TRANSMISSION

The challenges posed by more renewables

The EU has very ambitious plans for renewable energy. It wants to see 20% of energy come from renewable sources by 2020. Each country has its own target to help achieve this overall goal. For the UK, this means that 15% of energy will have to come from renewable sources – which implies a 35% target for renewable electricity. Meeting such a target will not only have massive cost implications but it will also have substantial knock-on impacts for running the transmission system – especially since most of the renewable capacity will be wind-based. So are there lessons that the UK could learn from other countries? In 2007, wind provided 19.7% of Denmark's electricity, a significantly higher proportion than in any other country. In the following article, **Paul-Frederik Bach*** offers his views on the implications of such a massive dash for wind will have for the grid.

There are three main areas that will be significantly affected by ramping up the proportion of intermittent renewable energy on an electricity system – system balancing, market performance and system security.

There must be a balance between consumption and production of electricity at any time. The normal frequency in Europe is 50 Hz. If there is a surplus of generation the frequency will go up. In case of shortage of generation the frequency will go down.

Normally the system operator plans on a day-ahead or an hour-ahead basis to ensure that there are resources available for supplying the expected demand of electricity throughout the day. The planning procedures depend on the market arrangements in the country concerned.

There will be differences between the plan and the real time operation. The demand may be different from expectation or power plants may have technical problems.

In order to maintain system frequency within secure limits the system operator must have a balancing mechanism allowing it to adjust either generation or consumption of electricity in real time.

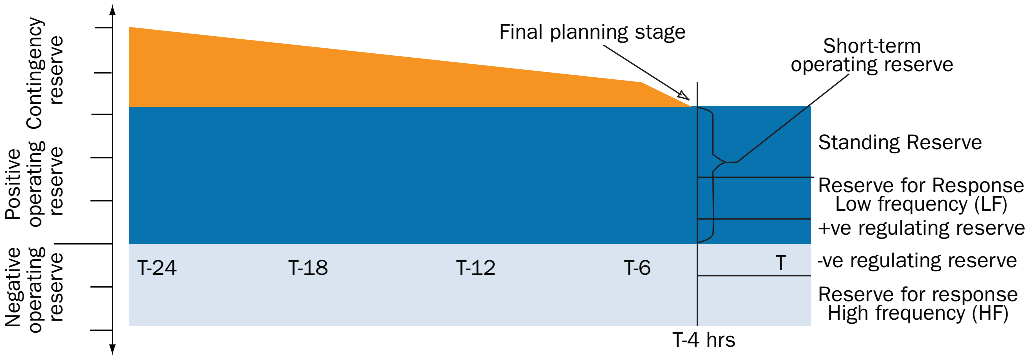
The magnitude of such deviations is manageable in a traditional power system. The system operator must have access to reserve capacity for the worst contingency, which is often loss of the largest generator.

In 2005 NETA (New Electricity Trading Arrangements, valid for England and Wales) was replaced by BETTA (British Energy Trading and Transmission Arrangements). The aim was to create one wholesale electricity market that included Scotland and with one independent system operator, National Grid.

The electricity market is based on bilateral trading between generators, suppliers, traders and consumers on a rolling half-hourly basis. The wholesale market has three stages:

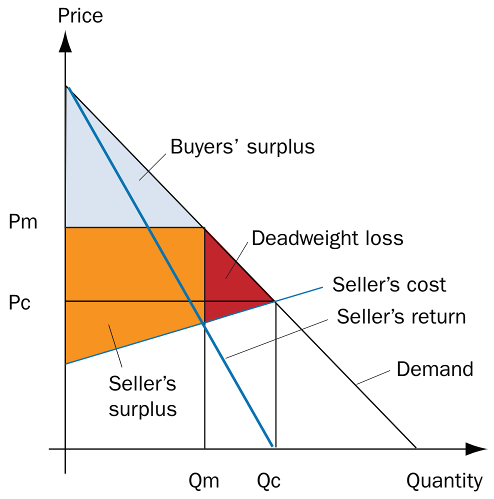
- Bilateral forwards and futures contract market up to 24 hours ahead of real time;
- Short-term bilateral markets with gate closure one hour ahead of real time;
- A balancing mechanism managed by National Grid.

