Simulating Resulting Voltages - DC Power Equipment - Lab Experiment – SPD Entry Point

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Background and Abstract

DC Power Feeds via cables is a common method of powering remote radio units installed on telecommunication towers.

There are known concerns within the PEG community that lightning strikes to the telecommunications tower will cause induced currents into these dc feeders.

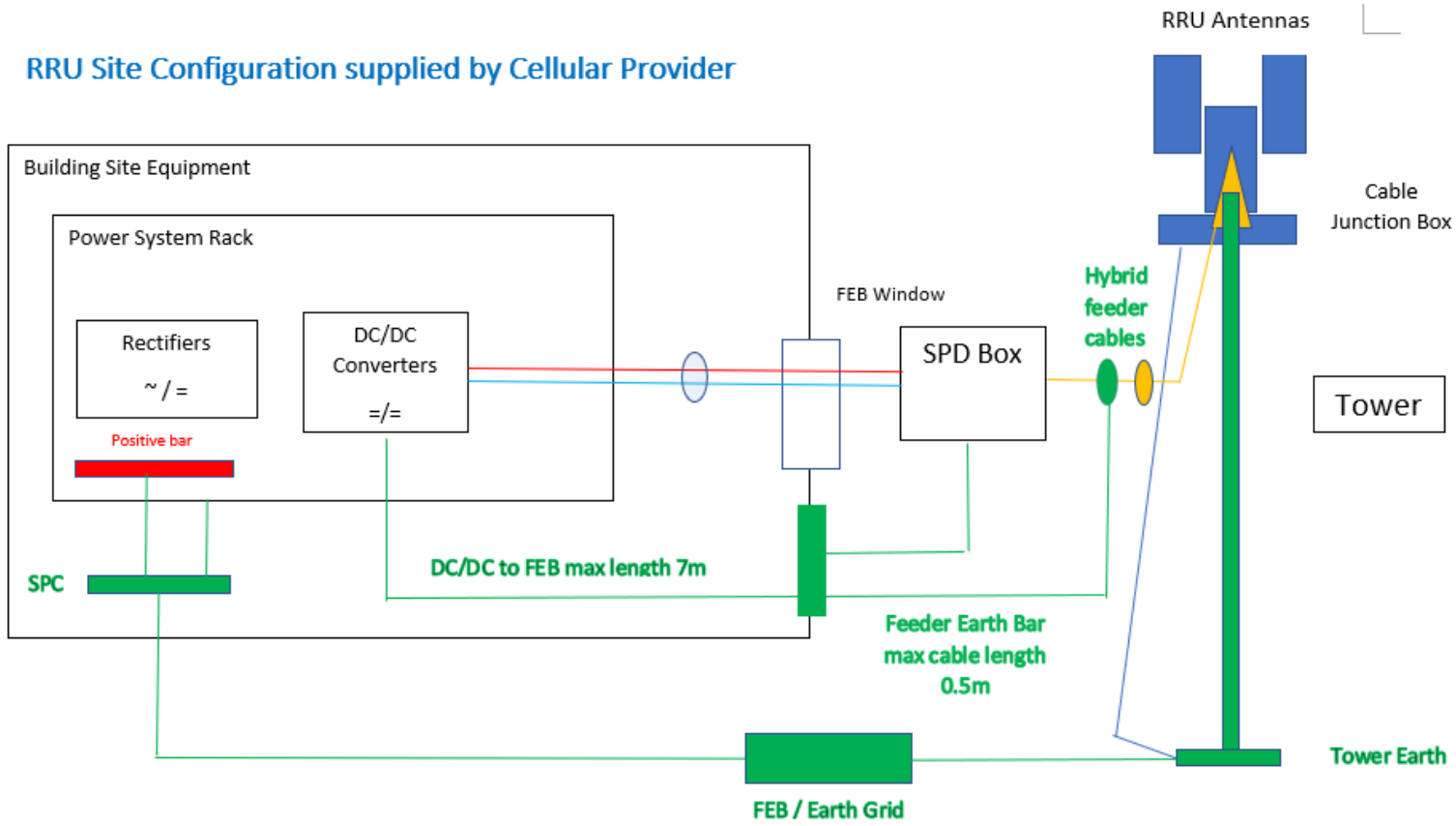
These surge current transients have the potential to cause damage to the telecommunications power and site equipment in shelters and cabinets.

To mitigate the risk of damage to the radio communication equipment, it is common practice to provide surge protective devices or SPD’s at the point on entry to the shelter or cabinet.

Simulating Line voltages on DC power Equipment

- Experimental setup
- DC SPD in line with telecommunications DC equipment rack
- 6kV/3kA Combination Wave applied on *simulated long line* input, right before SPD
- If line length between SPD is varied, (between SPD and rack) are resulting line voltages affected?
- Goal: Does the cable length have an effect on the voltage seen at equipment rack?

Tower - Remote Site Configuration Diagram



- Supplied by Telecommunications provider
- Important for setting up test case to simulate real world installation
- Supplied expertise and guidance throughout testing – DC equipment rack
- Quarterly meetings to share progress and milestones

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The Combination Wave - Transient Characteristic

Combination Wave Characteristics

- Defined and characterized in IEEE 62.41.2.
- 1.2/50 µs Open Circuit Voltage Waveform
- 8/20 µs short circuit current waveform

