Build4Asia Conference 2016

Energy and Information Correlation

Ir Dr F.C. Chan

5 May 2016

Energy and Information Correlation

- Thermodynamics Laws
- Szilard's Engine
- Information Thermodynamics
- History of Energy and Information
- Energy and Information Correlation
- Sustainable Development
- Conclusion

Thermodynamics Laws

- **Thermodynamics is the study of the effects of work, heat and energy on a system**

- **All of thermodynamics can be expressed in terms of four quantities**
  - **Temperature (T)**
  - **Internal Energy (U)**
  - **Entropy (S)**
  - **Heat (Q)**
  - **Work (W)**

The First Law of Thermodynamics

- **Thermodynamics is the study of the effects of work, heat and energy on a system**

- **The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.**

$$\Delta U = Q - W$$

Adiabatic Process Q=0 No Heat Transfer
Isothermal Process Constant Temperature
Isobaric Process Constant Pressure
Isochoric Process Constant Volume

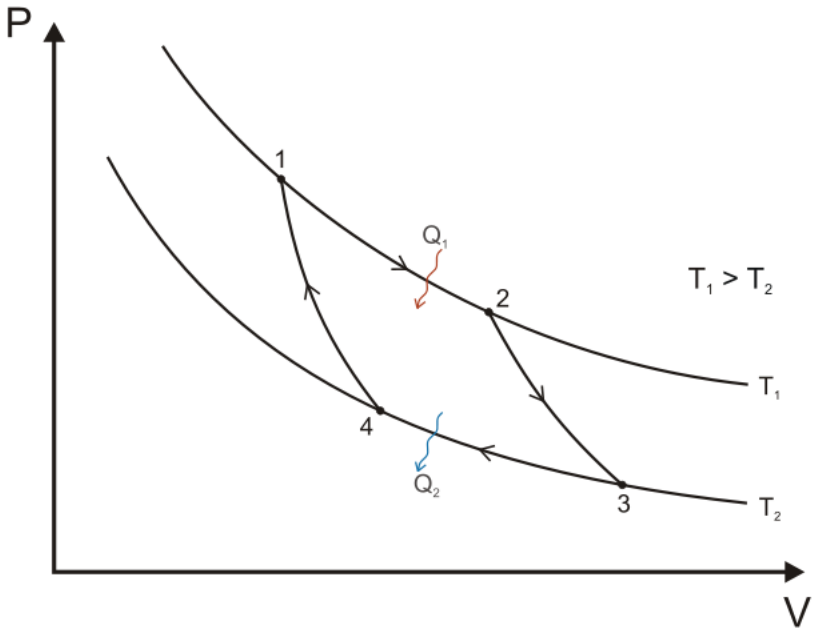
The Second Law of Thermodynamics

- Heat flows spontaneously from a hot object to a cold object
- The second law of thermodynamics introduces the notion of entropy (S), a measure of system disorder
- U is the quantity of a system's energy and S is the quality of a system's energy
- A device which transforms heat into work is called a heat engine

The Second Law of Thermodynamics

- **A device which transforms heat into work is called a heat engine**

- **Carnot Cycle (The area under the PV curve represents the quantity of work done in a cycle)**



- **Curve A (1 → 2): Isothermal expansion at T_H**
  - **Work done *by* the gas**
- **Curve B (2 → 3): Adiabatic expansion**
  - **Work done *by* the gas**
- **Curve C (3 → 4): Isothermal compression at T_C**
  - **Work done *on* the gas**
- **Curve D (4 → 1): Adiabatic compression**
  - **Work done *on* the gas**

The Second Law of Thermodynamics

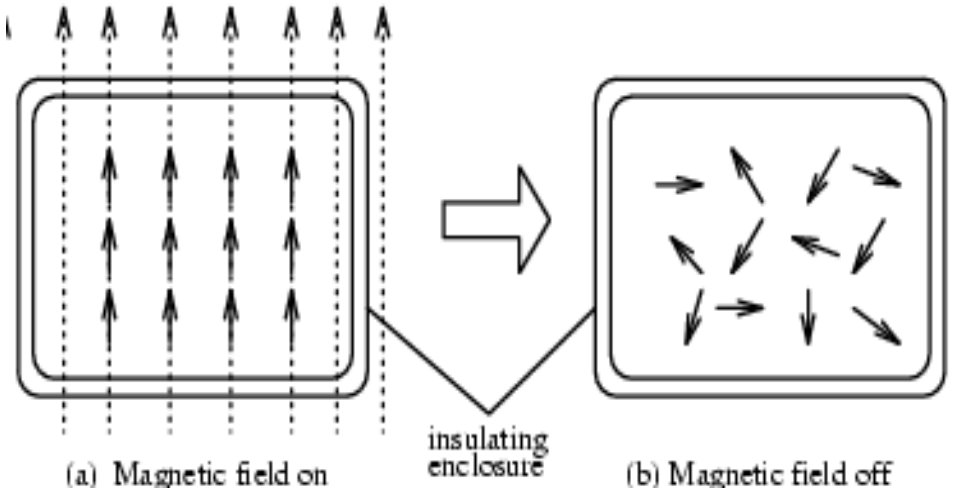
- **Heat engines require a hot reservoir to supply energy (Q_H) and a cold reservoir to take in the excess energy (Q_L)**
- **The thermal efficiency η of a heat engine is**

$$\eta = 1 - Q_L/Q_H$$

- **It is impossible for any system to have an efficiency of 100% (η = 1)**
- **It is impossible for any process to have as its sole result the transfer of heat from a cooler object to a warmer object.**

The Third Law of Thermodynamics

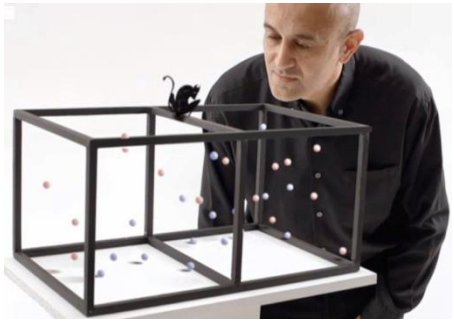
- **No system can reach Absolute Zero Temperature**
- **MIT researchers achieved 450 pico-Kelvin in 2003 (less than ½ of one billionth!)**
- **Molecules near these temperatures have been called the fifth state of matter:**
  - **Super-fluidity and super-conductivity happen at these temperatures**



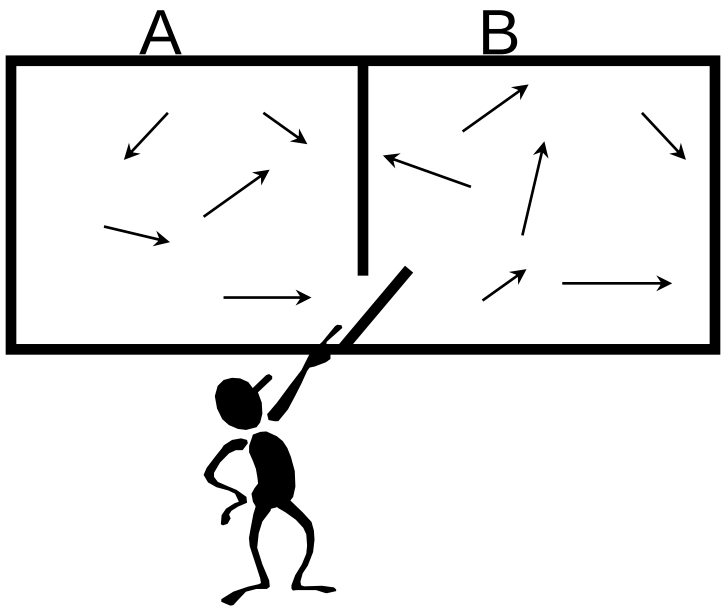
Maxwell's Demon & Szilard's Engine

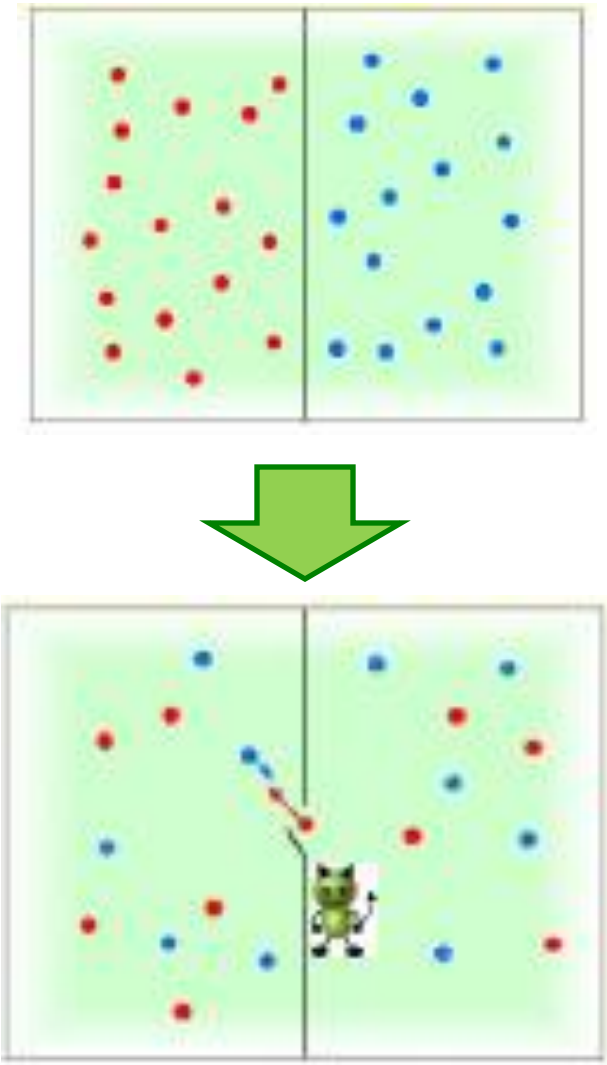
- In 1871, J.C. Maxwell devised the idea of the Demon to show the probabilistic nature of the second law: an intelligent being capable of measuring the position and momentum of the particles in a gas could in principle violate this law, for example by inducing a flow of heat from a cold source to a hot one.
- The Szilard Engine was a thought experiment, devised by Leo Szilard in 1929. It was a refinement on some of the Maxwell's Demon models of the time. The engine demonstrates how a possession of information might have thermodynamic consequences, and in principle constitutes a single heat bath engine.