Figure 1: NGT operating reserves



Source: National Grid

Figure 2: Monopoly economy



Source: Paul-Frederik Bach

National Grid must purchase balancing services from market players providing 'offers' (for more generation or less consumption) and/or 'bids' (for less generation or more consumption). The mechanism operates on a 'pay as bid' basis(1). The settlement process is managed by Elexon(2).

Reserve requirements(3)

National Grid must provide the short term operating reserve requirement for the system. The operating reserve is supposed to cover the risk of imbalance due to, for instance, loss of power plants and demand forecast errors. The risk of not meeting demand at a given time must be less than 1 in 365.

The operating reserve consists of:

- regulating reserve (frequency control, both directions);
- reserve for response (at high or low frequencies, both directions);
- standing reserve.

National Grid has defined a ±0.2 Hz operational limit for the frequency. The statutory steady state limits are ±0.5 Hz.

Besides the operating reserve a certain capacity is available as contingency reserve. This capacity consists of so-called 'cold' units. They need at least four hours to become ready for generation. The contingency reserve for a given time of day will be steadily decreasing until four hours ahead of real time (see *fig. 1*). This means that National Grid can call for contingency reserve to be converted to operating reserve in due time.

It is important to understand the nature of this rolling planning in order to be able to estimate the operational consequences of an increasing share of wind power.

Long term perspectives

To address climate change concerns, wind power plant, perhaps together with a new generation of nuclear power plant, are supposed to provide an increasing share of electrical energy in the coming years.

Unfortunately, both wind power and nuclear power have the common feature that they are not very well suited for 'load following'. The reasons are both technical and economical.

Nuclear power is designed for baseload operation – which means a constant high generation and a high annual capacity factor(4). It can cover the baseload part of the demand assuming that somebody else will cover the peaks.

Wind power follows wind variations at the generation sites. The capacity factor is low. There is only a poor correlation between the wind power profile and the remaining demand profile. It is for other technologies to provide the energy in time to fit the demand profile.

It is likely that traditional fossil fueled power plants will be those flexible workhorses for the next few years. During that period new technologies, such as electrical storage devices and flexible demand mechanisms, must be developed in order to reduce the dependence on fossil fuel.

Supporters of wind power and nuclear power will claim that their technologies can perform load following. It may be true to some degree but to do so will come at a cost. The operators of wind and nuclear plants will probably prefer to sell cheap electricity during surplus periods. Therefore technologies which can use cheap electricity, when available, could be important elements of the future energy system.

Wind power forecasts will be more and more important as the share of wind power increases. There are considerable errors in wind power predictions. This will probably intensify the trade in the short term bilateral market and particularly in the balancing market. The system operator must anticipate lack of capacity due to forecast errors in due time for activating the contingency reserve.

A 20 year period could be considered as a reasonable transition time for the replacement of thermal power plants as the main source of such flexible capacity. Hopefully the short term market activities will expose the opportunities for new technologies and encourage market players to support the necessary research and development activities.

The useful electricity market

The market is often discussed in the same way as religion – some believe in the market and some do not.

With a large number of distributed generators it is impossible to do without a wholesale market since the central despatch and monitoring of thousands of small power plants will not be efficient. The market is needed as a tool for optimization of power system operation.

However, a market must be carefully organized. A market model must be tailored for the local conditions in each case and must be maintained and improved all the time. And there is a considerable risk of market failure. Among the general conditions for efficient electricity markets are:

- a suitable number of market players;
- all relevant information must be available to all market players;
- normally no trading constraints (for instance bottlenecks in the grid);
- sufficient liquidity in each market segment;
- all physical trading must be properly recorded and collected;
- mandatory metering and settlement.

