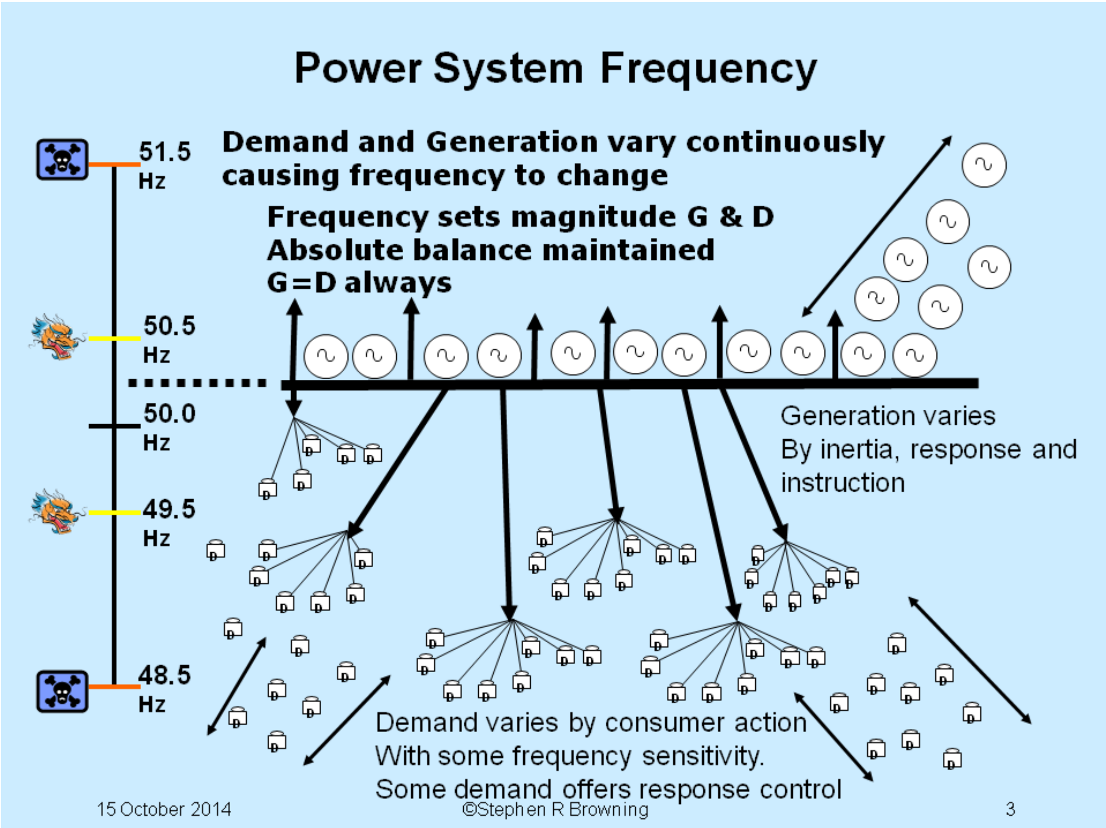
Electricity System Operation - Fundamentals of Matching

Electricity flows from Alternator to Appliance at near the speed of light and there is no storage in the wires. Thus, each Electricity system is always in perfect balance. At Every Instant Sum of Actual Generation Power = Sum of Actual Demand Power.

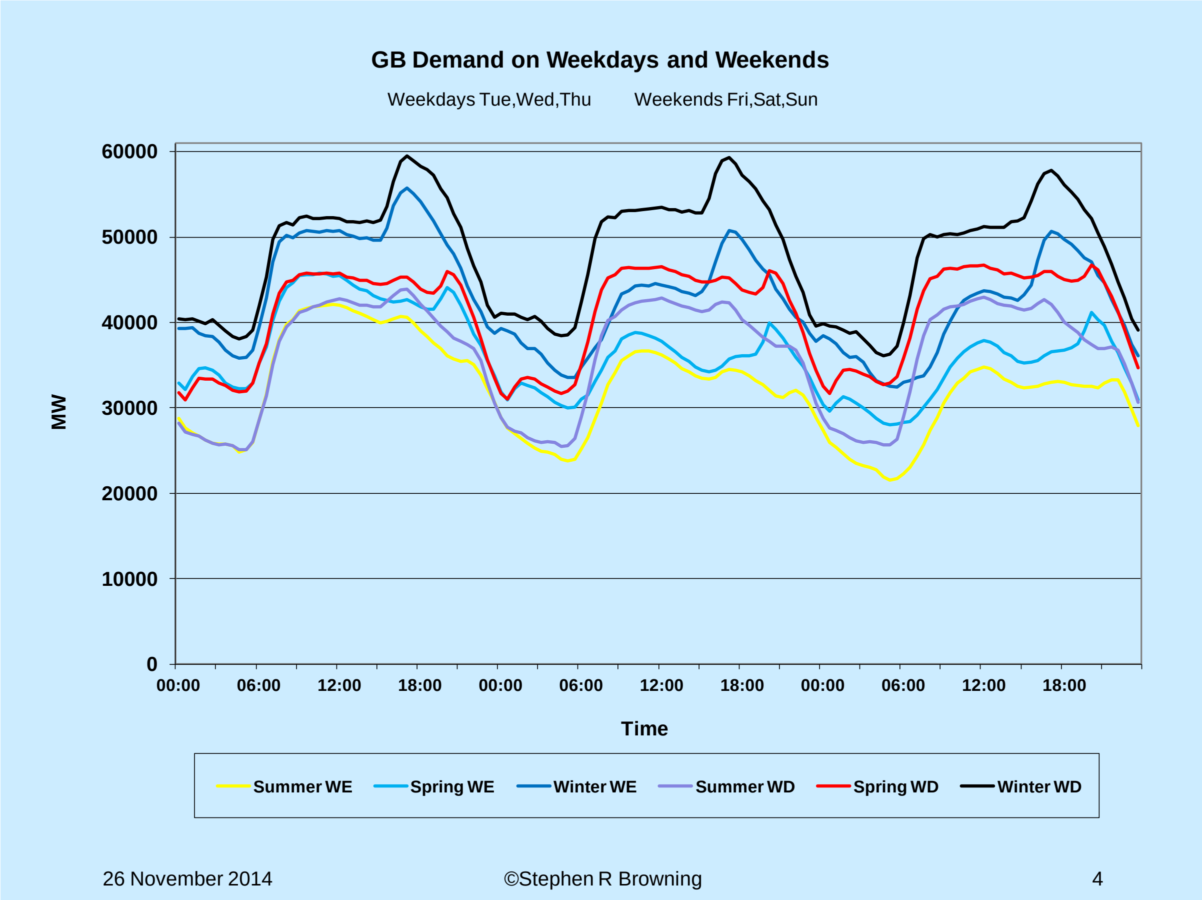
On an AC system, this rule is maintained in real time by the frequency, whose deviation from nominal (50 or 60 Hz) represents the difference between 'required demand' and 'delivered demand'.



