Enhanced protection modelling approach for power system transient stability studies using individual phase and sequence voltages

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Introduction

Existing state-of-the-art protection models for transient stability studies

- For typical dynamics studies, the network is assumed to be balanced.
- Hence these studies typically involve the representation of positive-sequence networks and models only.
- Unbalanced faults are represented by an effective fault impedance in the positive sequence network.
- Existing protection models used in transient stability studies (generator protection, load shedding, etc.) use only positive sequence quantities such as voltages, currents etc. to trigger any actions.
- Given that majority of the faults seen in the system are unbalanced faults, this could be inadequate with the increasing penetration of inverter-based resources.

Limitations of the existing models

- The voltages of the un-faulted phases in the vicinity of an unbalanced fault may reach very high levels, likewise the faulted phase voltages may reach very low levels causing high phase currents.
- These severe conditions may persist for a duration sufficiently long to trigger tripping actions by the protection elements or protective functions in IBR controllers.
- Likewise, there may be some protection elements utilizing the negative sequence voltages/currents.
- If standard positive sequence protection models are used for dynamic simulations, one could fail to predict the loss of some units.

Proposed modifications

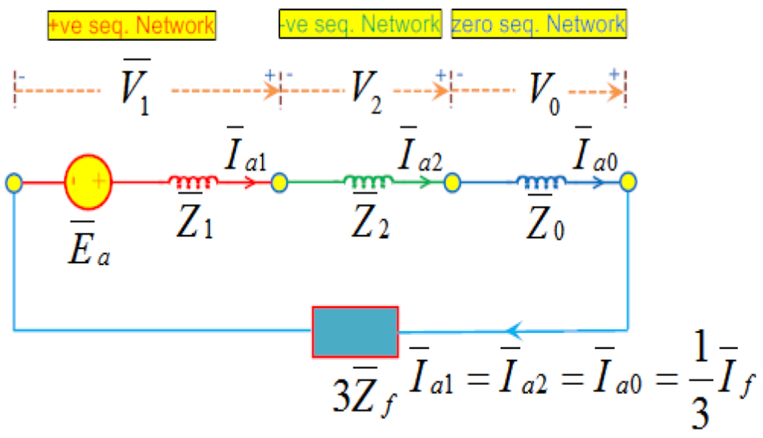
- Use of protection models using sequence/individual phase quantities.
- No additional data necessarily required than that used for standard transient stability simulations.
- Minimal additional computations needed over existing computations involved in transient stability simulations.
- Could have a significant impact on studies involving delayed clearing of faults.
- Not practical to model entire interconnection-wide base cases in a detailed three-phase domain for all transient stability studies, proposed approach is aimed at trying to achieve a middle ground, such that more information about the system behaviour is obtained and protection systems are more realistically represented in RMS studies.

Data assumptions

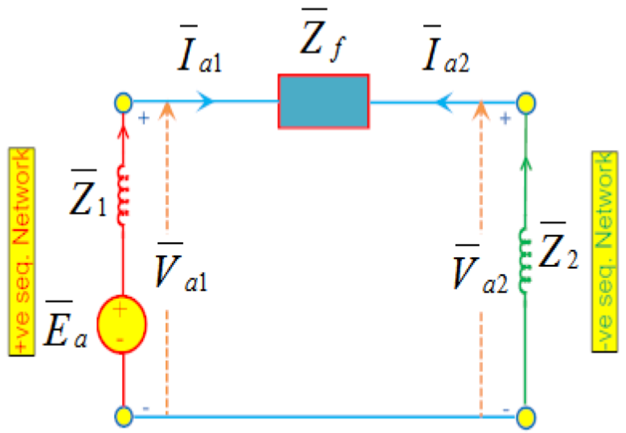
- If zero, negative sequence data is available, it is used for the calculations
- In the absence of negative sequence and zero sequence network data, set up default data using the positive sequence data (e.g. For transmission lines, $Z_2 = Z_1$, $Z_0 = 3{*}Z_1$)

Sequence Network for Unbalanced Faults

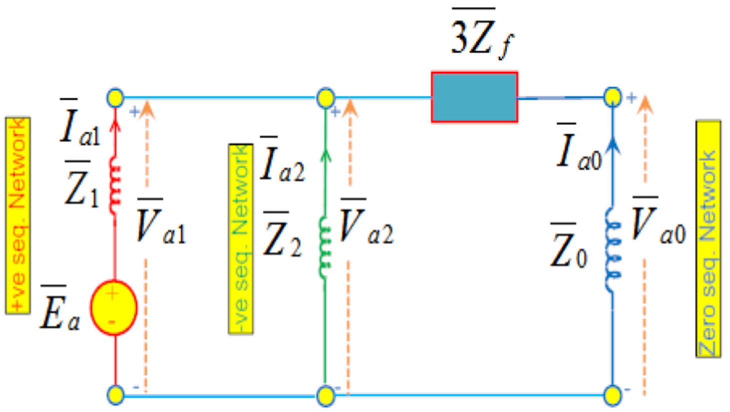
SLG fault:



