Grid-Parallel and Islanding Operation Challenges of a Large Battery Energy Storage System at Cape Cod

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Inverter-based resources (IBRs) are non-traditional generation sources. IBR output may contain apparent positive and negative-sequence quantities that are not coherent with each other; as such, the traditional phasors used to determine fault direction do not reliably indicate the direction of faults sourced by IBRs [12].

Thus, the inverter may inject negative sequence current to the system during a fault, as shown in Fig. 9.

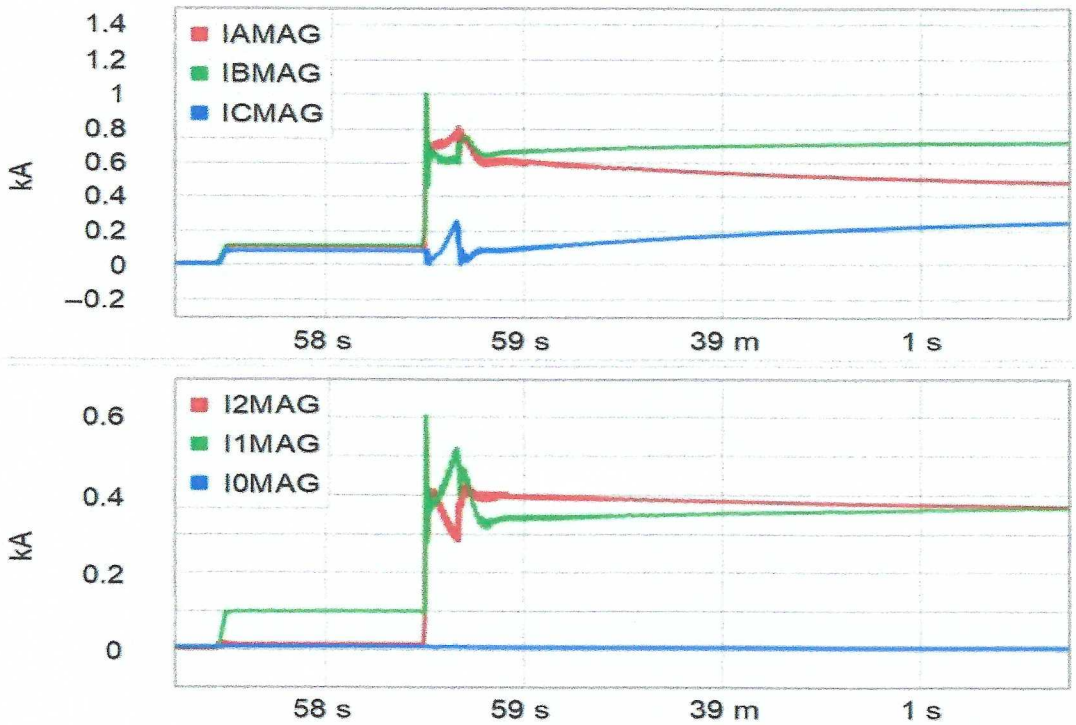


Fig. 9. Phase and sequence currents of a bolted AB fault when the inverter is in Virtual Impedance mode

Use of G.E. PSLF models for short circuit studies has been used in order to be compliant with NERC MOD-032 Standard ("Data for Power System Modeling and Analysis), which requires consistent steady-state, dynamic, and **short-circuit models**.

Using WECC G.E. PSLF base cases using the "ScCalculation" option and running dynamic simulation faults (which include the contribution of induction motors modeled in the composite load model to fault currents and generally show 10% higher fault currents than the static models) have agreed well (within 10%) with the short circuit values calculated by the standard short circuit programs such as ASPEN and Electrocon software.

As the base cases developed by WECC generally only have positive sequence data provided by the member systems, in order to do unbalanced fault calculations using the G.E. PSLF software models certain common assumptions must be made by the short circuit algorithms, as noted below:

When initializing fault analysis data, the PSLF Short Circuit Calculation sets up positive sequence data as follows:

--- All line and transformer positive sequence impedances are left unchanged

--- All loads are converted to equivalent constant shunt admittance, yl1

--- All fixed shunts and static VAR devices are treated as fixed shunt admittances, ys1, equal to the present shunt admittance values

--- Generators are set up as Thevenin equivalents of constant voltage behind the generator source impedance Zg1 (Zgenr + Zgenx)

--- D.C. converters are blocked

When initializing fault analysis data, the PSLF Short Circuit Calculation applies the following assumptions to set up negative and zero sequence data:

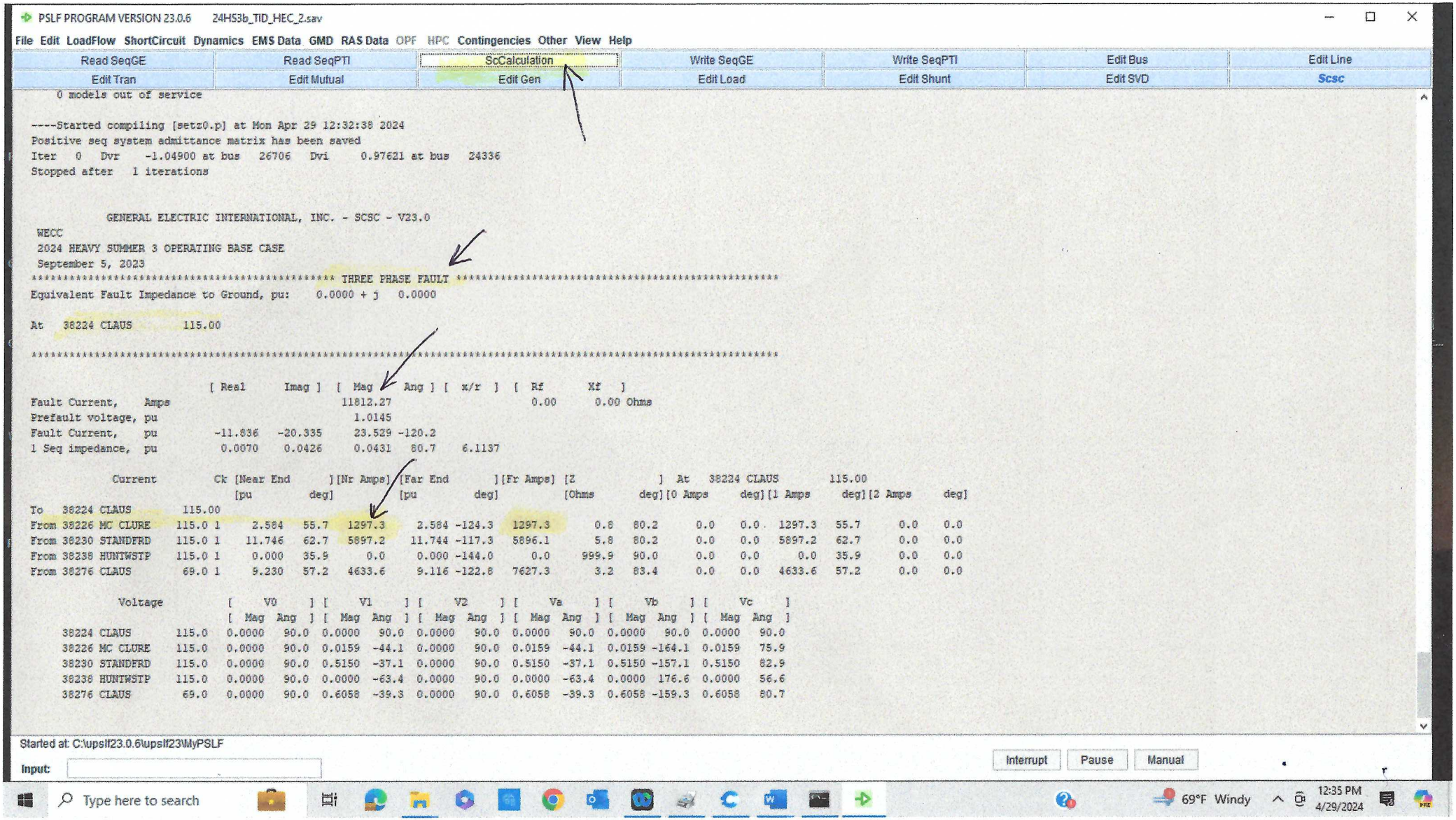
For transmission lines: $Z2 = Z1$, $b2 = b1$, $Z0 = 3Z1$, $b0 = b1/2$

