Integrated Volt Var Control (IVVC) Issues for the future

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Conrad Technical Services LLC

Outline

- The IVVC opportunity and challenge
  - Billions in benefits available
  - Ability to prove recovery
- Can we do it
  - Voltage standard support
  - Voltage Standard C84.1 requirements
  - Regulatory support on the other side of the meter
  - How smart do we need to be?
- Will it persist?
  - Equipment response to voltage
  - Current and future state
  - Influence of technology and world standards

Peak demand opportunity (US)

760,000 MW	MW Reduction at CVR Factor				
Reduction	0.5	0.7	0.9	1.1	1.3
1%	3,800	5,320	6,840	8,360	9,880
2%	7,600	10,640	13,680	16,720	19,760

$500/kW	$ Billion of replacement capital at CVR Factor				
Reduction	0.5	0.7	0.9	1.1	1.3
1%	$ 1.9	$ 2.7	$ 3.4	$ 4.2	$ 4.9
2%	$ 3.8	$ 5.3	$ 6.8	$ 8.4	$ 9.9

$2,500/kW	$ Billions of replacement capital at CVR Factor				
Reduction	0.5	0.7	0.9	1.1	1.3
1%	$ 9.5	$ 13.3	$ 17.1	$ 20.9	$ 24.7
2%	$ 19.0	$ 26.6	$ 34.2	$ 41.8	$ 49.4

Energy opportunity

4,119,000 GWh in play	GWh Reduction at CVR Factor				
Voltage Reduction	0.5	0.7	0.9	1.1	1.3
1%	20,595	28,833	37,071	45,309	53,547
2%	41,190	57,666	74,142	90,618	107,094

$40/MWh	$ Billions of energy at CVR Factor				
Voltage Reduction	0.5	0.7	0.9	1.1	1.3
1%	$ 0.8	$ 1.2	$ 1.5	$ 1.8	$ 2.1
2%	$ 1.6	$ 2.3	$ 3.0	$ 3.6	$ 4.3

http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

Opportunity summary

- Assume 1% savings demand and energy for the US
- Demand
  - 7,600 MW reduction
  - $3.8 B at $500 / kW
  - $19 B at $2,500 / kW
  - Over 5,000 wind turbines we don't need (1.5 MW per unit)
- Energy
  - $ 1.6 B per year at $40 / MWh
  - Savings can always be there 8,760 hours per year
- Other
  - No impact on land
  - Customers don't have to do anything

Example of Smart Grid Business Case

- Three major benefits
  - Metering – 55%
  - Distribution – 40%
  - Outage – 5%
- Looking deeper into distribution
  - Direct expense reduction – 5%
  - Avoided cost – 95%
    - Almost 80% of avoided cost was in voltage control
    - Balance was various distribution capital and maintenance savings
- About 30% of entire case is in voltage control

What about lost revenue?

- Lots of complexities – so these are just thoughts
- Energy component (operating cost)
  - Less revenue, but lest cost as well
  - Fuel cost adjustment may lag but balance
- Demand component (lost margin)
  - Some demand return in energy declining blocks
  - Definite loss on demand charges until next rate case
- Next rate case
  - Incumbent investment true-up
  - Additional return for IVVC investment
  - Other soft factors

Must earn recovery to keep momentum

- Some lessons from Demand Side Management
  - Claimed large savings opportunity
  - Did not anticipate the challenges for recovery true-up
  - Many projects started without solid baseline
  - Persistence arguments
  - Recovery failed and program dropped
- Our challenge to not repeat
  - Prove beyond reasonable doubt that we saved 1%
  - Good baseline now.
  - Plan for rock solid defense at true-up
  - Some presentations are more convincing than others
  - Tackle persistence head-on

Voltage Standards

A solid footing for using our allocation of the resource

Our most important people

V = R * I

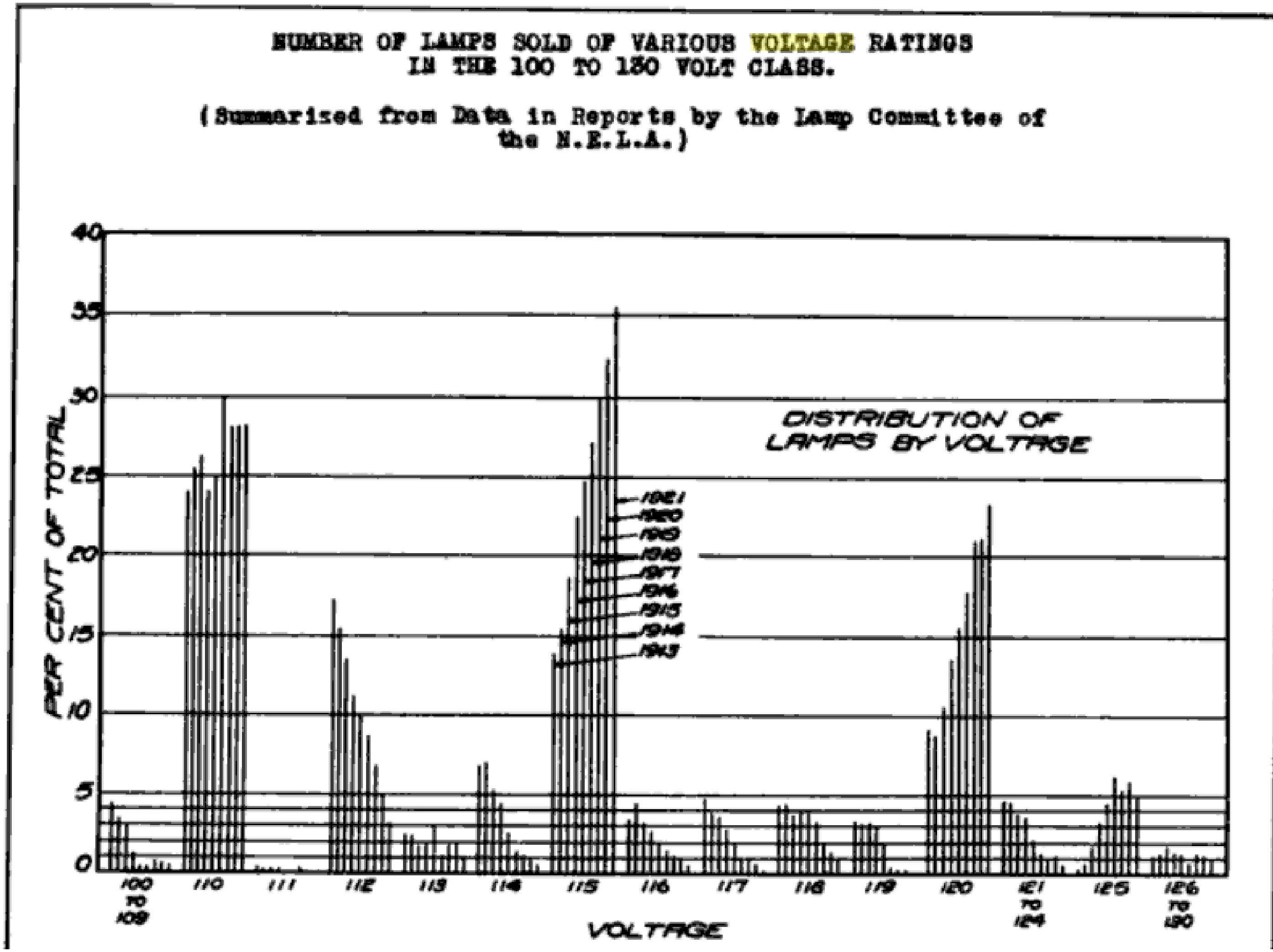
Alessandro *Volta*

Georg Simon *Ohm*

Andre-Marie *Ampere*

Voltage drop is a valuable "resource" in our industry

Industry light bulb trends in 1922

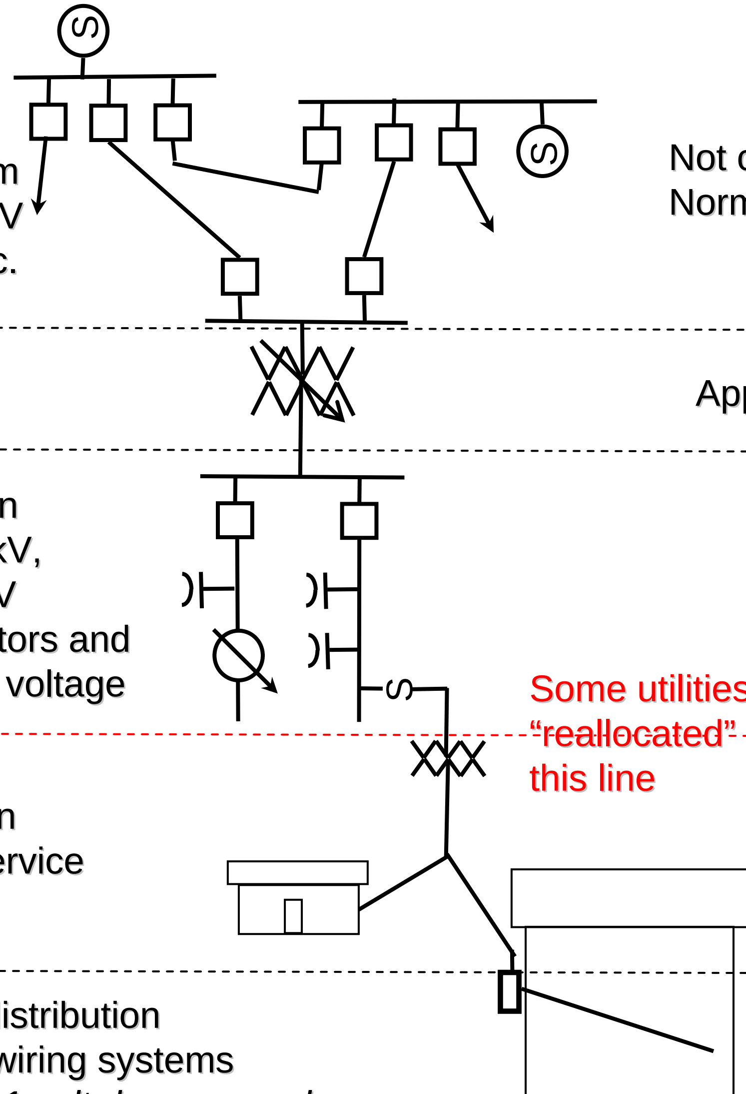


National Electric Light Association, May 1922

2006 Revision to C84.1

- Scope expanded to voltages above 230 kV
- Retired IEEE Std 1312-1993 (R2004),
- Also retired predecessor to IEEE 1312, ANSI C92.2-1987.
- We now have one standard for all preferred voltages and their ranges in the United States
- C84.1 published by ANSI C84 committee represented by all interested parties
- ***If utilities, building designers, and product manufacturers all do their part, customers can enjoy full use of the products without worry. (plug and play)***

ANSI C84.1 voltage drop and ranges



HV and EHV
Bulk Electric System
44 kV, 69 kV, 100 kV
138 kV, 230 kV, Etc.

