Energy Efficiency: Motors and Smart Meters

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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

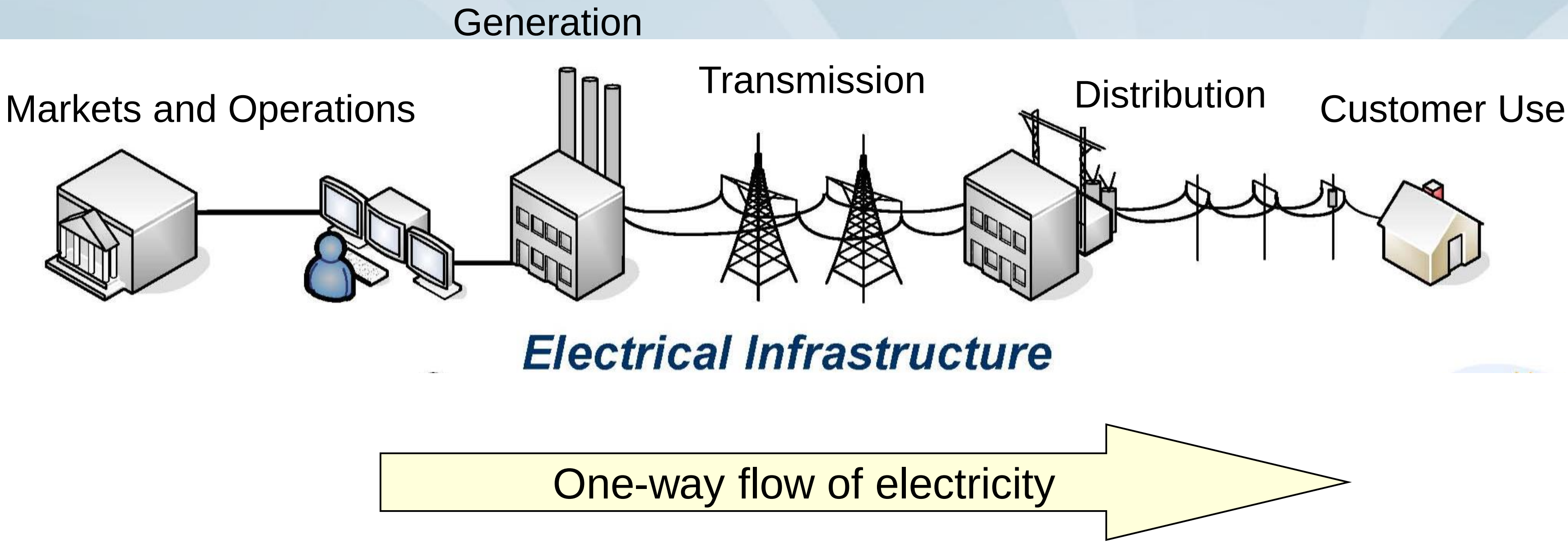
Efficiency and Greenhouse Gas Reductions

- Labeling Programs for appliances
- Efficiency standards for appliances (mandatory & voluntary)
- Regulation or incentives to replace inefficient lighting
- Regulations encouraging renewable generation
- Efficiency standards for:
  - Motors
  - Distribution Transformers

Methods for Reduction of Greenhouse Gases

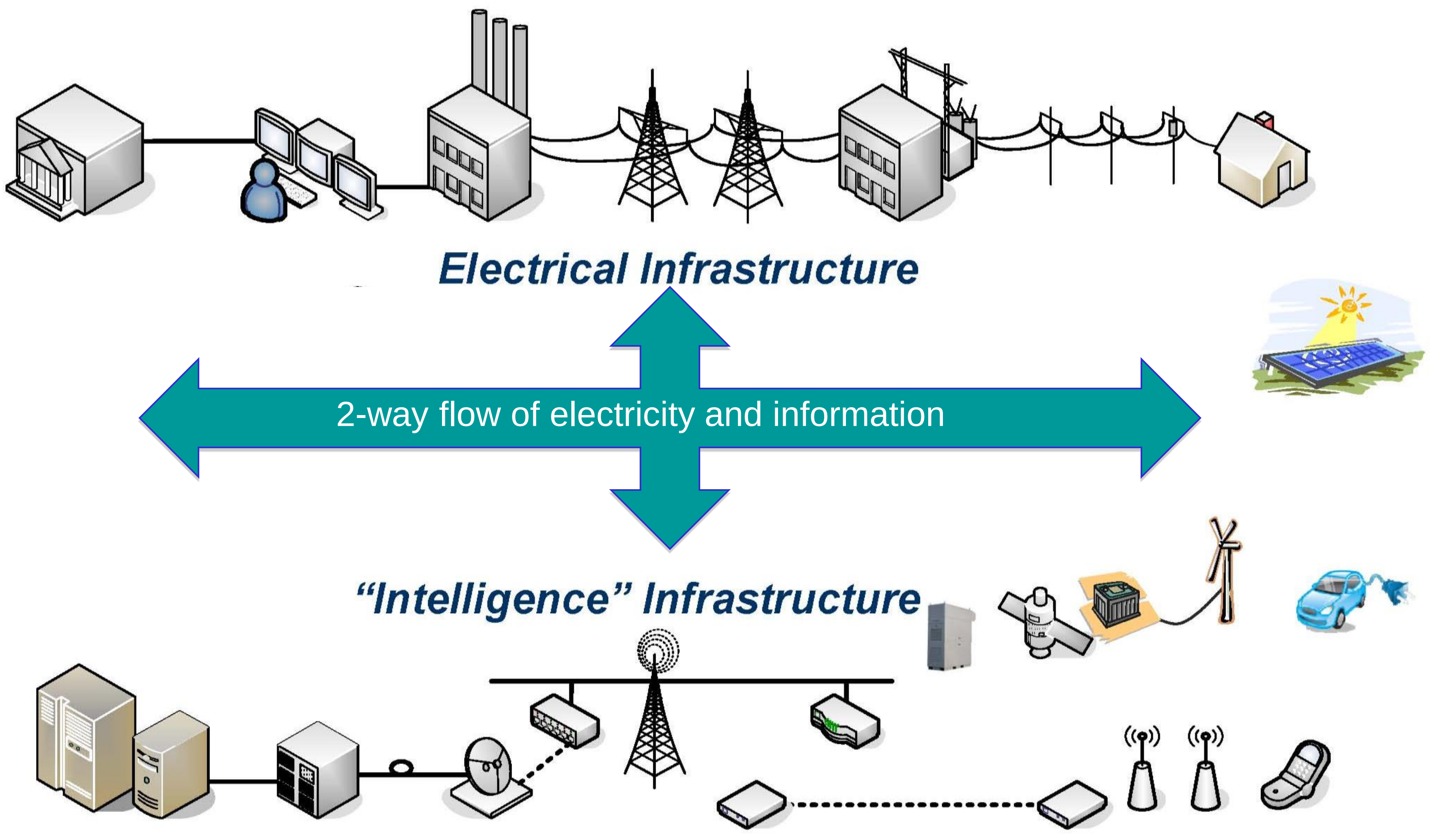
- Increasing renewable energy generation
- Encouraging Electric Vehicle Usage
- Efficient Building Standards – LEED
- Energy Usage Information
- Smarter Grids
- Distributed Energy Resources

Today's Electric Grid



- *Centralized, bulk generation, mainly coal and natural gas*
- *Responsible for 40% of human-caused CO_2 production*
- *Controllable generation and predictable loads*
- *Limited automation and situational awareness*
- *Lots of customized proprietary systems*
- *Lack of customer-side data to manage and reduce energy use*

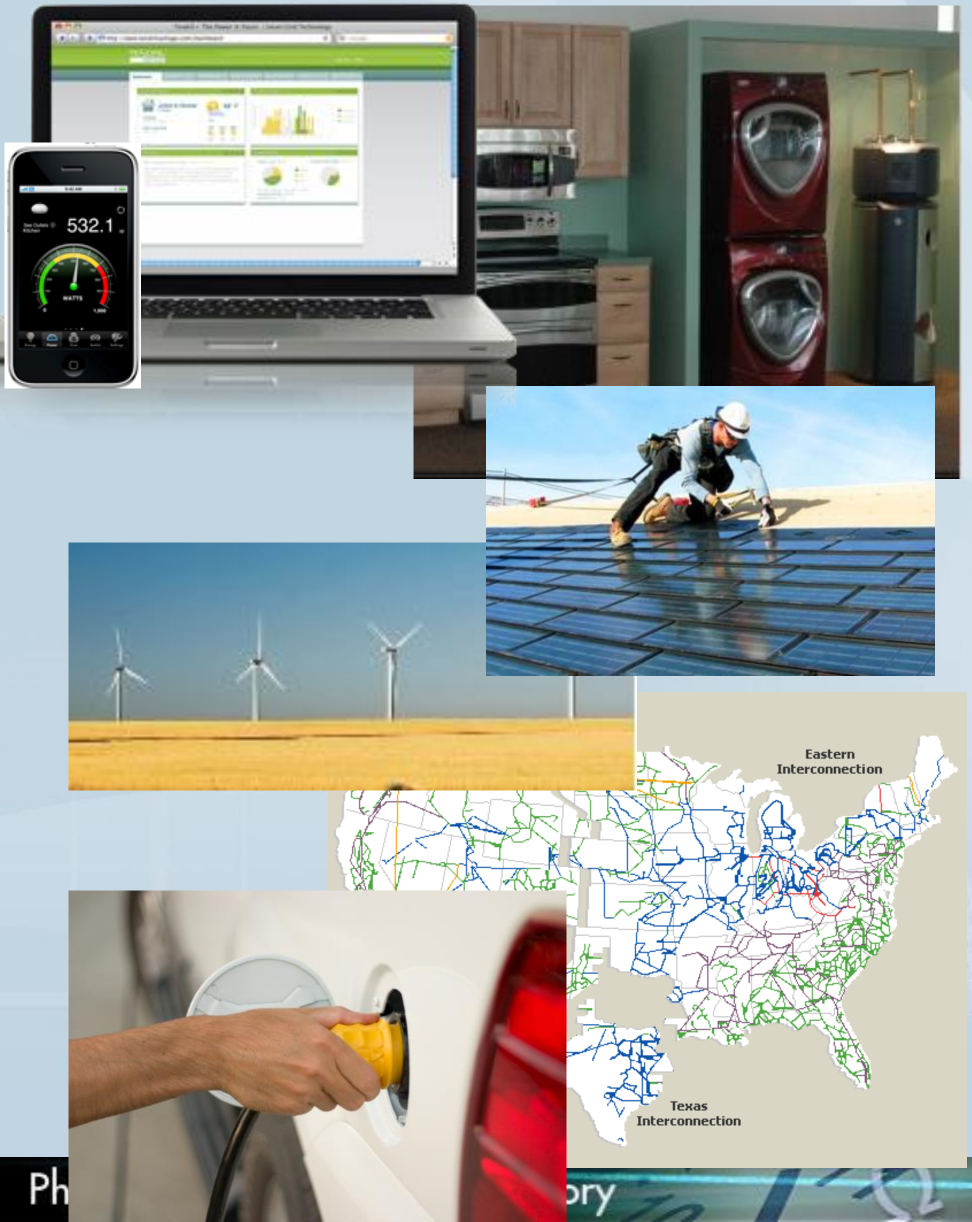
Smart Grid: The "Energy Internet"



Standards Provide a Critical Foundation

Graphics courtesy of EPRI

What is the Smart Grid?



The Smart Grid integrates information technology and advanced communications into the power system in order to:

- Increase system efficiency and cost effectiveness
- Provide customers tools to manage energy use
- Improve reliability, resiliency and power quality
- Enable use of innovative technologies including renewables, storage and electric vehicles

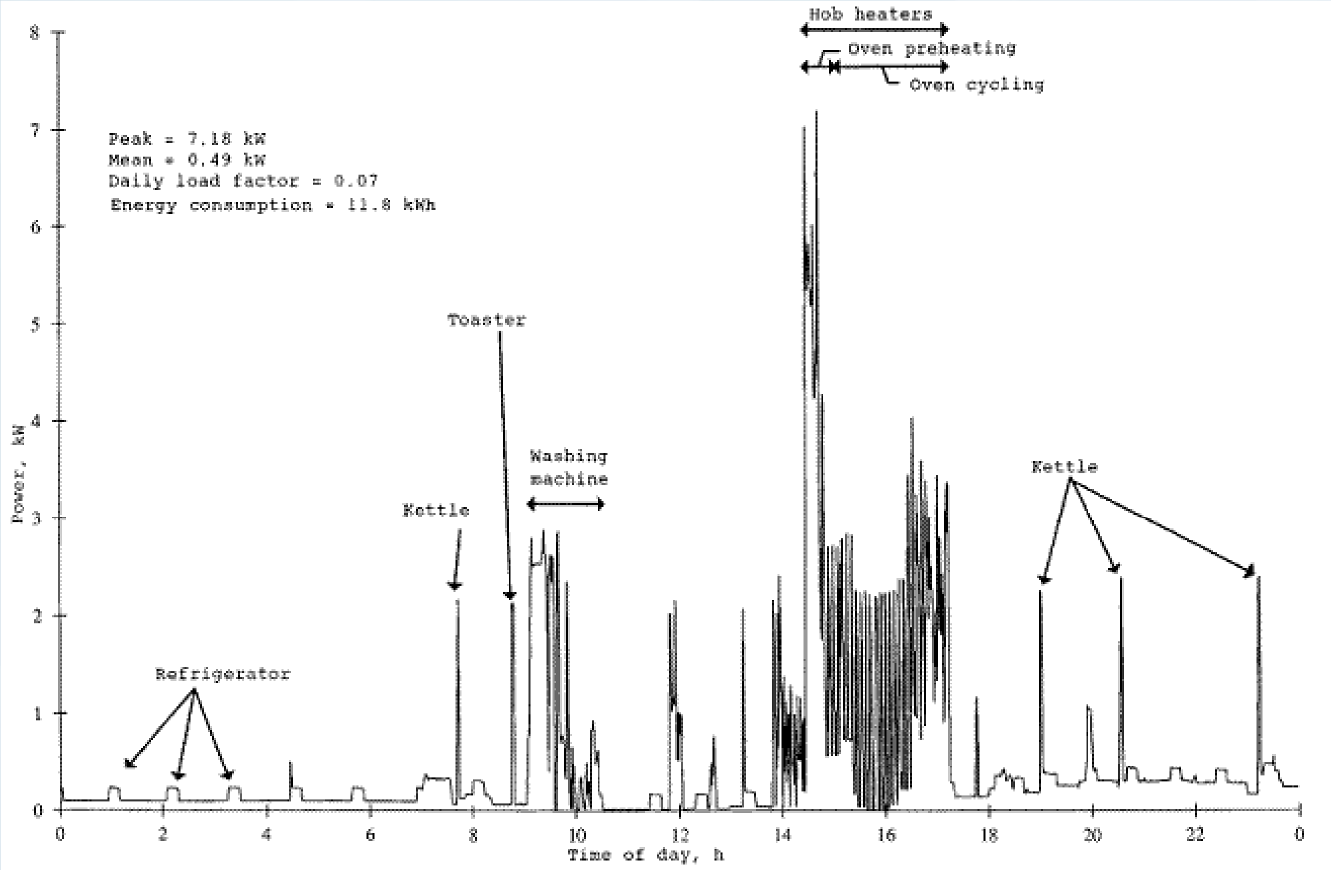
What Will the Smart Grid Look Like?

- High use of renewables – 20% – 35% by 2020
- Distributed generation and microgrids
- Bi-directional metering – selling local power into the grid
- Distributed storage
- Ubiquitous smart appliances communicating with the grid
- Energy management systems in homes as well as commercial and industrial facilities linked to the grid
- Growing use of plug-in electric vehicles
- Networked sensors and automated controls throughout the grid

Smart Meters

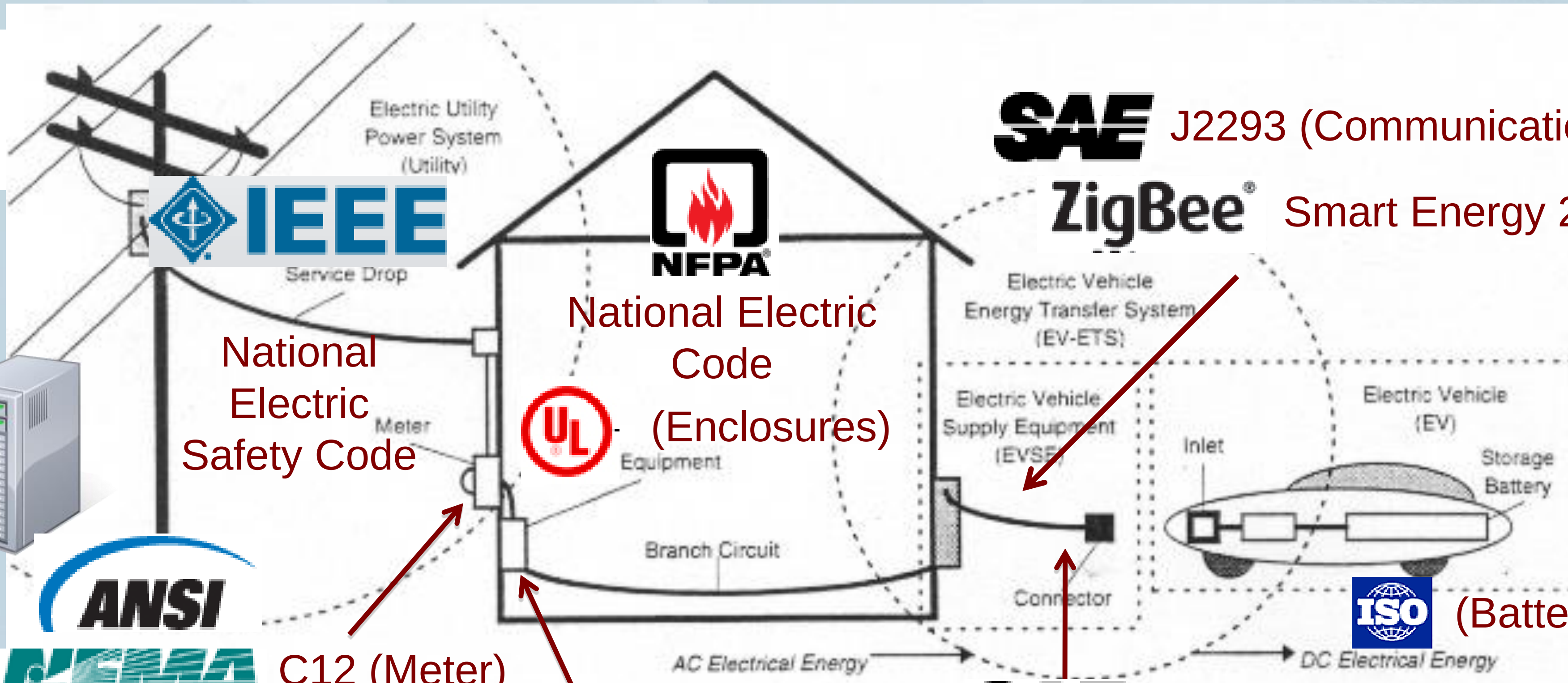
- Smart meters that provide near-real time usage data
- Time of use and dynamic pricing
- Distribution automation and efficiency
- Energy management systems in homes as well as commercial and industrial facilities linked to the grid
- Growing use of plug-in electric vehicles
- Phase Identification