For transformers: $Z0 = Z2 = Z1$

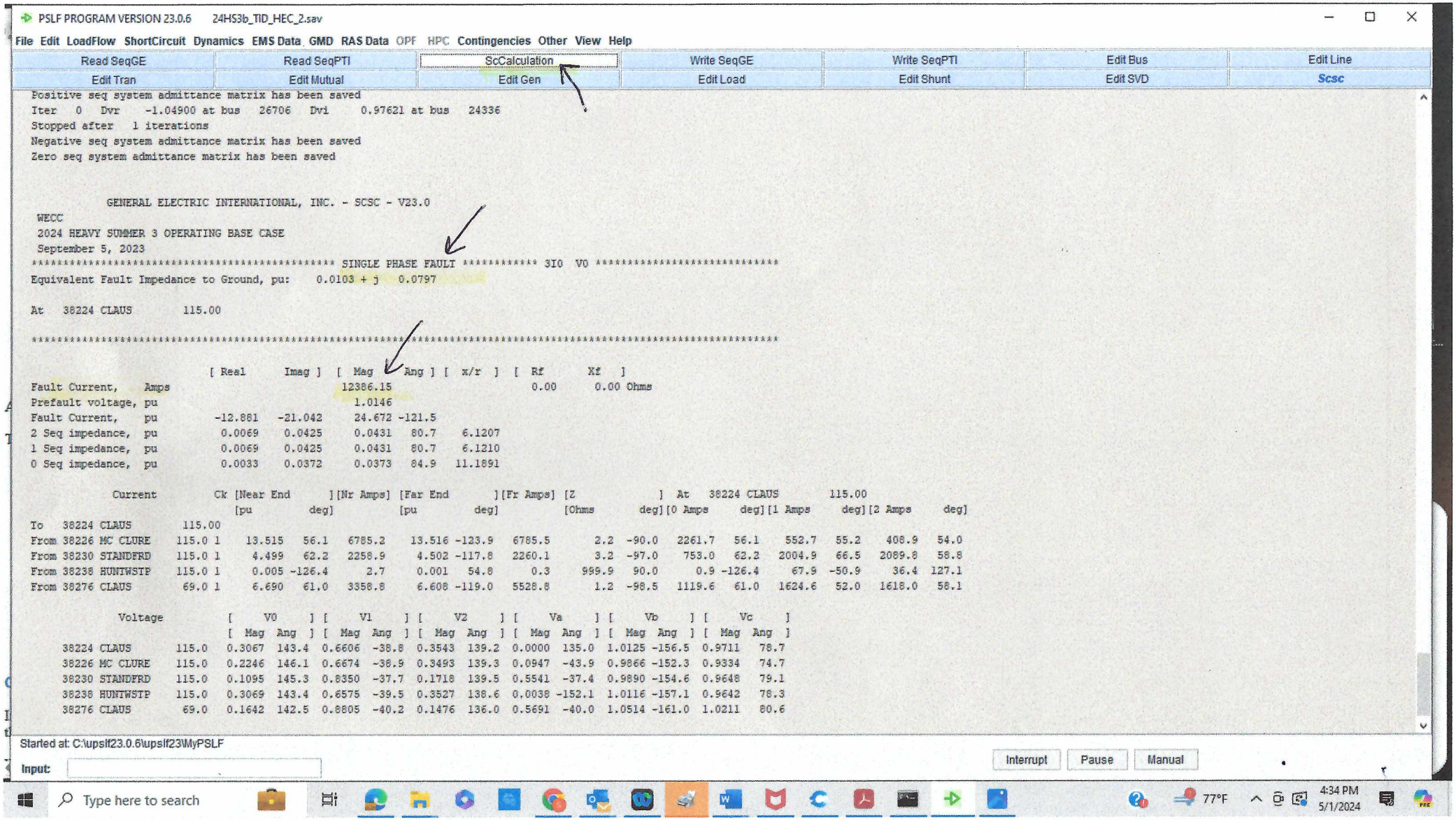
For loads: $y12 = y11$, $y10 = 0$

For shunts: $ys2 = ys1$, $ys0 = 0$

5

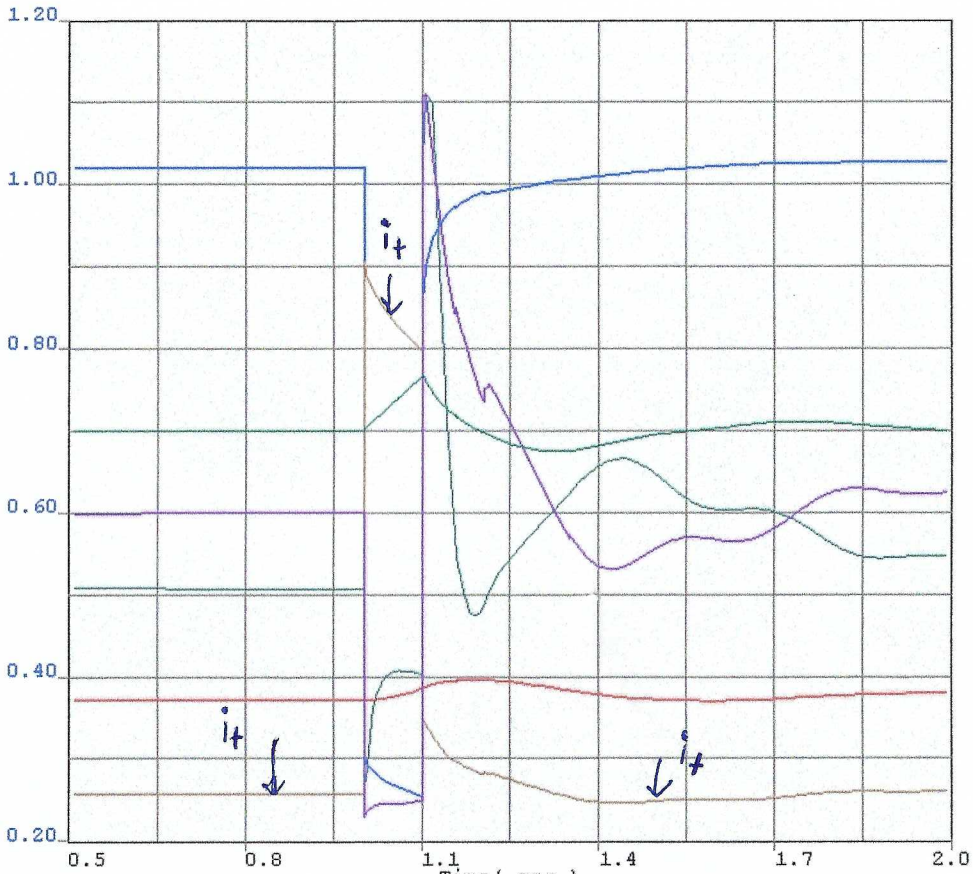

PSLF PROGRAM VERSION 23.0.6 24HS3b_TID_HEC_2.sav
File Edit LoadFlow ShortCircuit Dynamics EMS Data GMD RAS Data OPF HPC Contingencies Other View Help
Read SeqGE
Read SeqPTI
ScCalculation
Write SeqGE
Write SeqPTI
Edit Bus
Edit Line
Edit Tran
Edit Mutual
Edit Gen
Edit Load
Edit Shunt
Edit SVD
Scsc
0 models out of service
----Started compiling [setz0.p] at Mon Apr 29 12:32:38 2024
Positive seq system admittance matrix has been saved
Iter 0 Dvr -1.04900 at bus 26706 Dvi 0.97621 at bus 24336
Stopped after 1 iterations
GENERAL ELECTRIC INTERNATIONAL, INC. - SCSC - V23.0
WECC
2024 HEAVY SUMMER 3 OPERATING BASE CASE
September 5, 2023
********** THREE PHASE FAULT **********
Equivalent Fault Impedance to Ground, pu: 0.0000 + j 0.0000
At 38224 CLAUS 115.00
[Real Imag] [Mag Ang] [x/r] [Rf Xf]
Fault Current, Amps 11812.27 0.00 0.00 Ohms
Prefault voltage, pu 1.0145
Fault Current, pu -11.836 -20.335 23.529 -120.2
1 Seq impedance, pu 0.0070 0.0426 0.0431 80.7 6.1137
Current Ck [Near End][Nr Amps] [Far End][Fr Amps] [Z] At 38224 CLAUS 115.00
[pu deg] [pu deg] [Ohms deg] [0 Amps deg] [1 Amps deg] [2 Amps deg]
To 38224 CLAUS 115.00
From 38226 MC CLURE 115.0 1 2.584 55.7 1297.3 2.584 -124.3 1297.3 0.8 80.2 0.0 0.0 1297.3 55.7 0.0 0.0
From 38230 STANDFRD 115.0 1 11.746 62.7 5897.2 11.744 -117.3 5896.1 5.8 80.2 0.0 0.0 5897.2 62.7 0.0 0.0
From 38238 HUNTWSTP 115.0 1 0.000 35.9 0.0 0.000 -144.0 0.0 999.9 90.0 0.0 0.0 0.0 35.9 0.0 0.0
From 38276 CLAUS 69.0 1 9.230 57.2 4633.6 9.116 -122.8 7627.3 3.2 83.4 0.0 0.0 4633.6 57.2 0.0 0.0
Voltage [V0] [V1] [V2] [Va] [Vb] [Vc]
[Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang]
38224 CLAUS 115.0 0.0000 90.0 0.0000 90.0 0.0000 90.0 0.0000 90.0 0.0000 90.0 0.0000 90.0
38226 MC CLURE 115.0 0.0000 90.0 0.0159 -44.1 0.0000 90.0 0.0159 -44.1 0.0159 -164.1 0.0159 75.9
38230 STANDFRD 115.0 0.0000 90.0 0.5150 -37.1 0.0000 90.0 0.5150 -37.1 0.5150 -157.1 0.5150 82.9
38238 HUNTWSTP 115.0 0.0000 90.0 0.0000 -63.4 0.0000 90.0 0.0000 -63.4 0.0000 176.6 0.0000 56.6
38276 CLAUS 69.0 0.0000 90.0 0.6058 -39.3 0.0000 90.0 0.6058 -39.3 0.6058 -159.3 0.6058 80.7
Started at: C:\upslf23.0.6\upslf23\MyPSLF
Input:
Interrupt
Pause
Manual
Type here to search
69°F Windy
12:35 PM
4/29/2024