Not closely regulated due to distances.
Normally about +5% to -10%

Transformer
from HV to MV

Apply voltage regulation here

MV distribution
4.16 kV, 12.47 kV,
24 kV, 34.5 kV
Pole mounted capacitors and
Regulators maintain voltage

Allocate 7.5% drop
Range A = +5% to – 2.5%
126 to 117 volts at MV

Some utilities
“reallocated”
this line

LV distribution
secondary and service

Allocate 2.5% drop
Range A = +5% to – 5%
126 to 114 volts at meter

LV distribution
building wiring systems

Allocate 5% drop
Range A = +5% to – 10%
125[Note 1] to 108 volts

Note 1: Assumes 1 volt drop somewhere

“Normal” Range A conditions

- *5.1.1 Range A—service voltage* Electric supply systems shall be so designed and operated that *most service voltages will be within the limits specified* for Range A. The occurrence of service voltages outside of these limits should be infrequent.
- *5.1.2 Range A—utilization voltage* User systems shall be so designed and operated that with service voltages within Range A limits, *most utilization voltages will be within the limits specified for this range*. Utilization equipment shall be designed and rated to give fully satisfactory performance throughout this range.

One survey showed 97% of utilities follow C84.1

“Infrequent” Range B

- _5.1.3 Range B—service and utilization voltages_ Range B includes voltages above and below Range A limits that necessarily result from practical design and operating conditions on supply or user systems, or both. *Although such conditions are a part of practical operations, they shall be limited in extent, frequency, and duration. When they occur, corrective measures shall be undertaken within a reasonable time to improve voltages to meet Range A requirements.* Insofar as practicable, utilization equipment shall be designed to give acceptable performance in the extremes of the range of utilization voltages, although not necessarily as good performance as in Range A.

Outside Range B –go fix it

- *5.1.4 Outside Range B—service and utilization voltages* It should be recognized that because of conditions beyond the control of the supplier or user, or both, there will be infrequent and limited periods when sustained voltages outside Range B limits will occur. Utilization equipment may not operate satisfactorily under these conditions, and protective devices may operate to protect the equipment. *When voltages occur outside the limits of Range B, prompt corrective action shall be taken. The urgency for such action will depend upon many factors,* such as the location and nature of the load or circuits involved, and the magnitude and duration of the deviation beyond Range B limits.

One survey showed 68% of utilities work around the clock to bring voltages back when they are outside Range B

Customer responsibility

- 215-2(b) FPN No. 2.: Conductors for **feeders** as defined in Article 100, sized to prevent a voltage drop exceeding 3 percent at the farthest outlet of power, heating, and lighting loads, or combinations of such loads, and **where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent**, will provide reasonable efficiency of operation.
- Article 210 - FPN 1:Conductors for **branch circuits** as defined in Article 100, sized to prevent a voltage drop exceeding 3 percent at the farthest outlet of power, heating, and lighting loads, or combinations of such loads, and **where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent**, will provide reasonable efficiency of operation.
- Codified in some states – Florida for sure
- ANSI/ASHRAE/IESNA Standard 90.1-2004 requires that feeder and branch-circuit voltage drop not exceed 2 percent and 3 percent, respectively

DOE adoption of ASHRE standard

ANSI/ASHRAE/IESNA Standard 90.1-2004

- Feeder conductors
  - Run between the service entrance equipment and the branch circuit distribution equipment
  - 2% maximum voltage drop allowed at design load
- Branch circuit conductors
  - Run from the final circuit breaker to the outlet or load
  - 3% maximum voltage drop allowed at design load
- These are more stringent than non-enforceable requirements in the National Electric Code (NEC)

World market may give some room

- US has the more stringent voltage regulation requirements than the rest of the world
- Example, EU documents indicate that the range of variation of the r.m.s. magnitude of the supply voltage, whether line to neutral or line to line to phase, Un ± 10 % for 95 % of a week.
- Most of the world adopts IEC requirements
- Universal power supply designs have broad range of tolerable voltages
  - 240 nominal on high side
  - 100 volts nominal on low side
  - Actual operation for nominal and allowable range in that nominal.

Integrated Volt Var Control

Objectives

Benefits

What Duke is doing today

Items we might encounter

- Customers with excess voltage drop in building
- Duke with excessive voltage drop in transformer, secondary and service,
- Three phase customers with off nominal taps at Utility transformer
- Internal transformers at unexpected taps
- Misuse of equipment – wrong voltage
- Too much voltage drop in system
- Miss coordination of equipment or trying to use wrong voltage
- Model inaccuracy

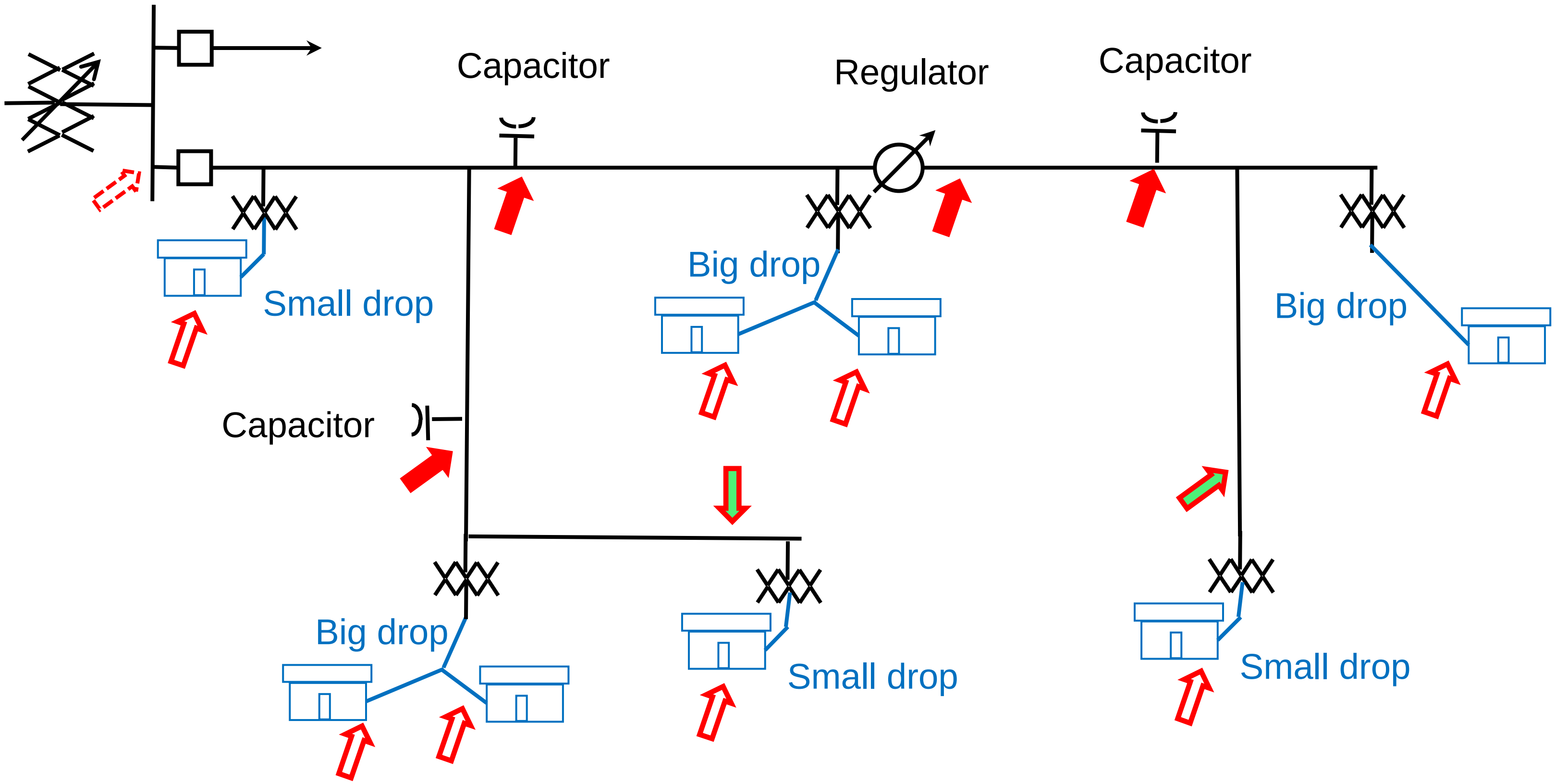
How smart do we need to be?

- Lack of detailed knowledge forces us to design extra margin in the system to account for the unknowns
- Each incremental piece of information allows us to remove some of the design margin
- Law of diminishing returns will find the point where the cost of more information exceeds the savings opportunity.
- We are on a path to quickly find the sweet spot with a broad variety of approaches.

The more we know, the better we get

- How much?
  - Voltage at substation – prefer all three phases
  - Voltage at line regulators – should know each phase
  - Voltage at line capacitors – typically only one of three phases but would like all three
  - Voltage at end of the line
  - Voltage at a sample of customer meters
- How often?
  - History from manual reads
  - “Real time”
    - Daily, Hourly, 15 min interval, instantaneous?

So how much do we need to know?