LL fault:



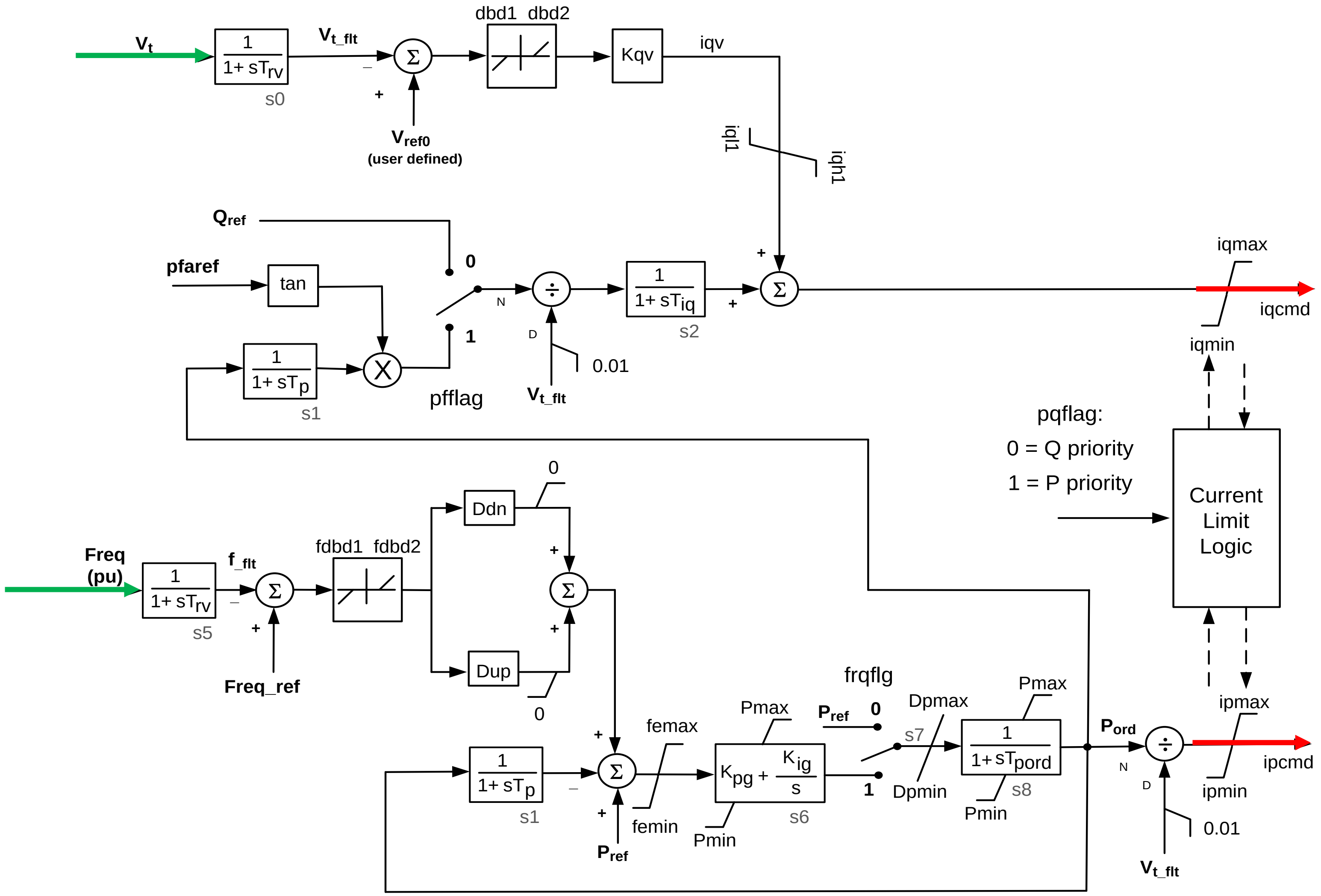
LLG fault:



Applications

Experimental modified version of distributed energy resources model (*der_a*) accounting for individual phase voltages in voltage cut-out block

