RELAY TRIP OUTPUT - X41: 6.7

PS1_4_HSPO3

POLE_SLIP_TRIP1

"C"-KEY

F001V011

Stability_Reset

ON

ACK

MMIALAR1

RS

DIV

MUL

SUB

COS

COS

SUB

MUL

GT

MMIALAR1

RS

Area1

Area2

ON

OFF

PS1_4_HSPO3

OFF

OFF

OFF

OFF

OFF

OFF

OFF
SLOW CYCLE PAGE - STEADY STATE CALCULATIONS (CYCLE TIME 1000mS)
Determine if machine is in steady state
Pre-fault Actual Transfer Angle

delta_G

Fault_detector

delta_T

delta_Tl

G

IN0

IN1

ADD

SEL
ITERATIONS TO DETERMINE $\delta_{Gen_1}$ & $\delta_{Tx}$ DURING THE FAULT

****************  ITERATION  #1  *****************

$\delta_c$ =

$\delta_{gen_{i0}}$ =

$\delta_{tx_{i0}}$ =

$\delta_{tx_{i3}}$ =

$\delta_{gen_{i3}}$ =

$\delta_{tx_{i3}}$ =

$P_{tx_{i3}}$ =

$V_{gen_{fault}}$ =

$V_{tx_{sec_{fault}}}$ =

$\sin$ =

$X_{2}$ =

$\frac{57.3}{D}$ +

$-\frac{2.0}{N/D}$

-------------

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

$\delta_{tx_{HV}}$ =

$\delta_{gen_{i1}}$ =

$\delta_{tx_{i4}}$ =

$\delta_{gen_{i4}}$ =

$\delta_{tx_{i4}}$ =

$P_{tx_{i4}}$ =

$V_{gen_{fault}}$ =

$V_{tx_{sec_{fault}}}$ =

$\sin$ =

$X_{q_{prime}}$ =

$\frac{0.017453}{D}$ -

$\frac{N/D}{D}$

-----------

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

$\delta_{gen_{i2}}$ =

$\delta_{tx_{i2}}$ =

$\delta_{tx_{i1}}$ =

$\delta_{gen_{i1}}$ =

$\delta_{tx_{i1}}$ =

$P_{tx_{i1}}$ =

$V_{gen_{fault}}$ =

$V_{tx_{sec_{fault}}}$ =

$\sin$ =

$X_{q_{prime}}$ =

$\frac{0.017453}{D}$ -

$\frac{N/D}{D}$

-----------

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

$\delta_{tx_{i5}}$ rad

$\delta_{trfr1}$ =

$\delta_{trfr1}$

-------------

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

$\delta_{tx_{i5}}$ rad

$\delta_{trfr1}$ =

$\delta_{trfr1}$

-------------
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 (postfault) is the Transformer 2 HV Voltage connected only to the shunt load (disconnected from transmission lines and generator 1)
THIS CALCULATION WILL BE INCLUDED IN POLESLIP RELAY ON GENERATOR 2 IN A REAL INSTALLATION

**GENERATOR 1 POWER ANGLE CALCULATION**

\[ \text{Power Angle0} = \text{Abs} \left( \text{Imp_line} \right) \cdot \text{Ctrl} = 1 \]

\[ \text{Transfer.Angle} = \text{Abs} \left( \text{Imp_line} \right) \cdot \text{Ctrl} = 1 \]

\[ \text{Numerator} = \text{Igen.pu} + \text{Transfer.Angle} \cdot \text{Alpha} \]

\[ \text{D +} \]

\[ \text{Paralleled pre-fault transmission line impedance} \]

\[ \text{Vgen.pu} \]

\[ \text{Xa2_corrected_pu} \]

\[ \text{AB Comparator} \]

\[ \text{Xq_prime} \]

\[ \text{Eq_prime} \]

\[ \text{Xtrfr} \]

\[ \text{Vtx_sec_postfault} \]

\[ \text{Pline1} \]

\[ \text{Qline1} \]

\[ \text{Pline_Total} \]

\[ \text{Qline_Total} \]

\[ \text{Rline_par} \]

\[ \text{Za_mag_corrected_pu} \]

\[ \text{Za2_mag_corrected_pu} \]

\[ \text{Za_angle_corrected_rad} \]

\[ \text{Za2_angle_corrected_rad} \]

\[ \text{Xtrfr2} \]

\[ \text{Vtrfr1_pu} \]

\[ \text{Vgen2_pu} \]

\[ \text{Vtrfr1_pu} \]
PSCAD Results: Generator A, Scenario 1, t_{fault} = 310ms (stable)

