EEEN60301 Power System Modelling
Introduction to Power Systems
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Introduction to Electrical Power Systems

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Function of a Power System:

- Generate electrical energy economically and with minimum ecological disturbance
- Transfer this energy over transmission lines and distribution networks with maximum efficiency and reliability
- Deliver electrical energy to consumers at virtually fixed voltage & frequency

Electrical Power Systems:

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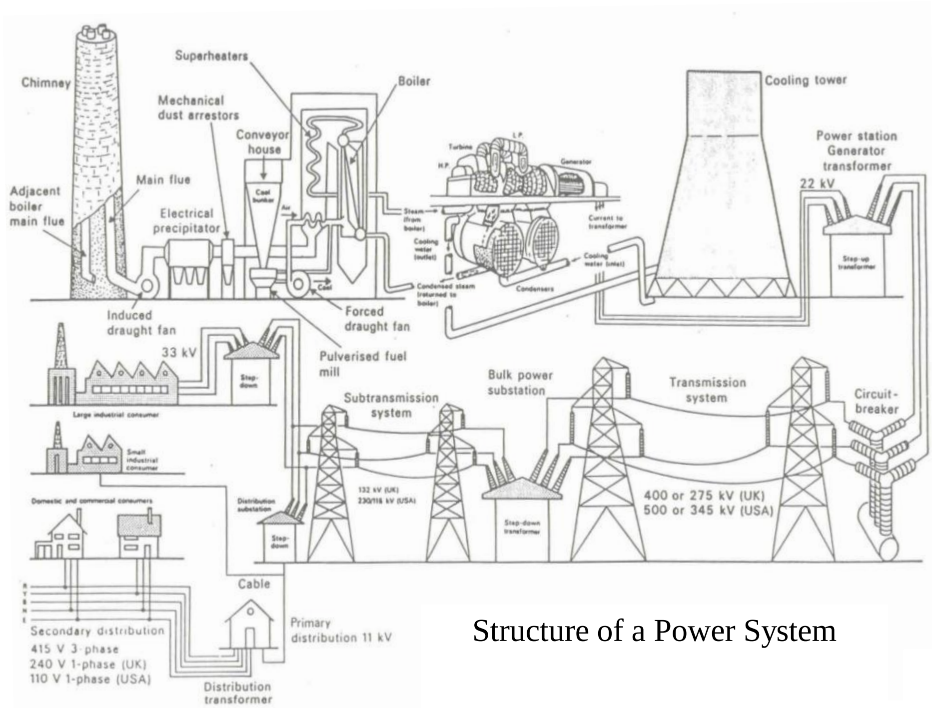
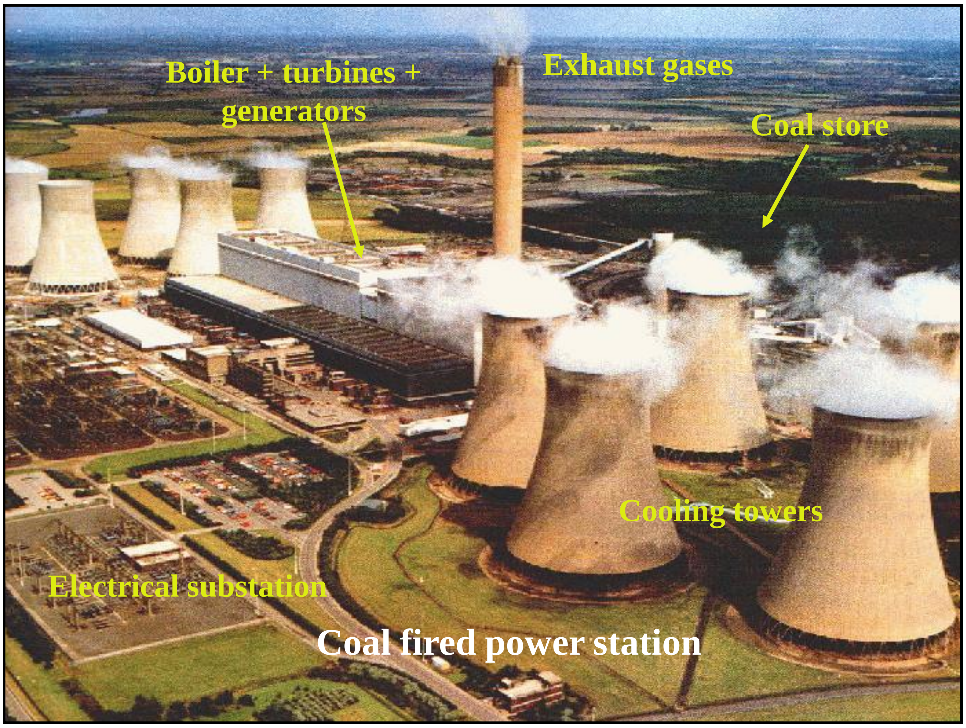
When compared with other man-made networks (e.g. communications, gas, water, sewage) electrical power systems are the most expensive in terms of capital invested, most influential in terms of disruption to our mode of life in case of breakdown, most visually intrusive in terms of impact on the landscape and the most ecologically intrusive in terms of thermal, chemical and potential radiological pollution.



Structure of a Power System



Generation:

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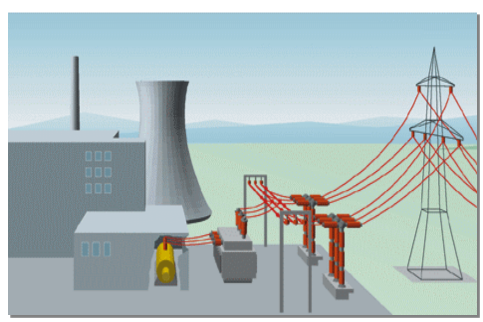
- Large synchronous generator driven by a steam turbine produces three phase electrical power at a typical voltage of 22kV line-line.