An authority must be appointed for market management. The transmission grid is the transport system of the electricity trade. Therefore the market management is usually made by or coordinated with the transmission system operator.

Electricity trading can be financial and physical. Financial trade (up to years ahead) contributes to stabilizing the market during periods of uncertainty. The electricity market in California collapsed in 2001, partly due to the lack of financial trades. The physical trade (day ahead and hour ahead) may include power exchanges and publicly available spot prices. Participation in the spot market may be mandatory or a supplement to bilateral trade.

Quality of market service

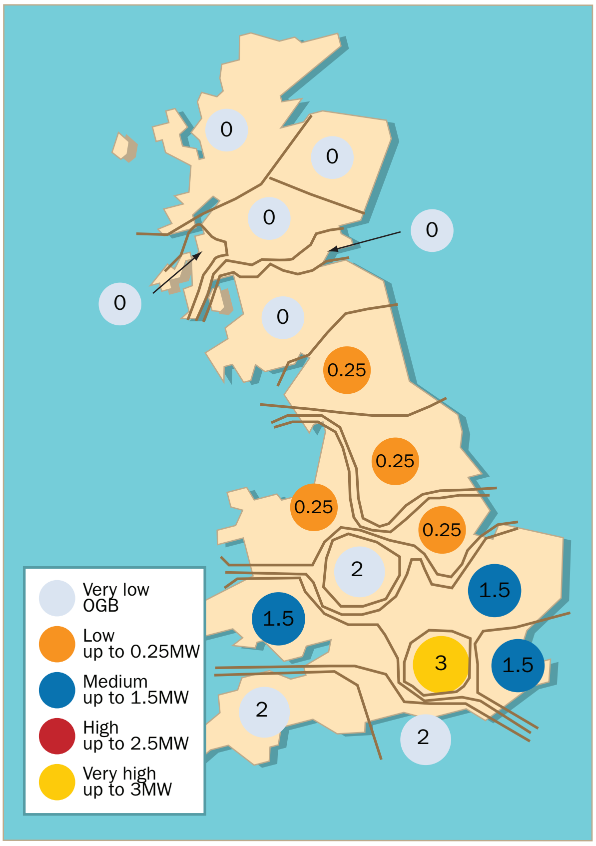
A stable and predictable trading framework will encourage more trade and contribute to better resource utilization. Transparent information and sufficient access to transmission capacity are among the important market service qualities.

The market rules must specify minimum information for all market participants. The information must be provided regularly by the market manager. It may include market statistics, maintenance schedules for grids and power plants and a list of approved market participants.

The capacity of the transmission system deserves special attention. It is known from economic theory that a monopolist can increase his profit by limiting the supply.

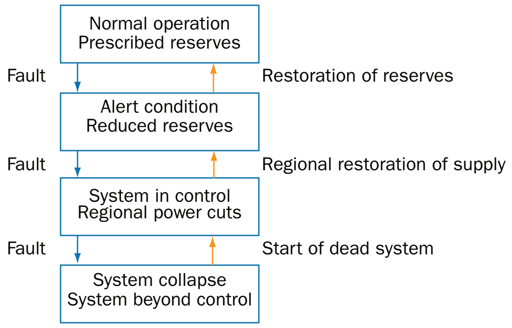
In the simple case shown (see *fig. 2*) Qc is the quantity traded in perfect competition and Pc the corresponding price. A monopolist would prefer to limit its sales to Qm and obtain the price Pm, because it would lose money on sale beyond Qm. The loss in social profit is called the deadweight loss.

Figure 3: Generation connection opportunities



Source: National Grid

Figure 4: Lines of defense



Maintaining control is more important than maintaining load

Source: Paul-Frederik Bach

Depending on settlement rules for transmission rights the grid owner may be reluctant in investing in transmission capacity up to Qc. Therefore it is important to give the grid owners proper incentives or obligations.

However, using principles from economic theory for the economic life time of a new grid element is not easy. It is impossible to predict conditions and traffic for each grid element. Common sense is at least as important as economic theory.