Substation SCADA

Line Sensors

Pole mounted caps and regs

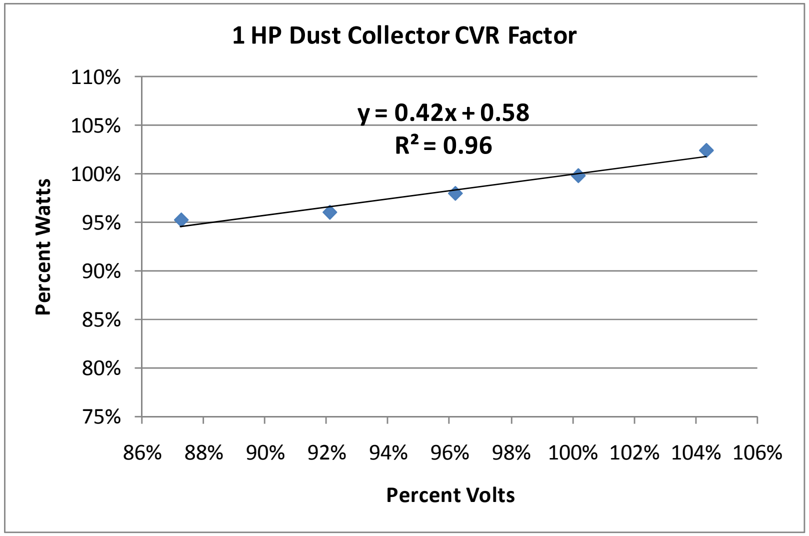
Every customer

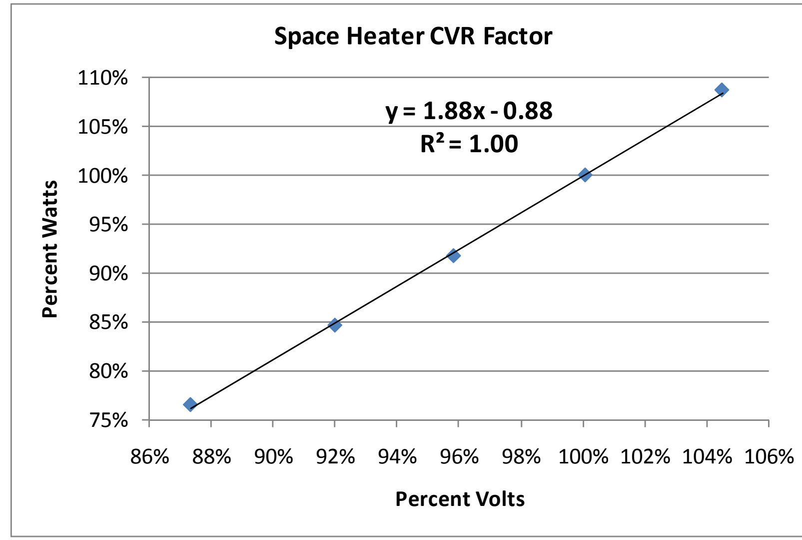
Will it persist

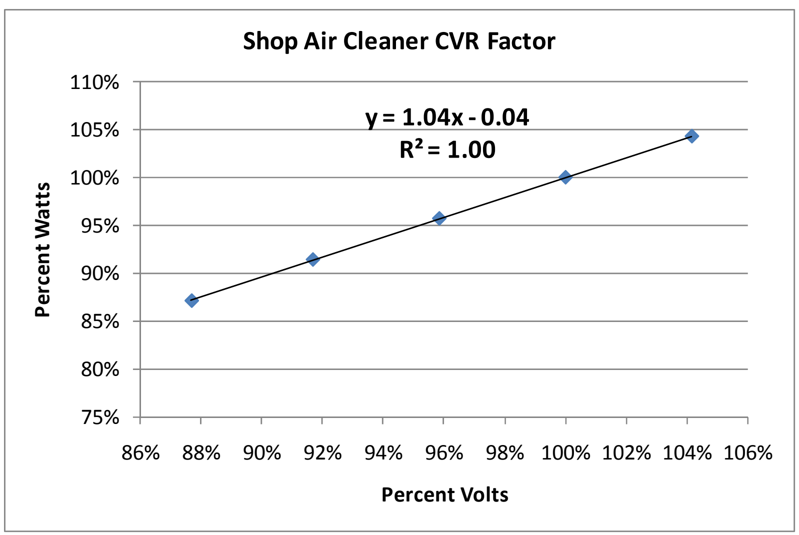
Current and future state

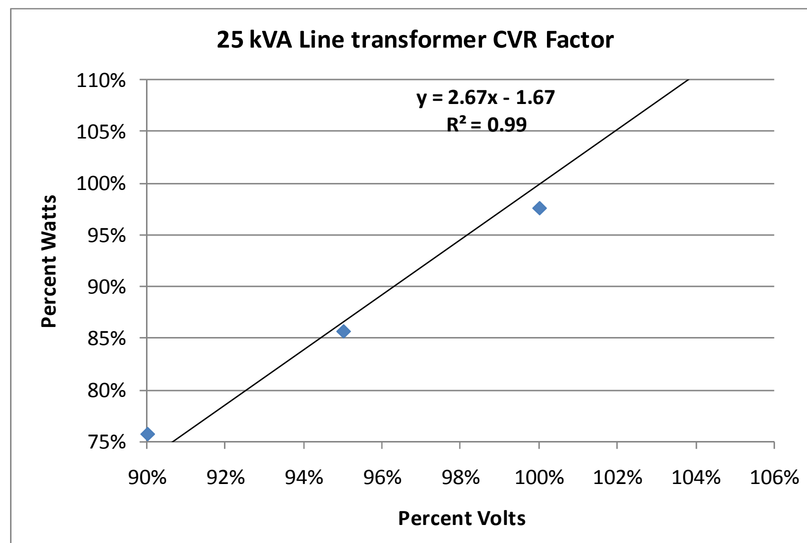
Influence of technology and world standards