Advanced Metering Interface -AMI



Power Usage to Personal Activity Mapping

Example: Electric Vehicles Require Many Standards



SAE J2293 (Communication)

ZigBee Smart Energy 2.0

NFPA National Electric Code

UL (Enclosures)

National Electric Safety Code

ANSI NEMA C12 (Meter)

SAE J1772 (Connector)

IEEE 1547 (Distributed energy interconnection)

IEC

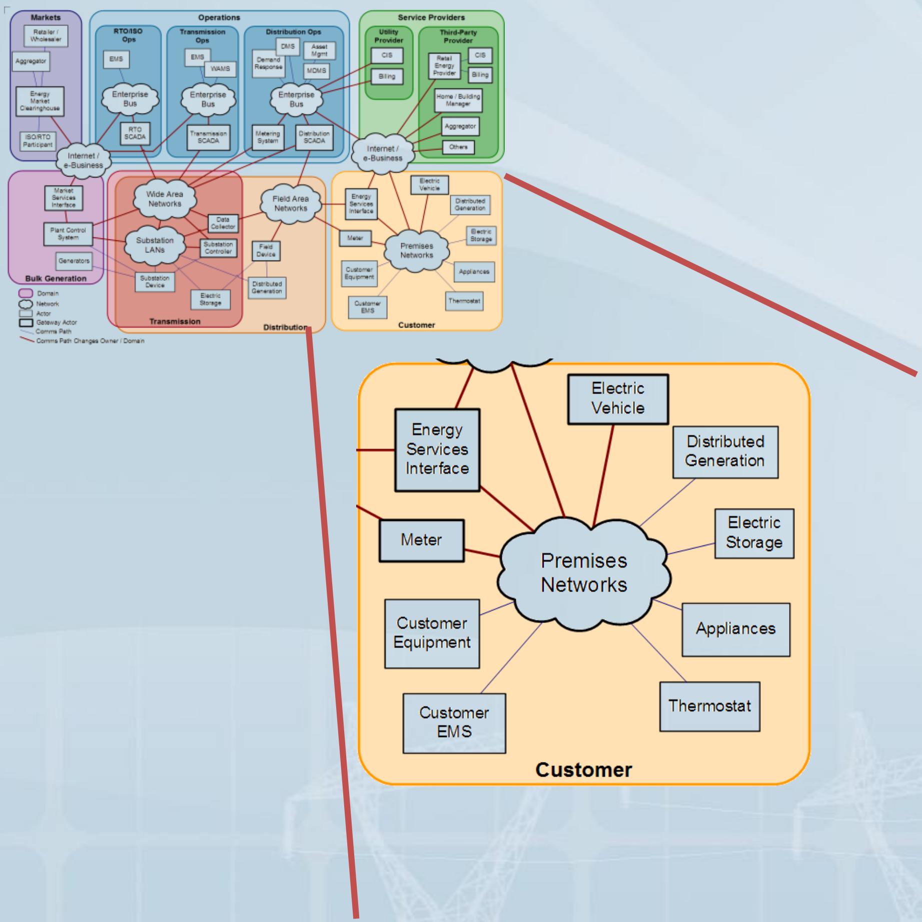
ISO (Battery)

IEC 61850 and 61970/61968 Information models

NAESB OASIS Demand response & price signaling

Consumer Electronics Can Drive Innovation on Customer Side of the Meter

NIST Smart Grid Reference Model



- Home area network
- Energy services interface
- Home energy management systems/apps
- Controllers
- Displays
- Sub-metering devices
- Embedded smart grid-aware intelligence

Energy usage information driving energy reduction

- The Green Button initiative is an industry-led effort that responds to a White House call-to-action to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly and computer-friendly format. Customers are able to securely download their own detailed energy usage with a simple click of a literal "Green Button" on electric utilities' websites.

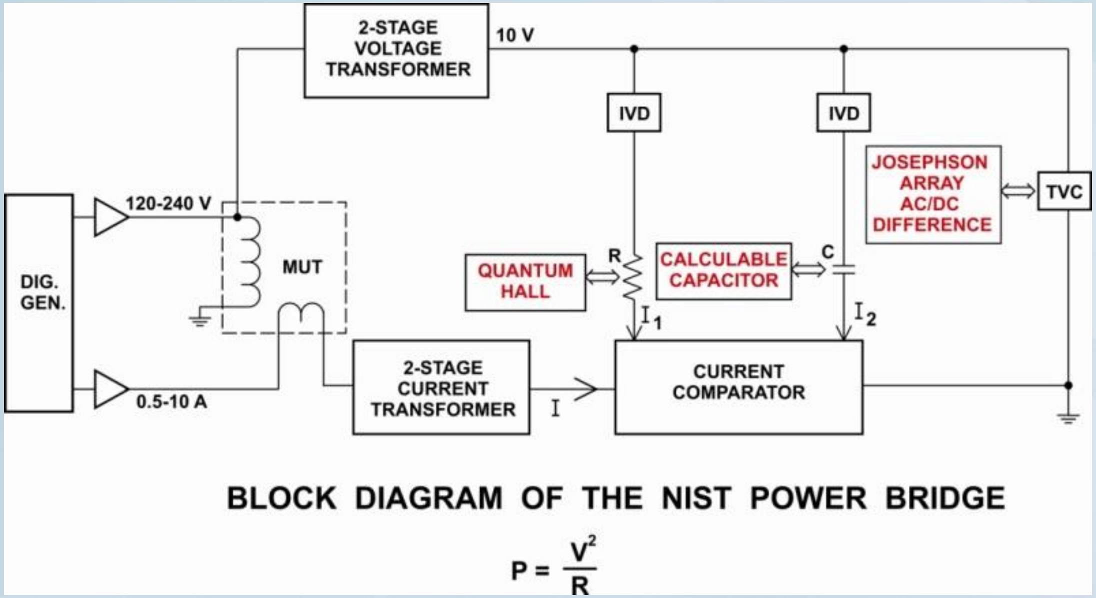
Green Button

- With their own data in hand, consumers can take advantage of a growing array of online services to help them manage energy use and save on their bills. Voluntary adoption of a consensus industry standard by utilities and companies across the country both enables and incentivizes software developers and other entrepreneurs to build innovative applications, products and services which will help consumers manager energy use by, for example, programming their home energy management devices, sizing and financing rooftop solar panels, and helping a contractor to verify their home energy savings more cost-effectively.
- Adoption of the Green Button data standard will also benefit utilities that receive numerous requests for data, are administering energy efficiency programs, are looking for avenues for greater customer engagement, and in many other ways.

Green Button

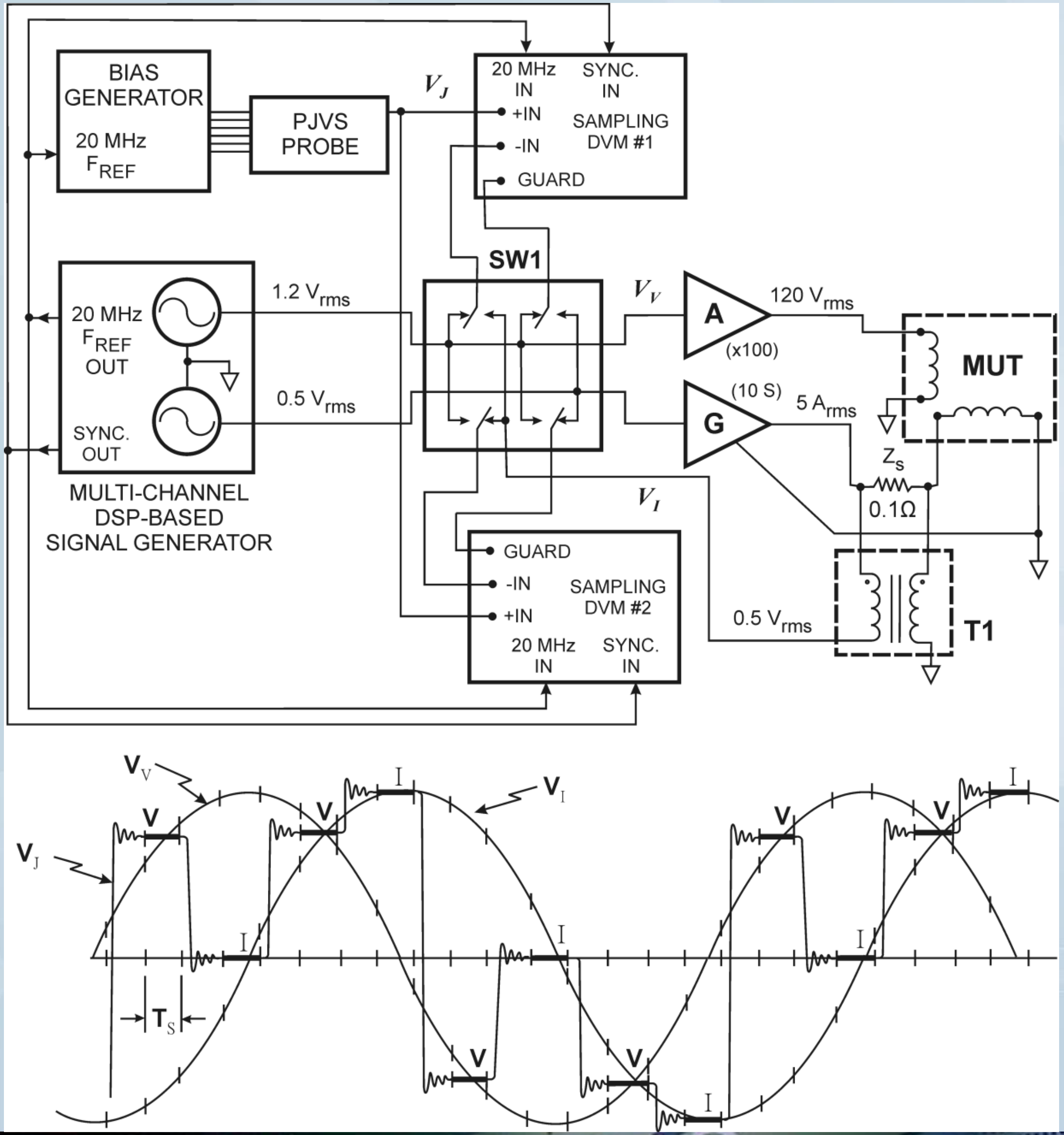
- The ESPI standard consists of two components: 1) a common XML format for energy usage information and 2) a data exchange protocol which allows for the automatic transfer of data from a utility to a third party based on customer authorization. All of the utilities that have committed to Green Button will implement the common XML data format in an easy to download manner.
- **What does Green Button data include?**
- The Green Button data standard is flexible enough to handle different types of energy data and time interval usage, and applications are being developed for both residential and commercial customers. The data can be provided in 15-minute, hourly, daily, or monthly intervals depending on what a utility decides to make available and what level of detail they are able to provide. The Green Button Initiative is not limited to utilities that have deployed smart meters that produce very detailed information about energy consumption, but also includes utilities that are able to provide only monthly billing data. The ESPI data standard can also be extended in the future to support natural gas and water usage information and other uses, and these options are being explored.
- **What is Green Button Connect My Data?**
- Many utilities are implementing *Green Button Download My Data* which means that the utility customer can download their own energy consumption data directly to their own computer, and if they so choose, upload their own data to a third party application. *Green Button Connect My Data* is a new capability which allows utility customers to automate the secure transfer their own energy usage data to authorized third parties, based on affirmative (opt-in) customer consent and control.

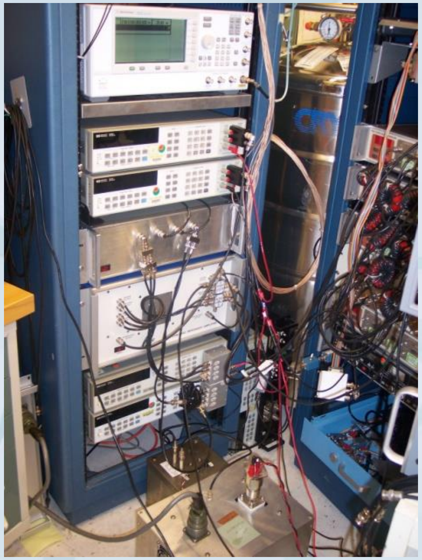
Power Bridge (32 years and going)



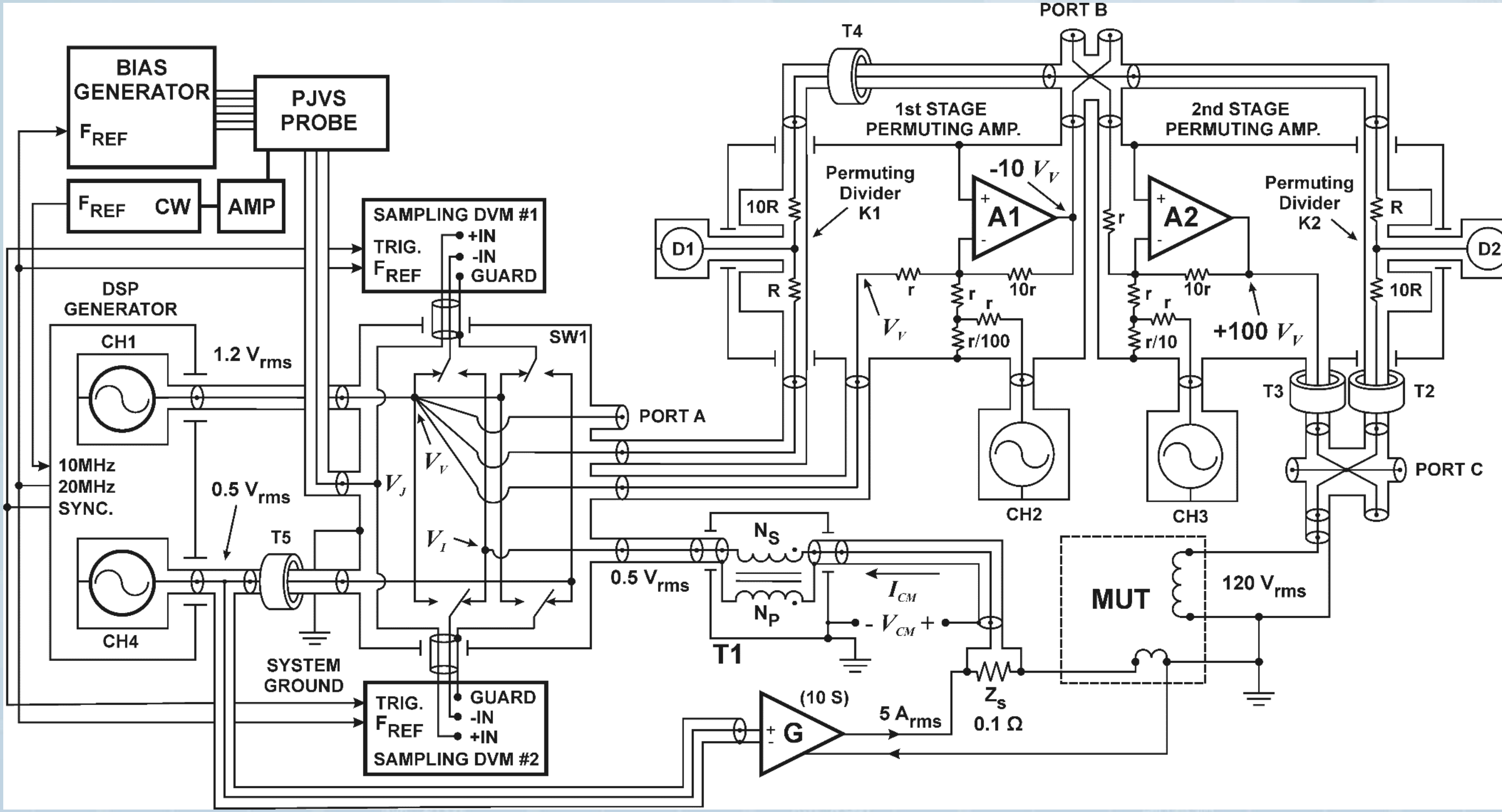
- Sinusoidal single frequency power measurement system
- Uses Voltage and resistance (at unity PF) to measure current

PJVS-Referenced Power Calibration Source





more detail…



BIAS GENERATOR
F_{REF}
PJVS PROBE
F_{REF} CW
AMP
SAMPLING DVM #1
TRIG.
F_{REF}
+IN
-IN
GUARD
DSP GENERATOR
CH1
1.2 V_{rms}
10MHz
20MHz
SYNC.
0.5 V_{rms}
T5
CH4
SYSTEM GROUND
SW1
PORT A
V_J
V_V
V_I
TRIG.
F_{REF}
GUARD
-IN
+IN
SAMPLING DVM #2
T4
PORT B
1st STAGE PERMUTING AMP.
2nd STAGE PERMUTING AMP.
Permuting Divider K1
Permuting Divider K2
-10 V_V
+100 V_V
A1
A2
D1
D2
10R
R
r
10r
r/100
r/10
CH2
CH3
T3
T2
PORT C
N_S
N_P
T1
0.5 V_{rms}
I_{CM}
- V_{CM} +
MUT
120 V_{rms}
Z_s
0.1 Ω
G
(10 S)
5 A_{rms}

Combining uncertainties (60 Hz)

Maximum type B uncertainty in *P* (active power) at any power factor

$$U_M = \pm[(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6)\cos\theta + (\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6)\sin\theta]$$

Combined uncertainty in *P* (active power) at any power factor

$$U_P = [1.08\cos^2\theta + 1.49\sin^2\theta + 1.11]^{1/2}$$

U_P for several power factors (60 Hz) in ppm

0º	30º	60º	90º
1.5	1.5	1.6	1.6

NIST Sampling Power Measurement System

- NIST has constructed a waveform sampling power measurement system to measure distorted (harmonic) waveforms
- We can use several different sources to generate the distorted power waveforms
- System comprised of Voltage Attenuator, 3 stage current transformer and shunts, digital sampler, computer
- Goal of measuring power to 5 kHz at 30 ppm.

Motor Energy Usage in the U.S.

Table 1-2. Percentage of Sector Energy Use by Motor-Driven Systems (2006)

Sector	Total Electrical Energy Use for Sector, Million kWh/year[1], 2006	Annual Motor-Driven System Energy Use, Million kWh/year	Percentage of Sector Use by Motor-Driven Equipment	Percentage of Total Motor-Driven Equipment Energy Use
Residential	1,351,010	297,000	22.0	20.8
Commercial	1,299,443	498,000	38.3	34.9
Industrial	1,011,134	632,000	62.5	44.3

Source: U.S. Energy Information Administration, Annual Energy Review, 2010

The total annual energy consumption due to motor-driven equipment in the U.S. industrial, commercial, residential, and transportation sectors was approximately 1,431 billion kilowatt-hours (kWh) in 2006. This amounted to 38.4% of total U.S. electrical energy use

Premium Energy Efficient Motor

- Manufacturers must use increased quantities of improved materials and design motors with closer tolerances to reduce losses and allow motor designs to meet NEMA Premium Efficiency Motor Standard requirements. Typical design modifications include:
- Use of a larger wire gage to reduce stator winding resistance and minimize stator I2R losses.
- Incorporate a longer rotor and stator to lower core losses by decreasing magnetic density while increasing cooling capacity.
- Selection of low resistance rotor bars. Larger conductor bars and end rings reduce rotor I2R losses.
- Modification of stator slot design to decrease magnetic losses and allow for use of larger diameter wire.
- Use of a smaller fan. An efficient cooling fan design reduces airflow and power required to drive the fan.

