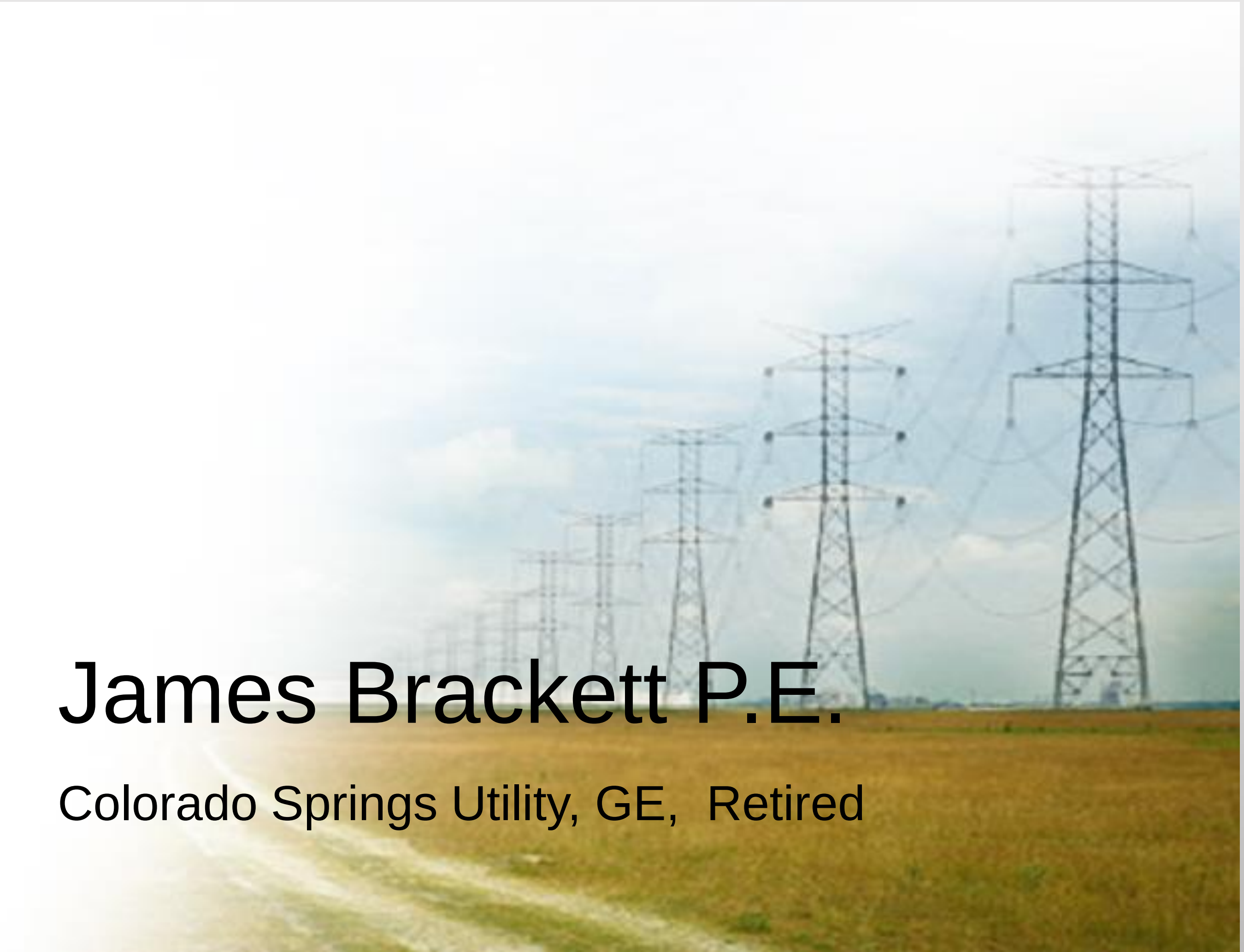
Power Quality Overview



James Brackett P.E.

Colorado Springs Utility, GE, Retired

What I will present today

- Introduction and thank you
- PQ overview
- Cause of PQ problems
- How Smart Grid, DER, VVAR and AMI fit in to PQ

How we Measure PQ, Utility Outages

IEEE Power Distribution Reliability Indices

ASAI - Average System Availability Index

(…total number of customer hours electric service is on)

SAIFI - System Average Interruption Frequency Index

(…how many outages in a year, interruptions/year)

SAIDI - System Average Interruption Duration Index

(…how many minutes in a year, minutes/year)

CAIDI - Customer Average Interruption Duration Index

(…how long each outage, minutes/interruption)

