IEEE P1564 Voltage Sag Indices Task Force

Denver, Colorado

June 8, 2004
10:00 AM to 12:00 PM

Introductions

Agenda

- Review Minutes from Last Meeting in Orlando
- Co Chair Presentation on Draft 6 and Discussion for Draft 7
- Next Meeting

IEEE P1564/D6

- Chief Concerns
  - Document is too long at 66 pages
  - Presents material that is out of scope partly because of dependency on characteristics to be defined in IEEE P1159.1 not final
  - Presents indices that are used by many electric utilities today but also gives equal treatment to indices used by only one electric utility
  - Its current breadth may be an impediment during balloting.

IEEE P1564 and IEEE P1366

- This task force was originally formed by members of the IEEE Working Group on System Design as a follow-up document to IEEE Std 1366. It also was formed by a task force in the IAS, but there was been little participation by this body since the P1564 founding.
- IEEE Std 1366 went through more than ten years of revisions for only 20 pages of standard material for relatively simple concepts of indexing sustained interruptions.
- Proposal: Use the IEEE Std 1366 model for IEEE P1564, which means we need a much simpler recommended practice than we have now.

Does IEEE P1564 Need to Define Magnitude and Duration?

- Not necessary from scope because the values should be provided by IEEE P1159.1.
- However, IEEE P1159.1 is not complete and may not be completed at the same time as IEEE P1564.
- Therefore, does IEEE P1564 define it for now?

P1564 Index: SARFI Usage is Widespread Worldwide

- Baltimore Gas and Electric
- CEM, Macau
- Con Edison
- China Light Power, Hong Kong
- E2I
- EPRI
- EPRI PEAC
- Electrotek Concepts
- Dranetz-BMI
- Hawaiian Electric Company
- Hydro One, Toronto
- Northeast Utilities
- ONS, Brazil
- PowerGrid, Singapore
- Power Standards Labs
- Public Service Electric and Gas
- Public Service New Hampshire
- San Diego Gas and Electric
- United Illuminating Company
- Taiwan Power Company
- Tennessee Valley Authority
- University of Wollongong, Australia

Other P1564 Sag Indices

- Sag Score
  - This index is out of place in IEEE P1564, because it actually is a system event characteristic (average lost voltage for measurement event with lowest rms voltage in fifteen minutes at one to seven PCC locations). Also, the index portion of the sag score computation is specific to only one special manufacturing contract
- Voltage Sag Energy Index
  - Used in practice by only one electric utility
- Sag Tables
  - Popular in European monitoring studies and therefore should be treated by IEEE P1564.
  - Computation requires same information as required by a duration-based SARFI index (time stamp, voltage magnitude, duration, monitor availability)

What do need to compute SARFI?

- The basic SARFI index requires only the following information to be collected at a monitoring location for each short duration rms variation:
  - Smallest voltage magnitude for a voltage sag or voltage interruption event or largest voltage magnitude during a voltage swell event
  - Time stamp of occurrence – needed for temporal aggregation of measurements
  - Monitor availability – needed to determine when a meter is on-line and ready to measure a short duration rms variation event. Without it, exact SARFI rates cannot be computed but estimated SARFI rates can.
- Optional Data
  - Number of customers experiencing each voltage sag magnitude – not practical at this time and probably will not be so for many years