The Power Demand varies continually by time, day, week and season.

Thus Electricity delivery is Unique as an Energy vector. There are no appropriate analogies. It requires that you get it to the Right Place at the Right Time and that will be (Laws of Conservation of Energy) at the Exact Rate (Power) required.

Therefore tight matching of Generation Power to Expected Demand Power is required. While maintaining Security (MW flow limits), Stability and Voltage (MVAr provision) at all points. While covering for any one of the large number of Credible faults occurring at any instant.



The frequency has to be kept within strict limits to avoid system degradation; usually +/- 1% for normal operation. If the frequency deviates beyond 2%, automatic disconnection and measures are necessary to arrest the slide and avoid collapse.

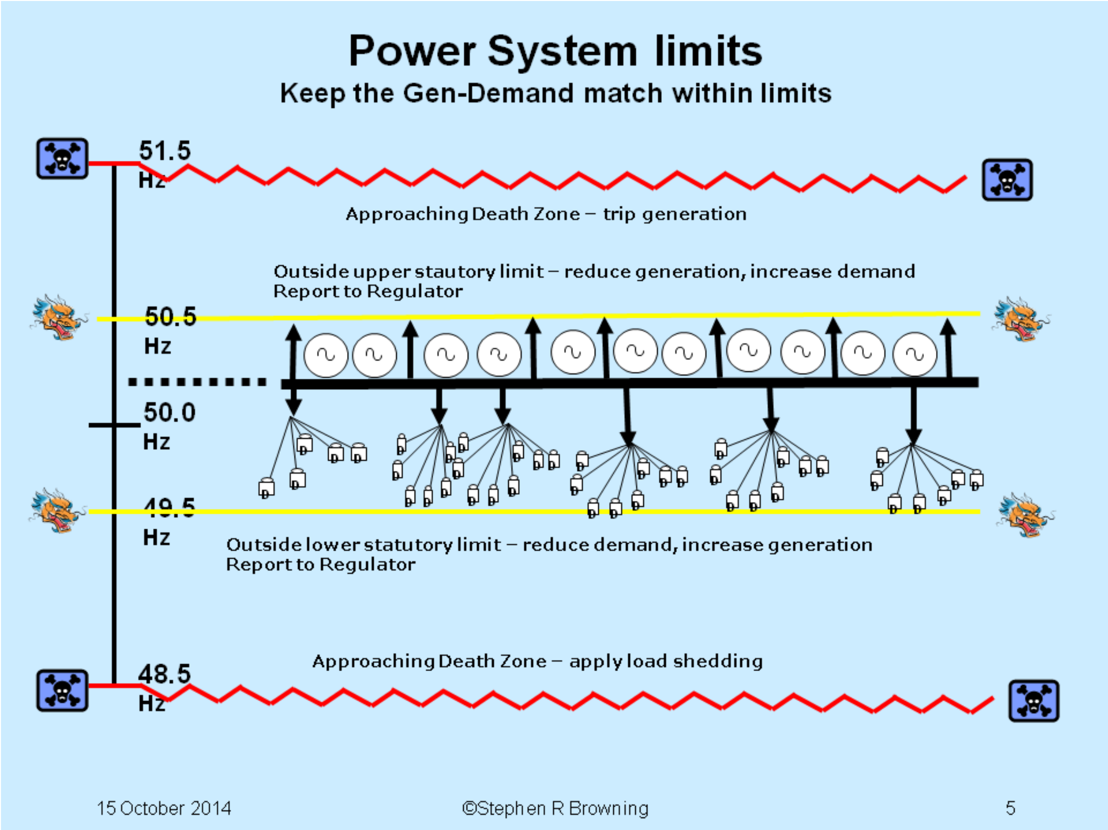
Therefore, within each system, Total Generation Power must be closely matched to Total Demand Power, as the latter would be with the Frequency at 50Hz. This means that both Generation and Demand must be predictable and an adequate level of control is required to allow the match to be set and adjusted for all times.

When frequency changes, Synchronous Generators will instantaneously release or absorb inertial energy and some (resistive and induction motor) demands will reduce. Extra generation (and increasingly demand) is set to provide additional response and backup for same so that any event, including the loss of the largest infeed, can be compensated without an excessive frequency deviation.

