Distributed Generation: What Problem Are You Asking It To Solve?

David G. Loucks, P.E.
Eaton/Cutler-Hammer
DaveGLoucks@eaton.com

What Is Distributed Generation?

Generation of Power closer to the point of use.

- Battery UPS
- Flywheel (Rotary UPS)
- SAG Corrector (Capacitor Storage)
- **S**uperconducting **M**agnetic **E**nergy **S**torage
- Microturbine
- Fuel Cell
- Photovoltaic
- Engine Generator (Diesel, **C**ompressed **N**atural **G**as)

Why Distributed Generation?

- **E**lectric **P**ower **R**esearch **I**nstitute and **E**dison **E**lectric **I**nstitute
  - Average power availability from utility = 99.96% (0.9996)
  - 8760 hrs/yr x (1 - 0.9996) = 3.504 hrs/yr
- Some processes cannot tolerate even 30 ms of power outage

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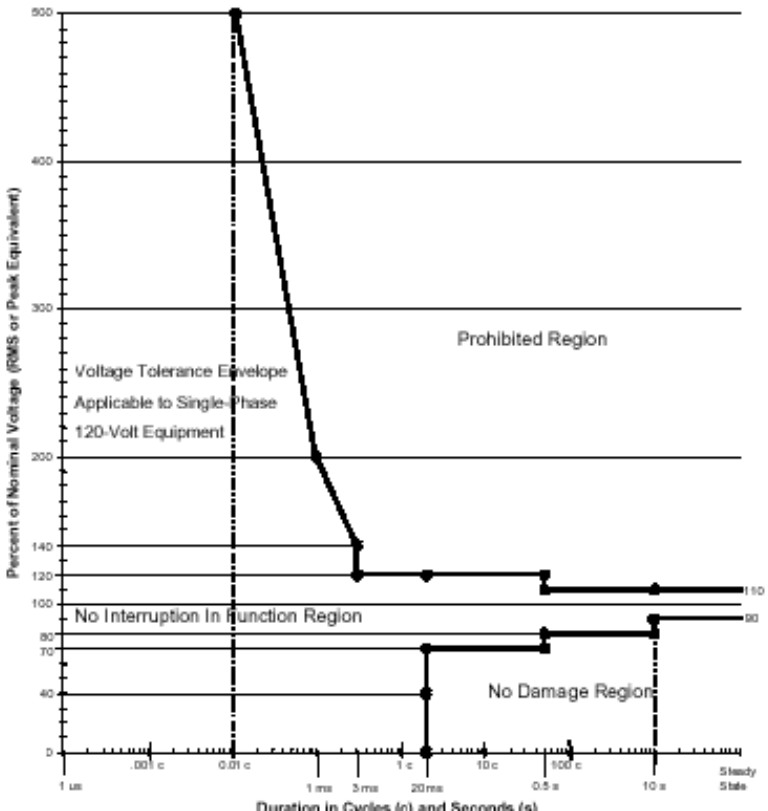
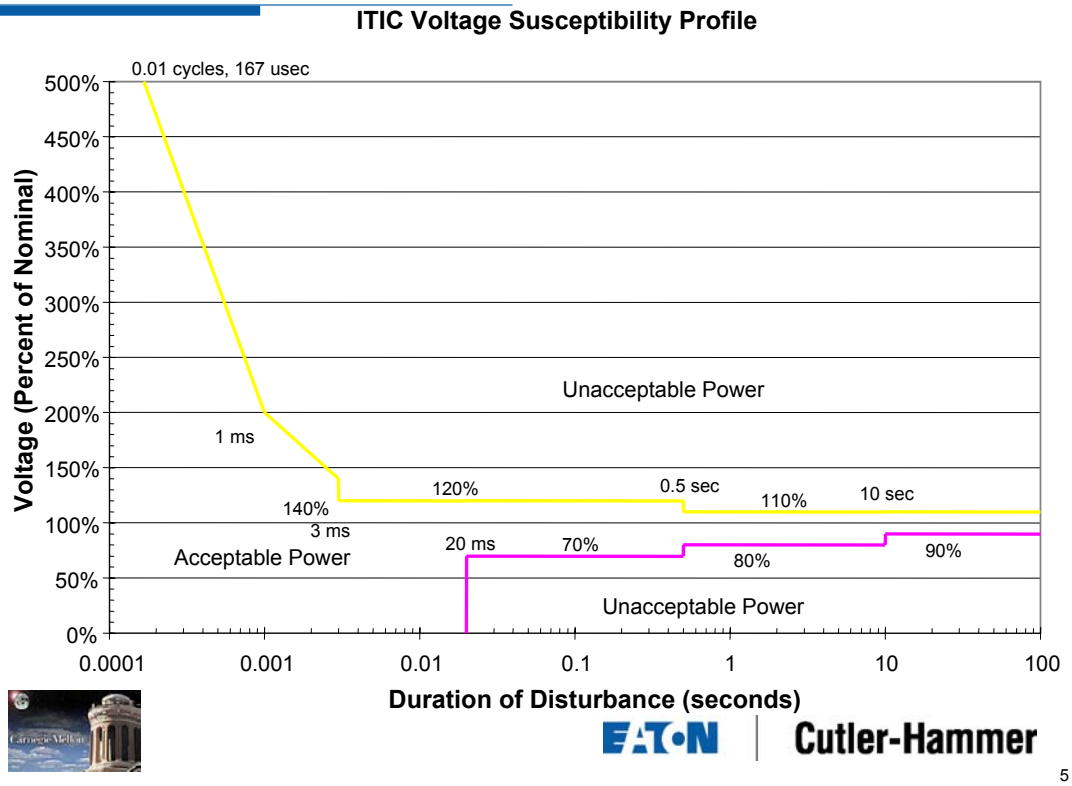
Information **T**echnology **I**ndustry **C**ouncil
http://www.itic.org/technical/iticurv.pdf

ITI (CBEMA) Curve (Revised 2000)