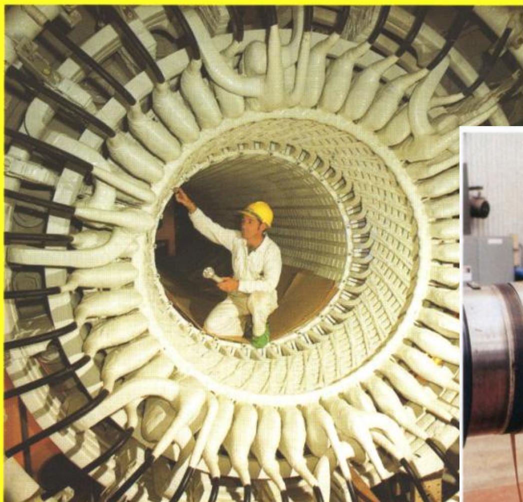


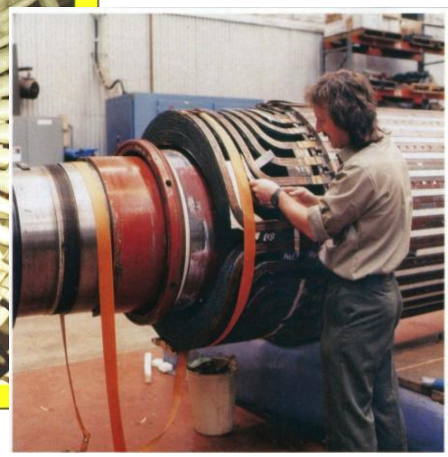
Q1. What is the output current per phase if a 500MW turbine +generator is used and is operating at its rated output power ?

500MW/3 ÷ (22kV/√3) = 13kA at 22kV

Q2. Why is the generator operating at 22kV rather than 400kV or 400V ?

Stator Winding of a 660MW Generator





Repairing a 200MW generator rotor

Stator of a hydro generator

Future:- Thermal Power Station burning domestic waste, river water cooling and gas/particle emission filtering

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What is a Power System?

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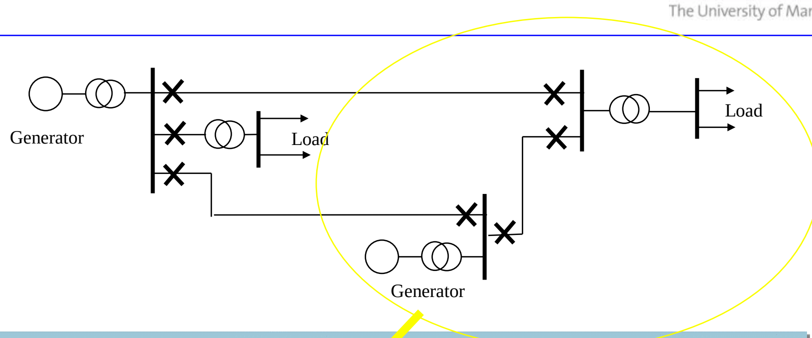
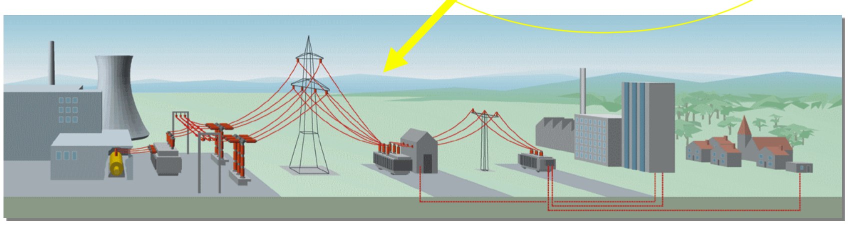
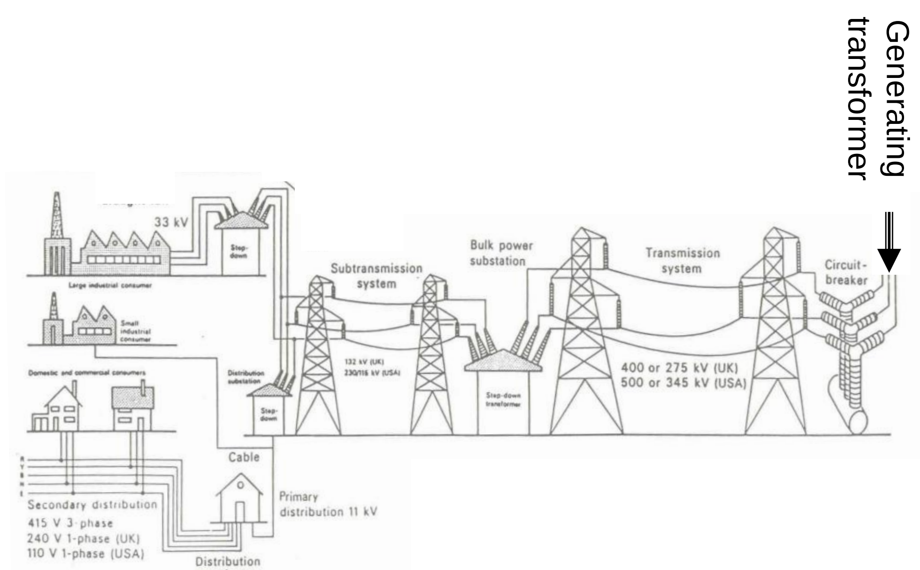




Transmission:

- Generator Voltage of 22kV is too low for transmission over long distance, hence step up to 275kV or 400kV (UK) using transformers.
  - 500MW = 13kA at 22kV = 1kA at 275kV
- At 275/400kV the power is transmitted via an overhead line to a bulk power substation for connection to the 400kV transmission network.

