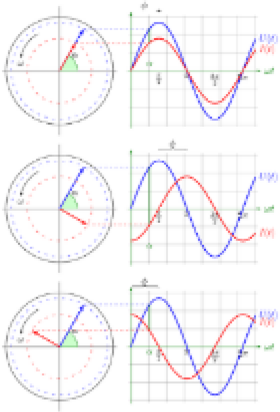
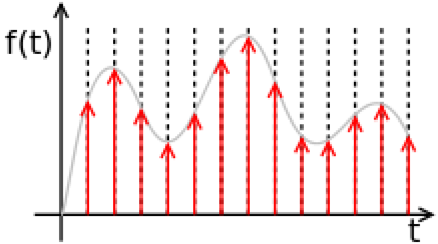


$$f(t) = \mathcal{L}^{-1}\{F\}(t) = \frac{1}{2\pi i}\lim_{T\to\infty}\int_{\gamma-iT}^{\gamma+iT} e^{st}F(s)\,ds,$$

$$z \stackrel{\text{def}}{=} e^{sT}, \quad x[n] \stackrel{\text{def}}{=} x(nT)\,. \quad X(z) = \sum_{n=0}^{\infty} x[n] z^{-n}$$



Electricity Metering: Discs to Digital…

Author: Chris Ailey

Role: Verification & Validation Architect

Date: October 19th, 2017

30 mins

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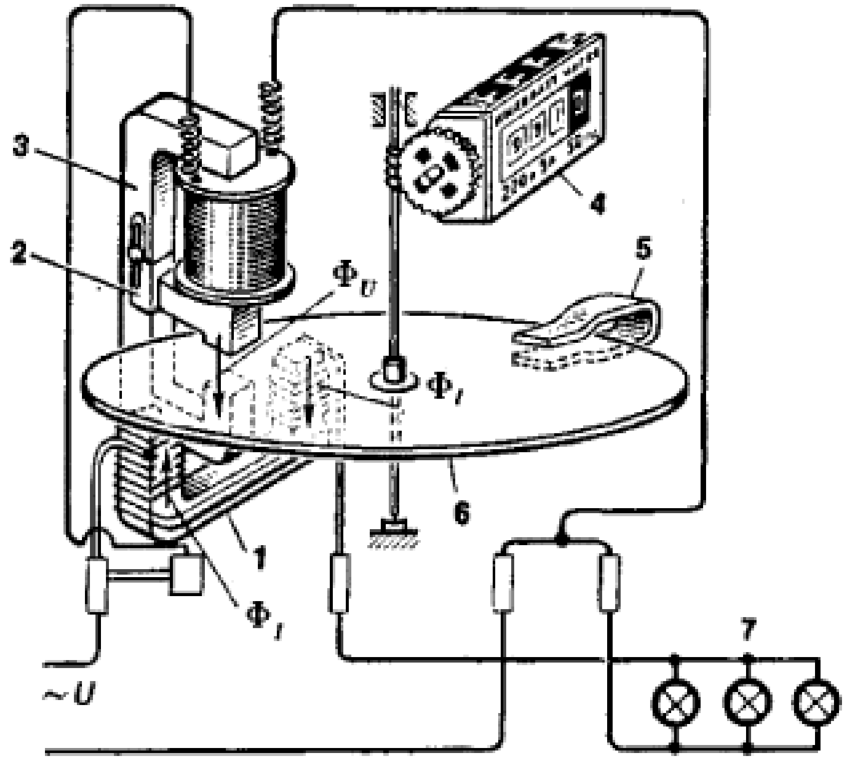
Electricity Metering: Discs to Digital …

- **Overview**
  - Electro-mechanical vs digital meters
  - Costs and benefits of going digital
  - International metrological committees
  - Evolution of metering standards
  - International approaches to revenue metering
- **Changing landscape of metering**
  - Technological developments and challenges
  - Implications of IoT and renewables
- **A Bright Future for Metering !!**
  - Technological promise and the challenges ahead …

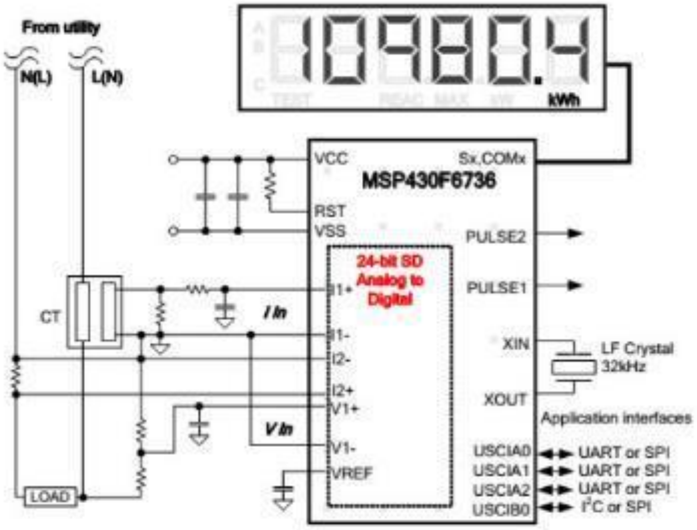
Electricity Metering: Discs to Digital …