Motor Efficiency Testing Standards

- IEEE 112, method B is called out in DOE
- IEEE 114 single phase induction motors
- IEC 60034-2-1
- CSA C390-10
- JEC-37
- BS-269

IEC Motor Standards

Field	IEC reference	Year of publication	Title	
Rating	IEC 60034-1, edition 12.0	2010	Rating and performance	Preview | Buy
Testing	IEC 60034-2-1, edition 2.0	2014	Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)	Preview | Buy
Testing	IEC 60034-2-2, edition 1.0	2010	Specific methods for determining separate losses of large machines from tests - Supplement to IEC 60034-2-1	Preview | Buy
Testing converter-fed motors	IEC/TS 60034-2-3, edition 1.0	2013	Specific test methods for determining losses and efficiency of converter-fed AC induction motors	Preview | Buy
Efficiency classes	IEC 60034-30-1, edition 1.0	2014	Efficiency classes of line operated AC motors (IE-code)	Preview | Buy
Guide	IEC 60034-31, edition 1.0	2010	Selection of energy-efficient motors including variable speed applications - Application guide	Preview | Buy

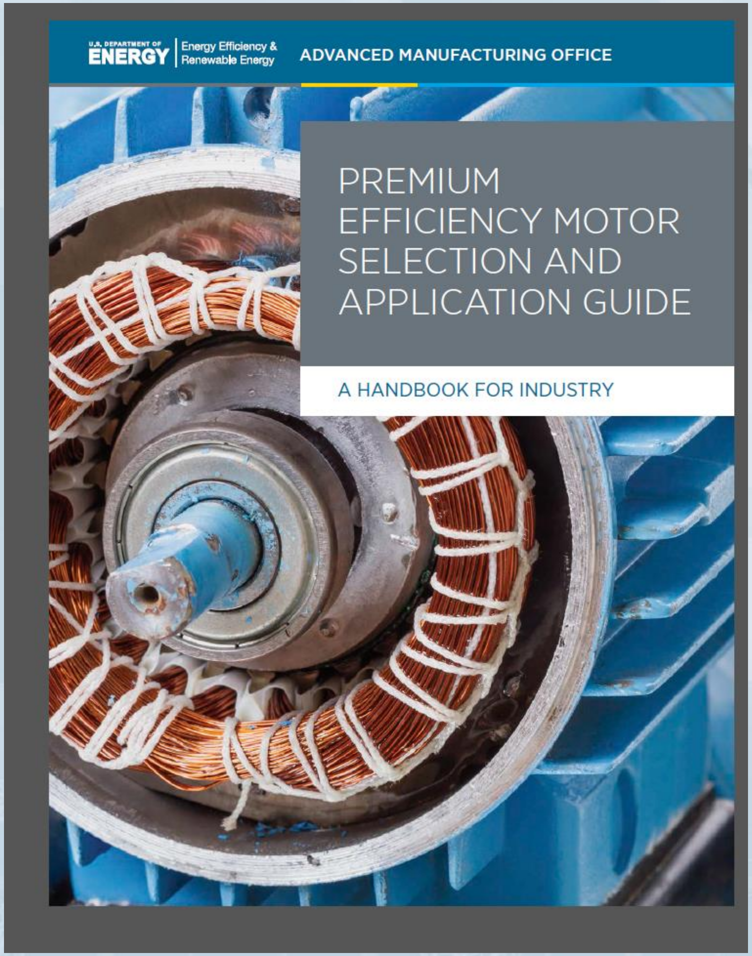
Work in progress

Field	IEC reference	Title	Status
Efficiency classes	IEC 60034-30-2	Efficiency classes of variable speed AC motors	New, expected to be published in 2016/17
Converters: efficiency classes and test methods	IEC 61800-9-2	Ecodesign for power drive systems, motor starters, power electronics & their driven applications - Energy efficiency indicators for power drive systems and motor starters	New, expected to be published in 2016/17

Motor Testing

- IEEE Std 112B, IEC 60034-2-1, CSA C390-10 give similar results
- Decide on a standard to use for testing
- Study on repeatability of IEEE 112B concluded results would be repeatable to about 0.5%.

DOE Premium Motor Selection and Application Guide



Motors

- When annual operating hours are above 2,000 hours per year, electric motors are extremely energy intensive. This explains why a seemingly small 2% to 3% improvement in energy efficiency can lead to significant annual energy and dollar savings.

DOE Efficiency Motor Software

- MotorMaster+ and MotorMaster International are available in the AMO Energy Resources Center at *www.manufacturing.energy.gov*.
- To help you identify, evaluate, and procure premium efficiency motors, AMO developed and maintains the MotorMaster+ software tool. MotorMaster+ is a free motor selection and management tool that supports energy management and motor system improvement planning by identifying the most efficient choice for a given repair or motor purchase decision. The tool includes a catalog of more than 20,000 low-voltage induction motors and features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

NIST Technical Note 1422

Electric Motor Efficiency Testing Under the New Part 431 of Chapter II of Title 10, Code of Federal Regulations: Enforcement Testing

K. L. Stricklett and M. Vangel

NIST Technical Note 1432

Test Procedures for Electric Motors Under 10 CFR Part 431

K. L. Stricklett and M. Vangel

NIST Technical Note 1427

An Analysis of Efficiency Testing Under the Energy Policy and Conservation Act: A Case Study With Application to Distribution Transformers

K. L. Stricklett, M. Vangel, and O. Petersons

IEEE

IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions

1459™

IEEE Power & Energy Society

Sponsored by the
Power System Instrumentation and Measurements Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

19 March 2010

IEEE Std 1459™-2010
(Revision of
IEEE Std 1459-2000)

Sample of Publications on IEEE 1459

IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 26, NO. 2, APRIL 2011

Discussion on Useless Active and Reactive Powers
Contained in the IEEE Standard 1459

Salvador Orts-Grau, *Member, IEEE*, Nicolás Muñoz-Galeano, José Carlos Alfonso-Gil, Francisco J. Gimeno-Sales, and Salvador Seguí-Chilet, *Member, IEEE*

A Smarter Meter: IEEE-1459 Power Definitions in an Off-the-Shelf Smart Meter

Andrew J Berrisford, *Member, IEEE*

IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 30, NO. 3, JUNE 2015

Time-Frequency-Based Instantaneous Power Components for Transient Disturbances According to IEEE Standard 1459

Moinul Islam, *Student Member, IEEE*, Hossein Ali Mohammadpour, *Student Member, IEEE*, Amin Ghaderi, *Student Member, IEEE*, Charles W. Brice, *Senior Member, IEEE*, and Yong-June Shin, *Senior Member, IEEE*

IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 26, NO. 3, JULY 2011

Comprehensive Definitions for Evaluating Harmonic
Distortion and Unbalanced Conditions in Threeand
Four-Wire Three-Phase Systems Based on IEEE Standard 1459

Sobhan Mohamadian, *Student Member, IEEE*, and Abbas Shoulaie

Where is the power of the IEEE 1459-2010?

Johan Rens
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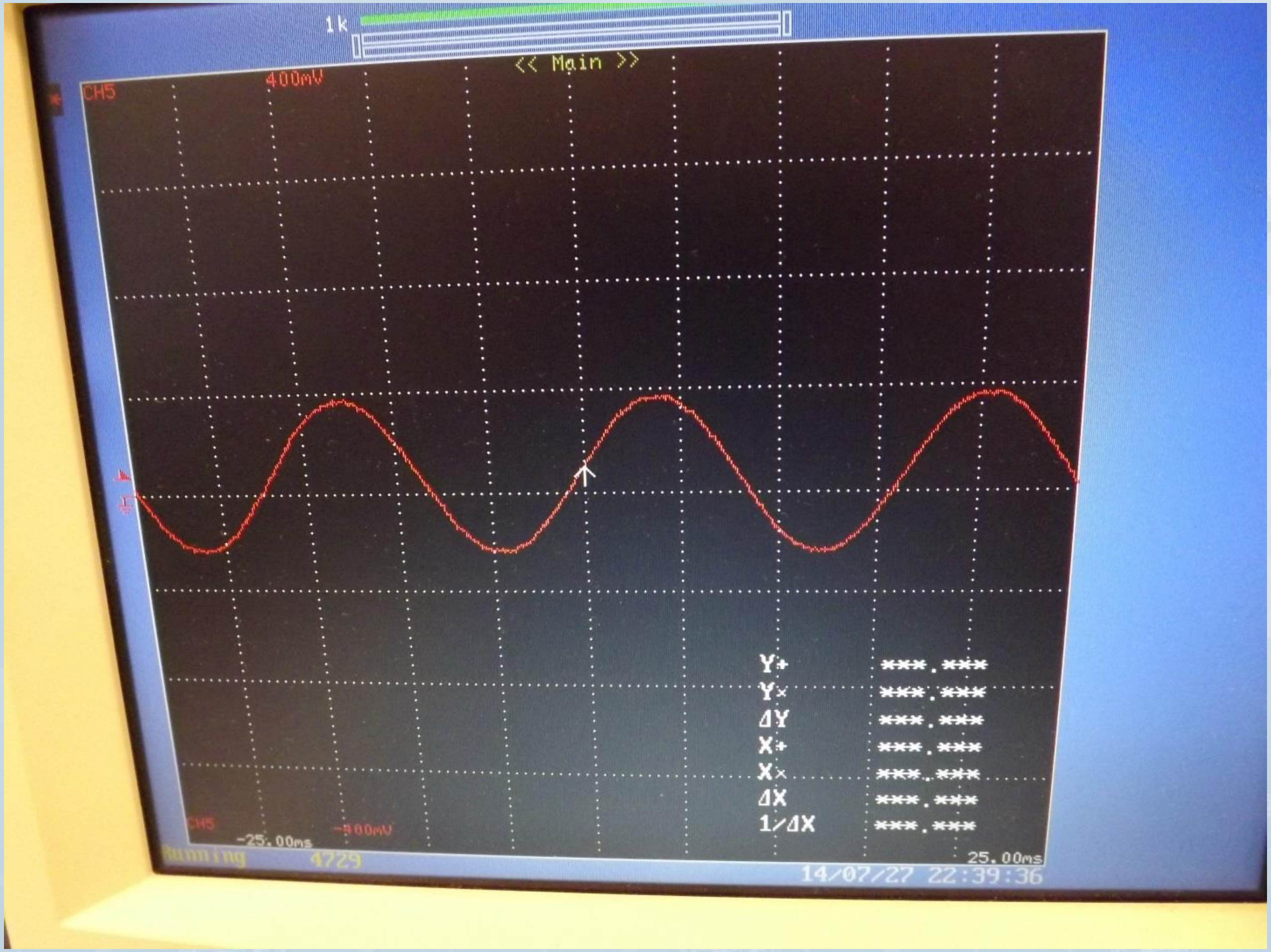
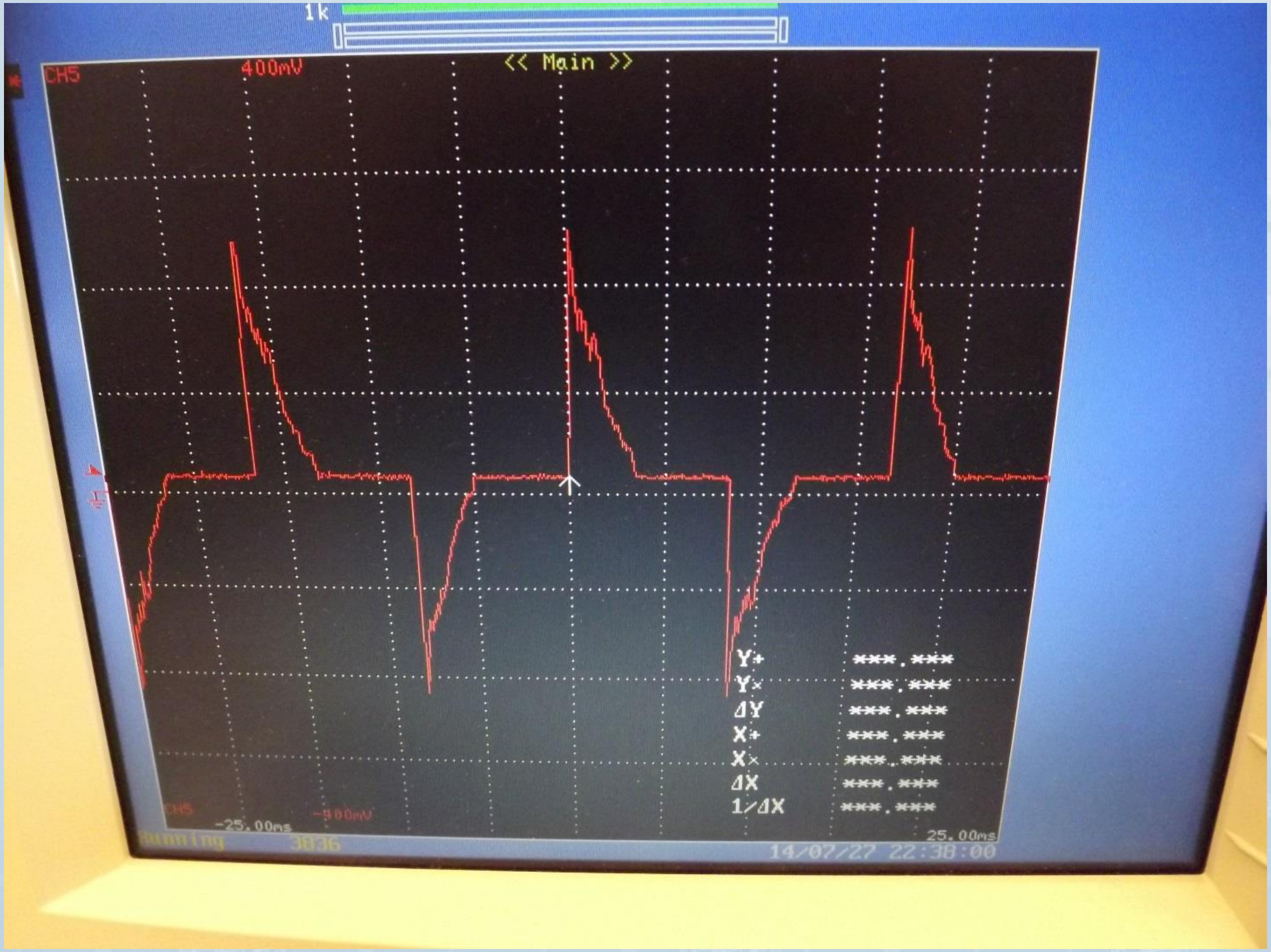
Tian van Rooyen, Francois de Jager
School for Electrical and Electronic Engineering
Potchefstroom Campus of the North-West Univ

