Automating Analytics of Electrical Load Impact due to Voltage Sags

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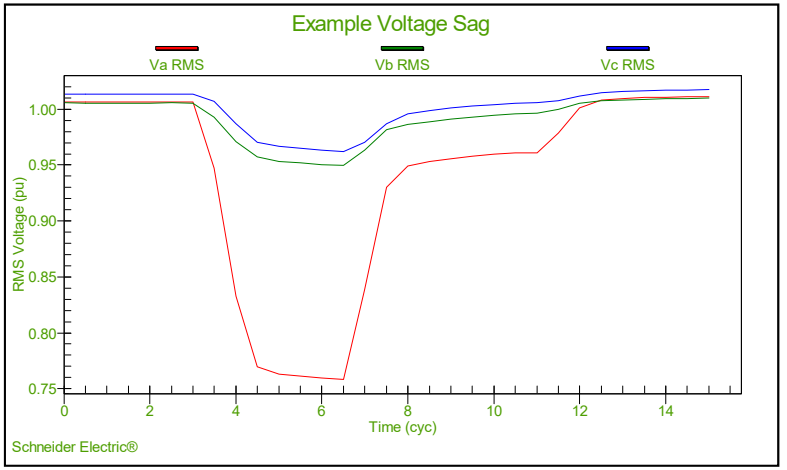
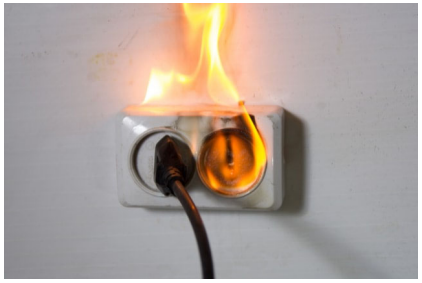
What are Voltage Sag and What are Their Impacts?

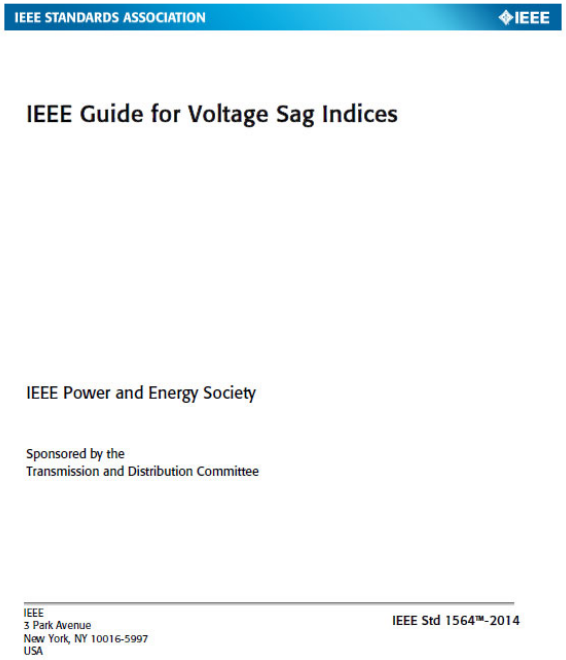
- Voltage sags are a brief reduction in rms voltage typically caused by electrical faults and load energization.
- IEEE Std 1409-2012 estimates that industrial and commercial customers experience an average of 56 voltage sags each year.
- EPRI estimates the American economy loses up to $188B annually due to poor power quality and associated productivity losses.