6


PSLF PROGRAM VERSION 23.0.6 24HS3b_TID_HEC_2.sav
File Edit LoadFlow ShortCircuit Dynamics EMS Data GMD RAS Data OPF HPC Contingencies Other View Help
Read SeqGE
Read SeqPTI
ScCalculation
Write SeqGE
Write SeqPTI
Edit Bus
Edit Line
Edit Tran
Edit Mutual
Edit Gen
Edit Load
Edit Shunt
Edit SVD
Scsc
Positive seq system admittance matrix has been saved
Iter 0 Dvr -1.04900 at bus 26706 Dvi 0.97621 at bus 24336
Stopped after 1 iterations
Negative seq system admittance matrix has been saved
Zero seq system admittance matrix has been saved
GENERAL ELECTRIC INTERNATIONAL, INC. - SCSC - V23.0
WECC
2024 HEAVY SUMMER 3 OPERATING BASE CASE
September 5, 2023
********** SINGLE PHASE FAULT ********** 3I0 V0 **********
Equivalent Fault Impedance to Ground, pu: 0.0103 + j 0.0797
At 38224 CLAUS 115.00
[Real Imag] [Mag Ang] [x/r] [Rf Xf]
Fault Current, Amps 12386.15 0.00 0.00 Ohms
Prefault voltage, pu 1.0146
Fault Current, pu -12.881 -21.042 24.672 -121.5
2 Seq impedance, pu 0.0069 0.0425 0.0431 80.7 6.1207
1 Seq impedance, pu 0.0069 0.0425 0.0431 80.7 6.1210
0 Seq impedance, pu 0.0033 0.0372 0.0373 84.9 11.1891
Current Ck [Near End][Nr Amps] [Far End][Fr Amps] [Z] At 38224 CLAUS 115.00
[pu deg] [pu deg] [Ohms deg][0 Amps deg][1 Amps deg][2 Amps deg]
To 38224 CLAUS 115.00
From 38226 MC CLURE 115.0 1 13.515 56.1 6785.2 13.516 -123.9 6785.5 2.2 -90.0 2261.7 56.1 552.7 55.2 408.9 54.0
From 38230 STANDFRD 115.0 1 4.499 62.2 2258.9 4.502 -117.8 2260.1 3.2 -97.0 753.0 62.2 2004.9 66.5 2089.8 58.8
From 38238 HUNTWSTP 115.0 1 0.005 -126.4 2.7 0.001 54.8 0.3 999.9 90.0 0.9 -126.4 67.9 -50.9 36.4 127.1
From 38276 CLAUS 69.0 1 6.690 61.0 3358.8 6.608 -119.0 5528.8 1.2 -98.5 1119.6 61.0 1624.6 52.0 1618.0 58.1
Voltage [V0] [V1] [V2] [Va] [Vb] [Vc]
[Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang] [Mag Ang]
38224 CLAUS 115.0 0.3067 143.4 0.6606 -38.8 0.3543 139.2 0.0000 135.0 1.0125 -156.5 0.9711 78.7
38226 MC CLURE 115.0 0.2246 146.1 0.6674 -38.9 0.3493 139.3 0.0947 -43.9 0.9866 -152.3 0.9334 74.7
38230 STANDFRD 115.0 0.1095 145.3 0.8350 -37.7 0.1718 139.5 0.5541 -37.4 0.9890 -154.6 0.9648 79.1
38238 HUNTWSTP 115.0 0.3069 143.4 0.6575 -39.5 0.3527 138.6 0.0038 -152.1 1.0116 -157.1 0.9642 78.3
38276 CLAUS 69.0 0.1642 142.5 0.8805 -40.2 0.1476 136.0 0.5691 -40.0 1.0514 -161.0 1.0211 80.6
Started at: C:\upslf23.0.6\upslf23\MyPSLF
Input:
Interrupt
Pause
Manual
Type here to search
77°F
4:34 PM
5/1/2024