- Measurement time matters
- Measurement algorithm matters

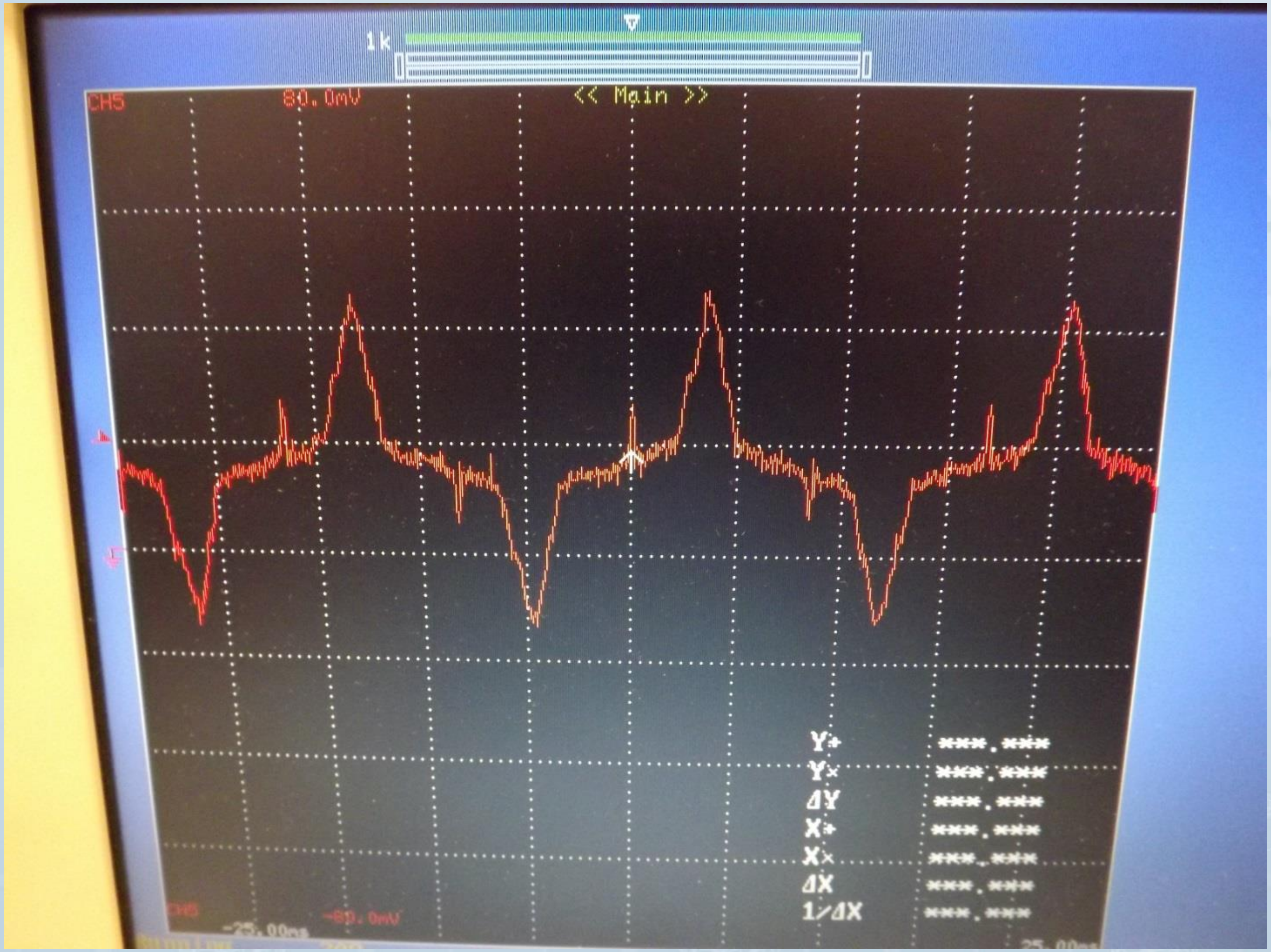
Incandescent Bulb
63.2 W, 1.0 PF



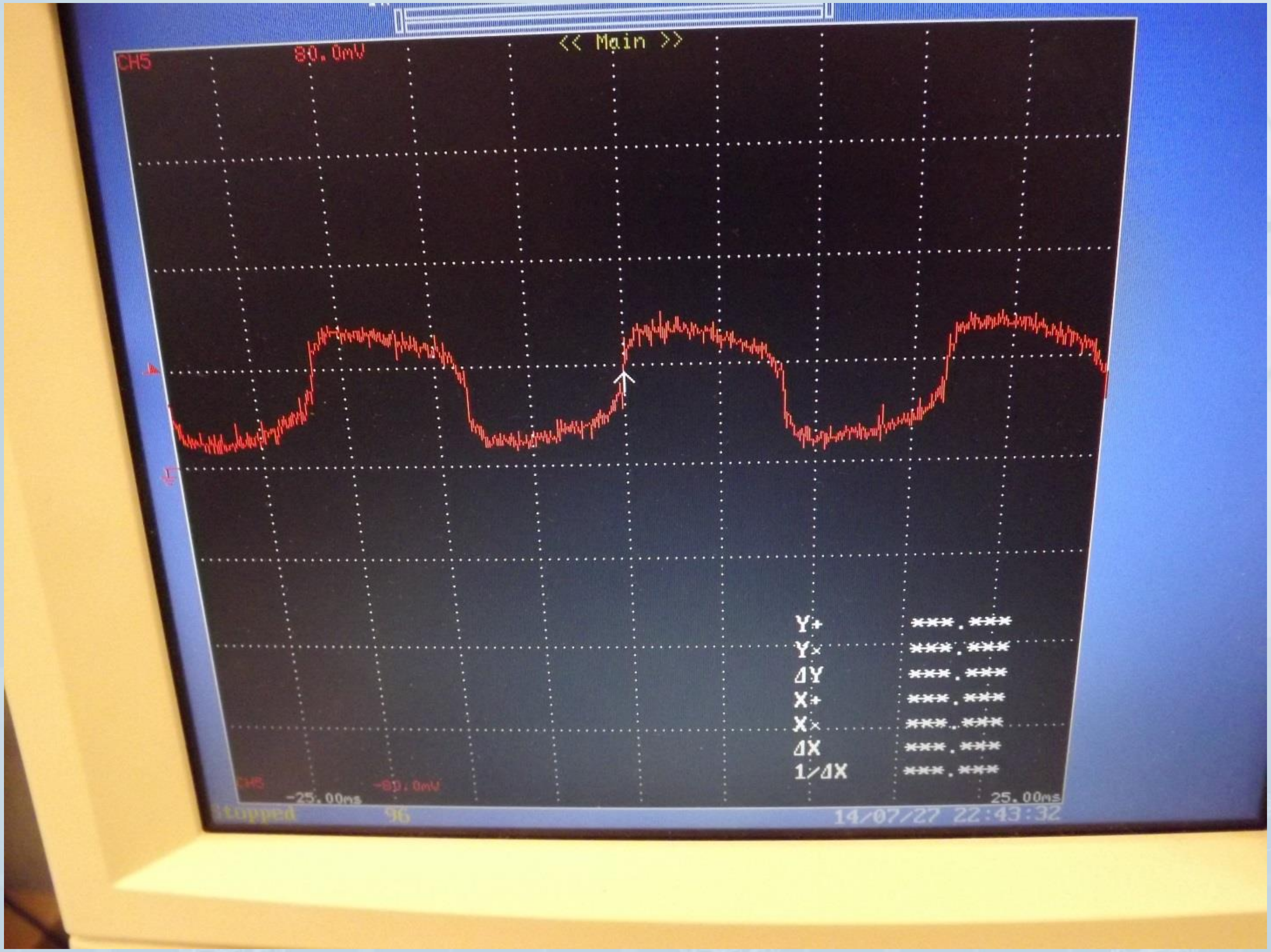
CFL Bulb
47.2 W, 0.59 PF



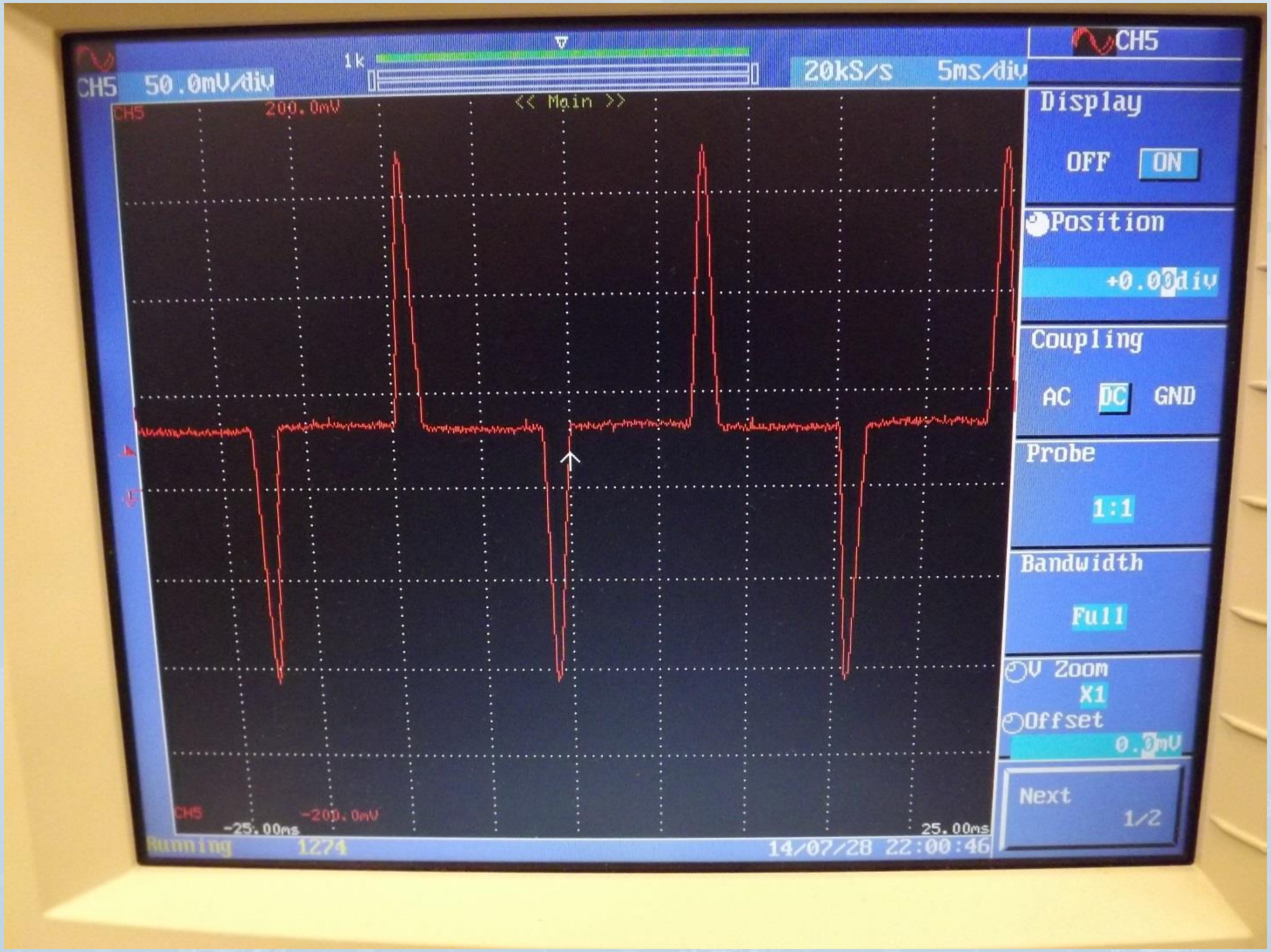
LED Bulb
10.4 W, 0.81 PF

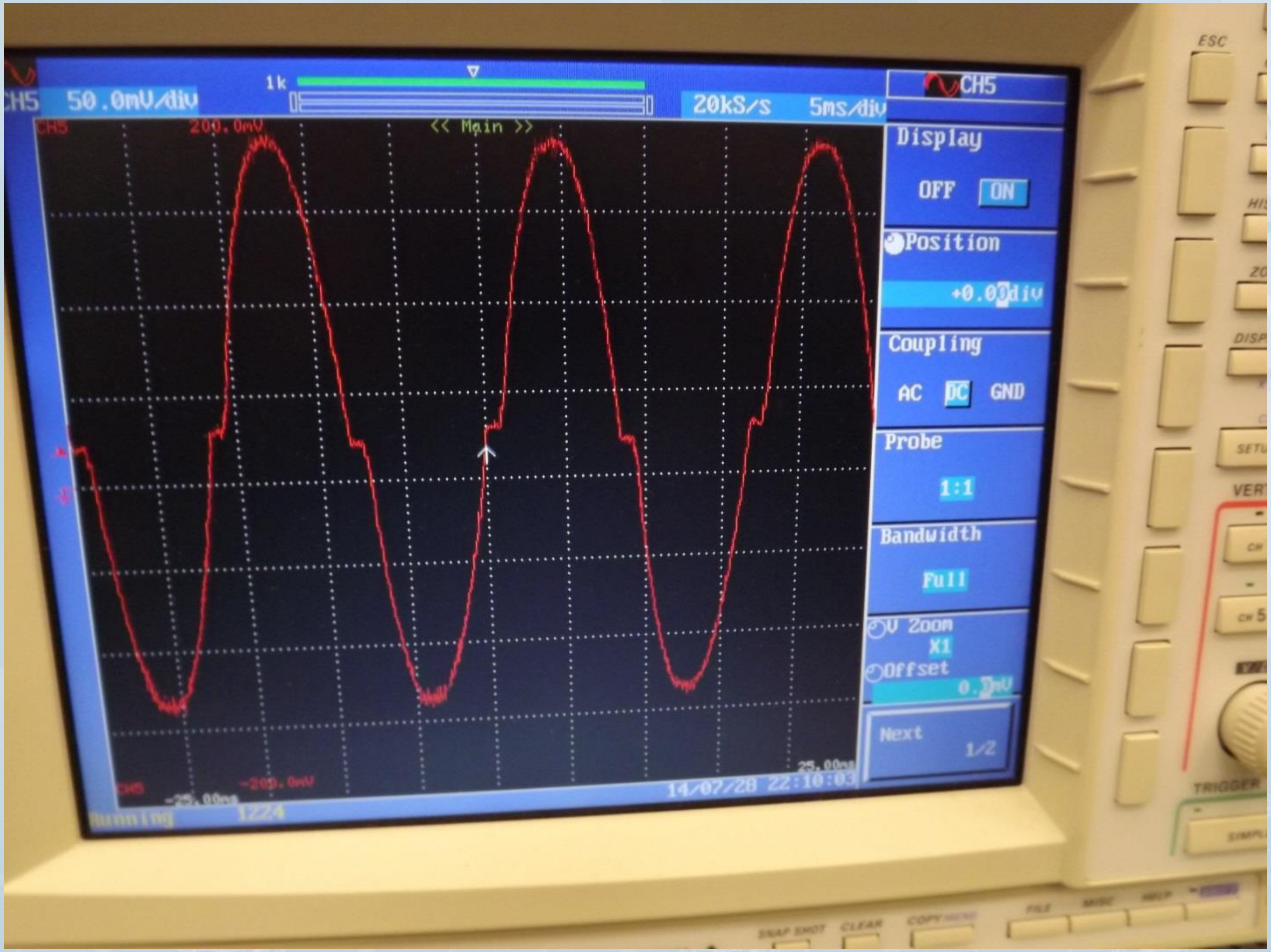


LED Bulb #2

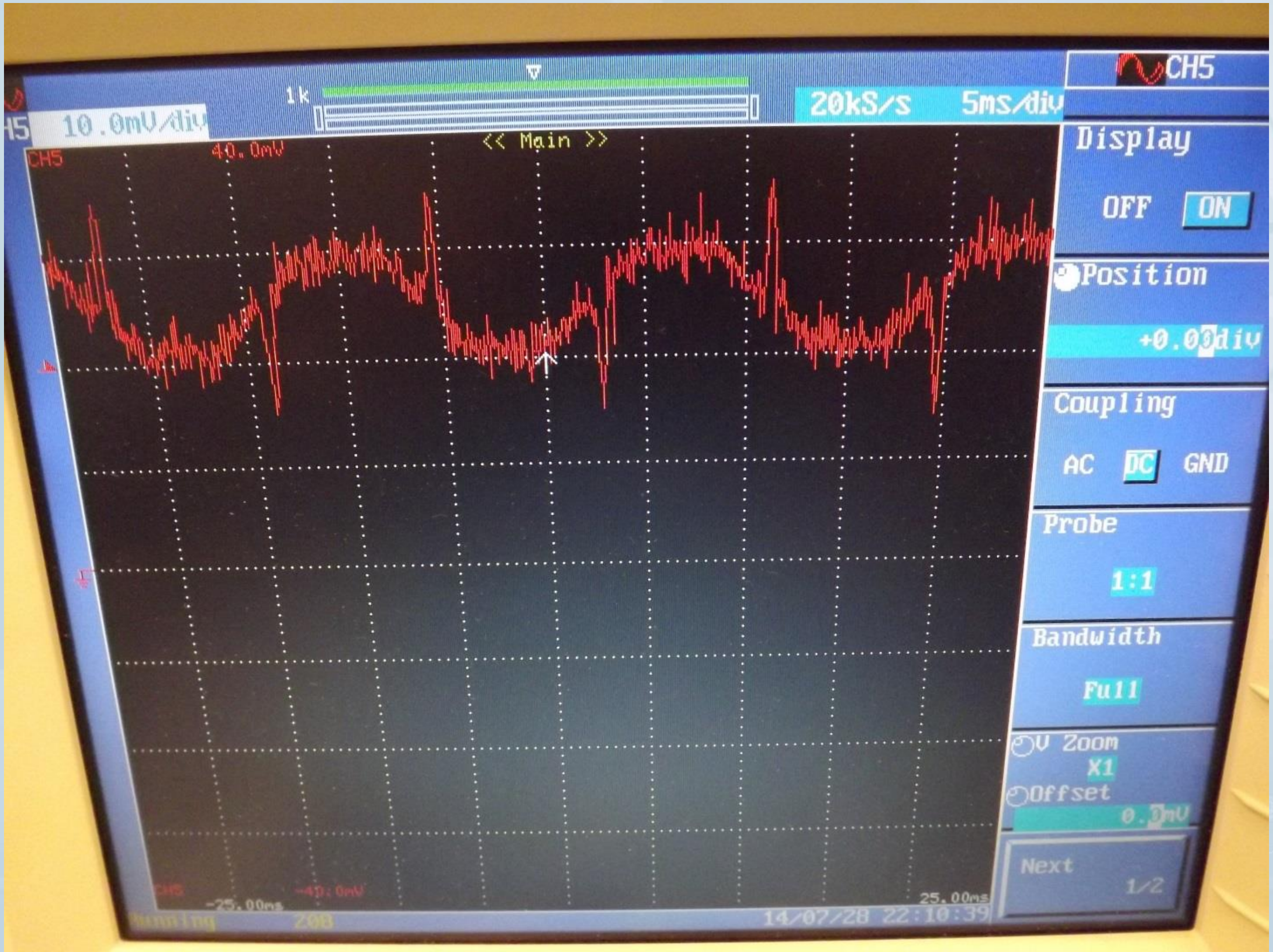


CH5
80.0mV
<< Main >>
Y+ ***.***
Y× ***.***
ΔY ***.***
X+ ***.***
X× ***.***
ΔX ***.***
1/ΔX ***.***
-25.00ms
25.00ms
stopped
14/07/27 22:43:32

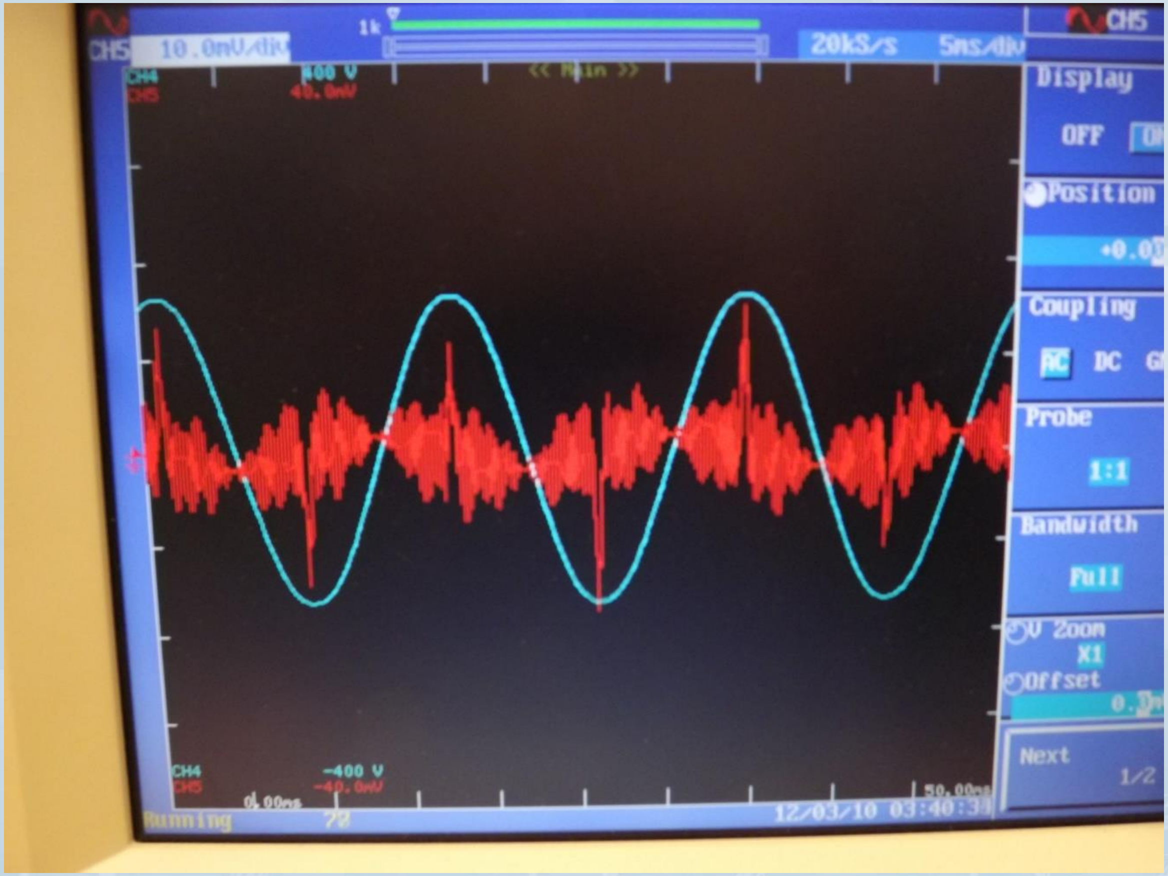

CH5 50.0mV/div
1k
20kS/s 5ms/div
CH5
200.0mV
<< Main >>
Display
OFF ON
Position
+0.00div
Coupling
AC DC GND
Probe
1:1
Bandwidth
Full
V Zoom
X1
Offset
0.0mV
Next
1/2
CH5
-25.00ms
-200.0mV
25.00ms
Running
1274
14/07/28 22:00:46


CH5 50.0mV/div
1k
20kS/s 5ms/div
CH5
200.0mV
<< Main >>
Display
OFF ON
Position
+0.00div
Coupling
AC DC GND
Probe
1:1
Bandwidth
Full
V Zoom
X1
Offset
Next 1/2
-200.0mV
-25.00ms
25.00ms
14/07/28 22:10:03
Running 1224

