Indices Used to Assess RMS Voltage Variations

D. Daniel Sabin

dsabin@electrotek.com

Why do we need rms variation indices?

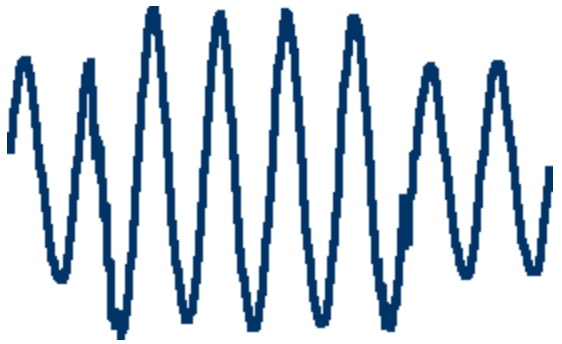
- Power providers are building databases of power quality with megabytes to gigabytes of measurements. These databases need to be summarized efficiently.
- There continues to be a lack of common terminology to assess utility service quality performance.
- The continues to be a lack of common terminology between utility and premium service customers.

Intent of Indices

- Individual customer level
  - serve as a specific metric of compatibility between customer processes and the electrical environment
- Utility system level
  - serve as a general quality metric to be used by the power provider for proactive planning and maintenance

RMS Voltage Variations

Voltage Sag



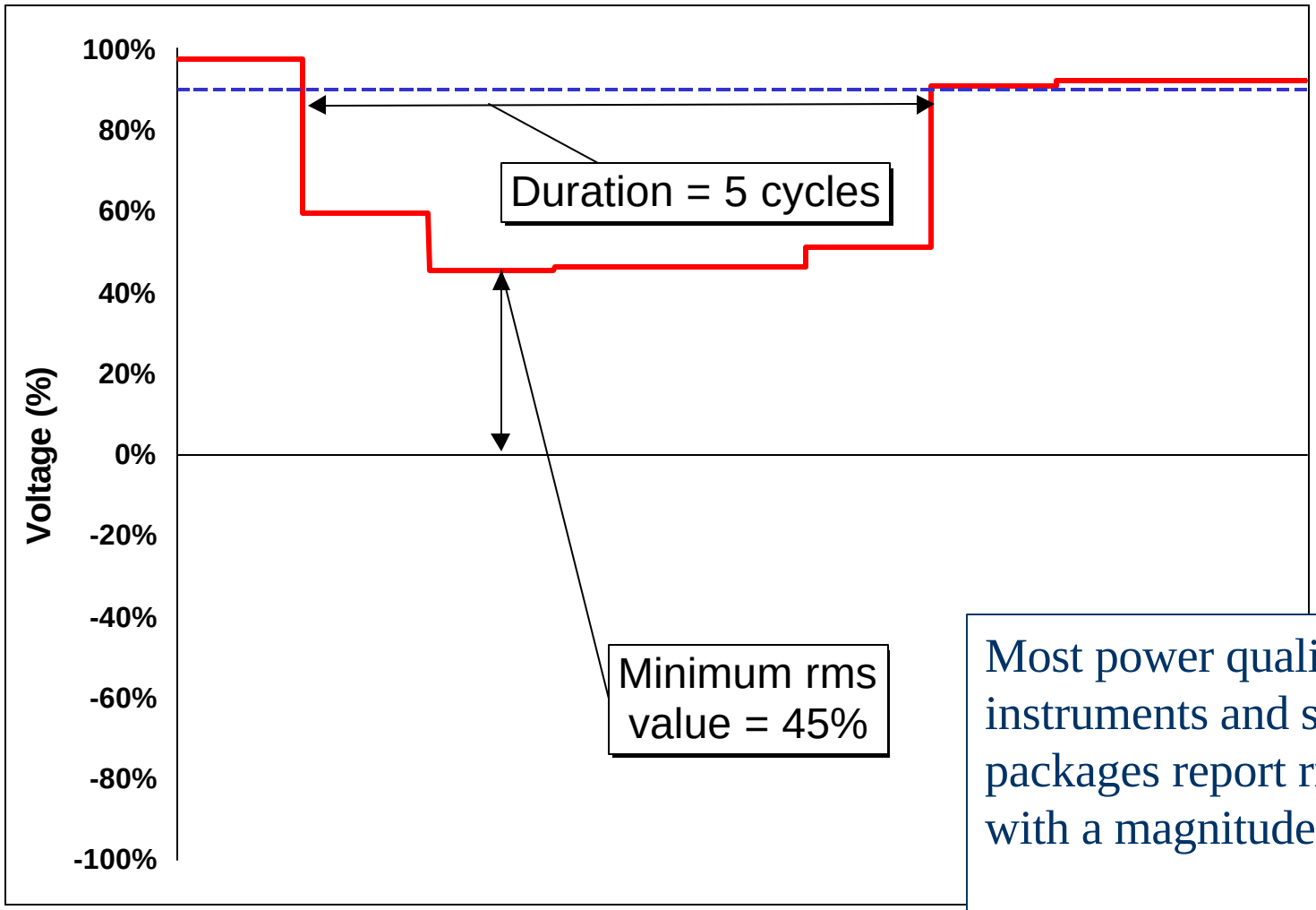
Voltage Swell

Voltage Interruption

Short Duration: System Faults
Load Inrush

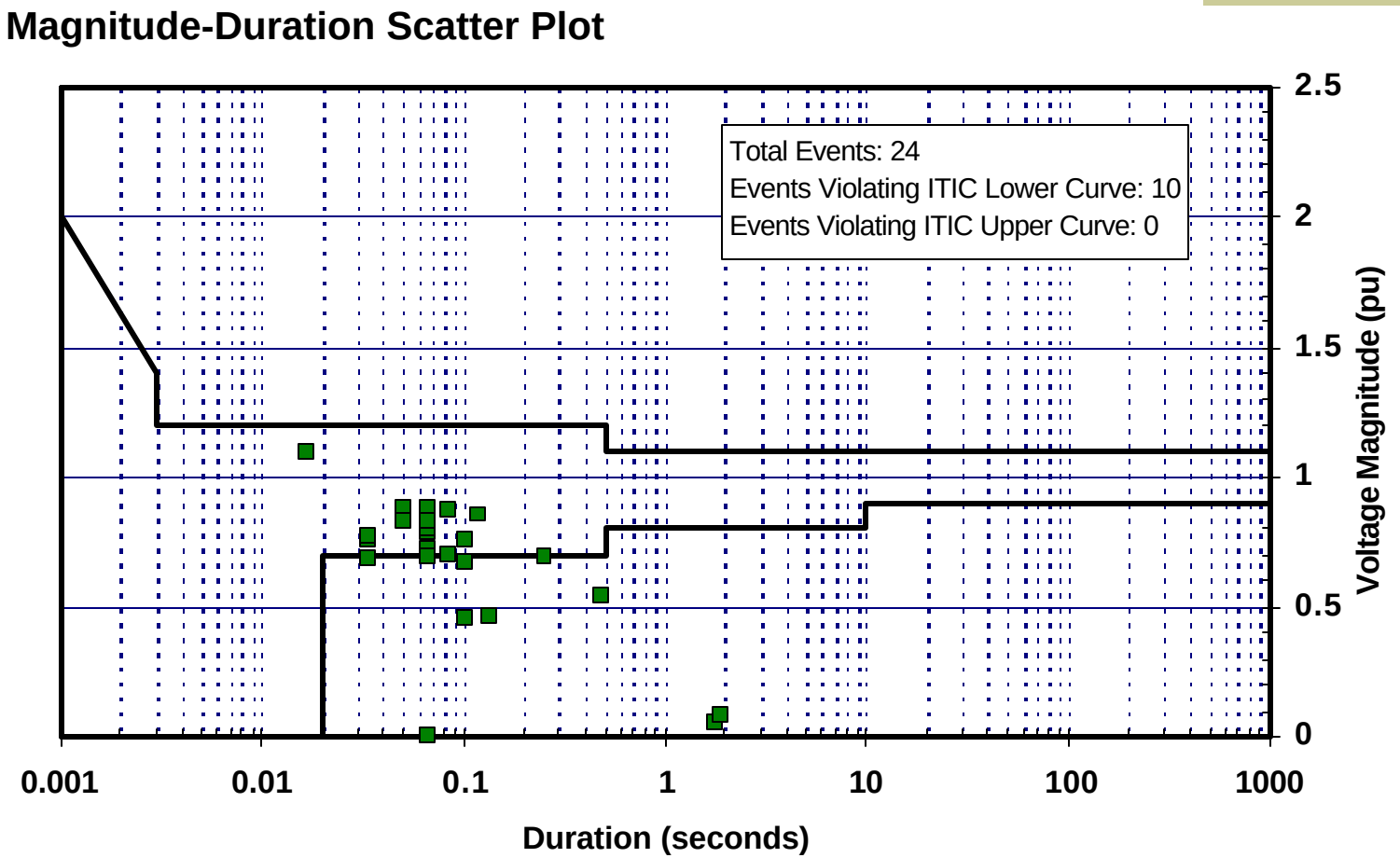