Various items

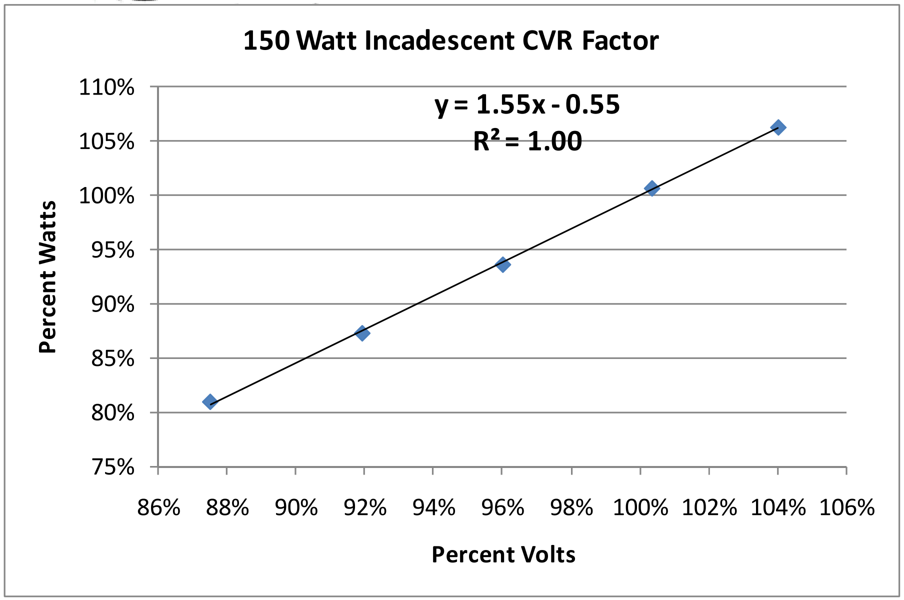


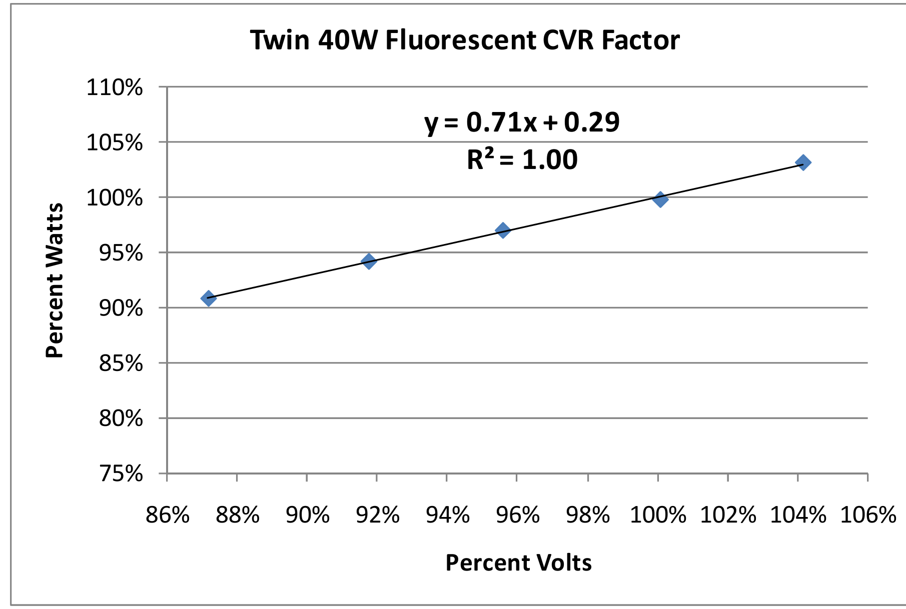


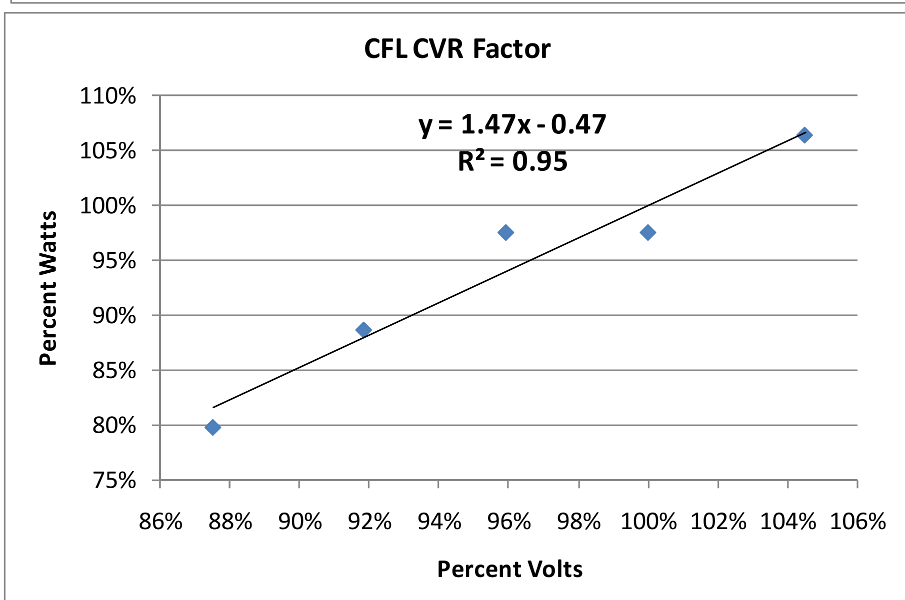


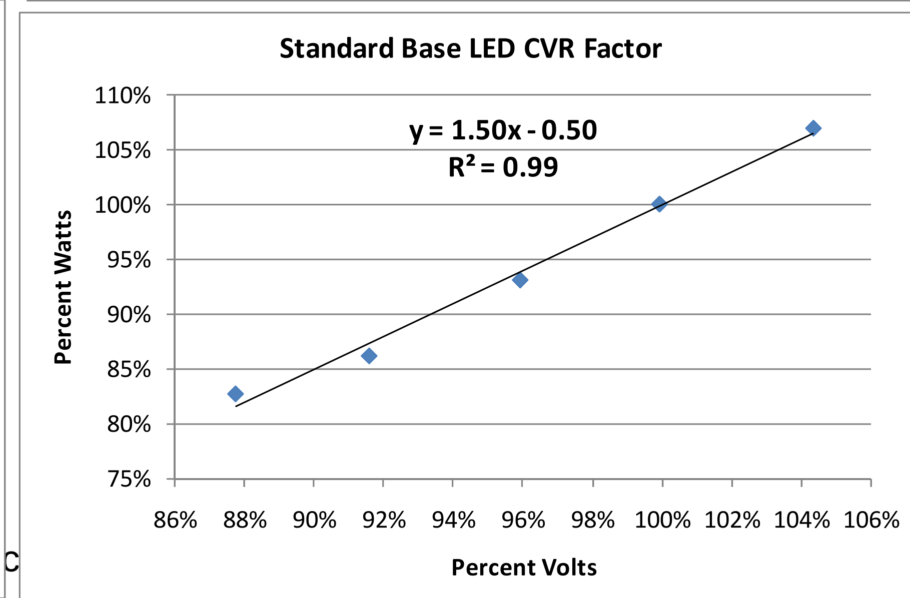


Lighting sample – load share will drop

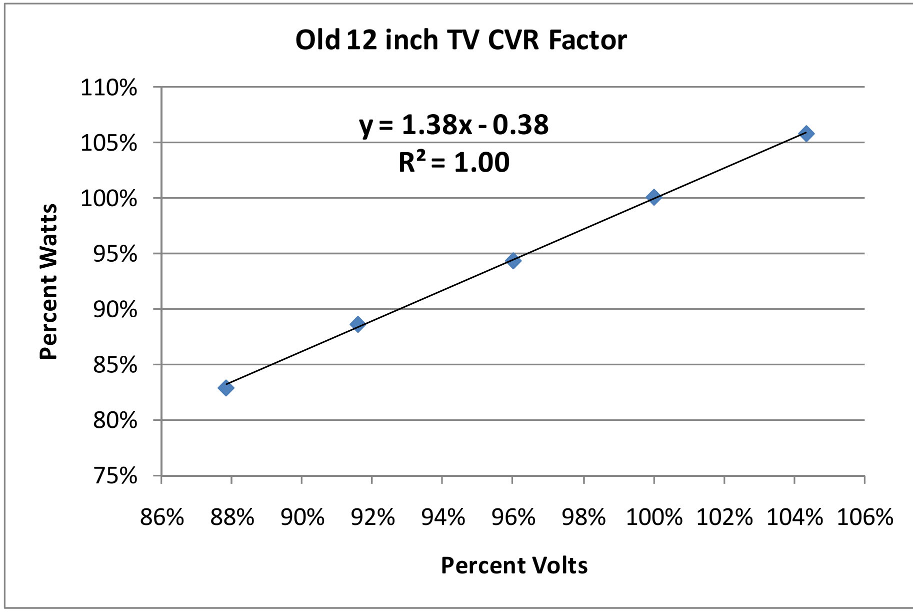


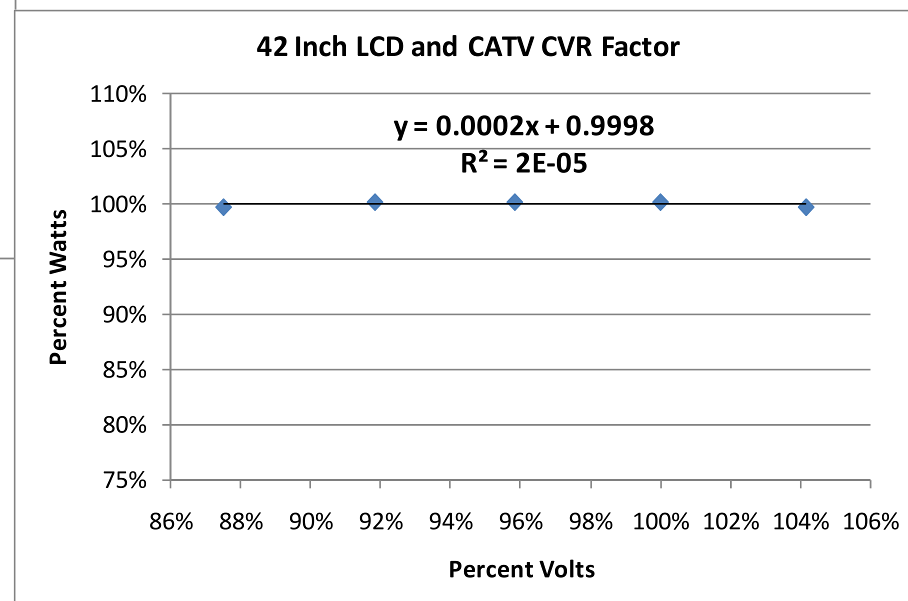






Televisions



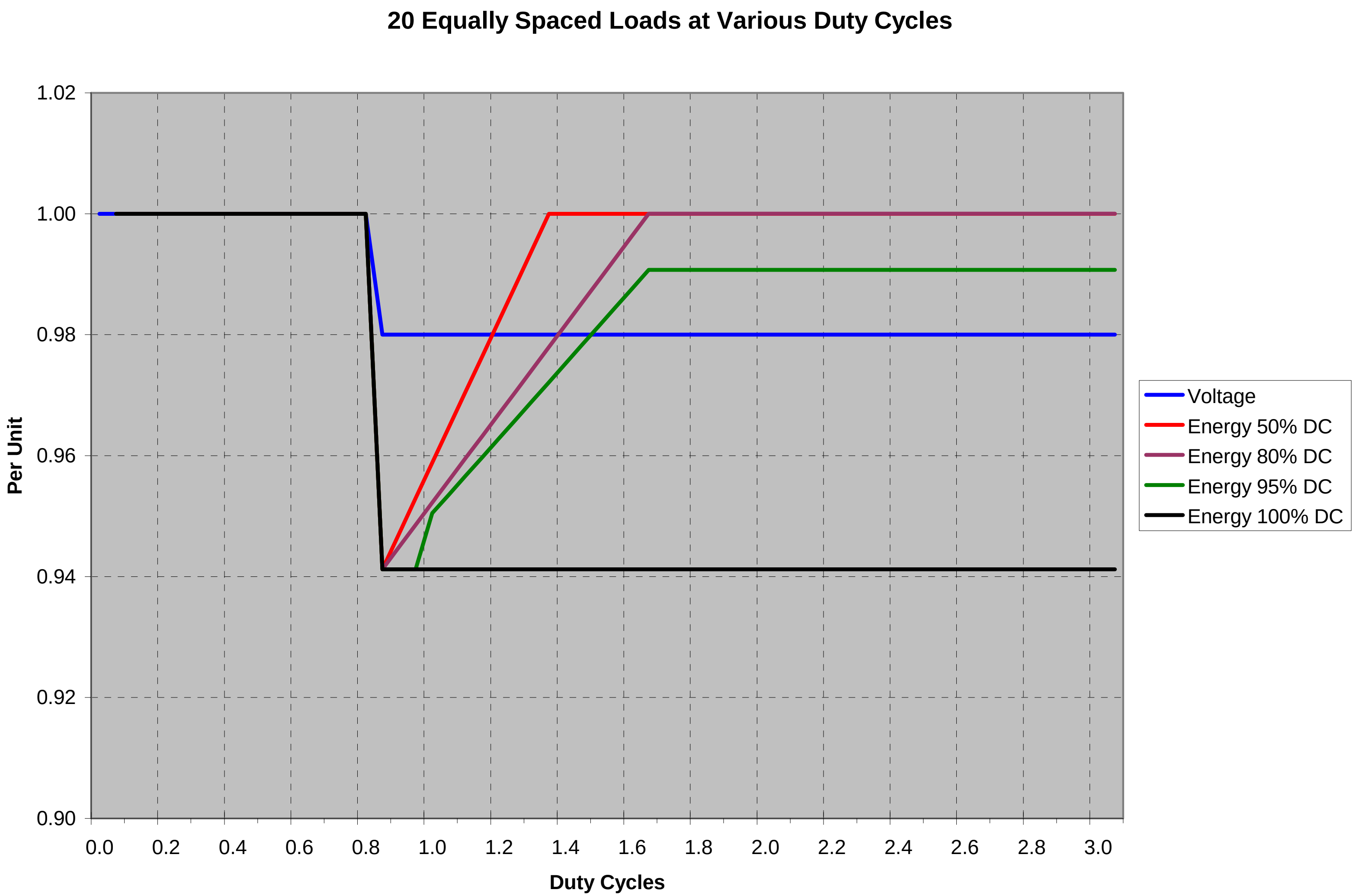


This may also apply to computers, motors drives, HVAC, and other appliances.