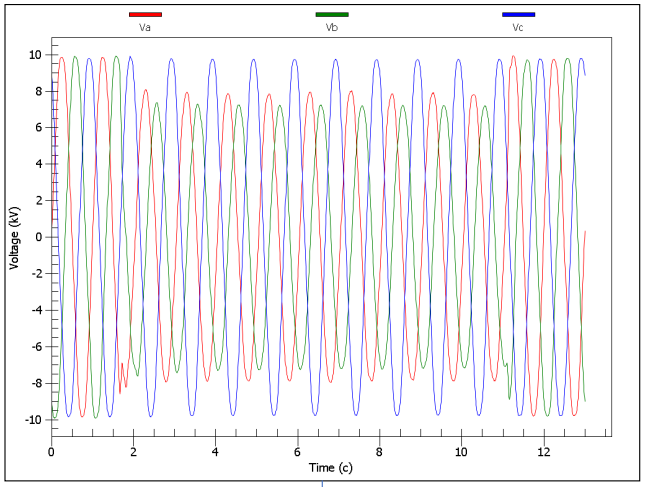


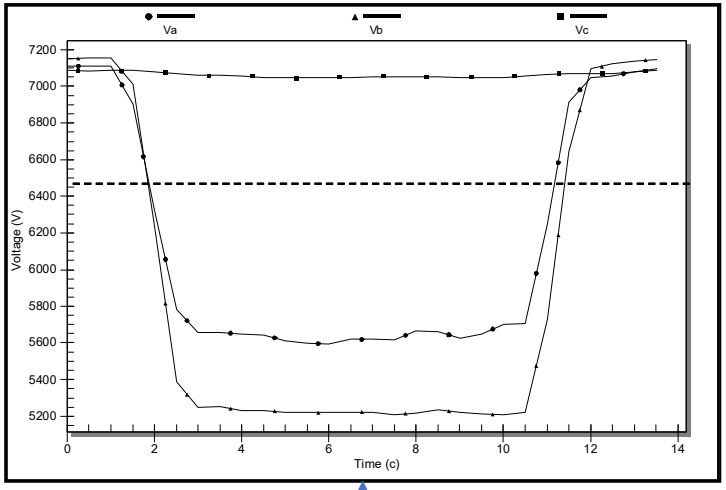
IEEE Std 1564-2014

- IEEE 1564 identifies voltage sag indices and characteristics of electric power and supply systems as well as the methods for their calculation methods.
- IEEE 1564 specifies methods to quantify the severity of individual voltage sag events, to quantify the performance at a specific location via single-site indices, and to quantify power system performance via system indices.
- The methods are appropriate for use in transmission, distribution, and utilization electric power systems.
- Single-site indices defined in IEEE 1564 include System Average RMS Variation Frequency Index (SARFI), voltage sag magnitude vs duration tables, voltage sag energy, and voltage sag severity.



IEEE Std 1564-2014 Method to Compute RMS from Voltage Waveforms





$$V_{rms(1/2)}(k) = \sqrt{\frac{1}{N}\sum_{i=1+k-N}^{k} v_i^2}$$

IEEE Std 1564-2014 Single Event Characteristics

- Magnitude-Duration
  - Retained Voltage
    - smallest one-cycle rms voltage (from series of rms values recomputed every half-cycle)
  - Duration
    - Time difference between beginning and end of voltage sag
- Threshold Recommendations
  - Sag Start Time: 90% of reference voltage
  - Interruption Start Time: 10% of reference voltage
  - Sag End Time: 91% of reference voltage
- Voltage Sag Energy, Voltage Swell Energy, Voltage Sag Severity

IEEE 1564 SARFI: System Average RMS Variation Frequency Index

- SARFI-X
  - SARFI-90: Count or rate of voltage sags and interruptions with retained voltage below 90% of voltage reference
  - SARFI-110: Count or rate of voltage swells with retained voltage above 110% of voltage reference
- SARFI-Curve
  - SARFI-ITIC: Count or rate of voltage sags and interruptions with retained voltage and duration below the lower portion of the ITI (CBEMA) Curve
  - SARFI-SEMI: Count or rate of voltage sags and interruptions with retained voltage and duration below the lower portion of the SEMI F47 Curve
- Temporal Aggregation, Monitor Availability

Time Stamp	Retained Voltage	Duration
2000-07-01 09:48:52	73%	9 c
2000-07-01 09:50:16	73%	9 c
2000-07-07 14:20:12	0%	82 c
2000-07-10 15:55:23	13%	100 c
2000-07-21 09:48:52	0%	2.6 s
2000-08-08 07:35:02	49%	34 c
2000-09-02 08:30:28	0%	41 s
2000-09-08 10:30:40	59%	40 c

Index	Count	Events per 30 Days
SARFI-90	8	2.61
SARFI-70	6	1.96
SARFI-50	5	1.63
SARFI-10	3	0.98

Improved PQ Applications: Understand Voltage Variations with SARFI Index

Transmission & Distribution Operators may run SARFI index at each of their customers to monitor and benchmark voltage variations, such as voltage sag, among their customers

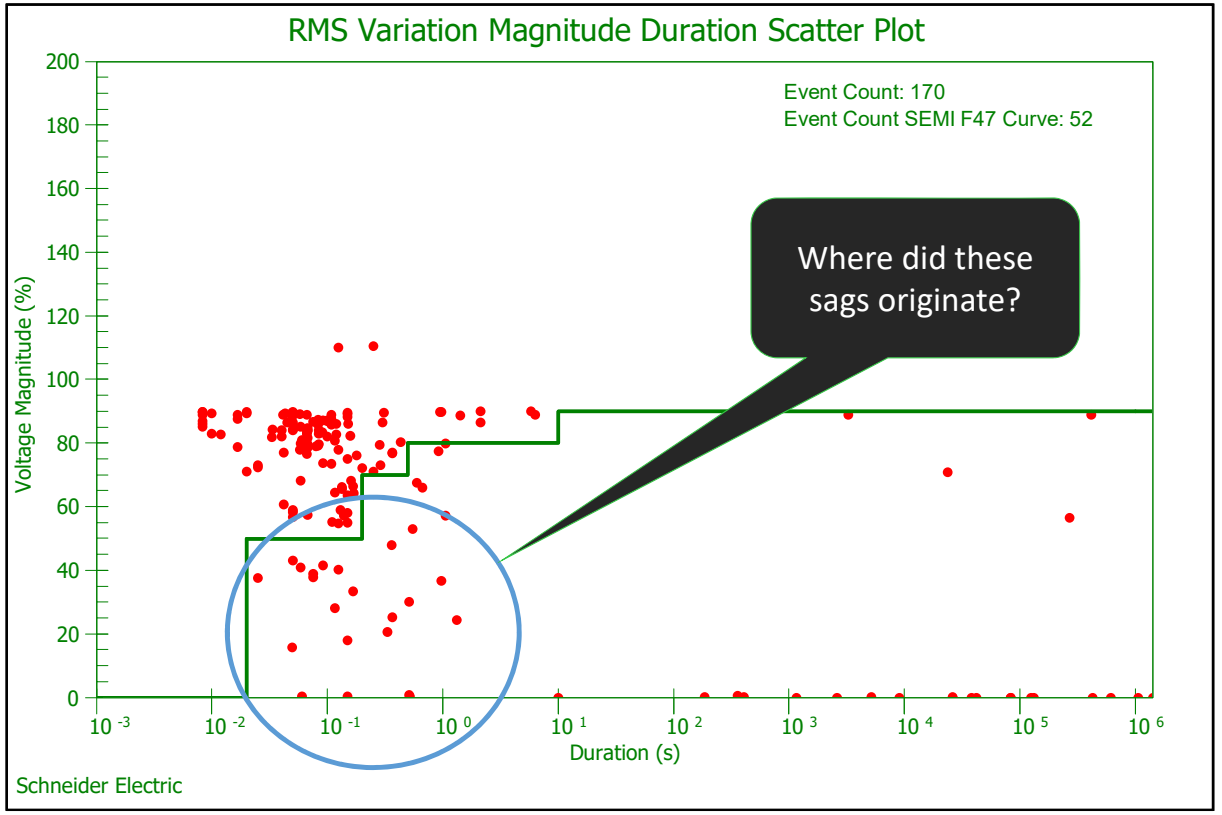
1/1/2019 12.00.00 AM - 1/1/2020 12.00.00 AM (Server Local)