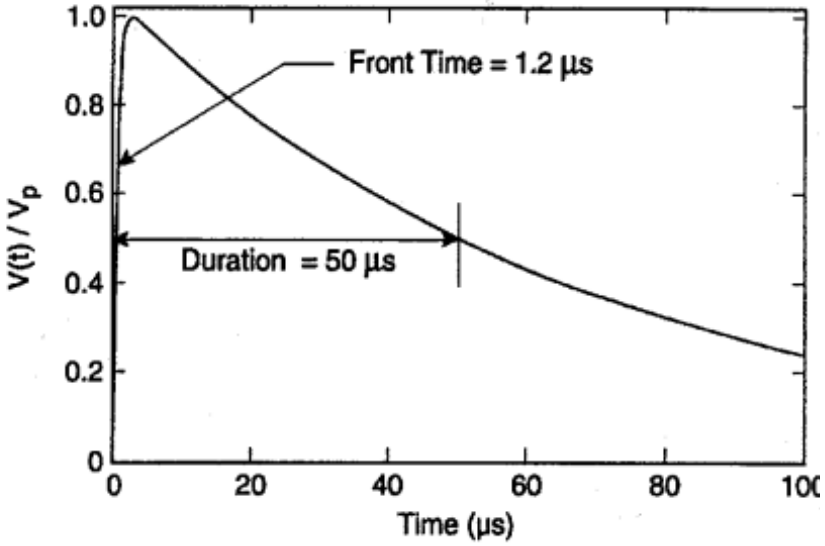

Figure 5—Combination Wave open-circuit voltage

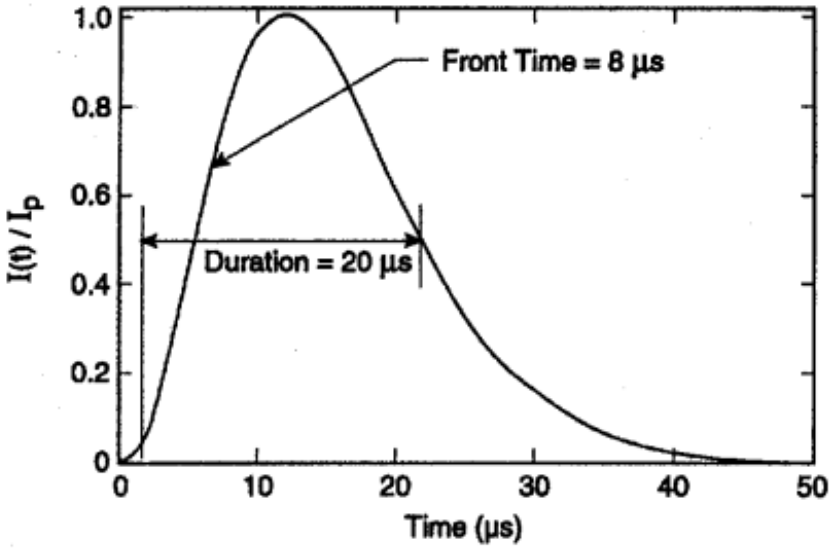

Figure 6—Combination Wave short-circuit current

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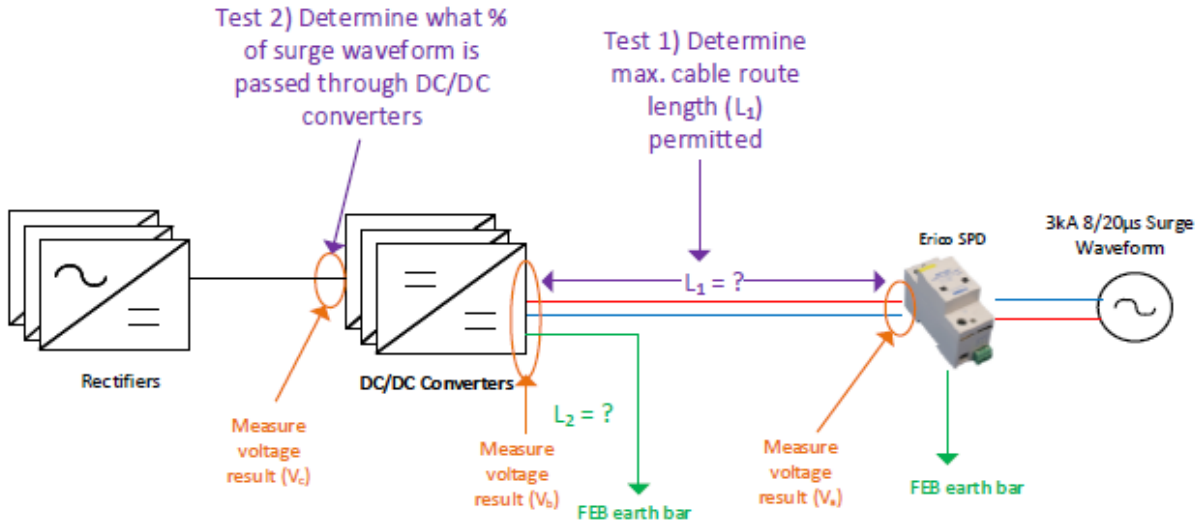
DC SPD Test Layout - Diagram

Test Case Layouts – Based on equipment sent



Test 1 & 2 (with DC/DC converters present):

- Aim to determine the maximum cable route length (L1) permitted between the SPD box and the DC/DC converter output, including the permitted distance between the SPD box and the DC/DC converter output.
- including the maximum cable route length (L2) permitted for the earth cable (between the DC/DC converters and FEB).) permitted for the earth cable (between the DC/DC converters and FEB).

1. Surge waveform used was the mentioned 6kv/3kA 1.2/50uS ,8/20µµs Combination Wave
2. Lengths tested: L = 0.7m, L = 1m, L=2m, L = 3m, L = 5m, L = 6m, L = 8m, L = 10m
3. Conducted Test on L = 10m with and without 4 x bends will impact the performance.
4. Measure resulting voltages at points Va, Vb and Vc. Determine the transient surge % at each point.

NOTES:

Current max. cable route length is maximum 7m. Current theory is that this is the maximum length before surge will exceed 1kA

The isolation of DC/DC converters (DC/DC converters used have a min. 1kA galvanic isolation between input & output chassis.

The DC/DC converter cable to FEB was listed as maximum cable route length of 7m.

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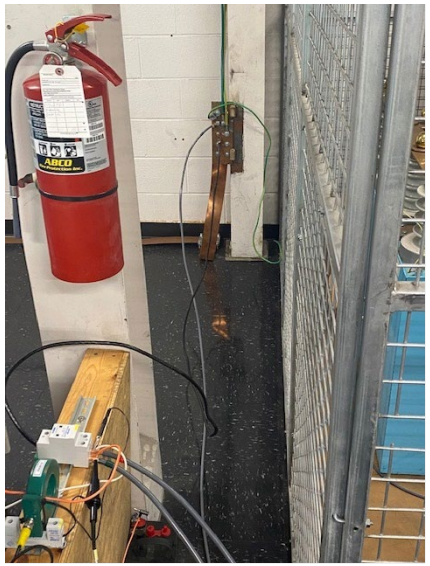
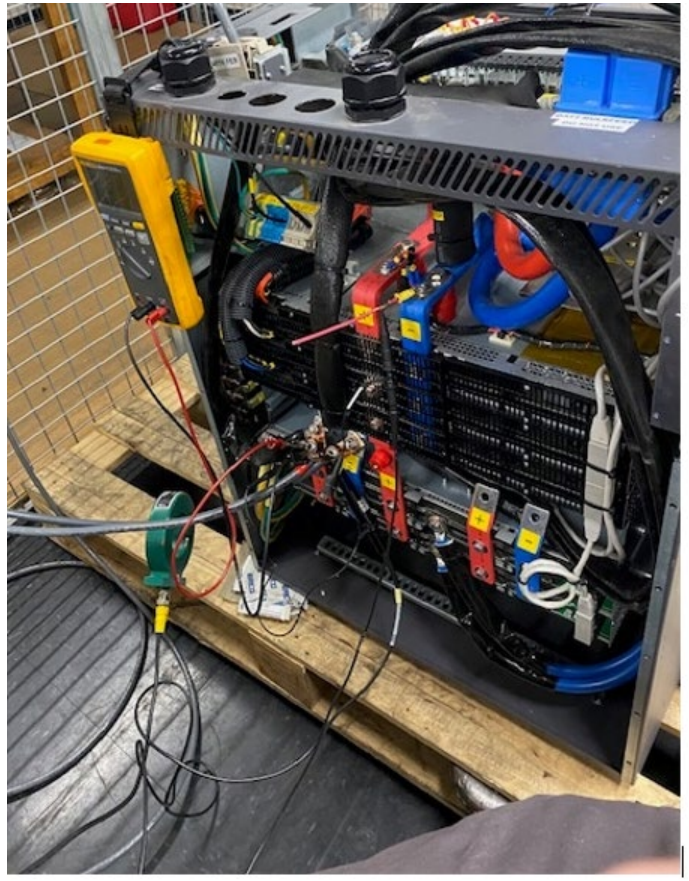
Test Configuration #1 – Initial Test Layout

- **Test Equipment Setup – Input side (Va)**
  - Combination Wave Generator
  - Digital O-scope
  - Battery Powered O-scope
  - One Tektronix P5100A HV Probe
  - CT to measure Input Current Waveform