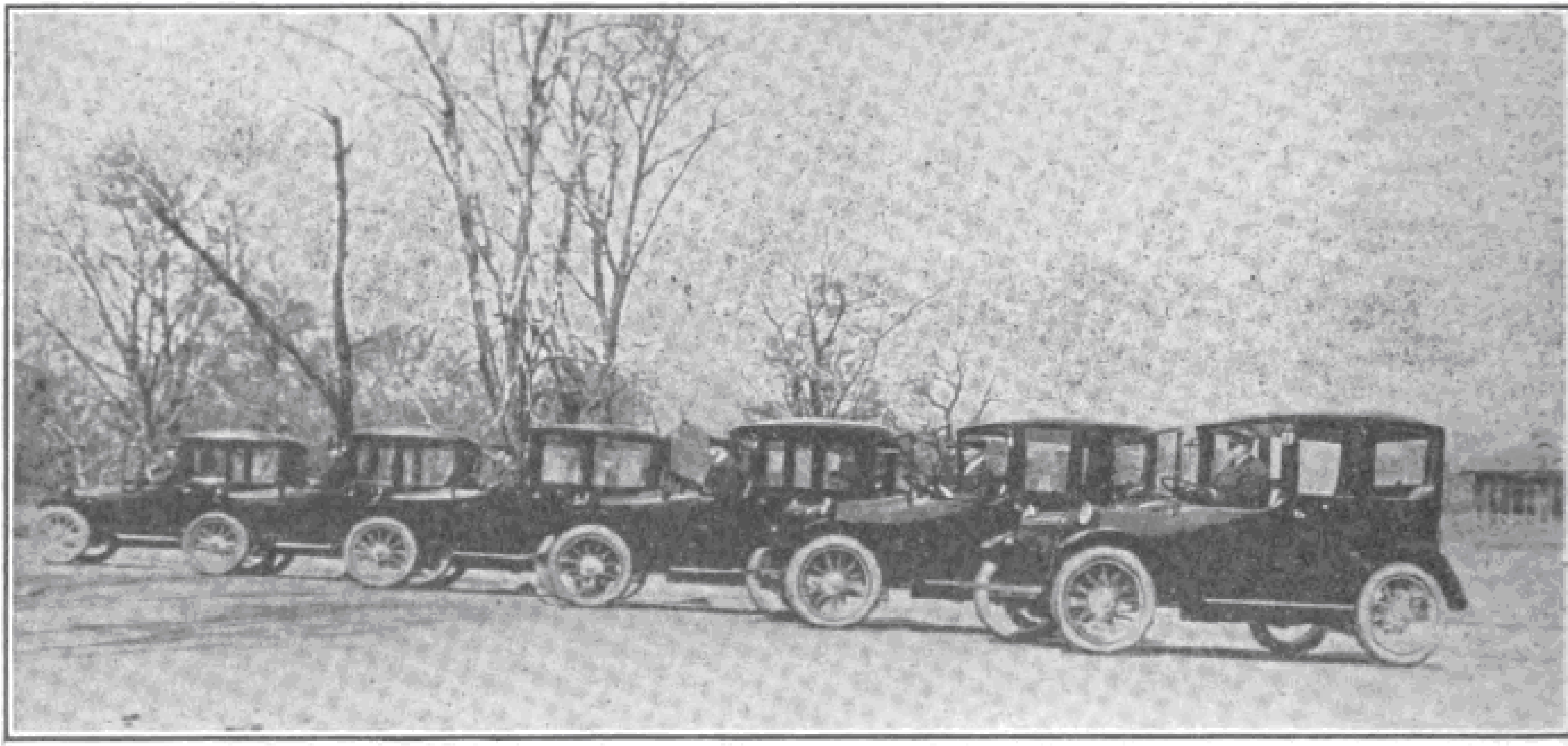
Thermostat response resistive load

	Voltage																					Energy 50% DC
0.00	1.00																					
0.05	1.00	1											1	1	1	1	1	1	1	1	1	1.000
0.10	1.00	1	1											1	1	1	1	1	1	1	1	1.000
0.15	1.00	1	1	1											1	1	1	1	1	1	1	1.000
0.20	1.00	1	1	1	1											1	1	1	1	1	1	1.000
0.25	1.00	1	1	1	1	1											1	1	1	1	1	1.000
0.30	1.00	1	1	1	1	1	1											1	1	1	1	1.000
0.35	1.00	1	1	1	1	1	1	1											1	1	1	1.000
0.40	1.00	1	1	1	1	1	1	1	1											1	1	1.000
0.45	1.00	1	1	1	1	1	1	1	1	1											1	1.000
0.50	1.00	1	1	1	1	1	1	1	1	1	1											1.000
0.55	1.00		1	1	1	1	1	1	1	1	1	1										1.000
0.60	1.00			1	1	1	1	1	1	1	1	1	1									1.000
0.65	1.00				1	1	1	1	1	1	1	1	1	1								1.000
0.70	1.00					1	1	1	1	1	1	1	1	1	1							1.000
0.75	1.00						1	1	1	1	1	1	1	1	1	1						1.000
0.80	1.00							1	1	1	1	1	1	1	1	1	1					1.000
0.85	0.98								0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941				0.941
0.90	0.98								0.059	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941			0.947
0.95	0.98									0.118	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941		0.953
1.00	0.98										0.176	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.959
1.05	0.98	0.941										0.235	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.965
1.10	0.98	0.941	0.941										0.294	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.971
1.15	0.98	0.941	0.941	0.941										0.353	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.976
1.20	0.98	0.941	0.941	0.941	0.941										0.412	0.941	0.941	0.941	0.941	0.941	0.941	0.982
1.25	0.98	0.941	0.941	0.941	0.941	0.941										0.47	0.941	0.941	0.941	0.941	0.941	0.988
1.30	0.98	0.941	0.941	0.941	0.941	0.941	0.941										0.529	0.941	0.941	0.941	0.941	0.994
1.35	0.98	0.941	0.941	0.941	0.941	0.941	0.941	0.941										0.588	0.941	0.941	0.941	1.000
1.40	0.98	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941										0.588	0.941	0.941	1.000
1.45	0.98	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941										0.588	0.941	1.000
1.50	0.98	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941										0.588	1.000
1.55	0.98	0.588	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941										1.000
1.60	0.98		0.588	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941	0.941									1.000

Load returns faster for short Duty Cycle



Electric taxi cab



Fleet of Electric Cabs in Operation in St. Louis.

National Electric Light Association, Jan-Dec 1917

Future load challenges

- Efficiency drives more solid state controllers
- Harmonic requirements often force “power factor corrected” electronics
- Broader adoption of IEC standards and designing for world markets
  - Voltage: 100 – 240 V ~
  - Frequency: 50 – 60 Hz
- May not be as responsive to CVR
- May also not be as responsive to frequency, thus making the grid a little less stable

Motor loads

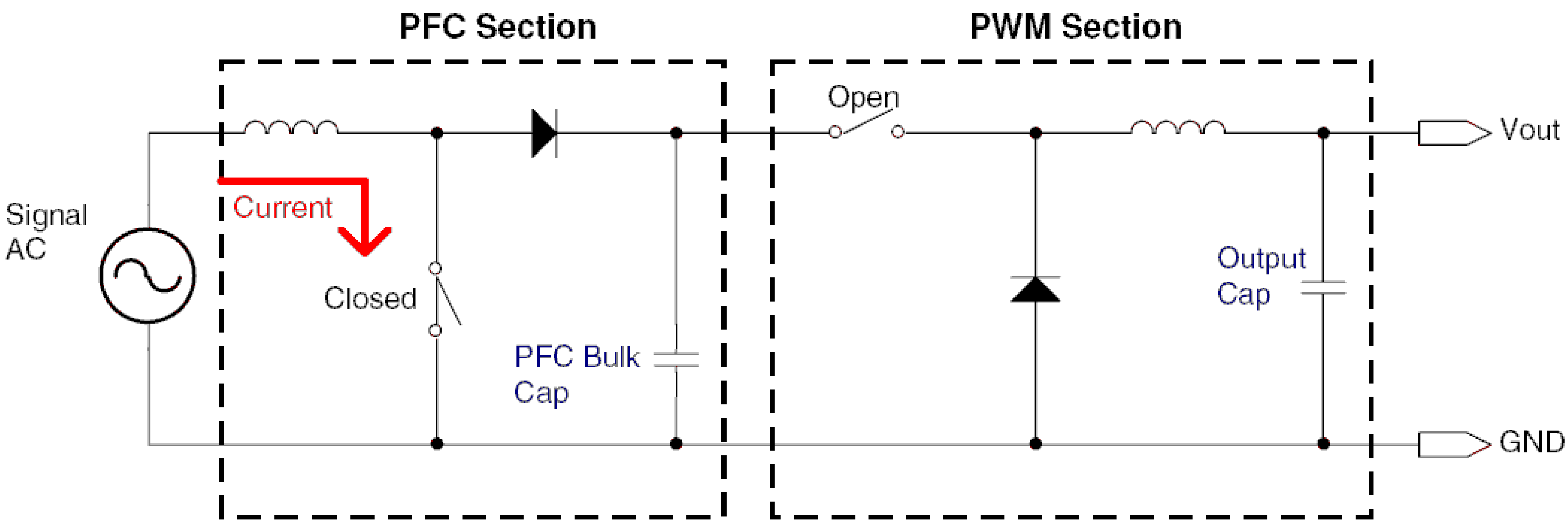
- Old systems
  - Constant standard speed motors
  - Dampers to control air flow
  - Valves to control air flow
  - Great opportunity for savings when motors underutilized
- New systems
  - Solid state controls ahead of motor
  - Control input/output power
  - Unresponsive to voltage and frequency

A solid state – more IEC influence

- Power factor correction (PFC) has been implemented for some time and is highly driven by regulations. It got a boost in power supplies in 2001, when the International Electrotechnical Commission (IEC) standard 61000-3-2 went into effect in Europe. This specification required new electronic equipment consuming more than 75W to meet certain standards for harmonic content, which basically required the use of PFC. Britain, Japan and China soon adopted similar standards, and any company selling equipment into these regions needed to meet these requirements. No similar requirements have gone into effect for North America, although PFC can help power supply manufacturers meet current North American energy efficiency standards.

  The total worldwide market for PFC (both passive and active) is expected to be approximately 1.3 billion units in 2006, increasing to 2.2 billion units in 2011, a compound annual growth rate of 11.4%.

The newer approach



This boost converter allows the circuit to draw power at lower portions of voltage wave and allows a broader range of acceptable voltages

More detail- one of many circuits

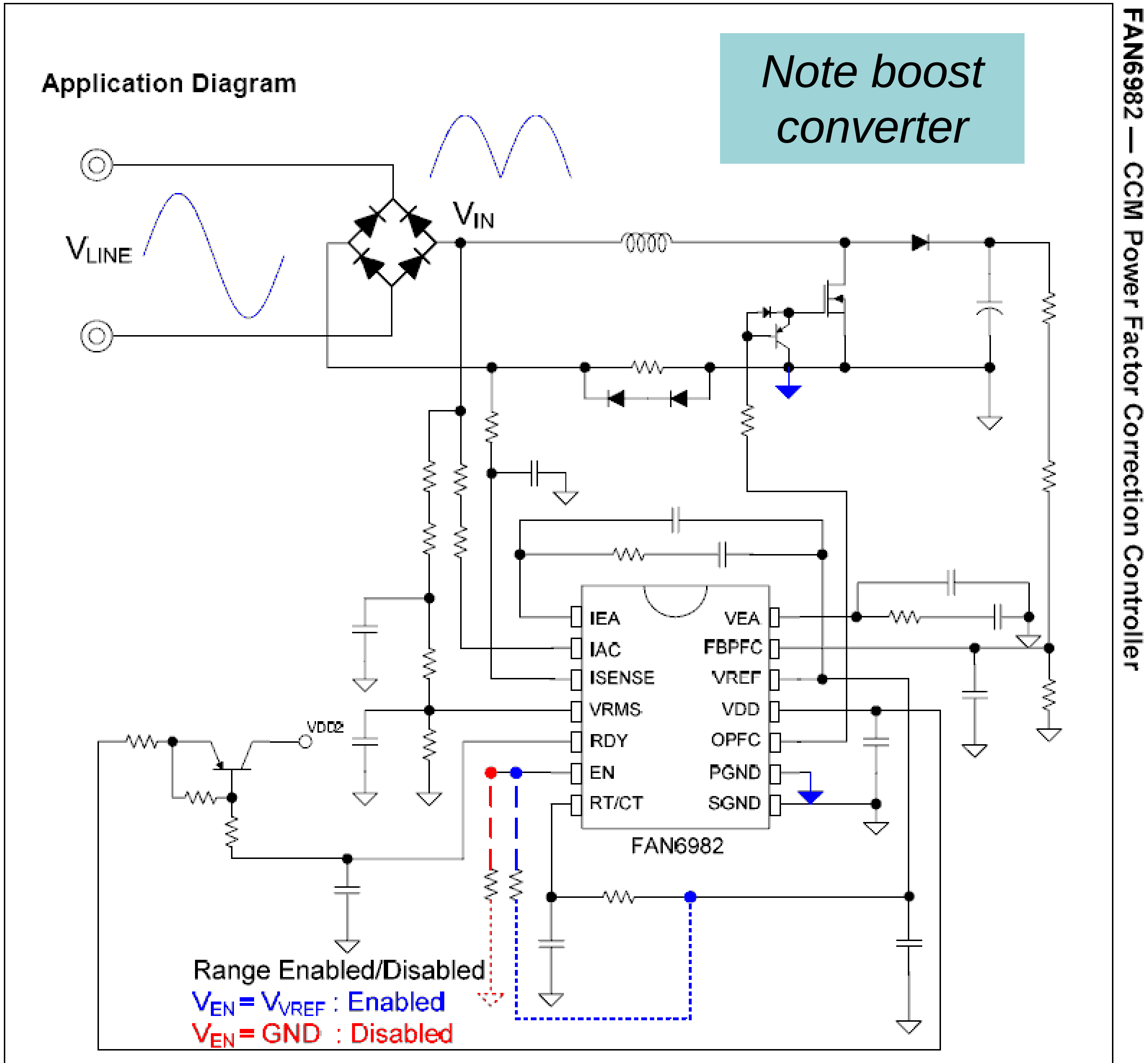
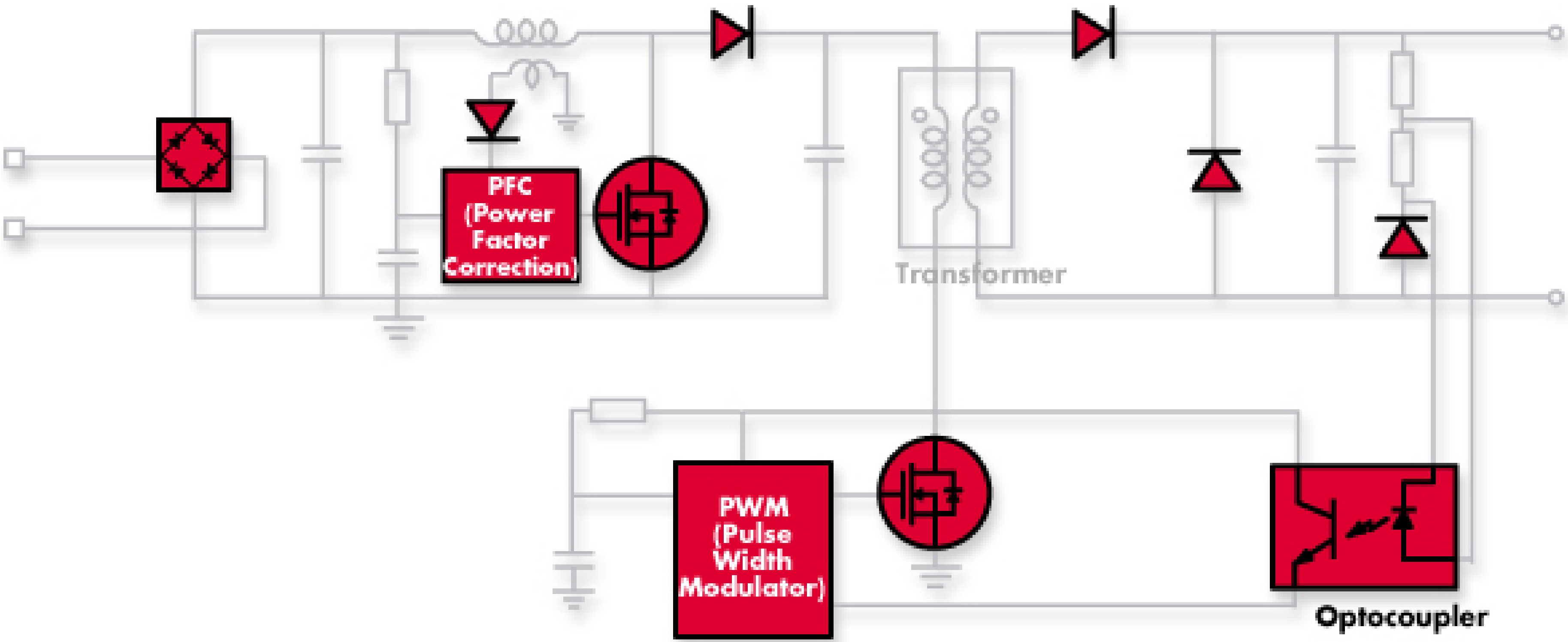