- **Mechanical Electricity Metering**
  - Disc spin indicates energy consumption rate
    - Kh [Wh/rev] traditionally
  - Inducing eddies in disk cause it to rotate - Lenz's Law
  - Not easy to re-configure
  - Limited number of metrics
  - Manual read of register
  - Remote communications or pulse train generation requires add-on modules
  - Traditionally, no on-board clock or calendar



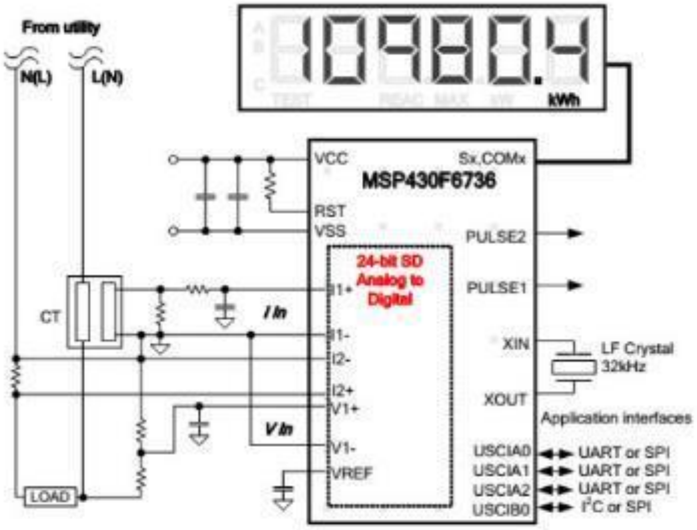
Electricity Metering: Discs to Digital …

- **Digital Electricity Metering**
- Transducers and digital sampling
- Easy to configure for a specific installation
  - Change CT/PT ratios, Different service types etc.
- Numerous metric algorithms
  - Energy, inst. power, voltage, current, PF, harmonics etc.
- Electrical pulse train indicates energy consumption rate
  - Kh [Wh/impulse] or [impulses/kWh]
- Native Communications functions
  - Supporting multiple protocols requires only FW
- High accuracy digital time reference



Electricity Metering: Discs to Digital …

- **Digitizing the Signals**
  - Transducers generate low voltage measurements
    - Voltages – Simple resistive voltage dividers
    - Currents – CTs, Hall effect sensors, Rogowski coils etc.
- **LV signals are sampled periodically by an Analog to Digital converter (A/D)**
  - Heuristic is to sample at least twice the maximum frequency in the signal
  - Anti-aliasing filters prevent “folding back” of high frequency samples
- **Samples are then input into algorithms which generate the power quality metrics**
  - RMS values, Power Factor, harmonics etc.
  - Energy values are derived by integrating or summing power values over “discrete” time



Electricity Metering: Discs to Digital …

- **Mechanical Meters**
  - Typically Class 1, 2 or 5 only
  - No waveform capture capability
  - Limited harmonic influence verification
  - No harmonics measurement capability
  - Traditionally manual register reads or pulse counting

- **Digital Meters**
  - Class 0.1, 0.2 and 0.5
  - Waveform capture and analysis
  - Wide harmonic measurement range
  - Power quality metrics
  - Register(s) available over communication channel(s)

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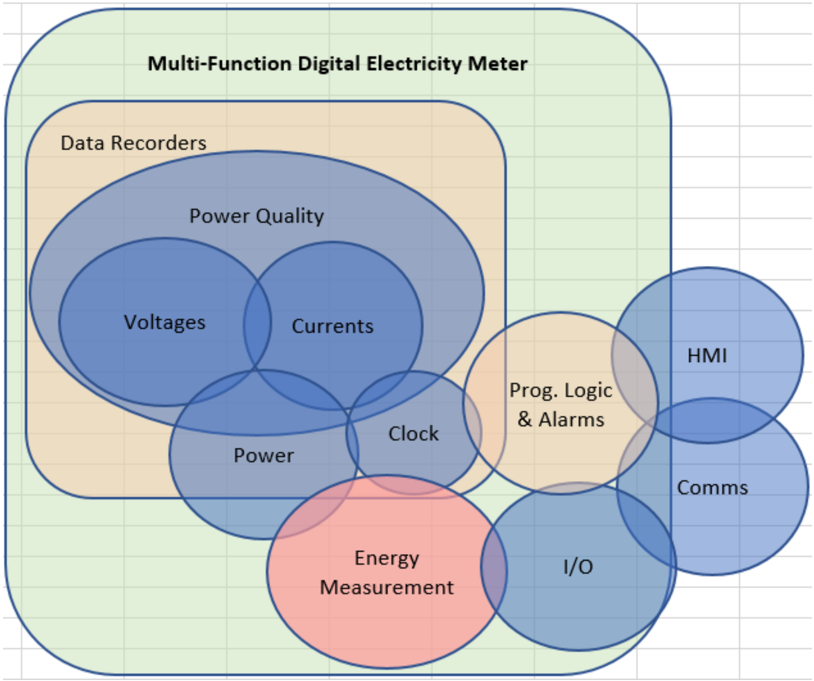
Electricity Metering: Discs to Digital …