Maxwell's Demon & Szilard's Engine

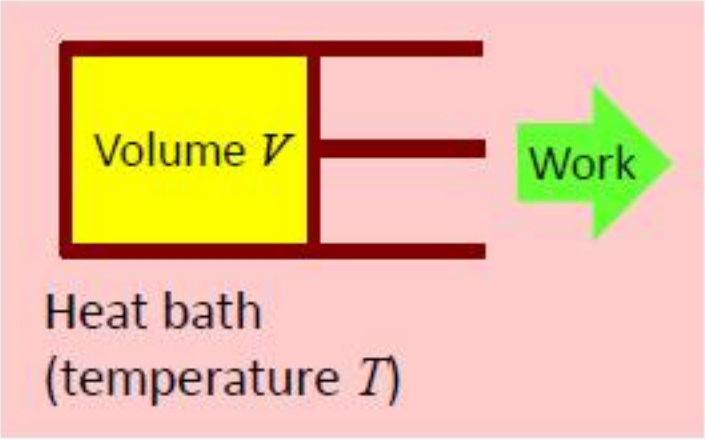


To allow only swifter molecule to pass from A to B, slower ones from B to A





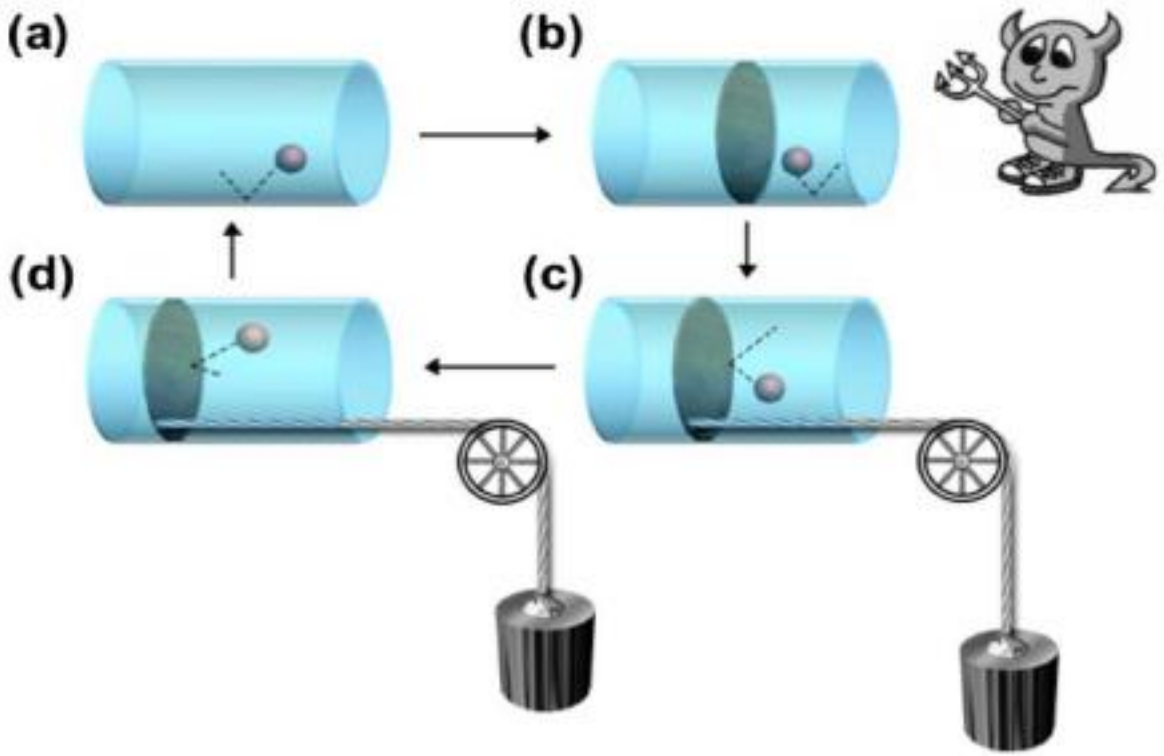
The Second Law of Thermodynamics (without Feedback)



$$W_{\text{ext}} \leq -\Delta F$$

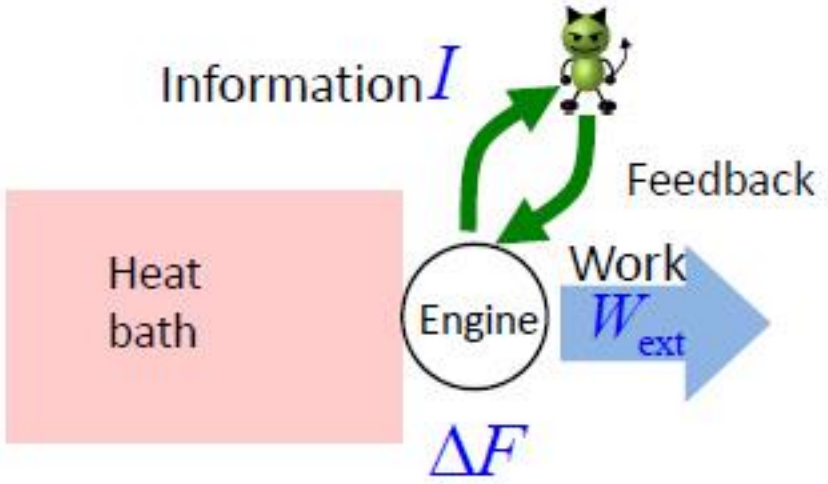
- **ΔF is the free Energy**

Maxwell's Demon & Szilard's Engine



$$W = Q = \int_{V/2}^{V} p dV = \int_{V/2}^{V} \frac{k_B T}{V} dV = k_B T \ln 2$$

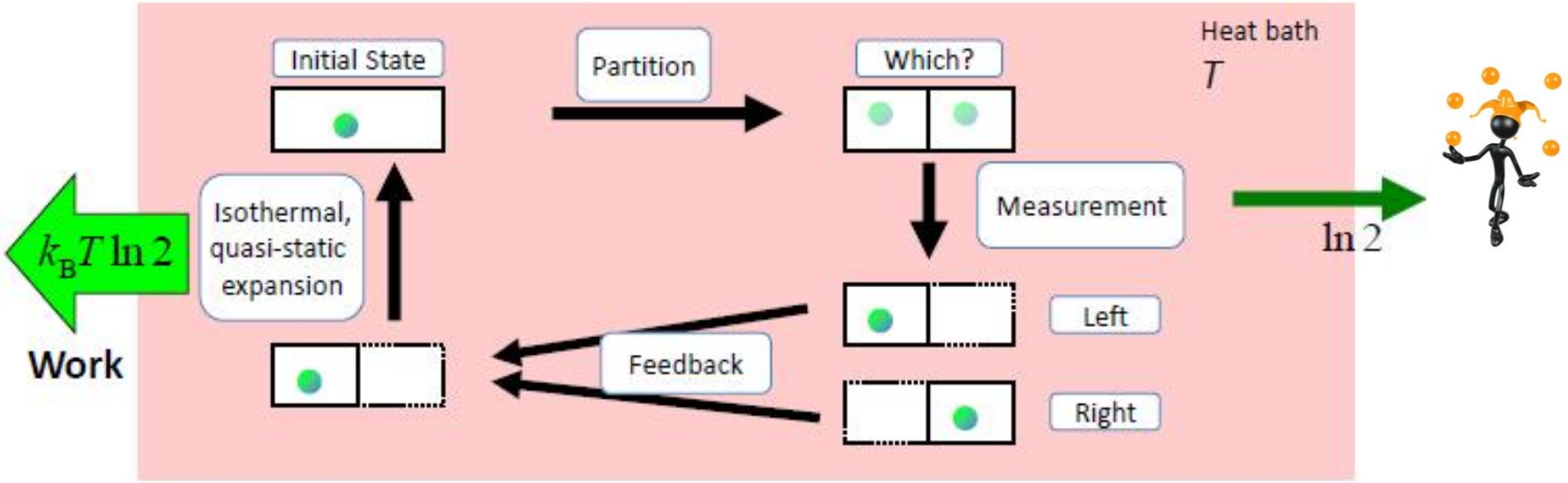
The Second Law of Thermodynamics (with Feedback)



- **ΔF is the free Energy**

$$W_{\text{ext}} \leq -\Delta F + k_B T \ln 2$$

Maxwell's Demon & Szilard's Engine



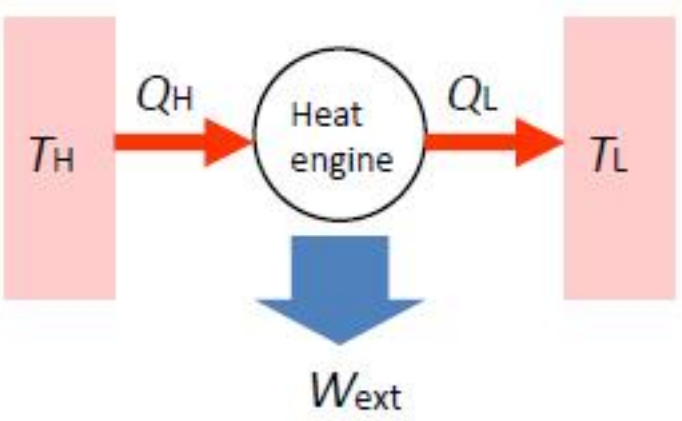
Entropy formula: $S = k_B T \log 2$

where $k_B = 1.38 \times 10^{-23}$ joules/Kelvin is the Boltzmann constant.

