Frequency Response Capability of the GB System in 2030

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***Abstract*—Real time balancing of electricity generation and demand in a power system is a necessary and very challenging task. An unbalance between the two is immediately reflected in a frequency change of the AC system. Operators have an extensive experience in balancing a network with a considerable amount of conventional generation, as has been the case in the past. However, in future power systems this task has to be handled differently. This is because of a change in the types of generators and a change in demand (e.g. electric vehicles). Predictions of the types of generation and demand that will be connected to the GB network are available in the public domain [1]. This work aims to analyse which of these technologies are capable of providing frequency support according to the available literature. Some generation provides only short term response and some technologies are more adequate for reducing rather than for increasing their power output. Hence the capability of providing response is split into inertial, primary and secondary response as well as low-frequency and over-frequency response.**

Future power system; inertial response; primary response; secondary response;

I. Introduction

National Grid constantly balances generation and demand to keep the system frequency within a statutory limit of 1% of nominal frequency (50 Hz) [2]. The system is balanced via a combination of different mechanisms such as inertial response, primary frequency control and secondary frequency control. When the demand exceeds generation levels, low-frequency response is necessary. Over-frequency response is used when there is a surplus of generation. The future GB system will have a different generation mix, to that seen in the past, and different loads. During this change, sufficient frequency response capabilities need to be available to ensure system security. Raised levels of intermittent renewable generation, such as wind and solar, increase the need for response services. Converter connected generators cause a loss of effective system inertia and renewable generation introduces a weather dependent change in the geographic location of power generation. Furthermore it is not straight forward to use renewable generators for frequency response services.

The prediction for the 2030 GB generation mix [1] is used together with relevant frequency response literature, to determine the challenges that this change may cause and the technological capabilities already available. Three predictions, namely slow progression, gone green and accelerated growth are provided in [1]. In this paper the gone green scenario is chosen, which assumes that renewable targets are met on time.

II. GB System in 2030

A. Generation

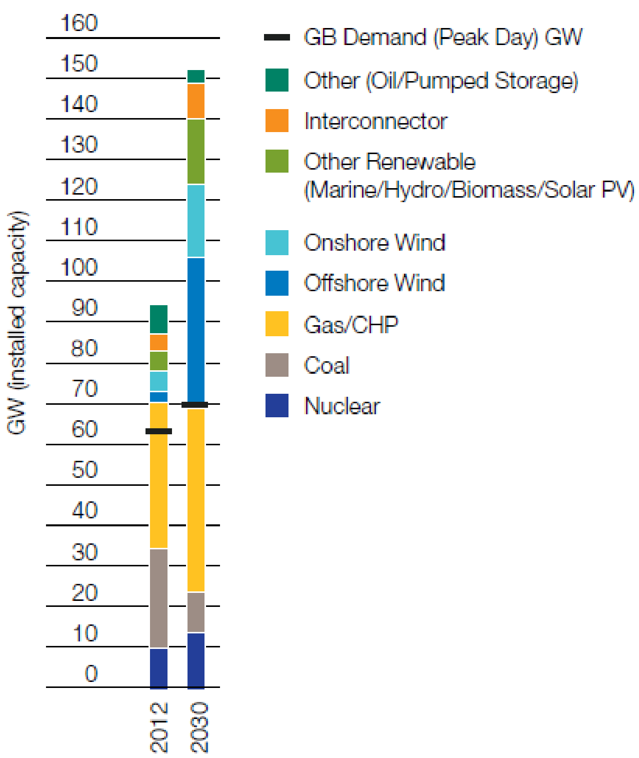

Figure 1: Change in generation mix for 2030 under gone green scenario, UK Future Energy Scenarios, National Grid [1]

Major drivers of the change in generation mix are the EU and UK government targets for renewable generation and greenhouse gas emissions [1]. Those targets include the Renewable Energy Directive, which demands 15% of the UK's energy from renewables by 2020. The Climate Change

Act introduced limits on the amount of greenhouse gases that can be emitted in the UK [1]. Figure 1 shows the change in generation mix by 2030 compared to 2012. It can be seen that coal and oil/pumped storage based generation decreases while all other generation increases. Renewable generation, in particular wind, shows the most significant increase reaching 70.9 GW [1].