Computer **B**usiness **E**quipment **M**anufacturers **A**ssociation



ITIC Voltage Susceptibility Profile



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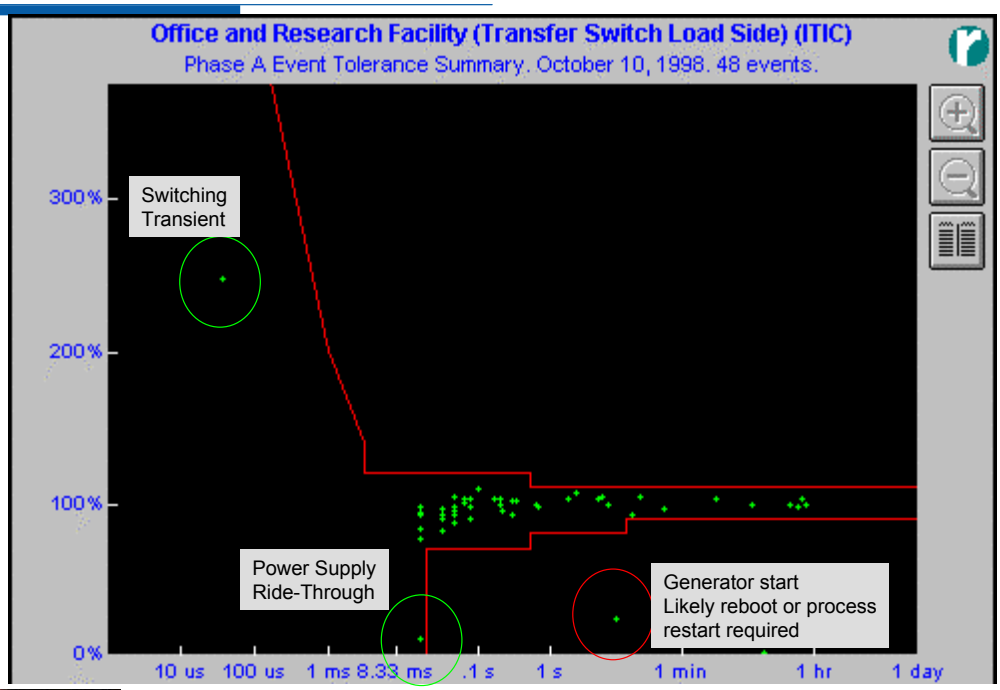
Voltage Tolerance Summary - ITIC Curve



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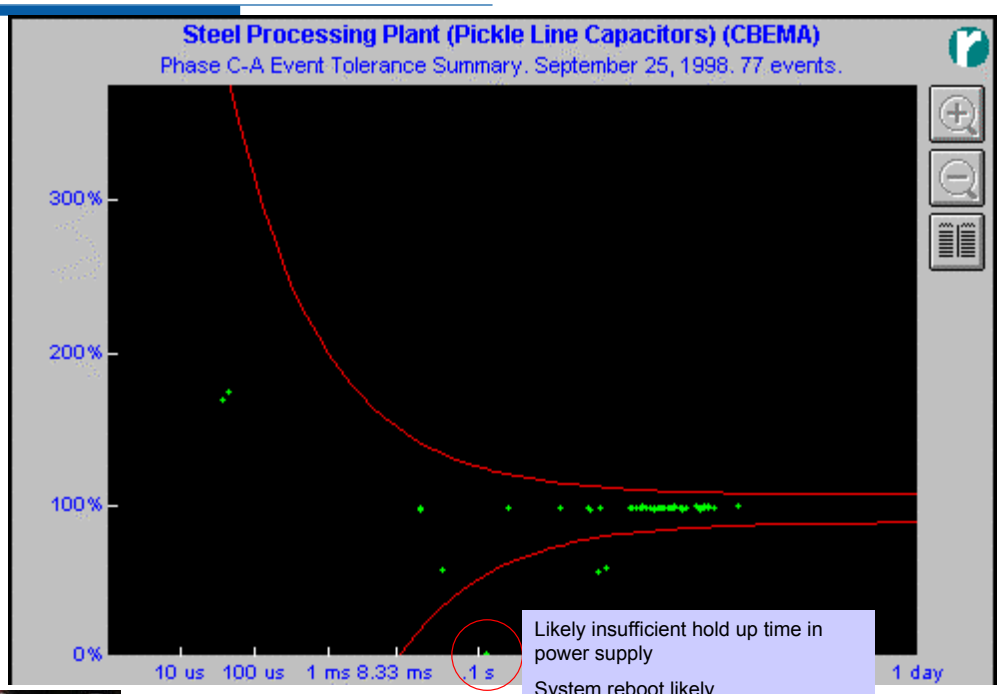
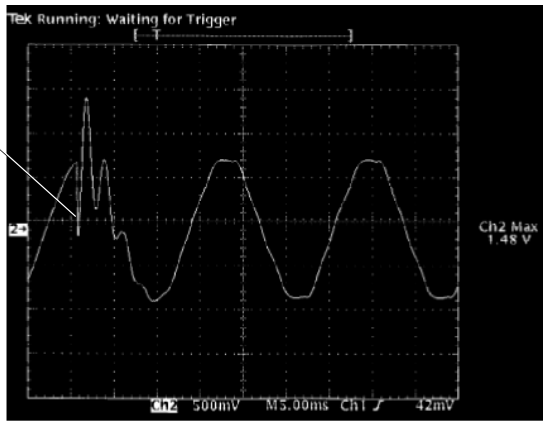


Other Problems

- Electronic equipment that use the ac sine wave zero-crossing for synchronization can be fooled by distorted voltage waveforms

Premature Zero-crossing



What is the Source of these Problems?