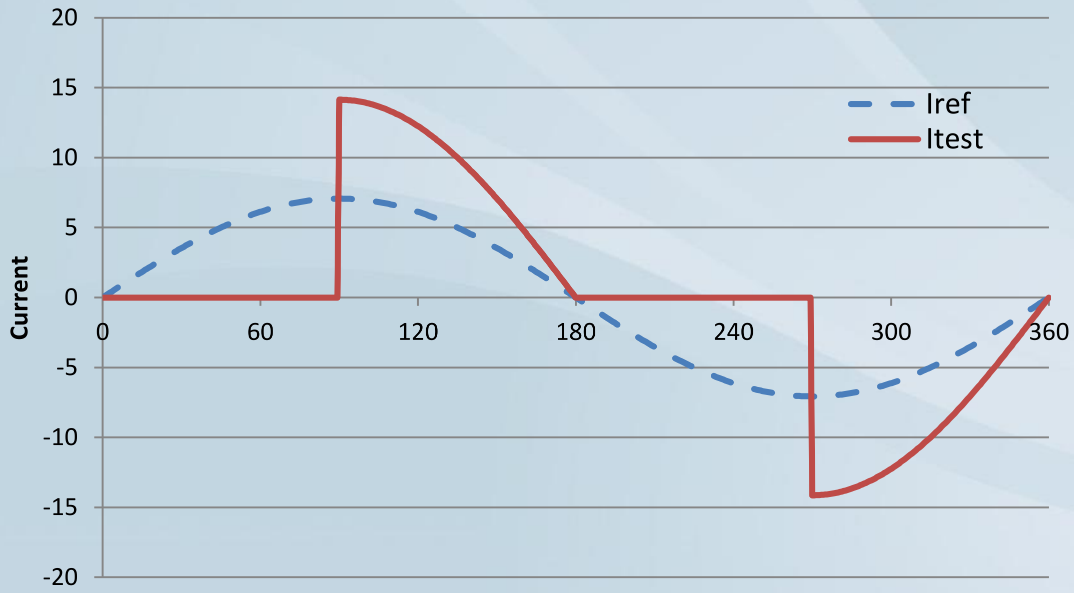
Monitor Standby
0.9 W, 0.22 PF



Laptop Power Supply



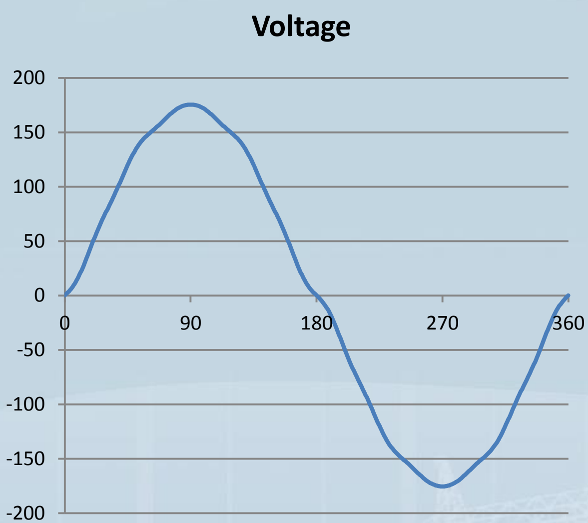
Harmonic Waveform Tests in Draft C12.20 Standard

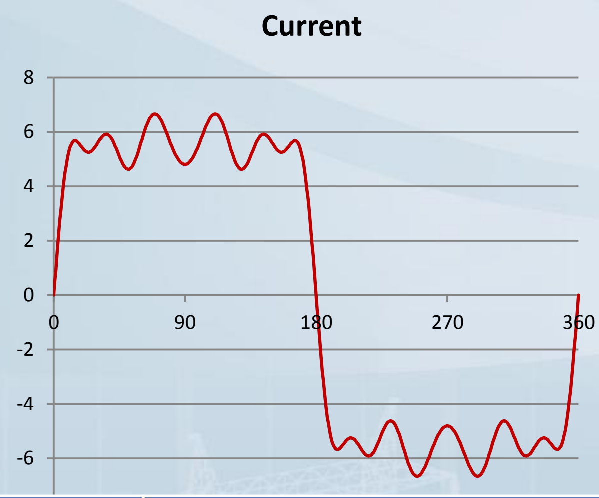


Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	V_{ref} Sinusoidal	90 Degree Phase Fired Waveform	±0.5%	±0.3%	±0.2%

Harmonic Waveform Tests in Draft C12.20 Standard

Harmonic	Voltage Amplitude % V_{ref}	Phase	Current Amplitude % I_{ref}	Phase	Energy
1	100	0	100	0	100.000
3	3.8	180	30	0	-1.140
5	2.4	180	18	0	-0.432
7	1.7	180	14	0	-0.238
11	1.1	180	9	0	-0.099
13	0.8	180	5	0	-0.040
				Total Energy	98.051

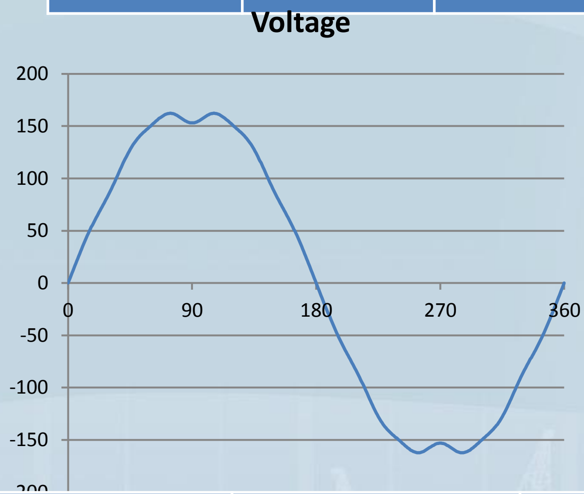


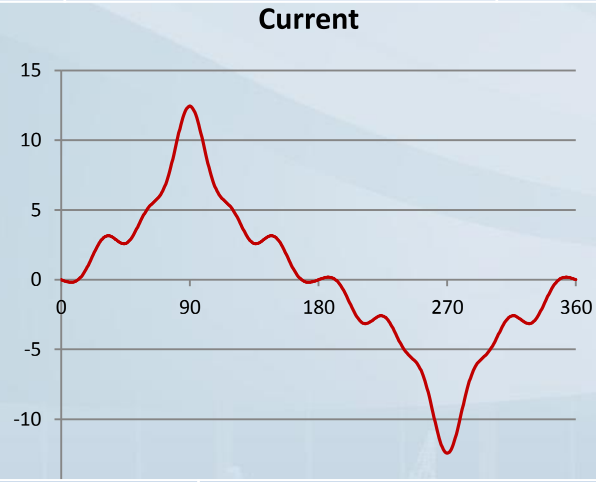


Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	V_{ref} Sinusoidal	Quardiform Current Waveform	±0.5%	±0.3%	±0.2%
(3)	Quardiform Voltage Waveform	Quardiform Current Waveform	±0.8%	±0.5%	±0.3%

Harmonic Waveform Tests in Draft C12.20 Standard

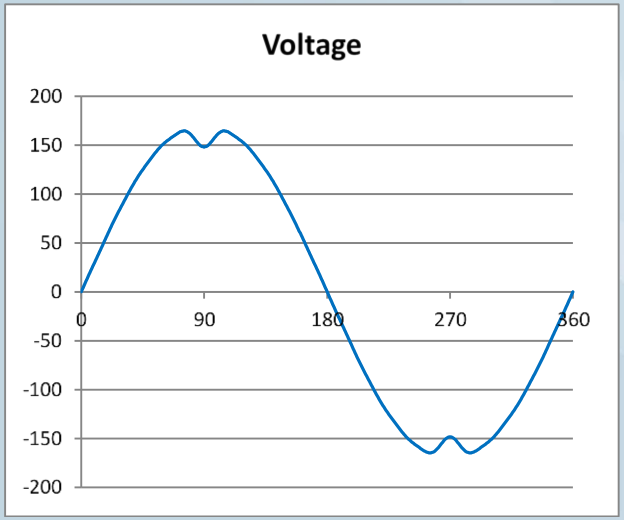
Harmonic	Voltage Amplitude % V_{ref}	Phase	Current Amplitude % I_{ref}	Phase	Energy
1	100	0	100	0	100.00
3	3.8	0	30	180	-1.140
5	2.4	180	18	0	-0.432
7	1.7	0	14	180	-0.238
11	1.1	0	9	180	-0.099
13	0.8	180	5	0	-0.040
				Total Energy	98.051

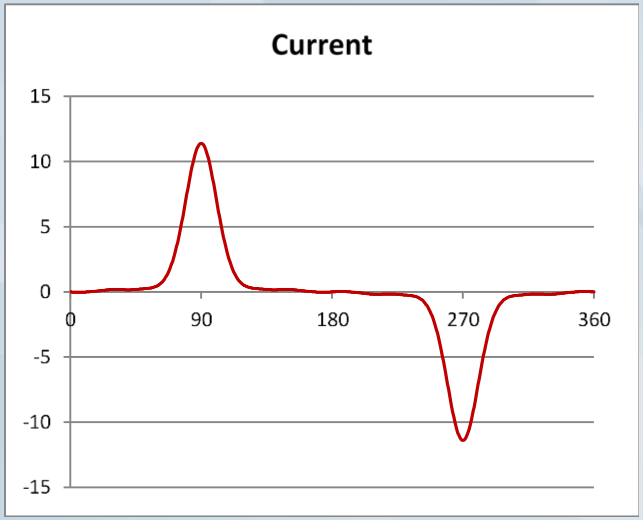




Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	V_{ref} Sinusoidal	Peaked Current Waveform	±0.5%	±0.3%	±0.2%
(3)	Peaked Voltage Waveform	Peaked Current Waveform	±0.8%	±0.5%	±0.3%

Harmonic Waveform Tests in Draft C12.20 Standard

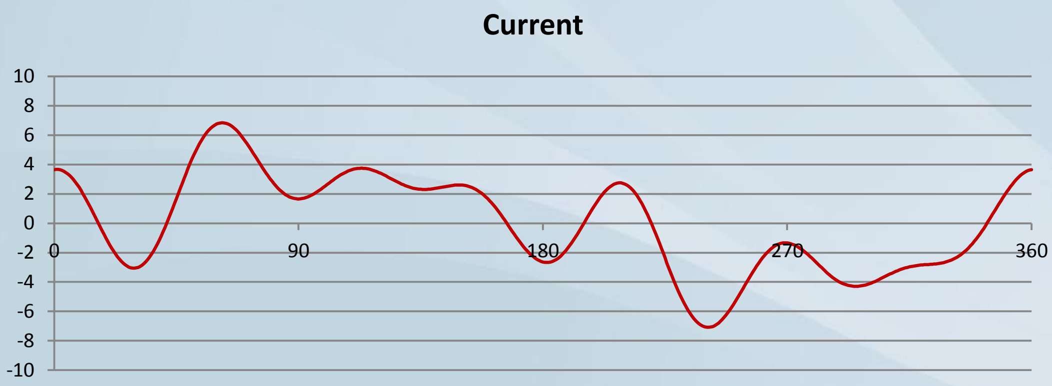




Harmonic	Voltage Amplitude % V_{ref}	Phase	Current Amplitude % I_{ref}	Phase	Energy
1	100	0	100	0	100.000
3	3.8	0	80	180	-3.040
5	2.4	180	60	0	-1.440
7	1.7	0	40	180	-0.680
9	1.5	180	22	0	-0.330
11	1.1	0	12	180	-0.132
13	0.8	180	5	0	-0.040
15	0.6	0	2	180	-0.012
17	0.4	180	1	0	-0.004
19	0.3	0	0.5	180	-0.0015
			Total Energy		94.321

Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	V_{ref} Sinusoidal	Pulse Current Waveform	±0.5%	±0.3%	±0.2%
(3)	Pulse Voltage Waveform	Pulse Current Waveform	±0.8%	±0.5%	±0.3%

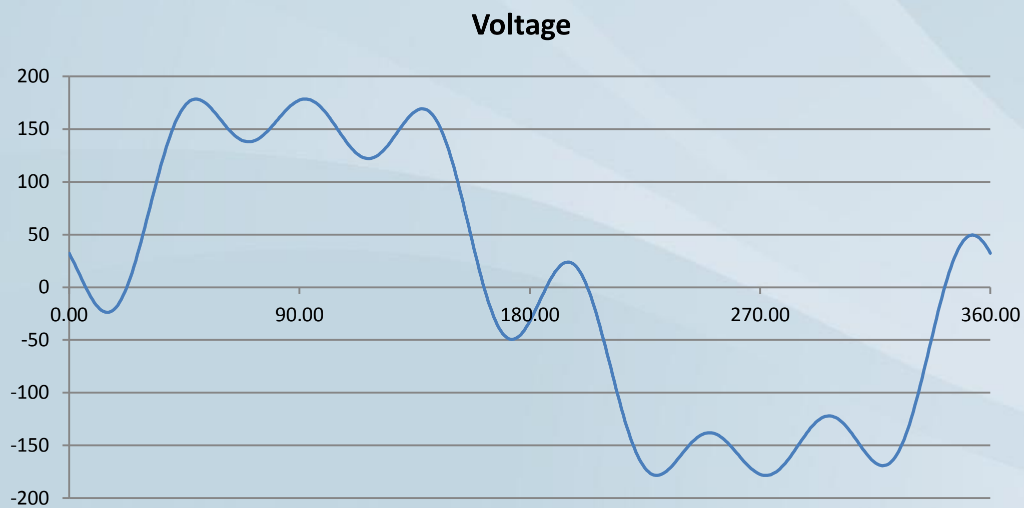
Harmonic Waveform Tests in Draft C12.20 Standard



Harmonic	Voltage Amplitude % V_{ref}	Phase	Current Amplitude % I_{ref}	Phase	Energy
1	100	0	100	0	100.000
2	0	0	5 ± 1	90 ± 2	0
3	0	0	18± 2	-160 ± 2	0
4	0	0	10± 2	110 ± 2	0
5	0	0	66± 3	130 ± 2	0
7	0	0	50± 3	50 ± 2	0

Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	V_{ref} Sinusoidal	MZC Current Waveform	±0.5%	±0.3%	±0.2%

Harmonic Waveform Tests in Draft C12.20 Standard



Harmonic	Voltage Amplitude % V_{ref}	Phase	Current Amplitude % I_{ref}	Phase	Energy
1	100	0	100	0	100.000
3	0	0	0	0	0
5	20 ± 2	155 ± 5	0	0	0
7	25 ± 4	155 ± 5	0	0	0

Condition	Voltage Waveform	Current Waveform	Maximum Deviation in Percent from Reference Performance		
			Accuracy Class		
			0.5	0.2	0.1
(1)	V_{ref} Sinusoidal	I_{ref} Sinusoidal	Reference	Reference	Reference
(2)	MZC Voltage Waveform	I_{ref} Sinusoidal	±0.5%	±0.3%	±0.2%

Measurement Canada Developments

- In October 2005, MC established the Volt-Ampere Joint Working Group (VA JWG) comprised of MC and electricity industry representatives with a mandate to identify and study the factors that contribute to inequity in the measurement of apparent energy and demand, and to make recommendations that would aim to minimize or eliminate the inequities found. Harmonic content was one of multiple factors identified and assessed.

- Thank you for your attention

- Contact: thomas.nelson@nist.gov

Algorithm Information is Critical

- Know what you are measurings
- What are you going to do with the data, what applications are you going to use, what are the application requirements (uncert., bandwidth, time,) all these are important
- If measurements from one instrument are used by another, does it need to know information about the number it is using? If it is a voltage measurement, is it rms/peak…that’s typically easy, but what about meas. Uncert, samples per cycle, number of cycles, bandwidth,..

What's a Watt?

- Watt IEEE Std 100 defines it to be power required to do work at rate of 1 Joule/Second
- Draft C12 VA standard defines watt to be:

Active power: The integral of the instantaneous voltage (V) times the instantaneous current (I) over precisely one cycle of the voltage waveform.

$$P = \frac{1}{T}\int_0^T V(t)I(t)dt$$

Where T is the period of the voltage waveform.

- Var
- VA
- Harmonics
- Interharmonics
- Sub Harmonics

Excerpt from IEEE 1459

Table 1—Summary and grouping of the quantities in single-phase systems with nonsinusoidal waveforms

Quantity or indicator	Combined	Fundamental powers	Nonfundamental powers
Apparent	S (VA)	S_1 (VA)	S_N S_H (VA)
Active	P (W)	P_1 (W)	P_H (W)
Nonactive	N (var)	Q_1 (var)	D_I D_V D_H (var)
Line utilization	$PF = P/S$	$PF_1 = P_1/S_1$	—
Harmonic pollution	—	—	S_N/S_1

IEEE Recommended Practices in Power Quality

IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

IEEE Power and Energy Society

Sponsored by the
Transmission and Distribution Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 519™-2014
(Revision of
IEEE Std 519-1992)

IEEE

IEEE Recommended Practice for Monitoring Electric Power Quality

IEEE Power & Energy Society

Sponsored by the
Transmission and Distribution Committee

1159™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

26 June 2009

IEEE Std 1159™-2009
(Revision of
IEEE Std 1159-1995)

IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems IEEE 519

- **harmonic (component):** A component of order greater than one of the Fourier series of a periodic quantity. For example, in a 60 Hz system, the harmonic order 3, also known as the “third harmonic,” is 180 Hz.

- **interharmonic (component):** A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating (e.g., 50 Hz or 60 Hz).

- The width of the measurement window used by digital instruments employing Discrete Fourier Transform techniques should be 12 cycles (approximately 200 ms) for 60 Hz power systems

- Very short time harmonic values are assessed over a 3-second interval based on an aggregation of 15 consecutive 12 (10) cycle windows for 60 (50) Hz power systems.

- Short time harmonic values are assessed over a 10-minute interval based on an aggregation of 200 consecutive very short time values for a specific frequency component.

- Very short and short time harmonic values should be accumulated over periods of one day and one week, respectively. For very short time harmonic measurements, the 99th percentile value (i.e., the value that is exceeded for 1% of the measurement period) should be calculated for each 24-hour period for comparison with the recommend limits in Clause 5. For short time harmonic measurements, the 95th and 99th percentile values (i.e., those values that are exceeded for 5% and 1% of the measurement period) should be calculated for each 7-day period for comparison with the recommended limits in Clause 5. These statistics should be used for both voltage and current harmonics with the exception that the 99th percentile short time value is not recommended for use with voltage harmonics.

Communication Standards

- ANSI C12.19
- DLMS/COSEM
- IEC 61850
- DNP3
- Others
- Communications between field devices
- I want to hear your thoughts on what you think would be a good metering/sensor protocol 10 years from now

Metering not under PUC Juristiction

- EV Charging - Commercial transactions covered by Weights and Measures
- Measurement testing procedures are being developed for EV chargers
- Type evaluation program is starting for accuracy testing of EV chargers
- Test equipment is being developed for field inspectors
- Submetering topic is getting underway

Semantics

- THD and different definitions of it
- Voltage (did they mean Vpeak to peak, Vpeak, Vrms ? Different "communities" use what it normal for their expertise and may assume you know what they mean and vice-versa

Measurement Canada Developments

- Recommendations of the VA JWG resulted in draft specifications that were provided for public consultation in early 2012. Following this consultation, MC established the Complex Measurement Implementation (CMI) JWG, which was mandated to consider new information and related measurement issues, address certain concerns raised by the industry and conclude on revisions to the draft specifications. At that time the draft specifications were contemplating various approaches to inclusion of harmonic content within a given LUM value. The CMI considered various factors in light of the IEEE's discontinuation of the Budeanu var determination methodology.

