WECC Short-Circuit Modeling Subcommittee

Blackbox Modelling of Inverter-Based Resources

for Short-Circuit Analysis (Part of DOE DE-EE0010658 Project)

November 14, 2024

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AGENDA

- DOE DE-EE0010658 Project
- Latest Update
- Result Comparison with EMT
- Lessons Learned
    - VRT Detection
    - VRT Injection
    - Angle Rotation for 3Ph Close-In Faults
    - Current Limits with I2 Injection
- Summary of Model Development
- Comparison of Aspen and PSCAD

SWAP Tool for IBRs
PG&E DE-EE0010658 Nov 14,2024

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A Sensitivity-Driven Wide Area Protection (SWAP) Coordination Tool for High Penetration of Inverter Based Resources (IBRs)
Pacific Gas & Electric Company (PG&E)
Award # DE-EE00010658

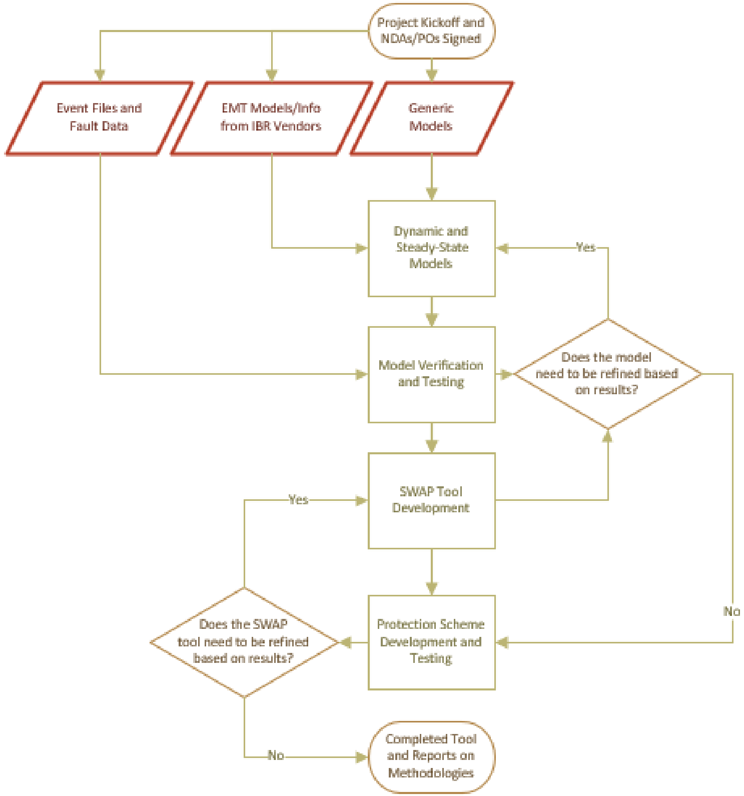
Project Objectives

- **Objective 1:** Improve IBR models used in short circuit programs to accurately capture the response of IBR at the Bulk Power System (BPS) level for fault and protection studies.

- **Objective 2:** Develop an automation tool that allows engineers to identify protection coordination and sensitivity issues by performing short-circuit and protection coordination studies in an IBR-penetrated grid by applying variations to the IBR models, faults, contingencies, etc.

- **Objective 3:** Develop new protection mitigation solutions schemes that complements the existing protection systems to ensure safe operation of the BPS with higher IBR penetration levels. Protection systems will include different types of line, bus, and transformer protection schemes.

Approach



Mike Jensen

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Supporting Organizations

Inverter Manufacturer

Relay Manufacturer

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Key Milestones & Deliverables

Year 1

- All the protection data is gathered and reviewed.
- First version of the IBR model is developed.
- The modeling specification document is ready.

Year 2

- IBR short-circuit model is verified and integrated.
- The SWAP coordination tool is ready.
- Wide-area coordination results are ready.

Year 3

- Protection solutions are developed
- Testing and validation of solution(s) completed.

Overview of Proposed Approach

1 Utility Perspective on IBR Protection Issues

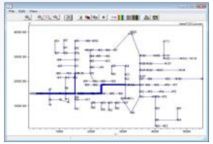
2 IBR Model Improvement

- Industry and Literature Survey
- Std./Code Requirements (e.g., IEEE Std. 2800)
- Manufacturer Data
- Utility System Data
- Fault Event Data

3 Model Validation (PSCAD model, Field data, test data, etc.)

Model Validation (HIL Type Testing)

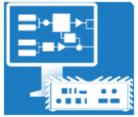
4 Sensitivity-Driven Wide-Area Protection Coordination Tool



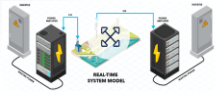
User Interface

Stochastic Scenario Planning (including generation profile, load conditions, penetration levels, IBR type, IBR location, fault type, fault location, etc.)

5 Protection Solution(s) and Implementation



6 Large-Scale Solution Validation and Verifications (HIL Testing)



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Utility Perspective

Modeling Challenges

- Fault simulation software vendors do not have a comprehensive IBR model.
  - The “Voltage Controlled Current Source” (VCCS) model has limitations.
- The current IBR models are removed when reducing the network
- Convergence issues with VCCS IBR models.
- It’s difficult to get modeling data in a timely manner from manufacturers. Manufacturers may want to sign non-disclosure agreements (NDA) that take months to finalize.
- Time domain analysis (using EMTP and PSCAD) is not practical.
- Most of the utilities are still modeling IBRs as synchronous machines.

