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4M18 Present and Future Energy Systems: Cribs for the 2015 Examination

This examination was largely essay based. Those who scored the top marks actually structured their answer to actually answer the question precisely as asked, and sometimes included relevant material from other lectures our outside the formal teaching as evidence of their wider comprehension. Standard answers to the generic question scored lower marks.

CRIBS

Q1 (a): the UK retrofit project

If the energy suppliers meet their carbon emissions targets, the level of work done to housing could strictly be small, and would be undertaken on a separate cost-benefit curve in terms of reducing energy bills by virtue of improved insulation etc, and more efficient appliances. If energy suppliers don't meet their emission targets in full, and this is the most likely scenario, then the housing stock needs to reduce energy by the amount needed to cover the overall emission reductions. There are retrofit examples of >50% emission reduction, but 50% seems likely to be an effective upper limit on what might be achieved.

THE SCALE OF THE PROBLEM:

COST to halve domestic energy use:
22M homes, ~£50K for all-round insulation, multiple glazing, draught-proofing, and most energy efficient new appliances
£5K not enough, £500K for complete rebuild! Total Cost>£1T = ~10% of total UK assets today.
Note £23Bpa spent on home improvement.
Equal amount more needed for retrofit.
Note: cutting emissions from today's value means that we cannot count already installed energy efficiency measures.

WORKFORCE just for retrofit:
Cambridge: 44K houses: 1/500 in UK stock.
3000 building workers for 10 years retrofit in Cambridge = 400K in UK for 40 years
Actual no. builders in Cambridge = 1500
i.e. need to double workforce just for retrofit

MATERIALS AND SUPPLY CHAIN
Need 2-fold increase of materials supply for 15 year project in Cambridge and use exclusively on retrofit
Supply chain doubles builder numbers
0.8M employed in retrofit for 20 years.
Comparable with NHS (at 1.3m)
Total retrofit spending = 25% of health – lower technology and simpler jobs all round

x11.69 in

FINANCING
Pay-back on basis of saving energy will be of order 50 years if energy bills go to £2K per household.
Must be justified by asset value growth.
Cost of finance requires <10 years payback: i.e. need energy bills 5 times now with continuing 80% energy inflation per decade this would make sense in 2030.
Only alternative to issue bonds with low returns.
Unattractive for most investors.

EMBEDDED CARBON FOOTPRINT
Insulating materials, glass and appliances, typical of construction materials, and including the waste materials is about 25% of embedded carbon of average house when built, or 200 tonnes.
CO_2 payback time = 30 years.

NON-DOMESTIC BUILDING:
Non-domestic buildings emit 66% of CO_2 of the domestic buildings, excluding any industrial processes. Scale all the above up by 66% to obtain total domestic plus non-domestic costs, labour and materials! Cost £1.7T

CONSEQUENCES
Command economy/taxation essential to get money
Conscription needed to guarantee workforce
>2% of UK GDP tied up for 40 years.
Calculations exclude any effects of new build in terms of cost, carbon budget, manpower etc.

Q1(b) Renewable energy sources

Renewable energy - low density of the energy
Hydropower – not much capacity in UK (.2kWh/p/d), contrast Norway, NZ
Biomass and bio-fuels – large area needed for harvesting
Wind power – strong roll out, little data on maintenance and up-time
Solar thermal power – the problems in Japan
Photovoltaic – 20 years lifetime not proven
Geothermal – Iceland and NZ
Wave and tidal power – rugged environment
Intermittency, back-up, grid modification

Technology	Cost range (£/MWh)
New nuclear	80–105
Onshore wind	80–110
Biomass	60–120
Natural gas turbines with CO2 capture	60–130
Coal with CO2 capture	100–155
Solar farms	125–180
Offshore wind	150–210
Natural gas turbine, no CO2 capture	55–110
Tidal power	155–390

What would be needed in UK in 2050 from RAEng report.

	Average delivered power GW(av)	Total installed capacity (GW)	Equivalent assets
Onshore wind	6.5	24	9,600 2.5 MW turbines[10]
Offshore wind	11.4	38	38 London Arrays[11]
Solar photovoltaics	7.2	72	25 million 3.2 kW solar panels
Wave	3.8	9.4	1,000 miles of Pelamis machines
Tidal stream	1.4	2.8	2,300 SeaGen turbines
Tidal barrage	2	8.5	1 Severn barrage
Hydro power	0.9	2.3	1,000 hydro schemes
Total	**33.2**	**157**	

Megacities: not enough adjacent land free for local sourcing of renewables that si not committed to food production: although that may change over the period, but not likely enough.
Not enough time for new inventions of energy sources to be developed and deployed if breakthrough happened tomorrow.
Fossil fuels (with or without carbon capture and storage) and nuclear are the default options for megacities in 2050.
Remote and off-grid communities already benefit and will continue to benefit from renewables plus local scale battery story for their energising.