- EPRI / EEI studies claim that 85 – 95% of utility reliability problems are due to distribution system problems
  - Limited Area
  - Outage can vary from < 1 second (recloser operation) to hours (equipment failure)

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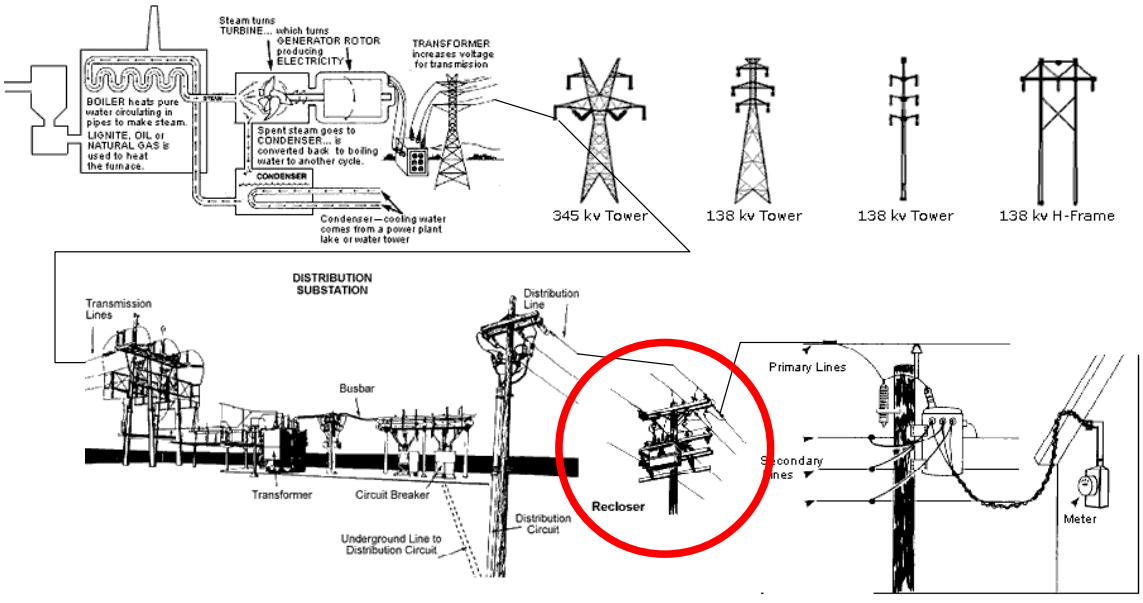
Utility Infrastructure



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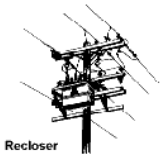
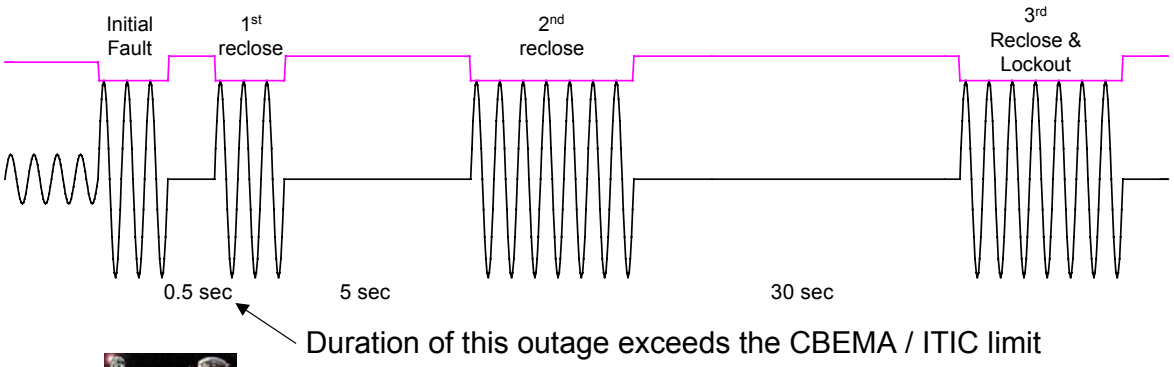
Short Duration Variations

- Recloser Operation on Distribution System
  - Over 80% of faults on overhead lines are temporary
  - Fault current, with typical reclosing intervals
  - Voltage profile *at substation* (upstream of fault)





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How Do We Address This Problem?

- We must first ask "what level of reliability is necessary?"
  - VISA processed $323,989,969,000 in check card volume in 2001 ($36.9 million per hour)
    - A shut down and reboot of the VISA processing center would have extraordinary consequences.
    - Does a landscape irrigation sprinkler pump on the same circuit require same reliability?
- Place alternate (distributed) source as close as possible to the critical load.
  - Reduces cost
  - Improves reliability

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Power Quality Definition

Summary of IEEE Std 1159-1995 Terms

CATEGORY	TYPES	TYPICAL DURATION	COMMON CAUSES
Transients	Impulsive, Oscillatory	Less than 1 cycle	Lightning, Switching Loads
Short Duration Variations	Sags, Swells, Interruptions	Less than 1 minute	Faults, Motor Starting, Utility Protective Equipment
Long Duration Variations	Sustained Interruptions, Undervoltages, Overvoltages	Over 1 minute	Poor Voltage Regulation, Incorrect Transformer Tap Setting, Overloaded Feeder, Utility Equipment
Voltage Imbalance	---	Steady state	Unbalanced Loads, Equipment Failure
Waveform Distortion	Harmonics, Notching, Noise	Steady state	Electronic Loads
Voltage Fluctuations	Flicker	Intermittent	Arcing Loads, Loose Connections
Power Frequency Variations	---	Less than 10 seconds	Poor Generator Control

Trend

- Is utility reliability improving or degrading?
  - Evidence is mixed

Evidence: Degrading

Posted on Sat, Sep. 21, 2002

PIONEER PRESS

State presses Xcel for records

BY TIM HUBER and DAVID HANNERS
Pioneer Press

Xcel stopped conducting routine maintenance, essentially refuting one of its own executives, Warren Birgel, who is in charge of electrical distribution control centers in Xcel's Upper Midwest service area. Birgel testified at an arbitration hearing earlier this year that "we do emergency maintenance and stuff, but the preventive maintenance has dried up."

NSP, a Minneapolis-based subsidiary of Xcel Energy, eliminated all but emergency maintenance on its equipment at the start of 2001. As a result, the employees claim, a system that 1.3 million customers rely on for their electricity has deteriorated so badly that altering the reliability figures is the only way the utility can meet state requirements.

NSP has such a large backlog of broken equipment in need of repair that work crews only have time to respond to emergencies, said the employees, who spoke on the condition that their names not be published.