Figure 1. Typical Application

Another flavor

Note boost converter



Modern power supply characteristics

Check your computer "brick"

Voltage: 100 – 240 V ~
Frequency: 50 – 60 Hz

Some with "CE" mark

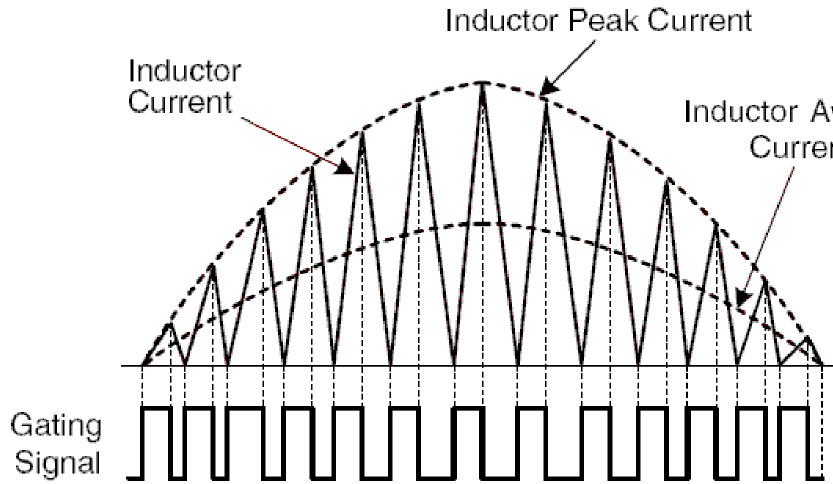


Figure 9. Discontinuous mode of operation

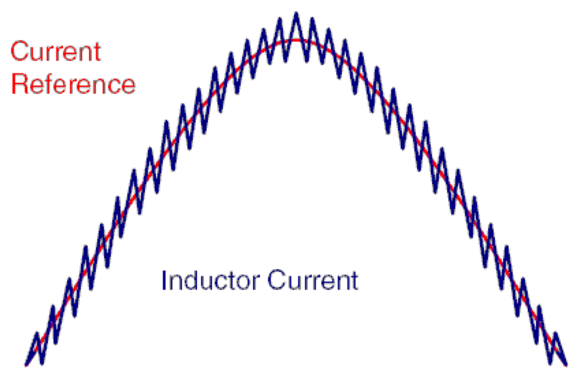


Figure 15. Typical Average Current Mode Waveform

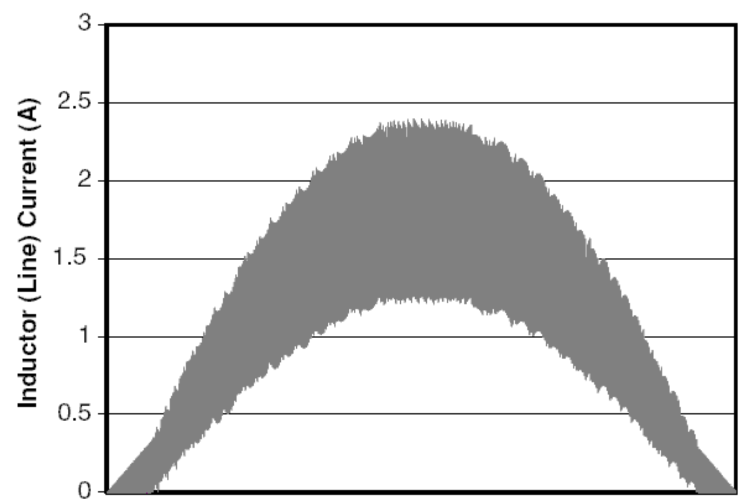
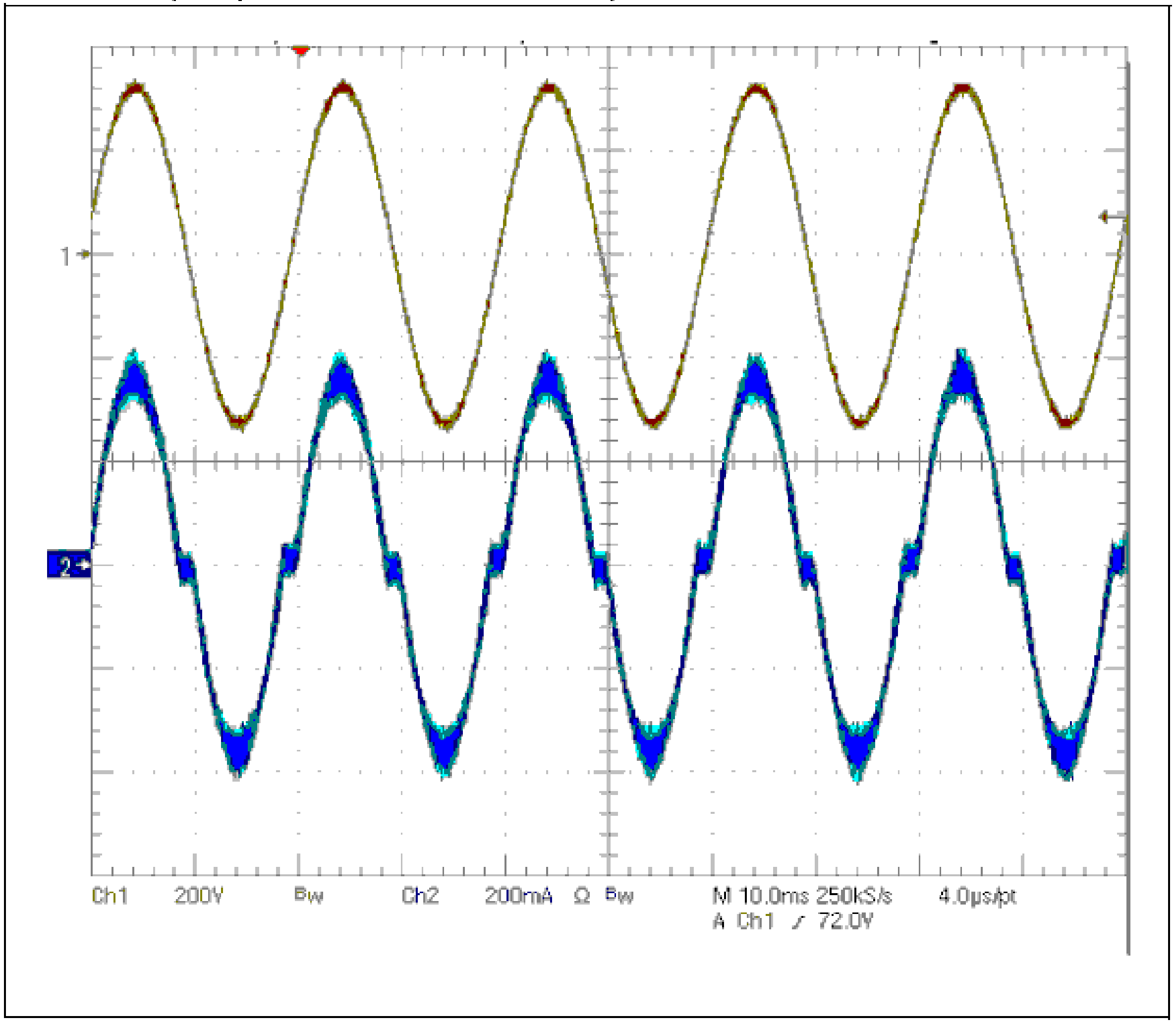