Transmission, Sub-transmission & Distribution Network



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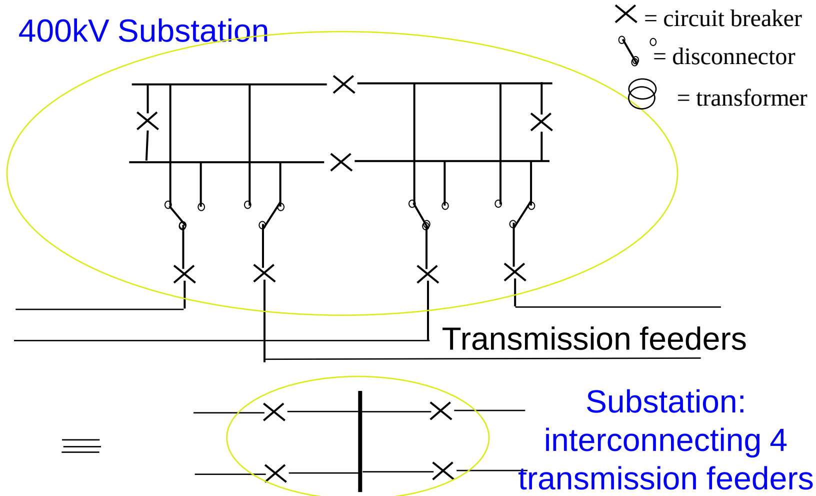
400kV Substation



Substation: interconnecting 4 transmission feeders

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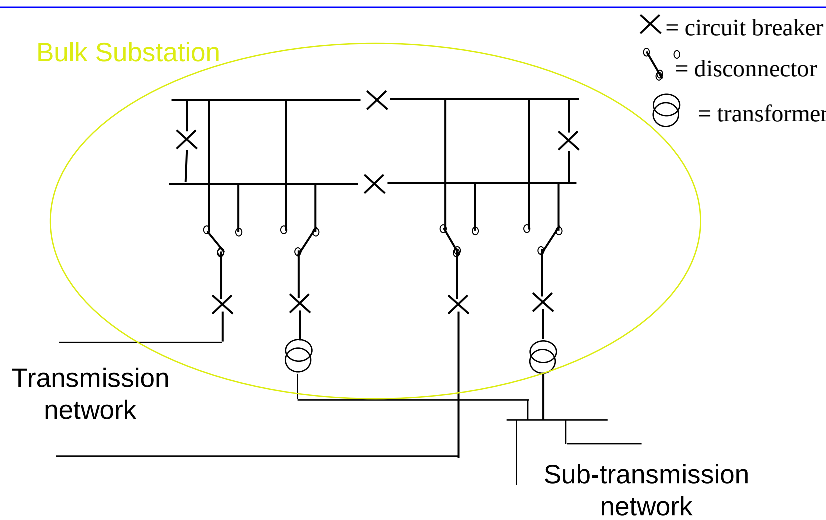
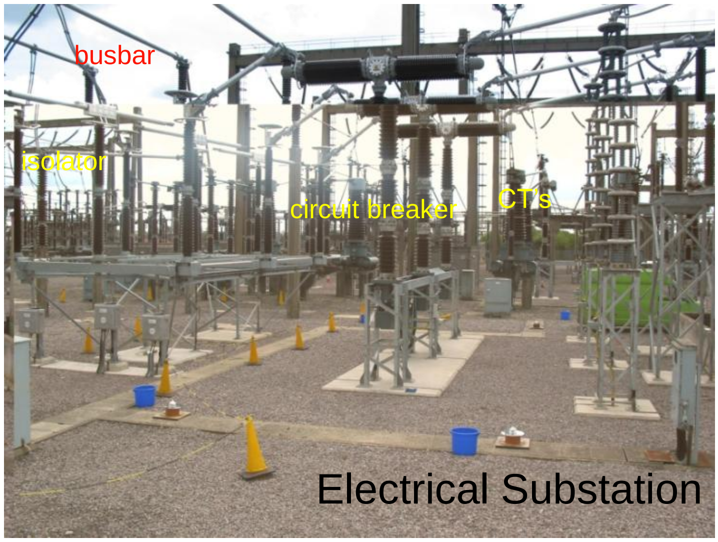
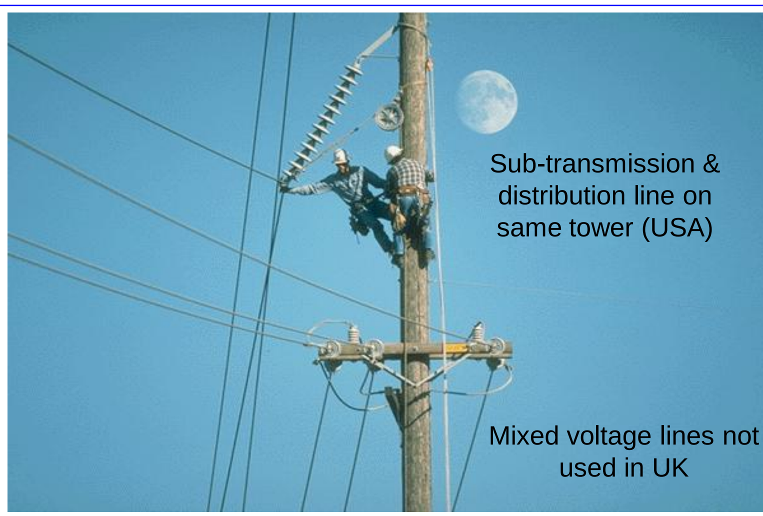
Transmission

Pylon of the Month!

Transmission Line after a Hurricane (India)




busbar
isolator
circuit breaker
CT's
Electrical Substation


Sub-transmission &
distribution line on
same tower (USA)
Mixed voltage lines not
used in UK

Distribution Network

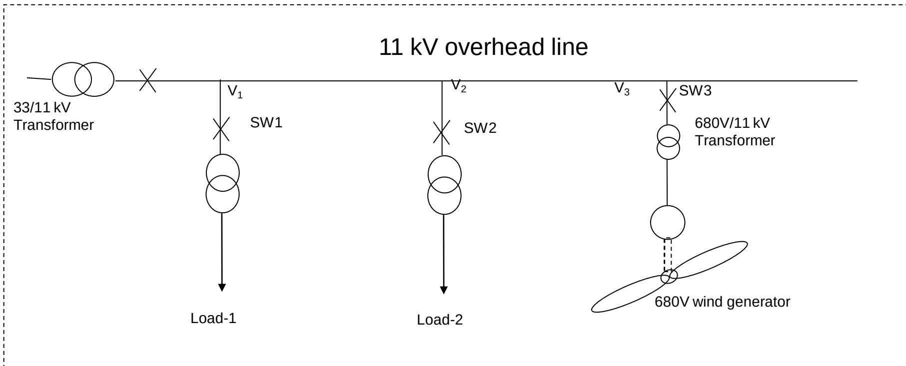
- In a UK distribution substation, the transmission or sub-transmission voltage is reduced to 33kV or 11kV
- Large industrial consumers are supplied at 33kV or 11kV
- Large commercial are supplied at 11kV
- Generally 33kV is then reduced to 11kV
- Finally, 11kV is stepped down to 415V 3-phase supply
- 3-phase 415V supply consists of three phases plus neutral
- Most consumers supplied via underground cable and fed from one-phase (line) and a neutral (plus an earth)