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Pacific Gas & Electric Company (PG&E)
Award # DE-EE00010658

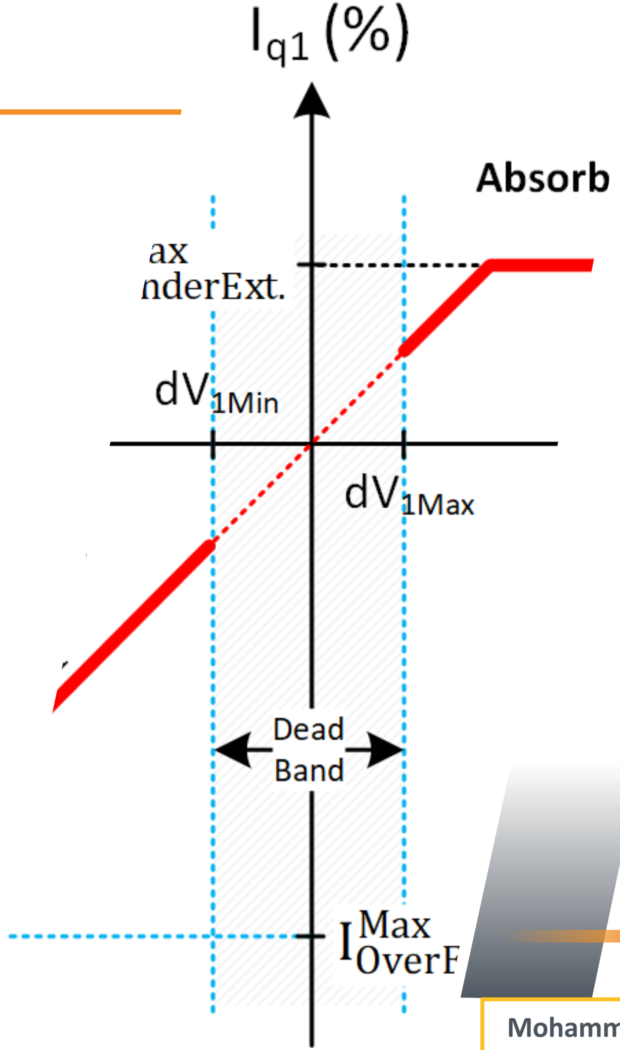
DOE Project

- Part of DOE project "Award Number DE-EE00010658"
  - Plan to develop SC Blackbox models for four vendors.
  - Three already completed.
- Modeling Approach
  - Use an agreed interface between ETAP and Aspen
  - Received PSCAD Blackbox models from three vendors so far
  - No detailed information provided by vendors about the control logic
  - Guess control logic related to short-circuit based on settings and EMT studies

Latest Updates

Modeling Approach

- Voltage Ride Through detection & injection logic
- Current limit logic especially in case of negative seq. injection
- Determine control strategy during angle rotation (close-in 3ph fault)
- Determine control strategy for pre-fault (load flow)
  - PQ priority, QV Droop, Current Limit



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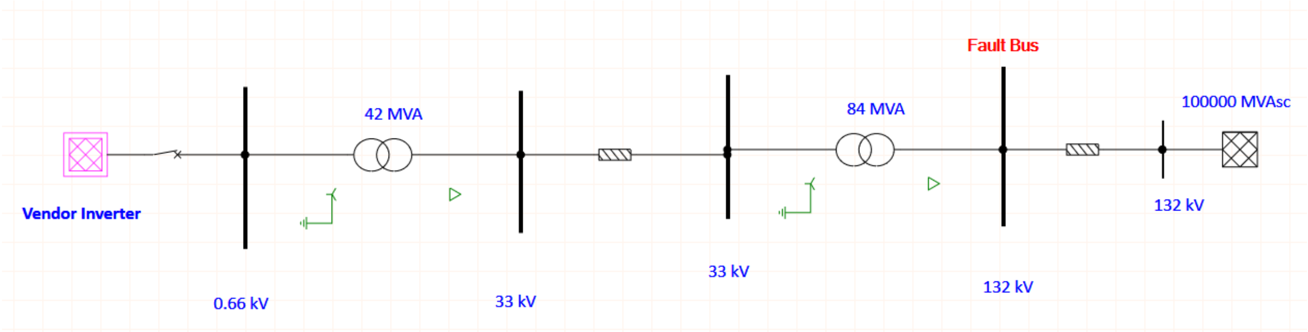
Result Comparison with EMT

Test Setup in ETAP



- Results are reported for default IBR settings
- Testing has been done for different settings
- Similar levels of error have been achieved.

Result Comparison ETAP with EMT

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Vendor 1

Errors for Close-in Faults

	$\|V_1\|$ (%)	$\angle V_1$ (°)	$\|I_1\|$ (%)	$\angle I_1$ (°)	$\|V_2\|$ (%)	$\angle V_2$ (°)	$\|I_2\|$ (%)	$\angle I_2$ (°)
3Ph	0.1	---	0.0	---	---	---	---	---
LG	0.0	0.05	0.3	0.12	0.1	0.04	0.2	0.40
LLG	0.0	0.13	0.1	0.44	0.1	0.07	0.1	0.20
LL	0.1	0.02	0.3	0.33	0.0	0.09	0.2	0.34

Errors for Remote Faults

	$\|V_1\|$ (%)	$\angle V_1$ (°)	$\|I_1\|$ (%)	$\angle I_1$ (°)	$\|V_2\|$ (%)	$\angle V_2$ (°)	$\|I_2\|$ (%)	$\angle I_2$ (°)
3Ph	0.0	0.07	0.0	0.16	---	---	---	---
LG	0.1	0.06	0.2	0.0	0.0	0.35	0.1	0.38
LLG	0.1	0.14	0.1	0.18	0.0	0.03	0.1	0.61
LL	0.2	0.04	0.5	0.02	0.1	0.14	0.2	0.34

Max Error
- Mag: 0.3%
- Angle: 0.44°

Max Error
- Mag: 0.5%
- Angle: 0.61°

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Result Comparison ETAP with EMT

Vendor 2

PLL Freeze

Errors for Close-in Faults

	$\|V_1\|$ (%)	$\angle V_1$ (°)	$\|I_1\|$ (%)	$\angle I_1$ (°)	$\|V_2\|$ (%)	$\angle V_2$ (°)	$\|I_2\|$ (%)	$\angle I_2$ (°)
3Ph	0.3	7.34	2.2	7.82	0.1	---	1.1	---
LG	0.1	0.00	0.4	0.11	0.1	0.33	0.5	0.04
LLG	0.4	0.14	1.7	0.61	0.2	0.04	0.6	0.30
LL	0.05	0.05	0.4	0.74	0.1	0.14	0.7	0.38

Max Error
- Mag: 2.2% , 1.7% (no PLL Freeze)
- Angle: 7.82°, 0.86°(no PLL Freeze)