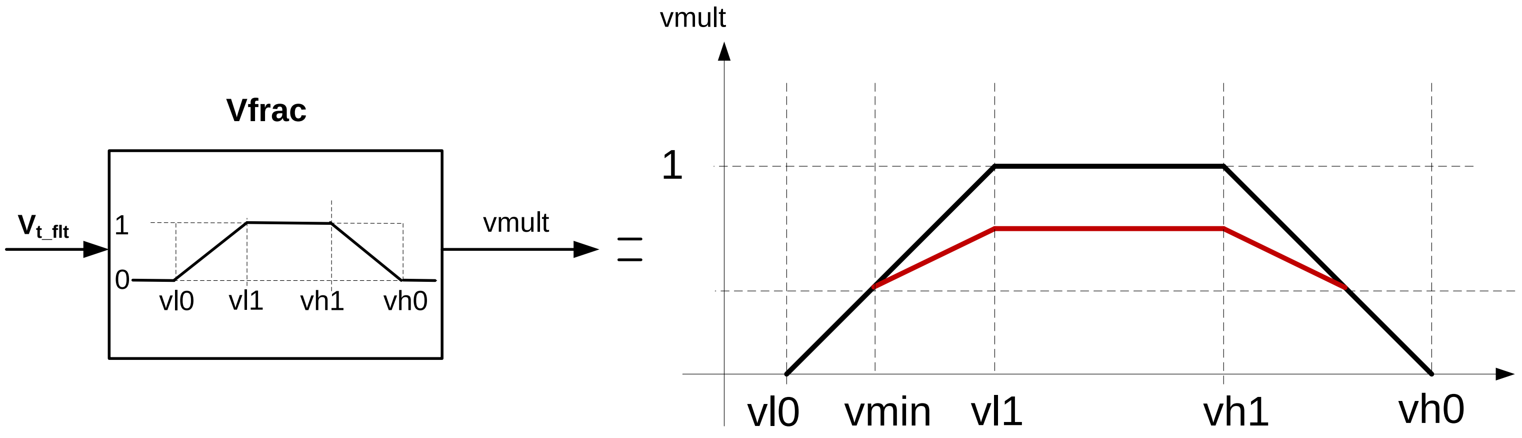
der_a model



Vt
1
1+ sTrv
s0
Vt_flt
Vref0
(user defined)
dbd1 dbd2
Kqv
iqv
iql1
iqh1
Qref
pfaref
tan
1
1+ sTp
s1
pfflag
0
1
N
D
0.01
Vt_flt
1
1+ sTiq
s2
iqmax
iqcmd
iqmin
pqflag:
0 = Q priority
1 = P priority
Current
Limit
Logic
Freq
(pu)
1
1+ sTrv
s5
f_flt
Freq_ref
fdbd1 fdbd2
Ddn
Dup
0
0
femax
femin
Pref
1
1+ sTp
s1
Pmax
Pmin
Kpg + Kig / s
s6
frqflg
Pref
0
1
Dpmax
Dpmin
s7
Pmax
Pmin
1
1+ sTpord
s8
Pord
N
D
ipmax
ipcmd
ipmin
0.01
Vt_flt

Experimental *der_a_ph* model: Use of individual phase voltage for the voltage cut-out block in *der_a*

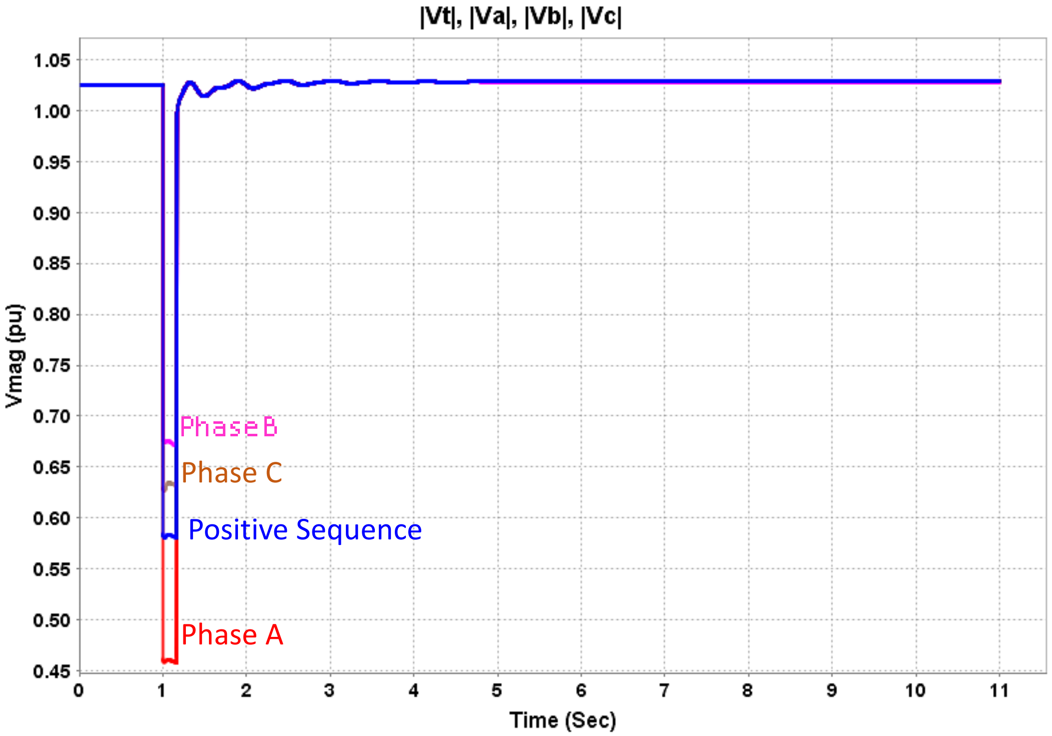
- Modified the voltage cut-out block logic in *der_a* to trip based on the lowest/highest phase voltage magnitudes instead of the positive sequence voltage magnitude
- ***NOTE: Experimental model for demonstration ONLY