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Evidence: Improving

- According to the Edison Electric Institute[1]
  - 1998 Distribution System Reliability: 99.17% (21 utilities reported)
  - 1999 Distribution System Reliability: 99.96% (62 utilities reported)
- 95% reduction in downtime (99.17% = 72.7 hrs/yr, 99.96% = 3.5 hrs/yr) in one year.
- But what about the claim "… altering reliability figures is the only way the utility can meet state requirements." Should we discount this as complaints from disgruntled workers after RIFs?

[1] http://www.eei.org/edg/system/1999_Reliability_Summ_Rpt.pdf

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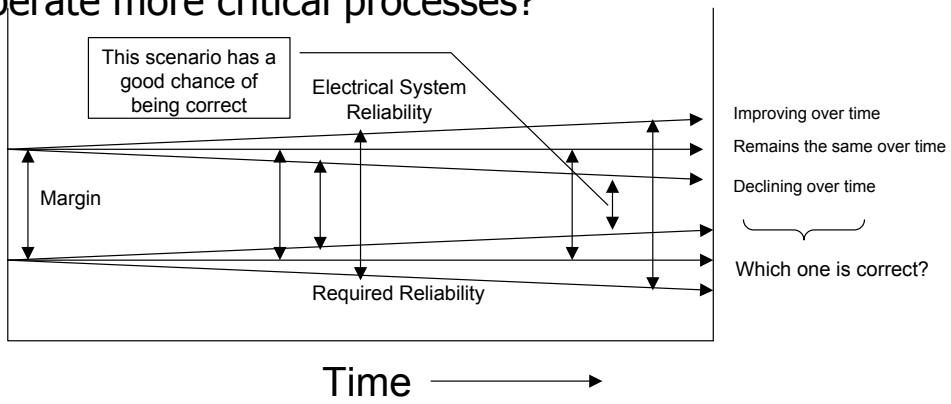
What About the Loads?

- Is the percentage of total grid capacity feeding electronic loads increasing?
- Is electronic equipment more or less tolerant of power anomalies?
- Are we relying on this electronic equipment to operate more critical processes?



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How Do We Fix This?

Technology	Cost	Issue
• Battery UPS	• $1000/kW	• Heavy metals, life
• Flywheel	• $500/kW	• Ride through time
• SAG Corrector	• $200/kW	• Ride through time
• SMES	• $500/kW	• Ride through time
• Microturbine	• $1300/kW	• Start up delay
• Fuel Cell	• $4000/kW	• Cost
• Photovoltaic	• $5000/kW	• Cost, availability
• Engine Generator	• $400/kW	• Emissions
• Wind	• $1000/kW	• Availability

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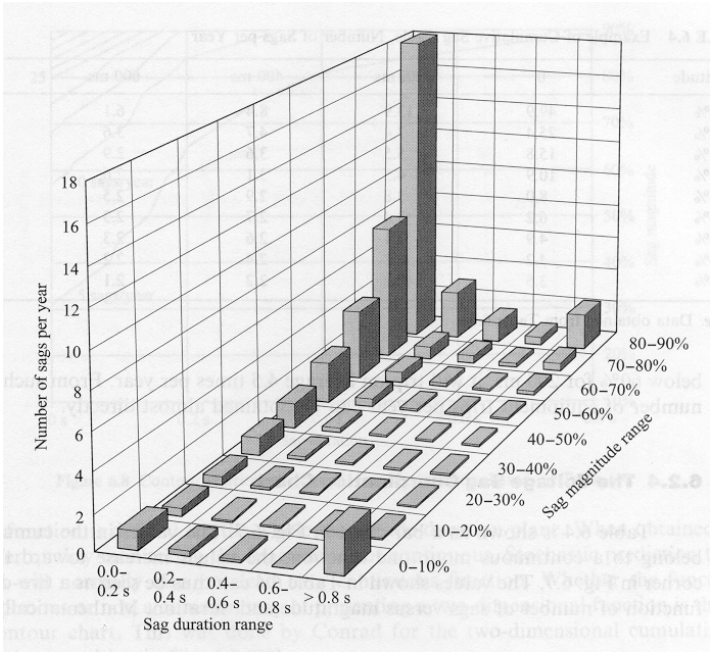
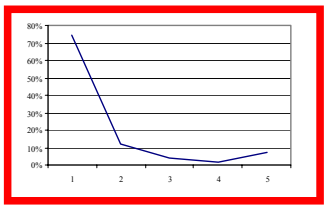
So Which Technology?



	0.2 s	0.4 s	0.6 s	0.8 s	>0.8 s
90	18	2.5	1	0.3	2
80	7.5	0.8	0.5	0.3	0.5
70	3.5	0.7	0.2	0.1	0.2
60	1.75	0.5	0.1	0	0.1
50	1	0.3	0	0	0
40	0.5	0.2	0	0	0.1
30	0.2	0.1	0	0	0.1
20	0.2	0	0	0	0.1
10	0.5	0.2	0.1	0	0.2
T	33.15	5.3	1.9	0.7	3.3
	75%	12%	4%	2%	7%

Sum= 44.4 93%



M.H.J. Bollen, "Understanding Power Quality Problems, Voltage Sags and Interruptions," IEEE Press, ISBN 0-7803-4713-7