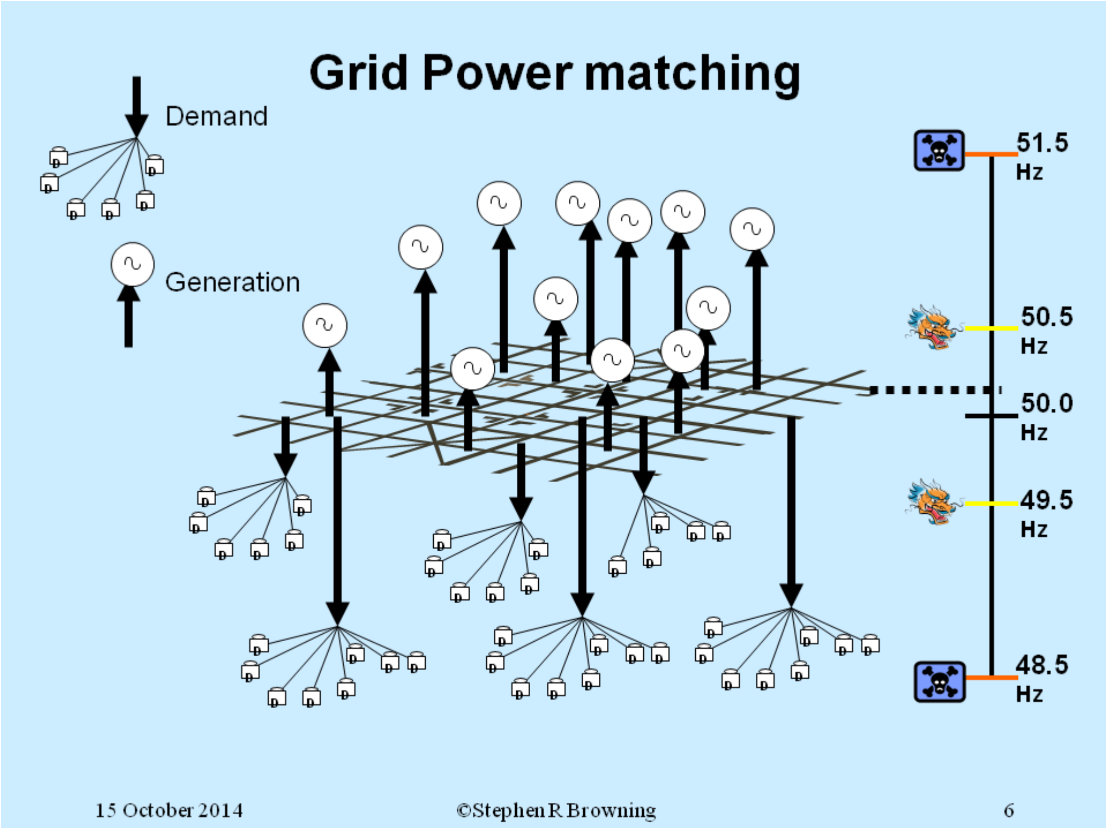
Thus control of each AC system is a

365*24*60*60*Infinity process - Every Instant counts

In fact each AC system is a giant machine comprised of machines and appliances coupled together by Electromagnetic waves. At the GB Peak we are pushing around 55 million BHP through the wires.



The transport system must be secure - under both steady state conditions and for any credible fault, both transmission and distribution must not be overloaded, have unacceptable voltage excursions or be unstable.