Experimental *der_a_ph* model: Use of individual phase voltage for the voltage cut-out block in *der_a*

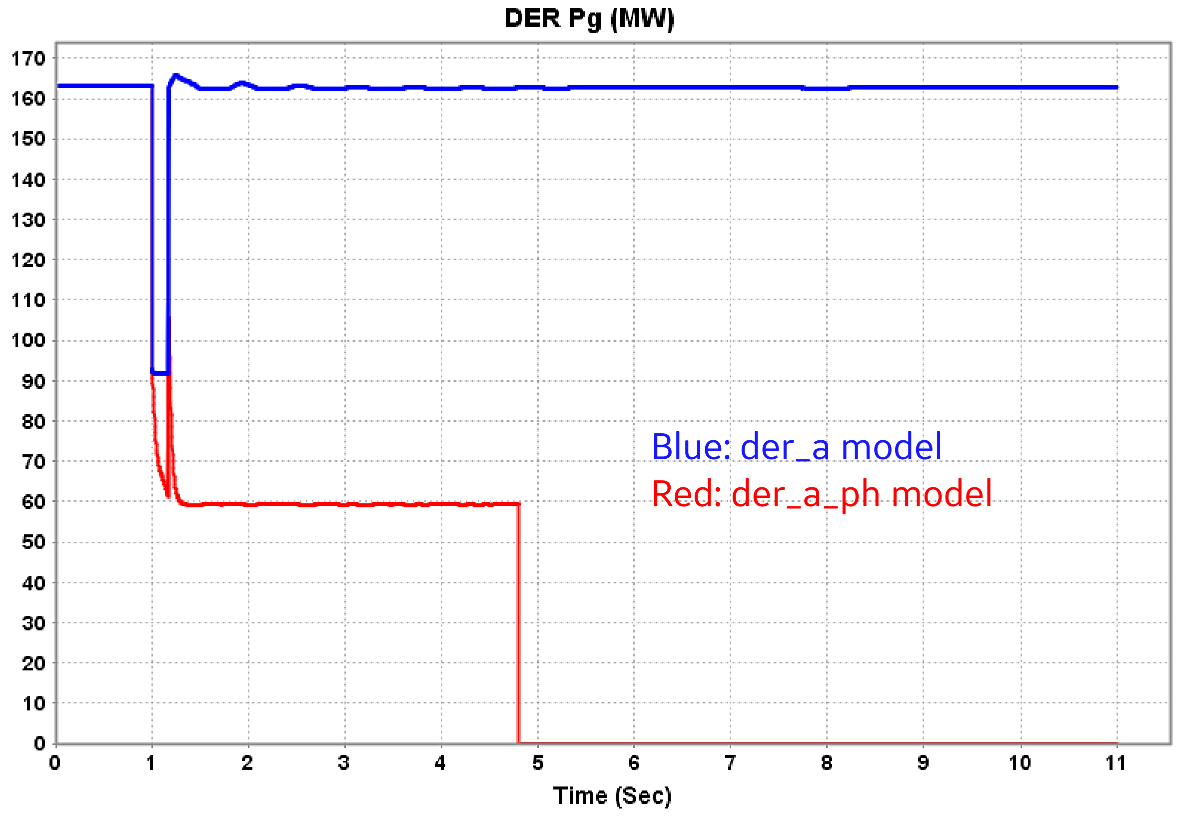
- Test: 9-bus simplified WECC system
  - 10-cycle SLG bus fault at high-side of GSU xfmr
- Default parameters used from NERC guideline [1]