Example of SARFI-70 Computed for Single Meter

Event List for Year at 13.2 kV Substation

Date and Time	Min Voltage	Date and Time	Min Voltage	Date and Time	Min Voltage	Date and Time	Min Voltage
1994-01-06 03:42:42.502	93.53%	1994-05-19 08:53:23.252	91.25%	1994-07-19 05:51:52.815	60.03%	1994-09-25 06:59:45.065	87.67%
1994-01-06 04:49:26.815	93.80%	1994-05-24 08:32:10.440	94.24%	1994-07-19 05:51:54.127	89.11%	1994-09-30 16:18:36.690	94.55%
1994-01-06 05:01:50.502	93.63%	1994-05-28 01:21:00.315	53.43%	1994-07-23 18:58:33.877	85.88%	1994-10-17 08:25:36.127	77.35%
1994-01-09 05:45:49.315	92.26%	1994-05-28 01:21:03.627	91.26%	1994-07-24 07:49:42.002	93.88%	1994-10-17 10:13:20.877	77.41%
1994-01-10 07:22:49.127	47.45%	1994-05-28 01:21:06.940	58.57%	1994-08-03 22:18:07.440	94.27%	1994-10-17 19:13:31.065	90.63%
1994-01-10 07:22:52.502	89.73%	1994-05-29 18:19:19.752	66.53%	1994-08-04 10:40:37.940	85.06%	1994-10-18 04:20:41.565	50.29%
1994-01-10 07:22:54.315	46.43%	1994-05-30 00:52:28.502	59.31%	1994-08-04 15:39:39.502	57.57%	1994-10-18 04:20:43.752	50.94%
1994-01-10 07:23:14.065	86.77%	1994-06-04 11:41:20.940	66.63%	1994-08-04 15:39:41.752	89.17%	1994-10-18 04:21:06.502	28.08%
1994-01-10 17:06:00.190	93.07%	1994-06-04 12:28:38.690	92.27%	1994-08-04 15:39:44.065	53.29%	1994-10-18 04:21:30.940	28.22%
1994-01-11 00:12:49.315	91.52%	1994-06-04 16:06:21.127	66.19%	1994-08-07 21:55:30.690	87.13%	1994-10-18 04:24:16.377	72.89%
1994-01-11 00:27:15.315	92.07%	1994-06-07 10:20:51.377	89.27%	1994-08-11 10:12:02.377	89.35%	1994-10-18 04:25:36.065	28.13%
1994-01-12 09:09:34.252	92.83%	1994-06-10 14:02:26.315	55.44%	1994-08-17 17:07:42.377	82.29%	1994-10-18 04:59:29.940	28.38%
1994-01-19 10:39:46.752	94.84%	1994-06-10 14:02:29.565	90.24%	1994-08-17 17:07:43.127	90.87%	1994-10-18 05:04:44.752	92.46%
1994-01-26 12:11:19.377	94.80%	1994-06-10 14:43:26.690	81.78%	1994-08-17 17:23:07.315	76.10%	1994-10-18 05:13:57.315	27.18%
1994-01-27 08:51:24.252	93.41%	1994-06-13 08:43:09.440	69.96%	1994-08-17 17:24:18.752	57.04%	1994-10-19 05:35:53.315	91.24%
1994-02-05 03:46:29.252	92.37%	1994-06-13 14:21:41.002	69.46%	1994-08-17 17:31:33.252	94.17%	1994-10-19 12:59:33.440	94.40%
1994-02-09 22:30:33.440	88.95%	1994-06-14 11:27:34.690	46.63%	1994-08-18 07:38:44.690	53.55%	1994-10-27 13:31:38.752	88.93%
1994-02-09 22:30:42.877	84.40%	1994-06-17 17:38:53.752	86.56%	1994-08-18 18:51:44.002	64.19%	1994-10-28 06:26:08.315	85.00%
1994-02-10 00:43:05.940	89.25%	1994-06-18 15:18:51.502	88.18%	1994-08-18 18:51:45.690	92.15%	1994-10-28 07:17:55.065	1.42%
1994-02-10 02:22:43.190	94.48%	1994-06-18 15:33:12.252	89.51%	1994-08-22 04:27:33.190	94.12%	1994-10-28 07:27:18.377	80.45%