Shortage of transmission capacity causes congestion and trading constraints. This means lost opportunities, inadequate resource utilization and poor market service to market participants. But, if congestion never occurs, it implies that too much money has been invested in the grid.

Providing a suitable level of service to the market participants in all locations and throughout the year could be an overriding principle. This means that congestion should only occur occasionally and in different locations. This policy requires a strong and meshed grid across all of the transmission area.

Congestion management

Alternative models for congestion management exist. In systems with nodal prices or area prices the market participants carry the risk of congestion in the form of higher prices to buyers and reduced prices to sellers. In other cases counter trade is used to neutralize overload. In these cases the system operator carries the cost of congestion.

In Great Britain the congestion problem seems to be most urgent in Scotland and on the border to England. National Grid is preparing a constraint management service(5) which seems to be a sort of counter trade. However, this system is on the top of a Transmission Network Use of System (TNUoS) tariff zones. There are 21 generation TNUoS tariff zones and 14 demand TNUoS tariff zones. The charges encourage users to reduce transmission from north to south in Great Britain.

The impact of wind power

A large proportion of new wind-generated electricity will come from offshore wind farms. National Grid has looked at a scenario with 19 GW offshore wind by 2020 together with 11 GW onshore wind. It is obvious (*see from the map fig. 3*) that no matter where the new wind power will be located it will require a substantial new transmission capacity.

Blackouts – when and where

		% lost load
New York	1977	100%
France	1978	75%
Belgium	1982	50%
Sweden	1983	100%
Greece	1983	67%
Japan	1987	25%
Quebec	1989	100%
Malaysia	1992	85%
Malaysia	1996	100%
Italy	2003	100%
NE USA	2003	100% of New York state
Central Europe	2006	Origin in Germany, affected Spain, France, Italy, Austria, Belgium, Croatia and Netherlands

Source: National Grid

The grid must not only have capacity for the wind power but also for the necessary reserve capacity which will probably be located elsewhere.

It may surprise some that new wind power depends so much on reinforcement of the primary grid. If any significant capacity of wind power is connected without a corresponding reinforcement of the transmission system the likelihood of congestion will increase with knock-on consequences for the market.

The intermittency of wind power will have an impact on market prices anyhow. Low prices will occur during periods of surplus, particularly if the surplus has not been predicted. The British market system with gate closure just one hour ahead of real time will give market participants very good opportunities to update their plans. There will be new business opportunities for flexible technologies. Flexible demand (such as battery charging) can prevent very low prices.

Wind power prediction tools will play an increasing role to all market participants. Development and sale of models and data could be a fast growing business area.

The British market model seems to be well suited for serving intermittent generation and for encouraging implementation of new flexible technologies provided that the sufficient transmission capacity is maintained.

System security problems?

Most people do not consider security of electricity supply as a problem. The intervals between serious incidents affecting the majority of people are so long that most people forget the previous incident. A 10 year interval is a typical planning assumption minimum.

Power system planners do remember the incidents however. They are used for a continual improvement of system security and efficiency. National Grid produced a list of a number of black-outs (*see table*) in its “Black Start Commercial Workshop” on August 30 2007 with the year and percentage lost load.

Each of these blackouts had serious consequences. The incidents are carefully analyzed and the reports are studied by other system operators in order to prevent recurrences. In spite of that new blackouts cannot be avoided. The reason is that the power systems continuously develop and that lessons learned in previous blackouts may have passed their sell-by date.

However, the introduction of significant tranches of wind power will challenge the traditional security strategies. The pioneering power systems will be testbeds for new security problems. The challenge will be to learn as much as possible to ensure the minimum of disturbance to power system users.

The traditional security strategy

On November 9 1965, a faulty back-up relay at Niagara

What role did embedded generation play in NG's close shave?

The role of embedded generation in a recent major security of supply incident in the UK has been highlighted in a new report* by National Grid, writes Dr Dominic Maclaine.

