Smart Energy Systems

Professor Grahame Holmes
Total energy entering the Earth's atmosphere is 174 petawatts (~5.5 million EJ/year), consisting of:

- solar radiation (99.978%, or nearly 174 000 000 GW; or about 340 W/m²)
- geothermal energy (0.013%, or about 23 000 GW; or about 0.045/W m²)
- tidal energy (0.002%, or about 3 000 GW; or about 0.0059 W/m²)
- waste heat from fossil fuel consumption (about 0.007%, or about 13 000 GW)

Overall Energy Consumption

Energy Consumption by fuel

Source: BP Statistical Review of World Energy June 2009

Yearly Solar fluxes & Human Energy Consumption

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<td>Solar</td>
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<td>Wind</td>
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<td>Biomass</td>
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<td>Primary energy use (2008)</td>
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<td>Electricity (2005)</td>
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Proven Reserves:  
- Coal – 23600 EJ (164 years)  
- Oil – 7400 EJ (43 years)  
- Gas – 7116 EJ (60 years)

Source: BP Statistical Review of World Energy June 2009
World Energy Consumption


Source: Alain Bucaille, AREVA Group, Presentation 10/05/2006
Patterns of US Energy Usage - 2005

ELECTRICITY GENERATION LOSSES

Summary of Energy Usage

Present Status

• There is more than enough incident Renewable Energy received by the earth each day to meet our needs.

• However, Renewable Energy is diffuse, and hence difficult and expensive to use.

• So, present energy use is based essentially on higher energy density fossil (non renewable) fuels, which are much cheaper to access and use.
Summary of Energy Usage

Future Status

• Non-renewable fuels are very limited (only several 10’s years remaining supplies).

• Mostly, their use creates substantial CO₂, which is a major contribution to Global Warming.

• Clearly, the present usage rates and energy sources are unsustainable in the long run.

• The question of how long we can continue with current practices is a subject of considerable debate (i.e. how long have we really got to change our behaviour??)
“Smart Energy” Paradigm Changes

Alternative “Smart Energy” Generation Sources
• New technologies to effectively extract and use renewable energy – wind, solar, waves, geothermal – for electrical generation.

Improved “Smart Grid” Energy Distribution
• Improved distribution of existing (electrical) energy, to better use existing assets, reduce capital expenditure and reduce losses.

Better “Smart Load” Energy Utilisation
• Better management of energy use to reduce losses
• New technologies to achieve the same outcome with less energy usage.
Alternative “Smart Energy” Sources

Wind Generation

Ararat, Victoria, Australia

Offshore, Denmark

Typically many 10’s of 2-3MW turbines = 200-300 MW/farm
Wind Generation

Installed Australian capacity at 2009:

1877 MW (1.3% of system)

Compares with:

Germany: 27.78 GW (8% of system)

Denmark: 24.1% of system

Wind generation cost is $0.05-$0.10/kWh depending on assumptions (comparable with fossil fuel generation).
Solar Thermal Generation

100-300MW systems are under construction. But very limited experience to date.

Kingman, Arizona

Source: Florida Light & power link
Alternative “Smart Energy” Sources

Solar Thermal Generation

Remote Dish: Stirling system generator

Planta Solar 10 (Spain): 11 MW (includes 1 hour steam storage)
Alternative “Smart Energy” Sources

PV Generation

Kyushu Japanese Microgrid System
Alternative “Smart Energy” Sources

PV Generation

Waldpolenz Solar Park, Germany: 40 MW

(generation cost approx $0.30 - $0.40/kWh)
Technical Issues

• Intermittent availability.
  – Larger scale generation penetration change main grid operating paradigms (wind generation “failure” in Texas in 2008).
  – Storage required for significant generation penetration.

• Variable Electricity “Quality”.
  – Requires power electronic conversion systems to convert DC to AC for PV, variable frequency to 50/60Hz for wind.