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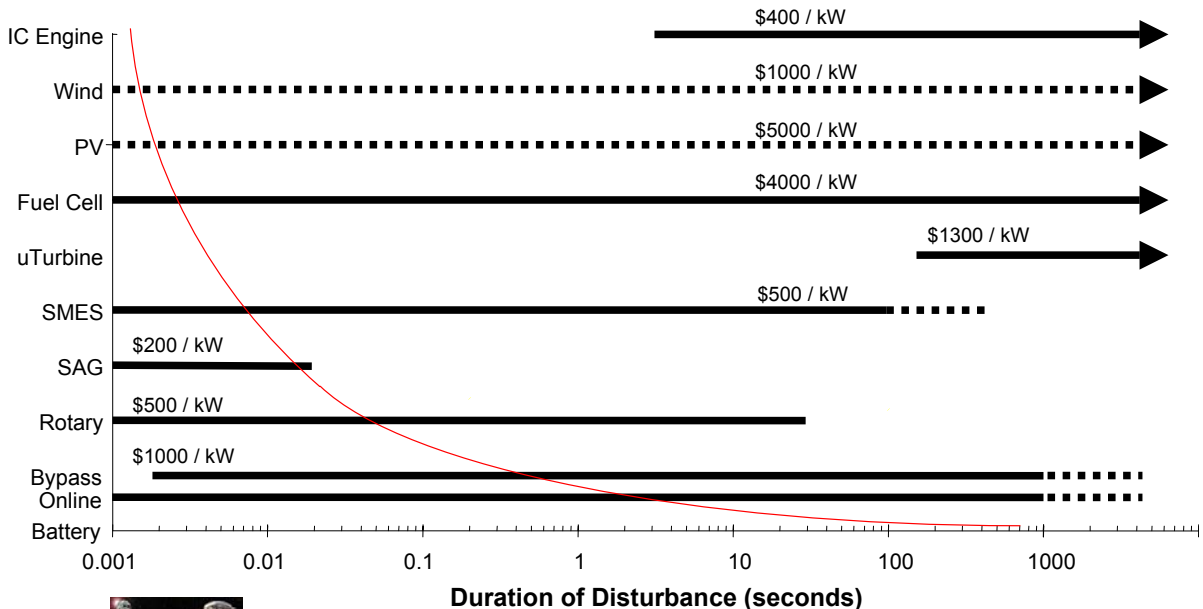
Response and Ride-Through



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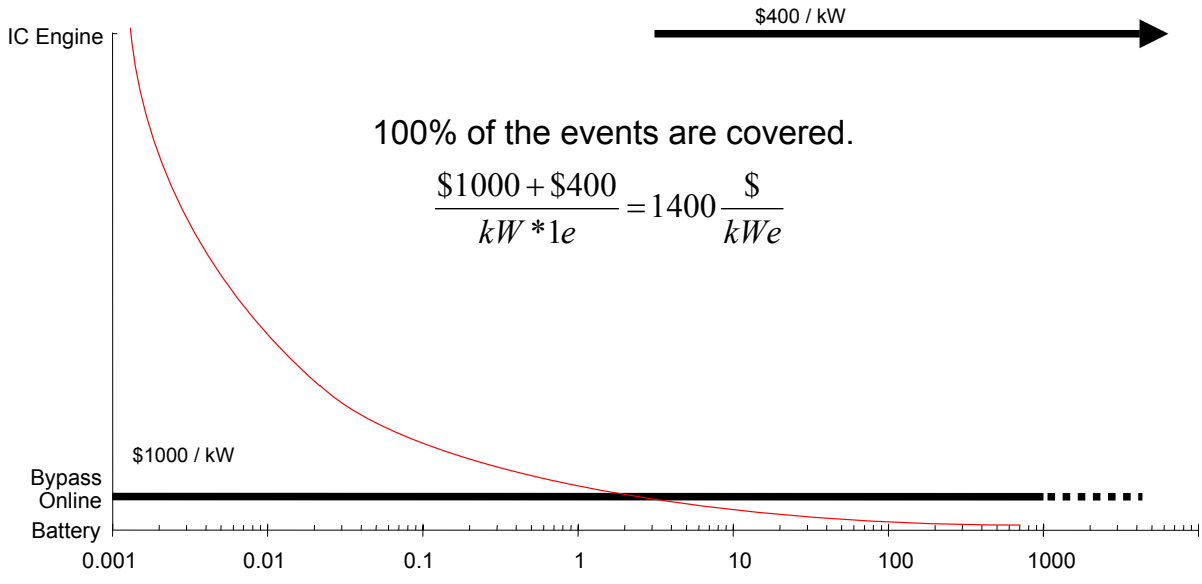
Most Common Option



100% of the events are covered.

$$\frac{\$1000+\$400}{kW*1e}=1400\frac{\$}{kWe}$$

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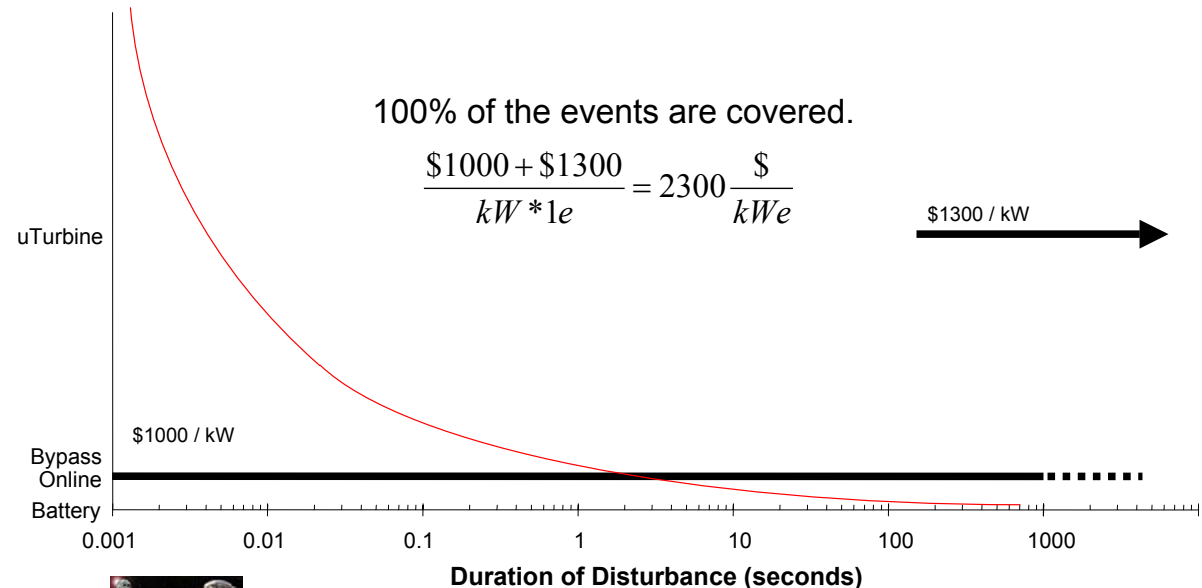
This Works Too



100% of the events are covered.