Param	Value
vl0	0.44 pu
vl1	0.49 pu
vh0	1.2 pu
vh1	1.15 pu
Timers	0.16 s

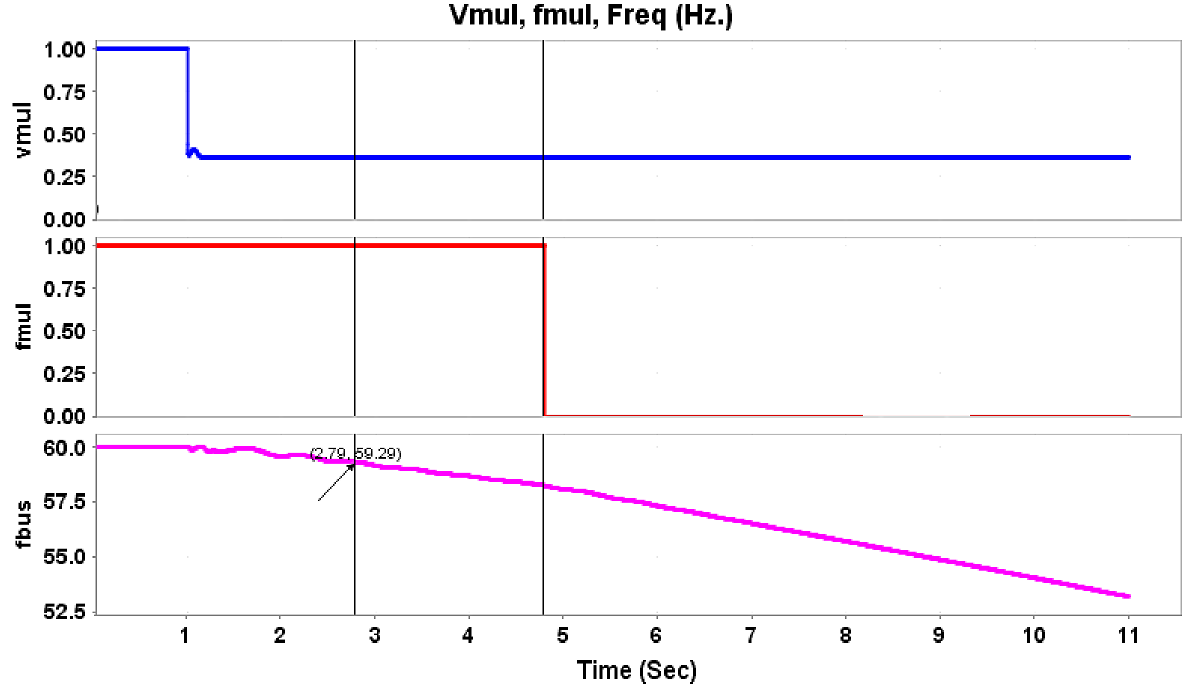


[1] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline-DER_A_Parameterization_2019-05-20.pdf

Experimental *der_a_ph* model: Use of individual phase voltage for the voltage cut-out block in *der_a*