Grid Power matching
Demand
Generation
51.5 Hz
50.5 Hz
50.0 Hz
49.5 Hz
48.5 Hz
15 October 2014
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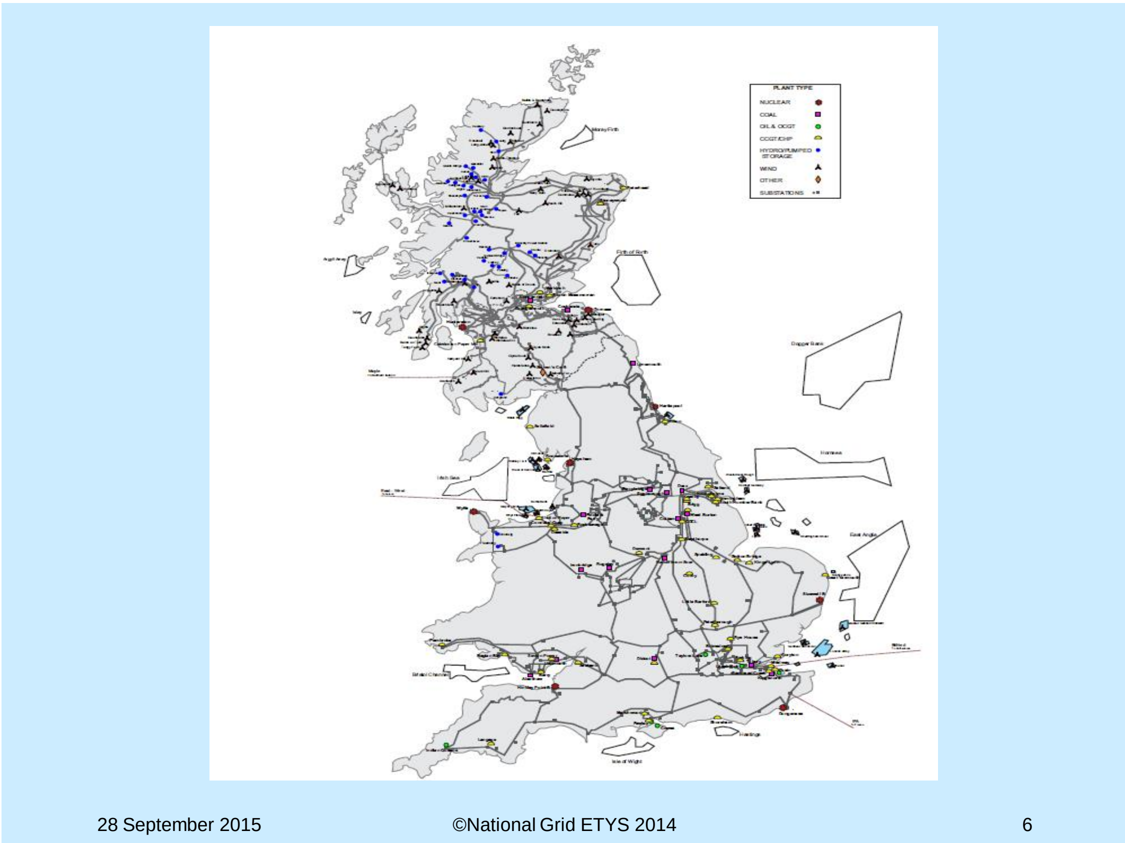
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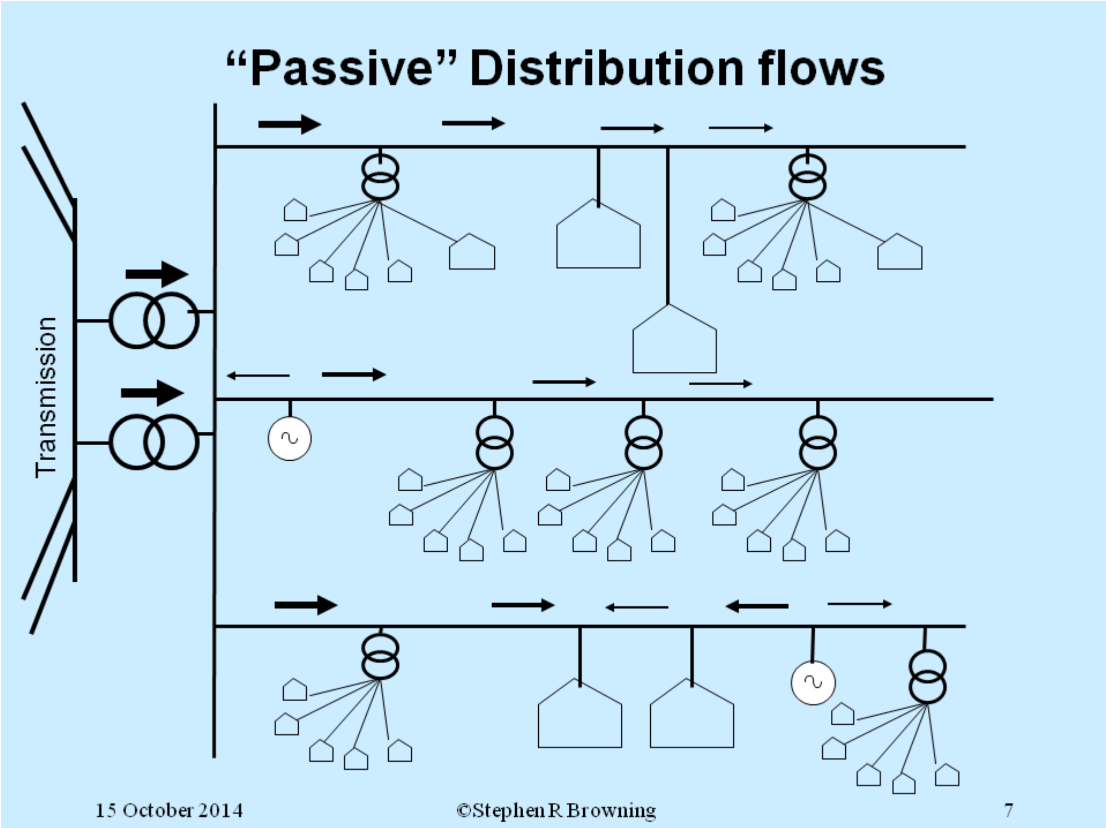
"Passive" Distribution flows
Transmission
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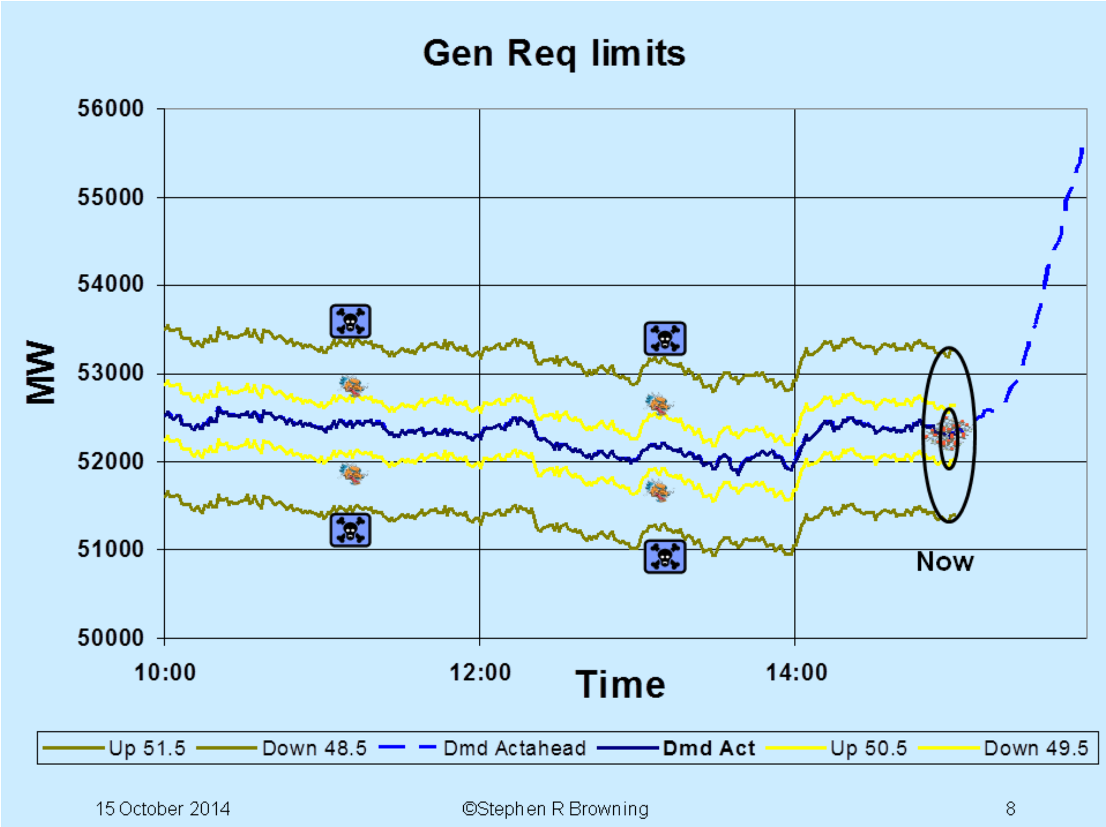