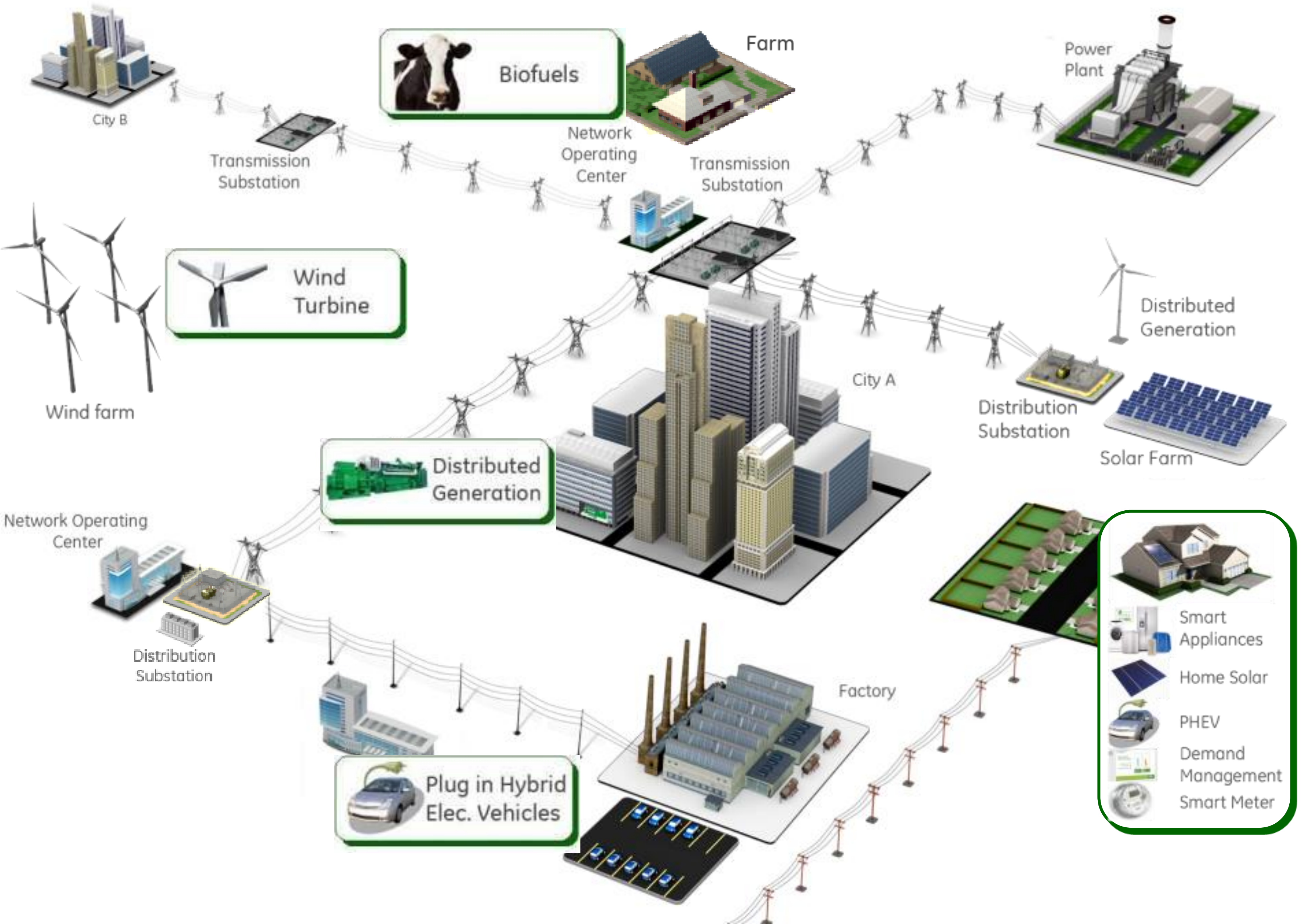
Outage Indexes

	2011	2012	2013	2014	2015	2016
ASAI	99.991	99.992	99.994	99.994	99.991	99.992
SAIFI	1.319	0.803	0.796	0.605	0.920	1.178
SAIDI	46.492	40.521	33.268	30.047	45.495	44.12
CAIDI	35.248	50.465	41.802	49.664	49.37	37.426
Total Number of Outages	**505**	**489**	**457**	**450**	**652**	**605**
# Customers	**177,825**	**182,238**	**187,302**	**191,997**	**196,803**	**200,906**

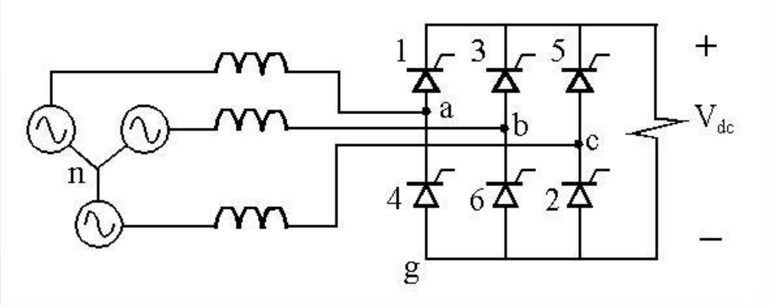
Outage Statistics

	Total # outages	Equipment Failure outages	Lightning outages	Animal on line outages	Animal on trans outages	Total # Animal outages	unknown outages
1986	711	142	109	5	173	178	73
1987	477	121	77	6	71	77	54
1988	456	138	73	19	82	101	44
1989	360	122	72	42	29	71	30
1990	409	142	71	24	49	73	26
1991	389	102	81	60	31	91	41
1992	453	99	101	78	22	100	32
1993	375	92	59	47	35	82	40
1994	460	111	105	41	23	64	37
1995	406	75	91	40	25	65	10
1996	493	109	116	51	43	94	31
1997	441	128	55	55	29	84	36
1998	388	90	75	45	28	73	
1999	472	111	88	52	29	81	
2000	505	111	89	63	50	113	

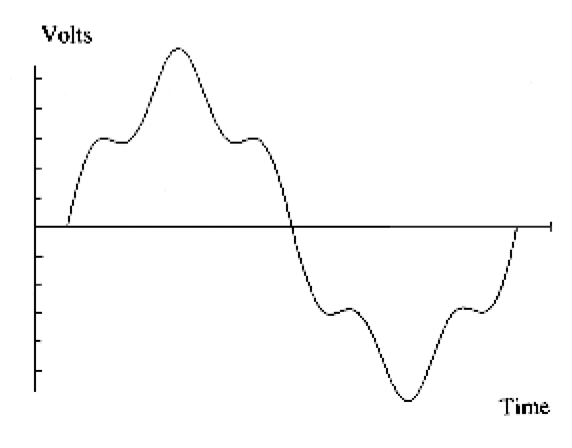
Potential DER throughout the Complex Modern Electrical Grids



Harmonic Distortion - mathematical representation of the distortion of the pure sine wave due to non-linear loads. Additional voltages with frequencies that are multiples of the fundamental 60Hz.



- Capacitors: Blown fuses, reduced capacitor life
- Motors: Reduced motor life, inability to fully load motor
- Fuses/Breakers: False/spurious operation, damaged components
- Transformers: Increased copper losses, reduced capacity
- Utility meters: Measurement errors
- Telephones: Interference
- Drives/Power Supplies: Mis-operation