Source	SARFI									
	10	50	70	80	90	110	120	140	ITIC	SEMI
Keating.Main_7650	1	2	4	14	72	0	0	0	4	1
Keating.Panel_H	1	1	4	14	86	0	0	0	5	1
Keating.Panel_E	1	1	4	14	86	0	0	0	5	1
Keating.Panel_M	1	1	4	14	86	0	0	0	5	1
Keating.Panel_M_Left	0	1	3	28	63	0	0	0	8	5
Keating.Panel_M_Right	0	0	4	23	61	0	0	0	7	3
Keating.Panel_R	1	1	4	14	86	0	0	0	5	1
Keating.RTU_5	1	1	4	14	86	0	0	0	5	1
Keating.Server_Room_IT_Load	1	1	1	10	38	0	0	0	2	2

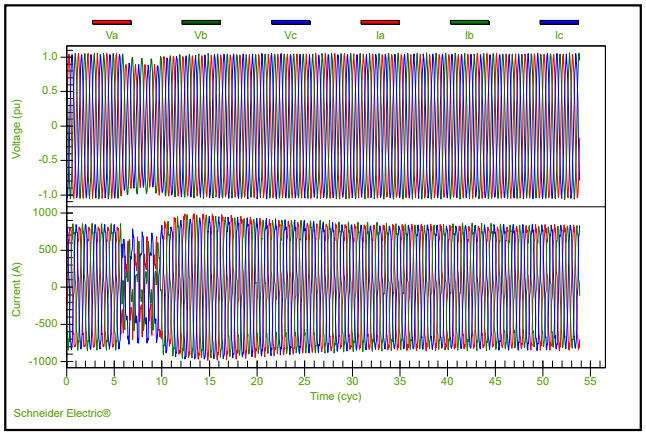
In order to know the number of voltage variations, such as voltage sag, from their utility, commercial and industrial facility managers may compute SARFI index at each of their plants at the service entrance.

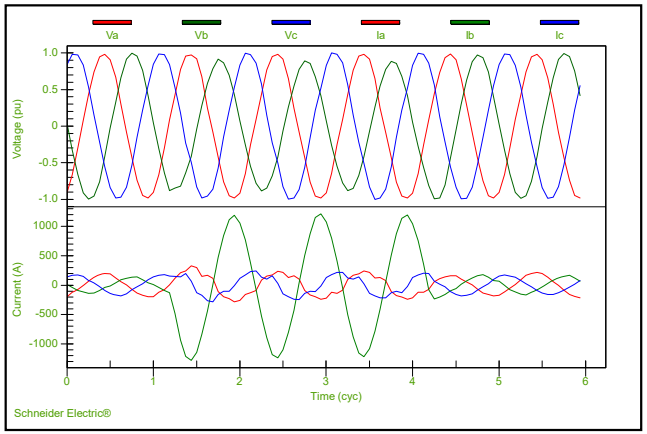
Analysis of Voltage Sags using Voltage Only

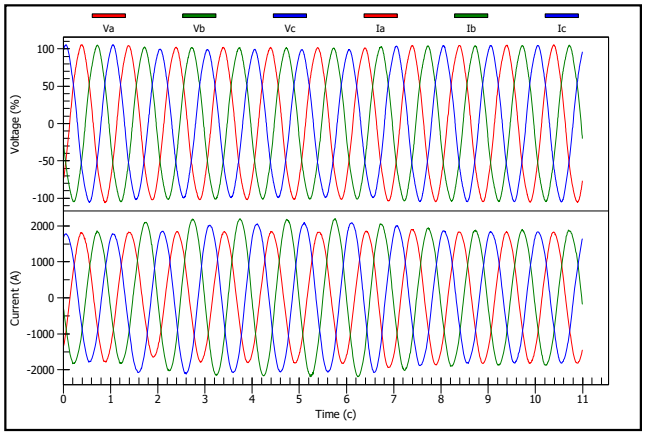
- Voltage Magnitude
- Event Duration
- IEEE Std 1159 Disturbance Category
- IEEE Std 1668 Sag Type
  - Type I: Single-Phase Sag
  - Type II: Line-Line Sag
  - Type III: Three-Phase Sag
- ITIC Charts/SEMI F47 Charts