2024 HS McClure Synchronous Gas Turbine Generator Response to 3PH FLT at CLS 115 kV Bus with 6 CYC Clearing

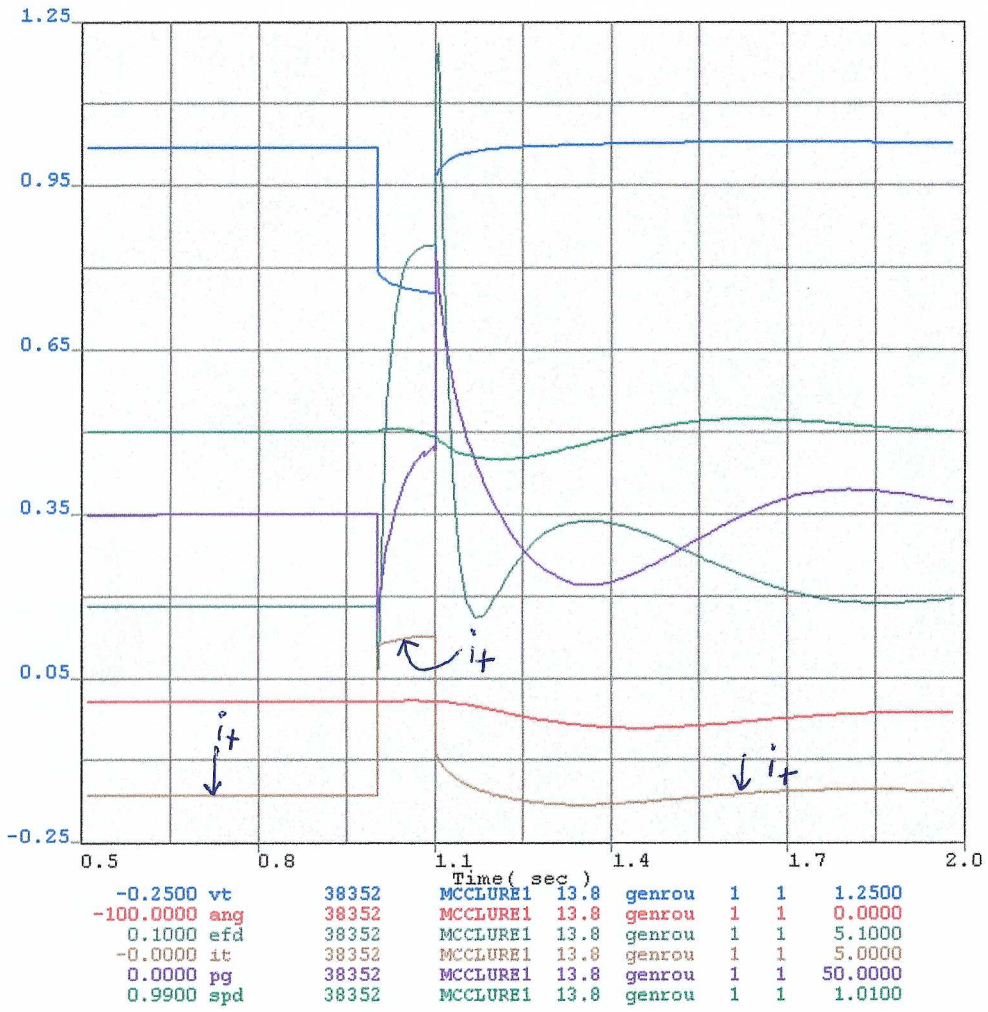
7



0.2000 vt	38352	MCCLURE1	13.8	genrou	1	1	1.2000
-100.0000 ang	38352	MCCLURE1	13.8	genrou	1	1	0.0000
0.0000 efd	38352	MCCLURE1	13.8	genrou	1	1	5.0000
0.0000 it	38352	MCCLURE1	13.8	genrou	1	1	5.0000
-0.0000 pg	38352	MCCLURE1	13.8	genrou	1	1	50.0000
0.9900 spd	38352	MCCLURE1	13.8	genrou	1	1	1.0100

2024 HS McClure Synchronous Gas Turbine Generator Response to LN-GND FLT at CLS 115 kV Bus with 6 CYC Clearing

8



-0.2500 vt	38352	MCCLURE1	13.8	genrou	1	1	1.2500
-100.0000 ang	38352	MCCLURE1	13.8	genrou	1	1	0.0000
0.1000 efd	38352	MCCLURE1	13.8	genrou	1	1	5.1000
-0.0000 it	38352	MCCLURE1	13.8	genrou	1	1	5.0000
0.0000 pg	38352	MCCLURE1	13.8	genrou	1	1	50.0000
0.9900 spd	38352	MCCLURE1	13.8	genrou	1	1	1.0100

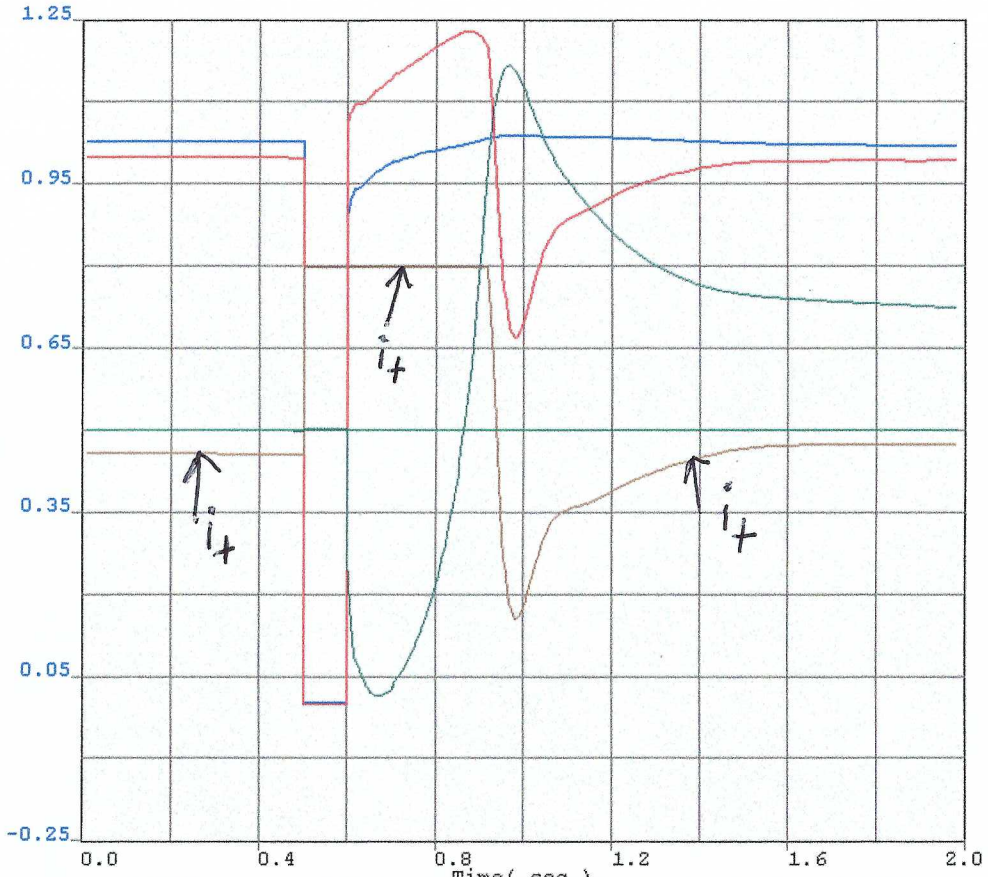
Update to latest Grid Forming Model (GFM) by Spencer Tacke (Auriga Corporation) 1-31-24