Long Duration: Regulation Problems

Magnitude-Duration Characterization of RMS Voltage Variations



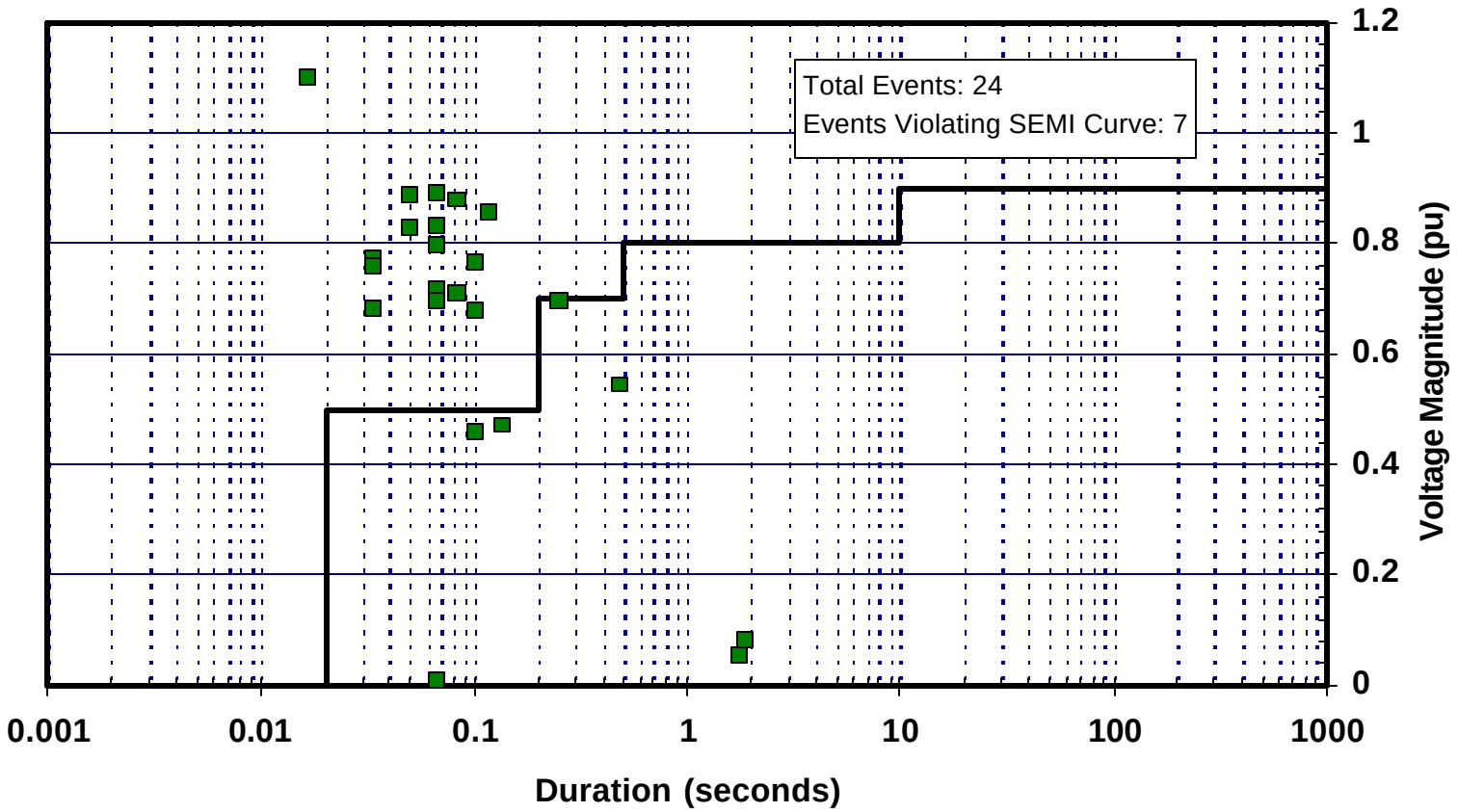
Most power quality monitoring instruments and software packages report rms variations with a magnitude and a duration.

Compliance with ITIC Curves - 1997



Compliance with SEMI Curve - 1998

Magnitude-Duration Scatter Plot



System Benchmarking

- What if we want to perform system benchmarking?
  - Comparing one customer service entrance to a substation
  - Comparing one substation to another or to a system as a whole
  - Comparing different distribution systems

$SARFI_X$ Index

- *System Average RMS Variation Frequency Index*
- Research sponsored by EPRI
- Number of specified short-duration rms variation per system customer
- Voltage threshold allows assessment of compatibility for voltage-sensitive devices
- First use came about because of EPRI R&D project

$$SARFI_{\%V} = \frac{\sum N_i}{N_T}$$

$\%V \equiv$ rms voltage threshold