Disturbance Direction Examples





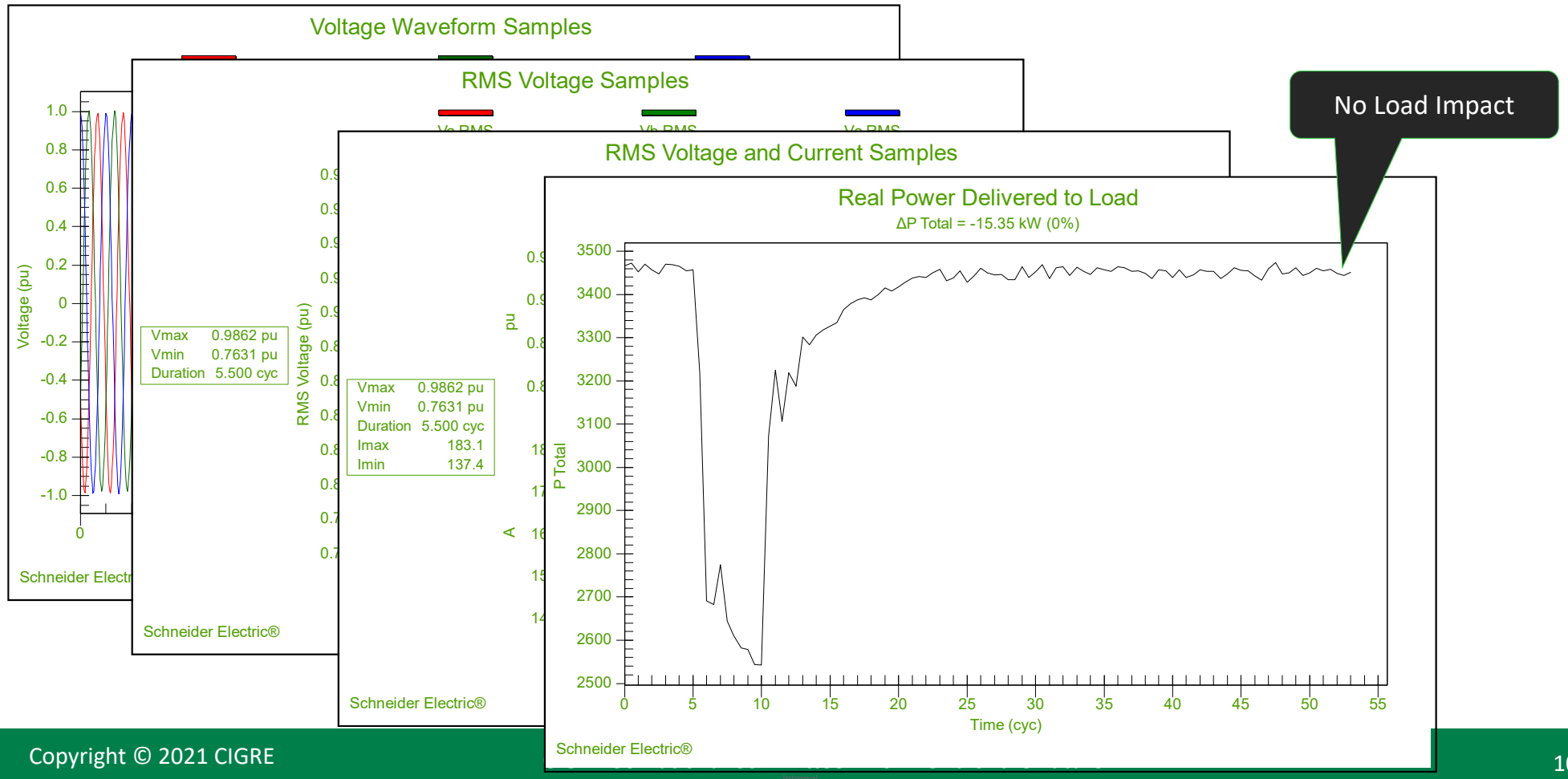


Upstream

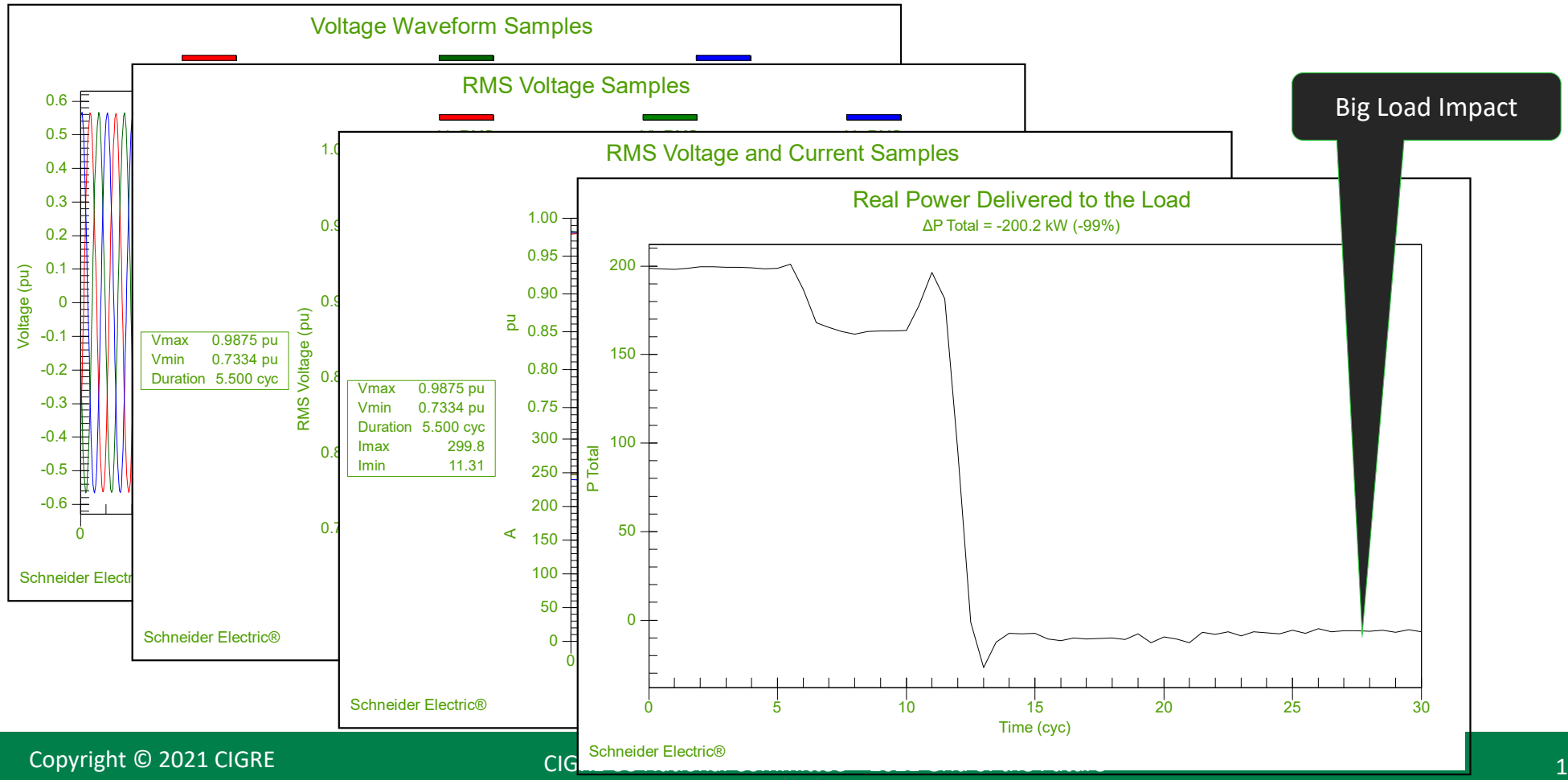
Downstream

Downstream

Load Impact Example #1



Load Impact Example #2



Analysis of Voltage Sags using Voltage Only

Voltage Only

- Voltage Magnitude
- Event Duration
- IEEE Std 1159 Disturbance Category
- IEEE Std 1668 Sag Type

Voltage with Current

- Disturbance Direction
- Load Impact / Load Change
  - Load Loss
  - Loss Increase