SPD to FEB connection

- Short Cable Length
- Directly connected to Earth bar
- As close as possible



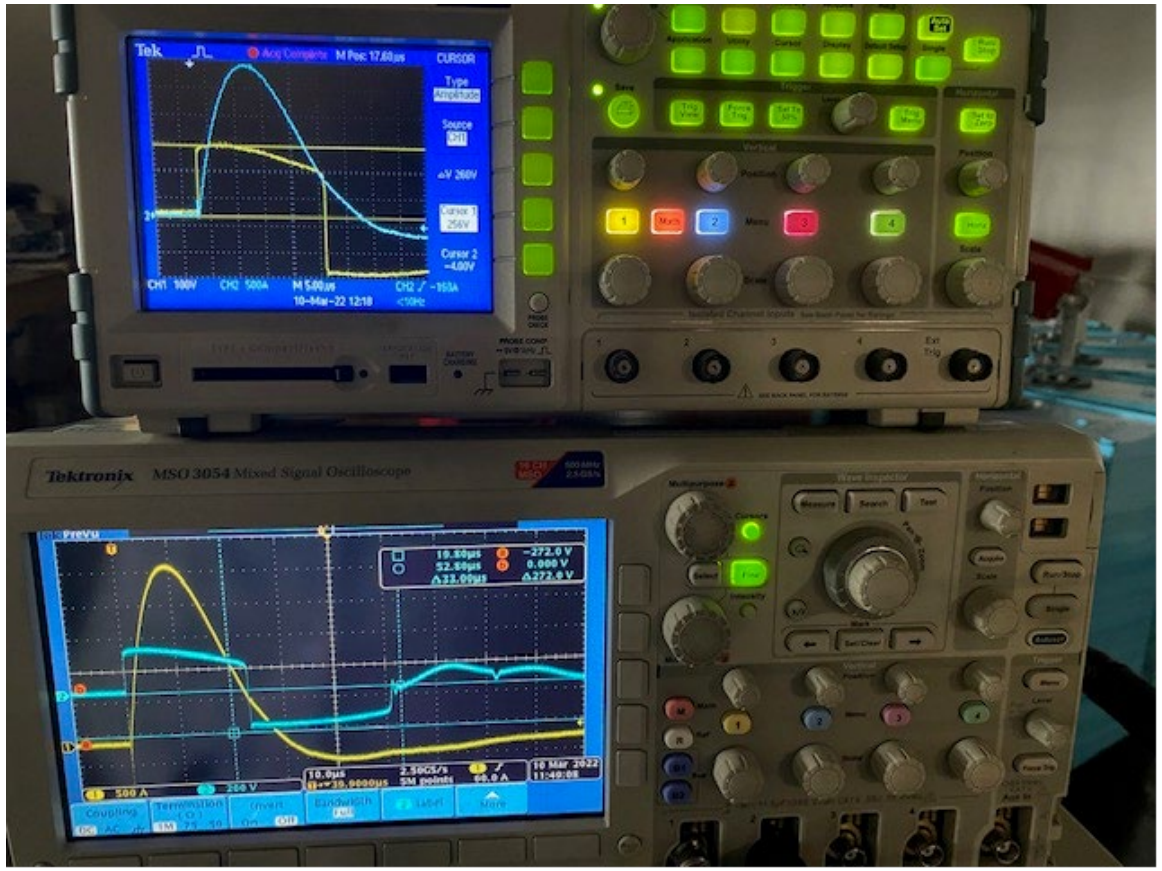
DC Equipment Rack

Showing CT on input to DC/DC Converter

Vc – Taken at Rectifier –

10x Scope probes used for Vc measurement.

Test Configuration #1 – Common mode TE Closeup



- Test Equipment Setup – Input side (Va)

  1. **Digital O-scope**
     - CT to measure I1 – Input Current
       - Channel 1 (I1)
     - One P5100A HV Probe
       - Channel 2 (Va)

  2. **Battery Powered O-scope**
     - CT to measure I1 – Input Current
       - Channel 1 (I1)
     - One P5100A HV Probes - Differential Mode
       - Channel 2 (Va)

Test Configuration #1 – Common mode Logbook

Test No.	SPD Part Number	Mode Tested	Cable Length (L-L to Sub-rack)	Cable Length from SPD - FEB earth bar	Surge Current (A)	Oscope Voltage Supply Type (Battery or AC)	Measured Current (A) - I1	Measured Current (A) - I2	Measured Voltage (V) (Va) - SPD side	Measured Voltage (V) (Vb) DC/DC side	Measured Voltage (V) (Vc) Rectifier Side	Waveforms (wav.)	Comments (System on/off, bends)
1	DC SPD	L - L	10m	1.5m	3kA	AC	2.68kA	348A	128.6V	70V**	53.6V	See Attached	ON
						BATT	2.64kA	340A	121.6	38.8V	21V	See Attached	
						AC	2.71kA	298A	146V	56.4V	29.4V	See Attached	OFF
						BATT	2.66kA	292A	144V	61.2V	92V	See Attached	
2		L-L with 4 90°bends	10m	1.5m	3kA	AC	2.710kA	362A	108V	60.2V	18.4V	See Attached	ON
						BATT	2.62kA	340A	98V	35.6V	53.6V	See Attached	
						AC	2.71kA	308A	113V	14.6V	1.18V	See Attached	OFF
						BATT	2.66kA	296A	106V	11.2V	1.04V	See Attached	
3		L - L	7m	1.5m	3kA	AC	2.72kA	800A	262V	32V	TBD	See Attached	ON
						BATT	2.68kA	800A	297.6V	30.4	TBD	See Attached	
						AC	2.64kA	672A	262V	27V	TBD	See Attached	OFF
						BATT	2.73kA	684A	240V	25.2V	TBD	See Attached	
4		L - L	6m	1.5m	3kA	AC	2.71kA	800A	262V	32V	TBD	See Attached	ON
						BATT	2.68kA	800A	236V	30V	TBD	See Attached	
						AC	2.74kA	760A	260V	29.2V	TBD	See Attached	OFF
						BATT	2.70kA	680A	240V	25.2V	TBD	See Attached	

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Test Configuration #1 – Common mode closeup

Test No.	SPD Part Number	Mode Tested	Cable Length (L-L to Sub-rack)	Cable Length from SPD - FEB earth bar	Surge Current (A)	Oscope Voltage Supply Type (Battery or AC)	Measured Current (A) - I1	Measured Current (A) - I2	Measured Voltage (V) (Va) - SPD side	Measured Voltage (V) (Vb) DC/DC side	Measured Voltage (V) (Vc) Rectifier Side	Waveforms (wav.)	Comments (System on/off, bends)
5	DC SPD	L - L	5m	1.5m	3kA	AC	2.72kA	924A	258V	38.8V	TBD	See Attached	ON
						BATT	2.64kA	912A	285.6V	36.8V			
						AC	2.75kA	784A	254V	32V			OFF
						BATT	2.74kA	792A	240V	31.2V			
6		L - L	4m	1.5m	3kA	AC	2.71kA	1.232kA	260V	47.2V			ON
						BATT	2.68kA	1.21kA	288V	46.4V			
						AC	2.73kA	1.080kA	260V	40.2V			OFF
						BATT	2.68kA	1.07kA	232V	38.8V			
7		L - L	3m	1.5m	3kA	AC	2.710kA	2.23kA	252V	48V			ON
						BATT	2.64kA	2.46kA	280V	75.2V			
						AC	2.710kA	1.620kA	262V	36.80V			OFF
						BATT	2.66kA	2.18kA	236V	71.2V			
8		L - L	2m	1.5m	3kA	AC	2.71kA	1.62kA	262V	59.6V			ON
						BATT	2.68kA	1.21kA	288V	46.4V			
						AC	2.71kA	1.396kA	252V	48V			OFF
						BATT	2.68kA	1.283kA	232V	46.2V			
9		L - L	0.7m	1.5m	3kA	AC	2.710kA	2.530kA	298V	87.2V			ON
						BATT	2.66kA	2.52kA	232V	80V			
						AC	2.74kA	2.29kA	248V	78.4			OFF
						BATT	2.74kA	2.26kA	232V	71.2V			