140, 120, 110, 90, 80, 70, 50, 10

$N_i \equiv$ # customers experiencing rms < $\%V$ for variation i
(rms > $\%V$ for $\%V$ >100)

$N_T \equiv$ total # system customers

So how do we compute the $SARFI_X$ index for a single site?

- $SARFI_x$ is the the count or rate of voltage sags below a given voltage threshold x%.
- Short-Duration Index: it only considers events with durations between ½ cycle and 60 seconds.

Time Stamp	Minimum Voltage	Event Duration
7/1/97 9:48	73%	9 cyc
7/2/97 9:50	73%	9 cyc
7/7/97 14:20	0%	82 cyc
7/10/97 14:26	13%	100 cyc
7/21/97 15:55	0%	2.600 s
8/2/97 7:35	49%	34 cyc
9/2/97 8:30	0%	41 s
9/8/97 10:30	59%	40 cyc

Index	Count	Rate per 30 Days
$SARFI_{90}$	8	3.93
$SARFI_{70}$	6	2.95
$SARFI_{50}$	5	2.46
$SARFI_{10}$	3	1.48

SARFI Indices with Magnitude and Duration

- $SARFI_{CBEMA}$
  - Rate of voltage sags below lower CBEMA curve
- $SARFI_{ITIC}$
  - Rate of voltage sags below lower ITIC curve
- $SARFI_{SEMI}$
  - Rate of voltage sags below SEMI curve
- $SARFI_{CustomCurve}$