Figure 10. Continuous Mode of Operation

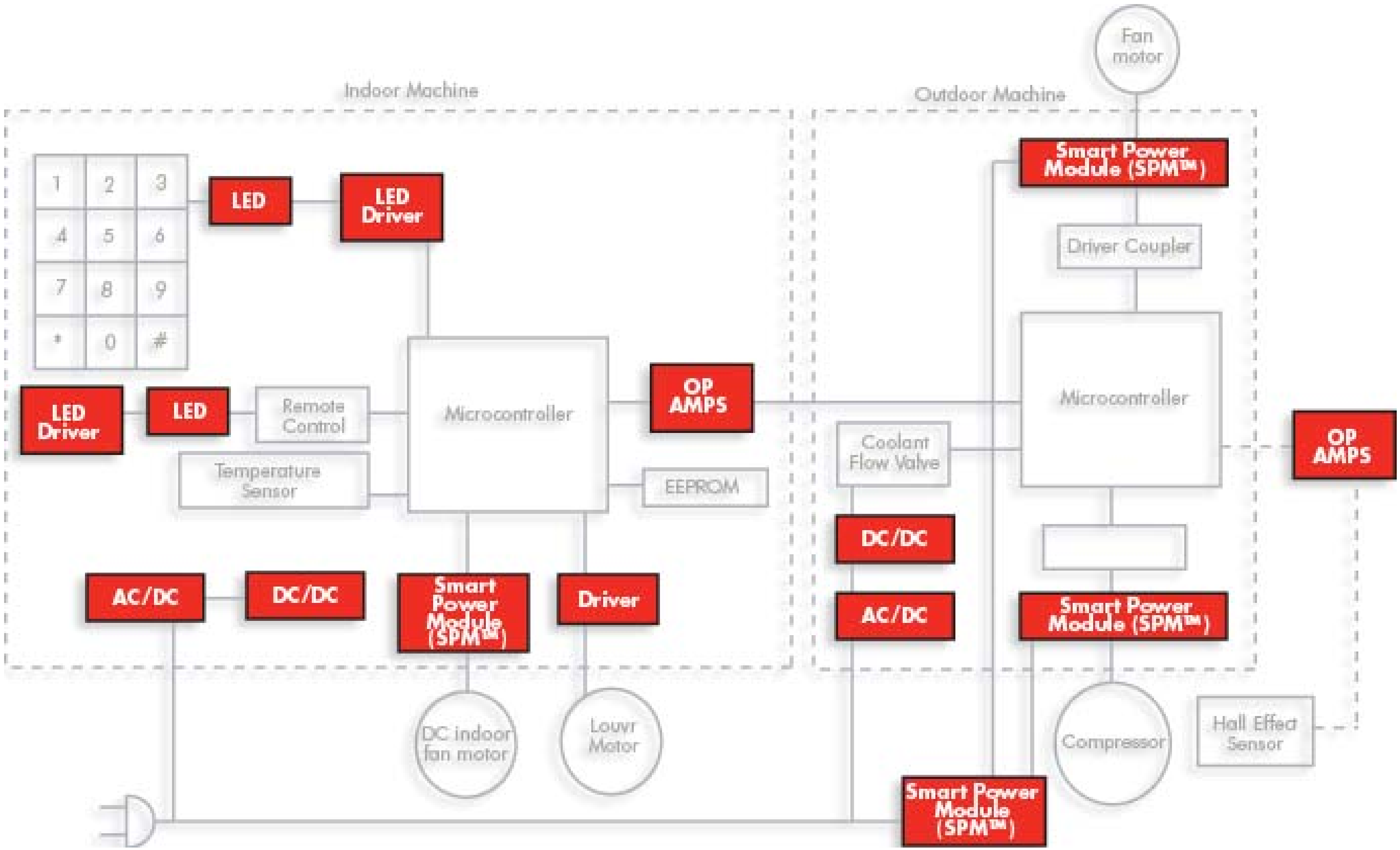
Ballast

Figure 4. Input voltage & current with modified EMI filter (compared to STEVAL-ILB002V1) PF = 0.994 THD = 10.3%



Note: Brown = Mains voltage, Blue = Input current.

Efficiency pressures on HVAC



Roll your own circuits for the future

Product	Watts	CVR Factor	Units	Total Power	Weighted CVR
Plasma TV (Sony)	416	0.08	200	83,200	0.003
Old 12 inch TV	35	1.38	45	1,575	0.001
1998 TV ~ 30 inch	91	0.05	30	2,730	0.000
Incandescent	150	1.55	1,000	150,000	0.117
LED Standard Base	2.9	1.50	10	29	0.000
CFl Standard Base	11.2	1.47	1,000	11,200	0.008
Twin 40W Fluorescent	89	0.71	400	35,600	0.013
1 HP Dust colector	771	0.42	100	77,100	0.016
100 W Resistor	100	1.90	5,000	500,000	0.480
Constant Power	100	0.00	10,000	1,000,000	0.000
Space Heater Uncontolled	637	1.88	75	47,775	0.045
42 inch LDC TV (Toshiba)	234	0.00	300	70,200	0.000
Total Power	**2,637**			**1,979,409**	**0.68**

- Have some stuff of what Duke was doing a month ago

Duke IVVC Initiatives in 2010

- EPRI Green circuits
  - Mc Alpine 2410 and 2412 alternating
  - Marietta 1201 and 1202 alternating
  - Noblesville 8th street
    - Circuits 1203, 1204, and 1205 are controlled
    - Circuits 1211, 1213, 1215 are the reference
- GE
  - Ferguson circuits 43 & 44 are controlled
  - Ferguson circuits 41 & 42 provide the reference
- AREVA
  - Avon South circuits 1251 and 1253 are controlled
  - Avon South circuits 1252, 1254, and 1256 will be modeled for reference but not controlled

McAlpine and Marietta (EPRI)

- Introduce resistance compensation in substation line drop compensator to lower voltage based on light load.
- Alternate LTC settings by remote control
- Alternate circuits between normal and CVR control
- Remote monitoring of voltages at locations expected to be low through capacitor controls
- Line capacitors correct power factor
- Early observations
  - One year of data showing more savings in summer than winter
  - One known customer concern near Mc Alpine substation
    - Transformer 2.5% off nominal taps
    - Possible excess voltage drop in facility

Ferguson (GE)

- *Local automatic control in the substation* manages substation voltage and capacitors
- Beckwith capacitor controllers – one circuit using GE MDS communication, the other Verizon
- Jim Lemke algorithm
- Flatten voltage first using estimated rise at each capacitor
- Then push as low as we feel comfortable using estimate drop from monitored points to lowest point
- Secondary feedback loop for VAR management
- Very similar to Noblesville

Noblesville (EPRI) (Cooper/Cannon)

- *Central server automatic control* manages substation voltage and capacitors
- Cooper capacitor controls IDEN communication
- Jim Lemke algorithm
- Flatten voltage first using estimated rise at each capacitor
- Then push as low as we feel comfortable using estimate drop from monitored points to lowest point
- Secondary feedback loop for VAR management
- Very similar to Ferguson

Avon South (AREVA)

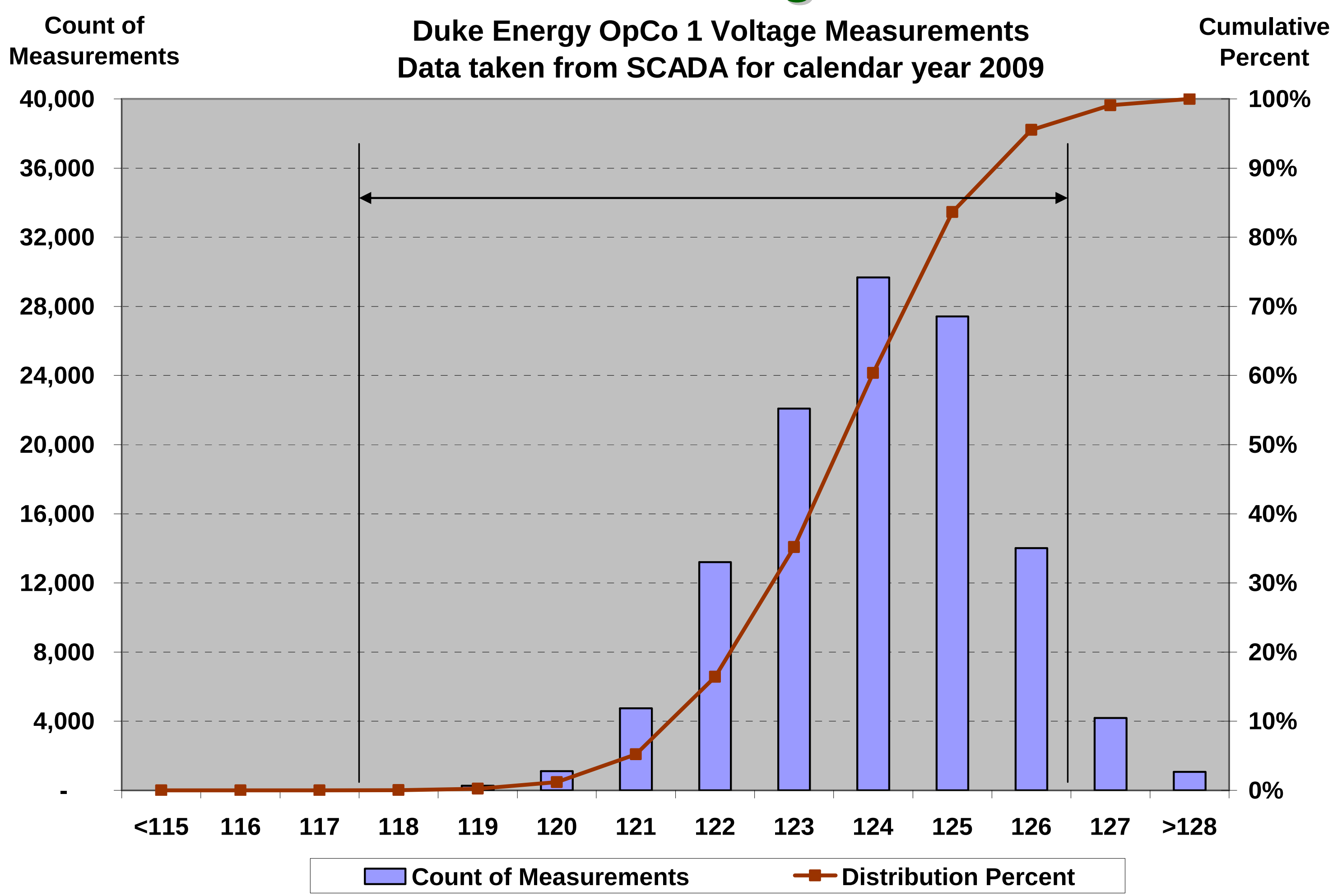
- Master control of substation voltage and capacitors is within Energy Management System
- Includes single phase load flow analysis
  - Better estimate of unmonitored voltage points at all times.
  - Should be able to push voltage a little lower
  - More opportunities to optimize
    - Energy consumption, Losses, Voltage
- Beckwith controls with Verizon communication
- Fallback mode for loss of master – auto adaptive capacitor control on voltage priority

Solid verification required

- Looking for about 1% changes on daily load curves that might move 30-40% or more
- Two modes to test
  - "Normal operation" savings at bottom of Range A
  - "Emergency operation" need to push into Range B
- Improve ability to build accurate models
- Alternate turning system on and off
  - Turn on for a few hours up to a day, then off, then on
  - Single circuit on one day & off the next
  - Alternate between two circuits or compare to ref
  - Compare to a baseline of adjacent circuits