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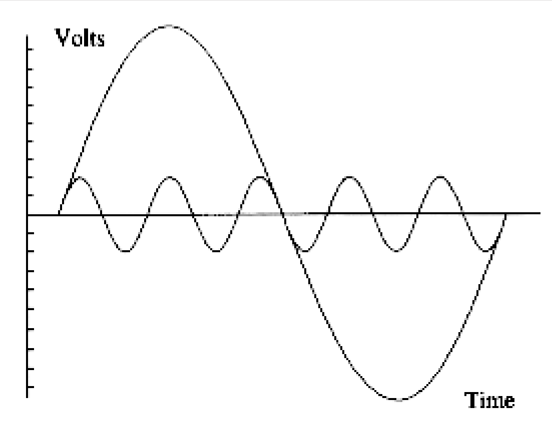
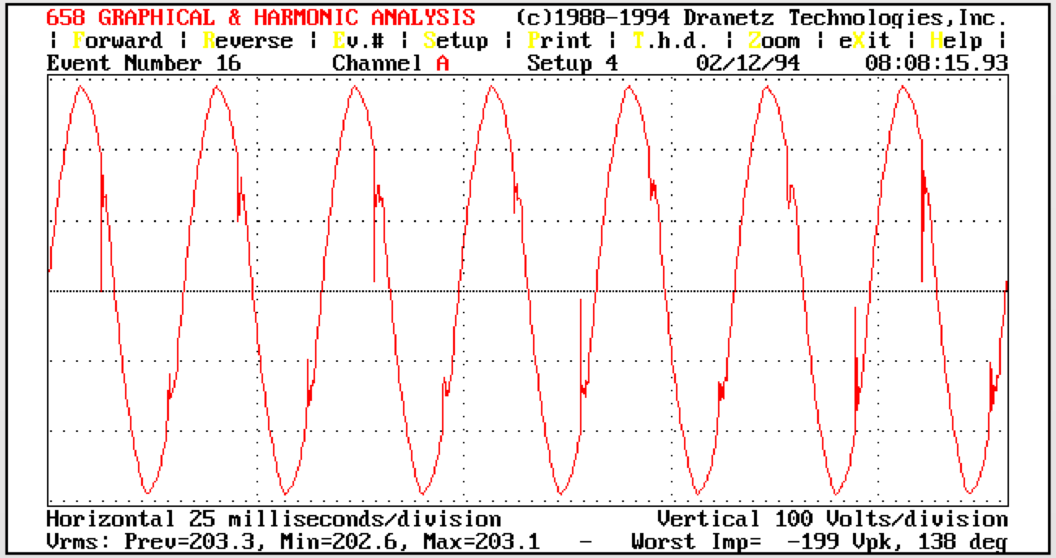
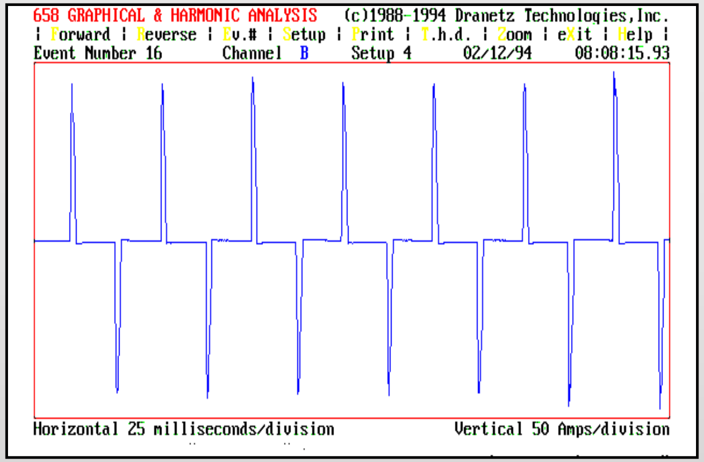


X-Ray Action


658 GRAPHICAL & HARMONIC ANALYSIS (c)1988-1994 Dranetz Technologies,Inc.
¦ Forward ¦ Reverse ¦ Ev.# ¦ Setup ¦ Print ¦ T.h.d. ¦ Zoom ¦ eXit ¦ Help ¦
Event Number 16 Channel A Setup 4 02/12/94 08:08:15.93
Horizontal 25 milliseconds/division Vertical 100 Volts/division
Vrms: Prev=203.3, Min=202.6, Max=203.1 - Worst Imp= -199 Vpk, 138 deg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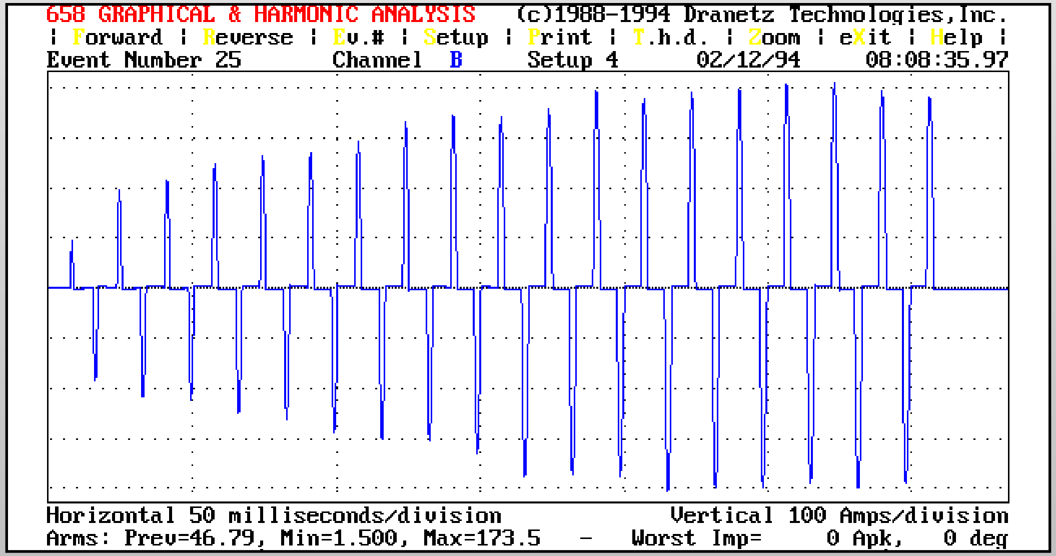
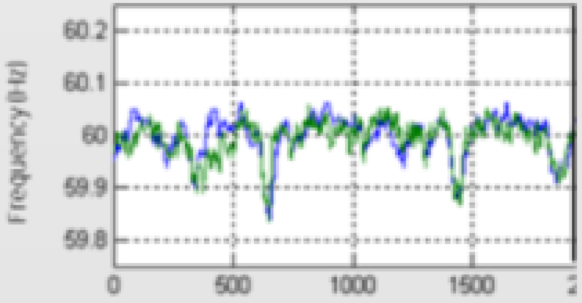
Event Number 16 Channel B Setup 4 02/12/94 08:08:15.93
Horizontal 25 milliseconds/division Vertical 50 Amps/division

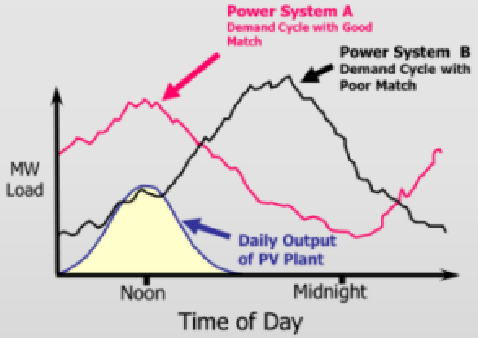

658 GRAPHICAL & HARMONIC ANALYSIS (c)1988-1994 Dranetz Technologies,Inc.
¦ Forward ¦ Reverse ¦ Ev.# ¦ Setup ¦ Print ¦ T.h.d. ¦ Zoom ¦ eXit ¦ Help ¦
Event Number 25 Channel B Setup 4 02/12/94 08:08:35.97
Horizontal 50 milliseconds/division Vertical 100 Amps/division
Arms: Prev=46.79, Min=1.500, Max=173.5 - Worst Imp= 0 Apk, 0 deg

Characteristics of variable renewables

With likely impact on the power system:

- Variability and intermittency
  - Limited predictability and forecasting capability (e.g. clouds, wind change)
  - Potential impact on grid stability
- Bidirectional power flows
- Fault current contribution
- Need for reserves (to cope with variability)
- Non Dispatchable





Today:

Current penetration is modest

All produced wind energy is taken, treated as negative load

Variability absorbed by operating reserves

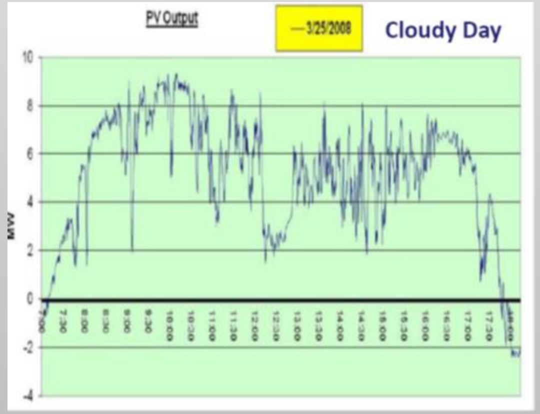
Integration costs are socialized

Tomorrow:

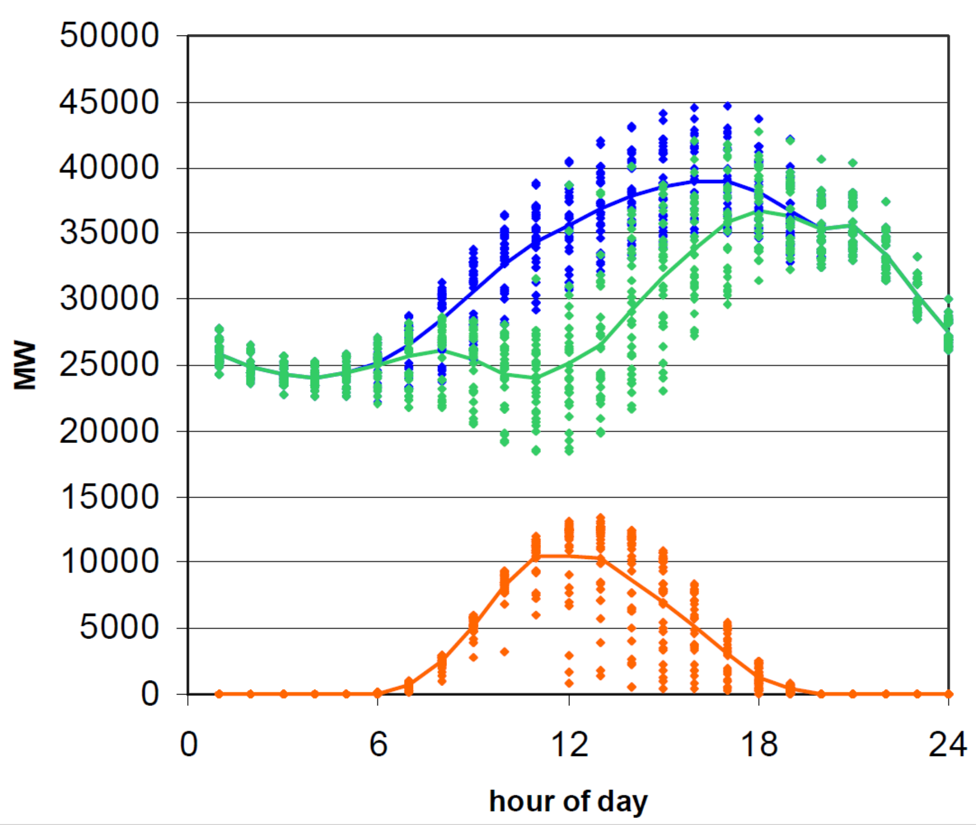
Deep penetration levels, diversity offers limited help

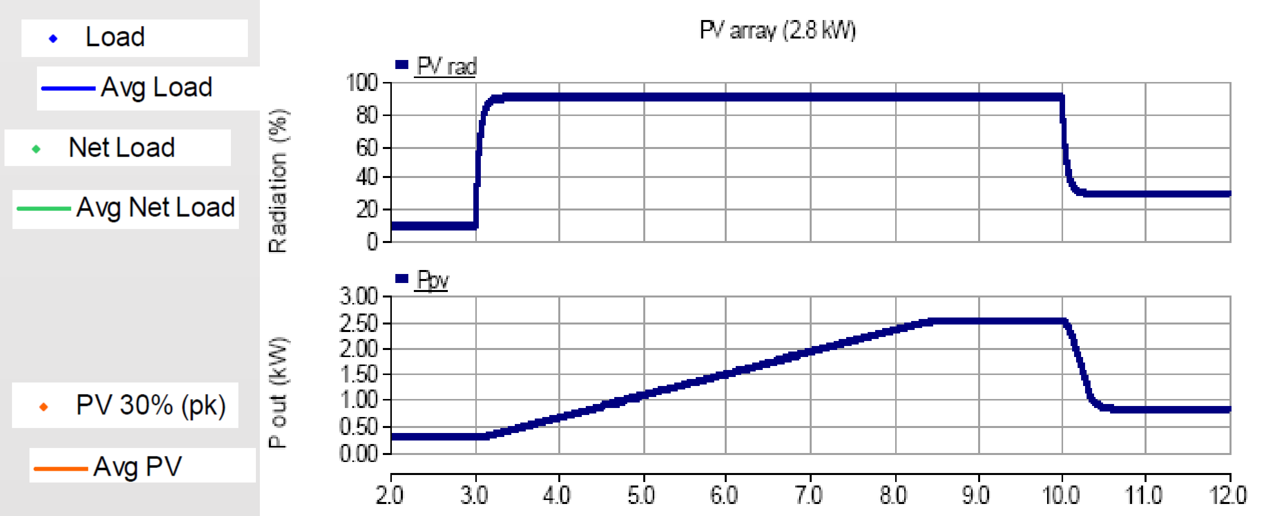
Too expensive to take all wind, must curtail