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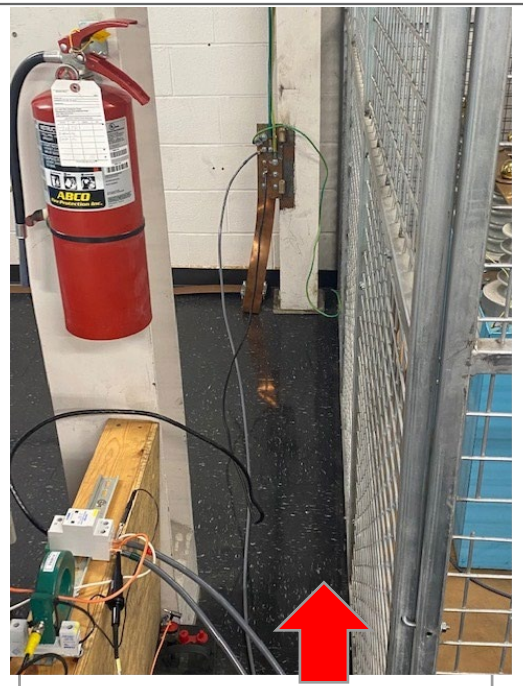
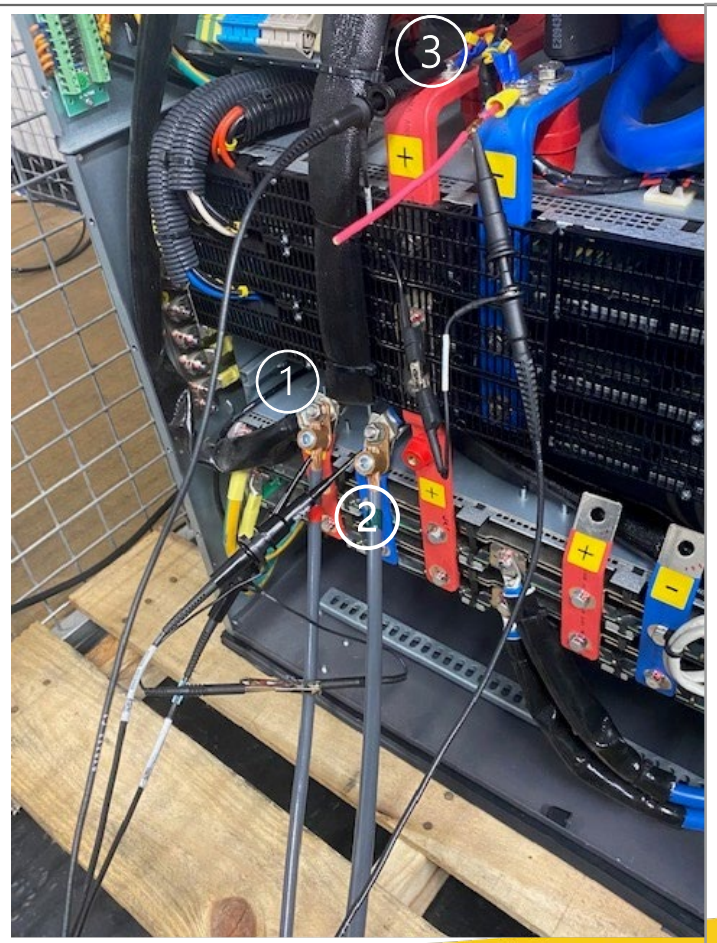
Test Configuration #2 – Differential mode closeup

- Test Equipment Setup – Input side (Va)
  - Combination Wave Generator
  - Tektronix Digital O-scope
  - Tektronix Battery Powered O-scope
  - Two P5100A HV Probe (CH1, CH2)
    - (GND, CH1-CH2)
    - Pearson 4418 CT – Input Current Waveform – (I1)



- 3m Cable Length to DC Rack
- 1.5m length to SPD Directly connected to Earth bar
- As close as possible in lab



DC Equip Rack

1

Positive Lead Grounded

2

(Vb) – DC/DC Conv.

3

(Vc) – Taken at Rectifier

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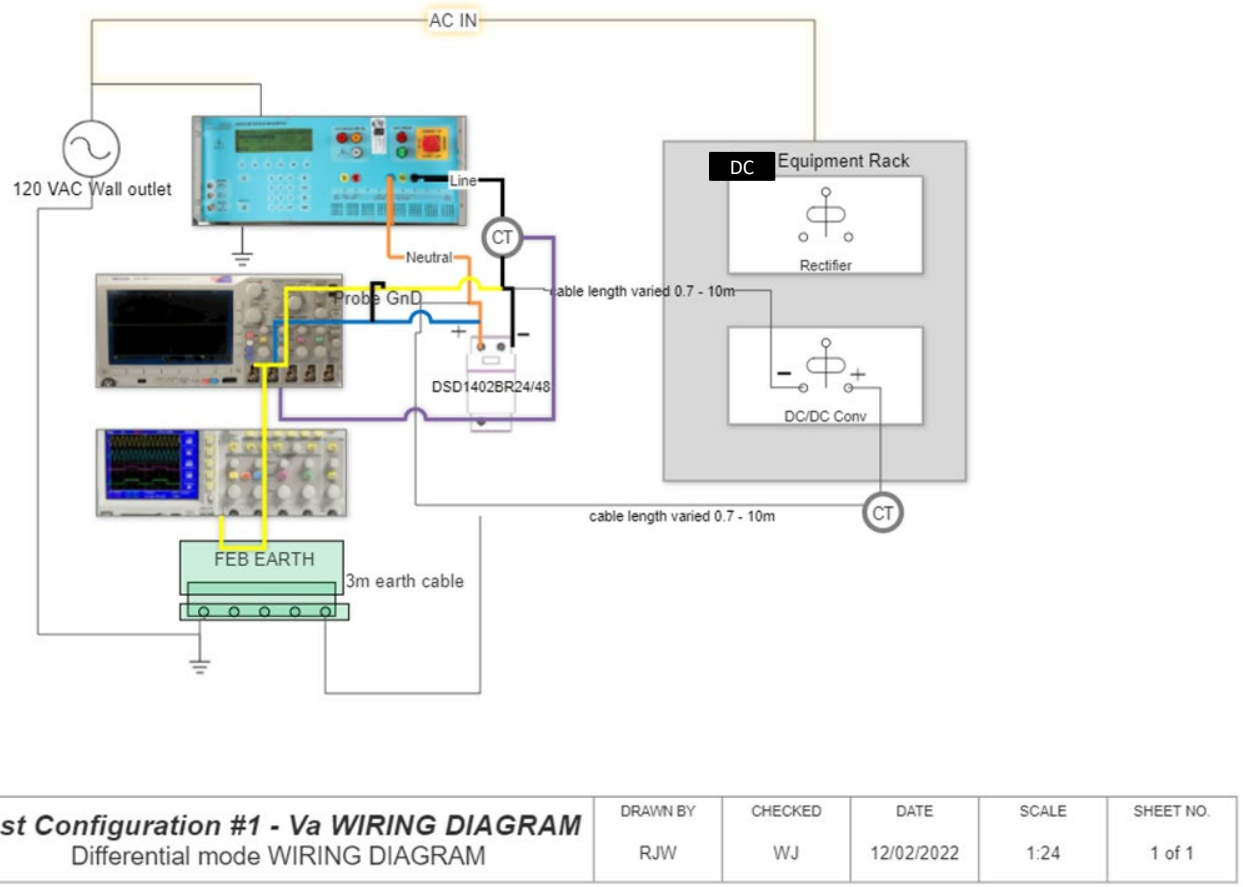
TC#2 – Diff mode diagram – “Long Line” Va, I1

Wiring Diagram

- Shows the connection of Test Equipment while in Differential mode – Input Side
  - Highlights Digital O-scope connections
    - Same connections utilized for Battery Power
  - Va measurement shown
    - 2x - P5100A Tektronix 100x HV Probe
  - I1 measurement shown (CT) taken using Pearson 4418 current transformer 1000:1