Errors for Remote Faults

	$\|V_1\|$ (%)	$\angle V_1$ (°)	$\|I_1\|$ (%)	$\angle I_1$ (°)	$\|V_2\|$ (%)	$\angle V_2$ (°)	$\|I_2\|$ (%)	$\angle I_2$ (°)
3Ph	0.5	0.12	1.2	1.15	---	---	---	---
LG	0.1	0.05	0.3	0.12	0.2	0.01	0.7	0.47
LLG	0.3	0.16	1.4	0.48	0.1	0.11	0.6	0.27
LL	0.3	0.12	1.4	0.78	0.14	0.06	0.3	0.48

Max Error
- Mag: 1.4%
- Angle: 0.78°

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Result Comparison ETAP with EMT

Vendor 3

Errors for Close-in Faults

	$\lvert V_1 \rvert$ (%)	$\angle V_1$ (°)	$\lvert I_1 \rvert$ (%)	$\angle I_1$ (°)	$\lvert V_2 \rvert$ (%)	$\angle V_2$ (°)	$\lvert I_2 \rvert$ (%)	$\angle I_2$ (°)
3Ph	0.1	---	1.0	---	---	---	---	---
LG	0.3	0.84	1.4	1.01	0.3	0.56	1.1	0.76
LLG	0.4	0.03	1.6	0.22	0.1	0.11	0.2	0.09
LL	0.3	0.03	1.5	0.2	0.1	0.07	0.3	0.11

Max Error
- Mag: 1.6%
- Angle: 1.01°

Errors for Remote Faults

	$\lvert V_1 \rvert$ (%)	$\angle V_1$ (°)	$\lvert I_1 \rvert$ (%)	$\angle I_1$ (°)	$\lvert V_2 \rvert$ (%)	$\angle V_2$ (°)	$\lvert I_2 \rvert$ (%)	$\angle I_2$ (°)
3Ph	0.2	0.22	0.7	0.45	---	---	---	---
LG	0.12	0.05	0.5	0.16	0.1	0.22	0.6	0.05
LLG	0.15	0.10	0.4	0.43	0.96	0.28	0.5	0.10
LL	0.1	0.04	0.4	0.40	0.0	0.24	0.9	0.09

Max Error
- Mag: 0.96%
- Angle: 0.45°

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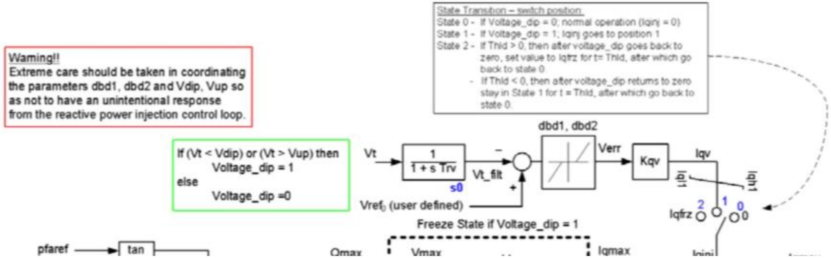
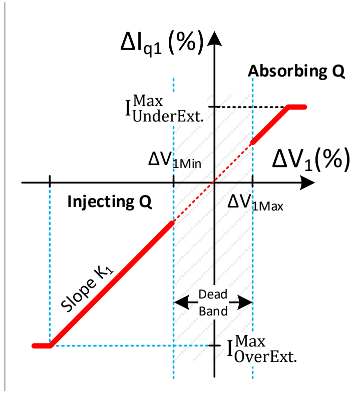
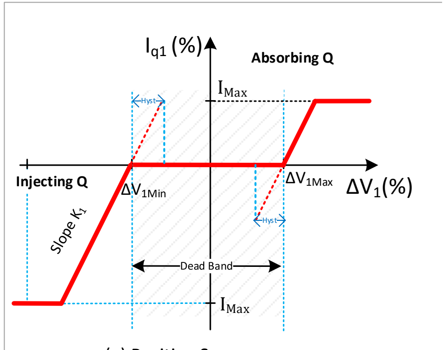
Lessons Learned

VRT Detection



- Vendor 1: Options for Positive seq. and Min Ph-Ph, Hysteresis
- Vendor 2: Min Ph-Ph, Hysteresis
- Vendor 3: Based on V_1 and V_2, Single Threshold + Timer





(a) Positive Seq.

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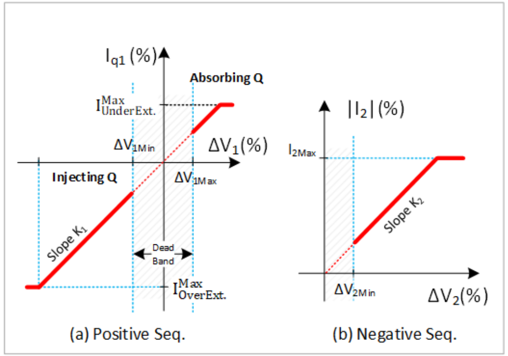
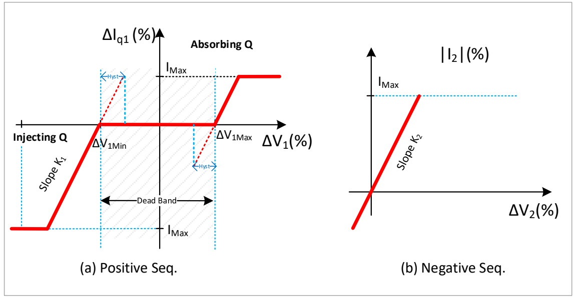
Lessons Learned

VRT Injection

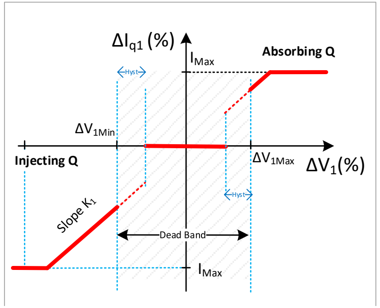
- Vendor 1: Options for Positive seq. and Min Ph-Ph for I_{q1}
- Vendor 2: Positive seq. for I_{q1}.
- Vendors 1&2 : Option for ΔV_1: V_{Nom} vs V_{Set}
- Vendor 3: Positive seq. for I_{q1}, deadband for $I_{2,}$ The maximum possible power factor angle is 79.5° (not 90°), when sufficient active power is available.