- **Multi-Functions … More than a Meter**
  - Basically industrial grade computers under glass
  - Power quality metrics
  - On-board data recorders provides trending information
  - Communications through numerous protocols and channels
  - Digital and analog I/O integration
  - On board memory and data recorders
  - State machine programmability
- **Increasing complexity has it trade-offs**
  - Sealing and anti-tampering provisions
  - Cyber-security provisions like encryption and RBAC



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Electricity Metering: Discs to Digital …

Metrology - Guide to the Expression of Uncertainty in Measurement (GUM)

- **Joint Committee for Guides in Metrology (JCGM)**
  - Developed by internationally recognized institutes
    - BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML
- **Covers any Metrological measurements**
  - Type A vs Type B measurement methods
  - Moving away from the idea of “true value” and “absolute error”
  - Now random and systemic uncertainties
  - Combination of uncertainties based on individual probability distributions
- **Approach is for measurement value reported with uncertainty and confidence interval**
  - Allows for better alignment of results from different laboratories

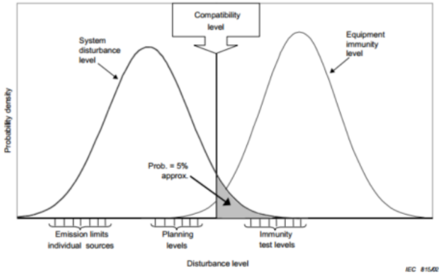
$$v = 2 * \sqrt{\frac{v_{base}^2}{4} + \frac{v_{voltage}^2}{4} + \frac{v_{frequency}^2}{4} + \frac{v_{unbalance}^2}{4} + \frac{v_{harmonic}^2}{4} + \frac{v_{temperature}^2}{4}}$$

$$e_c = 2 * \sqrt{\frac{e_{base}^2}{3} + \frac{e_{voltage}^2}{3} + \frac{e_{frequency}^2}{3} + \frac{e_{unbalance}^2}{3} + \frac{e_{harmonic}^2}{3} + \frac{e_{temperature}^2}{3}}$$

Electricity Metering: Discs to Digital …

Standards – Scope of Type Testing

- **Numerous applicable standards**
  - ANSI C12.20 – 2015
  - IEC 62052-11 and IEC 62053-22 (ed.2 2018)
  - OIML R46
- **Generic Scope**
  - Accuracy & repeatability with Influence quantities
  - Mechanical, environmental and durability
  - EMC & Safety
- **Class 0.1 performance definition in latest versions of both ANSI and IEC standards**



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Electricity Metering: Discs to Digital …

Standards – ANSI Scope of Testing

- **ANSI C12.20 – 2015 now has 44 tests !!**
  - **6 more** over and above the 2010 edition
  - Accuracy Class 0.1 definition
- **Test scope**
  - Accuracy over range and influence quantities
  - EMC & Safety
  - Mechanical and environmental
- **New accuracy tests for waveforms**
  - Shark-Fin, Quadiform, Peaked and Pulse
  - Multiple zero crossings on current and voltage

ANSI C12.20	Descriptions Of Certification Tests
Test #1	No Load
Test #2	Starting Load
Test #3	Load Performance
Test #4	Effect of Variation of Power Factor
Test #5a or 5b	Effect of Variation of Voltage
Test #6	Effect of Variation of Frequency
Test #7	Equality of Current Circuits
Test #8	Internal Meter Losses
Test #9	Temperature Rise
Test #10	Effect of Register Friction
Test #11	Effect of Internal Heating
Test #12	Effect of Tilt
Test #13	Stability of Performance
Test #14	Effect of Polyphase Loading
Test #15	Insulation
Test #16	Voltage Interruptions
Test #17	Effect of High Voltage Line Surges
Test #18	Effect of External Magnetic Field
Test #19	Effect of Variation of Ambient Temperature
Test #20	Effect of Temporary Overloads
Test #21	Effect of Current Surges in Ground Conductors
Test #22	Effect of Superimposed Signals
Test #23	Effect of Voltage Variation-secondary Time Base
Test #24	Effect of Variation of Ambient Temperature -Secondary Time Base
Test #25	Electrical Fast Transient/Burst
Test #25a	Effect of electrical oscillatory SWC test
Test #26	Effect of Radio Frequency Interference
Test #27	Radio Frequency Conducted and Radiated Emission
Test #28	Effect of Electrostatic Discharge (ESD)
Test #29	Effect of Storage Temperature
Test #30	Effect of Operating Temperature
Test #31	Effect of Relative Humidity
Test #32	Mechanical Shock
Test #33	Transportation Drop
Test #34	Mechanical Vibration
Test #35	Transportation Vibration
Test #36	Weather Simulation
Test #37	Salt-spray
Test #38	Rain-tightness
Test #39	90 Degree Phase Fired Waveform
Test #40	Quadriform Waveform
Test #41	Peaked Waveform
Test #42	Pulse Waveform
Test #43	Multiple zero crossings on current
Test #44	Multiple zero crossings on voltage