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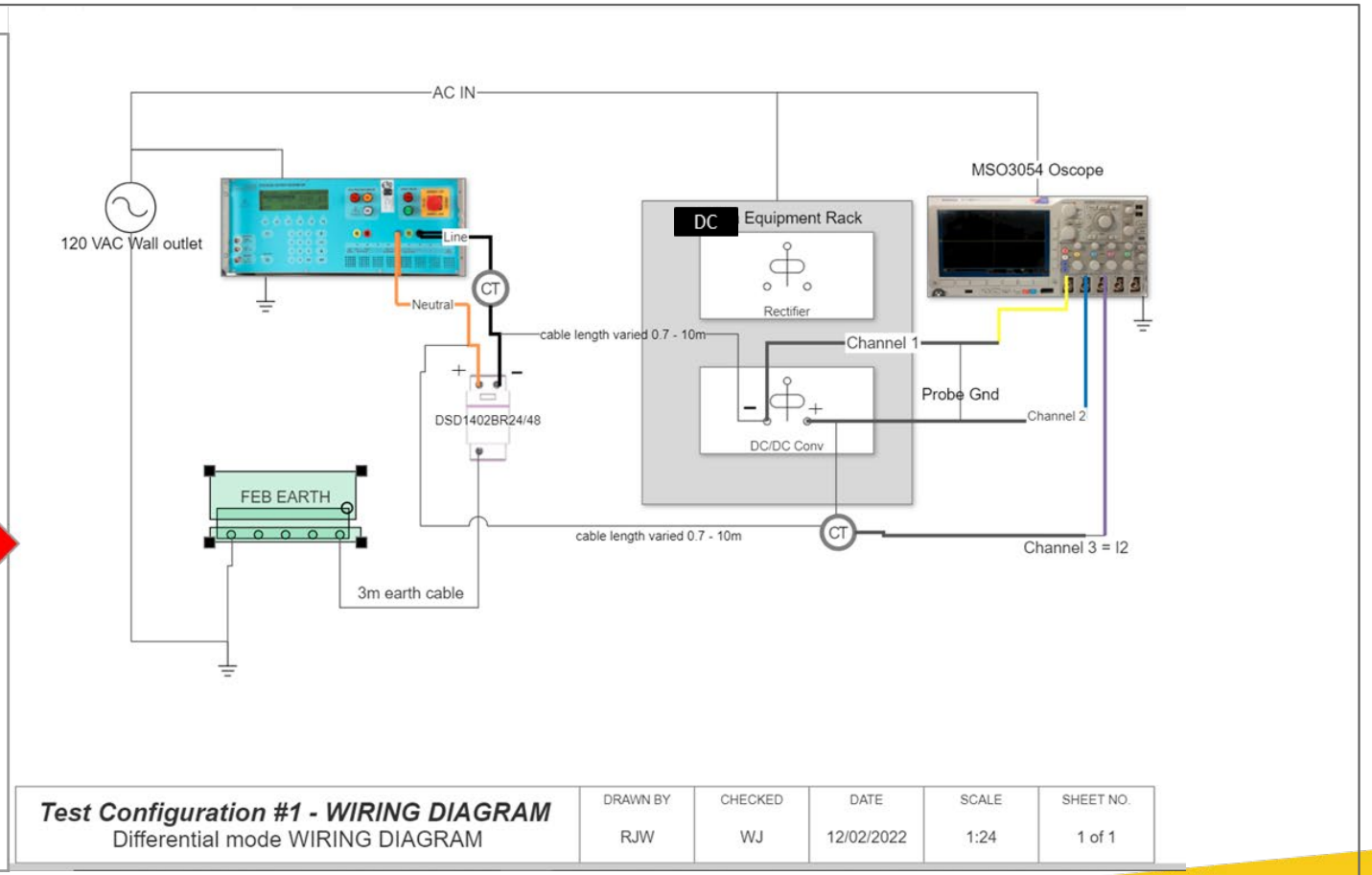
TC#2 – Diff mode diagram – “Rack Side” Vb, Vc

Wiring Diagram

- Shows the connection of Test Equipment while in Differential mode – Rack Side
  - Colors of connections are made to highlight the trace outputs
  - Highlights connection of Digital Oscope connection
    - Same connection made for Battery Power
  - Vb measurement shown
  - Vc measurement is taken same way at the Rectifier)
    - With 10x Scope probes (not 100x) (better resolution)



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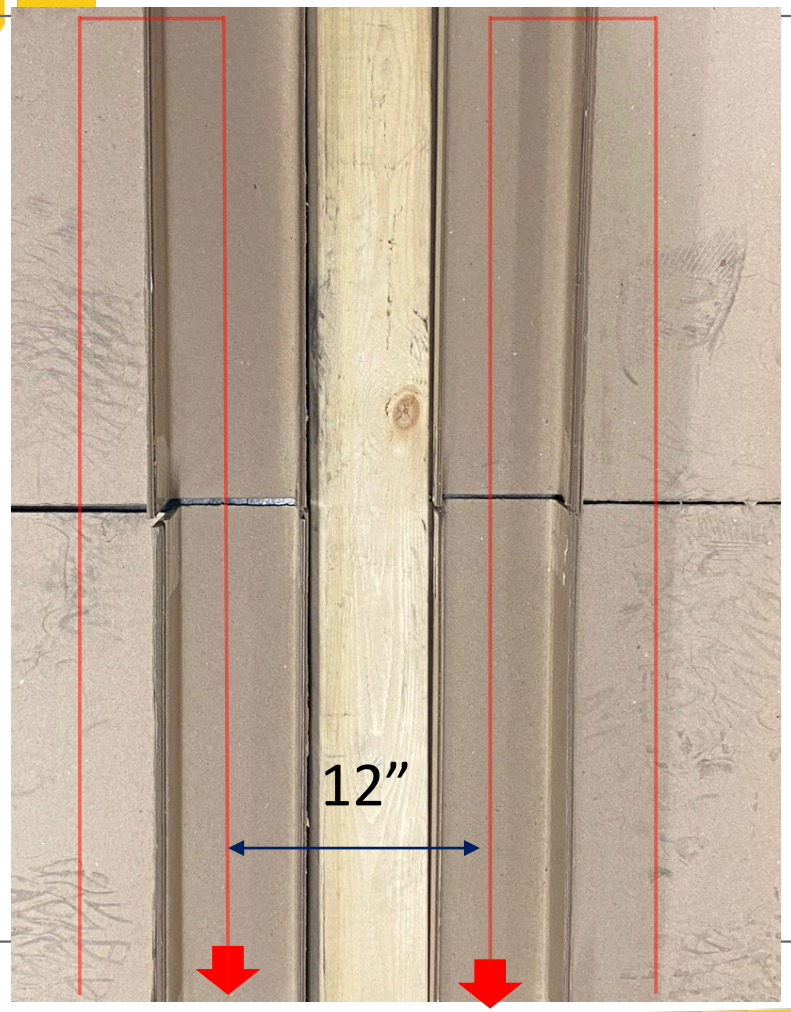
TC#2 – Cable Channels to ensure seperation



1. Cable channels were created to separate cables during testing

2. Cables ran to equipment rack as neatly as possible to eliminate possible mutual inductance on cable during surge event. L = - V di/dt

Cable was shortened one meter at a time by cutting and restriping the ends.

1. Cables connecting DC SPD to DC/DC Converter positive and negative terminals

   - Curve shown illustrates cable path through the channels.
   - Red Arrows towards equipment rack
   - Why was this done? To minimize variation in mutual inductance during surge event by keeping distance between conductor's constant.
   - To reduce the effects of noise and distortion on the surge test results when shortening the cable lengths.

TC#2 – Diff mode Test Logbook

Test No.	SPD Part Number	Mode Tested	Cable Length (L-L to Sub-rack)	Cable Length from SPD - FEB earth bar	Surge Current (A)	Oscope Voltage Supply Type (Battery or AC)	Measured Current (A) - I1	Measured Current (A) - I2	Measured Voltage (V) (Va) - SPD side	Measured Voltage (V) (Vb) DC/DC side	Measured Voltage (V) (Vc) Rectifier Side	Waveforms (wav.)	Comments (System on/off, bends)	AC or BATT
1	DC SPD 48 VDC	L - L (seperated)	10m	1.5m	3kA	AC	2.73kA	260A	272 V	55.5 V	<3V	TEK003 (Va) TEK004 (Vb) TEK005 (I2) TEK008 (Vc) TEK009 (Vb)	ON	AC
							2.73kA	340A	274 V	38.8 V	4.4 V	TEK000-TEK002 (Va) TEK013 Vb TEK006 (Vc) TEK007 (I2)	OFF	
1						BATT	2.73kA	260A	272 V	55.5 V	3V	Phone images	ON	BATT
							2.72kA	340A	252 V	26V	20V	Phone images	OFF	
2		L-L with 4 90°bends				AC	2.74kA	260A	317V	76V	7.6V	TEK20-21(Va,I1) TEK022 (Vb) TEK023 (I2) TEK024 (Vc)	ON	AC
							2.74kA	330A	320V	24.8 V	13.8 V	TEK015 (Vb) TEK016 (I2) TEK017 (Vb12)TEK018 (Vc) TEK019 (Va)	OFF	
2						BATT	2.72kA	264A	248V	26.4	2.2V	Phone images	ON	BATT
							2.70kA	330A	240V	26 V	6.4 V	Phone images	OFF	