1994-02-10 02:23:26.940	94.53%	1994-06-20 16:12:47.565	80.00%	1994-08-22 13:45:54.940	94.11%	1994-10-28 14:26:36.002	82.37%
1994-02-17 13:48:27.877	69.27%	1994-06-20 18:16:21.815	82.97%	1994-08-24 04:58:31.502	94.96%	1994-10-30 11:24:50.002	93.22%
1994-02-26 10:53:44.065	87.73%	1994-06-23 12:06:30.690	64.76%	1994-08-24 11:59:57.315	76.06%	1994-10-31 07:10:58.440	90.23%
1994-03-02 18:33:22.502	73.05%	1994-06-23 12:06:32.002	85.24%	1994-08-26 02:20:12.065	75.00%	1994-11-01 09:11:35.877	4.75%
1994-03-02 18:33:24.877	91.68%	1994-06-23 12:10:32.440	17.12%	1994-08-26 02:20:14.315	90.24%	1994-11-01 15:34:46.065	67.61%
1994-03-05 02:28:34.002	94.16%	1994-06-25 06:34:39.752	92.81%	1994-09-02 13:46:27.752	57.26%	1994-11-01 16:22:15.127	93.52%
1994-03-10 01:16:42.565	69.85%	1994-06-25 17:07:01.252	79.92%	1994-09-02 13:46:30.377	46.78%	1994-11-10 00:55:33.502	92.08%
1994-03-20 01:16:54.690	92.91%	1994-06-25 17:07:02.565	91.33%	1994-09-02 13:46:52.627	88.92%	1994-11-10 14:15:11.877	90.98%
1994-03-26 23:26:15.502	69.83%	1994-06-27 14:00:57.190	72.48%	1994-09-03 05:33:12.252	93.92%	1994-11-12 08:07:35.002	89.33%
1994-04-01 09:57:20.565	94.21%	1994-06-30 11:15:47.815	93.75%	1994-09-03 06:13:42.440	77.93%	1994-11-13 09:32:38.627	94.67%
1994-04-03 03:50:04.377	92.81%	1994-06-30 12:03:44.252	93.02%	1994-09-03 06:13:45.752	90.81%	1994-11-14 06:45:16.252	92.30%
1994-05-13 11:05:39.190	86.61%	1994-07-05 07:40:10.815	47.68%	1994-09-07 12:20:27.940	93.28%	1994-11-24 21:41:32.127	91.65%
1994-05-15 01:06:22.502	47.98%	1994-07-05 10:34:40.752	81.08%	1994-09-08 16:51:41.002	91.97%	1994-11-29 14:32:16.190	83.48%
1994-05-15 01:06:24.752	85.09%	1994-07-05 13:37:57.940	69.28%	1994-09-09 04:25:44.252	91.89%	1994-12-02 06:24:11.565	94.00%
1994-05-18 16:15:11.502	45.54%	1994-07-05 13:37:59.502	88.27%	1994-09-09 05:59:22.502	91.99%	1994-12-02 10:25:46.190	94.16%
1994-05-18 16:15:14.002	44.22%	1994-07-06 06:04:26.315	30.98%	1994-09-09 08:47:26.565	94.86%	1994-12-02 10:43:32.065	93.66%
1994-05-18 16:15:37.565	42.12%	1994-07-06 06:04:50.065	83.25%	1994-09-10 07:20:13.002	93.41%	1994-12-10 10:51:53.690	91.24%
1994-05-18 16:16:00.065	42.23%	1994-07-08 07:37:07.002	91.32%	1994-09-13 06:02:32.565	81.51%	1994-12-12 01:16:27.252	94.45%
1994-05-18 16:29:59.065	90.00%	1994-07-09 10:29:41.002	81.66%	1994-09-21 13:21:50.440	66.91%	1994-12-18 08:51:10.690	87.86%
1994-05-18 22:45:44.127	86.34%	1994-07-11 21:44:27.815	79.83%	1994-09-24 06:58:50.502	46.14%	1994-12-18 08:51:12.940	73.11%
1994-05-19 00:46:18.752	92.73%	1994-07-16 15:07:00.502	92.65%	1994-09-24 06:58:52.815	89.18%	1994-12-31 07:51:56.815	62.25%
						1994-12-31 07:51:58.127	91.82%