• Large numbers of small distributed generation systems.
  – Rewrite the fundamental operating principles of electrical grid networks! (compare train to automobile transport systems).
Grid Level Energy Storage

Source: Kluza, MIT Thesis, 2009
Current Structure of Electrical Grid

Source: Kluza, MIT Thesis, 2009
Current Structure of Electrical Grid

- Large Scale Generation Plant located near primary energy source.
- High Voltage High Power transmission network to transport energy to load centres.
- Terminal and substations to reduce voltage levels.
- Lower Voltage Distribution Network to distribute electrical energy.
- Consumers are the end of the distribution chain.
- Marketing operating principles have been overturned by privatisation in recent decades.
- Technical principles of operation are essentially unchanged for some decades.
U.S. power transmission grid consists of about 300,000 km of lines operated by around 500 companies

Current Structure of Electrical Grid

New York State Electric Power Grid

Nodes → Generators, Transformers, Busbars, Loads

Edges → Transmission / Distribution Lines

Existing Grid: Electrical energy is transferred from large scale concentrated generation sources to (typically) distant load centres via a network of transmission and distribution lines. Energy balance is maintained by continuously adjusting generation to match demand.

Increasing Pressures include:
- Demand Growth
- Need to reduce reliance on fossil fuel sources
- Inclusion of distributed and renewable generation sources
- Aging infrastructure

Smart Grid: A de-centralised power system network that includes intelligence at various generation and load node points to enable consumer interaction as part of the electrical energy supply process. Improves efficiency and usage of infrastructure.
Low End “Smart Grid”: Local PV Generation

- Limited Local Generation (mostly PV panels)
- Small Scale energy penetration levels
- Grid acts as a benign “big brother to guarantee supply
Improved “Smart Grid” Electrical Networks

Emerging Paradigm Shift: Larger levels of Distributed Generation
New Grid Structure: Complex interconnection of subsystems

Source: Nature
Why change to a “Smart Grid”?

Reduced Losses?

Centralised Supply Industry

Base load coal fired power station
\[ \eta \approx 33.1\% \]

Transmission losses \(\approx 8\%\)

Distribution losses \(\approx 6\%\)

Effective energy utilisation \(\approx 28.5\%\)

Distributed supply Industry

Distributed utility of tomorrow

1. Central power station
2. Solar power plant
3. Combined heat and power plant
4. Microturbine
5. Fuel cell
6. Wind power plants
7. Smart house
8. Commercial building
9. Hospital
10. Apartment building
11. Commercial building
12. Village

RMIT PTRI Presentation: Smart Energy
Why change to a “Smart Grid”? 

Load Peak Levelling?

VIC1 30 minute Demand and Price for period 30/08/2010 00:00 to 01/09/2010 04:00

RMIT PTRI Presentation: Smart Energy
Why change to a “Smart Grid”?

• Objectives:
  – Demand side management
  – Improved efficiency of operation and energy distribution
  – Automatic reconfiguring and self healing capability
  – Improved utilisation of existing infrastructure
  – Increased penetration of distributed and renewable generation

• Realisation of this vision presents numerous technological challenges:
  – Communications infrastructure to allow real time data flow
  – Intelligent sensor and measurement technology
  – Advanced subsystems, including storage, distributed electrical generation plant, intelligent and interactive loads
  – Advanced control and actuation methods
“Smart Grid” Electrical Networks

Technical Issues

• Radically changed grid structure.
  – Move from uni-directional to distributed bi-directional energy flow.
  – Existing system operating limits are managed by relatively unsophisticated control capability and simple technology limits.
  – Large scale distributed generation will rewrite the fundamental operating principles of electrical grid networks! (compare train to automobile transport systems).

• Electrical Storage.
  – Essential to manage the intermittent nature of renewable and distributed generation.
  – Can be actual stored energy, or virtual storage (interruptible loads).

• Electrical Market place.
  – Manage the change from being the primary energy provider, to only supplying when local renewable generation is unavailable.
“Smart Load” Energy Usage

Includes both

• Improved Load management.