Main Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

- Fault_cleared
- Area 2_gen
- Area 1_gen
- Fault_detect
- Area 1_tx
- Area 2_tx

- Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

- delta_gen_i5
- Gen Power Angle (deg)
- delta_tx_i5
- Transformer angle

PSCAD Results: Generator A, Scenario 1, t_{fault} = 320ms (unstable)
PSCAD Results: Generator A, Scenario 2, t_{fault} = 310ms (stable)

PSCAD Results: Generator A, Scenario 2, t_{fault} = 320ms (unstable)
PSCAD Results: Generator A, Scenario 3, t_{fault} = 310ms (stable)

Main: Graphs
PSCAD Results: Generator A, Scenario 4, t\text{fault} = 310\text{ms} (stable)
PSCAD Results: Generator A, Scenario 5, fault = 490ms (stable)

PSCAD Results: Generator A, Scenario 5, fault = 500ms (unstable)
PSCAD Results: Generator B, Scenario 1, t_{fault} = 160ms (stable)

M ain:
Graphs

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

M ain:
Graphs
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 4, t\_fault = 180ms (stable)

Main:

Graphs

4.20
4.40
4.60
4.80
5.00
5.20
5.40
5.60
...
...
...

-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0

y (rad/s)

Speed Deviation

Speed Deviation 2

Speed Deviation 3

Speed Deviation 4

506x740

Fault_cleared

Area 2\_gen

Area 1\_gen

Fault_detect

0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0

y (pu)

Fault_cleared

Fault_detect

Area 1\_tx

Area 2\_tx

0.00
0.20
0.40
0.60
0.80
1.00
1.20

y (pu)

Vgen\_pu

Vgen\_postfault

Vtrfr\_pu

Vtx\_sec\_postfault

0.00
0.20
0.40
0.60
0.80
1.00
1.20

y (pu)

delta\_gen\_i5

Gen Power Angle (deg)

delta\_tx\_i5

Transformer angle

113x755

-20
0
20
40
60
80
100
120

y (deg)

Vgen\_postfault

Vtrfr\_pu

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

Main:
Graphs

- Speed deviation
- Speed deviation 2
- Speed deviation 3
- Speed deviation 4

Fault_cleared
Area 2_gen
Area 1_gen
Fault_detect

- Fault_cleared
- Area 1_tx
- Area 2_tx

Vgen_pu
Vgen_postfault
Vtrfr_pu
Vtx_sec_postfault

delta_gen_i5
Gen Power Angle (deg)

delta_tx_i5
Transformer angle

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

Main:
Graphs

- Speed deviation
- Speed deviation 2
- Speed deviation 3
- Speed deviation 4

Fault_cleared
Area 2_gen
Area 1_gen
Fault_detect

- Fault_cleared
- Area 1_tx
- Area 2_tx

Vgen_pu
Vgen_postfault
Vtrfr_pu
Vtx_sec_postfault

delta_gen_i5
Gen Power Angle (deg)

delta_tx_i5
Transformer angle
PSCAD Results: Generator C, Scenario 1, t\text{fault} = 106 ms (stable)

Main:

Graphs

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

Main:

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

Main:

Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault_cleared

Area2_gen
Area1_gen
Fault_detect

Vgen_pu
Vgen_postfault
Vtrfr_pu
Vtx_sec_postfault

delta_gen_i5
Gen Power Angle (deg)
delta_tx_i5
Transformer angle

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

Main:

Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault_cleared

Area2_gen
Area1_gen
Fault_detect

Vgen_pu
Vgen_postfault
Vtrfr_pu
Vtx_sec_postfault

delta_gen_i5
Gen Power Angle (deg)
delta_tx_i5
Transformer angle
PSCAD Results: Generator C, Scenario 3, t\text{fault} = 121\ ms (stable)

Main:

Graphs

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

Main:

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

- Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

- Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect
- Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

- Delta_gen_i5
- Gen Power Angle (deg)
- Delta_tx_i5
- Transformer angle

PSCAD Results: Generator C, Scenario 4, t_{\text{fault}} = 130 ms (Gen 1 STABLE)
PSCAD Results: Generator C, Scenario 5, t\_fault = 220 ms (stable)

Main:
Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault cleared
Area2\_gen
Area1\_gen
Fault detect
Area1\_tx
Area2\_tx

Vgen\_pu
Vgen\_postfault
Vtrfr\_pu
Vtx\_sec\_postfault

Delta Gen\_i5
Gen Power Angle (deg)
Delta Tx\_i5
Transformer angle
PSCAD Results: Generator D, Scenario 1, t_fault = 190 ms (stable)

Main:

Graphs

PSCAD Results: Generator D, Scenario 1, t_fault = 200 ms (unstable)
PSCAD Results: Generator D, Scenario 2, t_{fault} = 200 ms (stable)