Too much reserve capacity =) lose GHG reduction benefits

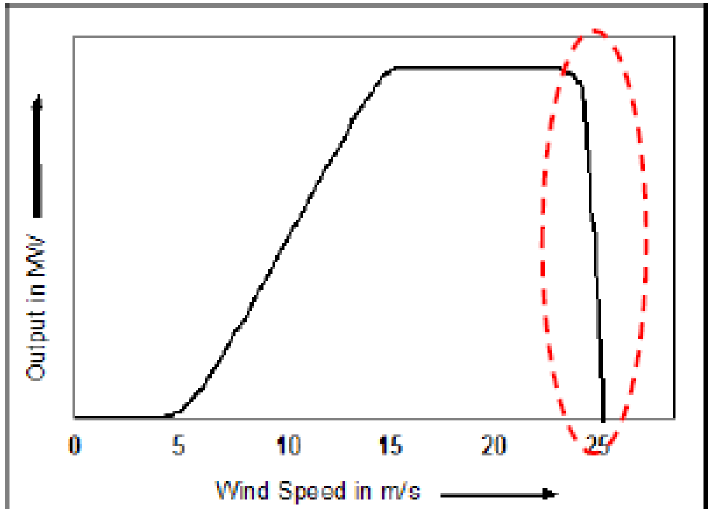


Intermittency of renewable generation



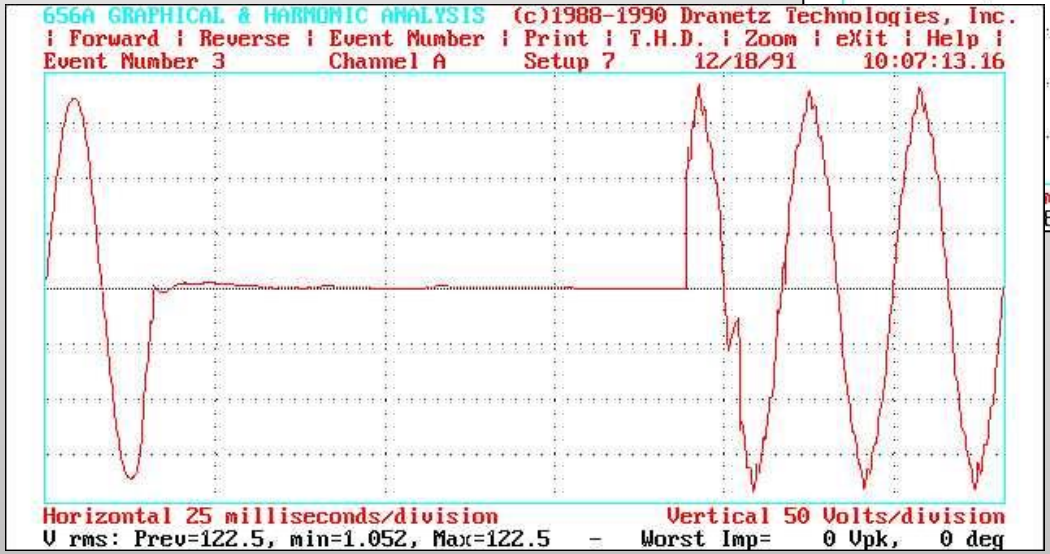


- Wind turbine output at various wind speed
  - *Main issue at cut-off speed*
- Solutions:
  - *Active pitch control*



DER Gen.

Harmonics/Frequency contro



61850 Logical Nodes for DER

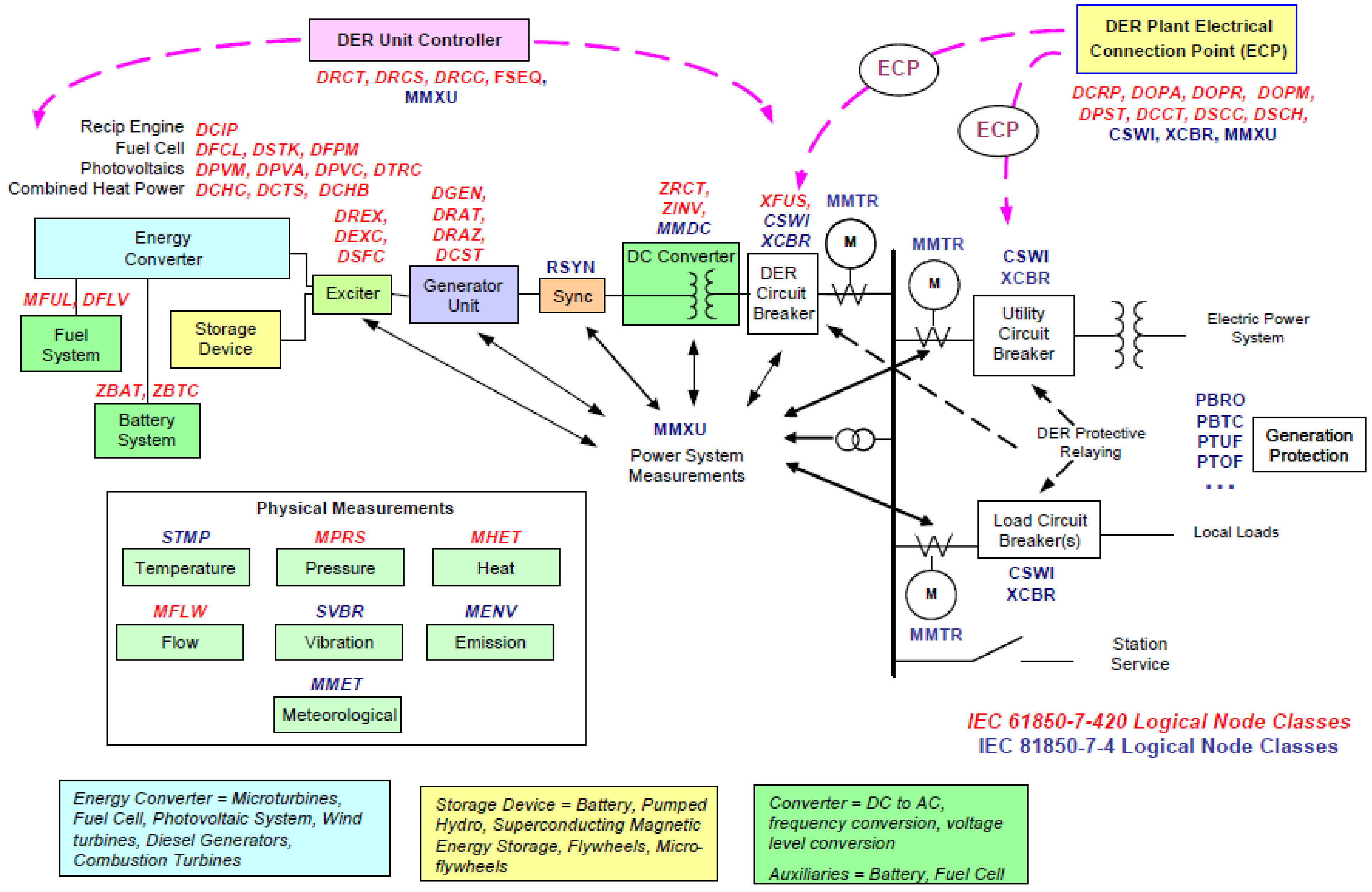


Figure 5 – Overview: Conceptual organization of DER logical devices and logical nodes