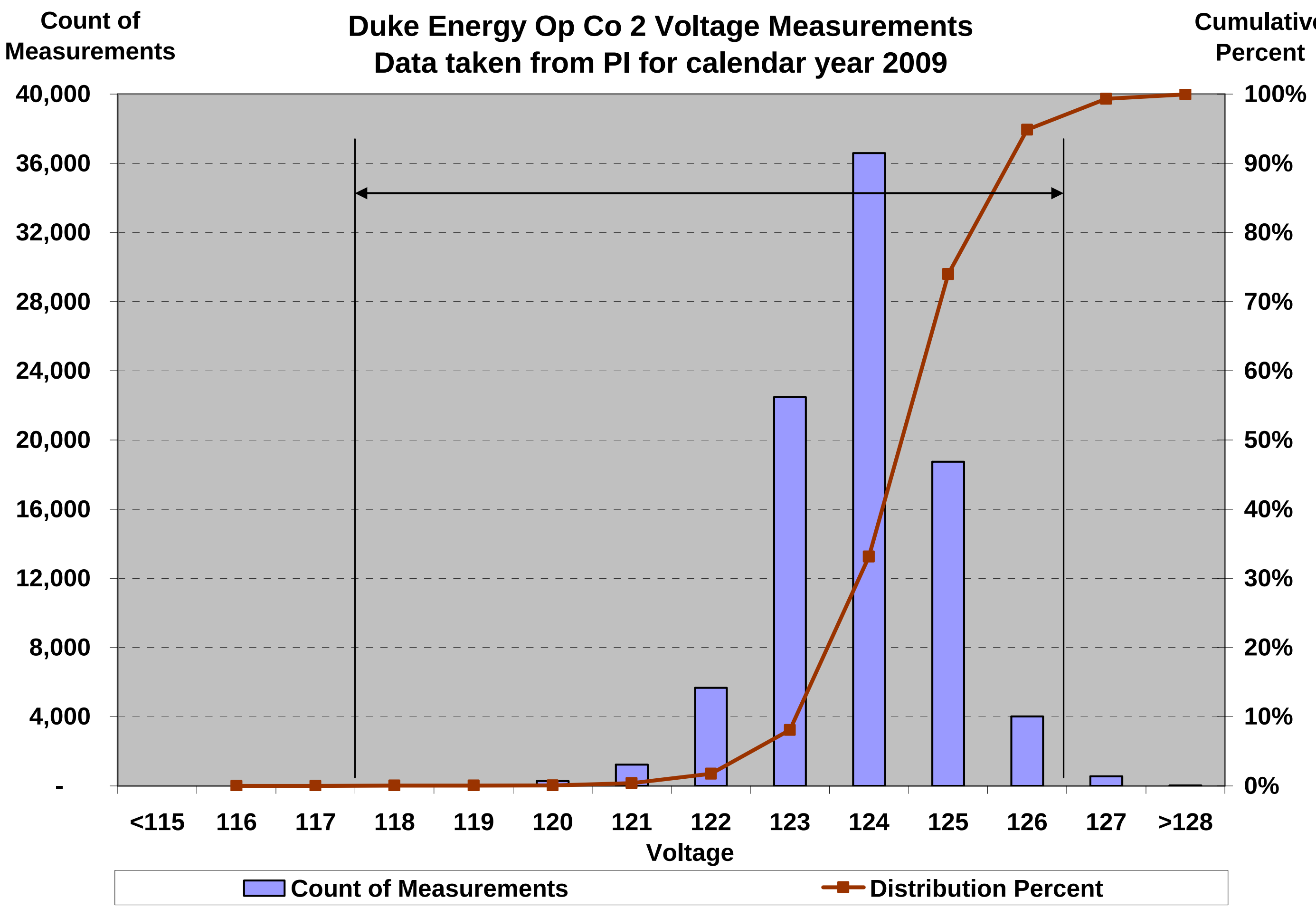
Op Co 1 Preliminary Baseline

- A little over 124 volt average



Op Co 2 Preliminary Baseline

- Just under 124 volts average



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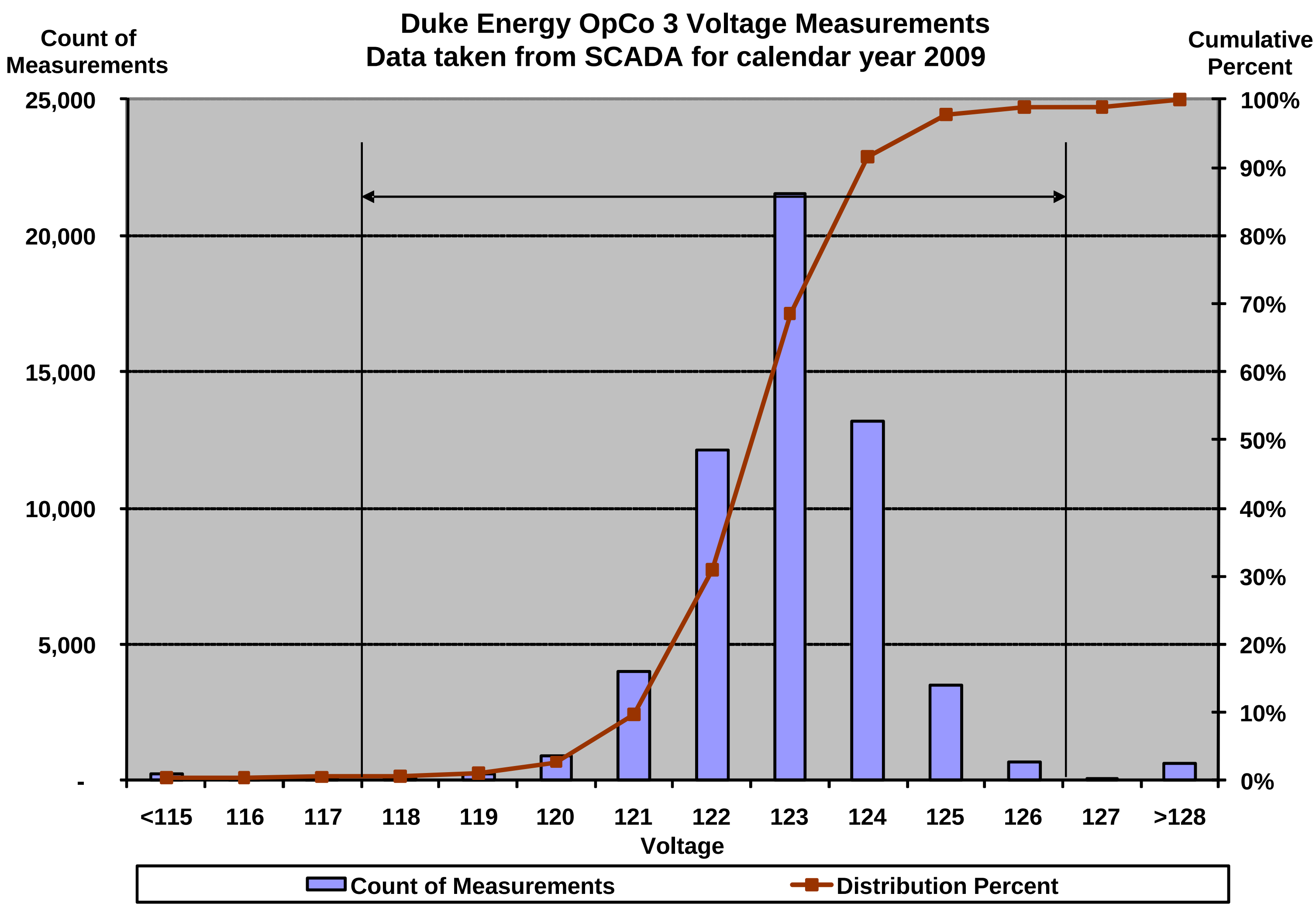
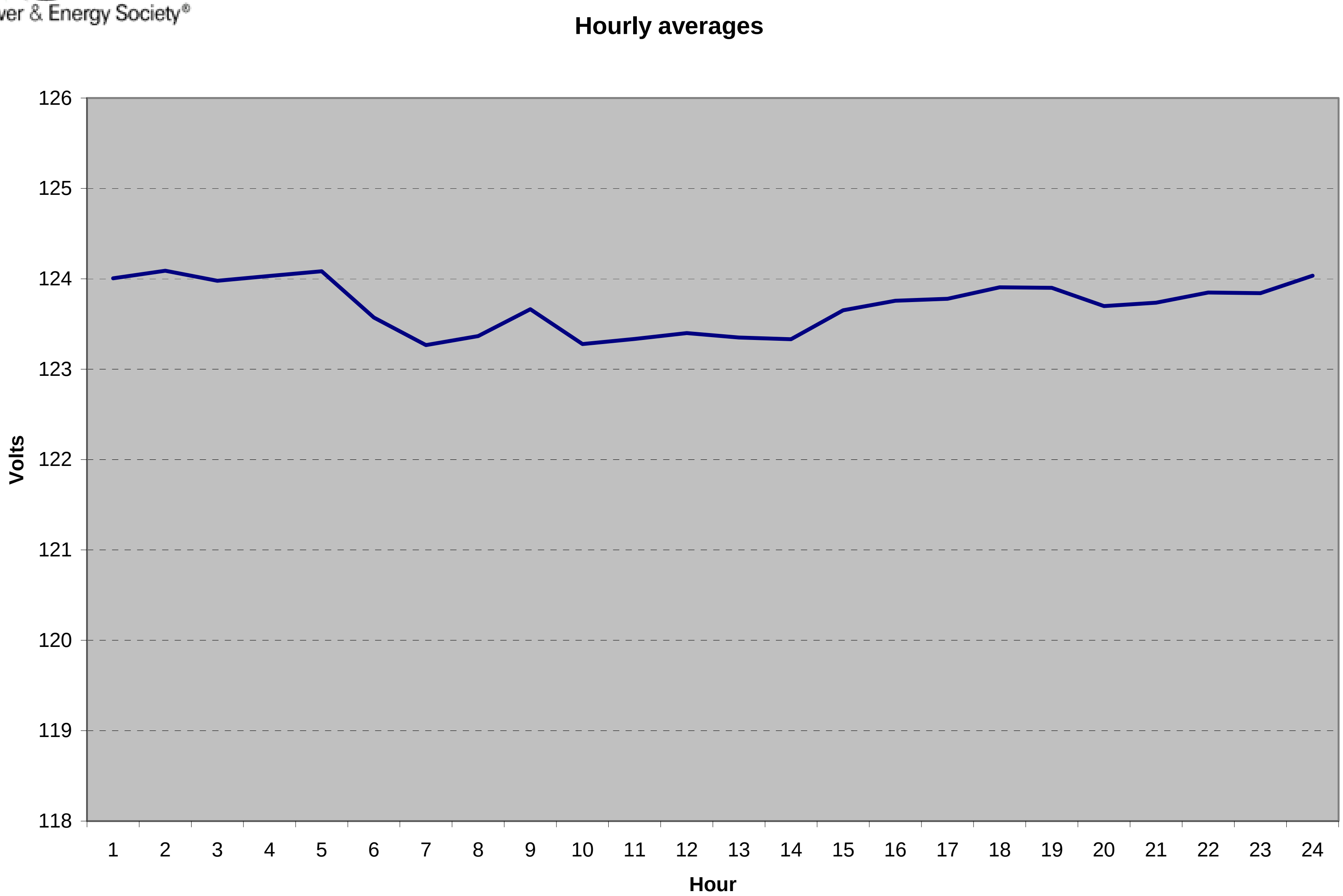
Op Co 3 Preliminary baseline

- About 123 volts average



Annual hourly averages for one Op Co



More on thermostat

- HVAC clogged filters

Next steps

- Carefully evaluate the overall IVVC opportunity
- Duke is in an excellent position to evaluate a host of strategies
- Understand the incremental value of each approach
- Develop solid verification strategies for continuing favorable regulatory treatment
- Learn how smart we really need to be
- Be as smart as we need to be to deliver maximum value

Questions?

Thank you

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