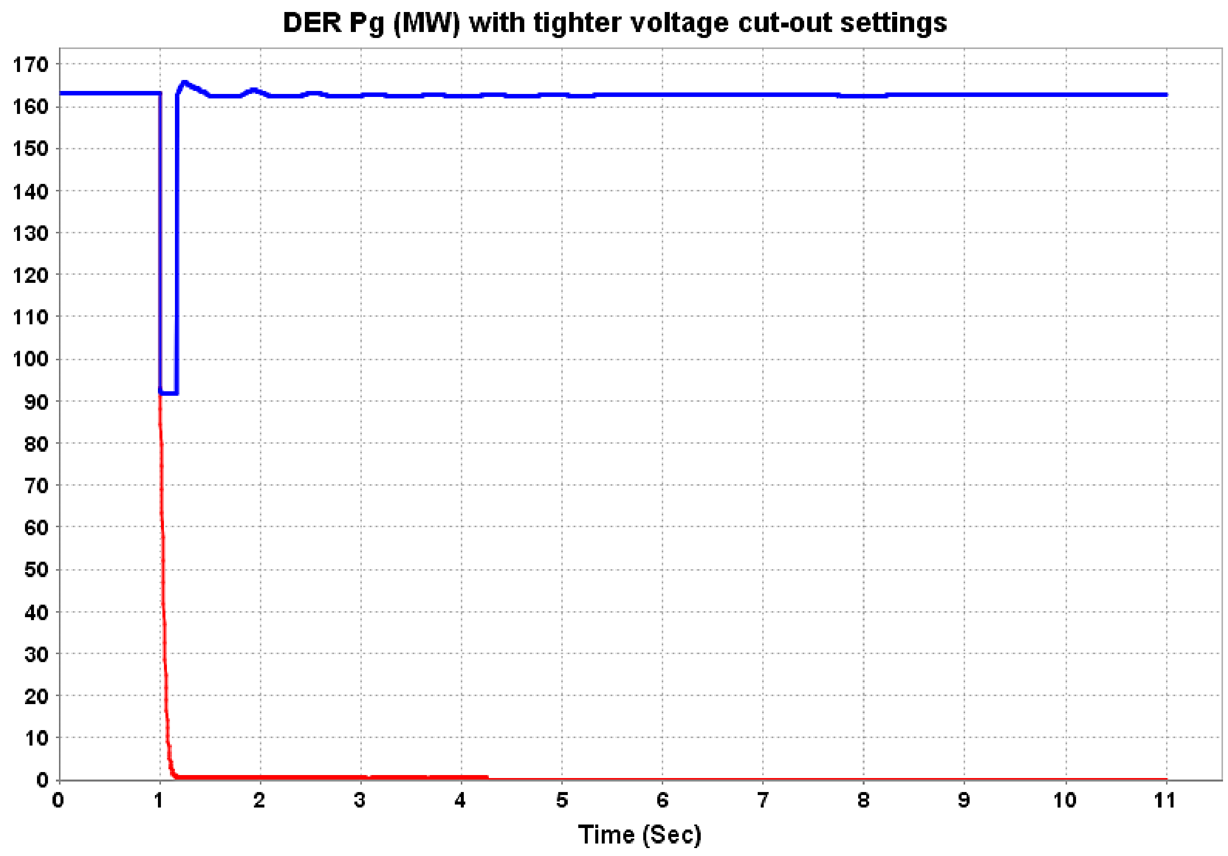


Voltage cut-out block output with *der_a_ph* model



Experimental *der_a_ph* model: Use of individual phase voltage for the voltage cut-out block in *der_a*

- Slightly tighter voltage trip thresholds
- Modified parameters: *vl0*=0.47, *vl1*=0.52



9-bus system, 10-cycle SLG bus fault at high-side of GSU xfmr:

Blue: der_a model

Red: der_a_ph model

Experimental modified version of generator low/high voltage protection model (*lhvrt*) accounting for individual phase voltages

Allow Per-phase Voltage/sequence Voltage-based Protection Modeling (user-defined models)

If lhvrt trips based on lowest/highest phase voltage:

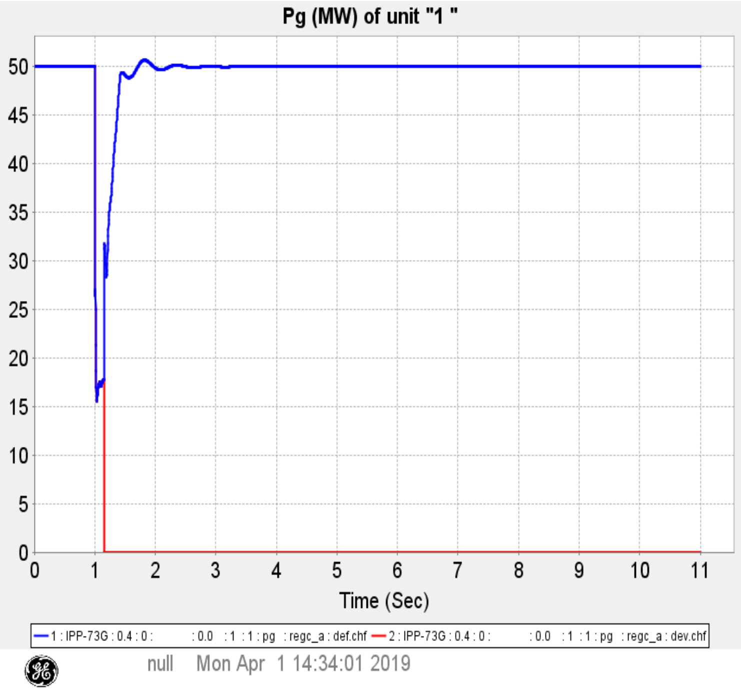
9-cycle single-line-ground fault applied at the high-side bus of step-up transformer for two PV plants :