Generic Model

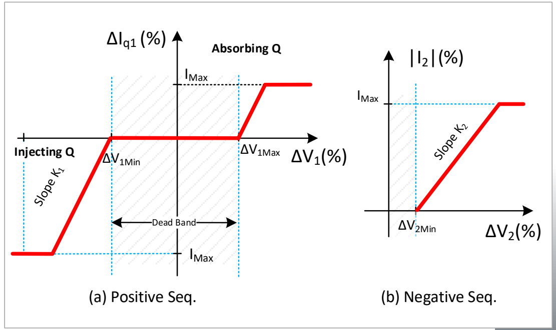




Vendor 1 & 2 (V_{Set})



Vendor 1 & 2 (V_{Nom})



Vendor 3

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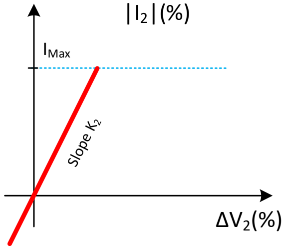
Lessons Learned

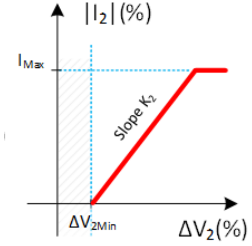
VRT Injection

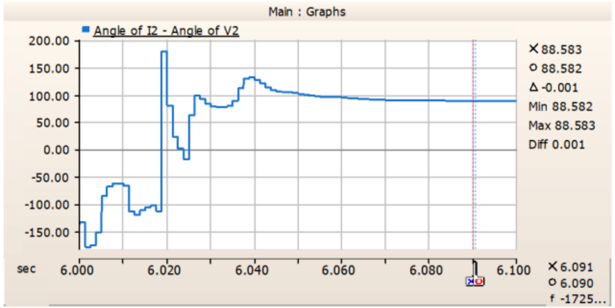
- I_2 injection is tied to VRT mode
    - Vendor 1: Independent
    - Vendors 2&3: Dependent
- Vendor 1&2: Negative seq. FRT curve passes through the origin.
- Vendor 3: Negative seq. FRT curve is continuous.
- Negative seq. transient is slow

Vendors 1&2

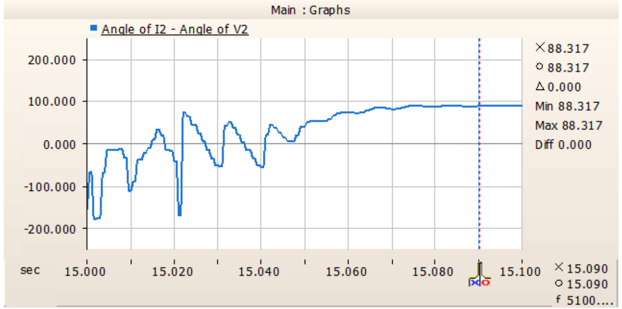


Vendor 3

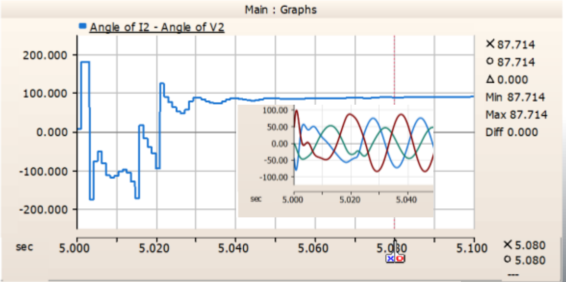




Vendor 1, BCG



Vendor 2, BCG



Vendor 3, BCG

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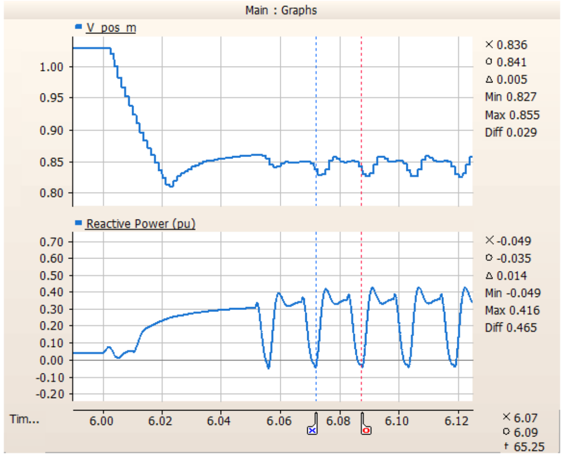
Lessons Learned

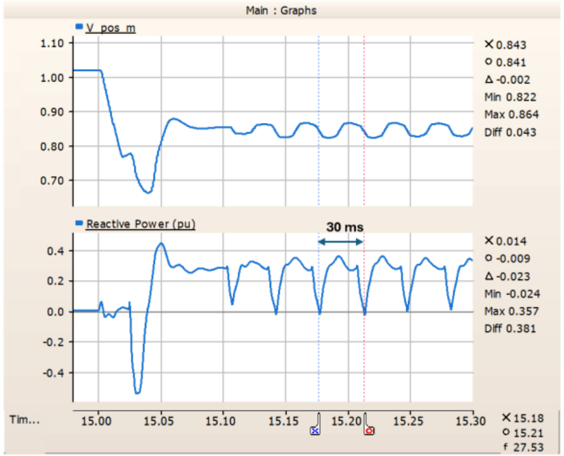
VRT Disabled Hysteresis

- In SC solver: Lock VRT mode after a preset iteration number.