Discussion Points

- Minimum RMS Voltage
  - It should be the minimum rms computed from a full cycle of data every half cycle as recommended in IEC 61000-4-30 and in draft versions of IEEE P1159.1.
- Maximum RMS Voltage
- Nominal Voltage
  - From IEC 61000-4-30, “the nominal voltage or a value of a voltage different from the nominal voltage obtained by agreement between the electricity supplier and a consumer.”
- Line-Line or Line-Neutral Voltage
  - When monitoring at a service entrance, assessment based of l-l or l-n voltages should based on agreement between the supplier and consumer
  - No clear recommendation for transmission or distribution monitoring. In practice, electric utilities monitor what is available through metering or protection transducers, with a preference for line-neutral

For SARFI-70, only consider events less than 70% of nominal voltage

Date and Time	Min Voltage		Date and Time	Min Voltage
1994-12-31 07:51:56.815	62.25%		1994-07-05 07:40:10.815	47.68%
1994-11-01 15:34:46.065	67.61%		1994-06-23 12:10:32.440	17.12%
1994-11-01 09:11:35.877	4.75%		1994-06-23 12:06:30.690	64.76%
1994-10-28 07:17:55.065	1.42%		1994-06-14 11:27:34.690	46.63%
1994-10-18 05:13:57.315	27.18%		1994-06-13 14:21:41.002	69.46%
1994-10-18 04:59:29.940	28.38%		1994-06-13 08:43:09.440	69.96%
1994-10-18 04:25:36.065	28.13%		1994-06-10 14:02:26.315	55.44%
1994-10-18 04:21:30.940	28.22%		1994-06-04 16:06:21.127	66.19%
1994-10-18 04:21:06.502	28.08%		1994-06-04 11:41:20.940	66.63%
1994-10-18 04:20:43.752	50.94%		1994-05-30 00:52:28.502	59.31%
1994-10-18 04:20:41.565	50.29%		1994-05-29 18:19:19.752	66.53%
1994-09-24 06:58:50.502	46.14%		1994-05-28 01:21:06.940	58.57%
1994-09-21 13:21:50.440	66.91%		1994-05-28 01:21:00.315	53.43%
1994-09-02 13:46:30.377	46.78%		1994-05-18 16:16:00.065	42.23%
1994-09-02 13:46:27.752	57.26%		1994-05-18 16:15:37.565	42.12%
1994-08-18 18:51:44.002	64.19%		1994-05-18 16:15:14.002	44.22%
1994-08-18 07:38:44.690	53.55%		1994-05-18 16:15:11.502	45.54%
1994-08-17 17:24:18.752	57.04%		1994-05-15 01:06:22.502	47.98%
1994-08-04 15:39:44.065	53.29%		1994-03-26 23:26:15.502	69.83%
1994-08-04 15:39:39.502	57.57%		1994-03-10 01:16:42.565	69.85%
1994-07-19 05:51:52.815	60.03%		1994-02-17 13:48:27.877	69.27%
1994-07-06 06:04:26.315	30.98%		1994-01-10 07:22:54.315	46.43%
1994-07-05 13:37:57.940	69.28%		1994-01-10 07:22:49.127	47.45%

46 total rms variation records triggered by power quality monitor

Temporal Aggregation

Date and Time	Min Voltage		Date and Time	Min Voltage
1994-12-31 07:51:56.815	62.25%		1994-07-05 07:40:10.815	47.68%
1994-11-01 15:34:46.065	67.61%		1994-06-23 12:10:32.440	17.12%
1994-11-01 09:11:35.877	4.75%		1994-06-23 12:06:30.690	64.76%
1994-10-28 07:17:55.065	1.42%		1994-06-14 11:27:34.690	46.63%
1994-10-18 05:13:57.315	27.18%		1994-06-13 14:21:41.002	69.46%
1994-10-18 04:59:29.940	28.38%		1994-06-13 08:43:09.440	69.96%
1994-10-18 04:25:36.065	28.13%		1994-06-10 14:02:26.315	55.44%
1994-10-18 04:21:30.940	28.22%		1994-06-04 16:06:21.127	66.19%
1994-10-18 04:21:06.502	28.08%		1994-06-04 11:41:20.940	66.63%
1994-10-18 04:20:43.752	50.94%		1994-05-30 00:52:28.502	59.31%
1994-10-18 04:20:41.565	50.29%		1994-05-29 18:19:19.752	66.53%
1994-09-24 06:58:50.502	46.14%		1994-05-28 01:21:06.940	58.57%
1994-09-21 13:21:50.440	66.91%		1994-05-28 01:21:00.315	53.43%
1994-09-02 13:46:30.377	46.78%		1994-05-18 16:16:00.065	42.23%
1994-09-02 13:46:27.752	57.26%		1994-05-18 16:15:37.565	42.12%
1994-08-18 18:51:44.002	64.19%		1994-05-18 16:15:14.002	44.22%
1994-08-18 07:38:44.690	53.55%		1994-05-18 16:15:11.502	45.54%
1994-08-17 17:24:18.752	57.04%		1994-05-15 01:06:22.502	47.98%
1994-08-04 15:39:44.065	53.29%		1994-03-26 23:26:15.502	69.83%
1994-08-04 15:39:39.502	57.57%		1994-03-10 01:16:42.565	69.85%
1994-07-19 05:51:52.815	60.03%		1994-02-17 13:48:27.877	69.27%
1994-07-06 06:04:26.315	30.98%		1994-01-10 07:22:54.315	46.43%
1994-07-05 13:37:57.940	69.28%		1994-01-10 07:22:49.127	47.45%