The Second Law of Thermodynamics

Conventional heat engine:

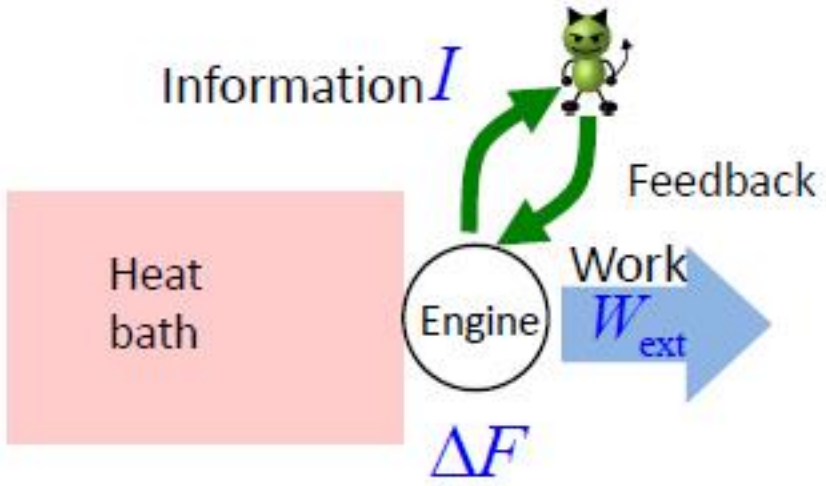
Heat → Work



Heat Efficiency:

$$\eta = W_{ext} / Q_H \leq 1 - T_L/T_H$$

Carnot Cycle



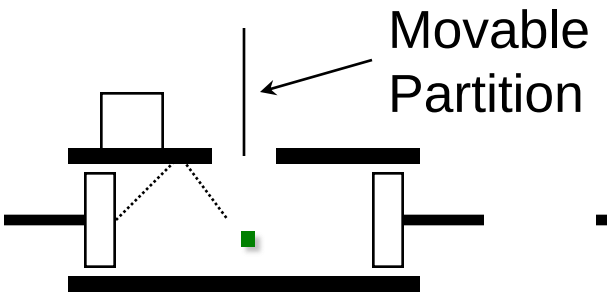
Work and Free Energy:

$$W_{\text{ext}} \leq -\Delta F + k_B T \ \ln 2$$

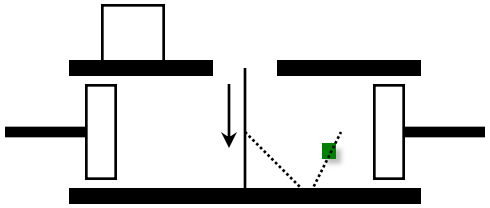
Szilard Engine

$$W_{ext} + \Delta F = k_B T \ \ln 2$$

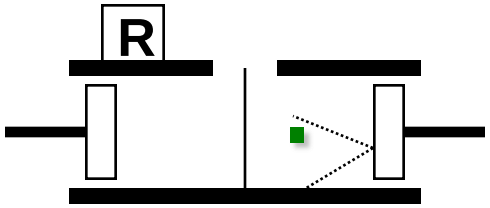
Maxwell's Demon & Szilard's Engine



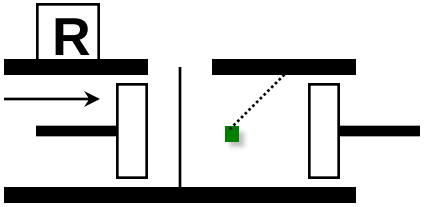
Initial state



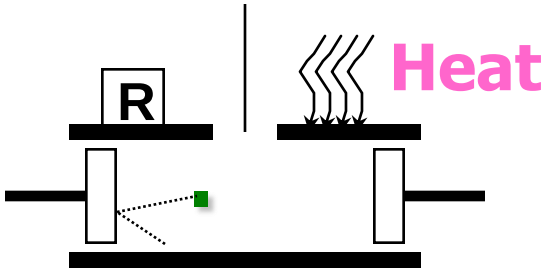
Molecule trapped



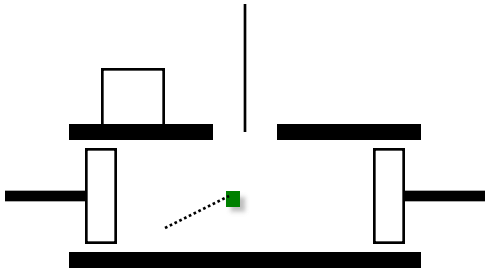
Record: right side



Left piston pushed in for free.

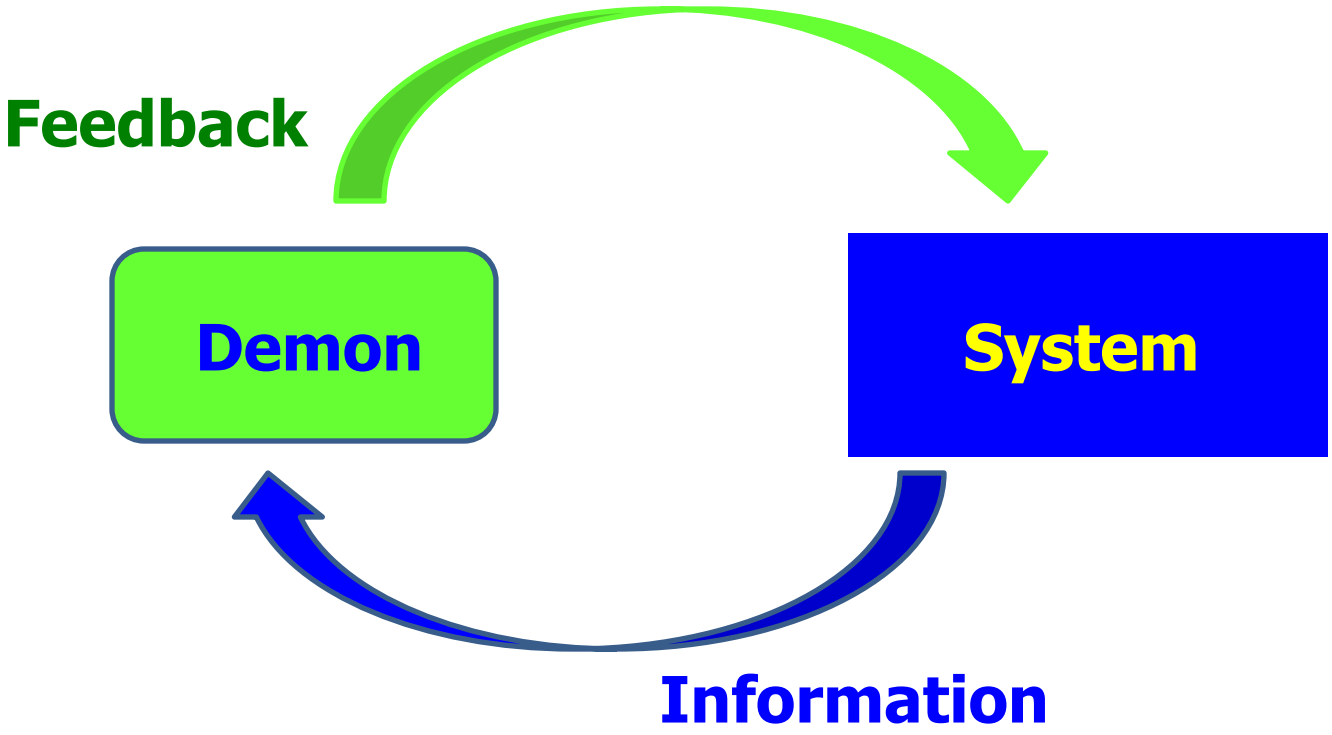


Separator lifted, molecule pushes left piston to left using heat from environment.



Memory is erased, back to initial state.