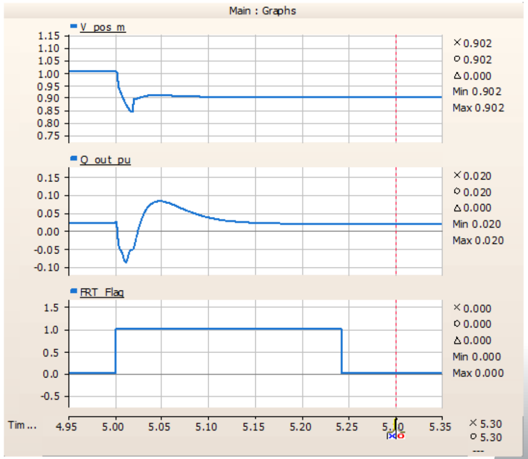
Vendor 1



Vendor 2



Vendor 3



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Lessons Learned

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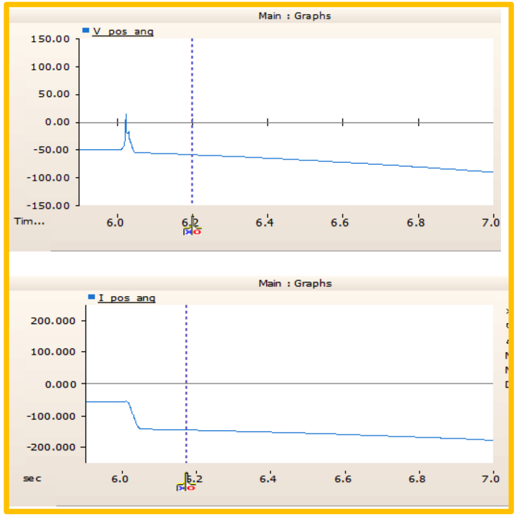
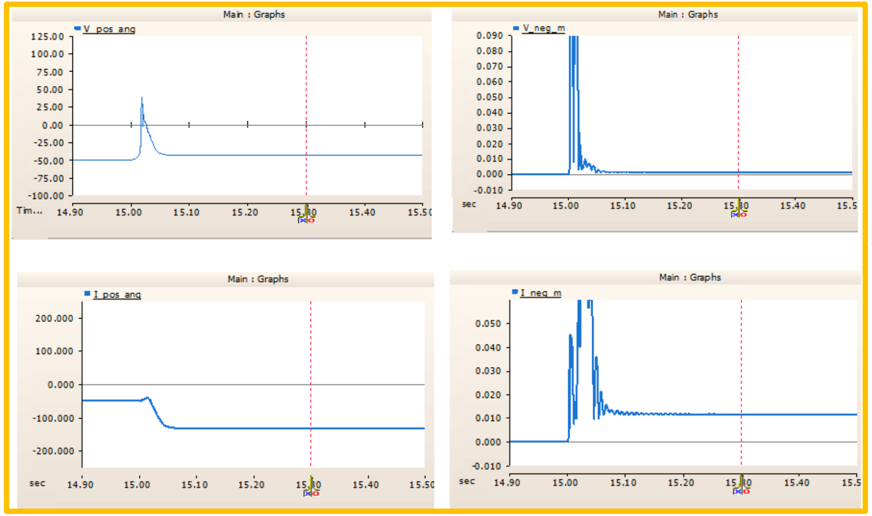
Angle Rotation for Close-in 3Ph fault

- IBR current impacts its own voltage
- IBR $\angle V_1 - \angle I_1 = 90°$ While $V_1 = Z_{loop} \times I_1$ & $\angle Z_{loop} < 90°$, IBR reference angle will rotate.

$\angle V_1 - \angle I_1 = 79.5°$

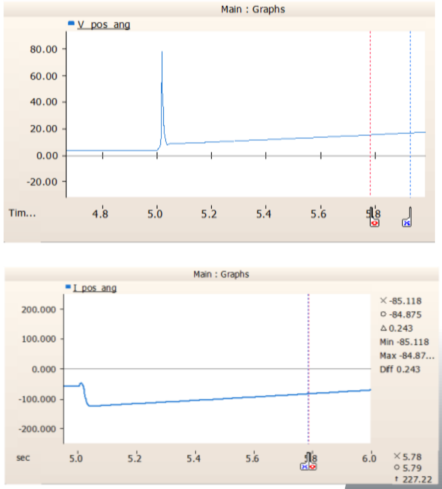


Vendor 1



Vendor 2

Injects I_2



Vendor 3

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Lessons Learned

Current Limit with I_2 Injection

- Vendor 1: I_2 Priority
- Vendor 2: Three options: I_1, I_2, Proportional, default is Proportional
- Vendor 3: Proportional , it keeps I_{d1} such that positive sequence power factor angle = 79.5°
- IEEE 2800-2022

> Assuming pre-fault negative sequence current output is zero or negligible, the negative sequence reactive current injection during a fault is an incremental negative sequence reactive current (ΔIR-2). If the *IBR unit*'s total current limit is reached, either ΔIR-1, or ΔIR-2, or both may be reduced with a preference of equal reduction in both currents. Additionally, the incremental positive-sequence reactive current (ΔIR-1) injection shall not be reduced below incremental negative sequence reactive current (ΔIR-2). In case of type III WTGs, the ΔIR-1 and ΔIR-2 injection during a fault is driven by machine parameters and control dynamics and may not be controllable in a manner described above.

- In certain cases, I_{d1} injection can help to reduce the total current, maximizing IBR active & reactive power support.
- It is not completely clear how vendors have implemented the current limiter in case of unbalanced faults.

Lessons Learned

Summary

- Blackbox modelling for SC analysis is a possible solution.
- Accuracy can be acceptable even without having vendor control diagrams.
- Is an NDA required to share a vendor Blackbox model for SC analysis?
- Differences in VRT detection and injection logics.
- Angle rotation is not addressed in control logics of most vendors.
- Current limitation logic during unbalanced faults is not clear.