Advancements in Distributed Energy Technologies

- ✓ Cadmium Telluride, Copper Indium Gallium Selenide (CIGS) and Amorphous Silicon (a-Si) Thin-film
- ✓ Multi-junction Photovoltaic (PV)
- ✓ Concentrating Solar PV (CSPV)
- ✓ Building integrated PV (BIPV)
- ✓ Distributed small-wind turbines
- ✓ Small 1-5 MW industrial biogas turbines (~ 40% efficiency)
- ✓ Recuperated small biogas turbines (34-43% efficiency)
- ✓ Microbial fuel cells
- ✓ Power Chips (up to 70% efficiency)
- ✓ Various wave, tidal and run-of-river technologies

Although DG is part of the Smart Grid world, it is not a new industry trend…. difference?… Scale, Technology and Public Interest

Deployment Scale

Small (W, kW)

Off-grid

Individual User

Simplistic

→

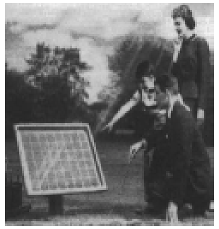
Large (MW)

Grid Connected

Grid-connected Users

Complex

Technology



Small (W, kW)

Low efficiency
Limited performance

→

Large (kW, MW)
Improved efficiency
Improved performance

Public Interest

Limited (on the individual basis)

→

High interest (MW size interest)

The Distribution Grid Was Not Designed with DG in Mind

- *Limited bi-directional power flow*
- *Limited or no telecommunication infrastructure allowing for two-way and real-time communication flow*
- *Limited or no back office operational capabilities to handle large scale data/information*
- *The distribution system equipment/infrastructure sizing (thermal capabilities) may not be adequate for medium and high penetration of DG*
- *The distribution system protection schemes, control and voltage regulation devices and settings may not be compatible with DG*
- *The distribution system grounding is not ideal for the interface of many forms of DG*
- *The utility service restoration and switching practices are not normally intended to be DG compatible*

Any medium or large size DG or large aggregation of DG can cause reliability, safety, power quality and equipment damage problems.

Integrated Volt / VAR Control (iVVC)

IVVC General Features:

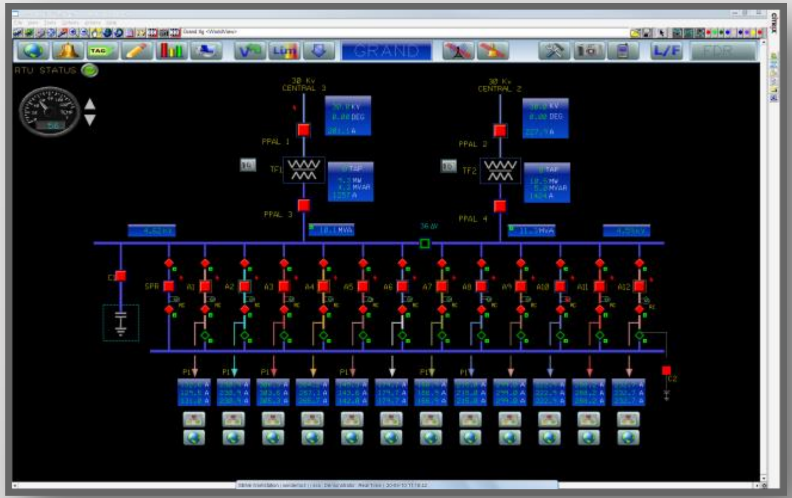
- Centralized at the Distribution Control Center
- Based on current state of the real-time network model
  - Normal and abnormal topology
  - Uses load flow calculations

IVVC Objectives:

- Load Minimization (via conservation voltage reduction)
- Loss Minimization
- Power Factor Correction

IVVC Controls:

- Switching capacitor banks in substation and/or on feeders
- Controlling substation transformer and line voltage regulator tap positions and/or their automatic voltage regulator set points

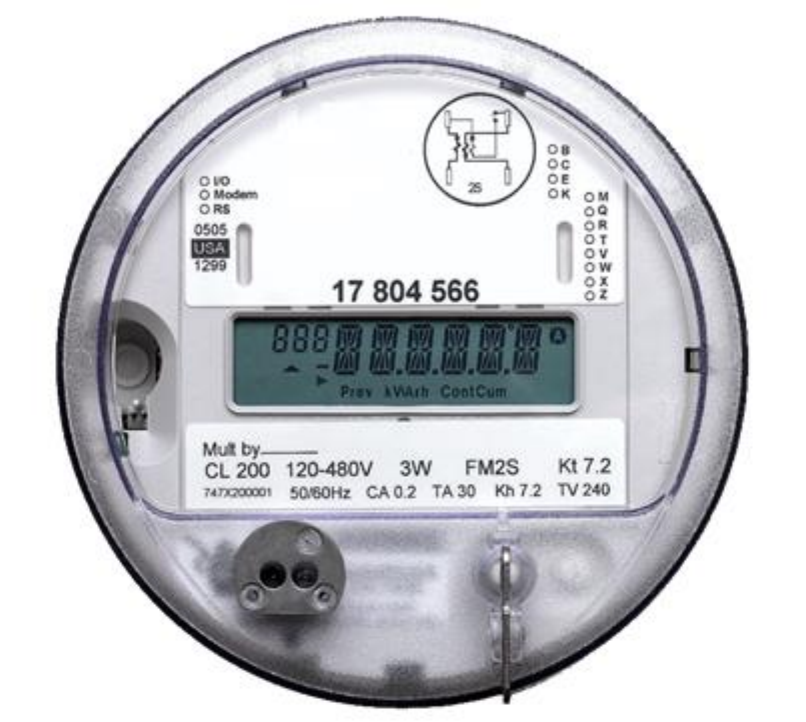


Uses real substation data: Load Flow combined with State Estimator is sufficiently accurate in calculating end-of-feeder voltages to ensure benefits of VVC

AMI Technology Driven Solutions

Many of today's electricity meters employ

- Integrated Digital Metering Circuits
- MDM database storage
- 32 bit Microcomputers
- Large Memories
- Software Engineering Advances
- New Power Supply Designs
- Capacity for Growth



Changing the economics of PQ Survey and Monitoring

Power Quality Monitoring at every Meter

Instrumentation: Real time Per phase RMS Voltage, Current, Frequency, Imputed Neutral Current, Power, Power Factor

Fast Voltage: Sag and Swell logging down to 1 cycle log with Min. or Max. voltage for each phase, coincident current, duration in cycles, and Date & time stamp

PQ Measures: V&I THD per phase, TDD per Phase, DPF, Distortion kVA, Distortion kVAh

Recording: 20 Channel recorder with Min. Max, and EOI

Auto Call-in: High or Low Voltage, Voltage Imbalance, Low PF, High Distortion, High Neutral Current, and Call-in during outage

Harmonic Analysis: Waveform data capture for PC analysis to 23rd

Data available locally or remotely on-demand or after an call-in

Distortion Measurements

Snap Shot and Cumulative Measures

- Distortion kVA and kVAh
- Distortion Power Factor (DPF) per phase and total
  where DPF = (Distortion kVA) / (Apparent Power kVA)
- Total Demand Distortion (TDD) per phase
  where TDD = (Total Harmonic Current) / (Rated Maximum Current)
- Total Harmonic Distortion (THD) - I_{THD} and V_{THD} per phase
- Imputed Neutral Current - I_N
- Squares - V^2h, I^2h, I^2h_N
- Voltages - V_{L-L}, V_{L-N}

Note: These values are always available for “real time” displays, but cannot be accumulated or recorded without the Q soft switch.