regfm_a1 38409 "TID_HEC" 115.00 "1" : #2 mva=100.00 "tpf" 0.02 "tqf" 0.02 "tvf" 0.02 "re" 0.02 "xL" 0.20 "imax" 1.2 "Emax" 1.15 "Emin" 0.0 "Pmax" 1.0 "Pmin" 0.0 "Qmax" 1.0 "Qmin" -1.0 "mp" 0.01 "mq" 0.05 "kpv" 0.0 "kiv" 5.0 "kppmax" 0.01 "kipmax" 0.1 "kpqmax" 3.0 "kiqmax" 20.0 "vflag" 1.0

reec_b 38409 "TID_HEC" 115.00 "1 " : #2 "mvab" 0.0 "vdip" 0.90 "vup" 1.1 "trv" 0.01 "dbd1" -0.10 "dbd2" 0.10 "kqv" 2.0 "iqh1" 1.0 "iql1" -1.0 "vref0" 0.0 "tp" 0.05 "qmax" 0.60 "qmin" -0.60 "vmax" 1.20 "vmin" 0.80 "kqp" 1.0 "kqi" 1.0 "kvp" 1.0 "kvi" 1.0 "tiq" 0.46 "dpmax" 1.0 "dpmin" -1.00 "pmax" 1.0 "pmin" 0.0 "imax" 1.0 "tpord" 0.460 "pfflag" 0.0 "vflag" 1.0 "qflag" 1.0 "pqflag" 0.0

repc_a 38409 "TID_HEC" 115.00 "1" : #2 "mvab" 0.0 "tfltr" 0.04 "kp" 0.0 "ki" 0.1 "tft" 0.0 "tfv" 0.04 "refflg" 1 "vfrz" 0.88 "rc" 0.0893 "xc" 0.6743 "kc" 0.04 "vcmpflg" 1 "emax" 5 "emin" -5 "dbd" 0.0010 "qmax" 0.2850 "qmin" -0.2850 "kpg" 0.0 "kig" 0.5 "tp" 0.0 "fdbd1" 0 "fdbd2" 0 "femax" 999 "femin" -999 "pmax" 1.0 "pmin" 0.0 "tlag" 0.04 "ddn" 0.04 "dup" 0.0 "frqflg" 0 "outflag" 0

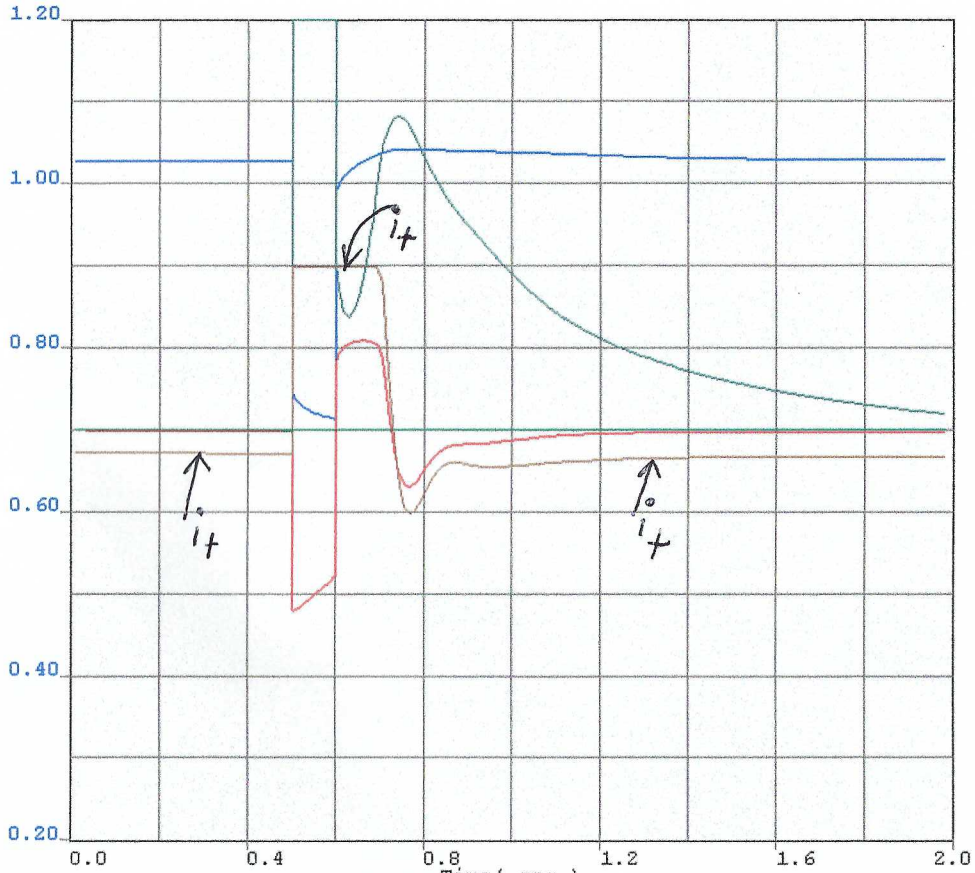
2024 HS PV Plant Response to 3 PH FLT at adjacent 115 kV Bus with 6 CYC Clearing and using the REGFM_A1 Grid Forming Inverter Model