B. Load

Figure 1 further shows peak demand in the UK is forecasted to increase only mildly by 2030. This is caused by three main factors. The weak economy causes a reduction in demand. Load levels are further reduced by energy efficiency improvements. Finally load is masked by small embedded generation, which is treated as negative demand [3]. The larger change is present in the behavior of demand. It is expected to be more flexible and price sensitive [3], due to smart meters, which are due to be installed in most households by 2020 [4]. These meters will provide the operator with up-to-date information about demand levels and enable demand side management. Electricity demand will increase by 19 TWh due to 3.2 million electric vehicles on the grid and another 3.2 TWh due to electric heat pumps.

III. Frequency Response

Frequency response can be split into several categories. One distinction is between under-frequency and over-frequency. Under-frequency, as in Figure 2, occurs when the demand is larger than the generation level. This commonly occurs due to loss of generation. The response to an under-frequency event can be split into several categories according to the time scale. During the first 10 seconds of a frequency dip synchronous generation increases, since generators are coupled to grid frequency. After 10 seconds generators providing primary frequency response will be fully available and providing response for at least 20 seconds. At this point secondary frequency response will take over.

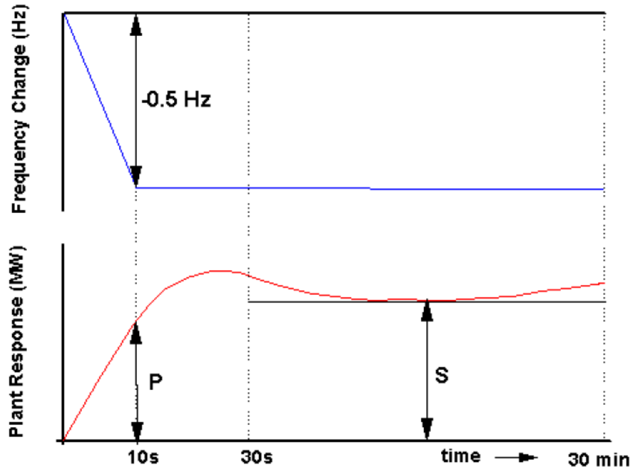

Figure 2: Under frequency response, National Grid, Grid Code [5]

Over-frequency response, as seen in Figure 3, occurs due to a generation surplus and works similar to under-frequency response. The high-frequency response or reduction in generation is required to be fully available within 10 seconds of the frequency rise.

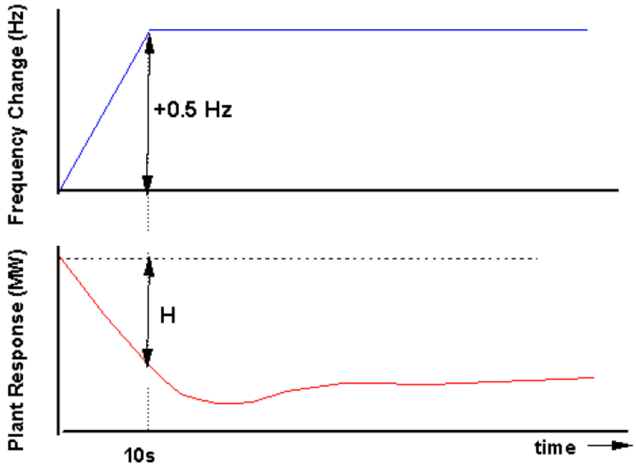

Figure 3: Over frequency response, National Grid, Grid Code [5]

National Grid has investigated future response requirements under the gone green scenario [6]. The response requirements for high frequency are not expected to change much. While the requirement for primary and secondary response increase significantly from the year 2019/20 due to the introduction of 1800 MW power stations, which increases the largest credible loss. A further slight increase in primary and secondary requirements for the 2020 scenario was found due to the significant increase in installed wind capacity. A decrease in system inertia caused by the large scale integration of asynchronous generation would lead to increasing dynamic response requirements. [6] discusses the possibility to amend the grid code to include a requirement for 'synthetic inertia' for plant that does not provide inertia. [7] reported that the future response requirements will be greater than those of the current GB system, due to the integration of more intermittent generation. The inertial, primary and secondary response of a power system are impacted by the integration of renewables, especially during low load situations [7].