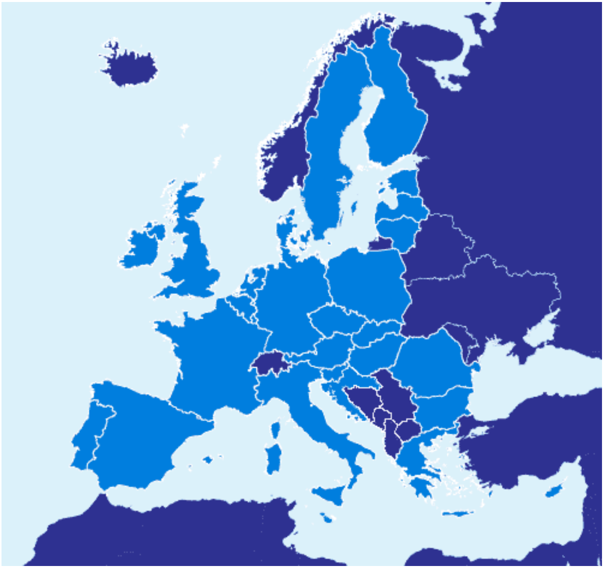
Electricity Metering: Discs to Digital …

Revenue Metering – International Approaches

- **Measurement Instrument Directive (MID)**
  - Applicable in EU member states (28) + others
  - Directive outlines the legal essential requirements for all instruments
  - EN50470 series of harmonized standards
  - Max Permissible Error (MPE) is a combination of uncertainties
  - Includes software requirements to ensure data integrity
- **Requirements also for the production facility**
  - ISO 9001 and EN 52058-31 requirements
  - Annual audits of manufacturing
- **Resealing period varies by country** (5 to 20 years)
- **Onus of correct commissioning resides with installer**
  - Training requirements vary by country .. See WELMEC website

CENELEC

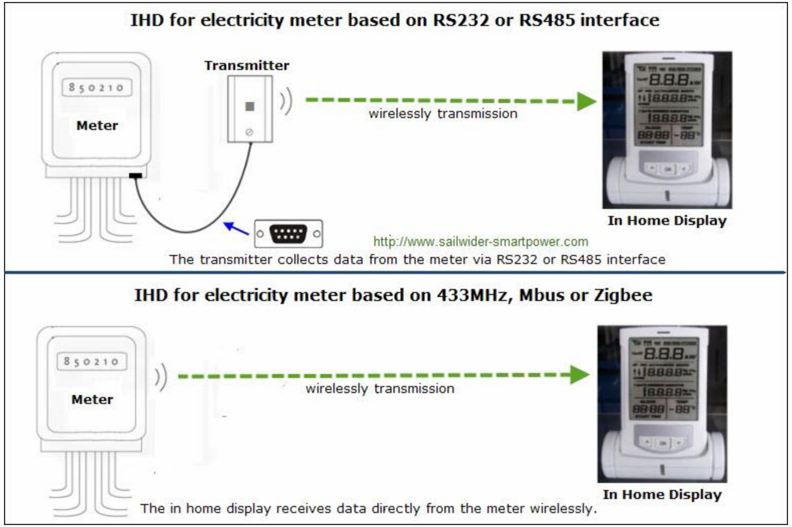
WELMEC
European cooperation in legal metrology



Electricity Metering: Discs to Digital …

The Future - Revenue Metering

- **ANSI C12.1 was first ratified in 1910**
- **Legislation always lags the technological potential** … **but there has been progress:**
  - Measurement Canada now has a specification to address remote displays (PS-E-17)
  - WELMEC (MID app guides) has a new guide (11.7) for a modular evaluation active energy meters
- **Potential revenue meter designs with customer demand today**
  - Single remote display for a number of metering points (tenant sub-metering, branch circuit monitoring etc.)
  - De-coupling of the voltage and current measurement channels
- **Why does a revenue meter require a local display ?**



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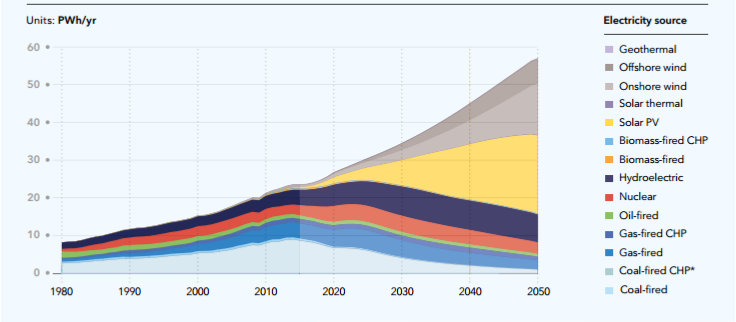
Electricity Metering: Discs to Digital …