$$\frac{\$1000+\$1300}{kW*1e}=2300\frac{\$}{kWe}$$

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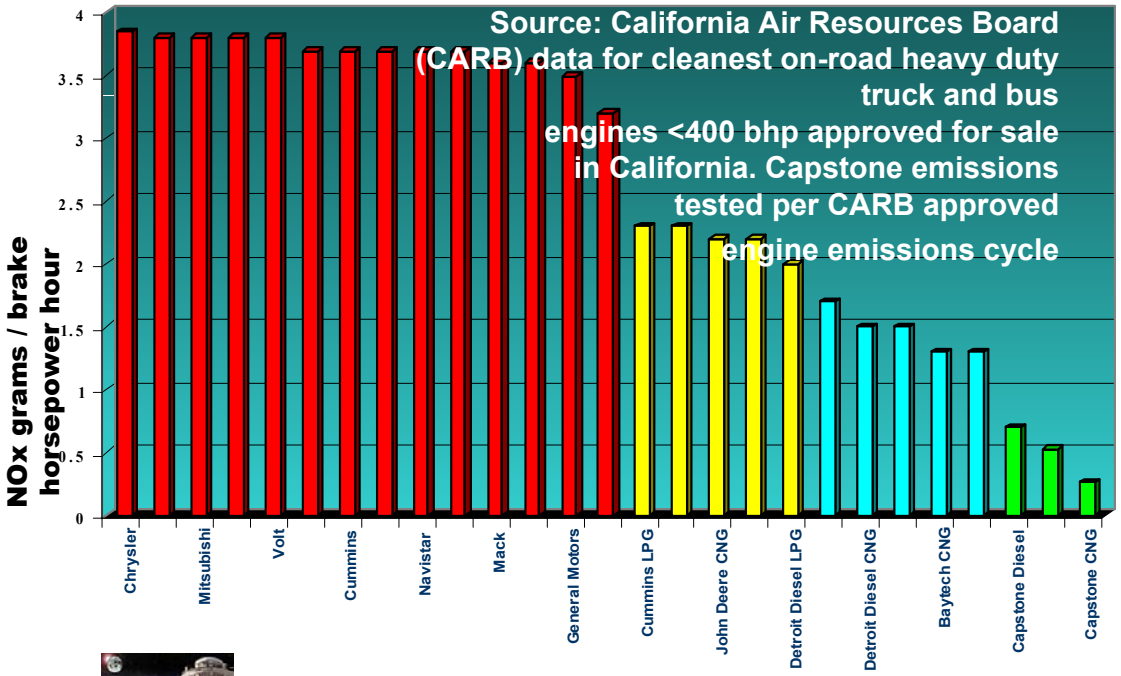
NO_x



Graphic Source: Capstone Turbine Corp.

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Emissions

"No other small technology we have evaluated can work reliably on landfill gas with NO_x emissions below the 30 ppm of flares. To achieve 1.3 ppm is remarkable. That approaches the level of fuel cells, but at a fraction of the cost."

– Ed Wheless, Los Angeles County Sanitation District, on a Capstone landfill gas application.

This is why someone is willing to pay $1300/kW vs. $400/kW (gen set)

Source: Capstone Turbine Corp.

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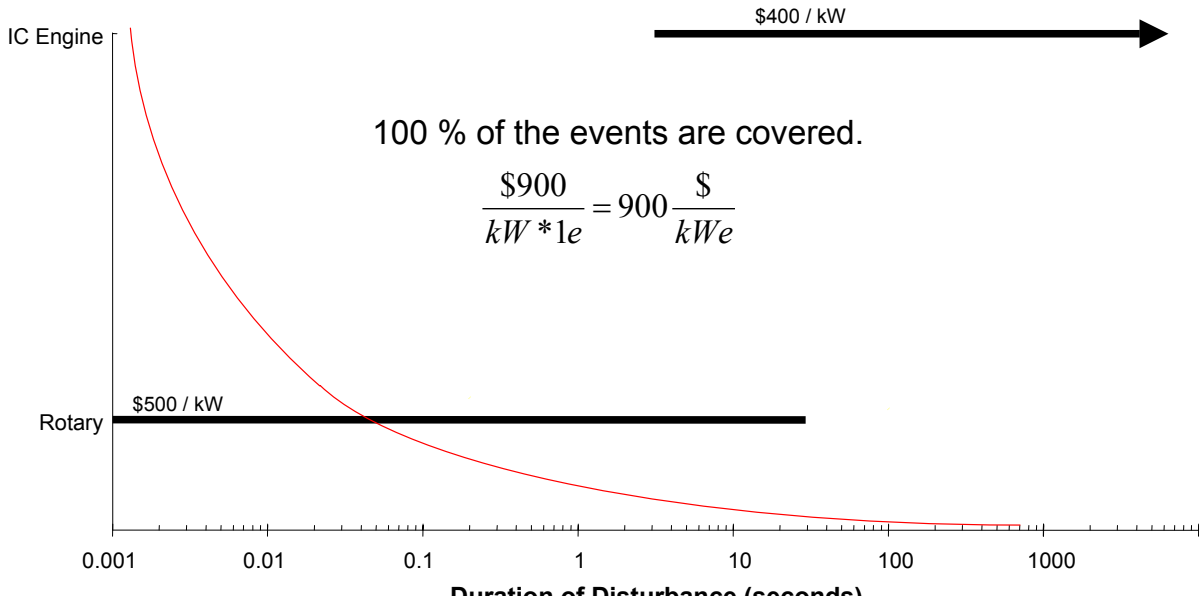
Best Value