Results: Comparison of PSCAD and IBR SC Models in Aspen

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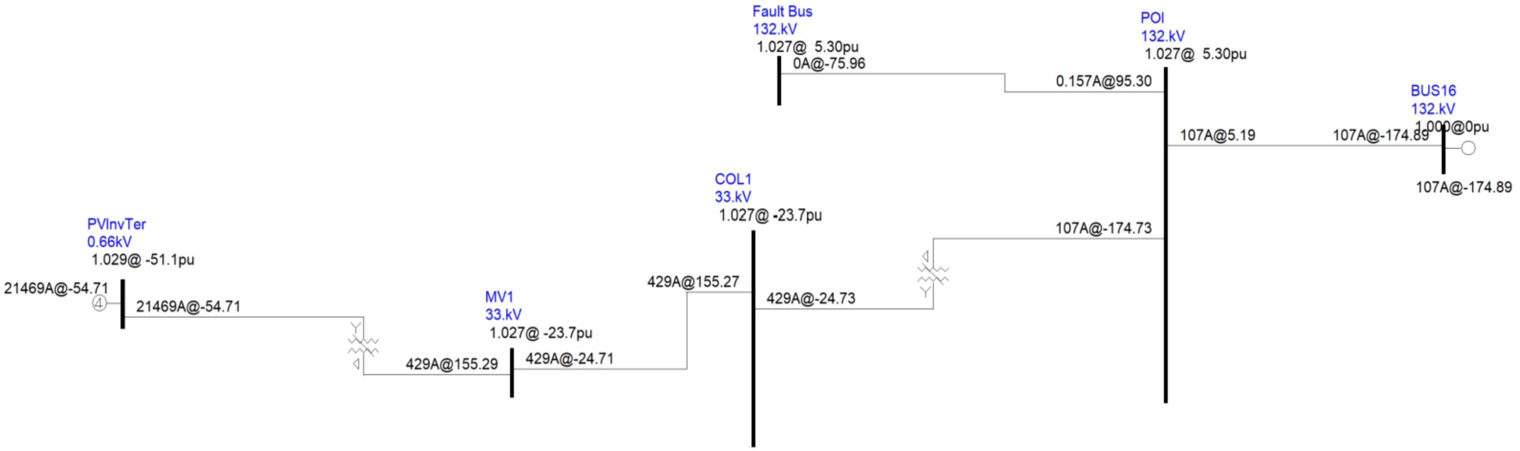
The three vendor models were compared with PSCAD and the Aspen DLL model.

- Details of Vendor 1 are shown as a representative example



Single Line used for the Aspen model comparisons.

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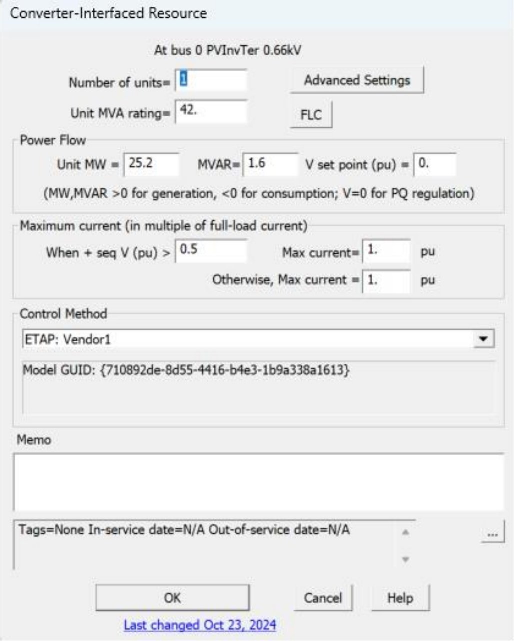
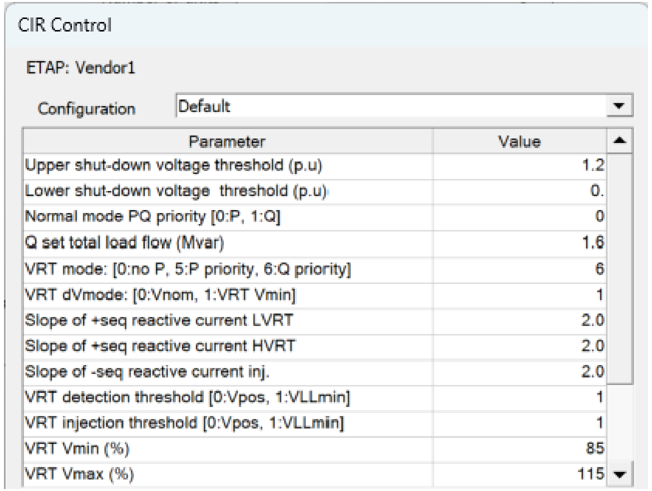
Results: Comparison of PSCAD and IBR SC Models in Aspen

Aspen CIR/DLL Model Configuration

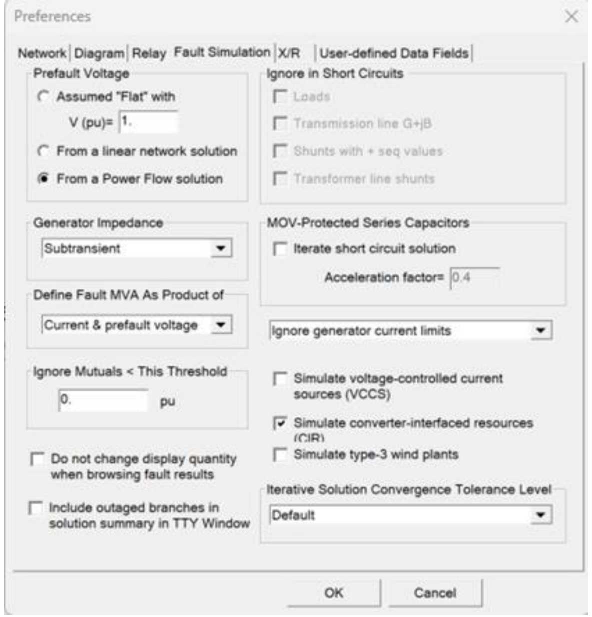



CIR Control

ETAP: Vendor1

Configuration: Default

Parameter	Value
Upper shut-down voltage threshold (p.u)	1.2
Lower shut-down voltage threshold (p.u)	0.
Normal mode PQ priority [0:P, 1:Q]	0
Q set total load flow (Mvar)	1.6
VRT mode: [0:no P, 5:P priority, 6:Q priority]	6
VRT dVmode: [0:Vnom, 1:VRT Vmin]	1
Slope of +seq reactive current LVRT	2.0
Slope of +seq reactive current HVRT	2.0
Slope of -seq reactive current inj.	2.0
VRT detection threshold [0:Vpos, 1:VLLmin]	1
VRT injection threshold [0:Vpos, 1:VLLmin]	1
VRT Vmin (%)	85
VRT Vmax (%)	115



Preferences

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Results: Comparison of PSCAD and IBR SC Models in Aspen