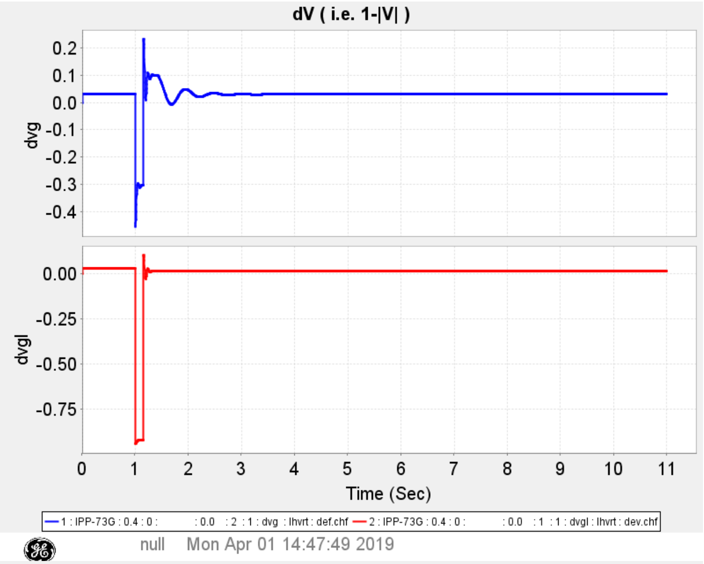
Blue: Official lhvrt model

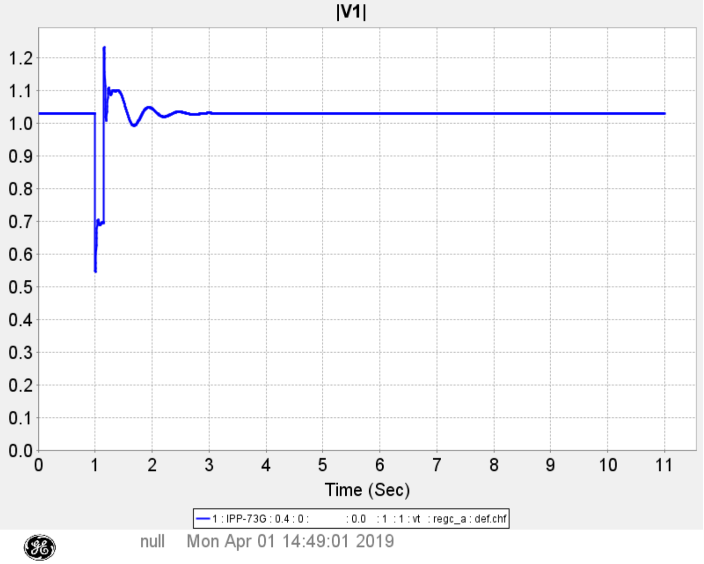
Red: Experimental lhvrt model

Two units tripped ~70 MW

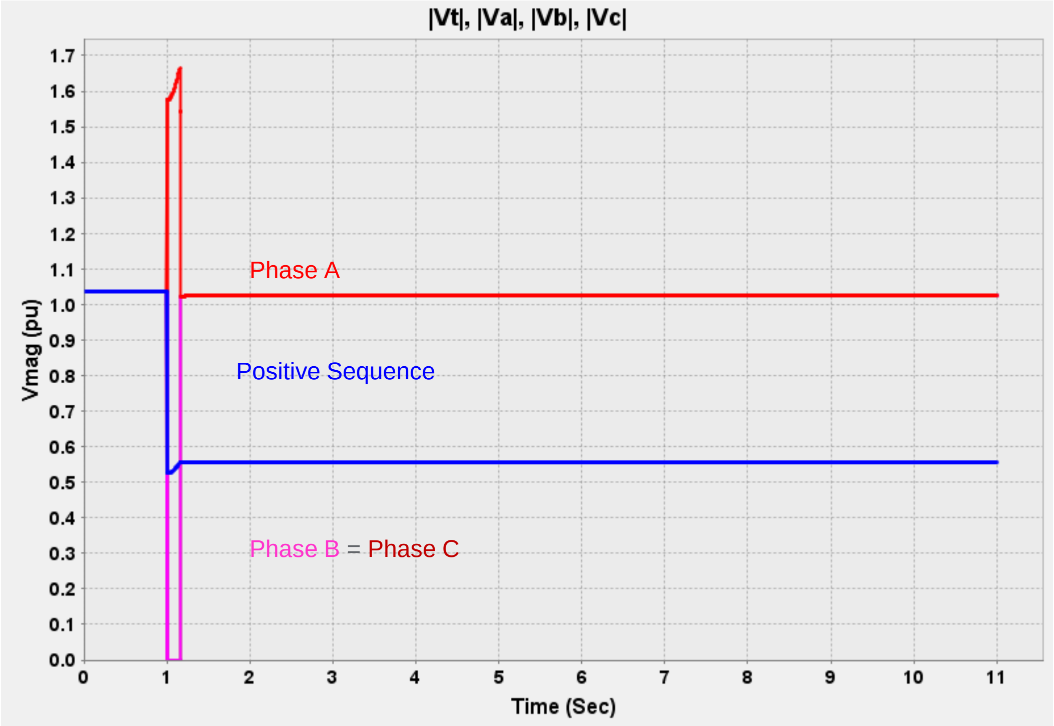
***NOTE: Experimental model for demonstration ONLY