Information Thermodynamics

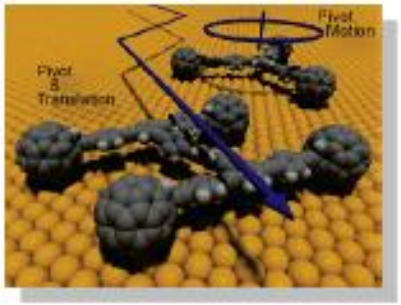


Information Heat Engine

Controller

Information

Feedback

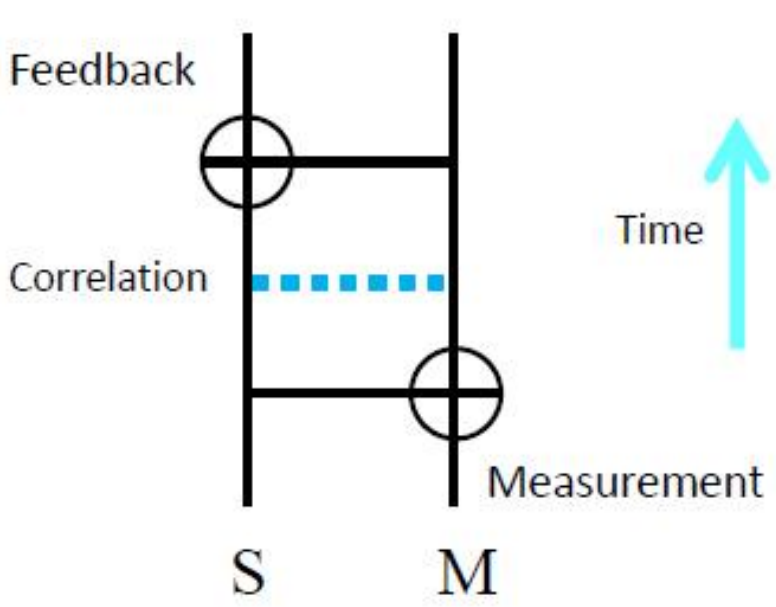


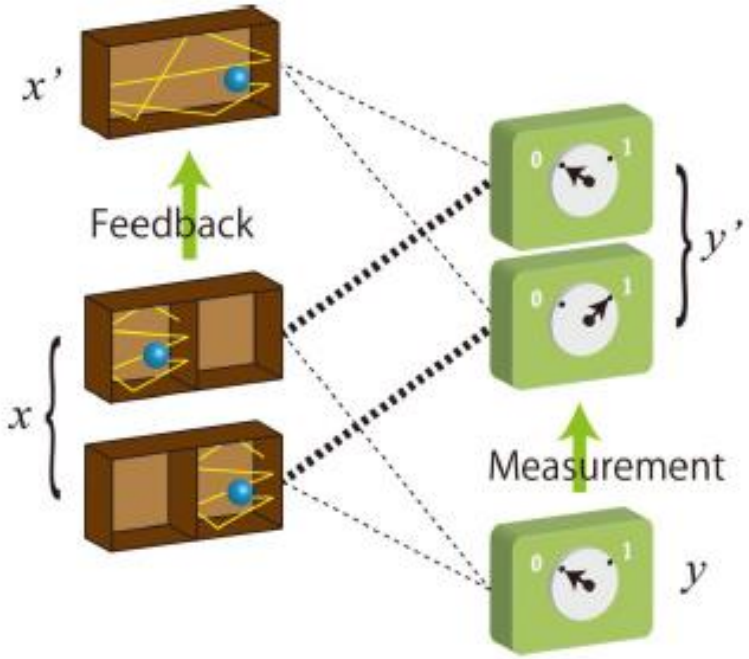
Small system

$k_B T \ln 2$

$k_B T \ln 2$

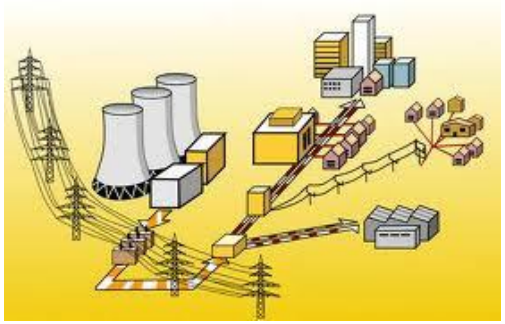
Information Heat Engine
Measurement and Feedback





Energy and Information Correlation

Human Behavior



Information

Energy

$$\sum I \Leftrightarrow \sum E$$

$\sum I$ - Various Information

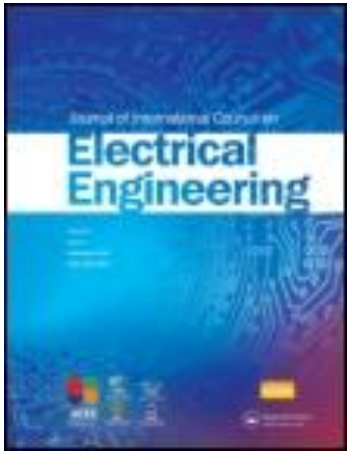
$\sum E$ - Various Energy

C.C. Chan 2012

More Information

Energy and Information Correlation - Towards Sustainable Energy

By C.C. Chan, F.C. Chan, and Dan Tu



The full paper can be downloaded from Open Access at http://bit.ly/1KA7SzR. The paper is published in the *Journal of Electrical Engineering* on 11 Jun 2015.

History of Correlation of Energy and Information

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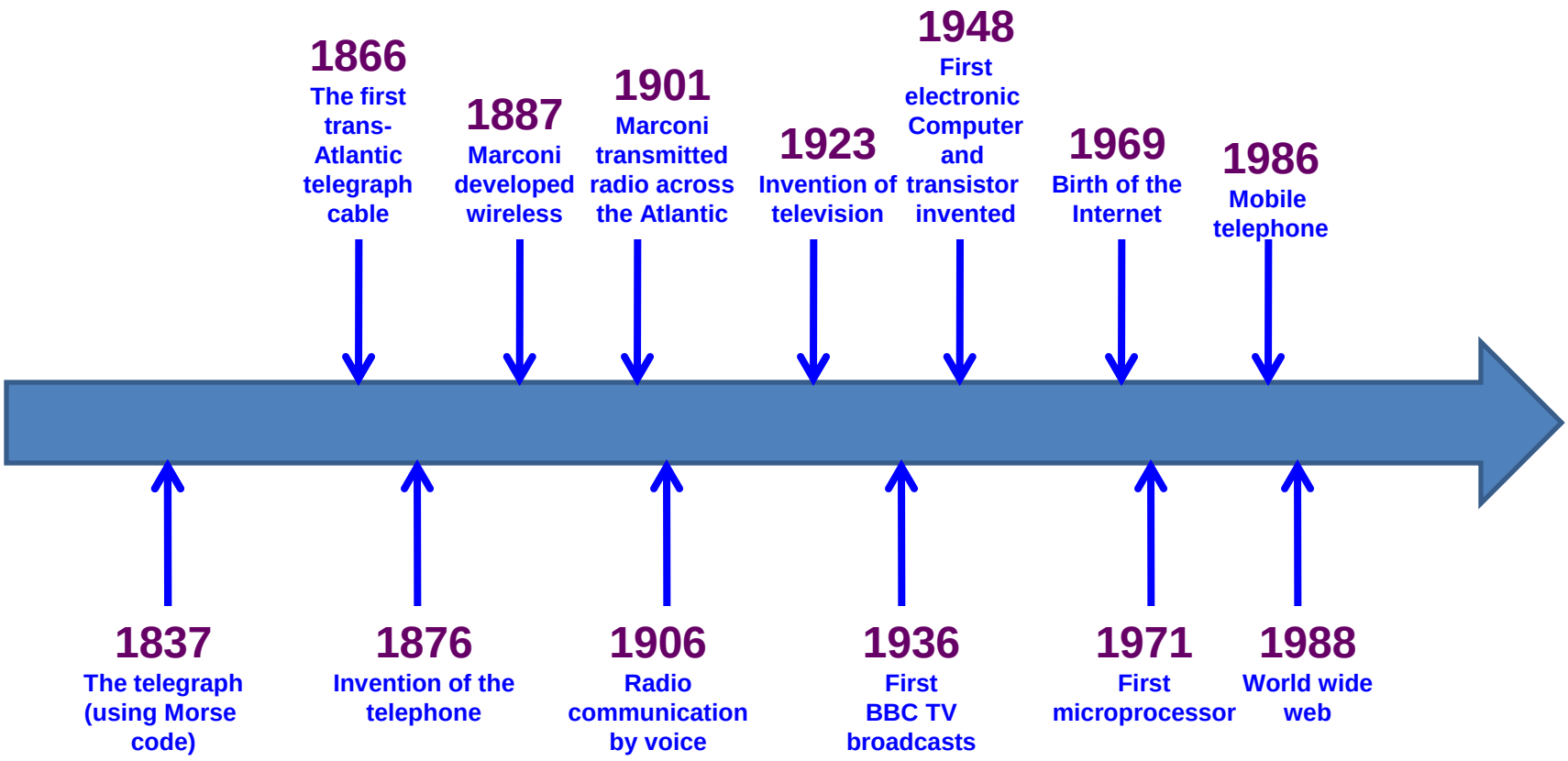
- **First Industrial Revolution (19th Century):**
  Main energy source: Coal
  Main IT: Telegraph

- **Second Industrial Revolution (20th Century):**
  Main energy source: Oil & Gas
  Main IT: Telephone, Radio, TV

- **Third Industrial Revolution (21st Century):**
  Main energy source: Towards renewable energy
  Main IT: Internet, Cloud Computing, Big Data Systems

History of Information Technology

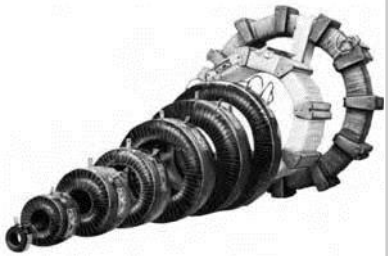


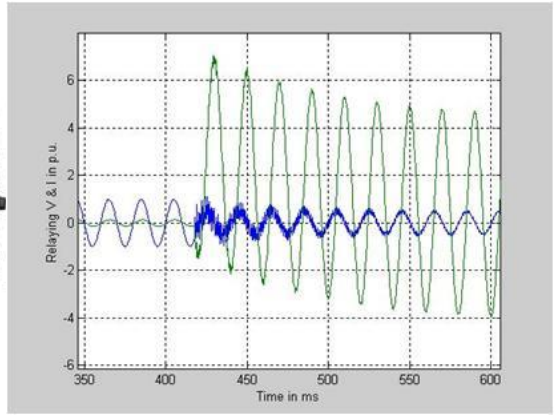
Electronic Communication Systems Timeline

Energy Information: Voltage and Current Transformers

Energy and Power Flow information are derived from VT and CT

- VT Ratio
- Class of VT
- Voltage Factor
- VT Connection





- CT Ratio
- CT Burden
- CT Primary Current
- Class of CT
- Ratio Error
- Phase Error
- Rated Saturation Factor

Energy Information: Voltage and Current Transformers

To manage the power systems network, the following information are required after obtaining the basic data from VT and CT:

- **Voltage meter**
- **Current meter**
- **Protection Relays (Overcurrent, distance etc)**
- **Energy meter (kWh)**
- **Power factor**
- **Maximum demand meter**
- **Voltage, current, power (via Transducers)**

The above information was provided in analogue in nature. Not much flexibility in further handling. Once it enters into the digital format, a wider spread of application is further developed.