But many events occurred close in time to another event that need to be treated as an aggregate.

Temporal aggregation should not be an optional component of IEEE P1564.

60 sec Temporal Aggregation

Date and Time	Min Voltage		Date and Time	Min Voltage
1994-01-10 07:22:49.127	46.40%		1994-07-05 13:37:57.940	69.30%
1994-02-17 13:48:27.877	69.30%		1994-07-06 06:04:26.315	31.00%
1994-03-10 01:16:42.565	69.90%		1994-07-19 05:51:52.815	60.00%
1994-03-26 23:26:15.502	69.80%		1994-08-04 15:39:39.502	53.30%
1994-05-15 01:06:22.502	48.00%		1994-08-17 17:24:18.752	57.00%
1994-05-18 16:15:11.502	42.10%		1994-08-18 07:38:44.690	53.60%
1994-05-28 01:21:00.315	53.40%		1994-08-18 18:51:44.002	64.20%
1994-05-29 18:19:19.752	66.50%		1994-09-02 13:46:27.752	46.80%
1994-05-30 00:52:28.502	59.30%		1994-09-21 13:21:50.440	66.90%
1994-06-04 11:41:20.940	66.60%		1994-09-24 06:58:50.502	46.10%
1994-06-04 16:06:21.127	66.20%		1994-10-18 04:20:41.565	28.10%
1994-06-10 14:02:26.315	55.40%		1994-10-18 04:25:36.065	28.10%
1994-06-13 08:43:09.440	70.00%		1994-10-18 04:59:29.940	28.40%
1994-06-13 14:21:41.002	69.50%		1994-10-18 05:13:57.315	27.20%
1994-06-14 11:27:34.690	46.60%		1994-10-28 07:17:55.065	1.40%
1994-06-23 12:06:30.690	64.80%		1994-11-01 09:11:35.877	4.70%
1994-06-23 12:10:32.440	17.10%		1994-11-01 15:34:46.065	67.60%
1994-07-05 07:40:10.815	47.70%		1994-12-31 07:51:56.815	62.30%

36 aggregated events

SARFI-70 Count is 36 events

300 s Temporal Aggregation

Date and Time	Min Voltage		Date and Time	Min Voltage
1994-01-10 07:22:49.127	46.40%		1994-07-05 13:37:57.940	69.30%
1994-02-17 13:48:27.877	69.30%		1994-07-06 06:04:26.315	31.00%
1994-03-10 01:16:42.565	69.90%		1994-07-19 05:51:52.815	60.00%
1994-03-26 23:26:15.502	69.80%		1994-08-04 15:39:39.502	53.30%
1994-05-15 01:06:22.502	48.00%		1994-08-17 17:23:07.315	57.00%
1994-05-18 16:15:11.502	42.10%		1994-08-18 07:38:44.690	53.60%
1994-05-28 01:21:00.315	53.40%		1994-08-18 18:51:44.002	64.20%
1994-05-29 18:19:19.752	66.50%		1994-09-02 13:46:27.752	46.80%
1994-05-30 00:52:28.502	59.30%		1994-09-21 13:21:50.440	66.90%
1994-06-04 11:41:20.940	66.60%		1994-09-24 06:58:50.502	46.10%
1994-06-04 16:06:21.127	66.20%		1994-10-18 04:20:41.565	28.10%
1994-06-10 14:02:26.315	55.40%		1994-10-18 04:59:29.940	28.40%
1994-06-13 08:43:09.440	70.00%		1994-10-18 05:13:57.315	27.20%
1994-06-13 14:21:41.002	69.50%		1994-10-28 07:17:55.065	1.40%
1994-06-14 11:27:34.690	46.60%		1994-11-01 09:11:35.877	4.70%
1994-06-23 12:06:30.690	17.10%		1994-11-01 15:34:46.065	67.60%
1994-07-05 07:40:10.815	47.70%		1994-12-31 07:51:56.815	62.30%