Vendor 1 System Configuration

Network elements	Parameters
Inverter	Voltage rating = 660 V (line-line)
	MVA rating = 42 MVA
	Active power set = 25.2 MW
	Reactive power set = 1.6 MVAR
PVXfrm (2-Wdg transformer)	Voltage rating = 0.66/33 kV
	Winding connection = YG/D
	Base MVA = 42 MVA
	Impedance = 0+j0.08 pu
PVCable	Impedance = 0.001 + j0.0314 Ω
GridXfrm (3-Wdg transformer)	Voltage rating = 33/132/33 kV
	Winding connection = YG/D/YG
	MVA rating: 42/84/42
	Base MVA for impedance calculation = 84 MVA
	Impedance between primary and secondary windings = 0+j0.06 pu Impedance between secondary and tertiary windings = 0+j0.06 pu Impedance between tertiary and primary windings = 0+j0.06 pu
Utility (modeled as the combination of an ideal voltage source in series with an impedance denoted as gridZ)	Voltage rating = 132 kV (line-line)
	$Z^{(1)}$ = 21.865 + j65.595 Ω $Z^{(0)}$ = 21.865 + j65.595 Ω

Vendor 1 Fixed Settings

K-factor for positive sequence LVRT	2
K-factor for positive sequence HVRT	2
K-factor for negative sequence	2
LVRT threshold voltage	85%
HVRT threshold voltage	115%
Hysteresis	5%
Voltage deviation reference	VRT Vmin
Current limit	%100
Current limit priority	-ve sequence

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Power flow results validation

- The power flow voltage and currents at the inverter terminal are compared with PSCAD results which is shown below.

	$\|V\|(pu)$	$\angle V(°)$	$\|I\|(pu)$	$\angle I(°)$
PSCAD	1.0285	-51.09	0.586	-54.8
ASPEN	1.029	-51.1	0.584	-54.71
Error	0.05%	0.02%	-0.34%	-0.16%

Load flow results validation for vendor 1

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FRT Settings for Vendor 1

Settings	Default Value	Description
Normal mode PQ priority [0:P, 1:Q]	0	The priority of active power or reactive power during the normal power flow.
VRT mode [0: no P, 5:P priority, 6:Q priority]	6	The vendor has 7 modes of current injection during VRT. Mode 0: $I = 0 + jk * dV$ Mode 5: $I = P_{prev} + j(I_{qprev} + k * dV)$; with P-priority Mode 6: $I = P_{prev} + j(I_{qprev} + k * dV)$; With Q-priority (note*: VRT modes 1,2,3 and 4 are not implemented in the dll. If one of these options are chosen, the default mode 6 will be used.)
VRT dVmode: [0:Vnom, 1:VRT Vmin]	1	This setting determines if the VRT curve passes through the origin or is continuous. Option 0 = Voltage reference for reactive current injection is nominal (1 pu) value. Option 1 = Voltage reference for reactive current injection is minimum VRT voltage threshold (eg. 0.85 pu).
Slope of +seq reactive current LVRT	2	K-factor for the positive sequence reactive current injection during LVRT.
Slope of +seq reactive current HVRT	2	K-factor for the positive sequence reactive current injection during HVRT.
Slope of -seq reactive current inj	1	K-factor for the negative sequence reactive current injection.
VRT detection threshold [0:Vpos, 1:VLLmin]	0	VRT mode is determined based on two options: 1) Positive sequence voltage < VRT threshold 2) Minimum line-line voltage < VRT threshold
VRT injection threshold [0:Vpos, 1:VLLmin]	0	The positive sequence reactive current injection is based on the deviation of (1). Positive sequence voltage, or (2). Minimum line-line voltage from the reference voltage used in VRT dVmode setting.
VRT Vmin (%)	85	Voltage threshold below which LVRT mode is ON.
VRT Vmax (%)	115	Voltage threshold above which HVRT mode is ON.
LVRT Hyst (%)	5	Hysteresis voltage in LVRT
HVRT Hyst (%)	5	Hysteresis voltage in HVRT
Use V1Ang-preF [If V1Mag<](%)	20	If inverter terminal voltage is less than this threshold, the phase angle of pre-fault voltage is used.

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Fault Study Cases for Vendor 1

Case#	Fault information	LVRT setting
1	3Ph fault @bus: POI $Z_f = 3.16 + j9.48\ \Omega$	Mode 0
2	3Ph fault @bus: POI $Z_f = 9.48 + j28.44\ \Omega$	Mode 5
3	3Ph fault @bus: POI $Z_f = 31.62 + j94.87\ \Omega$	Mode 6
4	AG fault @bus: POI $Z_f = 0.0 + j0.0\ \Omega$	VRT detection and injection based on Vpos; and VRT mode 0
5	AG fault @bus: POI $Z_f = 0.0 + j0.0\ \Omega$	VRT detection and injection based on Vpos; and VRT mode 5
6	AG fault @bus: POI $Z_f = 15.8 + j47.44\ \Omega$	VRT detection and injection based on Vpos; and VRT mode 6
7	AG fault @bus: POI $Z_f = 0.0 + j0.0\ \Omega$	VRT detection and injection based on VLLmin; and VRT mode 6
8	BCG fault @bus: POI $Z_f = 0.0 + j0.0\ \Omega$	VRT detection and injection based on Vpos; and VRT mode 6
9	BCG fault @bus: POI $Z_f = 15.8 + j47.44\ \Omega$	VRT detection and injection based on VLLmin; and VRT mode 6
10	BC fault @bus: POI $Z_f = 0.0 + j0.0\ \Omega$	VRT detection and injection based on Vpos; and VRT mode 6
11	BC fault @bus: POI $Z_f = 7.9 + j47.44\ \Omega$	VRT detection and injection based on VLLmin; and VRT mode 6

*Z_f is modelled on the line behind the Fault Bus

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Fault Study Case Results for Vendor 1