Intelligent Protection, Automation, Control & Supervision (IPACS) System

System Control

- SCADA control & status and Monitoring to improve CML

Communication Link

Remote Access

- IPACS can be fully accessed at remote offices
- Speed up fault investigation and supply restoration
- Enhance customer services

Communication Link

IPACS

Distributed Architecture

132/11kV Substation

Communication Link

Communication Link

Communication Link

Control

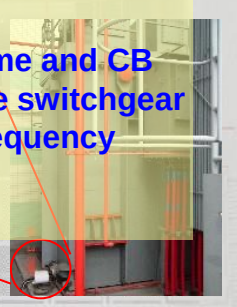
- Bay Module at individual Panel
- Using Select-before-operate to increase control security
- No single component caused whole system shut down

Protection

- Bay Module is a multi-function relay
- No additional wiring is required to alter its functions
- Maximum security and scalability

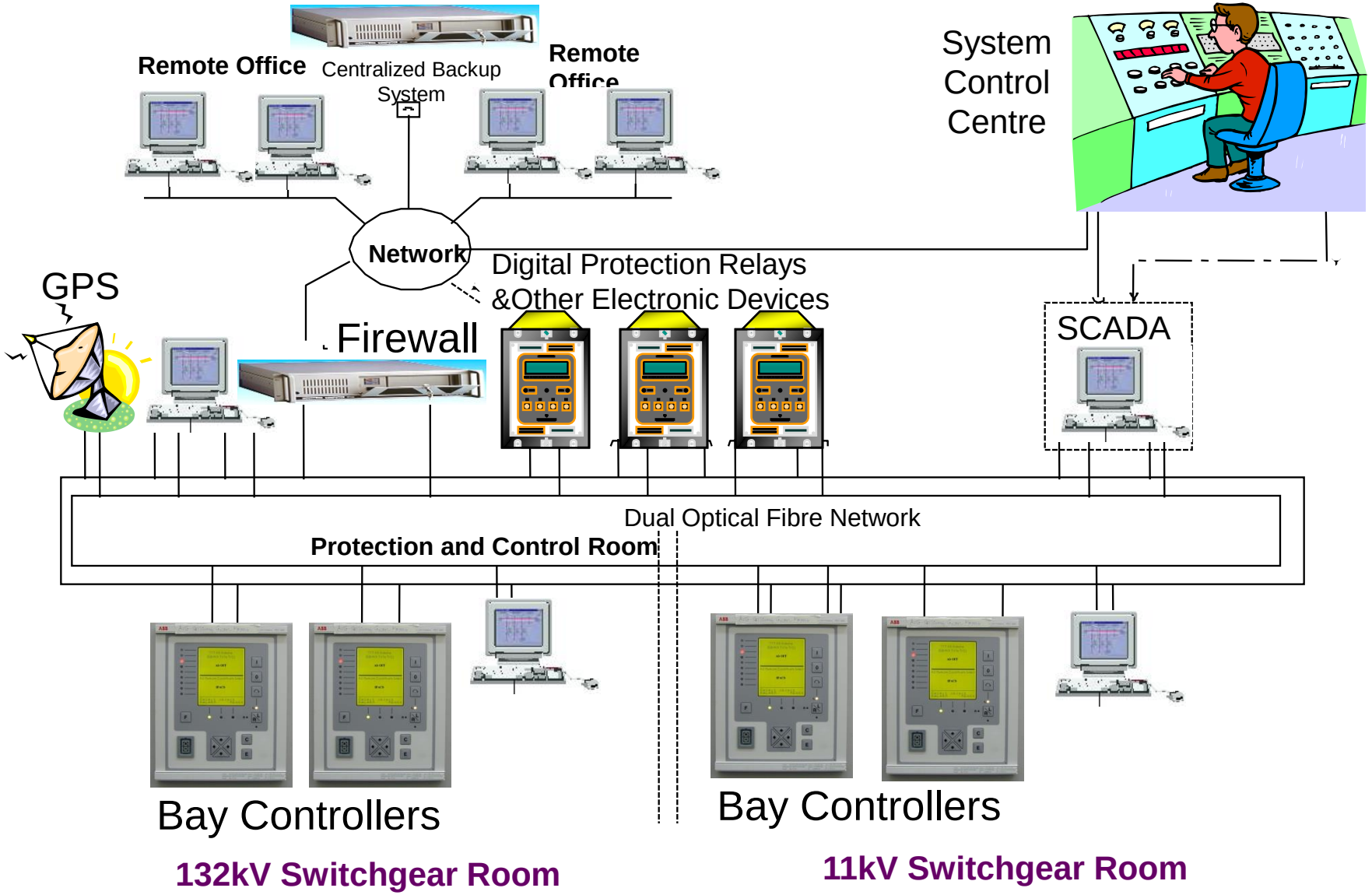
Monitoring

- On-line DGA provide data for transformer predictive maintenance
- CB traveling time and CB wear can reduce switchgear maintenance frequency