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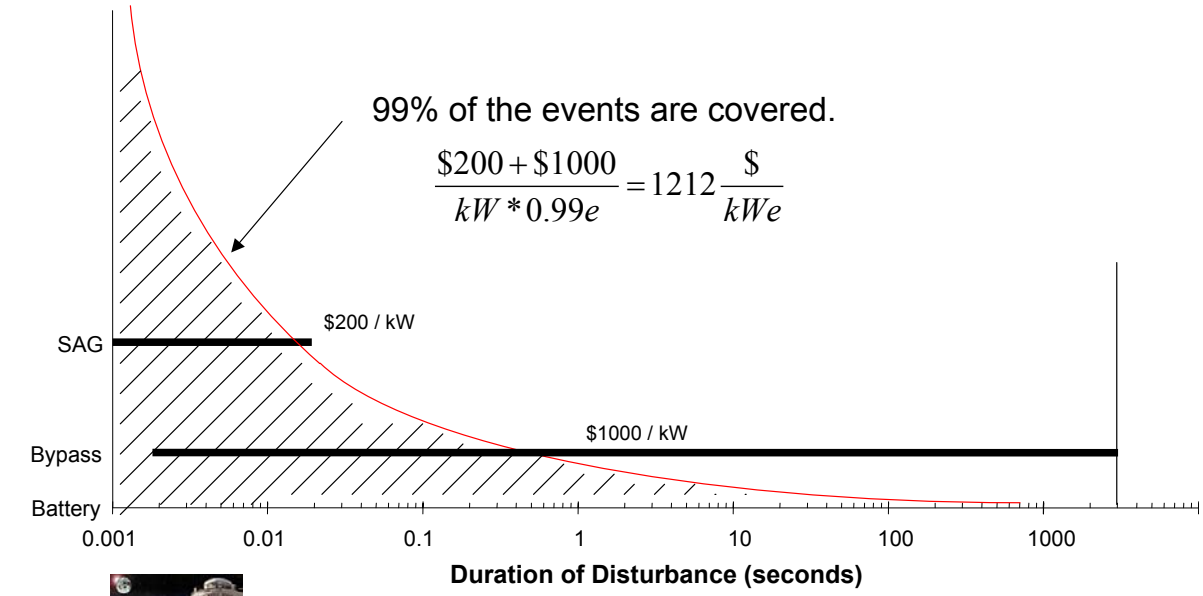
Another Low Emission Choice



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Summary

UPS + Gen Set	1400 $/kW event (100% coverage)	Most common
UPS + Microturbine	2300 $/kW event (100% coverage)	Lowest emission 100% coverage
Rotary UPS + Gen Set	900 $/kW event (100% coverage)	Lowest cost 100% coverage
UPS + SAG Corrector	1212 $/kW event (99% coverage)	Lower cost, low emission solution 99% coverage

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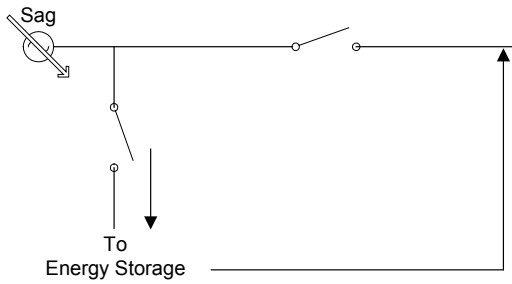
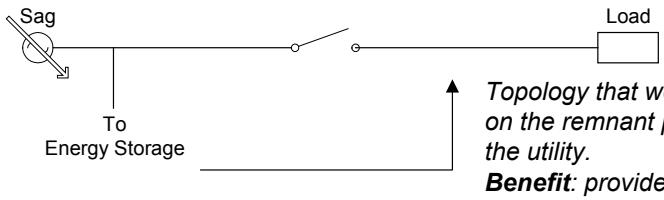
Parallel Connected SAG



Topology that would not use the remnant power from the utility. Operates by injecting current to provide output wave shape support.
***Benefit**: extended operation during 1-phase fail.*



Topology that would use on the remnant power from the utility.
***Benefit**: provides extended operation during 1-phase fail since source of power available on other two wires*

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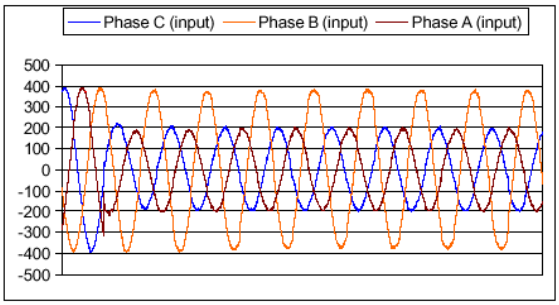
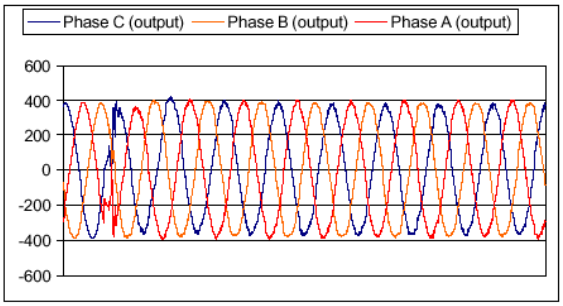
Before/After: Sag Correction





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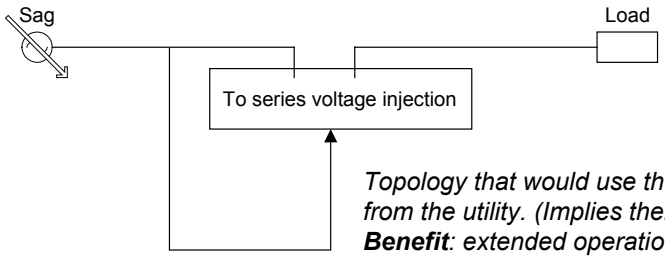
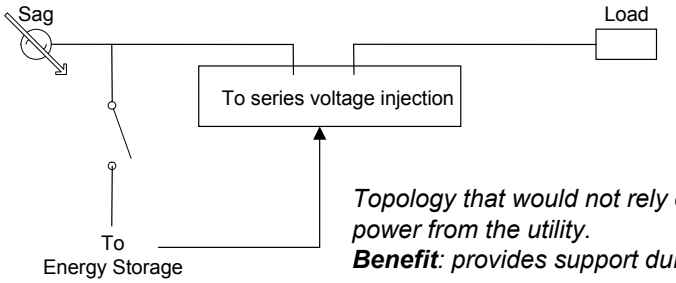
Series Connected SAG



Topology that would use the remnant power from the utility. (Implies there is some)
***Benefit**: extended operation during 1-phase fail.*



Topology that would not rely on the remnant power from the utility.
***Benefit**: provides support during 3-phase fail.*