- Also Possible: Source Identification

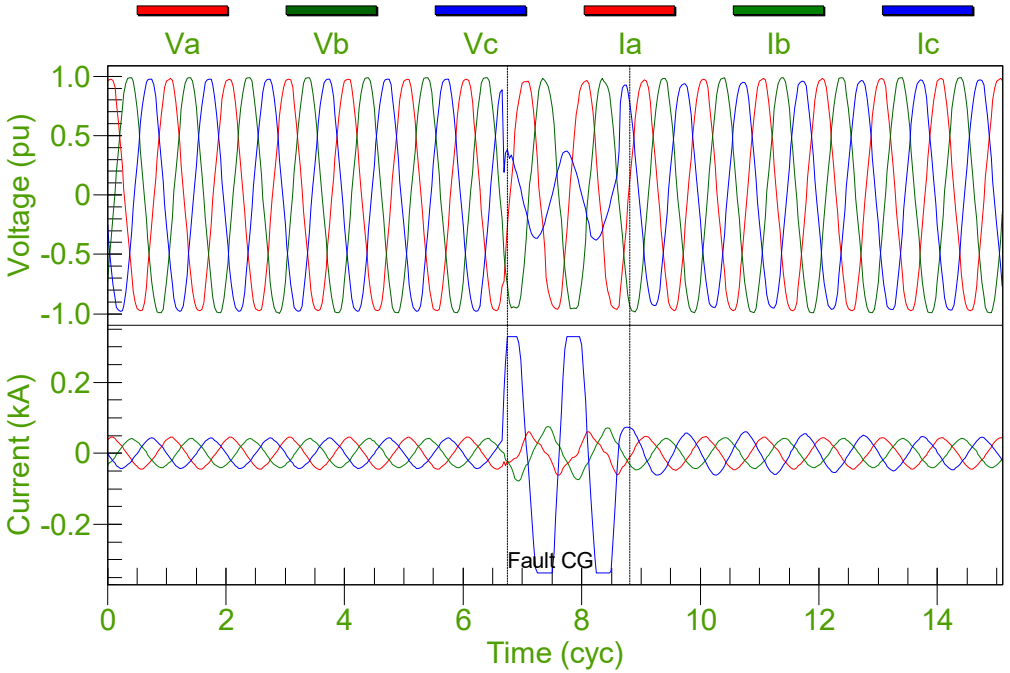
$$\text{Active Power} = P_{(1/2)}(k) = \frac{1}{N} \sum_{j=1+k-N}^{k} v_j i_j$$

$$\text{Load Change} = P_{(1/2)}(K) - P_{(1/2)}(0)$$

Downstream Single-Phase Fault

Type I Instantaneous Voltage Sag - Downstream Single-Phase Fault

Max Voltage	1.027 pu
Min Voltage	0.3522 pu
Max Current	0.2808 kA
Min Current	0.02693 kA
Load Change	-10.43 kW
Load Change	-2.67%
RMS Duration	2.813 cyc
Positive-Sequence Rotation	True