Diagnostics and Cautions

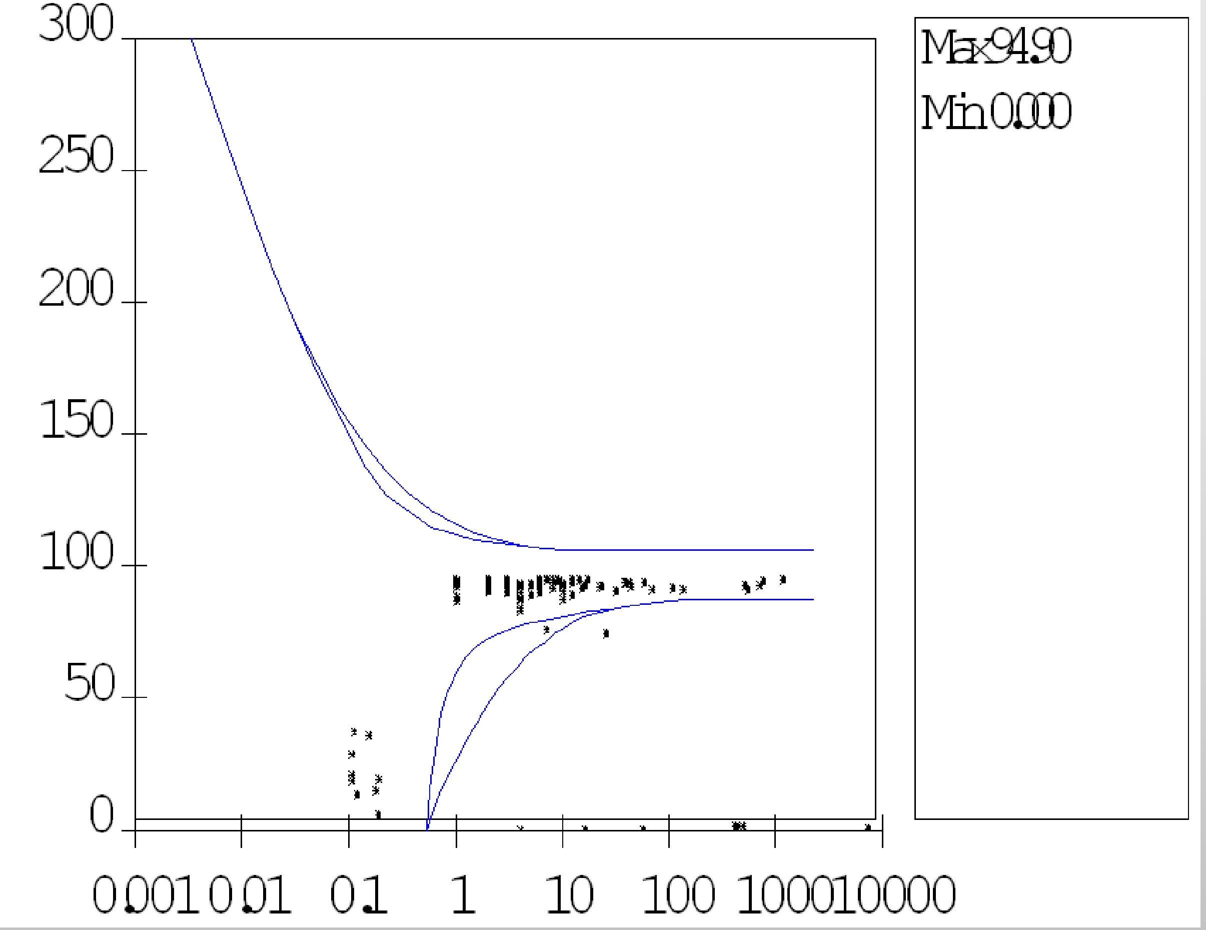
Programmable levels and duration

- Diagnostic 1 - Polarity, Cross Phase, Reverse Energy Flow
- Diagnostic 2 - Voltage Imbalance
- Diagnostic 3 - Inactive Phase Current
- Diagnostic 4 - Phase Angle Alert
- Diagnostic 5 A, B, C, T - High Distortion
- Diagnostic 6 - Under Voltage, Phase A
- Diagnostic 7 - Over Voltage, Phase A
- Diagnostic 8 - High Neutral Current
- Caution 000400 - Under Voltage
- Caution 004000 - Demand Overload
- Caution 400000 - Received kWh
- Caution 040000 - Leading kVArh