3.3kV feeder supplying 400V 3-phase load

Conversion from overhead line to cable

Distribution substation

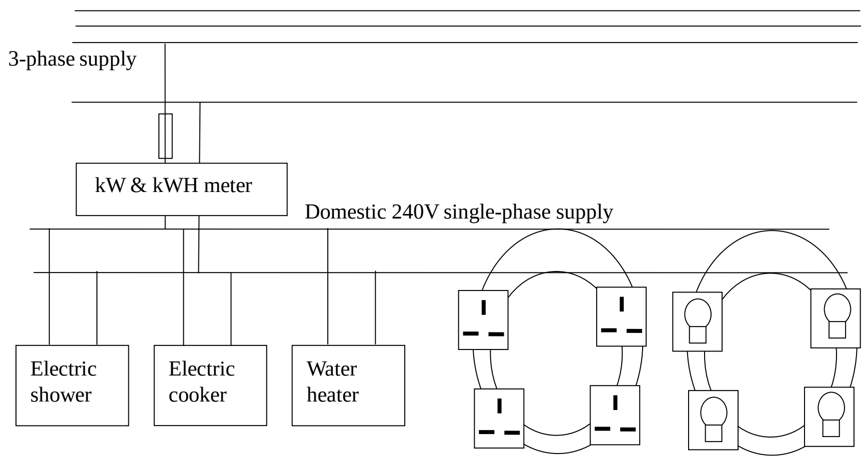
11kV Radial rural distribution feeder with wind generator



LV Distribution Network (400V)

- 3-phase 400V supply consists of three phases plus neutral
- Normally supplied by 4-core underground cable
- Most consumers connected to one-phase (line) and neutral
- An earth is supplied to consumers for protection purposes
- The earth is connected to the outer metal casing of electrical appliances, if an insulation breakdown occurs, the casing becomes live, the fuse blows and the consumer is protected.
- Fuses in a domestic distribution box are now being replaced by over-current operated miniature circuit breakers (mcb’s). Operate at ten’s of amperes.
- Residual current tripping devices (RCD) are also used to protect consumers. Operate when difference between line and neutral current is greater than 50mA (reduces risk of electrocution).

Domestic 240V electrical system



Revision:- What is an electrical power system?

Sources of electrical energy:-

generators convert mechanical energy into electrical energy
mechanical energy derived from steam in thermal power station
mechanical energy also extracted from a wind-turbine or a gas-turbine.

Transmission network:-

overhead lines are used across the country and cables in urban areas
generated power = consumed power, demand increases must be matched by increases in generation
system frequency (50Hz) increases if generated power > demanded power
system frequency (50Hz) decreases if generated power < demanded power
system frequency is controlled to be 50Hz.

Distribution network:-

transfer power from transmission network to regions, towns and homes
discuss reasons for different voltage levels.

Environmental impact:-

impact of fossil fuels on air quality, CO2, SOX, NOX emissions
advantages/disadvantages of renewable energy sources and nuclear
Economic cost of different sources of energy and need for reliability

Revision

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- Why 50Hz or 60Hz?
  - lower frequencies cannot be used due to flicker in filament lamps
  - iron losses increase in proportion to frequency
  - leakage reactances increase in proportion to frequency
  - capacitive reactance between lines reduce with freq.
  - interference with telephone lines increase with freq.
  - higher frequencies enable smaller motors, generators and transformers.
- Remember electrical networks were first designed in the 1890's:- hence 50 or 60Hz was sensible choice.

Revision

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- Why 3-phase?
  - Increases the rating of a.c. generators
  - a.c. allows conversion of electrical to mechanical energy
  - Comparative capacity of machines operating with different phases:
    - 1-phase = two connecting wires = 1.00 capacity
    - 2-phase = three connecting wires = 1.41 capacity
    - 3-phase = three connecting wires = 1.50 capacity
    - 4-phase = four connecting wires = 1.53 capacity
    - ∞-phase = ∞ connecting wires = 1.57 capacity
  - Hence power gains beyond 3-phase are small,
  - 3-phase only needs three wires and
  - polyphase systems = balanced rotating magnetic field in machines

Revision

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- Why such a variety of voltages?
  - Power received by the load is: $P = V.I.\cos\phi$
  - Percentage transmission loss is $P_{loss} = I^2R \times 100\% / P$
  - For efficient transmission P_{loss} should be minimised.
  - Hence reducing I reduces power loss, but if P is to be held constant V must be increased proportionally
  - Implies high transmission voltage is desirable
  - Problem:- higher voltages = taller towers + longer insulator strings + broader rights of way + more expensive plant & construction costs
  - Compromise between rising capital costs as voltage increases and greater losses as voltage reduces.

What is distributed, dispersed or embedded generation?

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Generation connected to a circuit from which other customers are supplied directly.