IV. Response by Technology

Since the future GB system will have increased low frequency response requirements and the behavior of both generation and load on the system is changing, it is interesting to see which of the expanding generation technologies can deliver frequency response services. To examine the current state of the art the relevant literature has been consulted.

A. Conventional generation

By 2030 a significant amount of coal fired plants will be retired due to stricter emission requirements. Remaining plants will either run limited hours or be converted to carbon capture and storage (CCS) plants. Gas generation is predicted to increase, even though carbon capture and storage technology is only starting to be installed around 2030 [1].

Gas fired plants, which will constitute a significant part of the generation fleet, are a well-tested and well-know technology. They have fast ramp rates and relatively low minimum generation levels; they can be shut down and started up quickly. These capabilities mean that they make good intermediate and peaking units for load following [8].

B. Wind

Wind generation will be a major part of generation in the 2030 system, as can be seen in Figure 1. Hence its capability to support the system is very important. An overview [9] of the grid code requirements on wind generation has shown that turbines in the GB system are required to be able to provide continuous operation in a range from 47.5 Hz to 52 Hz. This is a larger frequency range than that of other countries with a high wind penetration, such as Denmark, Germany, Spain, Ireland or China [9].

Knowing that wind turbines can operate in a large range of frequencies, their capability to provide a response to frequency deviations is of interest. In general wind turbines can change their output very fast which means they can be used for various frequency response tasks. The fastest response to system changes is inertial response. Wind turbines connected to the grid via DC technology do not react to frequency drops by increasing their power output in the same way as synchronous machines. To overcome this and to be able to use the fast ramp rate of wind generators major research effort has been undertaken in the field of inertia emulation [10, 11, 12]. [12] modified the DFIG control system to introduce an inertial response. They found that the kinetic energy supplied by the DFIG was greater than that of a fixed-speed wind turbine. [13] concluded their work by warning that systems with a large share of emulated inertia by wind turbines have a higher uncertainty due to variations in the regional wind conditions. They recommend analysis of the location of wind generation with local wind forecasts as part of the dynamic study.

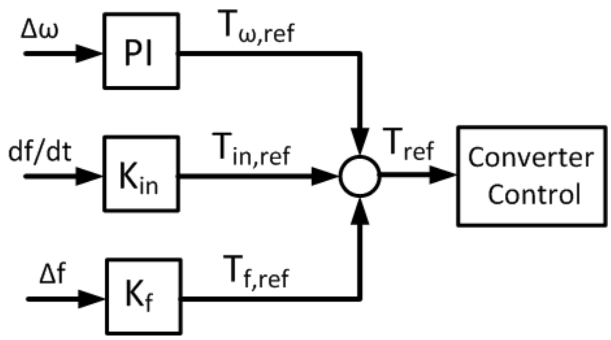

Figure 4: Inertia emulation for wind turbines [10]

Further work has been conducted on the primary frequency response of wind turbines using the kinetic energy stored in the turbine [10, 14] and the possibility to curtail the wind for load following [15]. Wind turbines can also very quickly reduce their output in response to over-frequency [16]. Even though wind turbines have the technical capability to support all types of frequency response, as shown in [17], curtailing wind power is very expensive [18]. Hence wind turbines are more likely to participate in short under-frequency response services and over-frequency response, since those services do not require keeping a reserve.

C. Other renewables

Most renewable power in the 2030 GB system is produced by wind generation; further renewable technologies include marine and hydro generators, biomass and solar PV. A project of the University of Kassel in cooperation with several companies has set out to prove the viability of a system that contains only renewable sources. For this project they linked 12.6 MW of wind, 5.5 MW of solar, 4 MW of biogas systems and a pump water storage with a capacity of 8.48 GWh. To balance the system the project used combined heat and power plants fueled on biogas and pumped water storage while wind and solar produce the bulk power [19].