Q2(a) The Kaya identity is:

$$CO_2\,emissions = \frac{CO_2\,emissions}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{Population} \times Population$$

The four terms of the product to the right side of this equation imply in turn the following mitigation strategies:

- Reducing the emissions of energy generation – for example by switching from coal to gas powered electricity, or gas powered electricity to nuclear or solar, or from fossil diesel to biodiesel.
- Reducing the energy intensity of the economy. In theory this can be achieved by improved energy efficiency, although this has often led to rebound effects (for example it becomes attractive to use more light bulbs if the cost of running each bulb is reduced, or the habit of people living in well insulated homes to raise the interior temperature rather than reduce their energy bill).
- Reducing wealth (income) per person. If we account for trade, this is in fact the only mechanism that has worked strongly in the UK (in the 2008 recession).
- Reducing the population. Practical mechanisms to achieve this are both politically and ethically challenging!

(b) Assuming the population remains constant, the Kaya identity reveals three strategies for mitigation in the UK. In turn:

- Reducing the carbon intensity of energy generation is politically attractive – if it were possible, this would apparently allow the population to continue becoming richer, without having noticed that they had had to deal with climate change. It's also practically attractive, as the number of energy company managers or shareholders that must be convinced to change is much smaller than the size of population that would need to change to reduce demand for energy. However, we don't have any definitely ready and acceptable technologies to achieve this decarbonised energy supply:
  - Nuclear power is technologically mature, and the UK population appears to accept it, but it requires government support (to cover the insurance costs associated with risk) and public sentiment in both Germany and Japan has moved strongly against Nuclear since the Fukushima tsunami
  - Wind power is technologically mature, but costly, and must be deployed at massive scale to create power comparable to conventional power stations. We do not yet now the limits of public acceptance for both area commitment and the cost of wind expansion
  - Solar power is becoming cheaper, but in the UK requires a huge area commitment – around one quarter of the surface of the UK would be required to replace all other energy sources with solar electricity – and we don't know the limits to what the public will accept
  - Carbon capture and sequestration, although much discussed among policy makers, has yet to be deployed at significant scale – world implementation in 2012 lead to capture and store 2.7Mt CO_2 out of a reported 50,600 MtCO_2 released by human actions.
- We have excellent technological opportunities to create a much more energy efficient future if we were starting from a clean sheet: the world record car (PAC II) does 15,000mpg, and the Volkswagen L1 does 190mpg; newly built passive houses require only about 10% of the energy in use compared to the average UK house today; we could make most products and buildings with half the material used today and keep them for twice as long. In this sense we have technologies available, but we are not starting from a clean sheet, and the transition from today's economy – which has developed assuming no-consequences from the energy supply – to a future low energy economy is difficult. The cost of retro-fitting houses looks

high, and small, light low energy cars would be at a disadvantage in a collision with heavy inefficient cars. The political challenge is therefore both to challenge the status quo, and to support a transition – and this requires wide scale buy in.

- All recent political developments in almost all countries have assumed that growth in GDP is the first priority of government. Only very recently has any challenge to this emerged. Many ‘technological’ solutions to reduce emissions would lead to reduced GDP – for instance if we repaired goods instead of replacing them, this would require more labour to save material, and generally labour is expensive and material cheap, so this would cost more – and hence reduce GDP. As yet, no British politician has been ready to discuss GDP reduction, or a steady state economy – which would otherwise be excellent mechanisms to reduce emissions.

Q2 (c) Scenario planning is used to tell a story that paints a complete picture of a possible future, built on one or two high-level assumptions about the major trends going forward. The usefulness is that the role of detailed developments in particular areas can be fitted into the big picture to see if that insertion makes sense or not – if not either the big assumption or the detailed development will have to be modified. One can also test out particular ideas or economic futures within the context of possible scenarios of the future.

The Shell scenarios consider a future world in one of two possible futures: Scramble, where no-one takes climate change seriously, and the world scrambles to react to climate changes and energy needs as and when they arise, on the basis of each nation looking after itself. On this picture points of friction multiply. In the Blueprint scenario, the world acts together in a coherent manner to have a planned evolution to take account of climate change in the future before it happens.

The National Grid looks at possible future scenarios for population change and economic circumstance to predict the likely future infrastructure needs for the UK and the USA where it operates.

Most commercial companies undertake some form of scenario planning associated with the launch of major new consumer products to see if and under what basis sales are likely to take off.

In the end a scenario is a possible future, and not the future.

Q3 (a):

- Frequency control: Excess demand causes the rotating machines to decelerate, hence results in a reduction in frequency. Excess supply causes the machines to accelerate thus resulting in an increase in frequency. These frequency deviations are monitored by feedback schemes on the generation side, which readjust the power generated accordingly.

  Main features:

  - Used to balance supply and demand at faster timescales.
  - Stability is an issue that needs to be addressed. Aggressive feedback relative to the lags in the system can lead to oscillatory responses.
  - Local disturbances can propagate throughout the network as they affect the power transfer between buses.

- The control schemes at faster timescales are decentralized, based on local frequency measurements.
- Larger faults can cause the machines to accelerate/decelerate away from equilibrium, and the system might not be able to return automatically to its normal operating point.

