4M18 CRIB 2017

1. (a) List:

- Multiple paths
- Multiple generators
- Self stabilising, reliable

Costly so the transmission grid has relatively few long lines, producing a sparse grid, so there are issues with balancing the flow, capacity, faults. These are being mitigated by adding HVDC links to either coast of the UK and HVDC interconnections with continental Europe.

(b) Measuring the voltage and phase at either end of the transmission line can be considered as smart grid infrastructure, as it is the first step in control.

The power flow equation is

$$\frac{V_1 V_2 \sin(\delta_1 - \delta_2)}{\omega L}$$

If the voltage and phase are known, then the power flow is known. It can then be adjusted by transformer voltage tap changing, or phase changing and possibly adding controlled series inductance and capacitance in the line.

Many students failed to properly describe the power flow in terms of the voltages and the phase differences. This is best done by quoting the classic equation given in lectures and previous exam papers.

(c) (i) Frequency Control. This is the mechanism used for balancing supply and demand at faster timescales and is based on the fact that if the supply is greater than the demand there will be an increase in the grid frequency, and, similarly, if the demand is greater than the supply there will be a decrease in grid frequency. Therefore control mechanisms exist that detect deviations in frequency from its nominal value and adjust generation accordingly.

Optimal Power Flow. This is the mechanism used for balancing supply and demand at slower timescales and is an optimisation problem that determines the power allocation within the network so as to minimise generation cost and also satisfy the various networks constraints

(ii) Smart appliances could contribute to frequency control as a form of demand side management, by adjusting their consumption when they detect large deviations in grid frequency:

Advantages: Could provide an ancillary service to the grid and also lead to a reduction in the need for excess capacity and spinning reserves.

Disadvantages: Appliances could synchronise leading to large transients in the aggregate demand. Stability issues also need to be considered as this is another feedback mechanism in the grid.

2. (a) Steel and Concrete are hugely energy intensive in manufacture.

Http://www.shell.com/energy-and-innovation/the-energy-future/scenarios/a-better-life-with-a-healthy-planet.html (Page 35).

Clearly a very high temperature is needed in steel making and concrete making. This high temperature means a lot of energy is used initially. Then the steel and concrete are designed for a specific building. Concrete can only be broken up. Steel can be returned to use in an Arc furnace, but uses a lot of electrical energy. A universal standard on beams of steel and fixed blocks of concrete could make recycling much easier, and low energy reuse. This would also mean that buildings are standardised and potentially modular. In reality, a higher priority for reduction in energy would be the accurate and reduced use of materials in making buildings, probably associated with factory build of modules (such as the top floor of the joint Kings/St. Catharine's building and the new building on the corner of Histon Road and Huntingdon Road). Alternatives to concrete could also be used, such as wood which could be burned. Making buildings which can be repurposed and designed for a long life is also important. *Many students failed to identify the importance of standardisation and modularity in the use of steel and concrete.*

(b) Rebound effect is the term used to describe the change in occupant behaviour following the installation of a retrofit measure. For example, an increase in the internal set-point temperature to improve comfort conditions. It results in post-retrofit energy consumption being higher than predicted.

Temperature takeback: increase in the average internal temperature of a building after retrofit measures have been implemented. This is common in fuel-poor buildings, which have inadequate thermal comfort to begin with.

The re-bound effect and temperature takeback can result in gross overestimation of energy savings from retrofits. It is thus important to consider them in energy saving calculations

(c) Transport can use much more bioethanol. It's 5% in most gasoline now, and can be increased to 10% easily. Beyond that it gets harder. Biodiesel can be mixed with Diesel, so the transport target can be met relatively easily in the short term. Moving to a large number of electric cars in this timeframe is near impossible but should make some impact by 2050, although limited by the grid infrastructure when a large proportion of vehicles are electric.