As previously reported (*see PUK 172*), on May 27 2008, National Grid suffered a major frequency problem on its transmission system. Trips at Sizewell and Longannet stations lead to the frequency falling to below the statutory limit of 49.14 Hz. Following this there was a further, as yet not fully explained loss, which led to a further drop in system frequency to 48.795Hz for eight minutes. Some believe that the loss of around 250 MW of embedded generation plant played a significant part in this further fall.

According to the report issued in July, National Grid says: "Theoretical analysis undertaken so far suggests that this last excursion could have been triggered by a further combined generation loss of around 250 MW or more. These generation losses resulted in system frequency being outside of National Grid's operational criteria and statutory limits for 11 and 9 minutes respectively.

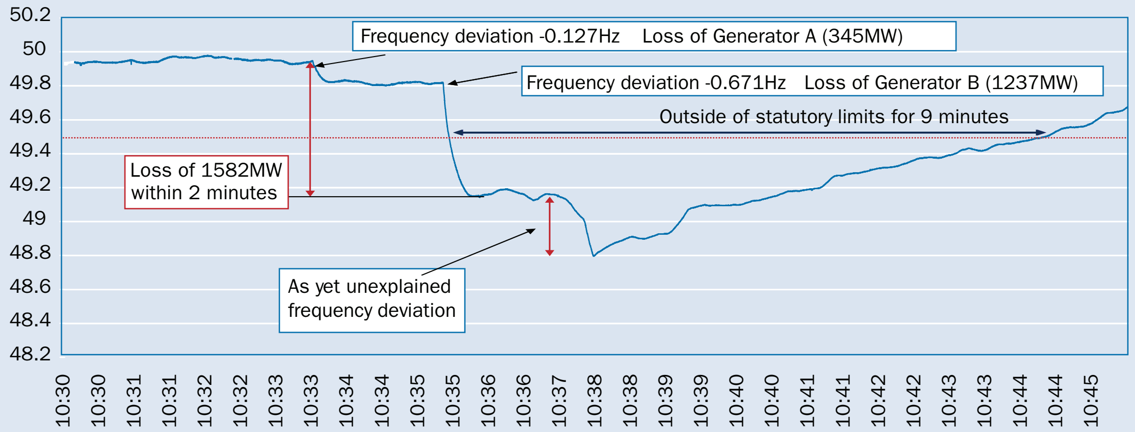
"Initial information obtained from the Distribution Network Operators (DNOs) indicates that some embedded generation plant did trip during the 27th May incident. The information received from DNOs to date, indicates that the known amount of embedded generation loss is approximately 250 MW but there is still thought to be some further trips at small power stations, the scale of which is still under investigation. This information has been requested from the DNOs."

Industry sources close to the DNOs told Platts that the vast bulk of that embedded generation was wind-based however nothing has been officially confirmed.

NG spokesperson Stewart Larque told Platts: "We and the industry are continuing work on examining the detail of this complex sequence of events to identify the lessons to be learnt through industry bodies such as the Energy Emergencies Executive Committee and the Grid Code Review Panel."

** "Report of the investigation into the automatic demand disconnection following multiple generation losses and the demand control response that occurred on the May 27 2008" is available from the National Grid web-site*

Frequency deviation following exceptional generation loss (1582MW)



Source: National Grid

caused a cascading power loss and a blackout that affected 30 million people in the northeastern USA and in Canada. As result of the incident a strategy for system security was developed including the principle – now known as the N-1 principle. The idea was that the power system must be able to withstand any single event without interruption of supply. A single event can be loss of a generator or loss of a transmission line.

On July 13 1977 a severe thunderstorm disconnected several important transmission lines to New York City. The operators struggled to defend the electricity supply but their resources were insufficient. The system collapsed after 59 minutes and the restoration of normal operation took 25 hours.

Extending the N-1 principle to N-2 or more was unrealistic for many reasons. A new strategy introduced new lines of defence (*fig. 4*) aimed at maintaining system control, but after disconnection of load, if necessary. Restoration plans should be prepared in advance, even for a black start.