Measurement Canada Developments

- MC and Canadian industry stakeholders (through the Canadian Electricity Association) have acknowledged that a measurement approach utilizing RMS values for LUMs does so without consideration of the directionality of the harmonic content. In other words, there is no manner to determine which party to a trade transaction is sinking or sourcing harmonic content, and thus the resulting LUM values may not equitably represent the actual trade of the electricity commodity.

Measurement Canada Developments

- Electricity sellers (generators and utilities) are in the business of selling a commodity; they provide the components of energy that are used by various consumer (purchaser) appliances via voltage and current in fundamental form. These parties do not generate, nor purport to sell harmonic content, yet RMS metering would in fact establish values of LUM that include harmonic content. The result is further inequity as the seller is recouping costs via their price per unit LUM for a product that they are not actually providing or selling.
- A foundational reason for using measurement of watt and var (measuring var directly) for establishing VA values is that both watt and var measurement (in absence of harmonics) can be defined consistently in AC single phase and AC polyphase environments. Watts are always along the X-axis and vars are always along the Y-axis, there is consistency and the var definition is complementary to that of the watt definition. VA on the other hand can be all over the 360 range of 4 quadrants, and while it can be consistently defined in DC, and AC single phase environment, its definition in the polyphase environment is more ambiguous. Hence from a legal metrology perspective VA should be derived from watts and vars

Measurement Canada Developments

- A key facet of MC approach to equity is that individual LUM values for energy be clearly distinguished by directionality; these values must be independently identified, assessed and attributed to the correct party (seller or purchaser). How a seller decides to use such values in the price per unit of the trade transaction is up to them, but from the perspective of the legislation in Canada, the information must be provided in an accurate, standard, and transparent manner.

Measurement

- The following 9 slides are courtesy of Andrew Berrisford from BC Hydro
- Andrew has spent many years working with measurements of harmonic power

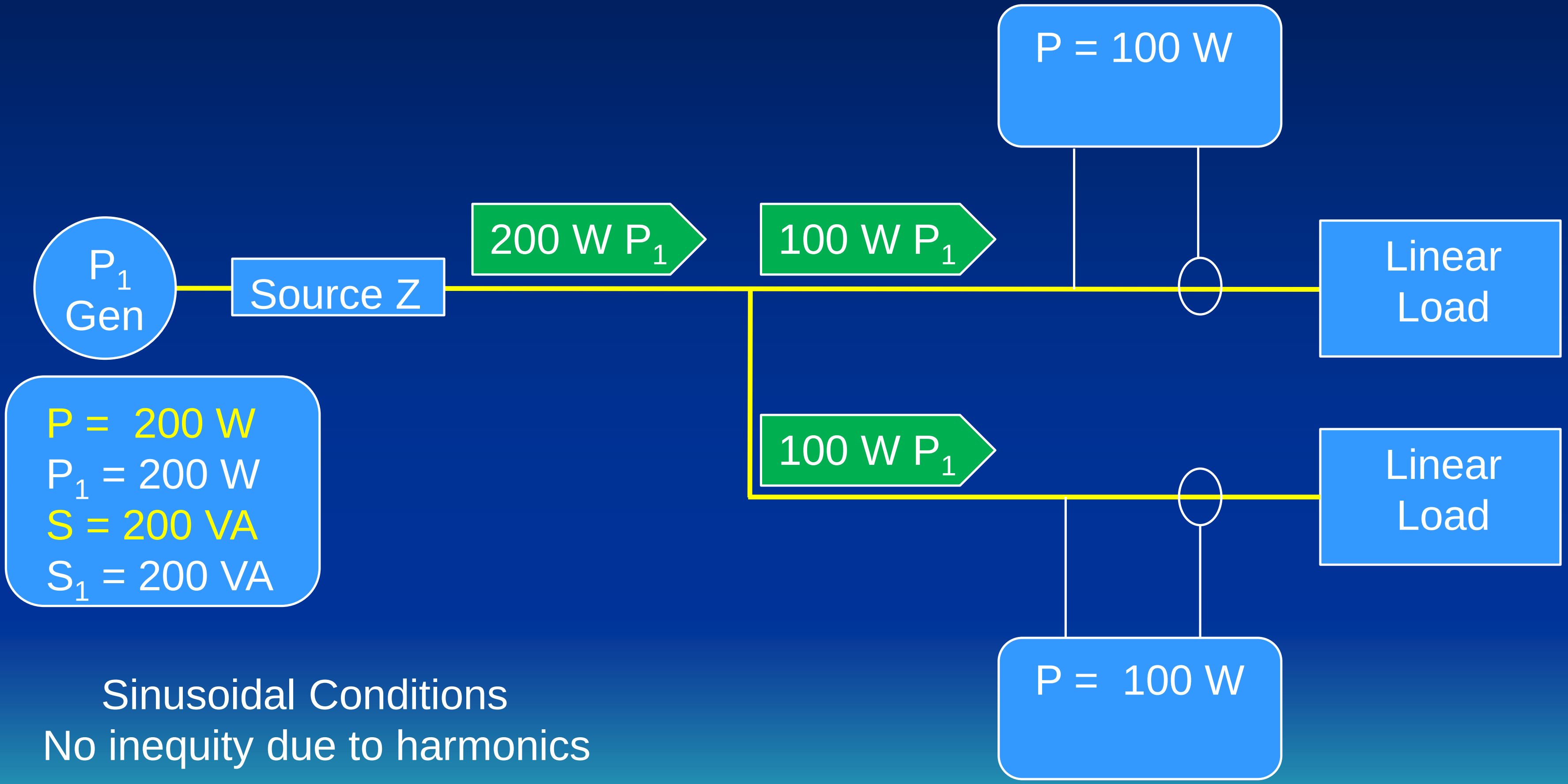
- andrew.berrisford@bchydro.com

Harmonic Power Flow Inequity

$P =$ 100 W
$P_1 =$ 100 W
$S =$ 100 VA
$S_1 =$ 100 VA

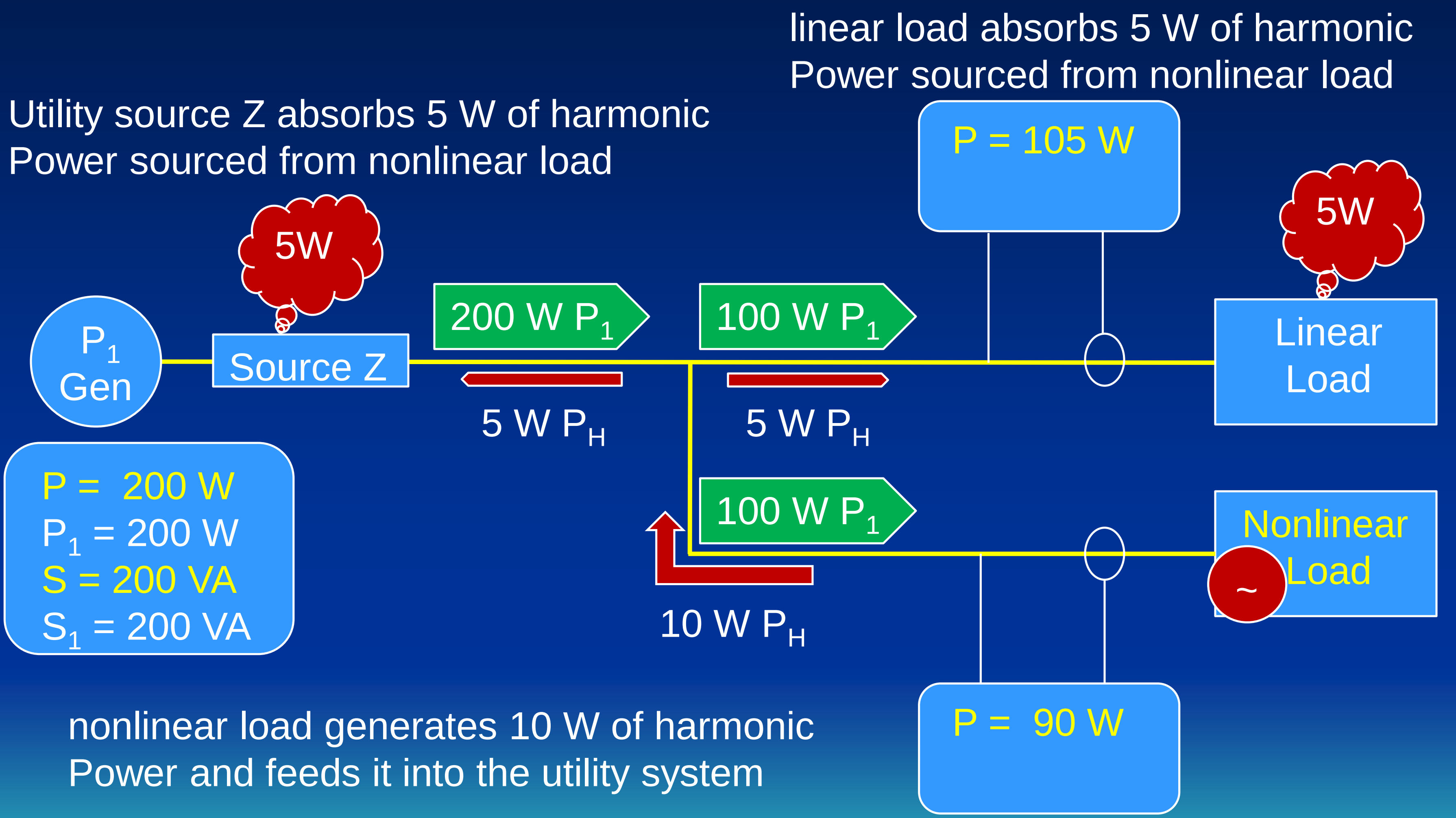
Sinusoidal Conditions
No inequity due to harmonics

Harmonic Power Flow Inequity



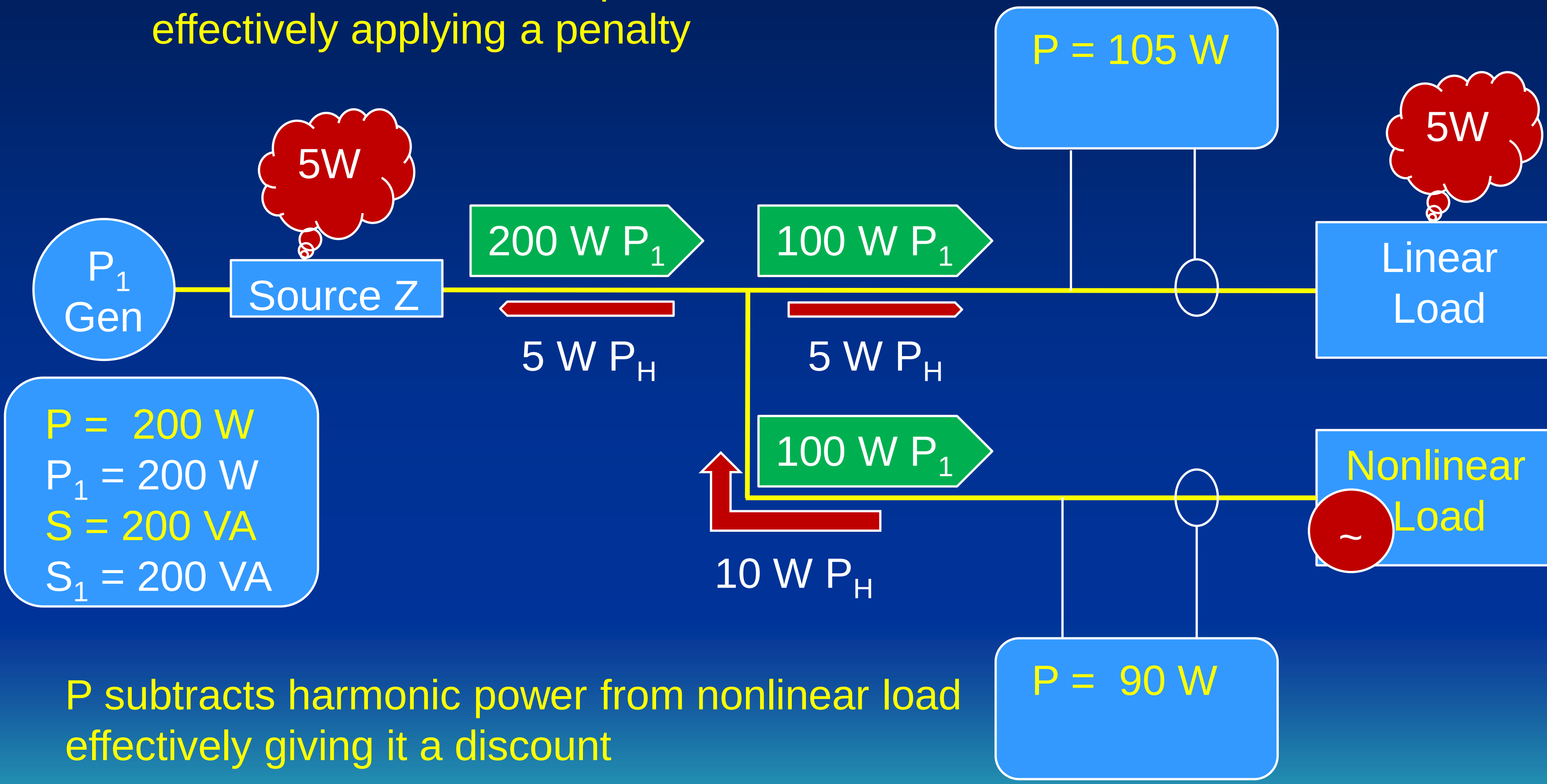
Sinusoidal Conditions
No inequity due to harmonics

Harmonic Power Flow Inequity



Harmonic Power Flow Inequity

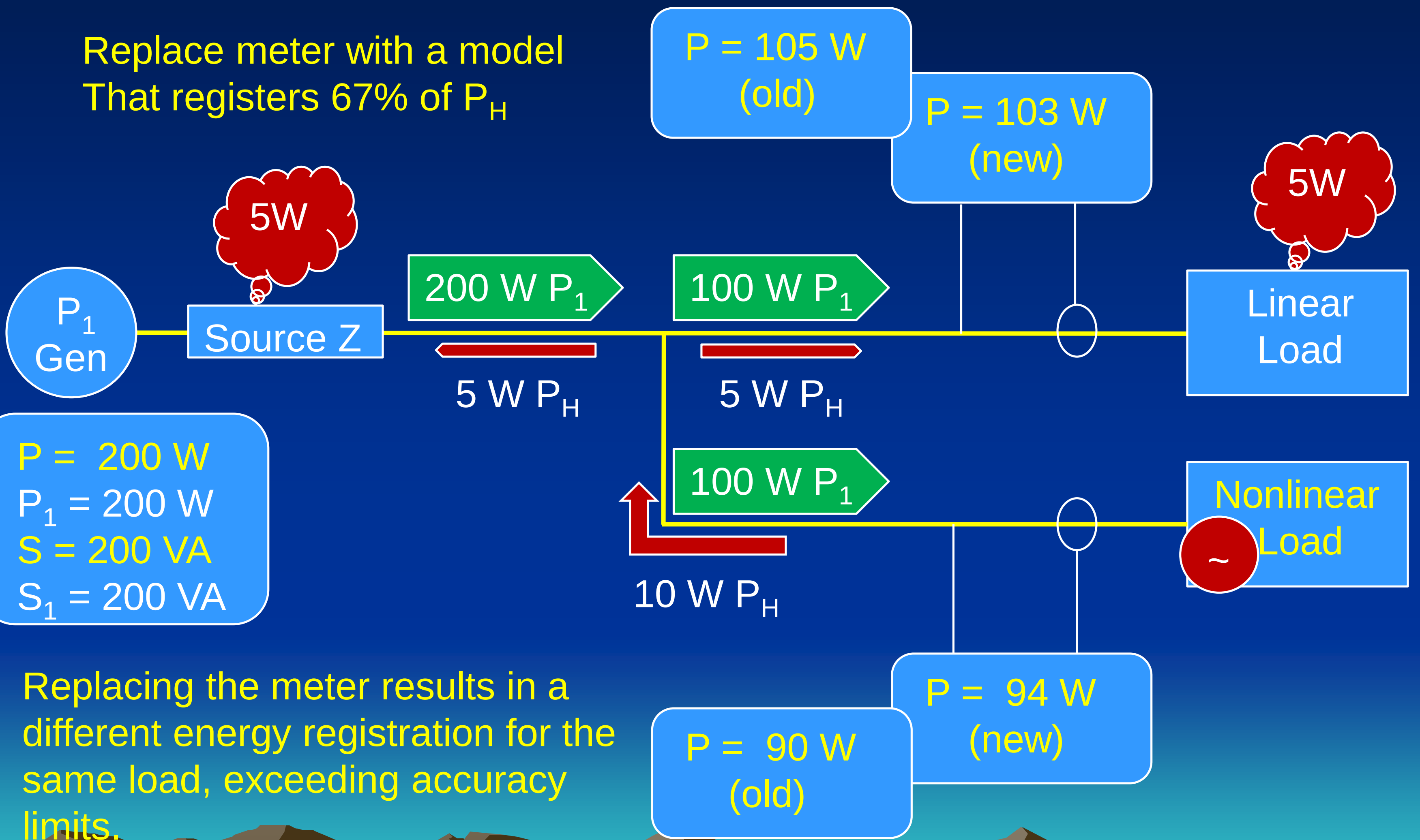
P meter adds harmonic power for linear load effectively applying a penalty



P subtracts harmonic power from nonlinear load effectively giving it a discount

Harmonic Power Flow Inequity

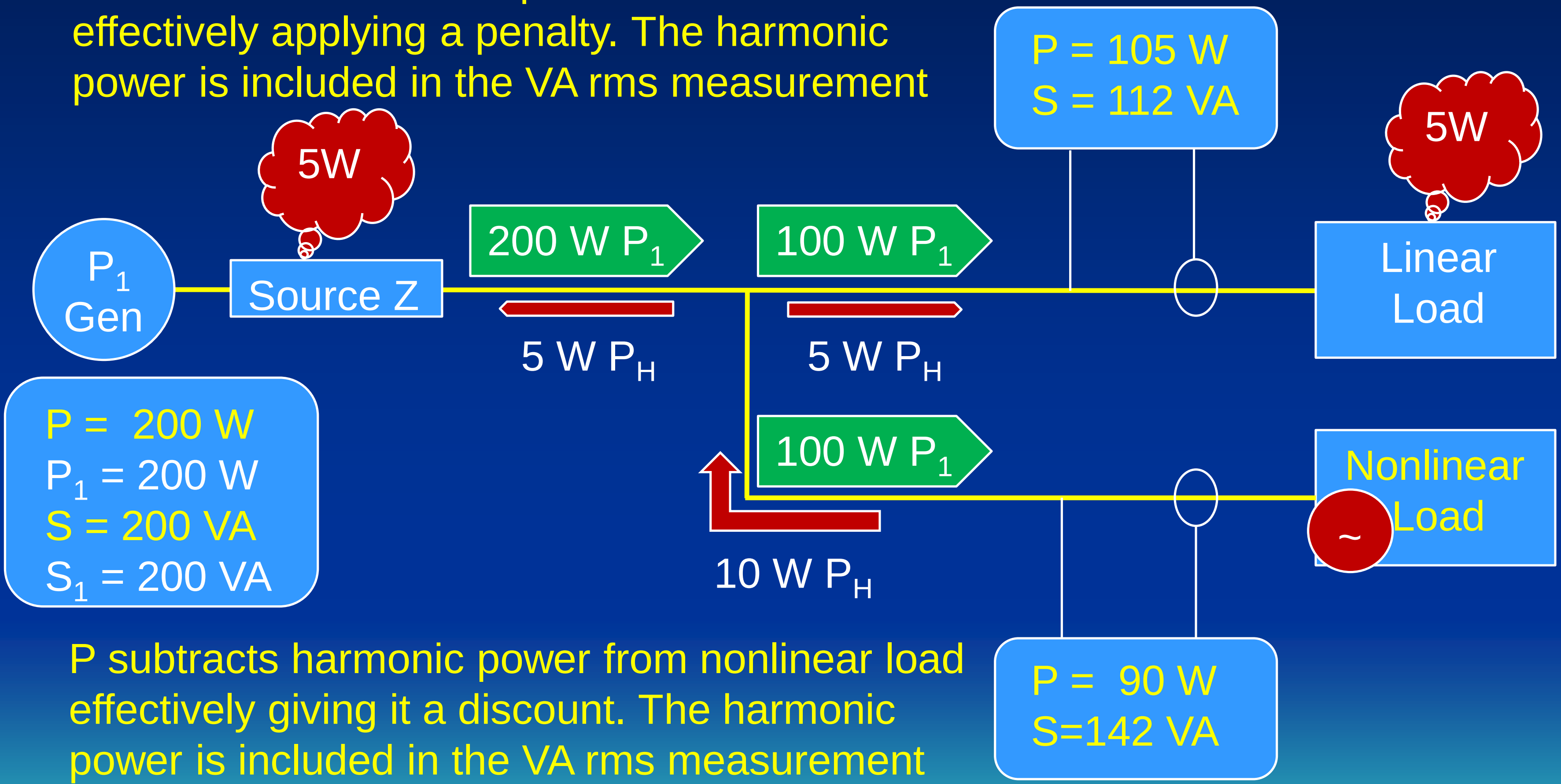
Replace meter with a model
That registers 67% of P_H



Replacing the meter results in a different energy registration for the same load, exceeding accuracy limits.