-0.2500 vt	38409	TID_HEC 115.0regfm_a1	1	1	1.2500
-25.0000 pg	38409	TID_HEC 115.0regfm_a1	1	1	125.0000
-50.0000 qg	38409	TID_HEC 115.0regfm_a1	1	1	50.0000
0.5000 it	38409	TID_HEC 115.0regfm_a1	1	1	1.5000
-1.0000 vinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000
-1.0000 pinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000

2024 HS PV Plant Response to 1 PH-GND FLT at adjacent 115 kV Bus with 6 CYC Clearing and using the REGFM_A1 Grid Forming Inverter Model

11



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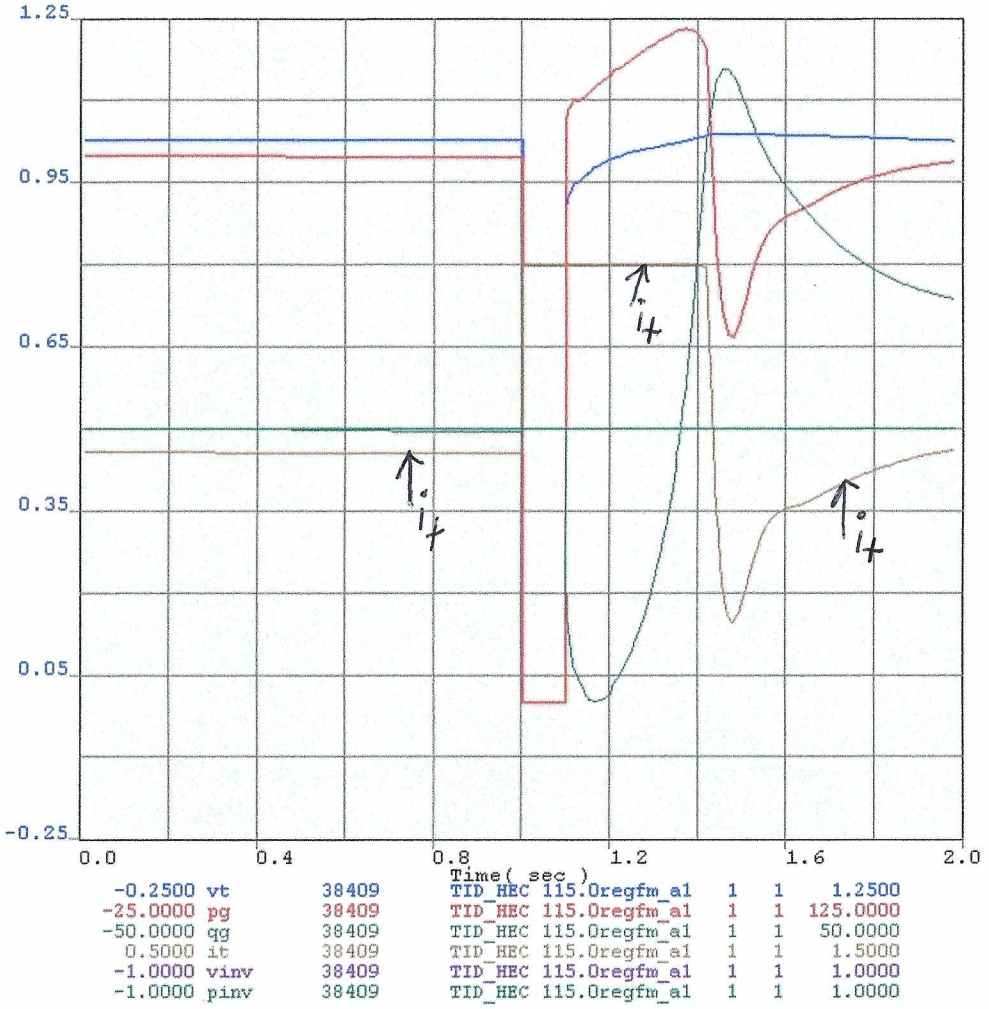
-50.0000 qg	38409	TID_HEC 115.0regfm_a1	1	1	50.0000
0.5000 it	38409	TID_HEC 115.0regfm_a1	1	1	1.5000
-1.0000 vinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000
-1.0000 pinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000