34 aggregated events

SARFI-70 Count is 34 events for this temporal aggregation setting

Counts versus Rates

- For comparing different monitoring locations, different systems, and different date ranges, we need to compute a SARFI Rate instead of a SARFI count
- Computing a rate means we need to compute or estimate the monitor availability for the monitoring instrument.

Monitor Availability Computation

- This example meter was available for only 319 days out of a possible 365 days. Therefore, its availability was 87.4%.
  - Available for only 7 days in April 1994, 29 days in May 1994, 10 days in August 1994. All other months were at full availability.

SARFI Rates

- For 300 second temporal aggregation, the SARFI-70 rate is computed to be 34 events divided by 319 days or 0.107 events per day
- The rate can also be scaled by multiplying by 30 or 365. These rates are all equal:
  - 0.107 aggregated events < 0.7 pu per day
  - 3.20 aggregated events < 0.7 pu per 30 days
  - 38.9 aggregated events < 0.7 pu per 365 days

Monitor Limited SARFI Computation

- The original EPRI definition of SARFI specified that we need to determine the number of customers experiencing each voltage magnitude. This is impractical at this time.
- In practice, SARFI rates are computed at transmission or distribution substation meters or at service entrances.

SARFI Computation for 25 Meters

Location	SARF-70
Site 1	38.903
Site 2	79.021
Site 3	23.384
Site 4	3.278
Site 5	36.614
Site 6	11.371
Site 7	66.250
Site 8	0.000
Site 9	2.000
Site 10	9.865
Site 11	45.000
Site 12	33.534
Site 13	64.152
Site 14	35.986
Site 15	67.000
Site 16	14.122
Site 17	27.528
Site 18	25.560
Site 19	1.629
Site 20	5.196
Site 21	9.569
Site 22	0.000
Site 23	15.870
Site 24	40.000
Site 25	46.149

- This table presents the same SARFI-70 computation for twenty-five monitoring locations.
- How do we get from here to a system value?

System SARFI Computations

- Simple Statistics
  - Mean: 28.01 events per 365 days (most common approach)
  - Median: 25.56 events per 365 days
  - 95th Percentile: 67 events per 365 days
- Weighted Averages
  - Each location is weighted more or less than others while computing a mean.
  - Weights are based on number of customers or a statistical weighting factor

Proposed Definition of SARFI-X

The system average rms variation index represents the average number of specified rms variation measurement events that occurred over the assessment period. For $SARFI_X$, the specified rms variations have a voltage magnitude less than X% for voltage sags and voltage interruptions, or a magnitude greater than X% for voltage swells. $SARFI_X$ may be weighted by the number of customers experiencing a voltage level if available