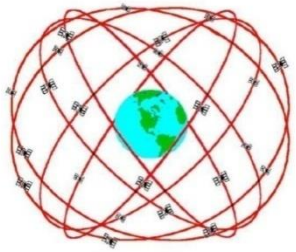


DGA

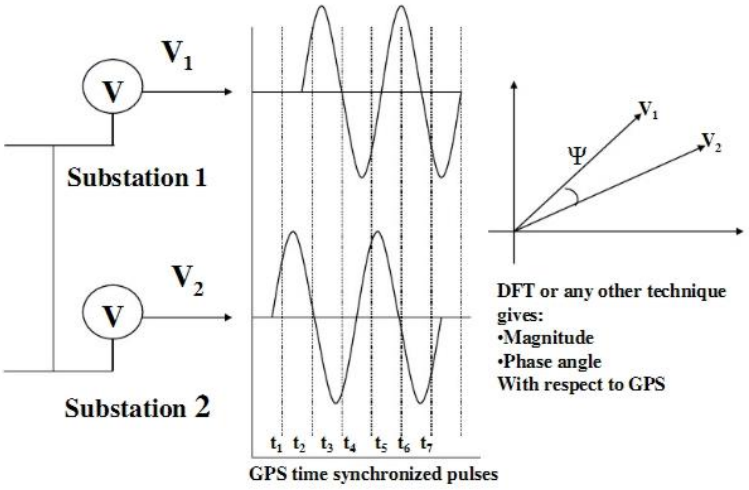
Typical IPACS Architecture



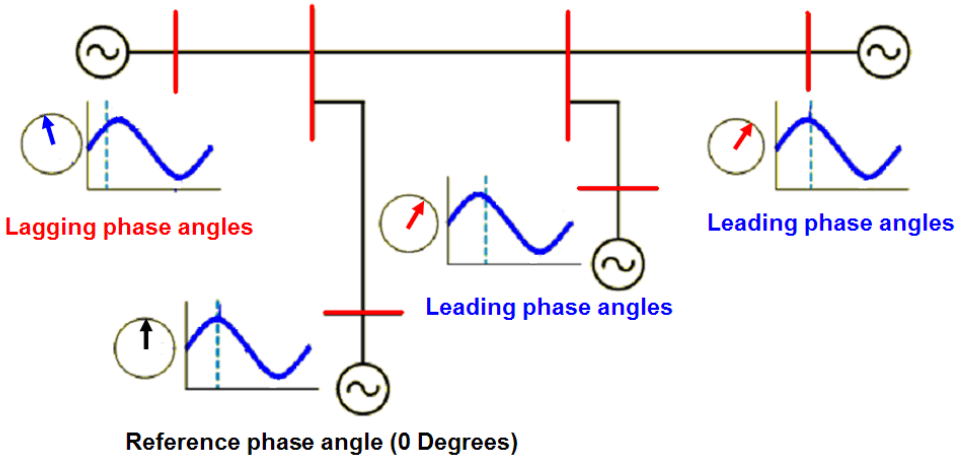
Phasor Measurement Unit



Global Positioning System Signals provide the absolute time reference

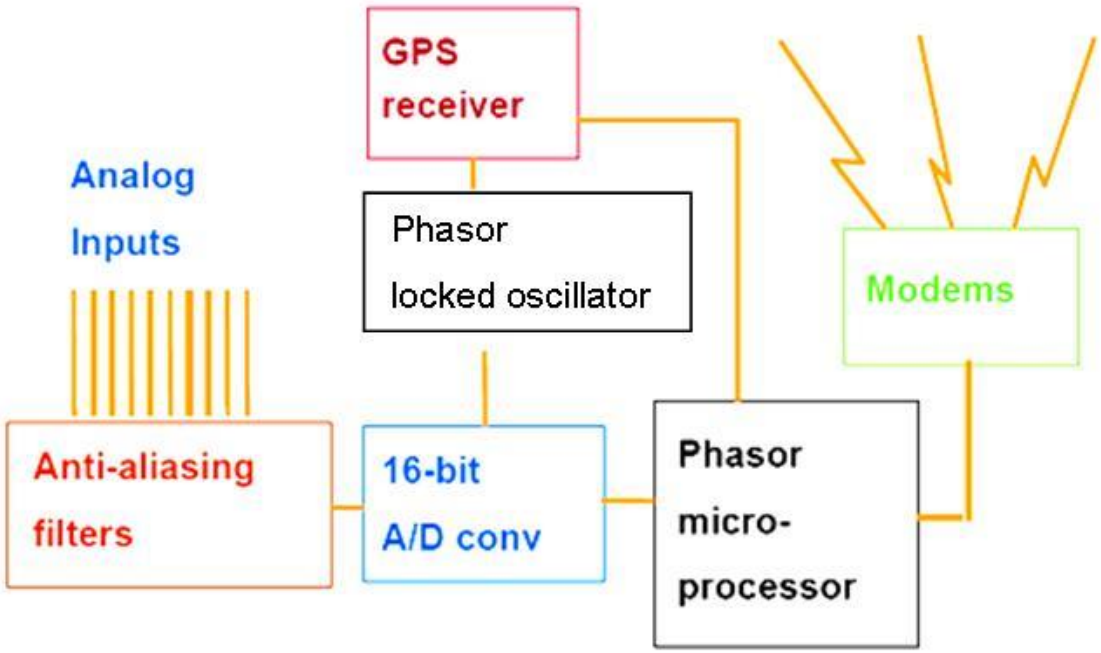


Phasor Measurement Unit



Phasors are synchonized with GPS signals

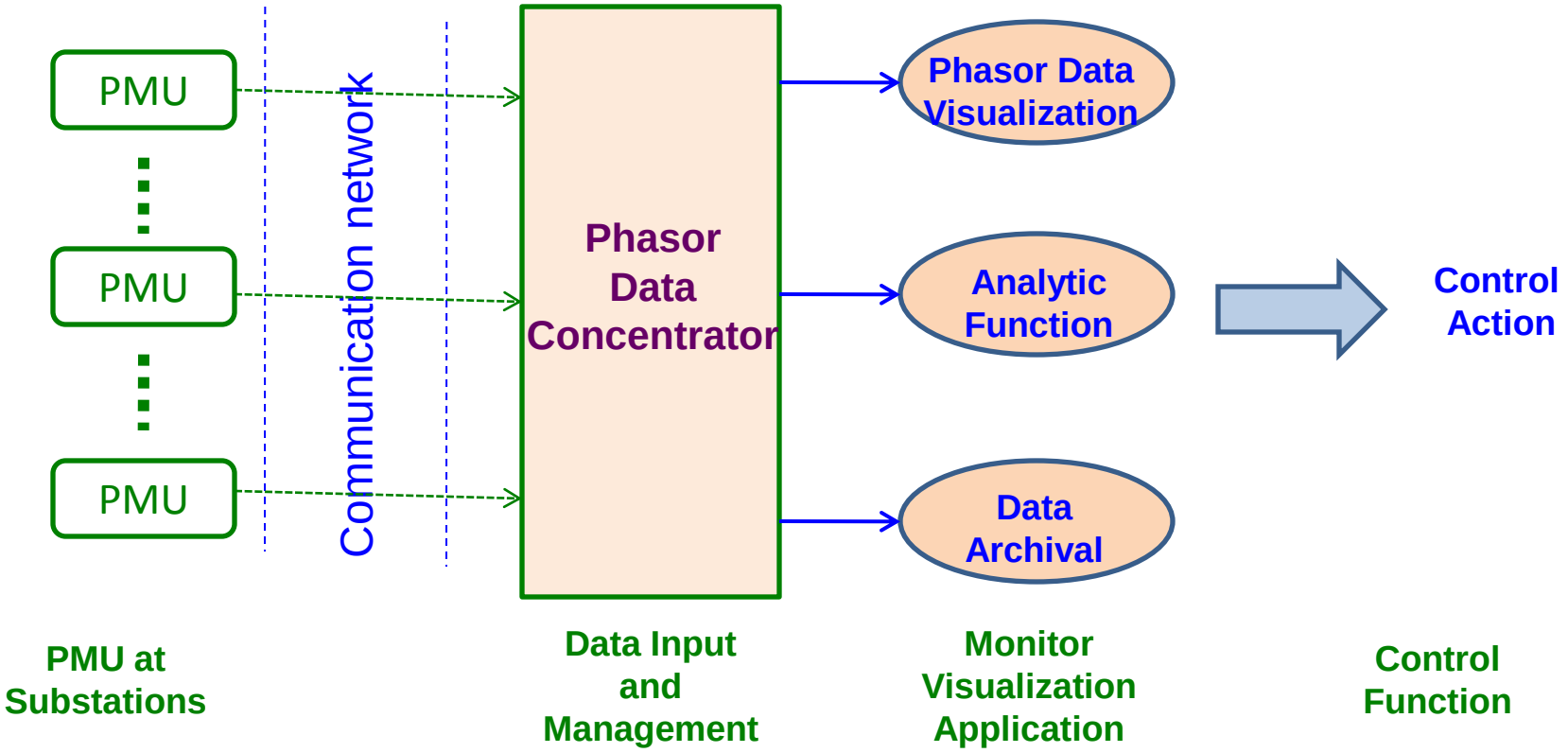
Phasor Measurement Unit (PMU)



Phasor Measurement Unit

PMUs provide fundamental frequency components of voltage and current, normally with 12 sample/cycle with 16 bit A/D converter with absolute time reference

PMU

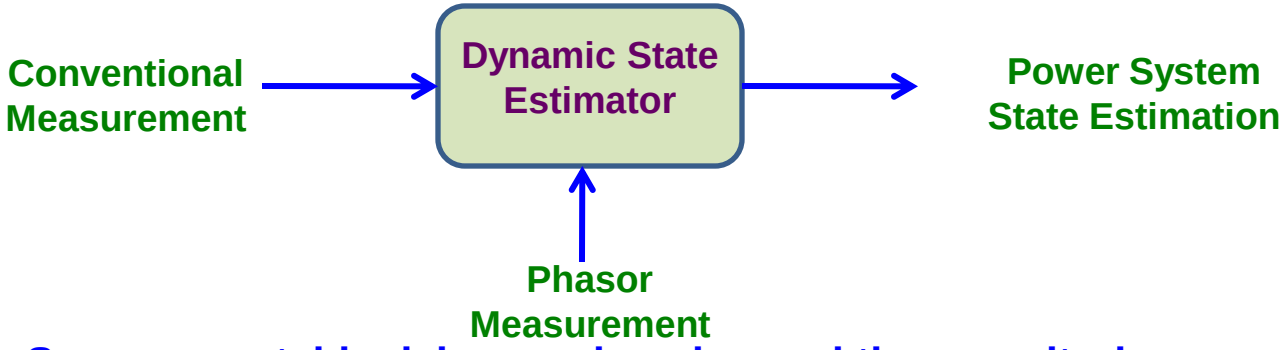


Application of Phasor Measurement Unit

PMUs are placed at strategic substations with information sent back to system control centre.

PMU Applications

Dynamic State Estimation



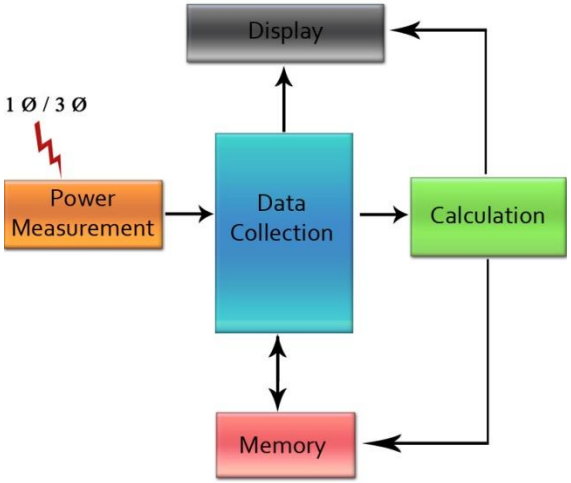
- Linear, Observability, Some acceptable delay – enhancing real time monitoring of power system
- Overcome the conventional deficiency in slow convergence and low accuracy level
- On-line dynamic system stability studies are possible, possibly enabling increase in power transfer capability

Adaptive Power System Protection

- Adaptive protection schemes can adjust its operating characteristics in response to changing power system conditions
- PMU opens a new spectrum for to enhance relay performance.
- Travelling waves, centralized system back up protection is now realistic