(2 kW – 100MW connected at 415 V - 132 kV)

e.g. Combined Heat & Power

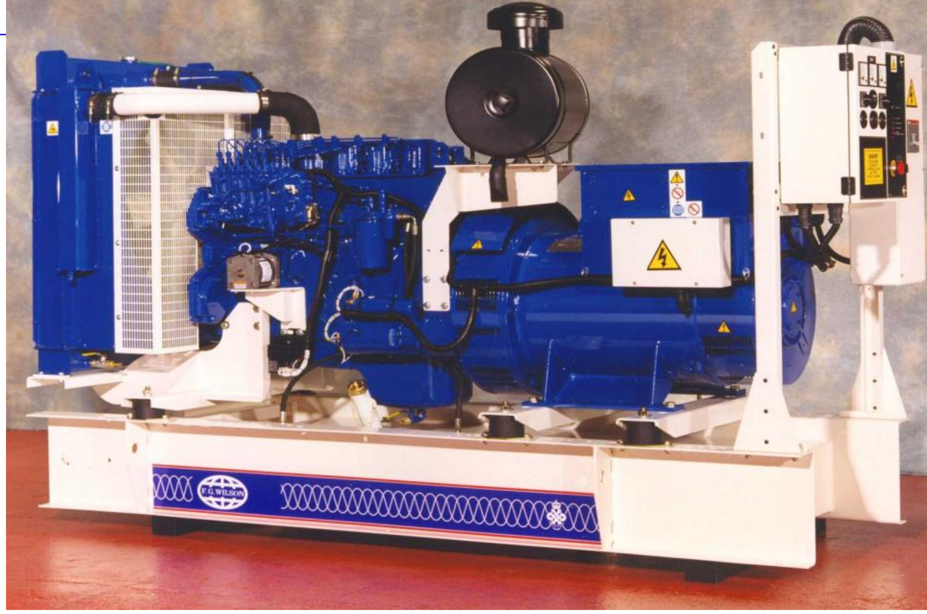
Co-generation: Diesel generators, micro-turbines (gas)

Wind turbines/Biomass/Photovoltaics

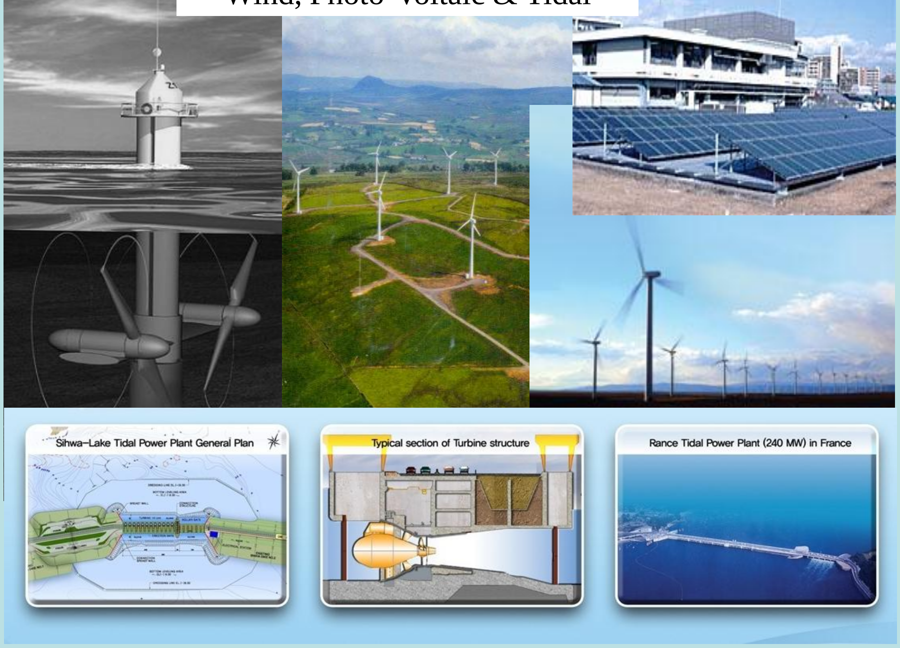
Fuel cells /Storage

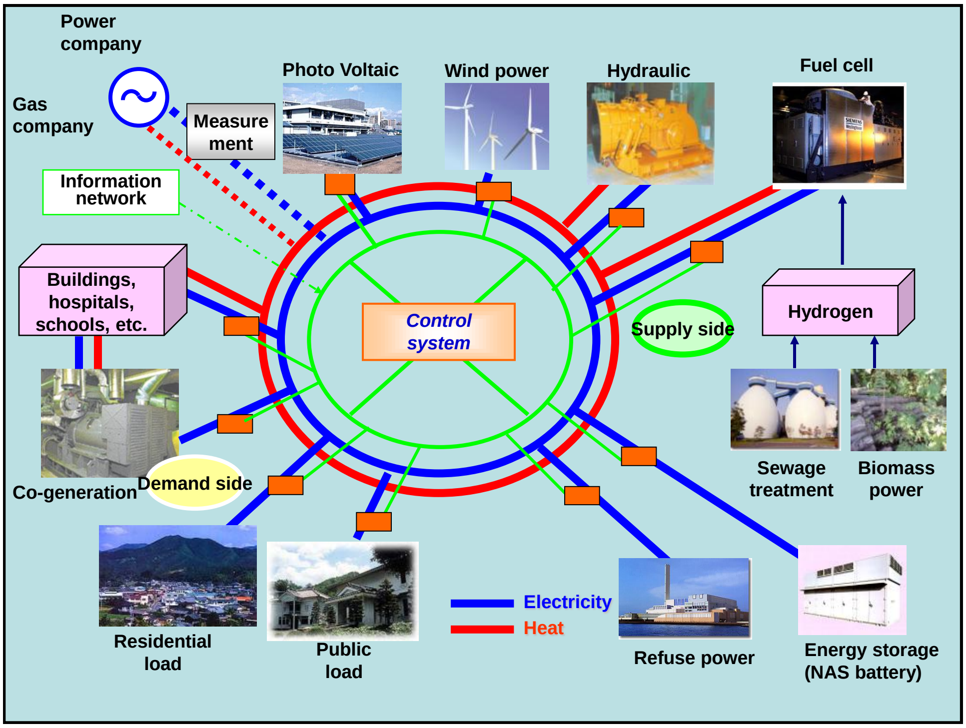
CIGRE definition of Dispersed Generation: not centrally planned not centrally dispatched and connected to distribution network

Diesel Generators:



Wind, Photo-Voltaic & Tidal

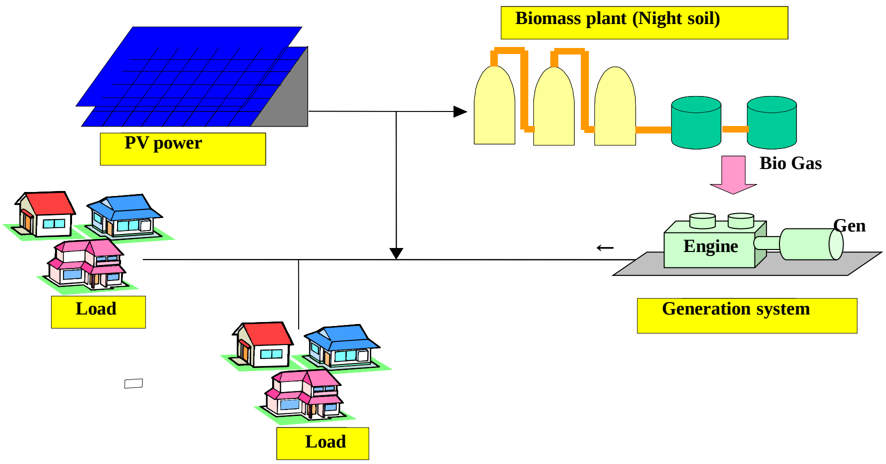




Features of distributed generation

- Renewable - resource led:
  - technology = induction generator, electronic interface (AC-DC-AC, DC-AC), DFIG (double fed induction generator).
- CHP - heat led:
  - technology = synchronous generator

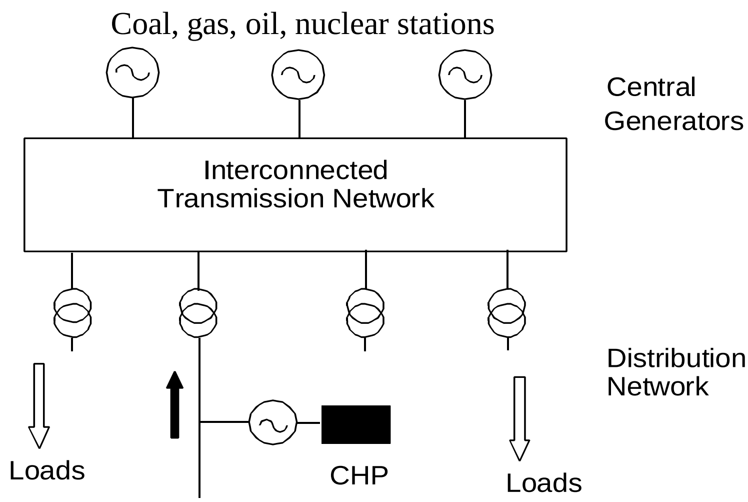
- Widely varying output and technical characteristics
- Many owners and operators
- Output does not usually respond to network conditions

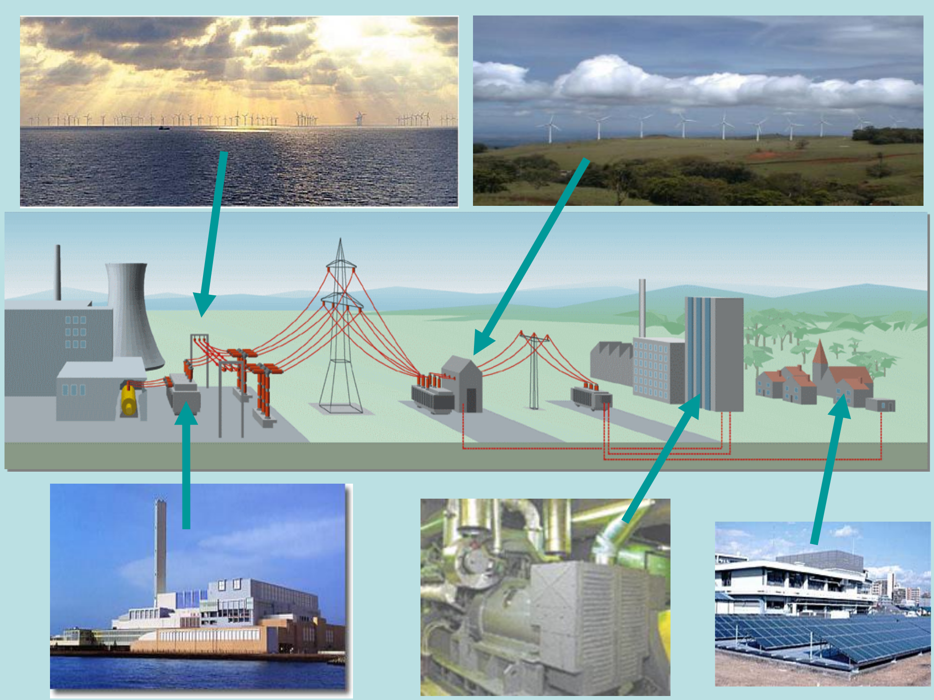


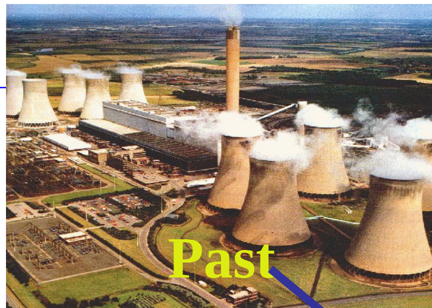
Historical perspective

- Before the construction of the UK National Grid **all** generation was embedded in distribution networks
- Objective of the CEGB was to generate and transmit **electricity** in the most economic manner (statement true in most countries)
- Some countries (e.g. Sweden) maintained town and city authorities and constructed CHP plants (provides district heating & local electricity generation)
- Objective of CHP:- minimise heating and electricity costs

Distributed Generation







Could we replace coal stations with wind generators?