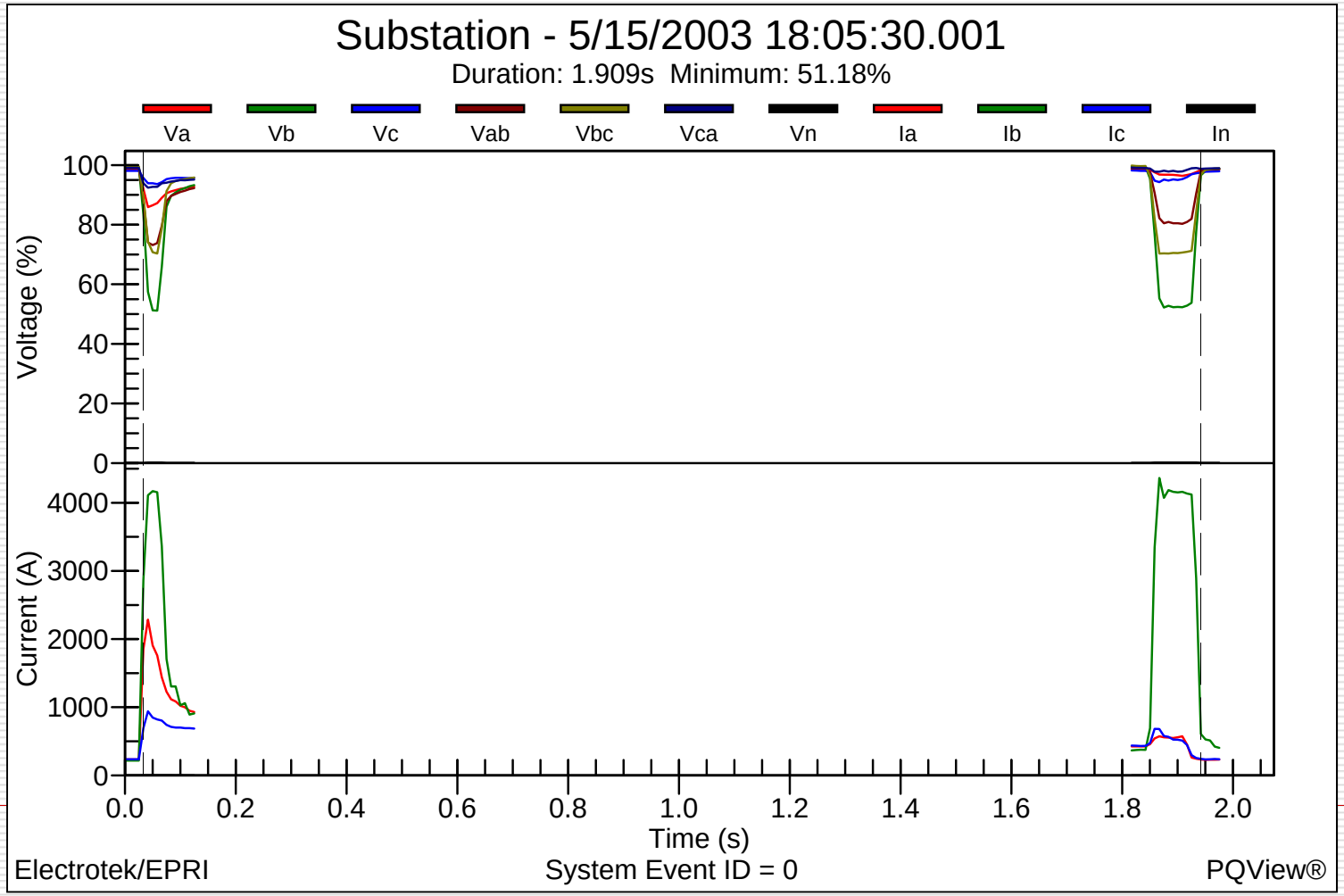
$$SARFI_x = \frac{\text{Total Number of Monitoring Locations (or Customers) Experiencing RMS Variation to X\%}}{\text{Total Number of Monitoring Locations (or Customers) Served}}$$