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TC#2 – Diff mode Test Logbook

3	DC SPD	L - L	9m	1.5m	3kA	AC	2.75 kA	292 A	268 V	20.8 V	6.4 V	TEK0028 (Vc) TEK0029(I2) TEK0030 (Vb) TEK0034 (Vb)	ON	AC
							2.75 kA	376 A	264 V	33.6 V	6.8 V	TEK0025 (Vb) TEK0026 (I2) TEK0027 (Vc) TEK0031 (Vb) TEK0032 (I1) TEK0033 (Vb)	OFF	
3			9m			BATT	2.68 kA	300A	268 V	19.6 V	6.4 V	Phone images	ON	BATT
							2.74 kA	374 A	260V	22.4 V	8 V	Phone images	OFF	
4			8m			AC	2.73 kA	446 A	264 V	44 V	5.6 V	TEK035 (Va) Tek037 (I1) TEK039-40 (Vb) TEK042 (Vc)	ON	AC
							2.73 kA	436 A	274 V	50 V	8.8 V	TEK036 (I1, Va) TEK038 (Vb) TEK041 (I2) TEK042 (Vc)	OFF	
4			8m			BATT	2.72 kA	386 A	264 V	30.4 V	4.0 V	Phone images	ON	BATT
							2.72 kA	400 A	256 V	39.2 V	4.4 V	Phone images	OFF	
5			7m			AC	2.75 kA	354 A	224 V	33.2 V	8 V	TEK048 (Vc) TEK050 (i2) TEK051 (Vb) TEK054 (Va) TEK055 (I1)	ON	AC
							2.75 kA	452 A	256 V	42.4 V	5.4 V	TEK045 (I2) TEK046 (Vb) TEK047 (Vc) TEK052 (I1) TEK053 (Va)	OFF	
4			7m			BATT	2.74 kA	340 A	256 V	26V	3.2 V	Phone images	ON	BATT
							2.74 kA	440 A	244 V	34 V	3.6 V	Phone images	OFF	
6			6m			AC	2.75 kA	392 A	222 V	38 V	6.8 V	TEK056 TEK057 (Va) TEK060-TEK061 (Vb) TEK062 (Vc)	ON	AC
							2.75 kA	504 A	274 V	40 V	7.6 V	TEK058 (Va) TEK059 (Vb) TEK063 (Vc)	OFF	
6			6m			BATT	2.73 kA	396 A	248 V	32 V	3.2 V	Phone images	ON	BATT
							2.72 kA	500 A	240 V	40 V	3.6 V	Phone images	OFF	
7			5m			AC	2.77 kA	368 A	216 V	36V	6.8 V	TEK066 (I2) TEK067 (Vb) TEK068(Vc) TEK071 (Va)	ON	AC
							2.75 kA	468 A	268 V	68 V	6V	TEK064 (Vb) TEK065 (I2) TEK069 (Vc) TEK070 (Va)	OFF	

TC#2 – Diff mode Test Logbook

Test No.	SPD Type Tested	Mode Tested	Cable Length (L-L to Sub-rack)	Cable Length from SPD - FEB earth bar	Surge Current (A)	Oscope Voltage Supply Type (Battery or AC)	Measured Current (A) - I1	Measured Current (A) - I2	Measured Voltage (V) (Va) - SPD side	Measured Voltage (V) (Vb /DCDC side	Measured Voltage (V) (Vc) Rectifier Side
6	DC SPD	Line - Line	4m	1.5m	3kA	AC	2.75 kA	552 A	222V	55.6 V	9.6 V
6						BATT	2.73 kA	576 A	216 V	37.6 V	1.0 V
6						AC	2.74 kA	600 A	268V	68.4 V	12.9 V
6						BATT	2.72 kA	580 A	256 V	48.8 V	3.8 V
7			3m			AC	2.65 kA	716 A	264 V	52 V	10.4 V
7						BATT	2.74 kA	880 A	256 V	60 V	4.0 V
7						AC	2.68 kA	750 A	216 V	63.8 V	11.2 V
7						BATT	2.72 kA	888 A	244 V	40 V	2.6 V
8			2m			AC	2.70 kA	956 A	280 V	56.4 V	5.2 V
8						BATT	2.74 kA	932 A	244 V	48 V	2 V
8						AC	2.70 kA	A	290 V	76.4 V	7.8 V
8						BATT	2.74 kA	936 A	244 V	63.2 V	2.8 V
9			0.7m			AC	2.70 kA	1.50 kA	252 V	64.4 V	3.2 V
9						BATT	2.74 kA	1.25 kA	264 V	94 V	3.6 V
9						AC	2.70 kA	1.550 kA	252 V	80.4 V	3.18 V
9						BATT	2.74 kA	1.25 kA	260 V	86 V	4.8 V

TC#2 – Diff mode – Va, Vb, Vc (Line Voltages)

AC SCOPE						
Cable Length (m)	Va(on)	Vb(on)	Vc(on)	Va(off)	Vb(off)	Vc(off)
10	272	55.5	3	274	38.8	4.4
10(b)	317	76	7.6	320	24.8	13.8
9	268	74.4	6.4	264	70.6	6.8
8	264	44	5.6	274	50	8.8
7	274	33.2	8	256	42.4	5.4
6	274	38	6.8	274	40	7.6
5	268	36	6.8	268	38	6
4	222	55.6	9.6	268	68.4	12.9
3	264	52	10.4	216	63.8	11.2
2	280	56.4	5.2	290	76.4	7.8
1	252	64.4	3.2	252	80.4	3.18

BATT SCOPE						
Cable Length (m)	Va(on)	Vb(on)	Vc(on)	Va(off)	Vb(off)	Vc(off)
10	272	55.5	3	252	26	20
10(b)	248	26.4	2.2	240	26	6.4
9	268	19.6	6.4	260	22.4	8
8	264	30.4	4	256	39.2	4.4
7	256	26	3.2	244	34	3.6
6	248	32	3.2	240	40	3.6
5	228	28.4	2.4	252	36	1.6
4	216	37.6	1	256	48.8	3.8
3	256	60	4	244	40	2.6
2	244	48	2	244	63.2	2.8
1	264	94	3.6	260	86	4.8

TC#2 – Diff mode – (Line Voltages) Transient %

- Shows the Transient % of Surge passed through the line for each cable length. (4-5%) Va (0.6-1%) Vb and 0.1% Vc.