Reasons for Distributed Generation

- Reduce environmental impact of generation
  - harness dispersed renewable energy resources
  - increase overall energy efficiencies (Combined Heat & Power)
  - reduce need for bulk fossil fuel generators
    (closure of "old" coal-fired stations)
- Future
  - DG provides system reinforcement
    (i.e. local real & reactive support)
  - DG provides fuel security (depends on energy source)

Issues:

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- Conventional energy sources:
  - coal, oil, gas, hydro, nuclear, impact on environment and society
- Future of conventional energy sources:
  - clean coal, combined cycle gas turbines, fission, fusion, $C0_2$ storage
- Renewable energy sources:
  - renewable fuels, wind, wave & tidal power, PV, energy networks
- Energy storage
  - bulk and domestic mechanical, chemical, water and heat storage
- Energy flexibility and conservation
  - domestic, vehicles, commercial, industry, shops, public attitude etc
- Education of society & strategies for sustainability
  - acceptance of need for change, revision of planning laws, true costs etc
  - energy usage, subsidies and taxation, energy audits, efficiency

Sustainable Energy Sources:-

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- Operating life:- energy produced > energy consumed
- High conversion efficiency
- Low energy construction
- Low environmental impact
- Economic and ergonomically acceptable designs
- Integration into existing energy networks
- Public & political acceptance
- Expansion of UK manufacturing base = employment
- Decommissioning:- Recovery of energy in materials

Diversified energy networks

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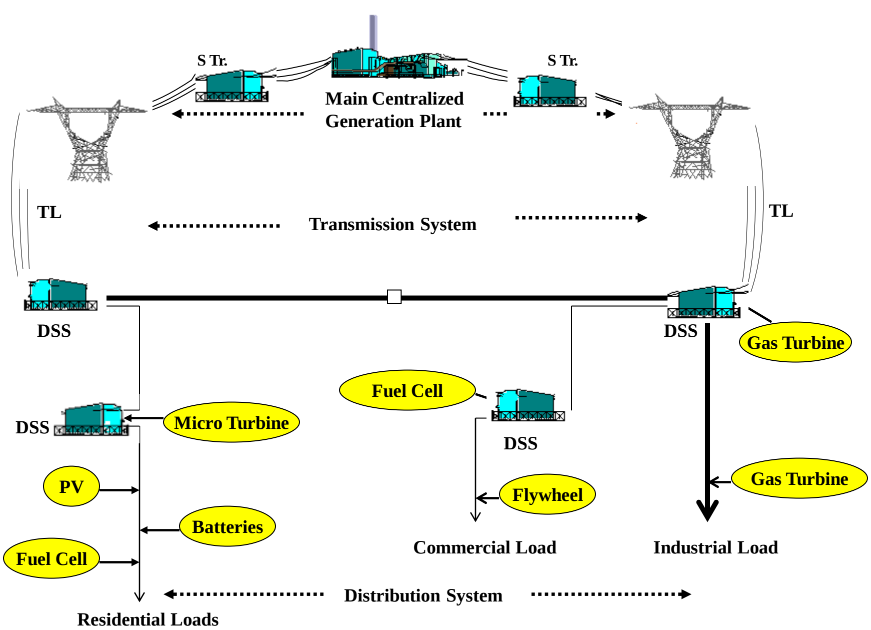
- Replacement of large fossil fuelled power stations with multitude of small renewable sources
- Requires radical re-think of how energy network operates
- Immediate:- conventional generation/storage technology
- Future:- fuel-cells, micro-generators, electronic interfaces, superconductors, chemical storage etc
- Loosely controlled hierarchy of generation, storage, load management
- Complex, active distribution networks with non-deterministic sources of economical low carbon energy



Distribution Network Is No More Vertically Operated

Passive Distribution Network

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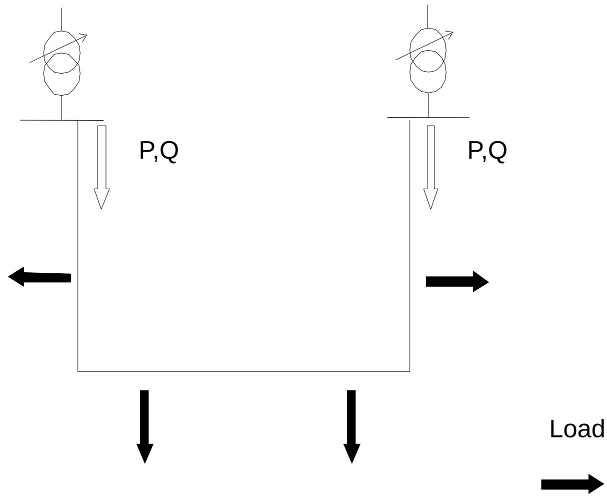

Dispersed Generation

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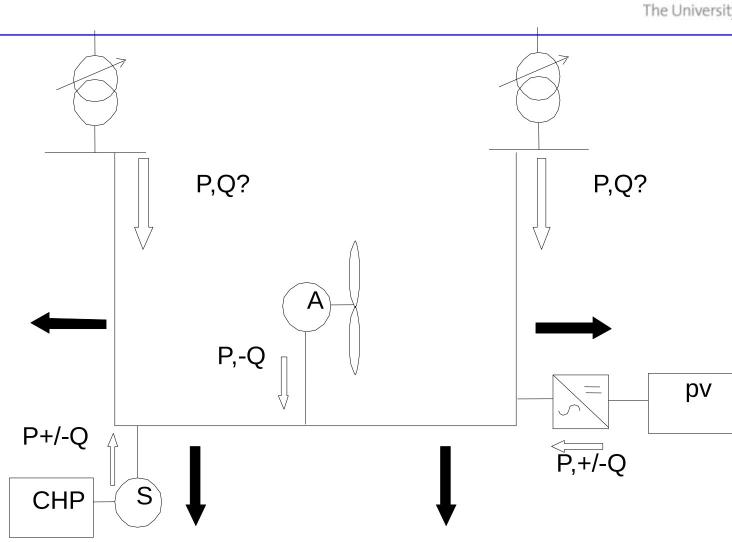


Benefits of DG:- Economics

a) Save world's fuels reservoirs

b) Save T&D Expansions Costs

c) Increase the electric power equipment lifetime

d) Can Be Installed incrementally

e) Provide Combined Heat and Power (CHP)