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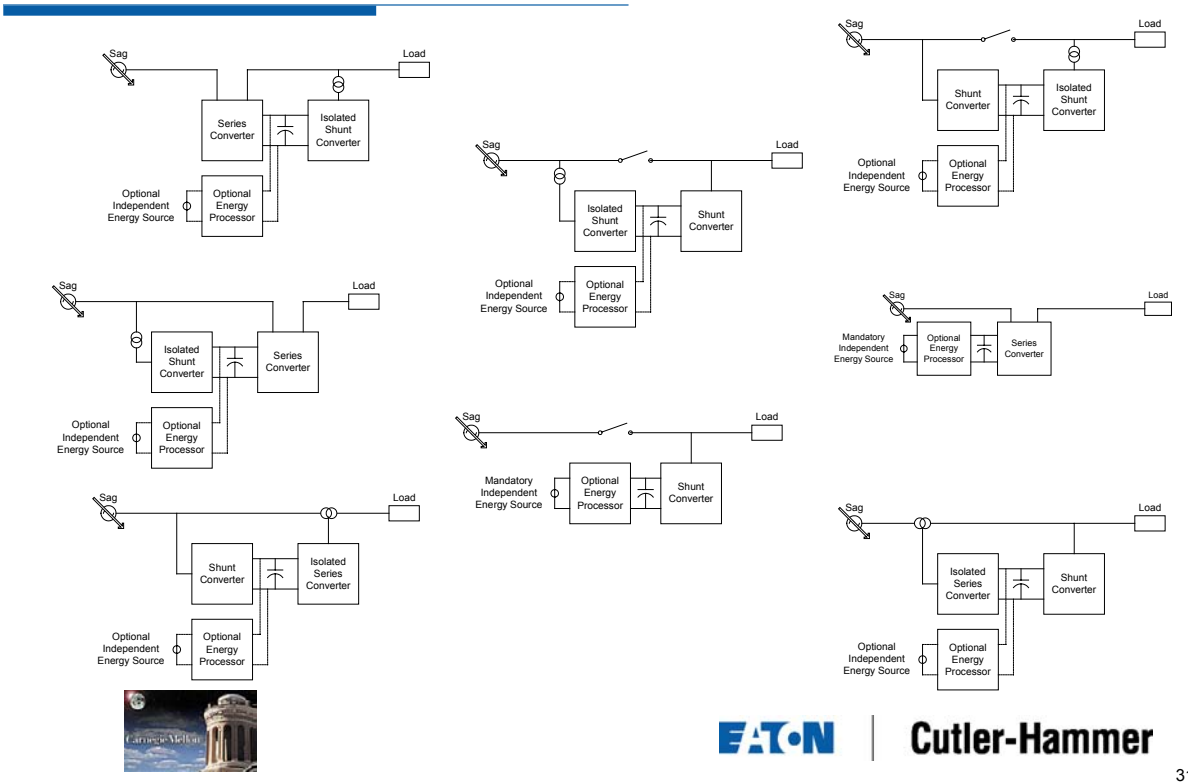
SAG Technology



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One Word of Caution

- We live in a world of non-linear loads
  - PCs, copiers, fax machines, printers, InFocus
  - All have switching power supplies
- Non-linear loads draw current that isn't proportional (linear) to instantaneous voltage
- Mathematically we represent this as a Fourier Series
  - Fundamental is 60 Hz
  - Fourier coefficients correspond to multiples of 60 Hz
- This problem tends to be masked by low impedance sources (utility), but exacerbated by high impedance sources (distributed generation).

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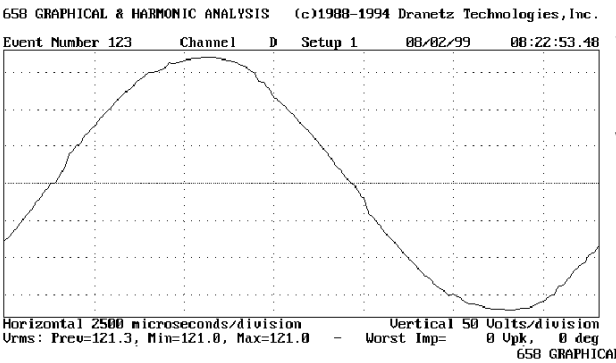
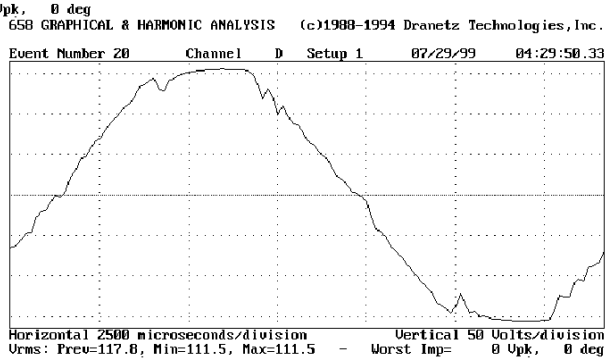
Voltage Distortion



When Load Powered from Utility:
Voltage Distortion: 2.3% THD

When Load Powered from Generator:
Voltage Distortion 5.7% THD

Same Load!



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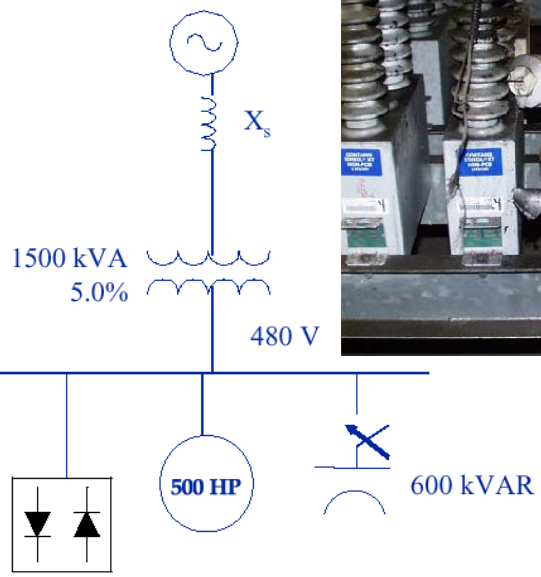
Parallel Resonance

$$f_R = \sqrt{\frac{MVA_{SC}}{MVAR_{CAP}}}$$



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There is more to say

… but I've run out of time!

Thank you for you interest

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