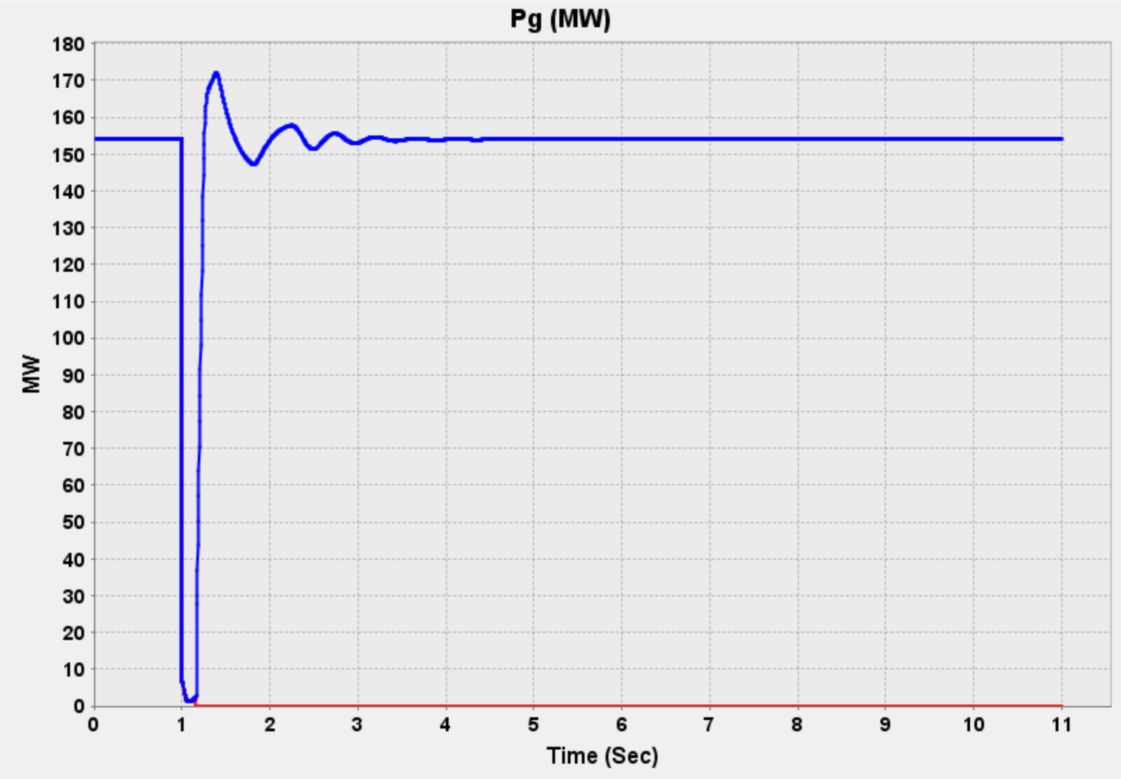




Modified *lhvrt* model



Phase A, B, C and positive sequence voltages at the PV terminal for LLG fault



Output of the PV unit for LLG fault: Blue : Original *lhvrt* model, Red : Modified *lhvrt* model using phase voltages.

WECC case 10-cycle solid LLG fault is applied at the terminals of a PV plant generating 155MW:

Blue: der_a model

Red: der_a_ph model

Other uses

- Could help parameterization of the der_a model unbalanced faults appropriately, since individual phase voltages can be monitored.
- Negative sequence current relay operation in conventional generators could be estimated during prolonged unbalanced conditions, such as a single line reclosing.
- The signals could also be used to capture motor contactor opening/closing actions more accurately.

Other uses

- Monitoring
- As more and more loads in the grid become drive-connected, one could also possibly take advantage the sequence/phase quantities to capture the behaviour such variable frequency drives more accurately in their models.
- Having access to these quantities could be useful in more accurate modelling of inverter-based resources such as the ability to model converter controls' protective functions, controls that actively suppress the negative sequence current produced by the inverter, and other such controls that use or control the negative sequence or zero sequence current injections.

GE Energy Consulting

https://www.geenergyconsulting.com/