SARFI Statistics from EPRI DPQ Project

	$SARFI_{90}$	$SARFI_{80}$	$SARFI_{70}$	$SARFI_{50}$	$SARFI_{10}$	$SARFI_{CBEMA}$	$SARFI_{ITIC}$	$SARFI_{SEMI}$
Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CP05	11.887	5.594	0.000	0.000	0.000	5.316	2.791	2.362
CP50	43.987	22.813	12.126	5.165	1.525	25.465	18.765	13.619
Mean	56.308	28.729	18.422	8.926	3.694	33.293	25.390	18.535
CP95	135.185	66.260	51.000	27.037	13.519	71.413	51.500	38.238
Maximum	207.644	103.405	70.535	56.311	35.689	149.488	140.768	140.768

SARFI Rates for Substation Locations of EPRI DPQ Project, from 6/1/93 to 6/1/95, rates in events per 365 days, 60-sec temporal aggregation, treated using sampling weights

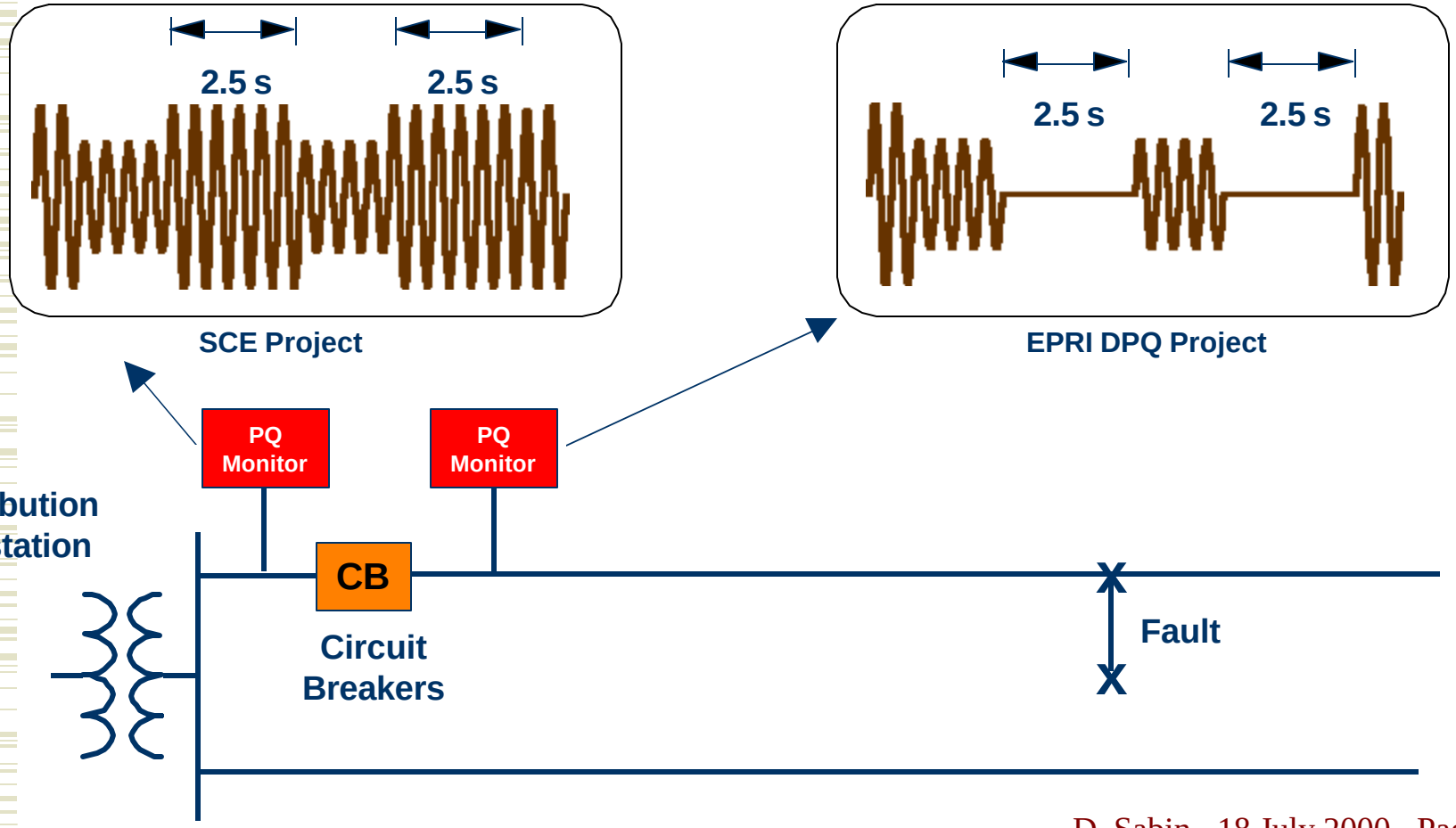
What utilities are using SARFI as part of their power quality assessment efforts?