Diagnostics and Cautions are logged and can trigger a Call-in

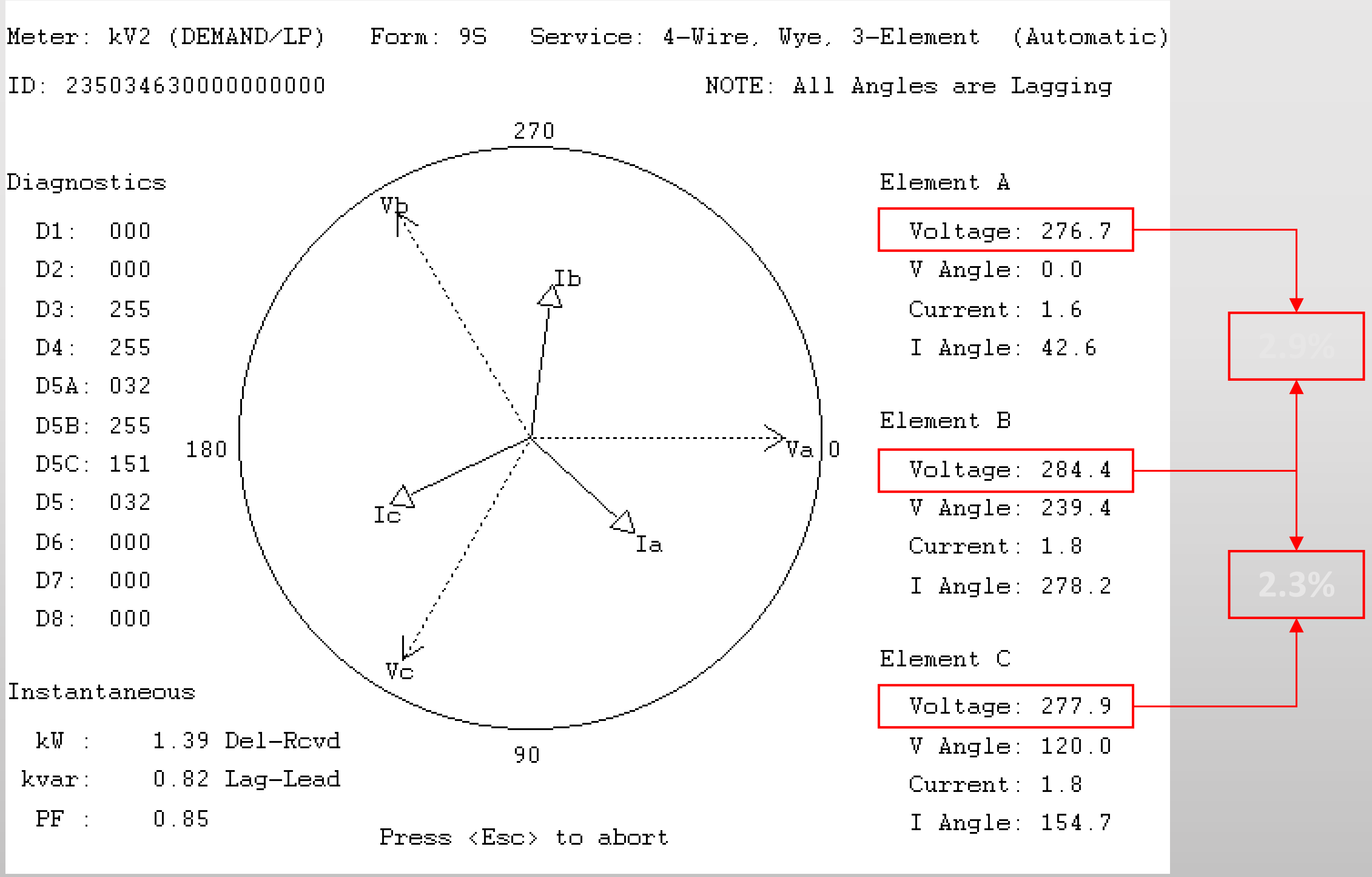
Diagnostics and Cautions tell us when to look closer

Computer Business Equipment Manufacturer's Association (CBEMA) guidelines



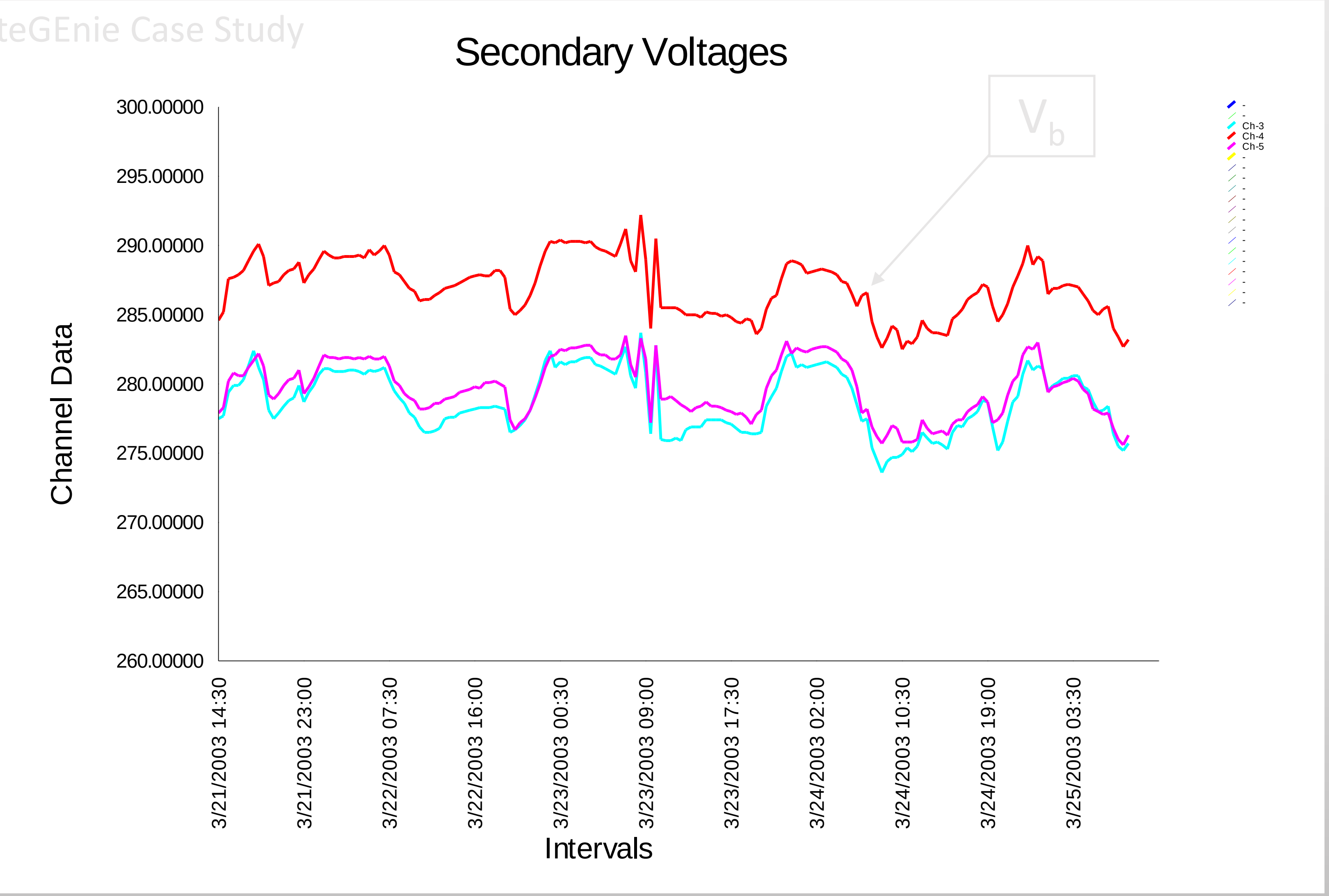
Meter Provided Phasor Information

SiteGEnie Case Study



… but was this a momentary occurrence?

SiteGEnie Information



MeterMate Load Profile shows the situation exists long term

A Final Note

Balance is required with respect to PQ concerns:

Economic value

Availability, Reliability, Efficiency

Rates tariffs and regulatory requirements

Customer energy needs

- Contact James Brackett

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- Questions??