Energy Meter

Electromechanical (Rotating Disk) Energy Meter

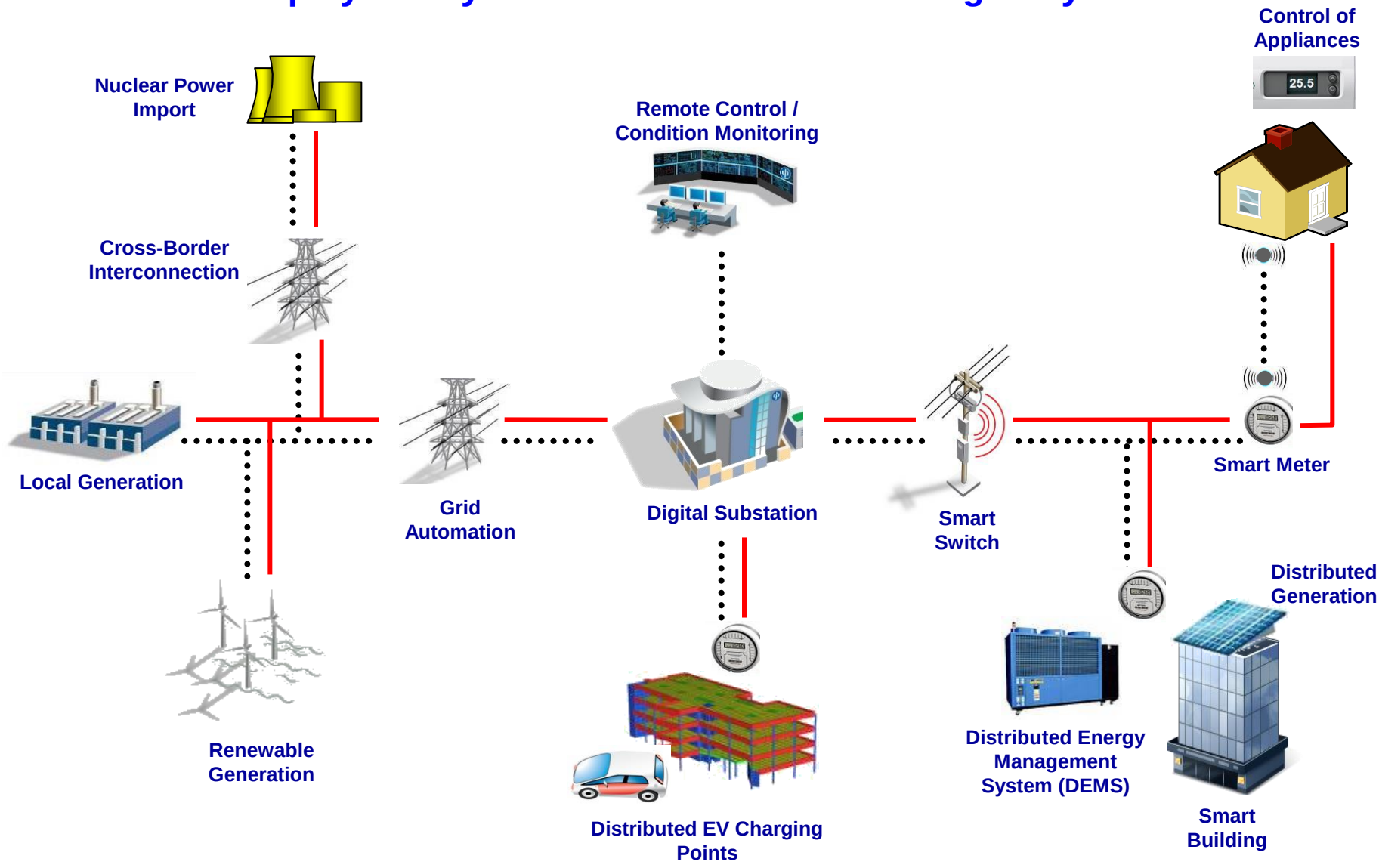


Smart Meter

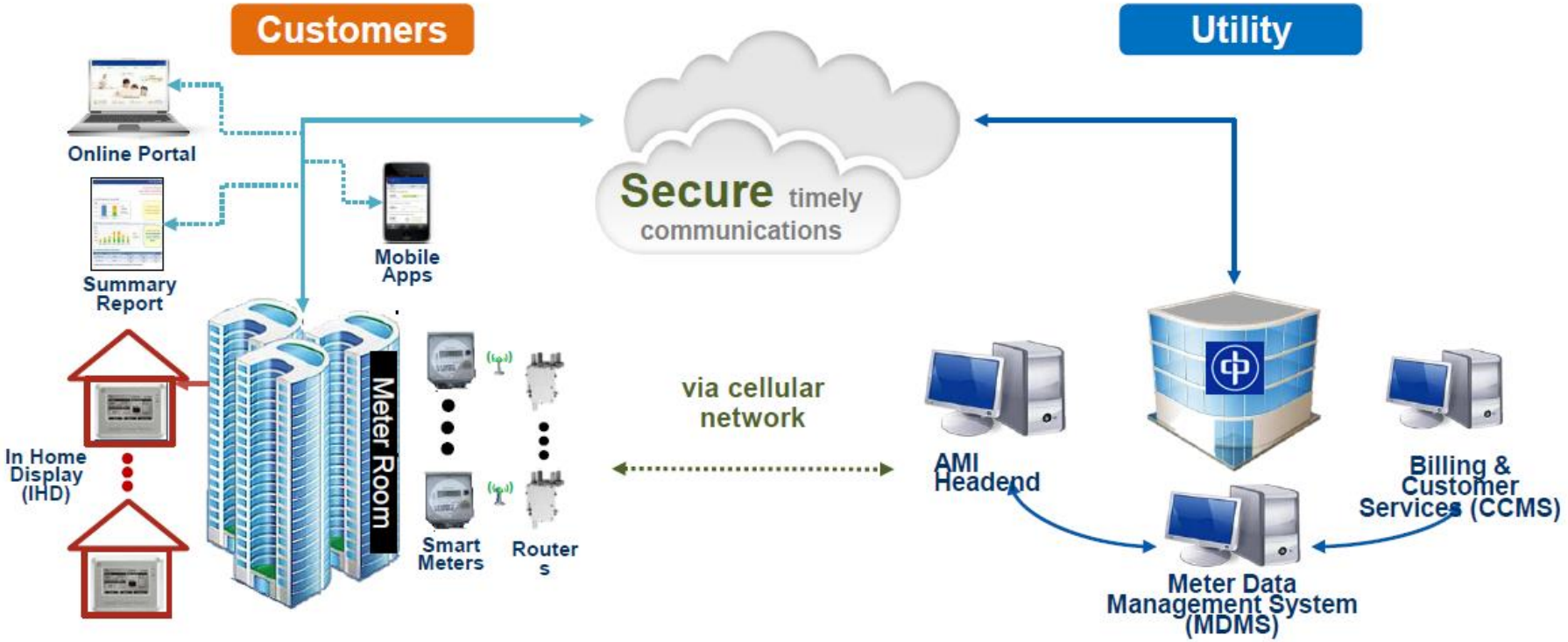
- Smart meter with remote meter reading capability
- Two way communications between supplier and customer
- Historical data can be stored

Smart Grid Technologies

Smart Meter plays a key role for a successful smart grid system



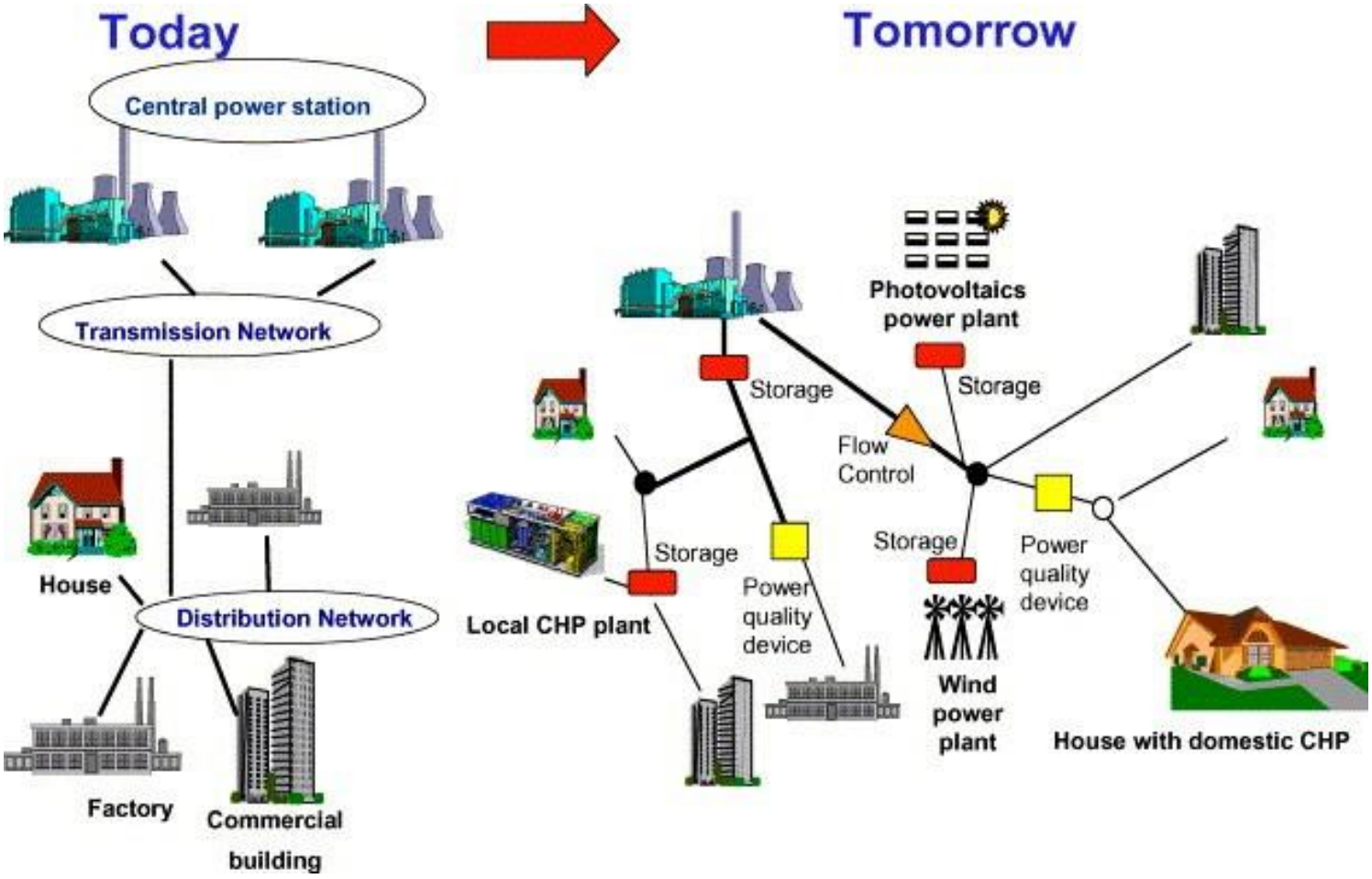
Advanced Metering Infrastructure (AMI)



A true integration of energy and information for effective and efficient consumption of electricity