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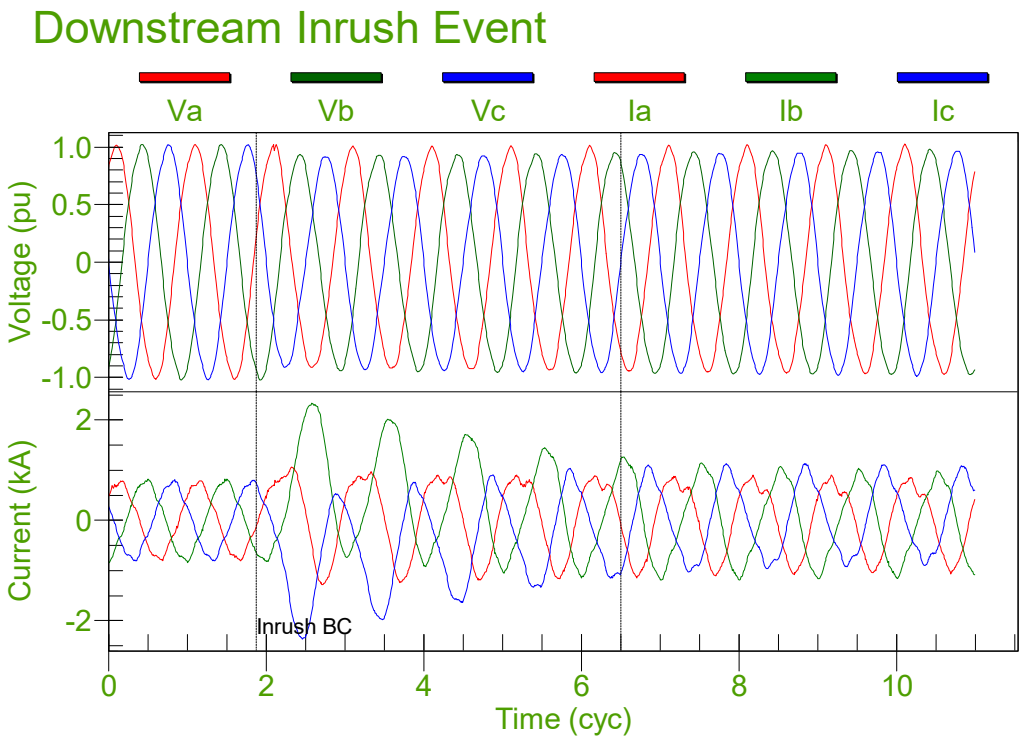
Downstream Inrush Event

Max Voltage	1.018 pu
Min Voltage	0.9100 pu
Max Current	1.353 kA
Min Current	0.5312 kA
Load Change	41.66 kW
Load Change	0.18%
RMS Duration	0 cyc
Positive-Sequence Rotation	True



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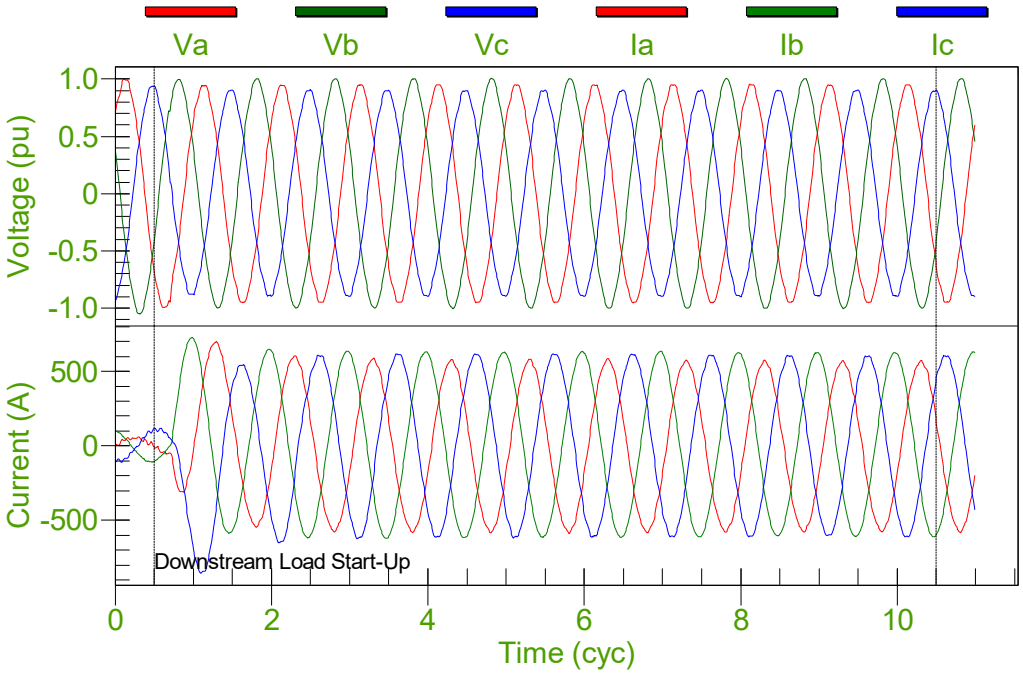
Downstream Three-Phase Load Start