Harmonic VA Inequity

P meter adds harmonic power for linear load effectively applying a penalty. The harmonic power is included in the VA rms measurement



P subtracts harmonic power from nonlinear load effectively giving it a discount. The harmonic power is included in the VA rms measurement

Types of Inequity

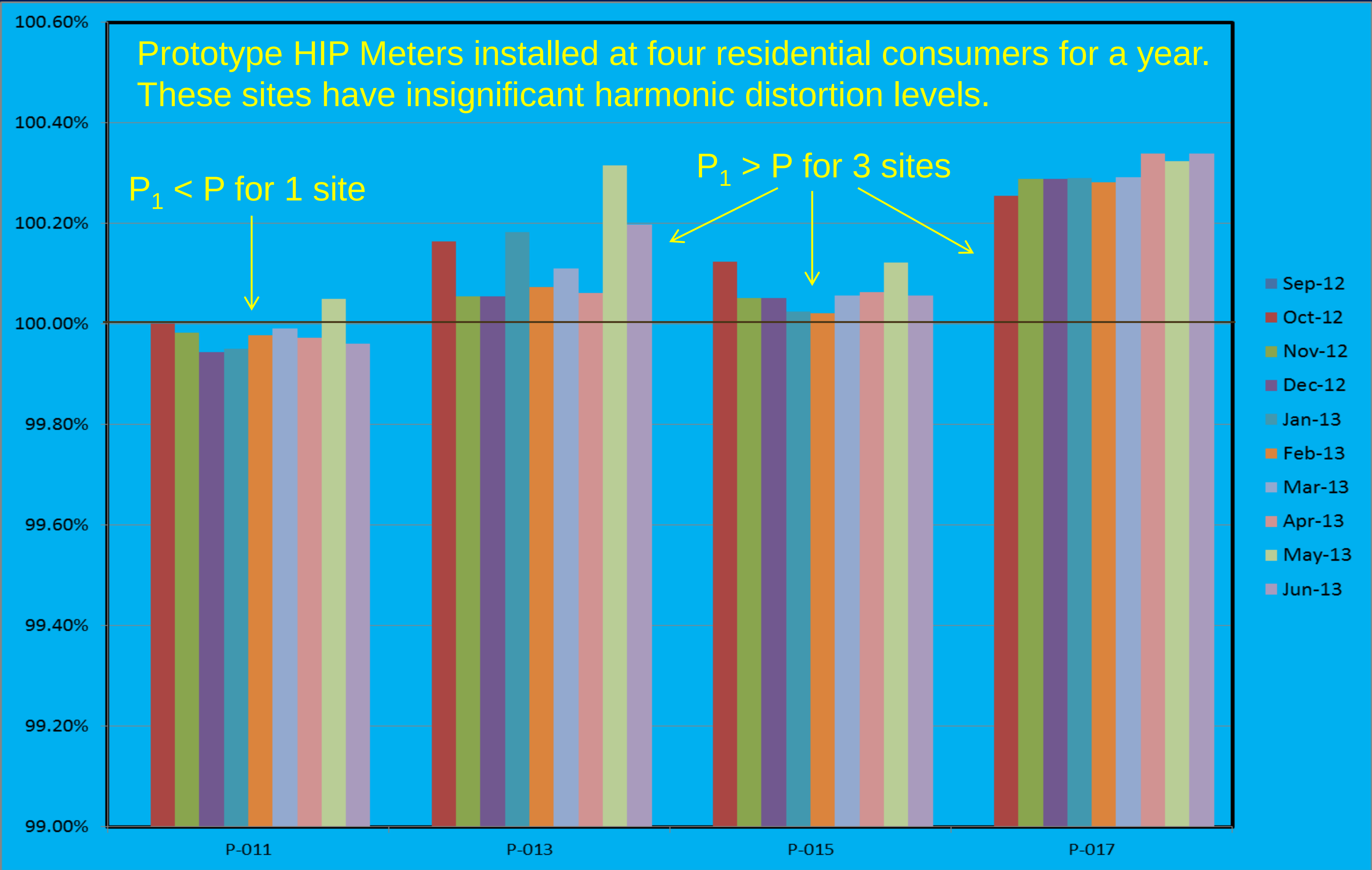
b) *Apparent Power Demand Inequity.*

Different meters applying different definitions or methods for S. This results in inequities:

a) Between consumers on the same rate but with meters that apply different methods.

b) A consumer that gets a meter replaced by another that applies a different method.

Prototype HIP P_1/P Comparison



Excerpt from Andrew Berrisford BC Hydro

Meter D_V (Voltage Distortion Power) and D_I (Current Distortion Power)

Calculate Ratio HF = D_I/D_V (similar to PF = P/S)

If this ratio is one or lower, the consumer is unlikely to be a Significant source of harmonics.

If the ratio is greater than one, the consumer is likely a generator of Harmonics. Apply Penalties like PF penalties, eg:

HF <= 1.1: No HF Penalty
HF > 1.1 but <= 1.2: 1% HF Penalty
HF > 1.2 but <= 1.4: 2% HF Penalty
HF > 1.4 but <= 1.6: 5% HF Penalty

This ratio does not penalise consumer for absorbing harmonics due To background voltage distortion

Electricity Meters

- What will be possible if 1% of meters were sending voltage and current readings every 5 seconds, how about 10% of the meters on the system?
- How well could meters be time synchronized on a feeder? What would that enable?
- Have any utilities looked into using success of IoT implementation at factories dramatic improvements for justifications for sensors in the grid?

Uncalibrated Data from Devices

- Light bulbs, incandescent, CFL, LED, LED desk lamp, power supply
- Laptop computer
- Computer monitor
- Fan
- Soldering iron

PF Measurements

Device	Watts	Power Factor
Incandescent light bulb	63.2	1.00
CFL	47.2	0.59
LED	10.4	0.81
LED	10.1	0.95
LED desk lamp	5.8	0.54
Fan	42	0.93
Laptop computer	23	0.51
PC Monitor	147.5	0.99
PC Monitor	0.9	0.22
Small power supply	34.1	0.74

Harmonics in IEC small appliances

- Some appliance manufacturers areincorporating PFC into their finished products. The European Union’s International Electro-Technical Commission adopted the IEC61000-3-2 standard that required, by Jan. 1, 2001, all equipment needing 75 W of power or greater and less than 16 A to meet standards for harmonic generation and, thus, meet PFC requirements. Thereafter, Britain, China and Japan adopted similar standards.
- North America does not presently have these requirements.

Distributed Renewable Generation

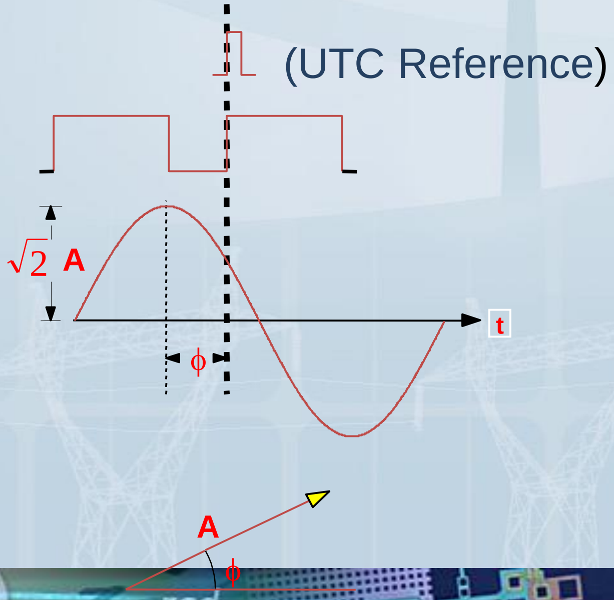
- Distribution scale variable generation (solar, wind) DER
- Duck Curve
- Loads “hidden” by DER
- Possible DC bus in the home?

Transactive Energy

- The term "transactive energy" is used here to refer to techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints. The term "transactive" comes from considering that decisions are made based on a value. These decisions may be analogous to or literally economic transactions. An example of an application of a transactive energy technique is the double auction market used to control responsive demand side assets in the GridWise Olympic Peninsula Project[1]. Another would be the TeMix work of Ed Cazalet[2]. Transactive energy techniques may be localized to managing a specific part of the power system, for example, residential demand response. They may also be proposed for managing activity within the electric power system from end-to-end (generation to consumption) such as the transactive control technique being developed for the Pacific Northwest Smart Grid Demonstration project[3,4]. An extreme example would be a literal implementation of "prices-to-devices" in which appliances respond to a real-time price signal.
- The current situation is that dynamic pricing is widely used in the wholesale power markets. Balancing authorities and others operations such as hydro desks routinely trade on the spot market to buy or sell power for very near term needs. In addition, dynamic pricing tariffs are being tried in a number of retail markets, for example, the PowerCentsDC dynamic pricing pilot[5].

Phasor and SynchroPhasor

- A Phasor is the complex form of an AC waveform (magnitude with a phase)
- GPS used to Reference All Grid Phasors to UTC
- SynchroPhasor standard IEEE C37.118



Points to Consider

- Measurement time can give different results depending on the waveforms
- Measurement algorithm can give different results depending on the waveforms
- Application may have assumptions about the algorithm and measurement time that are incorrect

What about automatic grid control?

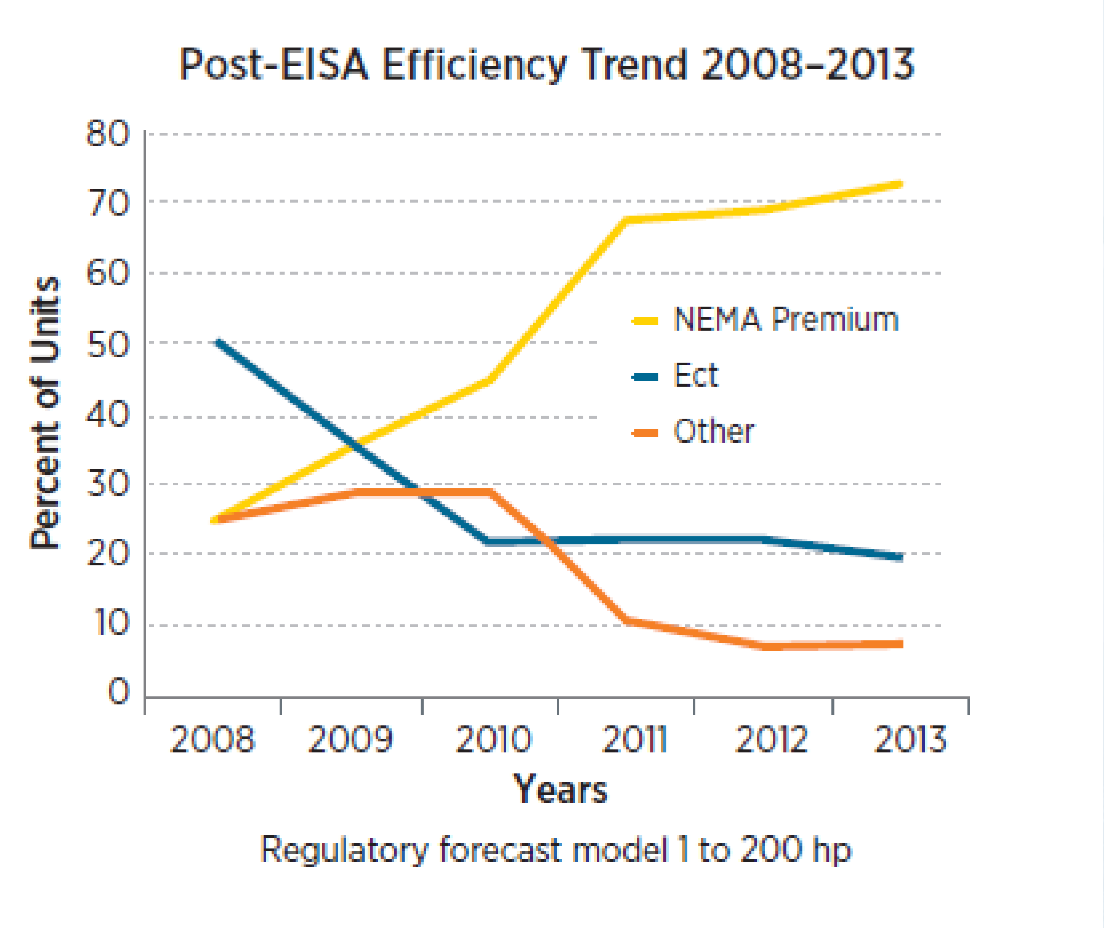
- Algorithm differences may cause more issues if you are using output of meter (sensor) used by automated grid control and the assumptions the controller has about the data coming into it