$$SARFI_x = \frac{\sum N_i}{N_T}$$

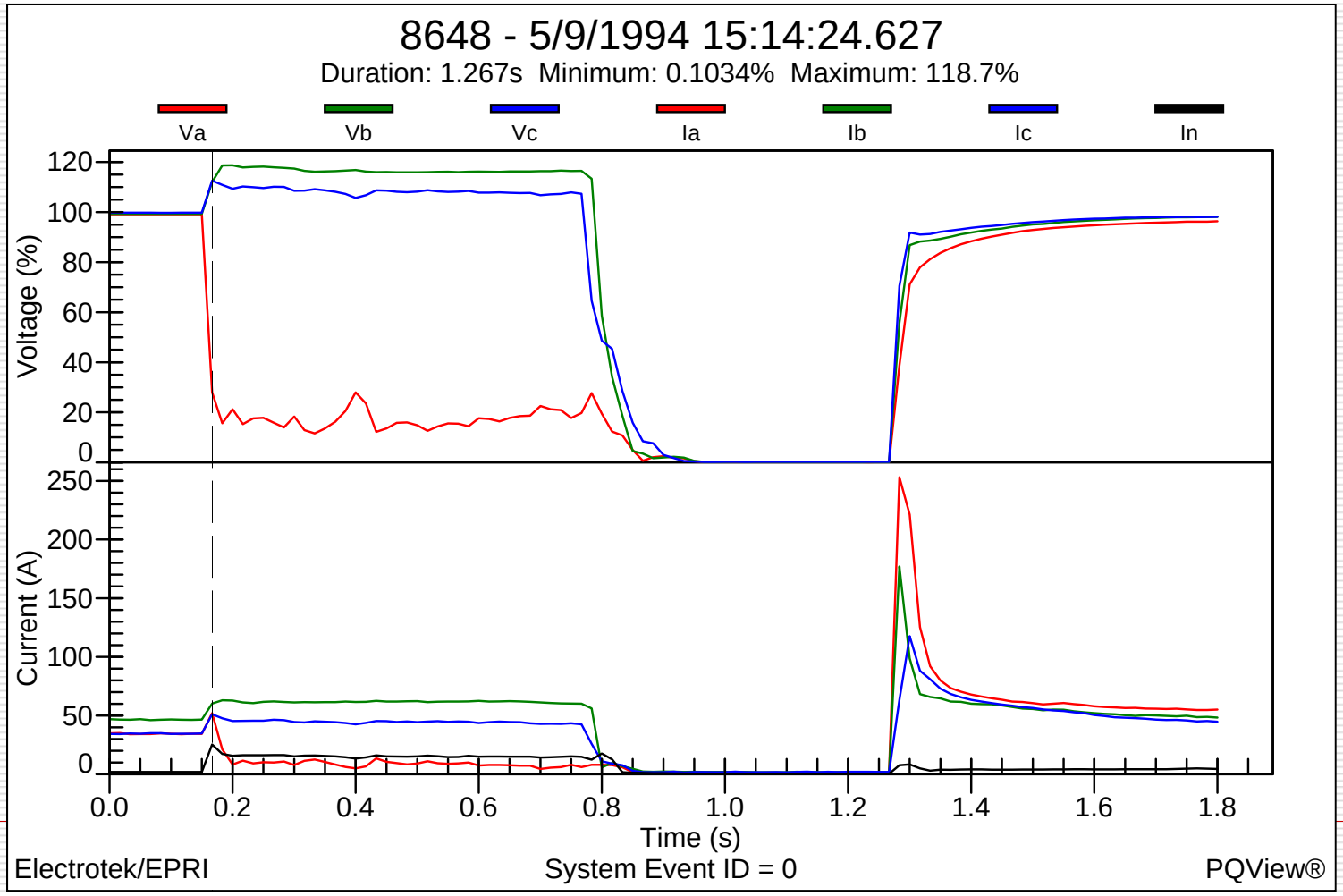
What about Duration?

- Needed for SARFI indices based on curves like SARFI-ITIC or SARFI-SEMI
- Needed to populate a sag table
- We will rely on IEEE P1159.1 definition
- Unfortunately, event duration calculation is imperfect
  - Multiple sags or swells close in time
  - Multistage events

Multiple Sags within 2 s



Multistage Event



Voltage Sag Table Based on the Values in IEC 61000-4-11

magnitude	duration of the voltage sag				
	< 1 cycle	1 cycle-200 ms	200-500 ms	0.5-5 seconds	≥ 5 second
70-80%					
40-70%					
10-40%					
≤10%					

Can expressed as a count or a rate

Proposed P1564 Outline

- Overview
- References
- Definitions
- Definitions of Indices
  - SARFI-X
- Application of the Indices
  - Sample System
  - Examples
- Rationale for Selecting Indices