- American Electric Power
- Baltimore Gas and Electric
- Consolidated Edison Company of New York
- Public Service Electric and Gas
- San Diego Gas and Electric
- Southern California Edison
- Tennessee Valley Authority
- United Illuminating Company

RMS Variation Aggregation

- Allows us to combine the measurements taken from different phases, trigger times, or locations into one aggregate event
  - Measurement aggregation
    - multiple phases or channels per measurement
  - Temporal Aggregation
    - breaker reclosing
  - Spatial Aggregation
    - multiple monitors per location

Why is Temporal Aggregation Important?



What Else is Available?

- DISDIP Table
  - Popular in IEC communities
- DECO SMC Sag Score
- ESKOM Table
- IEEE 1159.2 Characterization

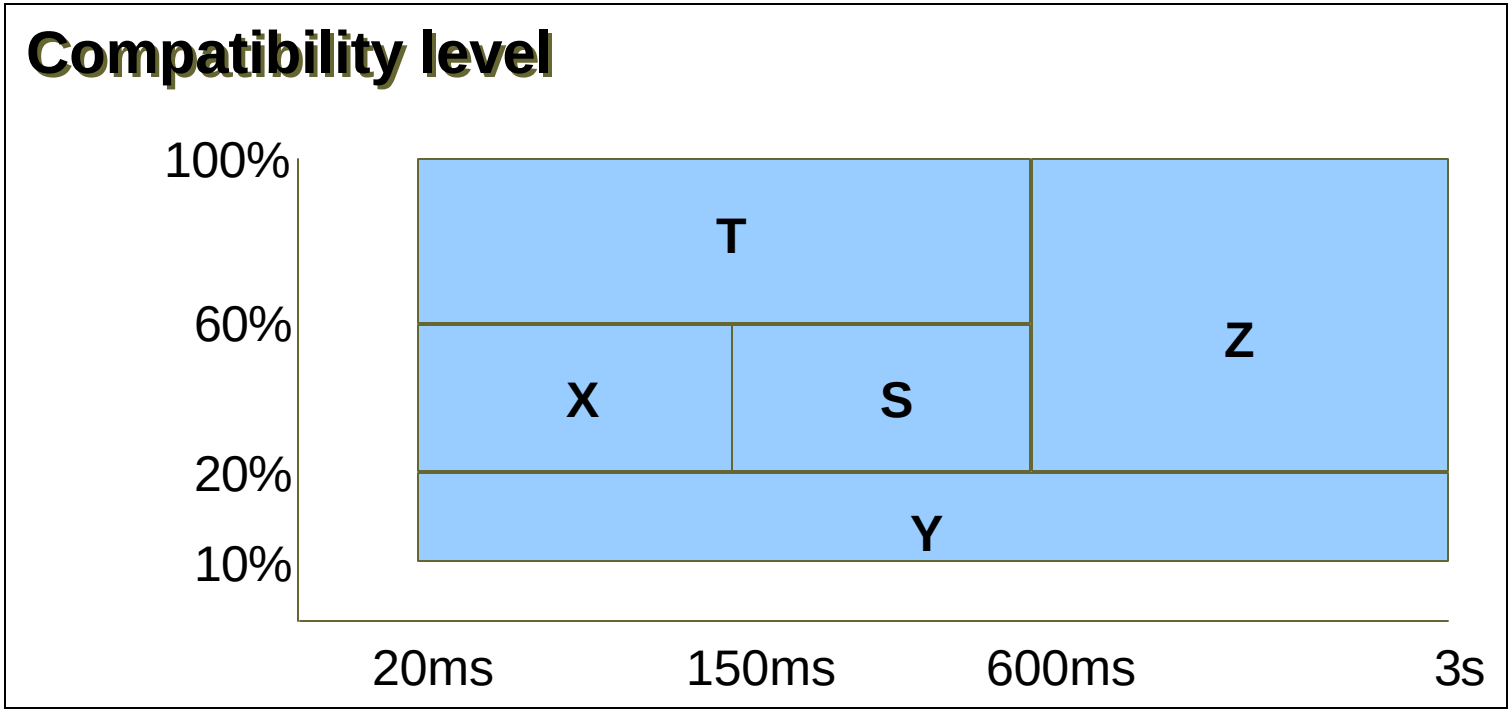
Sag Score

- Detroit Edison's uses a "sag score" to administer its voltage sag contracts with its automotive customers.
- Sag score is the average per unit voltage lost.
- Spatial and temporal aggregation
  - Sag agreements only consider the worst sag each 15-minute period per location