Standards Come From Many Sources

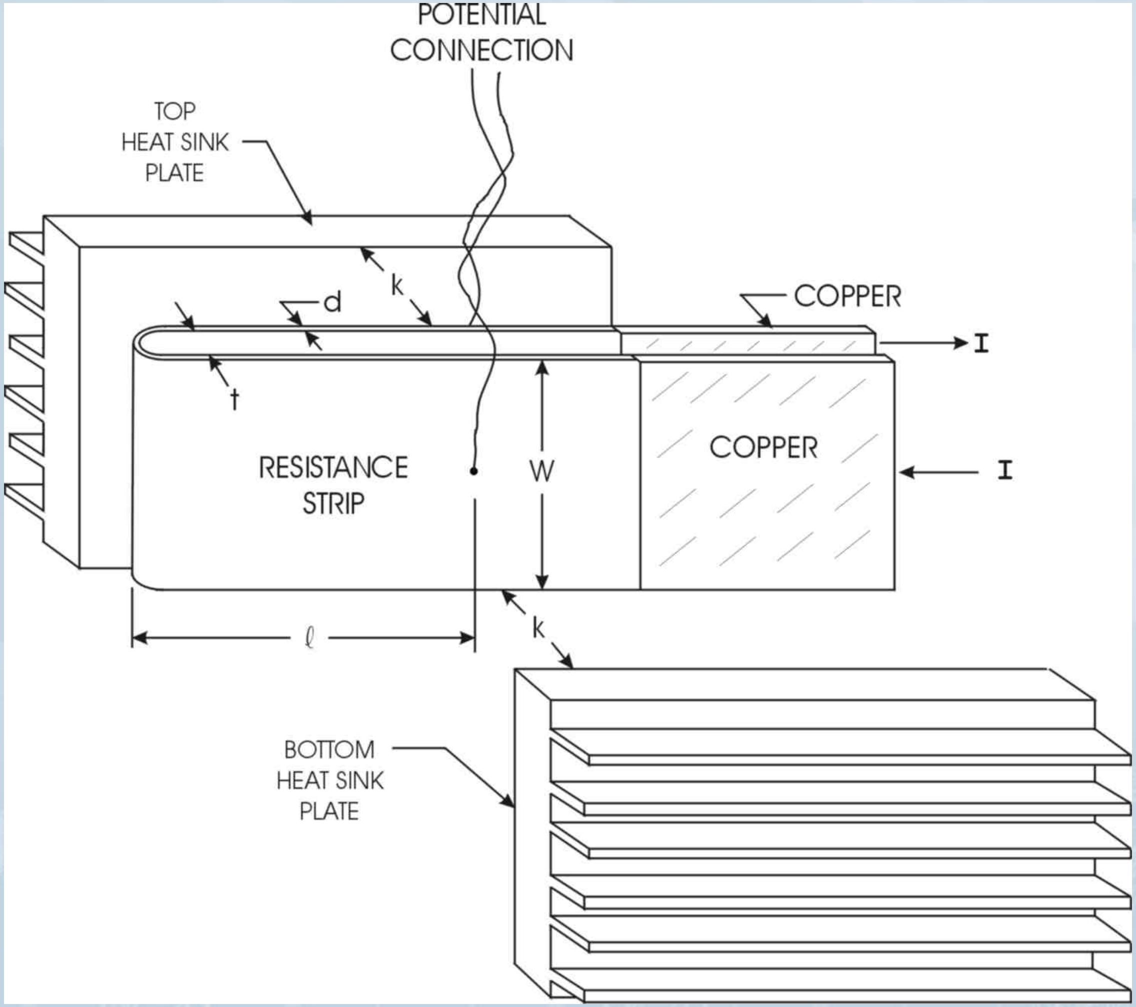
International

Global Consortia

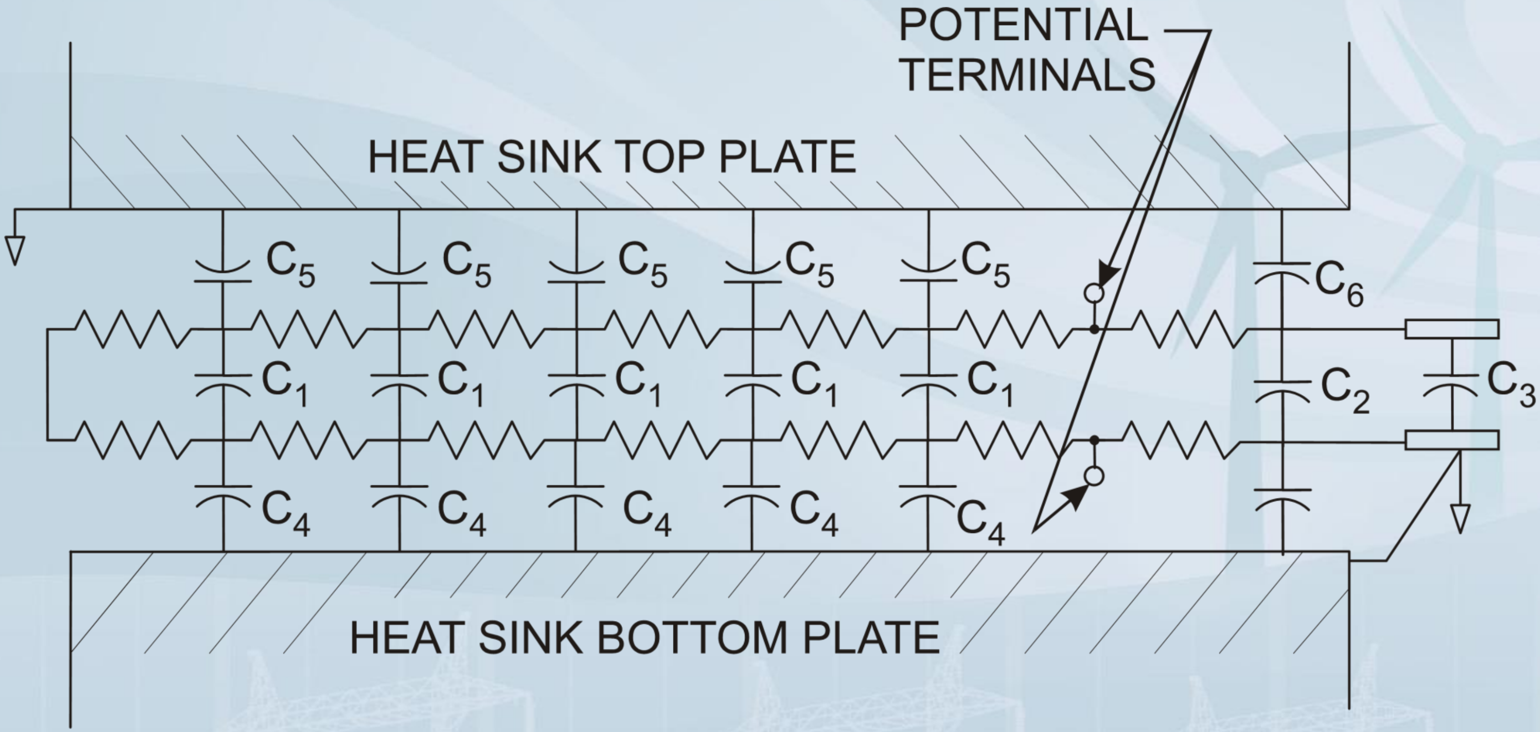
Regional and National


Post-EISA Efficiency Trend 2008–2013
Percent of Units
80
70
60
50
40
30
20
10
0
NEMA Premium
Ect
Other
2008
2009
2010
2011
2012
2013
Years
Regulatory forecast model 1 to 200 hp

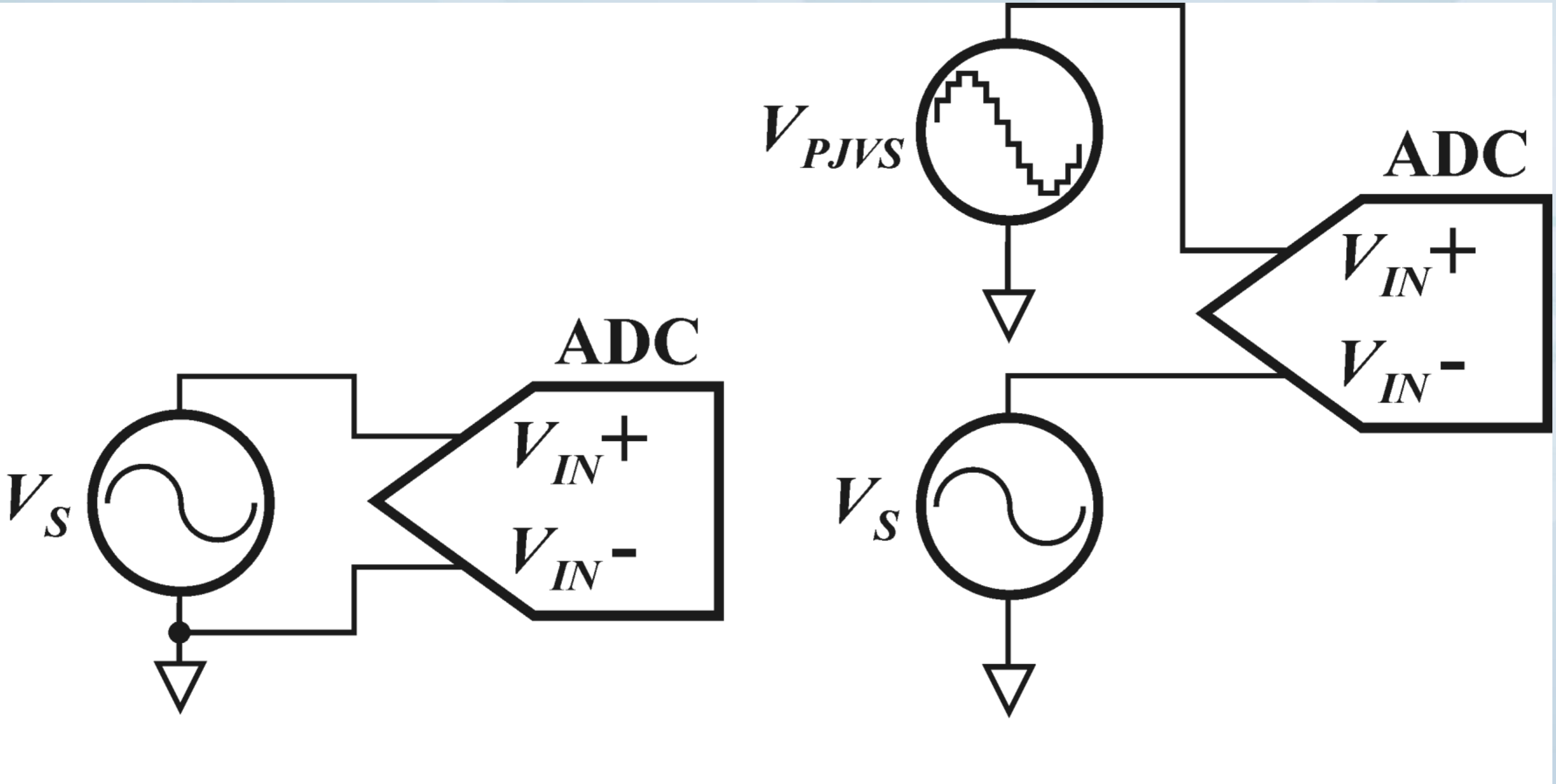
Bifilar shunt design



Bifilar shunt circuit model



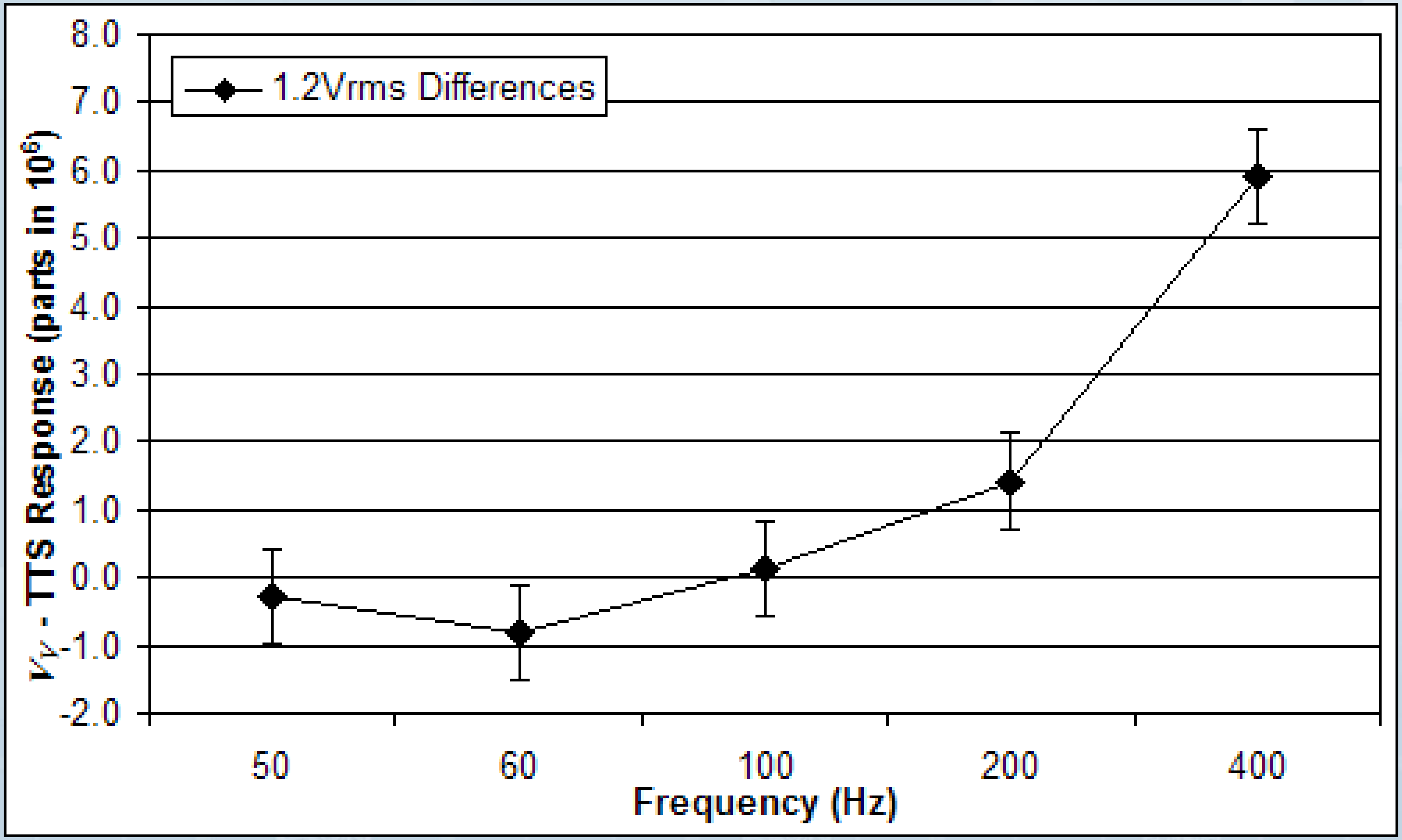
How do we generate and measure V, I, θ ?



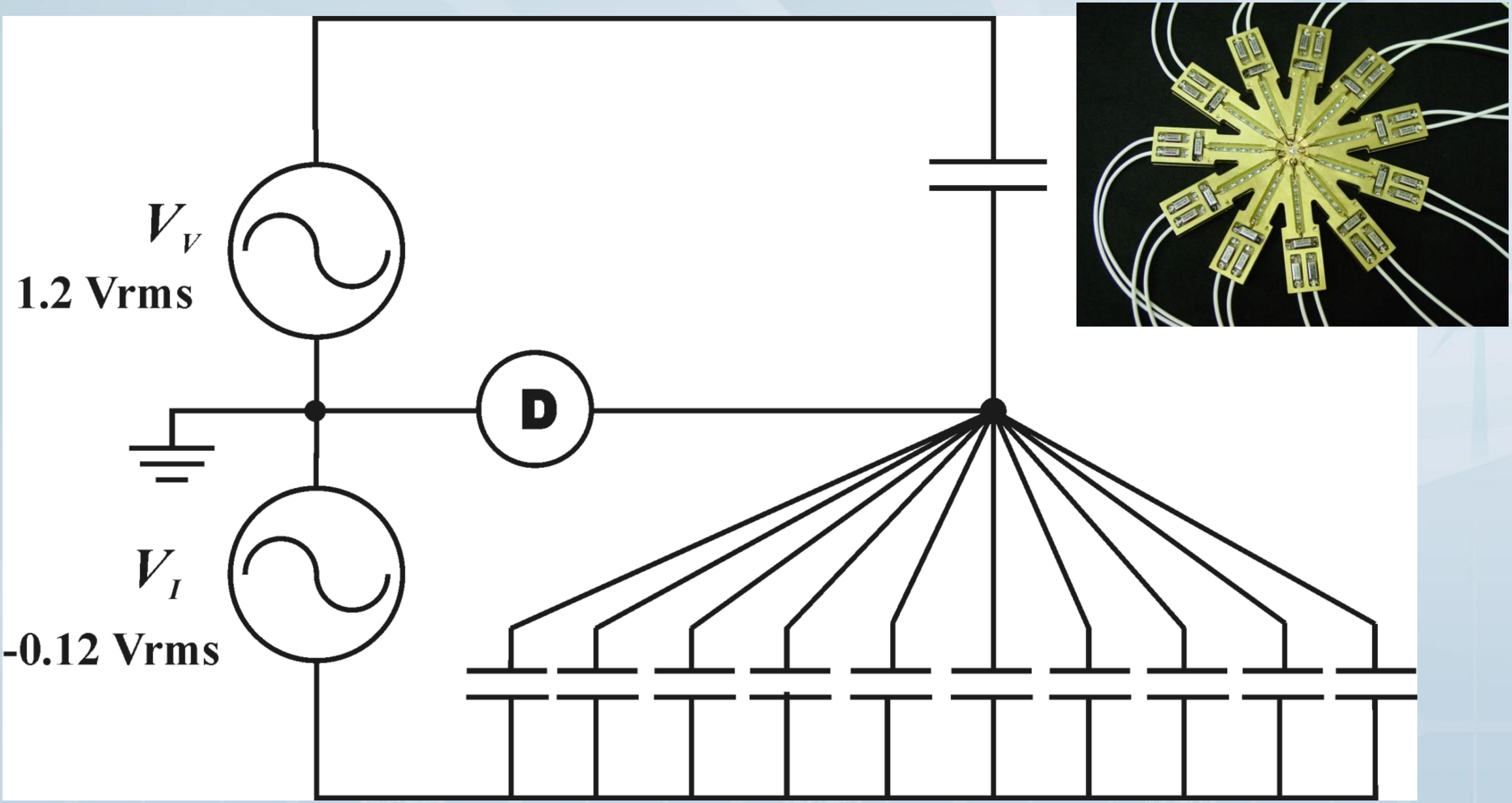
(a) Normal Mode Sampling

(b) Differential Mode Sampling

Agreement between PJVS-referenced signal generation and a thermal transfer standard (TTS)



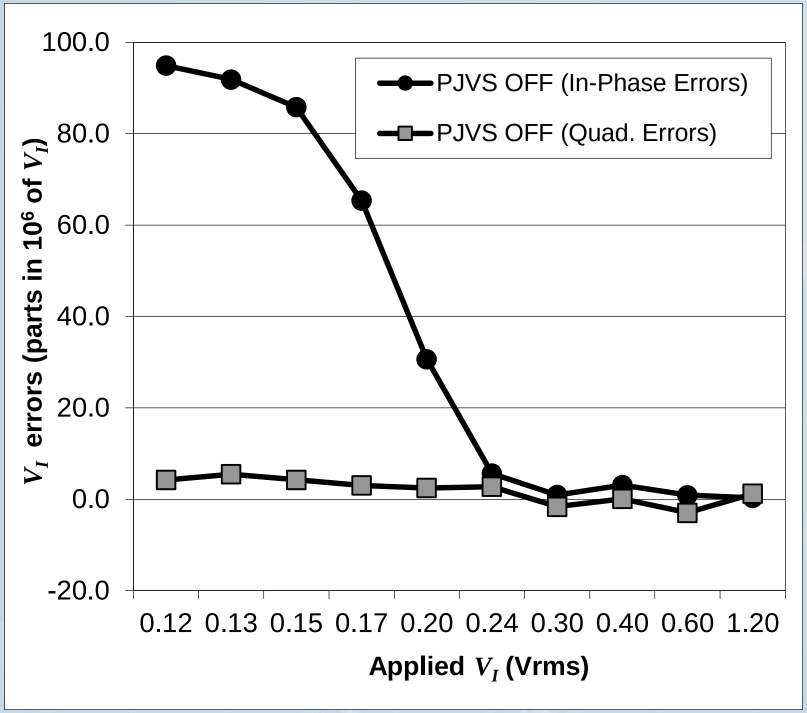
Permuting capacitance measurements of V_V / V_I ratios and voltage amplifier gain/phase.

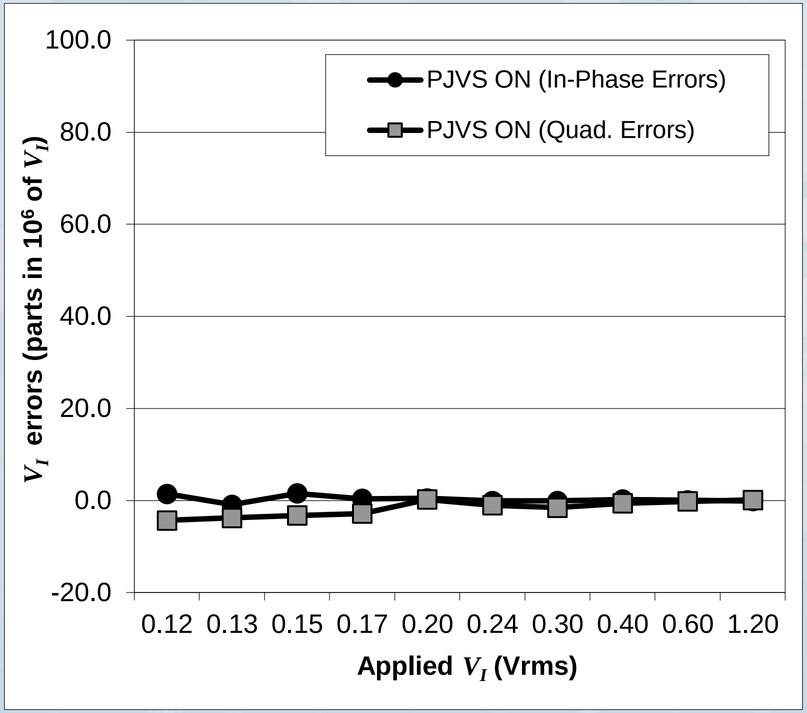


Current circuit

- Current transducer based on a 0.1 Ω shunt
- Bifilar shunt (based on Laug, Souders (NIST) design)
- AC characteristics known
- Temperature-controlled (< 1 μΩ/Ω from 0.1 – 10 A)
- Long term stability of better than 0.2 μΩ/Ω /year (traceable to the QHR)
- 3-Stage, amplifier-aided, 1:1 voltage transformer (based on Miljanic, So, Moore (NRC) design) to reject the common-mode voltage at the shunt output (negligible error contribution, determined in-situ)

Direct sampling vs. differential sampling V_V / V_I ratio





Bifilar shunt frequency response