Type III Instantaneous Voltage Sag - Downstream Load Start

Max Voltage	1.017 pu
Min Voltage	0.8904 pu
Max Current	523.9 A
Min Current	128.1 A
Load Change	98.66 kW
Load Change	106.14%
RMS Duration	9.563 cyc
Positive-Sequence Rotation	False



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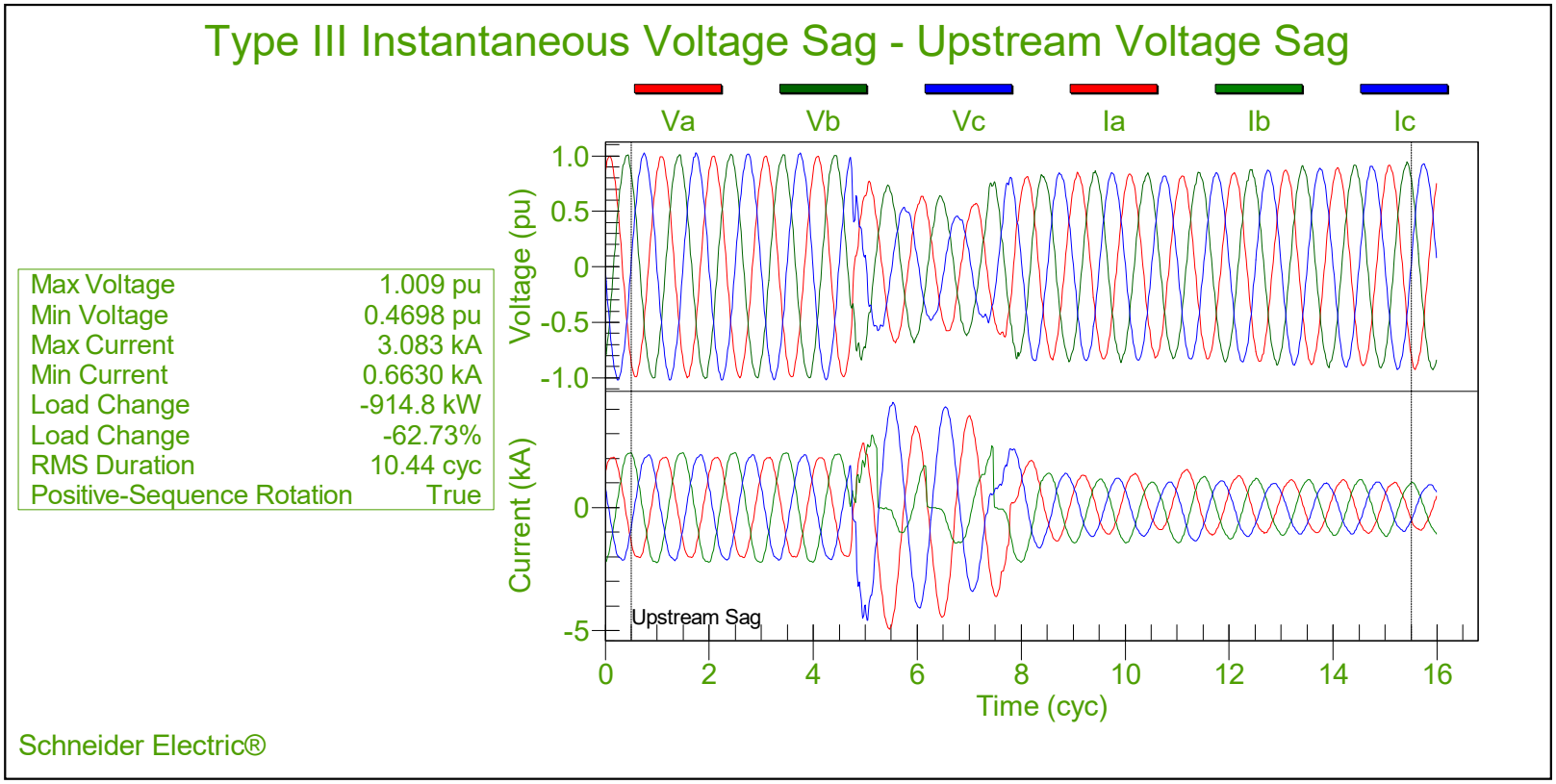
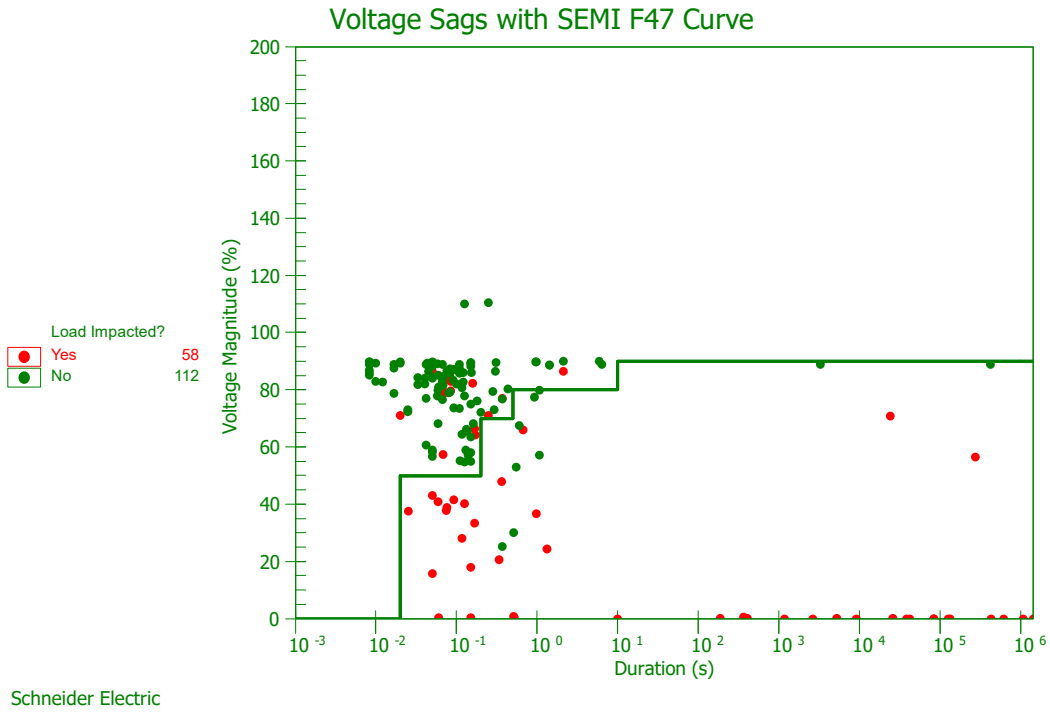
Upstream Voltage Sag