• More effective/reduced consumption technical solutions to achieve the same (or better) outcome.
Improved Load Management - Smart Meters

- More accurate billing (avoiding human error)
- Awareness of their energy consumption through daily/monthly report
- Demand-response leads to energy savings
- Monthly invoice of real consumption
Smart Metering of Energy Usage

- Asset Management
  - Load profiles, Maintenance Planning, Optimisation
- Tariff Regulatory
  - Tariff Design
- Anti-Theft
  - Reduce Tampering
- Outage
  - Outage Detection, Prevention Notification, Restoration
- Vegetation Management
  - Blink Target Trimming Verification
- Billing Customer
  - Pre-pay, real-time pricing Billing-accuracy
- System Control
  - Network Performance
- Safety
  - Line Status
- Settlement
  - Remote connect, order
- Collection
  - Revenue Lift Automatic Shut-off
- Metering
  - Reading TOU Billing
- Load Forecasting
  - Active Load Control Planning
- Demand Management
  - Demand Reduction Peak Shaving
- Fieldwork Management
  - Verification
- SMs

RMIT PTRI Presentation: Smart Energy
Claimed Benefits of Smart Meters

- Easier process flow from “Meter to Bill”
- Saves manual labor cost associated with meter reading and data processing
- Fewer complaints on meter reading errors
  - results in cost savings at call centers
- Measuring power quality
  - Energy balance ($E_{in} = E_{out}$)
    - easier detection of energy losses (possible fraud) in the network
- Fast detection of disturbances in the energy supply
- Demand-response leads to energy savings and more efficient use of electricity generating capacity and the electricity grid
- Limit energy use in the event of regional power shortages
- Easier disconnection of defaulters
- Early warning of blackouts
Technically Improved Load Systems

- Downlight Conversion Kits to Energy Saving
- Standard LED Lamps
- Energy Saving Compact Fluorescent Lamps
- High Power LED Lamps
- Energy Saving Downlight Kits - Compact Fluorescent
- Lighting Accessories

Source: lighting retailer catalogue
Technically Improved Load Systems

Wide Screen Flat, Low Power, LCD Televisions

Source: Sony website
Technically Improved Load Systems

Induction Heating Cooktops

“Power Electronics” – the underpinning technology of Smart Energy Systems

- Power Electronic Converters transform electrical energy from one form to another.
  - Examples: 240 Vac -> 12 Vdc
  - 3 phase 415Vac -> VVVF for motor drive
- Conversion is achieved by switching discrete packets of energy, to minimise losses.
- These energy pulses are smoothed to an average result using an output filter (explicit or implicit).
“Power Electronics” – the underpinning technology of Smart Energy Systems

Typical Power Semiconductors

Source: Powerex website
“Power Electronics” – the underpinning technology of Smart Energy Systems
“Power Electronics” – the underpinning technology of Smart Energy Systems

Uninterruptible Power Supply

Source: Creative Power Technologies
Overview:
- Power Rating: 4kW
- Input Voltage: 60-90VDC
- Output Voltage: 240VAC 50Hz, MEN
- Ambient: -10 – 60°C
- Cooling: Forced
- Protection: ELB
- EMI standard compliant

Description:
The front end of the converter steps up the dc input voltage to produce a 400V bus through a phase-shifted square wave H-bridge stage. An output single phase H-bridge produce a single phase PWM waveform which is filtered to produce a 240V output. The output is compatible with an MEN system and has a built-in earth leakage breaker.

Source: Creative Power Technologies
“Power Electronics” – the underpinning technology of Smart Energy Systems

- Large scale grid connection of distributed and renewable generation will require major advances in high power inverter technology
- Multilevel systems: innovative usage of series or parallel device chains
- Today’s systems: Mega-watt drives rated up to 13.8kV
Future “Smart Energy” Research Directions

- Large scale energy storage
- Improved PE conversion systems: cost, efficiency
- Data management of meter and sensor networks
- Integration of significant levels of distributed generation from renewable sources
- System stability and robustness with distributed network generation and load structural changes
- Automation of loads to dynamically respond to changing grid conditions and energy availability
- Distributed grid power factor correction
- Investigations into combined cycle heat & electricity generation
Smart Energy will transform the existing supply and usage of electrical energy, including

- “Smart” generation for increased utilisation of renewable sources and greater efficiency
- “Smart” transmission technology with active compensation, and integrated diagnostic equipment for self-healing
- “Smart” loads to better manage demand and energy usage
Thank you!