2024 HS PV Plant Response to 3PH FLT with 6 CYC Clearing and using the REGFM_A1 Grid Forming Inverter Model

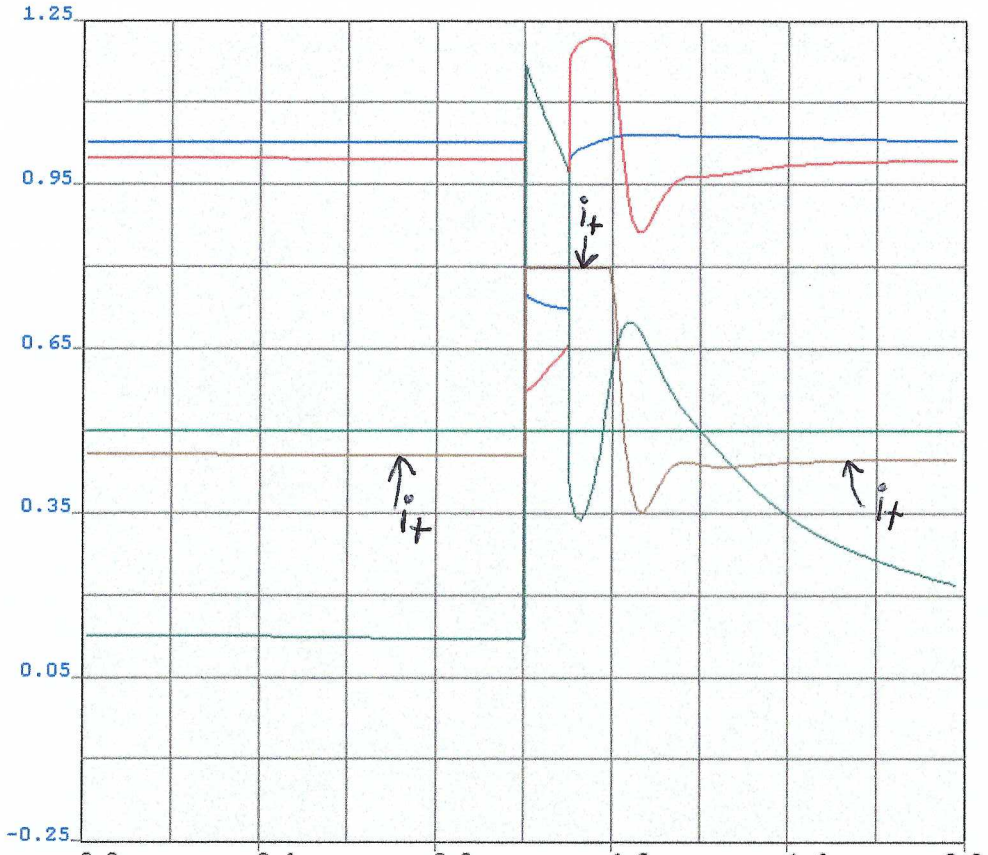
12



-0.2500 vt	38409	TID_HEC 115.0regfm_a1	1	1	1.2500
-25.0000 pg	38409	TID_HEC 115.0regfm_a1	1	1	125.0000
-50.0000 qg	38409	TID_HEC 115.0regfm_a1	1	1	50.0000
0.5000 it	38409	TID_HEC 115.0regfm_a1	1	1	1.5000
-1.0000 vinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000
-1.0000 pinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000

2024 HS PV Plant Response to 1PH-GRN FLT with 6 CYC Clearing and using the REGFM_A1 Grid Forming Inverter Model

13

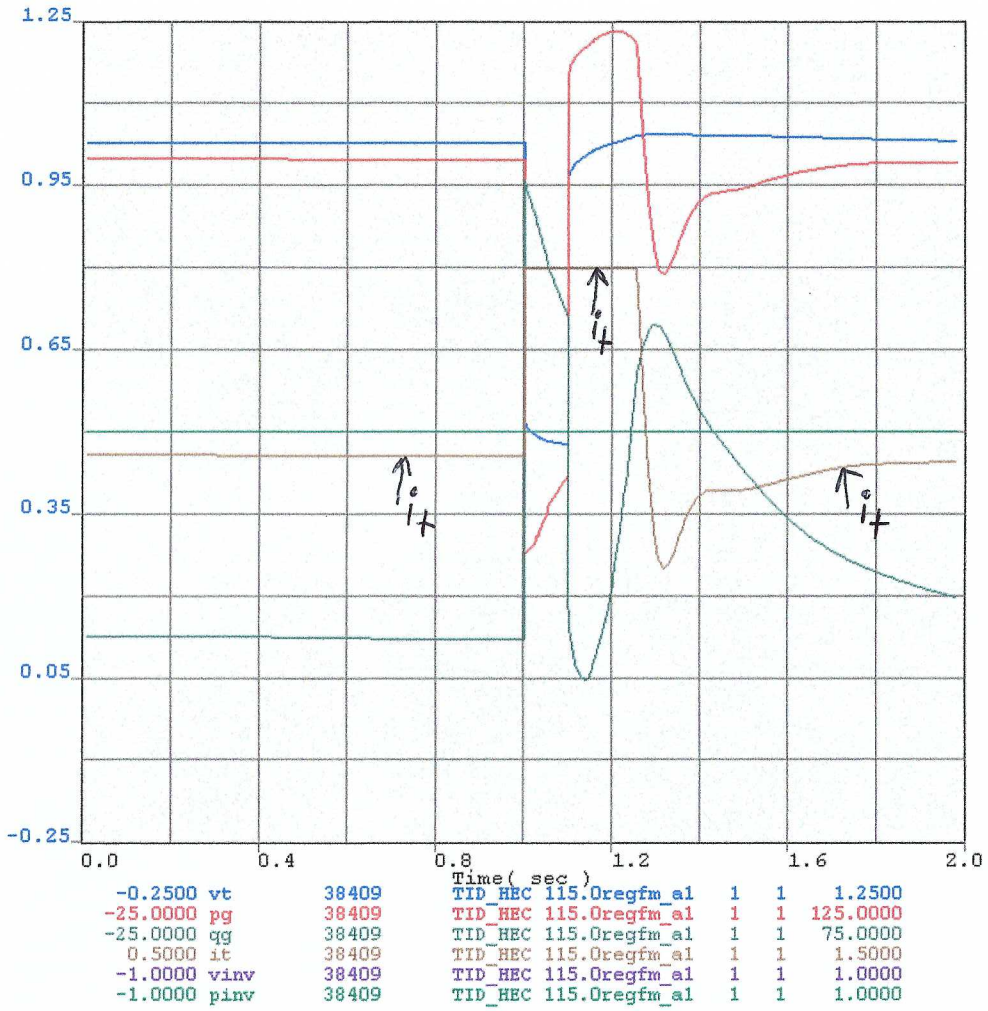


-0.2500 vt	38409	TID_HEC 115.0regfm_a1	1	1	1.2500
-25.0000 pg	38409	TID_HEC 115.0regfm_a1	1	1	125.0000
-25.0000 qg	38409	TID_HEC 115.0regfm_a1	1	1	75.0000
0.5000 it	38409	TID_HEC 115.0regfm_a1	1	1	1.5000
-1.0000 vinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000
-1.0000 pinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000

2024 HS PV Plant Response to LN-LN FLT with 6 CYC Clearing and using the REGFM_A1 Grid Forming Inverter Model

<Public>

14



-0.2500 vt	38409	TID_HEC 115.0regfm_a1	1	1	1.2500
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-25.0000 qg	38409	TID_HEC 115.0regfm_a1	1	1	75.0000
0.5000 it	38409	TID_HEC 115.0regfm_a1	1	1	1.5000
-1.0000 vinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000
-1.0000 pinv	38409	TID_HEC 115.0regfm_a1	1	1	1.0000