Heating is already gas based, also with oil and coal, with some electricity. Heating also represents about 30% of our total energy consumption and is installed already. There is no immediate solution. Hydrogen could be added to about 5% in gas, but that's it. Biomass boilers are too big for most homes. Ground heatpumps have not proved very effective as the heat is low grade and it only works in a well insulated building and take time and money to install. So buildings need insulation first (treat heating as a system). Hydrogen needs to come from oversupply in electricity and needs hydrolysers to be built at very significant capacity. CHP (systems approach) could be used in domestic buildings but this requires all of new build to use it to have enough impact. Larger heating schemes such as Addenbrookes is adding a large CHP scheme and this could be heavily incentivised for large institutions such as Cambridge University. Government incentives need to not be in opposition to each other - Not one or other, but all. A strategic systems approach is needed. *Part (c) was generally well answered though few mentioned the potential use of CHP.*

3. (a) For coal, the combustion equation is

$$CH_{0.5} + 1.125\ O_2 \rightarrow CO_2 + 1/4\ H_2O$$

Therefore the heat released per kmole of CO2 emitted is

$$20/(12+.5)=1.6 \text{ MJ}$$

Assuming a relatively good power station, an unabated plant would have an efficiency of 45% giving

$$20/(12+.5)\times 0.45=0.72 \text{ MJ of electricity per kmol of CO2 emitted.}$$

For gas the amount of electricity generated per kmol (assuming an CCGT efficiency of 55%) is

$$42/(12+4)\times 0.55=1.44 \text{ MJ of electricity per kmol of CO2 emitted.}$$

This simple calculation shows that for power plants without carbon capture, natural gas is a more environmentally friendly fuel. As expected, it contains less carbon per joule of energy released, and can be used in a much higher efficiency power station. The only advantage of coal is its relative abundance and the ease at which it can be transported and stored. Many countries do not have access to a plentiful supply of natural gas or the infrastructure to use it. The use of LNG partly solves the problem of pipeline infrastructure, but coal is still attractive to those countries with no natural gas storage or distribution system. In reality energy generators tend to respond to price. Gas is currently cheap owing to fracking. Future carbon taxes would also tend to push the use of gas, which could be unintended. If carbon capture and storage is implemented, the CO2 is captured, but at the cost of an energy penalty which will increase the amount of fuel consumed by about a quarter. Thus, if carbon taxes become sufficiently high, CCS may become attractive and coal may be as benign as gas. The more likely scenario would be a switch to gas which makes a huge difference to the CO2 output without the imposition of an energy penalty. For example, in the UK it would not now be possible to build a coal fired plant without CCS, but an unabated gas plant would be allowed under the current rules. Other countries without access to gas are likely to continue with coal but won't implement CCS without international agreements on carbon tax or subsidy. *Few students recognised coal as easy to transport and store, which is important globally.*

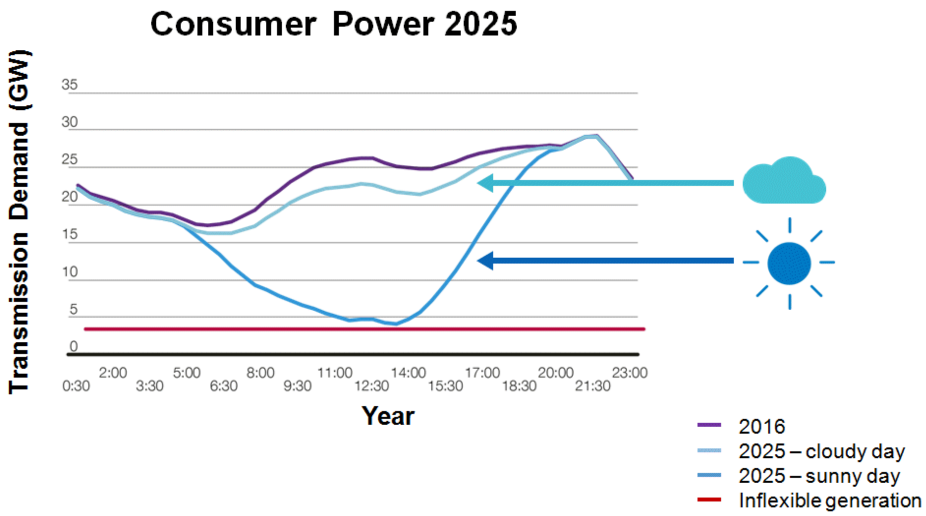
(b) (i) The advantages of a CHP scheme (not in order!)