The Future - PQ storm on the horizon

- **Inverter “rich” generation is a new presence on the grid**
  - Proliferation of renewables forecast to continue
  - Inverter switching can spectrally “pollute” the mains
  - Can negatively effect equipment operations and lifetimes
  - New immunity requirements for 2-150kHz for meters (EN 50579)
- **PQ analysis like EN50160 and IEEE519 at more PCCs**
  - Trend in both of these standards has increasing bandwidth
    - EN50160 has increased from 25^{th} to 40^{th} harmonic (2.4kHz)
    - IEEE519 has increased from 35^{th} to 50^{th} harmonic (3kHz)
- **Given the trends, its reasonable to expect the PQ measurement bandwidth to continue to broaden**

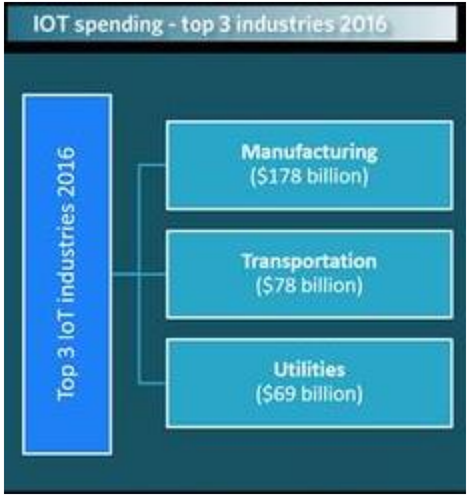
FIGURE 6. WORLD ELECTRICITY GENERATION BY SOURCE



Electricity Metering: Discs to Digital …

The Future – Internet of Things

- **Explosion in the number of connected devices**
  - Forecasts project 30 billion devices by 2020
- **Its really all about providing more customer value**
  - Turing data into actionable information
  - Modelling and automating more scenarios



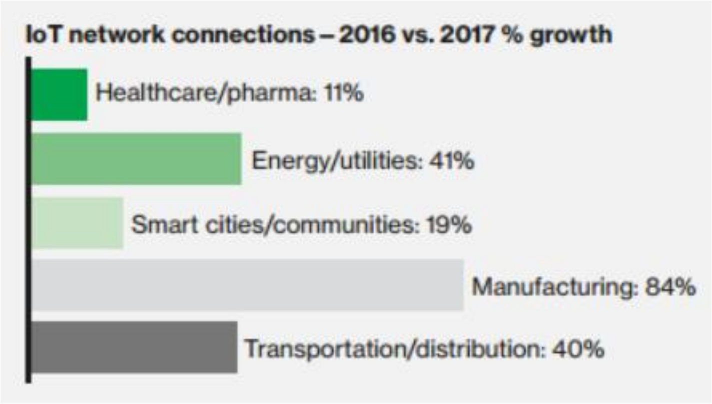
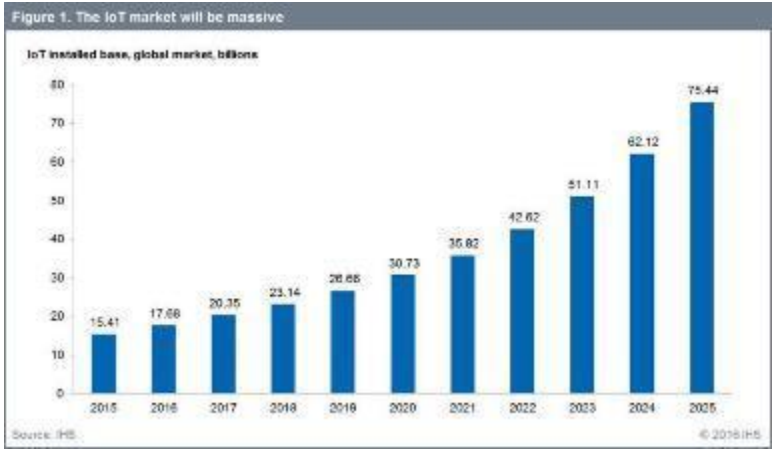


Figure 1: Year-on-year growth in Verizon IoT network connections



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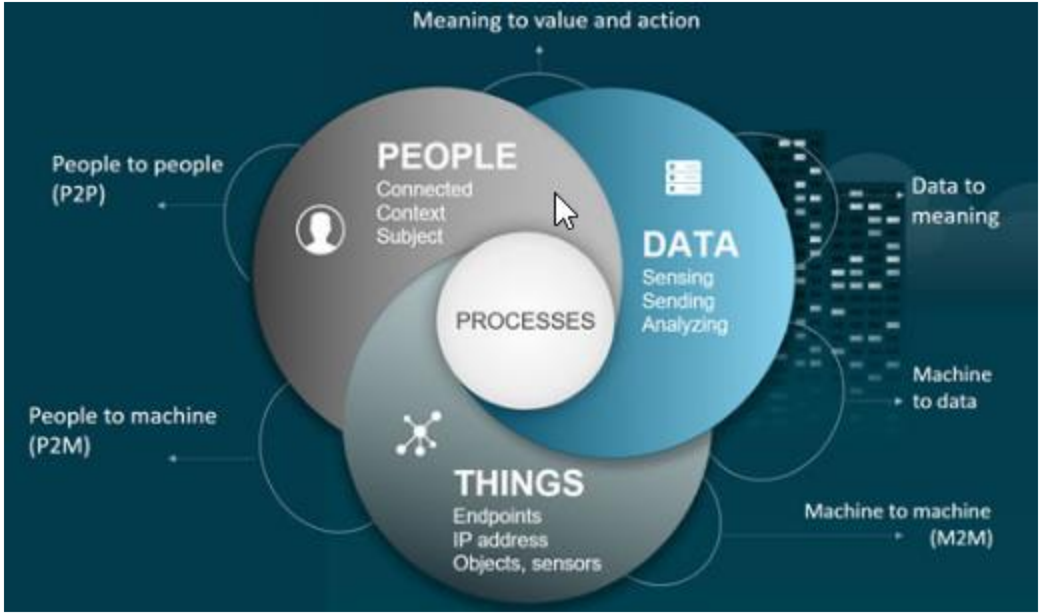
Electricity Metering: Discs to Digital …