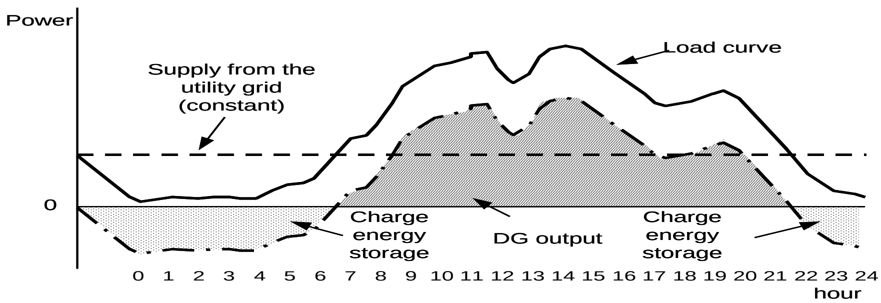
f) Not Restricted by Geographically Limitations

g) Reduce wholesale power price (Location Margin Pricing)

Benefits of DG:- Operation

- Positive Impact on Network Voltage profile
- Reduce System's Power Losses
- Satisfy the Thermal Constraints of T&D feeders
- Help for "Peak Load Shaving"
- Maintain System's Continuity, Stability & Reliability
- Provide Local Reliability (in case of emergency & main source outage as standby generation)
- Maintain System's Security and reinforce the Critical Electric Power Infrastructure (Islanding)
- Positive Impact on Environment & eliminate/reduce emissions

new-build estates with micro-generators, PV & storage



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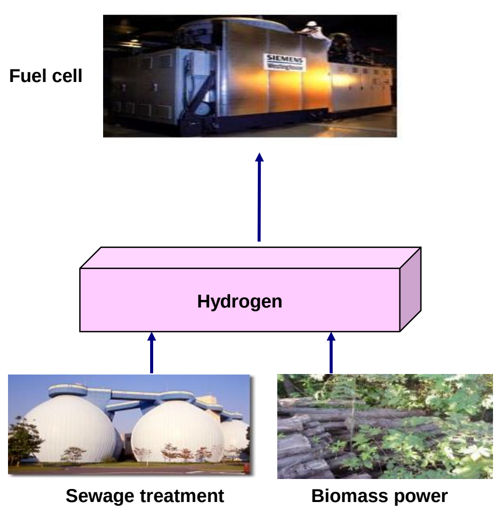

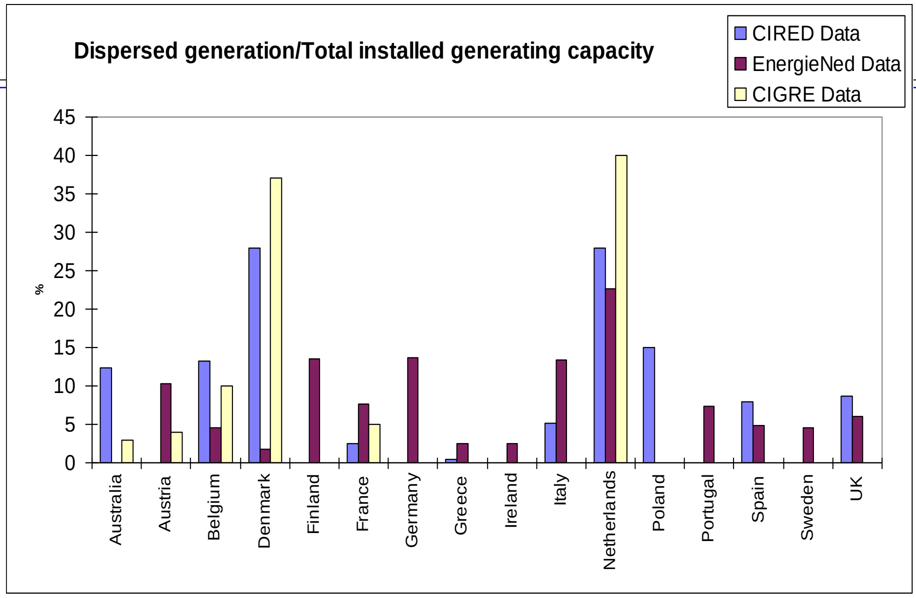

Distributed generation & consumption in Denmark (source Eltra)

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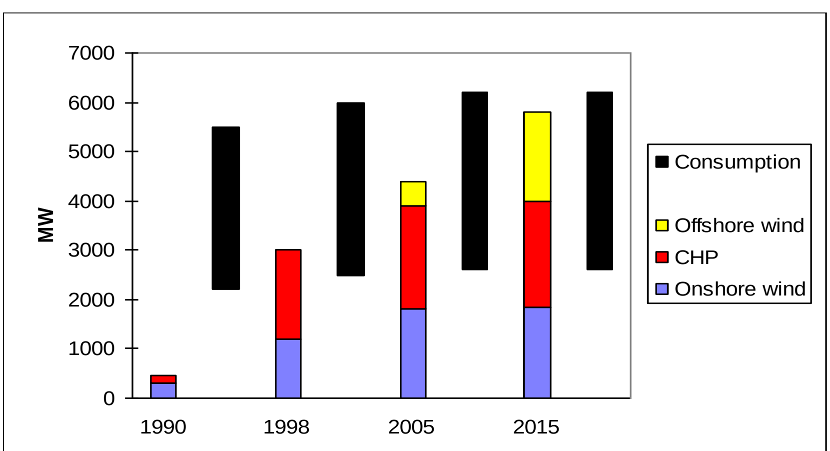

Q & A:- Options for Electrical Energy in 2020

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- Starting point:- generation in 2006
  - Peak demand = 60,000MW, minimum demand = 18,000MW, average = 35,000MW.
  - Gas = 43%, coal = 30%, nuclear = 18%, wind = 4%, water = 2%, oil = 2%, other = 1%.
- Will average demand in 2020 reduce, increase or stay constant?
- Estimate 2020 average demand?
- What will cause the change?
- Should the UK build new nuclear power stations? (remember if no nuclear station built, nuclear contribution by 2020 = approx 5%)
- Should we build more gas fired power stations? (uses imported gas)
- Should we build more wind-generators? (remember wind is not continuous, average output from a 3MW machine is 1MW)
- Should we build more conventional coal stations? (what about Kyoto)
- Will we have the technology to build economic clean coal power stations?

- Estimate the average output in MW from gas, coal, nuclear, wind, water, oil and other power stations by 2020?

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Q & A

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