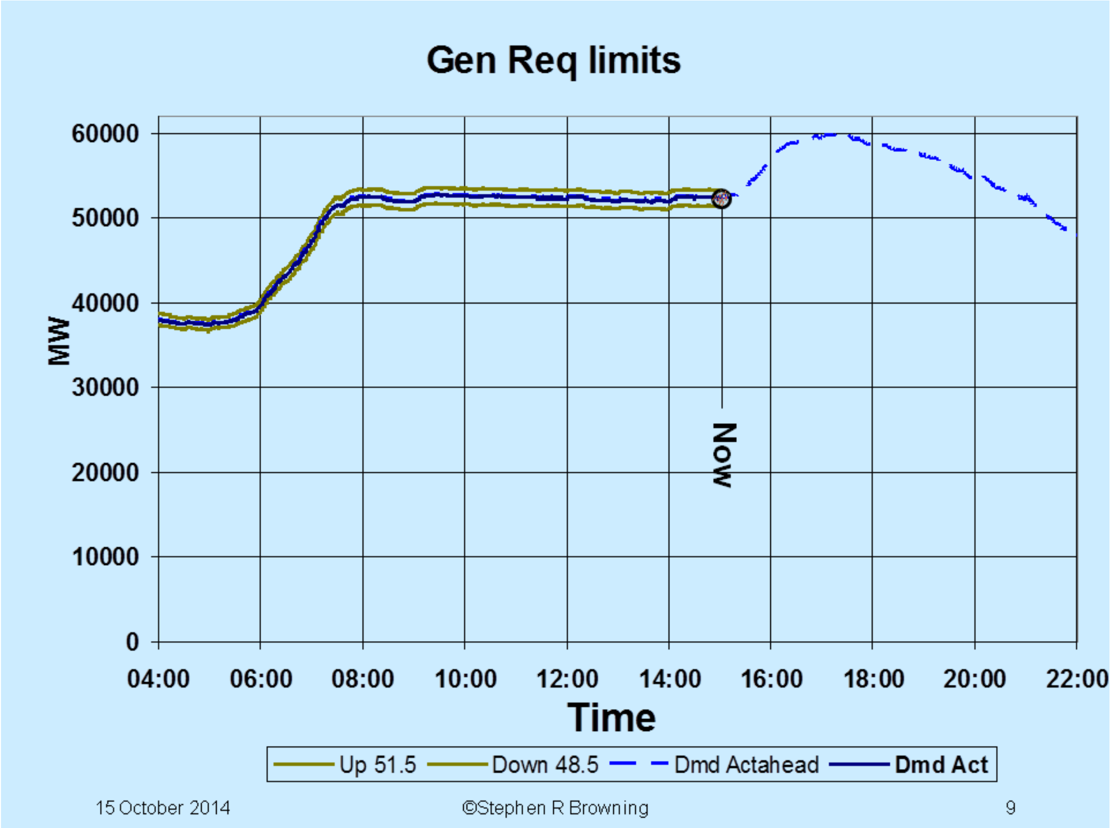
We can try to show the overall deviation limits in terms of maximum excursion from 'generation requirement = required demand'. On a large power system resistive load will react. Motors and other inductive loads can also respond. However, if control systems are set to maintain constant speed or output the frequency correction will be nullified.