Causes Downtime to Downstream Load



Recommendation: Automate Sag Impact Analysis

- ITIC and SEMI F47 Charts with Load Impact Color Codes and Disturbance Direction Color Codes

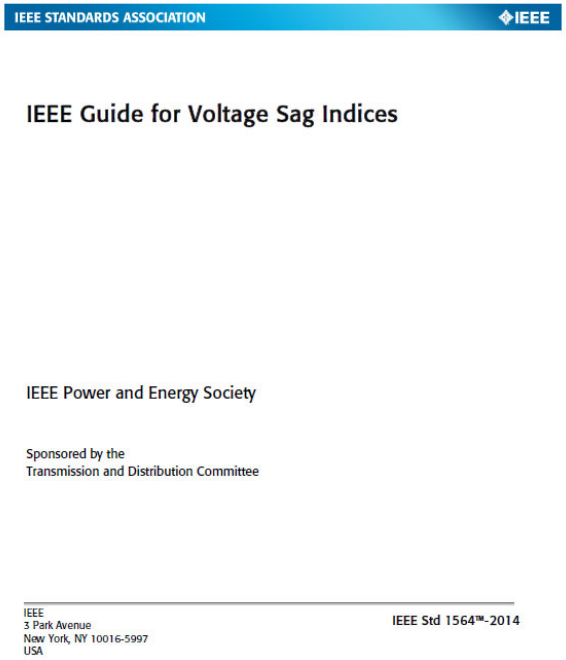


Recommendation: Enhance IEEE Std 1564

- The IEEE PES Transmission & Distribution Committee just started a project to revise IEEE Std 1564.
- Recommendation: Enhance Mag-Dur Indices:

Voltage Magnitude & Duration

Voltage Magnitude & Duration
+
Sag Type
+
Disturbance Direction
+
Load Impact


IEEE STANDARDS ASSOCIATION IEEE

IEEE Guide for Voltage Sag Indices

IEEE Power and Energy Society

Sponsored by the
Transmission and Distribution Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1564™-2014

Recommendation: Use Natural Language PQ Event Descriptions in Software using Voltage and Current Waveform Analysis

Upstream Voltage Sag	98% Load Loss
Downstream Inrush Event	25% Load Loss
Downstream Load Start	10% Load Gain

Benefits of Automatic Voltage AND Current Waveform Analysis

Commercial / Industrial

- Quickly determine did voltage sag originate inside the plant or from utility
- Rapidly identify which sags resulted in load loss and quantify the impact
- Provides information needed to select best option for voltage sag mitigation

Transmission & Distribution Systems

- Faster response time to power interruptions: Reduced Interruption Duration (SAIDI)
- Automatic benchmarking using SARFI indices by source
- Improved customer satisfaction

How can you participate in voltage sag impact standardization?

- **IEEE P1564 Guide for Voltage Sag Indices**: Working group is revising IEEE Std 1564-2014. Next Meeting in January 2022 at the IEEE PES Joint Technical Committee Meeting: https://pestechnical.org/

- **IEEE P2938 Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags**: Working group is developing a guide to describes how to carry out cost and loss economic-assessment of voltage sags: https://sagroups.ieee.org/2938/

- **SEMI Standards F47 Voltage Sag Immunity Task Force** is focusing on potential adjustments to equipment design, facility design, utility systems or standards to further reduce voltage sag induced losses by the semiconductor industry: https://www.semi.org/

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