$$Sag\ Score = 1 - \frac{1}{3}\left(V_A + V_B + V_C\right)$$

ESKOM Voltage Dip Table

- Count number of voltage sags in rectangular magnitude-duration bins



ESKOM Voltage Sag Indices

- Voltage Sag Performance Requirements

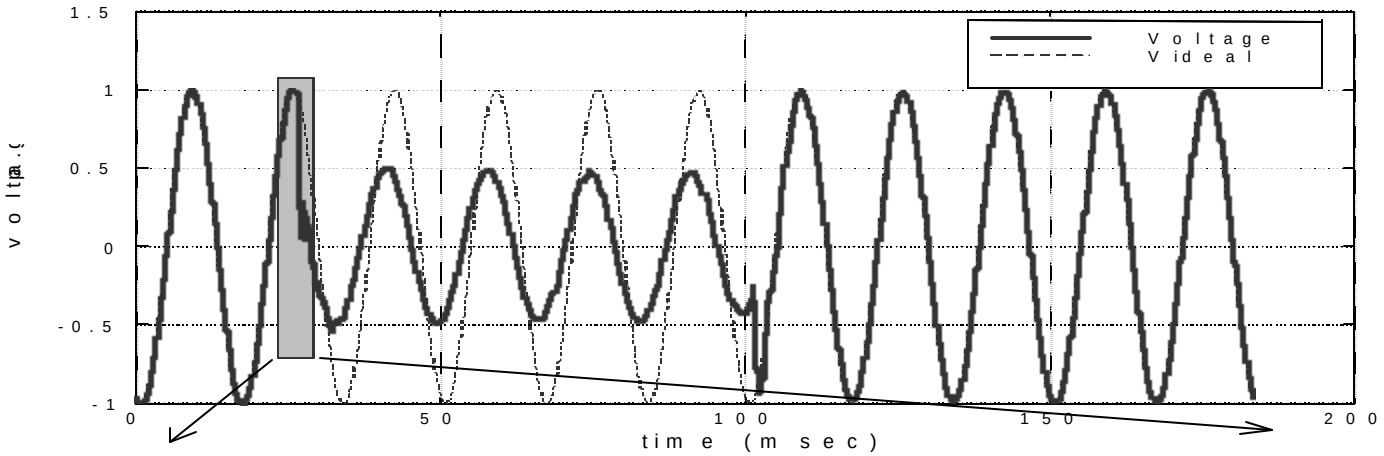
	S	T	X	(Y)	Z
6.6 kV to 44 kV	30	30	100	150	20
>44 kV to 132 kV (rural)	69	54	215	314	49
>44 kV to 132 kV	25	25	80	120	16
>132 kV to 765 kV	11	6	45	88	5

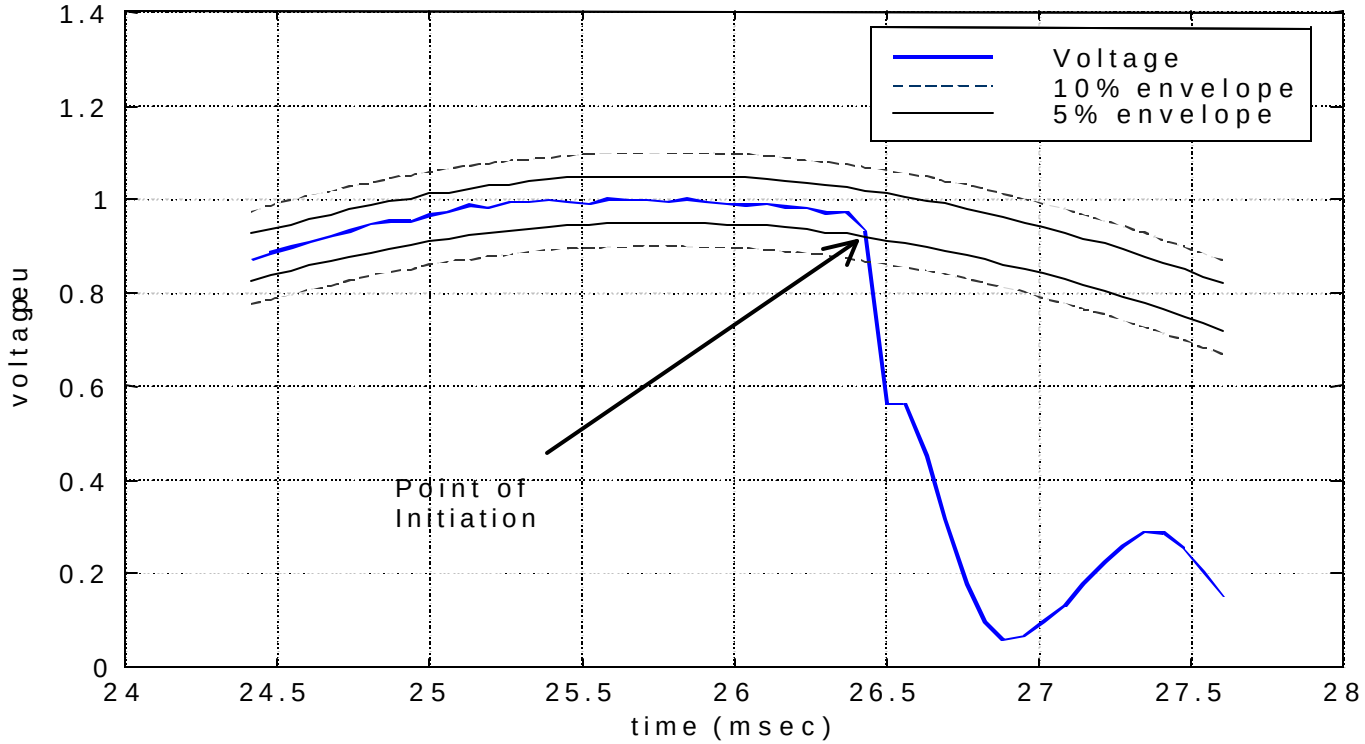
- Indicative levels for ESKOM System

	S	T	X	(Y)	Z
6.6 kV to 44 kV	10	8	50	75	10
>44 kV to 132 kV (rural)	25	15	100	150	20
>44 kV to 132 kV	10	10	50	80	5
>132 kV to 765 kV	3	3	33	40	2