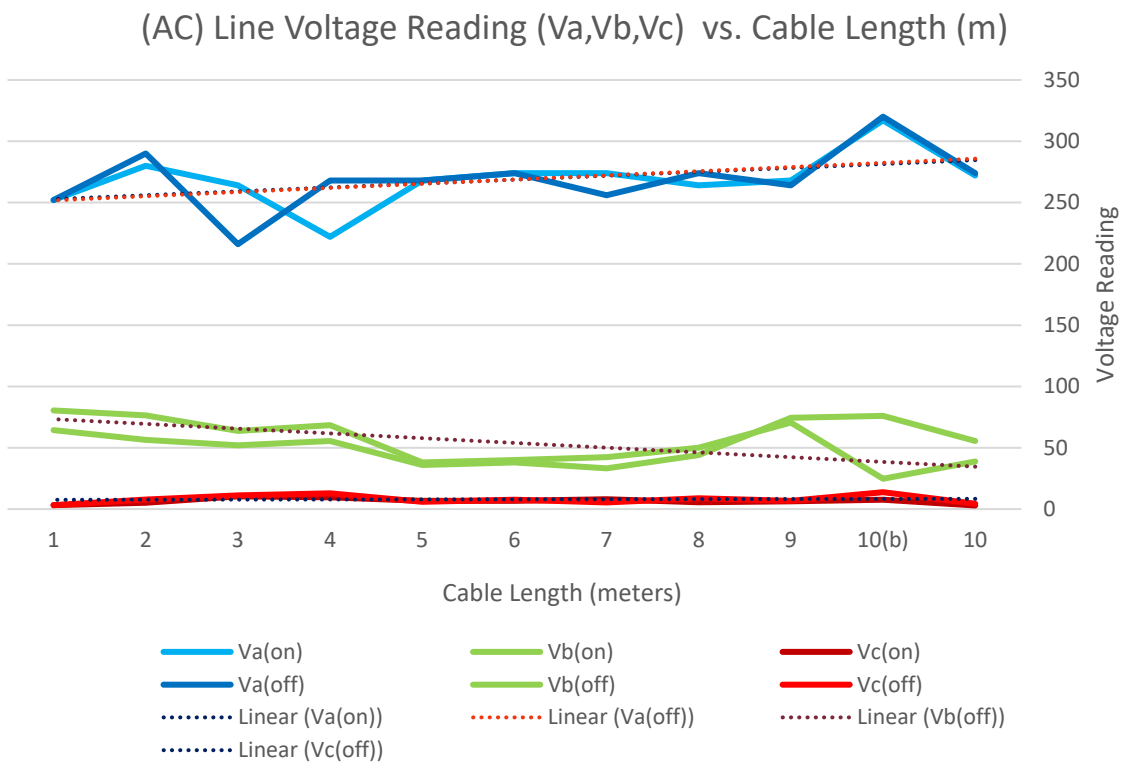
AC SCOPE

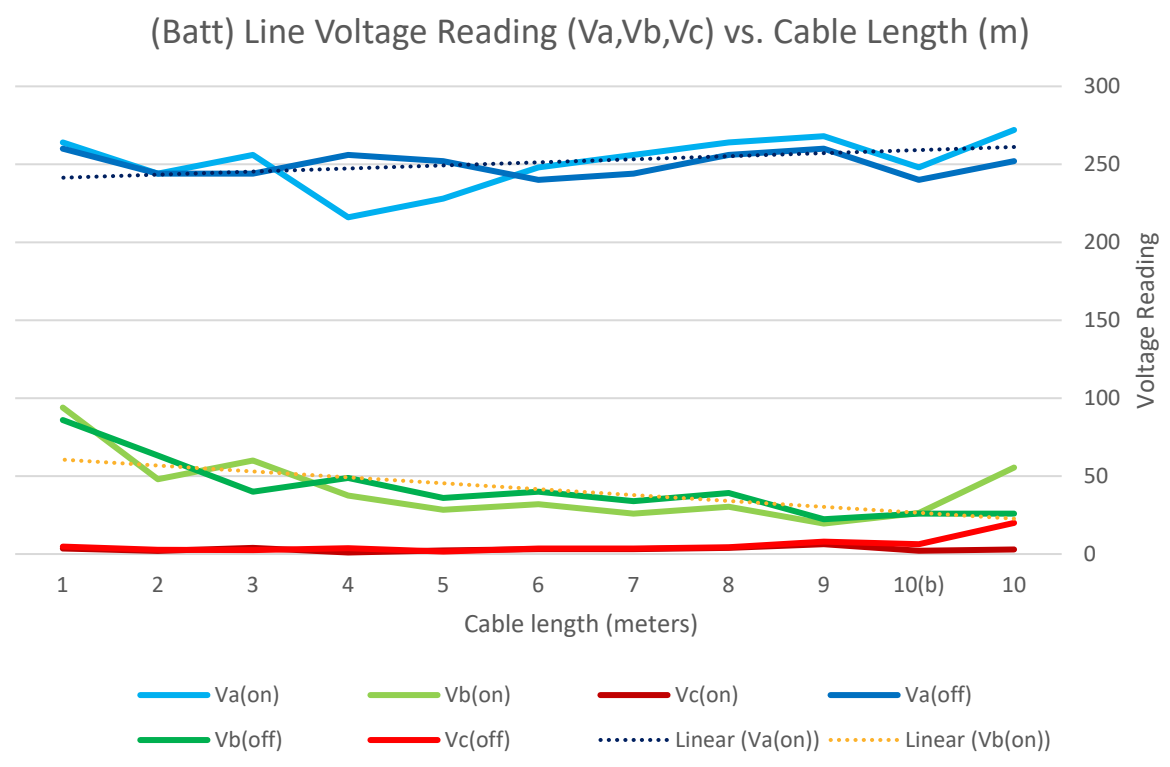
Cable Length (m)	Va(on)	Transient % (Va)	Vb(on)	Transient % (Vb)	Vc(on)	Transient % (Vc)	Va(off)	Vb(off)	Vc(off)
10	272	4.5	55.5	0.9	3	0.1	274	38.8	4.4
10(b)	317	5.3	76	1.3	7.6	0.1	320	24.8	13.8
9	268	4.5	74.4	1.2	6.4	0.1	264	70.6	6.8
8	264	4.4	44	0.7	5.6	0.1	274	50	8.8
7	274	4.6	33.2	0.6	8	0.1	256	42.4	5.4
6	274	4.6	38	0.6	6.8	0.1	274	40	7.6
5	268	4.5	36	0.6	6.8	0.1	268	38	6
4	222	3.7	55.6	0.9	9.6	0.2	268	68.4	12.9
3	264	4.4	52	0.9	10.4	0.2	216	63.8	11.2
2	280	4.7	56.4	0.9	5.2	0.1	290	76.4	7.8
1	252	4.2	64.4	1.1	3.2	0.1	252	80.4	3.18

BATT SCOPE

Cable Length (m)	Va(on)	Transient % (Va)	Vb(on)	Transient %(Vb)	Vc(on)	Transient % (Vc)	Va(off)
10	272	4.5	55.5	0.9	3	0.1	252
10(b)	248	4.1	26.4	0.4	2.2	0.0	240
9	268	4.5	19.6	0.3	6.4	0.1	260
8	264	4.4	30.4	0.5	4	0.1	256
7	256	4.3	26	0.4	3.2	0.1	244
6	248	4.1	32	0.5	3.2	0.1	240
5	228	3.8	28.4	0.5	2.4	0.0	252
4	216	3.6	37.6	0.6	1	0.0	256
3	256	4.3	60	1.0	4	0.1	244
2	244	4.1	48	0.8	2	0.0	244
1	264	4.4	94	1.6	3.6	0.1	260