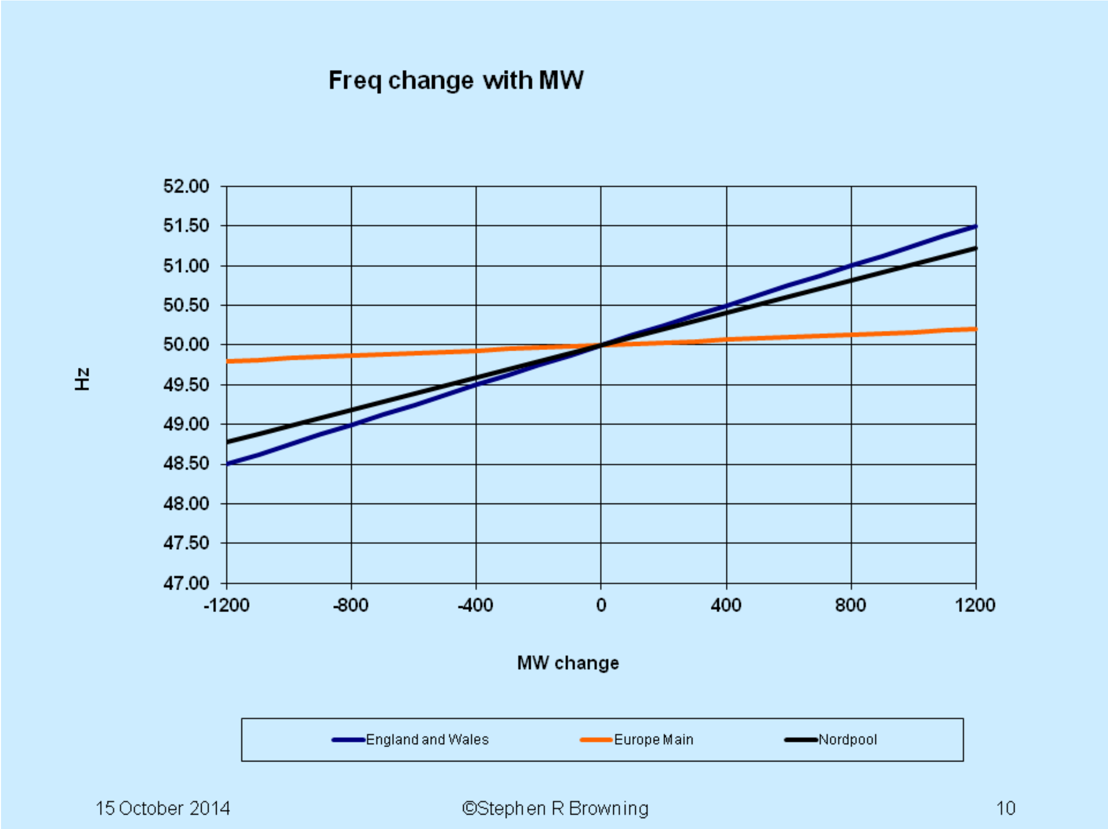
This graph shows that the mismatch of generation delivered to that required has to be tightly controlled. This assumes that demand is 40% frequency sensitive.