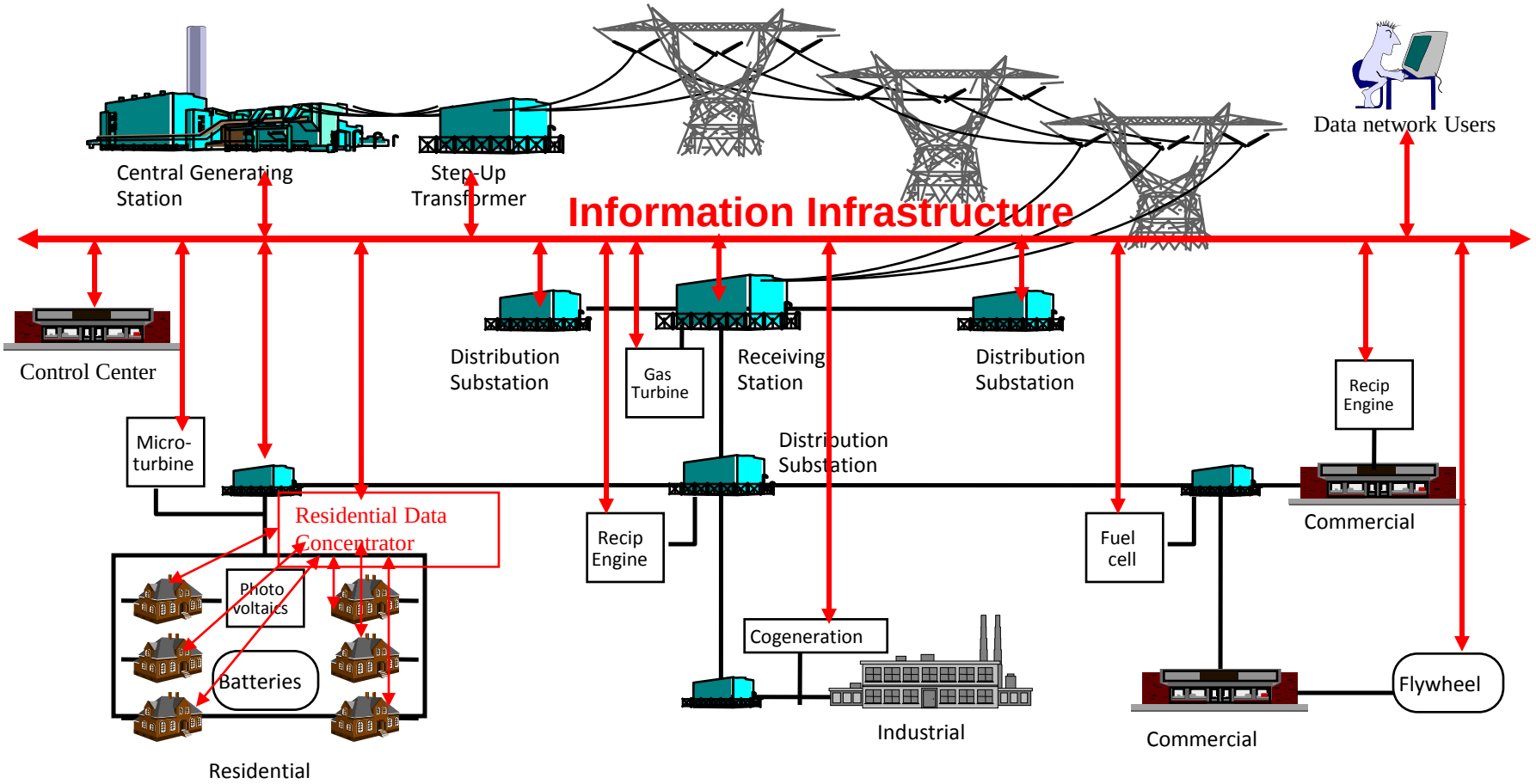
Next Generation of Power Systems

Centralized and Distributed Power Systems



Features of Smart Grid: Integration of Energy & Information

Power Infrastructure

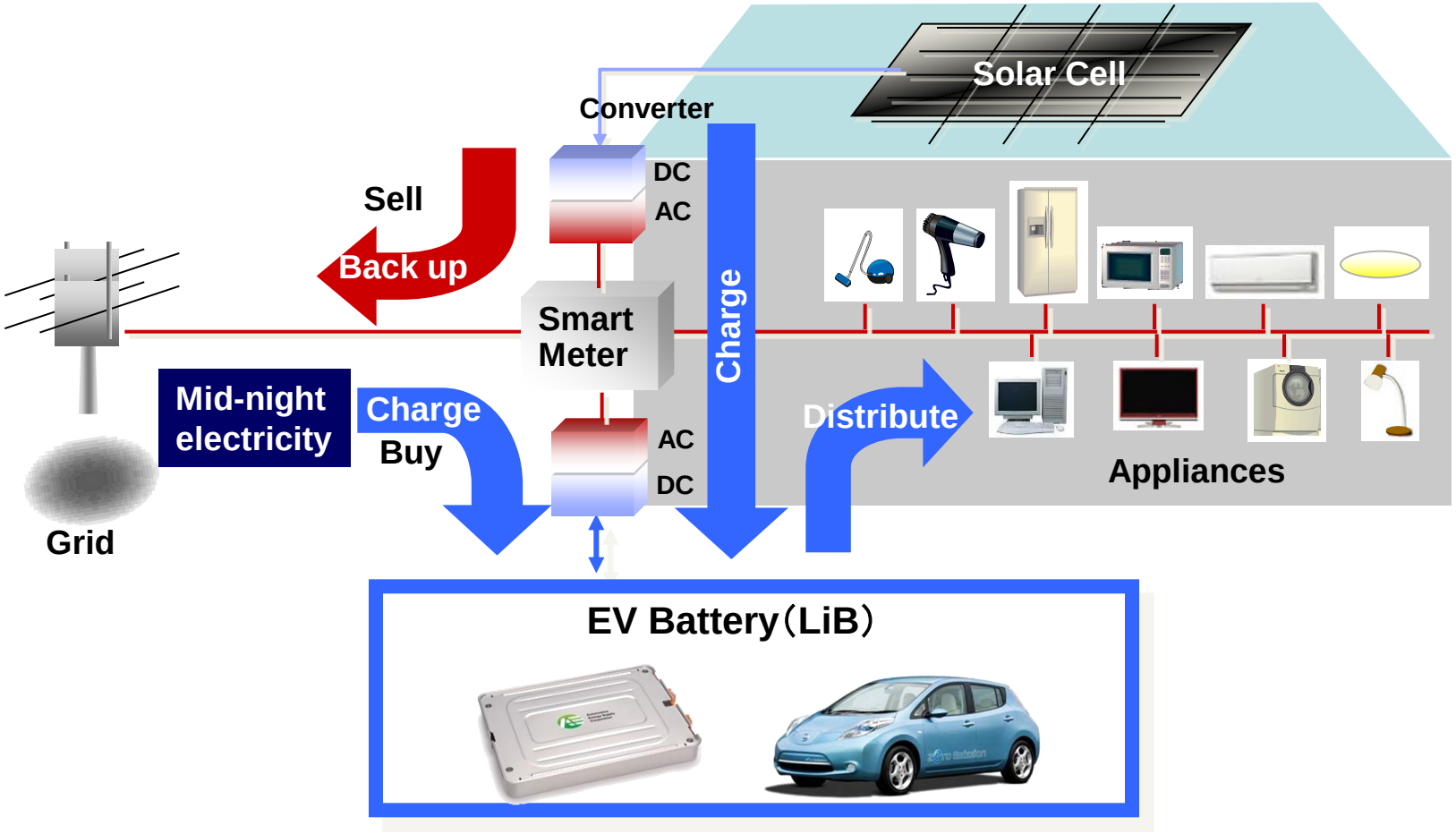


Source: EPRI

Revolution of Energy Consumptions

Smart House：

- Increase in low carbon electricity generation and reduction in peak demand
- Management of energy storage by EV and/or Lithium ion battery



Energy Systems Development Trends

Development characteristics

- **Green**
- **Comprehensive**
- **Informative**
- **Intelligent**

Energy or Information?*

Igor Čatić[1], Maja Rujnić-Sokele[1], Borislav Dadić[2]

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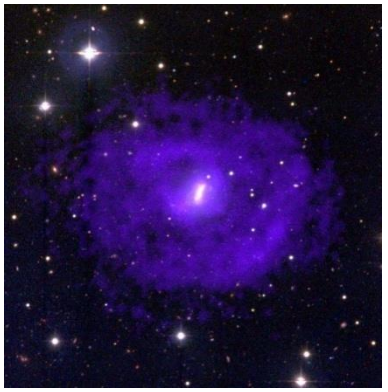

For the Big Bang to occur, it not only covers matter, energy but also includes information, which is divided into data and command. A question is raised "Who made the natural laws that are transmitted in the form of information to energy during Big Bang?".

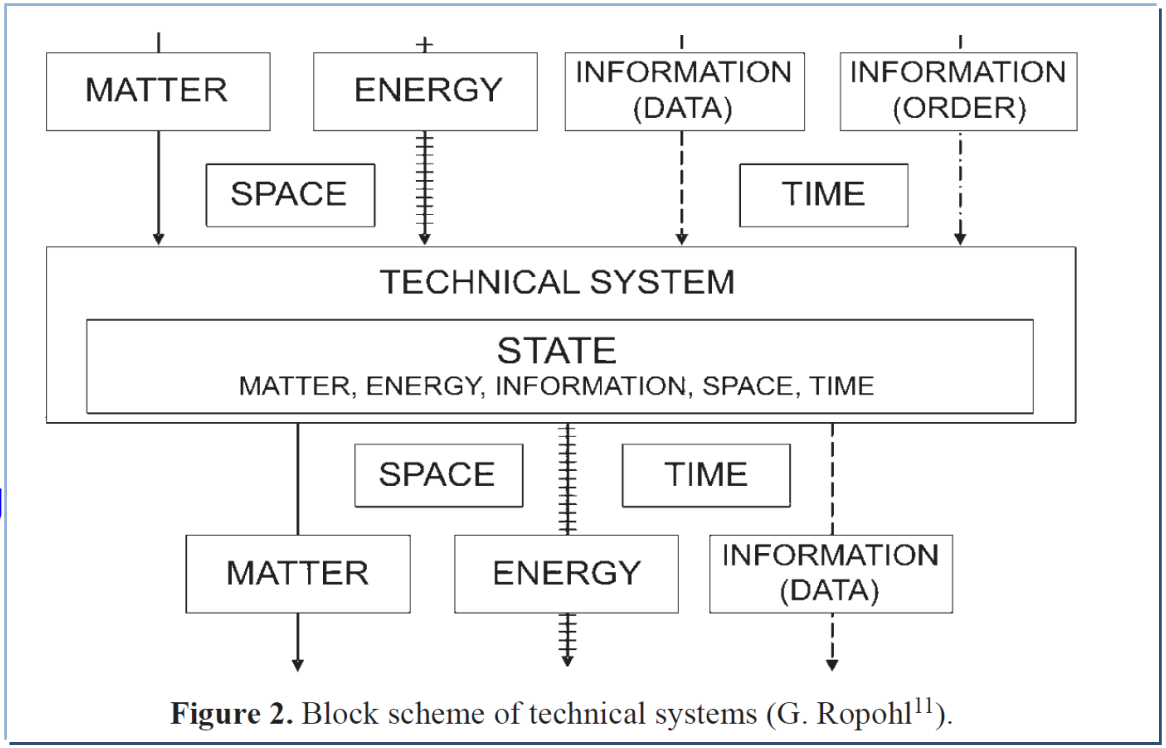

Figure 2. Block scheme of technical systems (G. Ropohl[11]).

Future

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"The future can not be predicted , but futures can be invented "

--Dennis Gabor , Nobel Laureate

Think the World, not just the Things

1. Global thinking instead of local thinking;
2. Circle thinking instead of linear thinking;
3. Closed loop thinking instead of open loop thinking;
4. Life cycle thinking instead of partial life thinking;
5. 3R thinking (Reduce, Re-use, Recycle);
6. Harmony thinking between human and nature.

Conclusion

- From Classical Thermodynamics to Information Thermodynamics. Szilard Engine and Maxwell Demon would have further development and application.
- Information is linked with Energy. Information can be interchanged with matter and energy.
- The correlation of energy and information is important for energy from production to usage chain.
- Integration of Energy and Information should be included in future technology and applications

Energy and Information Correlation

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