This is the simplified version of the defence strategy which has been implemented in most power systems since then.

The strategy has been successful, for instance in Great Britain on May 27 2008 (*see box above*), when the loss of two power plants (1582 MW) caused automatic disconnection of 581 MW of consumption. The system control was maintained and the disconnected supply was resumed within an hour.

The weak points

Why cannot such an excellent strategy prevent the large blackouts mentioned earlier? The answer is that a combination of circumstances caused a loss of control. However, few common characteristics deserve attention:

- **Flash-over to trees:** Overhead lines must be inspected regularly in order to prevent trees from growing up to the conductors. A heavily loaded line gets warmer and the increasing sag moves the conductor downwards. When a flash-over has disconnected a line the remaining lines will carry more loads, sag more and move closer to the trees. (USA 2003 and Italy 2003);

- **Shortage of reactive power:** While shortage of active power is easily detected as a frequency drop, lack of reactive power is a creeping problem. A low voltage is not necessarily alarming, and when the operator becomes aware of the problem it is usually too late to prevent a system collapse. (France 1978 and USA 2003);

- **Inefficient monitoring and communication:** A highly meshed grid may oftem has several system operators. Each operator is responsible for his own geographic area. Nobody can monitor the entire system, and the co-ordination of relay setting may be insufficient. (USA 2003, Italy 2003 and central Europe 2006).

Efficient management in these few areas could have prevented loss of control in several cases. The coordination of system control between transmission system operators in meshed grids is still at a modest level, so the risk of blackouts has not been eliminated.

The impact of new wind power

If it were able to predict the security problems that might arise from new wind power it would be possible to take precautions and prevent the problems. Although a lot of analysis has been conducted a few surprises will probably be inevitable.

Increased wind capacity in distribution network may cause surprises because distribution and transmission system operators do not have a strong tradition for shared data and close coordination in most countries. The transmission system operators cannot monitor the embedded generation. For instance, has the loss of 250 MW of embedded generation been widely reported as a factor behind the problems in the UK on May 27?

Embedded generation combined with demand shedding consumers can both important services to grid operators. It will be a further challenge to organize the cooperation between transmission and distribution grid operators in a way which allows these local resources to be efficiently utilized.

The present level of operational reserve has been carefully calculated by National Grid based on experience and probability calculations. However, it is difficult to estimate the necessary amount of operating reserves when there is a large proportion of wind power on the system. Common sense and practical experience will probably be as important as advanced calculations.

Power system stability depends on the system inertia (which determines how quickly it responds to shocks) and the short circuit capacity of large power plants (which provides a certain robustness to grid operations). When the traditional large units are decommissioned these resources must be provided from other sources.

However, the necessary level of inertia and short circuit capacity that are needed for system stability are not very well defined. In future, it is possible that, without much traditional capacity left, there will be reason to test alternative stability measures and to verify the stability limits. Of course such experiments have a risk of system disturbances. Permanent lack of suitable resources would imply an increased risk of instability.

On a more gloomy note, there could be mounting political pressure to connect large amounts of wind power before the necessary infrastructure is in place. Unfortunately, politicians maybe less eager to support reinforcement of the transmission grid so the system operator could end up being alone with a responsibility for a poor market service and an increased risk of system disturbances.

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(1) See http://www.nationalgrid.com/uk/Electricity/Balancing/

(2) http://www.elexon.co.uk/default.aspx

(3) See Andrew Ryan: NGT's Role in Securing Reserve, http://www.nationalgrid.com/NR/rdonlyres/012BE506-F6A1-4D16-BADD-C7A2FC49C52D/1913/NGTs_Role_in_Securing_Reserve.pdf

(4) The net capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time and its output if it had operated at full nameplate capacity the entire time

(5) http://www.nationalgrid.com/NR/rdonlyres/A6D8BBE2-E59A-4DEB-8705-8F1D8F3E1A72/22048/CMS_OpForum_Final_Dec07.pdf