and here is what the 'limits tunnel' looks like on the total demand.



The level of frequency response to demand change varies, depending on the size of the interconnected system.



So, we need to be able to predict both demand and generation, and ensure that the match is kept within tolerance, for all timescales from immediate out to planning while ensuring the transport system is secure.

To do this, it is necessary to predict and model the demand (with its continuous variation) overall and by location. We need to model generation (prices, dynamic constraints), also by location, to be able to set the match and predict network loadings and voltage/stability conditions in detail.

We need to make sure the 'match' is close enough for all the lead instruction timescales, with adequate automatic compensation for losses of plant and demand....

Working from the current instant these processes are

Damping - Response - Reaction - Reserve - Dispatching - Scheduling - Commitment - Planning(Operational) - Construction - Consents - Scoping

Electricity vs Gas - Operating Logistics

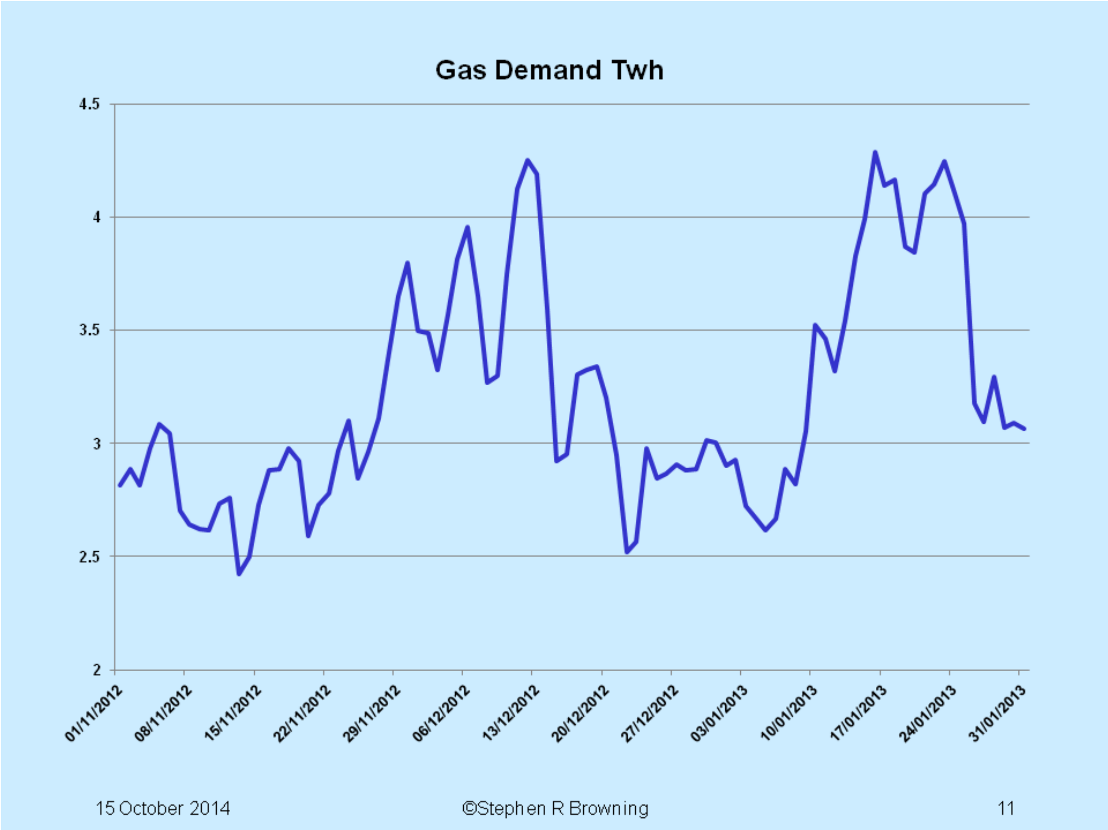
These two main energy delivery systems are totally different. Electricity moves from alternator to appliance at the speed of light with no storage whatsoever in the wires. Gas can be compressed and decompressed. Whenever gas is pumped into a section of pipe, a doubling of the pressure would mean that the stored energy in that section of pipe has also increased by a factor of 2. Thus the pipework (linepack) and gasometers hold an incredible amount of storage.