Main:
Graphs

PSCAD Results: Generator D, Scenario 2, t_{fault} = 212 ms (unstable)

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

Main:
- Graphs

Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

Voltage
- Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

Speed deviation
- Speed deviation
- Speed deviation 2
- Speed deviation 3
- Speed deviation 4

Transform angle
- Transformer angle

delta_gen_i5
- Generator Power Angle (deg)

delta_tx_i5
- Transformer angle

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

Main:
- Graphs

Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

Voltage
- Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

Speed deviation
- Speed deviation
- Speed deviation 2
- Speed deviation 3
- Speed deviation 4

Transform angle
- Transformer angle

delta_gen_i5
- Generator Power Angle (deg)

delta_tx_i5
- Transformer angle
PSCAD Results: Generator D, Scenario 4, $t_{\text{fault}} = 200$ ms (stable)

Main:
- Graphs

Vgen_pu
- Fault_cleared
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

delta_gen_i5
- Gen Power Angle (deg)

delta_tx_i5
- Transformer angle
PSCAD Results: Generator D, Scenario 5, fault time = 320 ms (stable)

Main:
Graphs

PSCAD Results: Generator D, Scenario 5, fault time = 330 ms (unstable)
PSCAD Results: Generator E, Scenario 1, t\(_{\text{fault}}\) = 209 ms (stable)

PSCAD Results: Generator E, Scenario 1, t\(_{\text{fault}}\) = 222 ms (unstable)
PSCAD Results: Generator E, Scenario 2, t\text{\textsubscript{fault}} = 217 ms (stable)

Main:
Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

- Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

- Vgen\text{\_pu}
- Vgen\text{\_postfault}
- Vtrfr\text{\_pu}
- Vtx\text{\_sec\_postfault}

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

Main:
Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

- Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

- Vgen\text{\_pu}
- Vgen\text{\_postfault}
- Vtrfr\text{\_pu}
- Vtx\text{\_sec\_postfault}
PSCAD Results: Generator E, Scenario 3, t_{\text{fault}} = 220 ms (stable)

- Graphs

- Speed deviation

- Fault detected

- Voltage

- Power angle

PSCAD Results: Generator E, Scenario 3, t_{\text{fault}} = 229 ms (unstable)
PSCAD Results: Generator E, Scenario 4, \( t_{\text{fault}} = 210 \text{ ms} \) (stable)

Main:

Graphs:

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault_cleared

Area2_gen

Area1_gen

Fault_detect

- Fault_cleared
- Fault_detect

Area1_tx

Area2_tx

Vgen_pu

Vgen_postfault

Vtrfr_pu

Vtx_sec_postfault

delta_gen_i5

Gen Power Angle (deg)

delta_tx_i5

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

Main:
Graphs

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

Main:
Graphs
PSCAD Results: Generator F, Scenario 2, t_{fault} = 202 ms (stable)

Main:

Graphs

PSCAD Results: Generator F, Scenario 2, t_{fault} = 213 ms (unstable)
PSCAD Results: Generator F, Scenario 3, \( t_{\text{fault}} = 204 \text{ms} \) (stable)

Main:

Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

delta_gen_i5
- Gen Power Angle (deg)

delta_tx_i5
- Transformer angle

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

Main:

Graphs

- Speed Deviation
- Speed Deviation 2
- Speed Deviation 3
- Speed Deviation 4

Fault_cleared
- Area2_gen
- Area1_gen
- Fault_detect

Vgen_pu
- Vgen_postfault
- Vtrfr_pu
- Vtx_sec_postfault

delta_gen_i5
- Gen Power Angle (deg)

delta_tx_i5
- Transformer angle
PSCAD Results: Generator F, Scenario 5, t fault = 334 ms (stable)

Main:

Graphs

2.80
3.00
3.20
3.40
3.60
3.80
4.00
4.20
...
...
...

-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
20.0
25.0

y (rad/s)

Speed Deviation

Speed Deviation 2

Speed Deviation 3

Speed Deviation 4

-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0

y (pu)

Fault_cleared

Area2_gen

Area1_gen

Fault_detect

-2.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0

y (pu)

Fault_cleared

Fault_detect

Area1_tx

Area2_tx

0.00
0.20
0.40
0.60
0.80
1.00
1.20

y (pu)

Vgen_pu

Vgen_postfault

Vtrfr_pu

Vtx_sec_postfault

0
20
40
60
80
100
120

y (deg)

delta_gen_i5

Gen Power Angle (deg)

delta_tx_i5

Transformer angle

PSCAD Results: Generator F, Scenario 5, t fault = 350 ms (unstable)