- Economic dispatch problem (or optimal power flow problem): how much energy to produce at each generator unit such that operation cost is minimized and network constraints are satisfied.

  Main features:

  - Solved at a much slower timescale than the adjustments carried out by means of frequency control mechanisms.
  - Can in general be a computationally intensive optimization problem due to the complexity of the network.
  - Takes into account network constraints (e.g. maximum/minimum power that can be generated by each unit, voltage constraints at the buses, transmission line constraints) and economic criteria, which are not normally incorporated in frequency control mechanisms mentioned above.

Relation between the two mechanisms: Economic dispatch sets the operating point for the network with fluctuations occurring at faster timescales being balanced by means of frequency control mechanisms.

Q3 (b):

Smart Grids:

- Demand-side management: Supply and demand are balanced by adjusting the demand.

  Ways this can be implemented include:

  - Dynamic pricing schemes that aim to shift demand in off-peak periods (demand-side management at slower timescales).
  - Smart appliances contributing to frequency control, i.e. appliances detect deviations in frequency and adjust their duty cycle accordingly (distributed demand-side management at faster timescale).

  Advantages: Can reduce peak demand, and also the requirements in spinning reserves.

  Challenges:

  - Stability of the network needs to be ensured.
  - Smart appliances could synchronize leading to large transients.
  - Consumers need to be appropriately incentivised.

- Automatic fast fault detection and grid isolation: Detect large disturbances in currents/voltages and automatically isolate appropriate areas of the network to prevent the faults from propagating.

Challenges: Detecting faults at a fast timescale is challenging due to the existing variations in the network under normal operating conditions. Also deciding what action to take immediately after the fault has been detected is in general a nontrivial task that requires a nonlinear analysis to be carried out associated with the underlying network dynamics.

- Storage: Use storage facilities to deal with the fluctuations in supply from renewable generation, i.e. store the energy produced so as to use it at a later stage as needed.

  Advantages: Reduction in the requirements in spinning reserves to balance the fluctuations in supply.

  Challenges:

  - Efficiency loss.
  - Storage facilities are in general large investments and their economic viability needs to be appropriately justified.
  - Deciding the optimal way the storage facilities should be used (i.e. should the energy be used now, or stored and used at a later stage when the demand/price will be higher at the expense of reduced efficiency) is in general nontrivial, and requires a forecast of future demand.
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Q4. (A) Explain why a grid connection is preferred in the transmission and distribution of electricity.

A grid allows the connection of many power generators to many and widely distributed consummers. [1]. It allows redundancy and maintenance [1].

Making a distinction between transmission and distribution describe briefly the sources of losses and their main characteristics.

There are losses in the transformers, lines and various equipment used for regulation such as power factor correction capacitors. In transmission, the voltages are high and the loading is fairly high so it is efficient, although the power factor regulator equipmeent is in transmission mostly, as in distribution it would belong to the consumer so not counted here. The lines and transformers have variable losses depending on the load (I^2*R) and the transformers also have fixed losses (magnetisation depending on the volume of the transformer). [6].

Hence discuss the importance of strategic planning, and the use of spinning serve.

Strategic planning is required in an attempt to accommodate 20 years of lifetime of equipment by correctly sizing it for the anticipated load, so as to minimise capital and running costs, while still being able to deliver the peak demand. Spinning reserve is held on the grid ready to deliver power quickly, but has fixed losses which are not being paid for directly by consumption of power - reducing overall efficiency. [4]

b) Scotland has large nuclear, coal fired, oil and ccgt power stations and also has substantial pumped storage power stations.

National Grid operates two AC transmission lines across the Scottish border to England, which transmit power from the power stations in Scotland to England. Scottish Power pays the National grid $40 m per year to connect Longannet Coal fired station to the grid. Scottish Power Transmission have joined with National Grid to buld the Western HVDC link, Hunterstone to Deeside, as shown in Fig. X.   The link comprises 384 km of subsea HVDC cable and around 33km of land based HVDC cable to the southern terminal. Around 3km of AC cable connects the southern terminal to the grid.

Making reference to the technical and commercial issues, describe the benefits of such a scheme and account for the features mentioned above.

The HVDC scheme adds transmission capability to the grid in terms of reliability, maintainability and capacity. Two lines is simply not ‘grid’ like, especially as there is likely to be an increase in North to South energy flow with the renewables coming on line, as well as the historical existence of large generating plant [2]. Since Scottish Power is paying National grid to carry their energy south, it makes sense to jointly own some of the transmission capacity and recover the transmission costs [2].   HVDC is attractive as it adds capacity without increasing the fault currents, is efficient over long distances (384km plus), has no overhead lines (e.g. it can run through a nature reserve), undersea cable is not prone to weather problems and does not need consent of lots of land owners. The use of overland cable allows it to easily get to the best point on the grid (33km +3km AC) to support the grid in the best way. HVDC is also good for integrating renewable energy as it can be used to quickly redirect energy flows [4].