Graphs – Data





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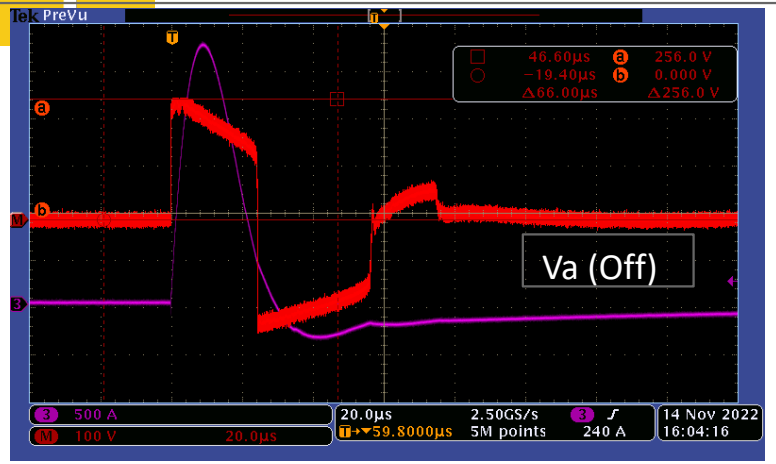
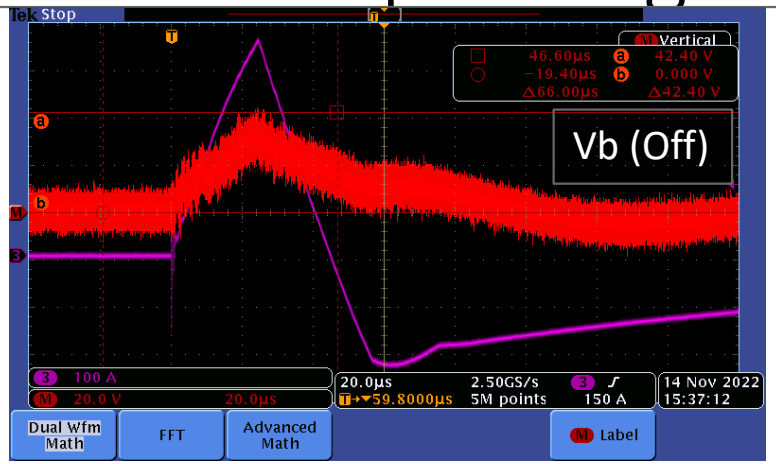
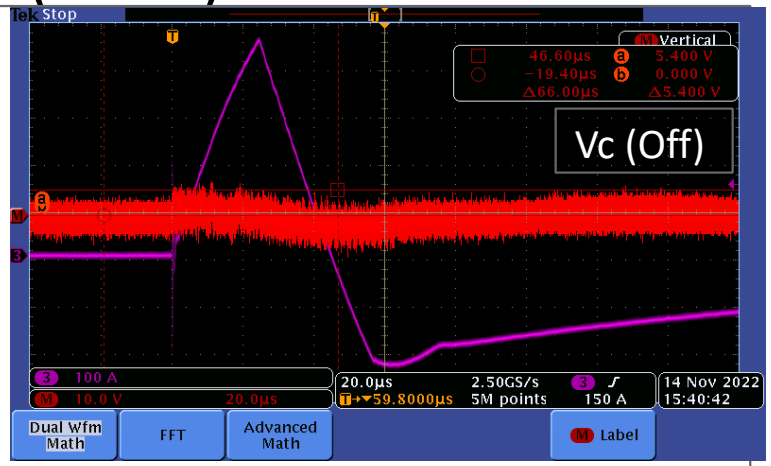
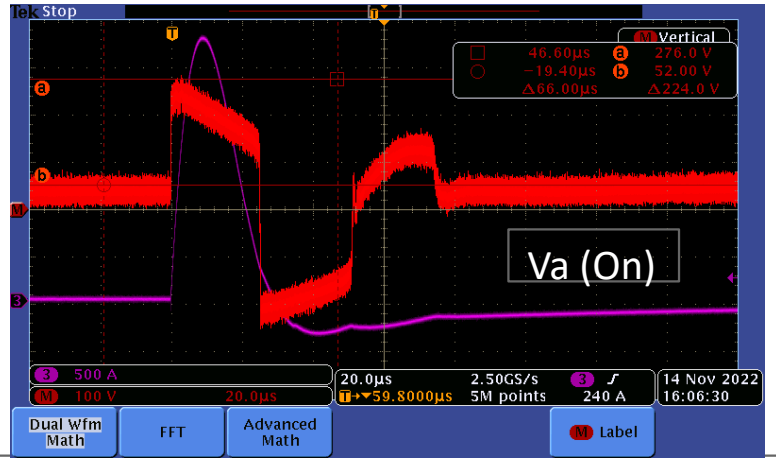
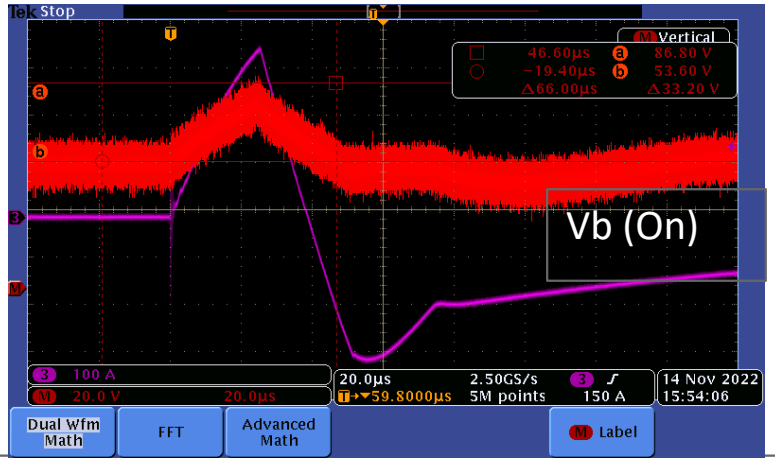
TC#2 – Diff mode – AC Scope Images (7 m)

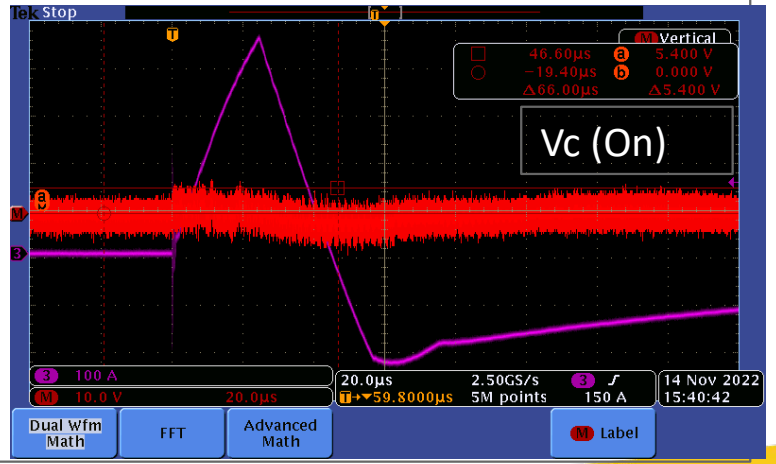












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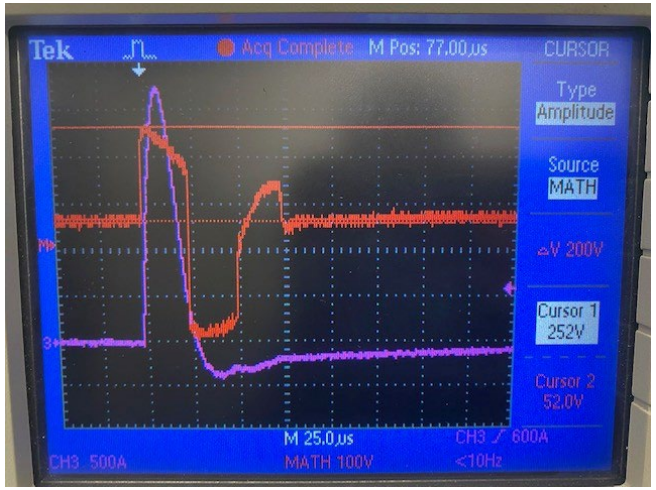
TC#2 – Diff mode – Batt Scope Images (7m)

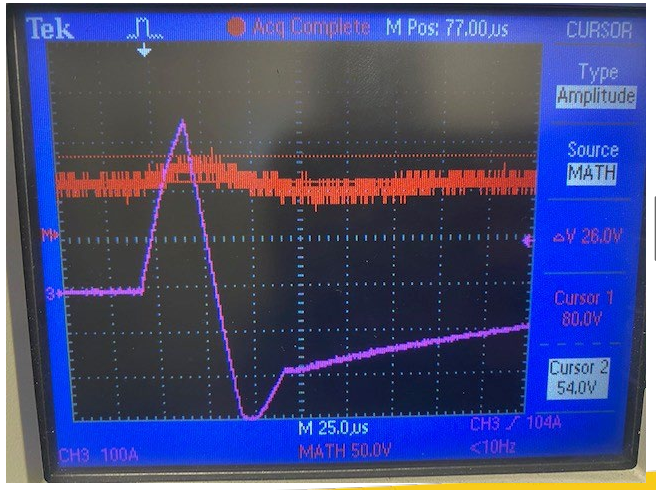
Va (Off)

Vb (Off)

Vc (Off)



Va (On)



Vb (On)

Vc (On)

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Closing Remarks

Interpret Results

- Effects of changing length of cable to supply rack
- Does the testing illustrate the effects of changing cable length on the line voltage?
- AC vs Battery powered measurement to improve noise canceling and ringing on AC line.
- Additional Test cases proposed: (further testing opportunities)
    - SPD at shelter entrance and right before equipment rack. (Recommended by nVent ERICO)
    - Very long cable 35-50m to determine if very long and thin cable will influence line voltage
- Comparison of Differential mode results vs Common Mode

In Closing

- Thank you all for your kind attention
- Please save your questions for the Q/A Session