The GB Gas system delivers @1100TWh/annum with variations from @5TWh/day on a Cold Winters day down to 1TWh/day in Summer. The linepack sits at @4TWh but the 'end of day' level is kept reasonably constant from day to day to ensure that stability and the correct pressure gradients are maintained. There are also large storage caverns both onshore and offshore (@33TWh and @3TWh respectively).

Like Electricity, the Gas demand will vary across each day and the 'Supply' (Beach and Interconnector Imports plus Storage withdrawal) have to be flexed to match Offtake (Demand + Interconnector Export + Storage Injection). Varying Gas production from 'wet' (Gas+Oil) wells is tricky as it is preferable to run the associated Oil production at a constant rate. Dry wells (Gas only) can in theory modulate their output more easily. Balancing Trades are executed each day to ensure the Linepack stays within its 'End of Day' Target range but the inherent storage allows for less frequent instructions.

For Electricity the Power (rate of energy delivery) Input to Demand must be tightly matched as described above. Many instructions are issued (10+ per half hour) to ensure stability is maintained.

Day to day Gas energy demand variation in the winter can also be quite marked as temperatures change. Linepack variations within day of @190GWh can occur, with maximum difference between start and end day Linepack values held below 65Gwh.


Gas Demand Twh
4.5
4
3.5
3
2.5
2
01/11/2012
08/11/2012
15/11/2012
22/11/2012
29/11/2012
06/12/2012
13/12/2012
20/12/2012
27/12/2012
03/01/2013
10/01/2013
17/01/2013
24/01/2013
31/01/2013
15 October 2014
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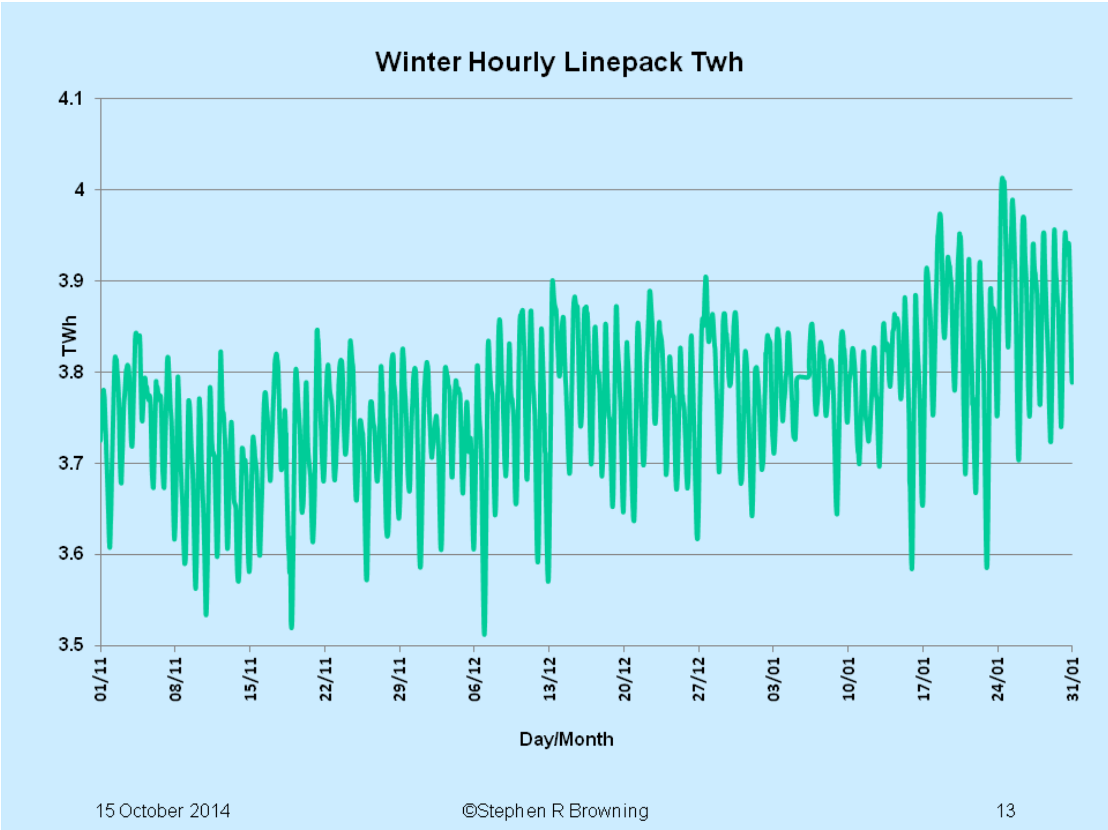
Winter Hourly Linepack Twh
4.1
4
3.9
3.8
3.7
3.6
3.5
TWh
01/11
08/11
15/11
22/11
29/11
06/12
13/12
20/12
27/12
03/01
10/01
17/01
24/01
31/01
Day/Month
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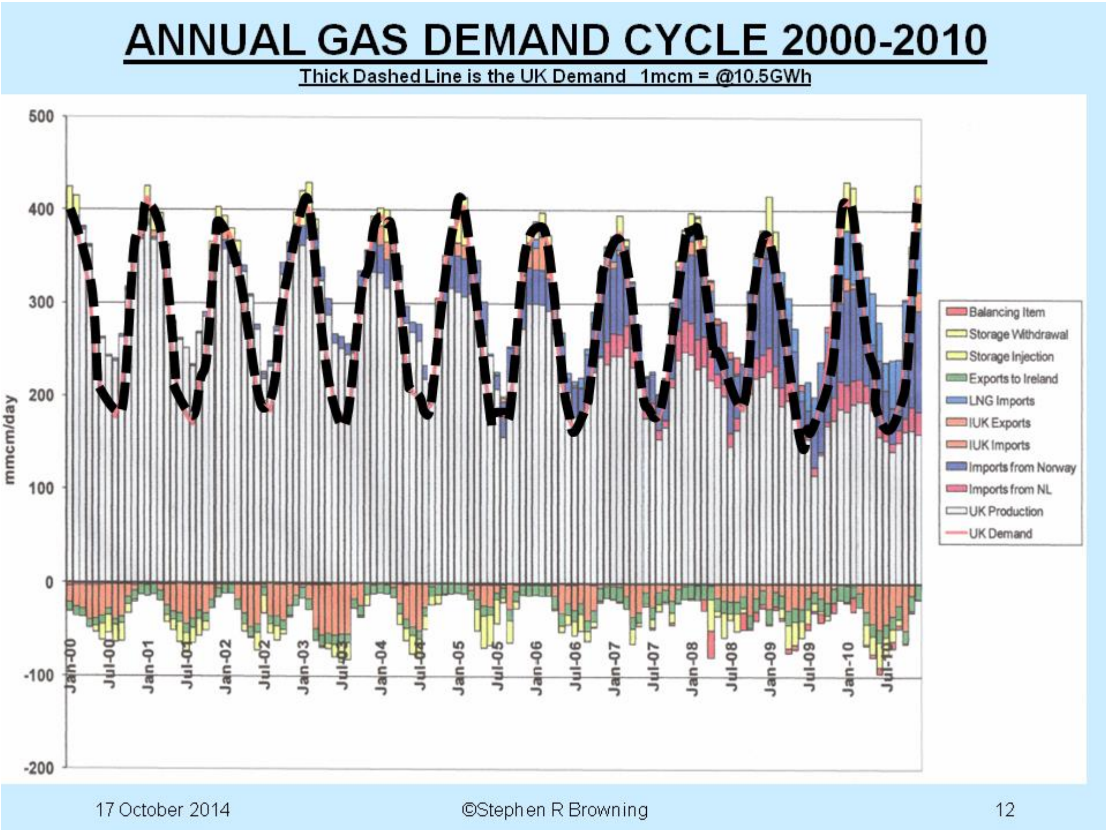
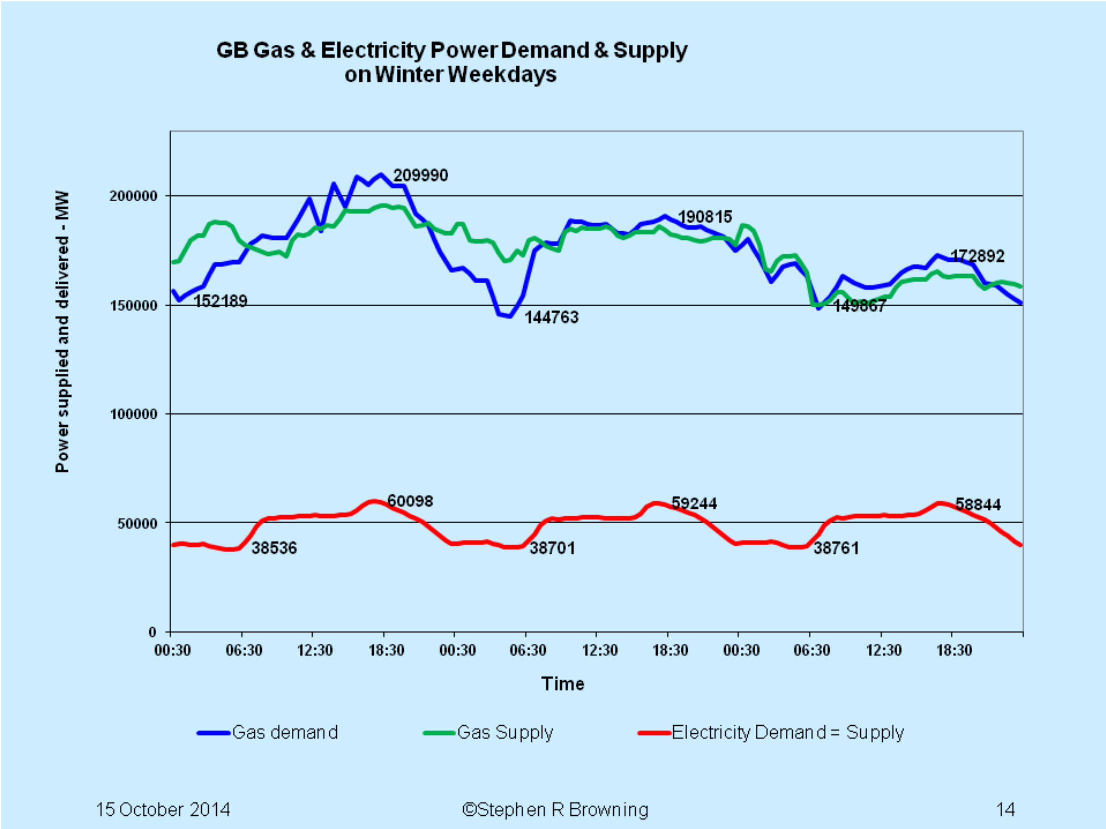
Here is a view of the Gas energy demand variation across a number of years, broken down by source. The large scale regulating duty has shifted from the UK Continental Shelf wells to the Norwegian Interconnector. You can see the extent to which storage stabilises the supply as the demand varies.



And here is an attempt to compare half hourly Gas and Electricity Power demand and supply (infeeds and generation respectively) across a December Peak period.



The slightly erratic nature of the Gas demand curve is due to it being derived from '2 minute' records of Supply and hourly 'Linepack change' data.