IEEE Task Force P1159.2 Waveform Characteristics

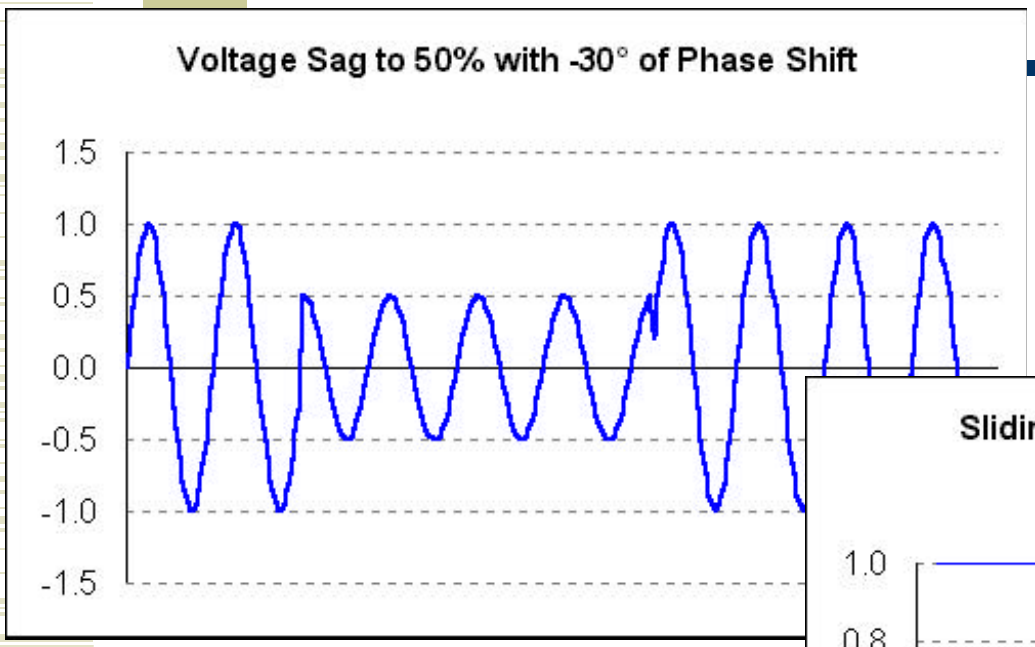
- What's New?
  - Point-in-Wave Characteristics
    - point of initiation, point of recovery, apparent duration
  - Transition Angles
    - initial transition angle, final transition angle, maximum phase angle during the event, post-event angle
  - Missing Voltage, Unbalance Ratio, Harmonic Distortion during Disturbance
  - Magnitude of three-phase diode rectifier bridge
- Will require a relatively more sophisticated power quality meter as characteristics as waveforms are needed, not just rms.