The Future – Metering, IoT and PQ synergy

- The Future of Metering is Bright ! ! !
- The shifting landscape will provide numerous opportunities
- The revenue meter is another device in the evolving spiral of the Internet of Things



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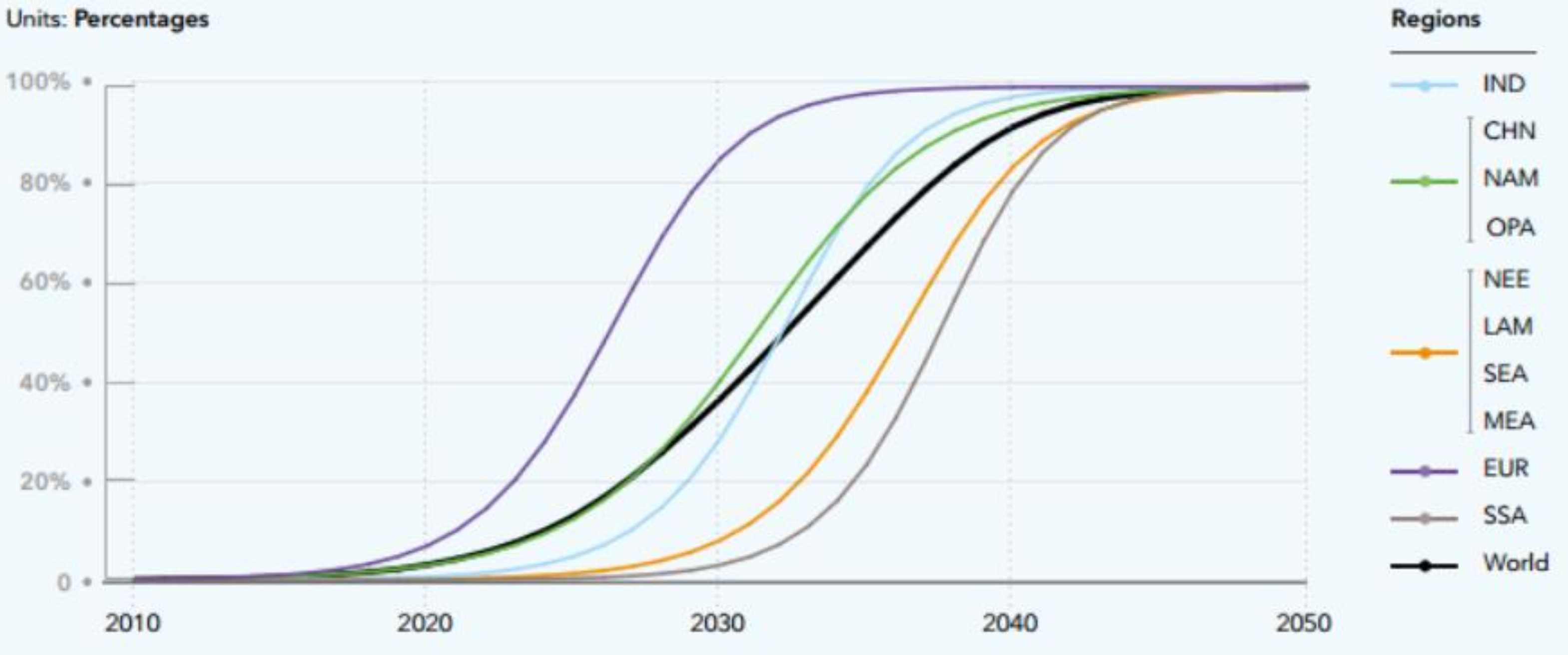
Thank-You !!

Any Questions ?