- Local generation of electricity (as a by product in many cases),
- The reduced need to have a reliable supply from the grid (e.g. An oil refinery or hospital needs electricity to run and keep safe!).
- The CHP gains efficiency by reusing the waste high grade heat.
- Many, such as Wissington, also use the low grade heat in tomato houses.
- Some are fired using Biomass, so they are further environmentally attractive.

CHP schemes typically exist in the distribution networks, as they are typically small relative to normal power stations. So power can be supplied locally, but many are ‘big’ in respect to their location. This raises issues of voltage stability, distribution grid capacity and scheduling the power. *Everyone knew CHP was good, but less than half could extend the list beyond the basic and comment on the grid issues.*

(ii) CCGT schemes exist in large power stations due to the complexity of raising steam from gas turbine exhaust gasses, so they must be large. They are also efficient so produce less carbon per unit electricity, and are mostly gas fired. Large generators are also managed by clear contracts. Small generators such as CHP need to be able to disconnect when not needed. The opportunity here is to use both types as back up suppliers in a market where the worrying factor is wind production varying. The CCGT can be more easily managed by individual contracts (as spinning reserve). CHP contracts are more likely for emergency grid support, but they are distributed and need some kind of aggregation and control. *Very few stated that CCGT was a bulk power source and therefore transmission connected, so missed the heart of the comparison.*

4. (a) [The problem as perceived is that the renewables have a very large installed capacity, because they have a lowish load factor. In fact this is not really true as wind load factor in 2015 was 39.7%, higher than that for CCGT and coal! Hydro was similar. Nuclear is at 75%.] On a sunny day we want the solar power, but the nuclear doesn't like being turned on and off, so we have an excess generation capacity problem, and even the CCGTs need to be kept hot with a minimum load. So our total generation could easily exceed our demand. In our curves we can see that there is an issue on a sunny day when the demand at midday is mostly met by solar, but on another day it is not.



In planning NG needs to consider the demand, the tides, the cloud and the wind. Solar and tides are very predictable, and daily, but the wind much less so and there may be calm for days.

Much of the solar will be located in the south, where there is most demand for electricity. The wind power in Scotland is very good, but delivering it to England is difficult. Also, the link needs to be bidirectional, for when the sun in the south shines, but the wind does not blow. Weather forecasting becomes very important, as decarbonising relies on not firing up coal or CCGT. It is notable that the new Pembroke CCGT power station is holding in reserve land for CCS, as the only route to high amounts of renewables on sunny days is to fire up CCGT with CCS for the early evening demand. Adding HVDC links either side of the country helps with devivering the power and helps support the grid and reduce fault currents, using the electonic interfaces at each end.

The question was taken from the National Grid guest lecture and yet few students seemed to understand the use of weather forecasting and idea that tides were also known.

(b) The Shell scenarios make it clear that Fossil fuels will remain in the world energy mix for the long haul. The increase in energy use by developing countries is too fast for renewables to keep up at reasonable costs, (energy return on investment) and coal in particular is a cheap dense source of energy, suitable for use in compact transmission grid connected power stations, placed at some distance from the city. Coal is easily and safely transported, without any technology such as pressurised containers so can be put in trains, loaded into ships, and the reverse in India, at very low cost. Therefore the investment in rail to the port. In future, CCS could address the carbon emissions, at the cost of efficiency.

Solar wind farms at these sorts of powers are grid connected so can use the land away from the cities. This reduces the demand on land needed near to the city for farm use. Mega cities are also likely to be energy intensive in terms of public transport, air conditioning and heating.

Most scenarios and reports accept that 'more of everything' is seen as the most acceptable way forward for developing countries to meet their increasing energy needs, hence the approach of Adani. Different scenarios suggest different uptake of renewables, but Adani has hedged successfully against any future.

Few students seemed to understand that 648MW Solar must be transmission grid connected, so that the low density of solar is not an issue. Most were keen on coal with CCS!

Dr Patrick R Palmer
10 November 2017