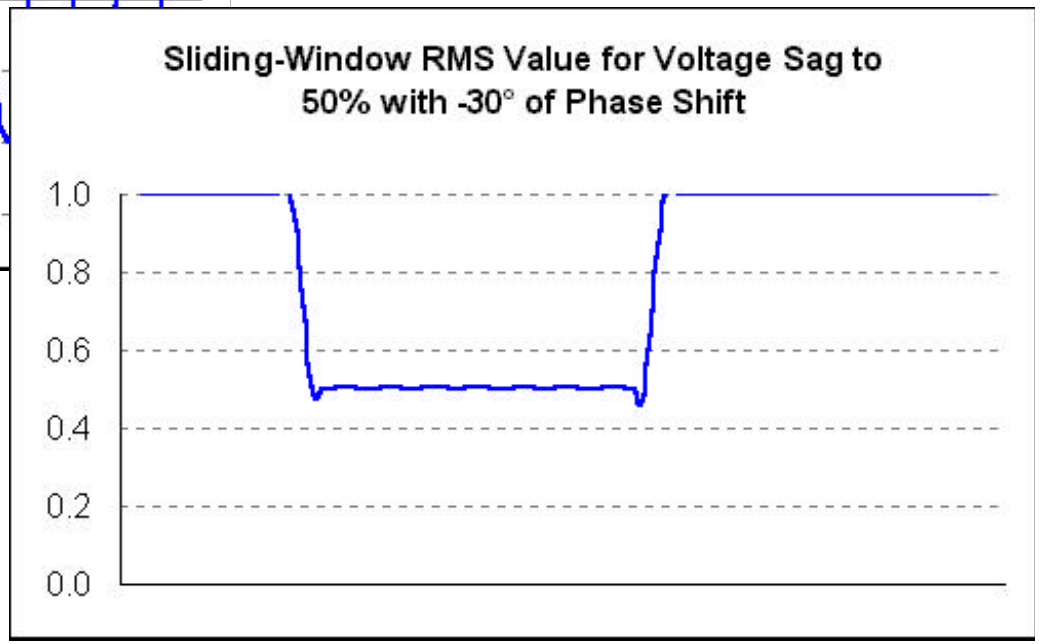




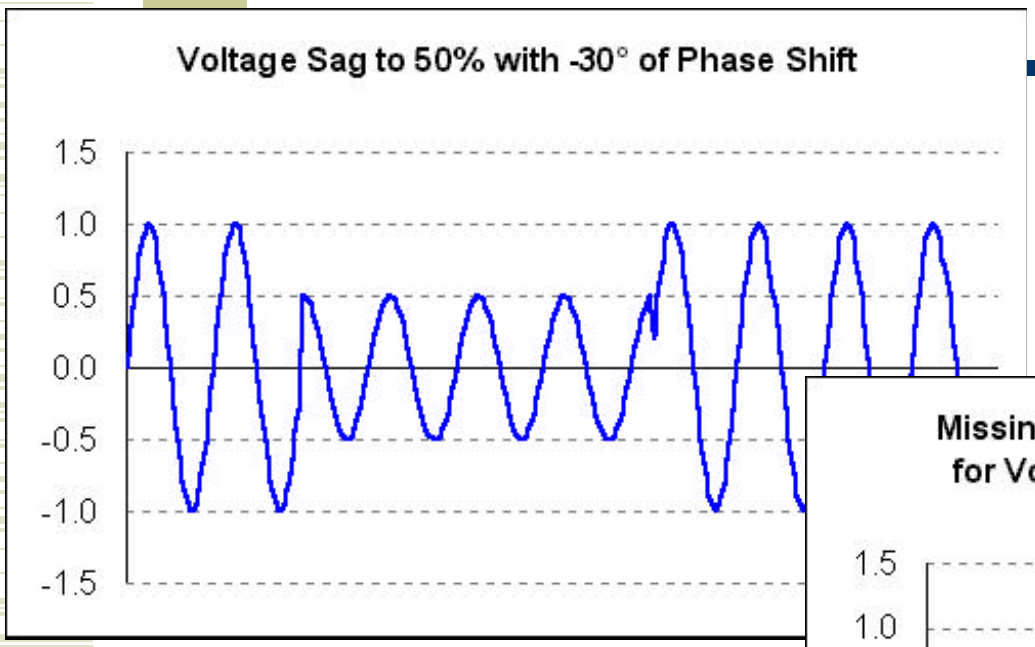
The POINT OF INITIATION (POI) occurs at 26.43 msec with phase angle of 105.47 degrees. The above waveform is a recorded waveform from field measurement.

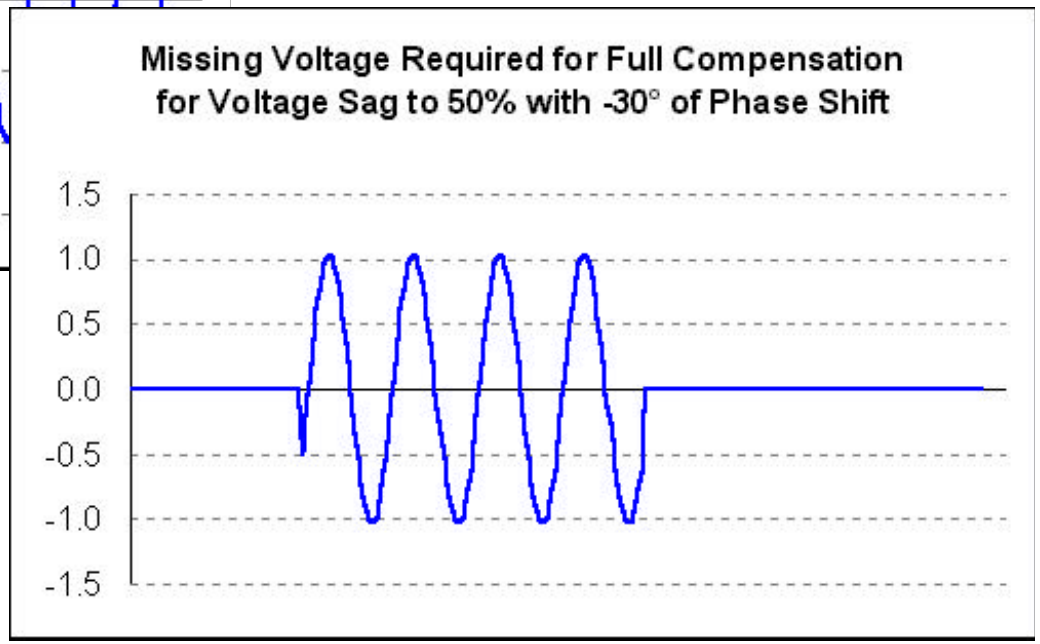
RMS Magnitude





“Missing” Voltage





Conclusions

- Indices are needed for standardization of terminology.
- Indices should be compatibility-based.
- Indices should allow for general planning or specific evaluation.
- Indices should be feasible to compute based on the data available. Simplicity!