FIGURE 3. MARKET SHARE OF ELECTRIC VEHICLES IN NEW LIGHT VEHICLE SALES



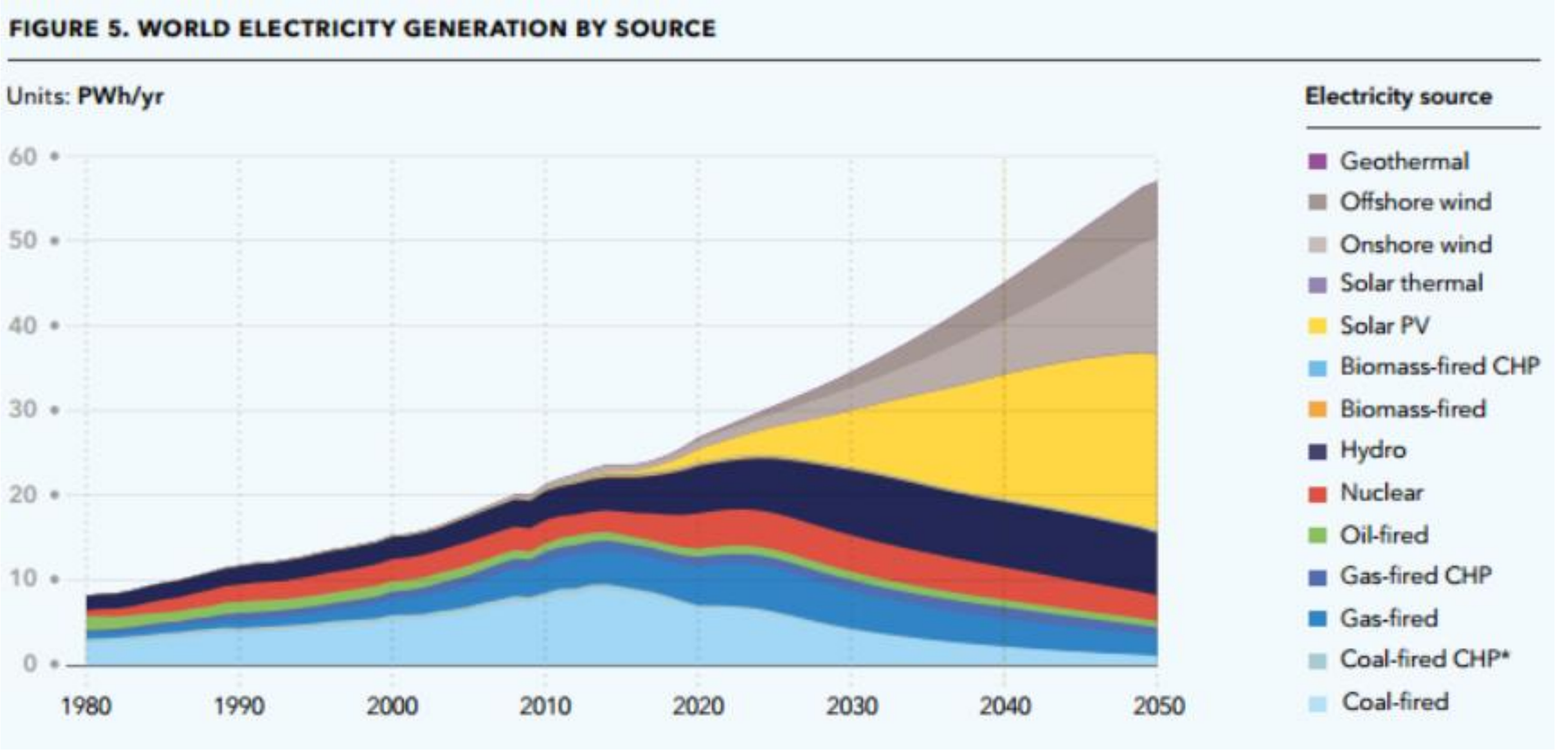
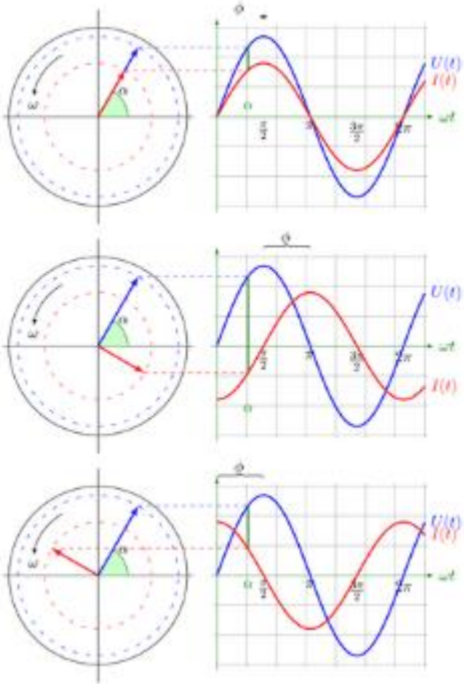
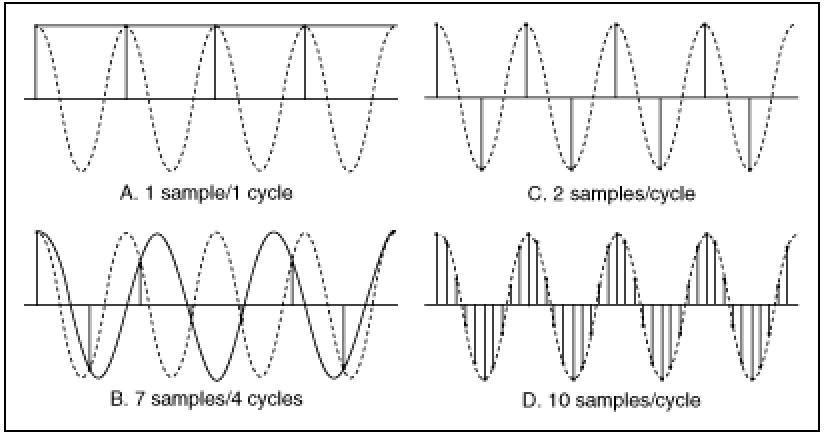