Case		$\lvert V_1 \rvert$ (pu)	$\angle V_1$ (°)	$\lvert I_1 \rvert$ (pu)	$\angle I_1$ (°)	$\lvert V_2 \rvert$ (pu)	$\angle V_2$ (°)	$\lvert I_2 \rvert$ (pu)	$\angle I_2$ (°)
1	PSCAD	0.257	-63.06	1	-153.07	---	---	---	---
	ASPEN	0.257	-62	1	-151	---	---	---	---
2	PSCAD	0.272	-28.25	1	-27.632	---	---	---	---
	ASPEN	0.276	-28	1	-29	---	---	---	---
3	PSCAD	0.673	-43.26	0.972	-66.8	---	---	---	---
	ASPEN	0.674	-43	0.97	-67	---	---	---	---
4	PSCAD	0.705	-60.23	0.295	-150.11	0.243	-117.93	0.486	-28.37
	ASPEN	0.704	-60	0.29	-150	0.244	-118	0.48	-28
5	PSCAD	0.717	-50.09	0.618	-80.366	0.248	-112.74	0.496	-23.25
	ASPEN	0.71	-50	0.62	-79	0.248	-113	0.49	-23
6	PSCAD	0.829	-47.86	0.726	-53.83	0.135	-109.99	0.27	-20.48
	ASPEN	0.829	-48	0.73	-54	0.135	-110	0.27	-20
7	PSCAD	0.745	-53.96	0.565	-105.38	0.252	-114.86	0.504	-25.36
	ASPEN	0.744	-54	0.56	-104	0.252	-115	0.5	-25
8	PSCAD	0.404	-60.186	0.606	-150.28	0.275	59.91	0.55	149.52
	ASPEN	0.403	-60	0.6	-149	0.275	60	0.55	150
9	PSCAD	0.733	-53.18	0.713	-106.81	0.151	65.312	0.303	154.83
	ASPEN	0.731	-53	0.72	-105	0.151	66	0.3	157
10	PSCAD	0.51	-58.82	0.37	-149.13	0.383	61.288	0.767	150.85
	ASPEN	0.509	-59	0.36	-148	0.384	61	0.76	151
11	PSCAD	0.817	-55.163	0.6	-123.52	0.224	59.88	0.449	149.4
	ASPEN	0.815	-55	0.6	-123	0.225	60	0.45	150

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Fault Study Case Percentage Comparison Vendor 1

Case	$\|V_1\|$ (%)	$\angle V_1$ (°)	$\|I_1\|$ (%)	$\angle I_1$ (°)	$\|V_2\|$ (%)	$\angle V_2$ (°)	$\|I_2\|$ (%)	$\angle I_2$ (°)
1	0.00	1.06	0.00	2.07	---	---	---	---
2	0.40	0.25	0.00	-1.37	---	---	---	---
3	0.10	0.26	-0.20	-0.20	---	---	---	---
4	-0.10	0.23	-0.50	0.11	0.10	-0.07	-0.60	0.37
5	-0.70	0.09	0.20	1.37	0.00	-0.26	-0.60	0.25
6	0.00	-0.14	0.40	-0.17	0.00	-0.01	0.00	0.48
7	-0.10	-0.04	-0.50	1.38	0.00	-0.14	-0.40	0.36
8	-0.10	0.19	-0.60	1.28	0.00	0.09	0.00	0.48
9	-0.20	0.18	0.70	1.81	0.00	0.69	-0.30	2.17
10	-0.10	-0.18	-1.00	1.13	0.10	-0.29	-0.70	0.15
11	-0.20	0.16	0.00	0.52	0.10	0.12	0.10	0.60

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Fault Study Case Percentage Comparison Vendor 2

Case	$\lvert V_1\rvert$ (%)	$\angle V_1$ (°)	$\lvert I_1\rvert$ (%)	$\angle I_1$ (°)	$\lvert V_2\rvert$ (%)	$\angle V_2$ (°)	$\lvert I_2\rvert$ (%)	$\angle I_2$ (°)
1	-0.30	-0.05	-1.00	0.63	---	---	---	---
2	-0.30	0.16	-1.10	1.19	---	---	---	---
3	0.30	-0.49	-0.90	-1.58	---	---	---	---
4	-0.50	1.00	-1.80	1.03	---	---	---	---
5	-0.20	-0.39	-2.00	0.52	0.40	-0.36	-2.80	-0.42
6	-0.40	-0.12	-3.20	-0.22	0.20	-0.10	-2.40	-0.13
7	-0.30	0.30	-2.70	0.21	0.30	0.33	-2.70	0.29
8	0.00	0.42	1.30	0.94	0.60	0.20	-2.80	0.74
9	0.70	-0.98	-1.80	-4.01	0.00	-0.57	0.00	-0.22
10	-0.30	0.30	-1.20	0.86	0.20	-0.64	-0.80	-0.26
11	-0.60	0.42	-2.80	0.84	-0.60	-0.29	2.40	1.53
12	-0.10	-0.04	-1.00	1.40	0.00	0.15	-0.40	0.83
13	-0.30	0.14	-2.00	1.57	-0.20	0.36	0.90	1.10
14	-0.50	-0.68	-2.10	-0.03	-0.70	0.93	1.60	1.50
15	0.20	-1.13	-0.10	0.56	0.10	0.42	-0.80	0.95
16	-0.20	-0.86	-1.80	0.80	-0.40	0.73	0.50	1.27

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Fault Study Case Percentage Comparison Vendor 3

Case	$\lvert V_1 \rvert$ (%)	$\angle V_1$ (°)	$\lvert I_1 \rvert$ (%)	$\angle I_1$ (°)	$\lvert V_2 \rvert$ (%)	$\angle V_2$ (°)	$\lvert I_2 \rvert$ (%)	$\angle I_2$ (°)
1	0.40	1.49	0.20	1.87	---	---	---	---
2	0.00	0.46	0.20	0.20	---	---	---	---
3	-0.20	-0.89	-1.30	0.24	-0.40	0.88	0.90	1.08
4	-0.10	0.02	0.80	0.34	0.00	0.20	0.10	0.37
5	-0.30	0.19	-1.80	1.30	-0.10	0.26	-0.10	0.46
6	0.00	-0.14	-0.10	0.63	-0.10	0.00	0.70	0.18
7	-0.30	0.16	-1.30	1.30	-0.80	0.18	0.10	0.36
8	0.00	0.57	0.50	0.56	-0.10	0.31	0.50	0.48

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Questions?