FIGURE 5. WORLD ELECTRICITY GENERATION BY SOURCE
Units: PWh/yr
60
50
40
30
20
10
0
1980
1990
2000
2010
2020
2030
2040
2050
Electricity source
Geothermal
Offshore wind
Onshore wind
Solar thermal
Solar PV
Biomass-fired CHP
Biomass-fired
Hydro
Nuclear
Oil-fired
Gas-fired CHP
Gas-fired
Coal-fired CHP*
Coal-fired

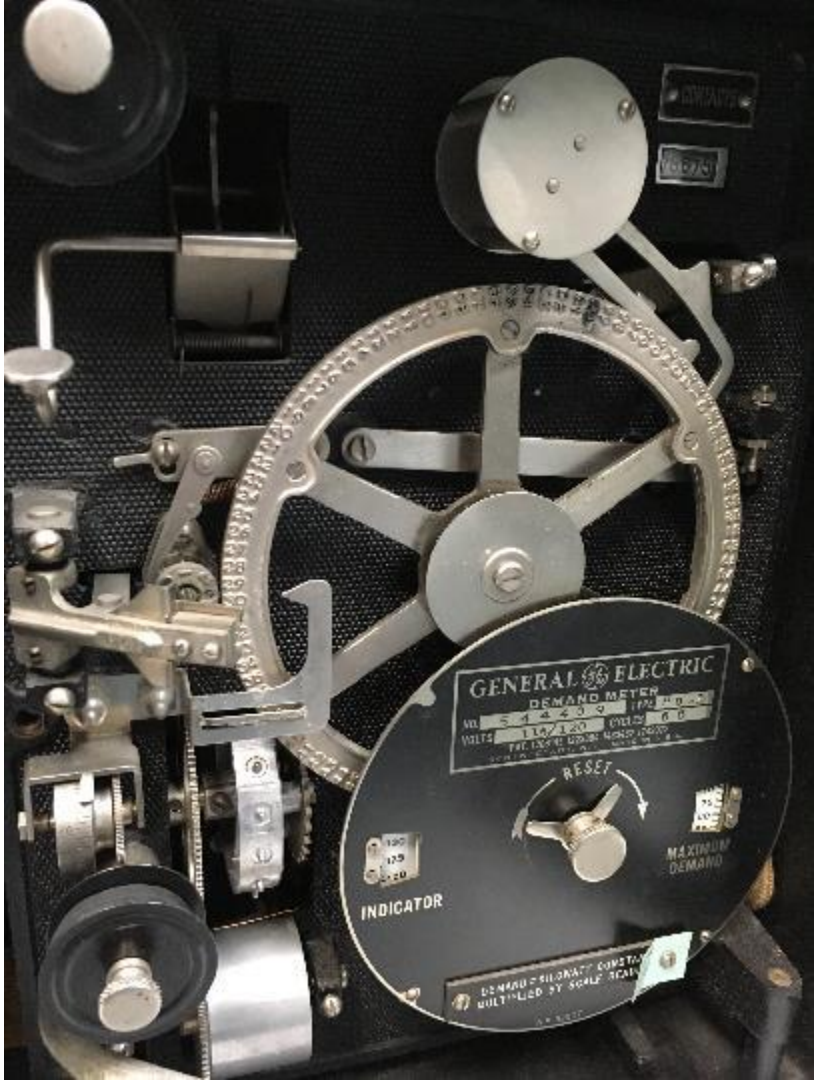

U(t)
I(t)
ωt


KILOWATT HOURS


A. 1 sample/1 cycle
C. 2 samples/cycle
B. 7 samples/4 cycles
D. 10 samples/cycle


KILOWATT HOURS
TEST DIAL


VOLTS.
MODEL 240
No
WESTON ELECTRICAL INSTRUMENT CO.
NEWARK, N.J. U.S.A.
AMPERES.
PATENTED
ADJUST FOR ZERO
OTHER PATENTS PENDING.


GENERAL ELECTRIC
DEMAND METER
RESET
MAXIMUM DEMAND
INDICATOR


kWh
MULT. X 2400
DS-63
2 ELEM.
0.12-10 A.
Khs 1.2
120 V.
60 Hz
P.T.
C.T.
Khp
4306751
CANADIAN GENERAL ELECTRIC
QUÉBEC, P.Q.