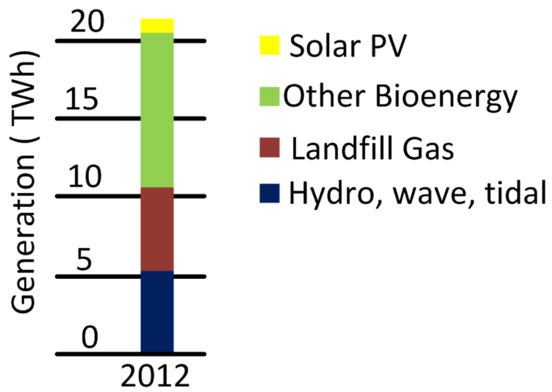

Figure 5: 2012 Mix of renewables other than wind [20]

In the UK most of the solar generation is micro generation embedded in the distribution system. There are several reasons that limit PV generators to contribute to frequency response. They would need to be coordinated via smart meters or other forms of communication. They are an intermittent form of generation, hence their response is stochastic. Further, since they are renewable generation it would be expensive to run them below their maximum capability and they do not carry any kinetic energy that could be used for inertial response. The main discussion around solar PV and frequency response has been the increased operating reserves required for its integration into the system [21].

Hydro generation is known to have a relatively fast response, which means it can do load following [8]. An incident in West China provided some experience of balancing a system with large frequency perturbations only with hydro power plants [22]. A study of the incident concluded that hydro generation can provide primary frequency response; however hydro-turbines react slower than steam turbines, due large dead-bands and suffer from reverse action. This means that as the hydro-turbine tries to increase its output, the output initially drops, which can lead to a larger frequency nadir [22].

Marine technologies are still under development with many different possible concepts under investigation. Mid 2011 three wave and five tidal devices were reported to be in the full-scale demonstration stage [23]. At the same time about another 15 devices each for wave and tidal were only in the concept stage. Without clear knowledge which marine technology or technologies will be championed for large scale implementation it is too early to speculate about their ability to provide the system with frequency services.

A number of generators running or considering to run on bioenergy in the UK are converted coal fired plants. Tilbury B power station [24] has been converted to operate on wood pellets, Eggborough power station has started to burn pellets in addition to coal [25]. Ironbridge is planning to operate with a mix of wood pellets and coal [26]. Drax is planning to convert some of its generation units to biomass [27] as well as Rugeley Power station [28]. Since these plants have previously been coal-fired stations it may well be possible that the frequency response behavior of these bioenergy generators will not differ from their pre-conversion behavior. The same holds for landfill gas fired plants.

D. Interconnector

Interconnectors completed after the 1st of April 2005 need to be able to provide mandatory frequency response according to the H/04 Grid code modification [29]. The Interconnector Basslink, connecting Tasmania with south-east Australia, is an example of an Interconnector that can be used for frequency control of either of the two AC networks [30]. The Estlink also has the capability for frequency control by changing the power order according to the frequency deviation [31]. [32] report about the frequency control operation of the VSC link Caprivi connecting Namibia and Zambia. During several months the south western Zambian grid was left in an island situation with only one generator in the network. The VSCs island mode was used to maintain the system frequency.

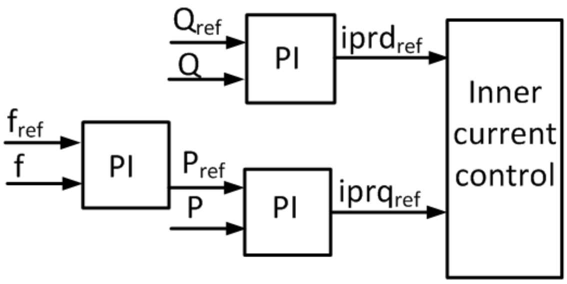

Figure 6: VSC frequency control by changing active power order

E. Nuclear

In the UK nuclear generation has traditionally been treated as a base generation. Reactors of the Magnox type had technical limitations that meant that those plants did not offer load following [33]. Newer nuclear plants have load following capabilities. The pressurized water reactor Sizewell B in the UK for example has been demonstrated in automatic frequency response operation mode [34]. This function is not normally called upon, since it affects the plant lifetime and hence is an expensive service. Other countries such as France and Germany have more frequently used nuclear plants in load following mode [33]. Even without the technical limitations of the past, this technology is likely to remain a base load in the UK for economic reasons [34].

F. Loads

The concept of adjusting demand levels in order to improve the balance between demand and generation in a power system is not new. National Grid has contracts with some loads that can reduce their demand by at least 3MW, to be able to use them as short term operating reserves [35]. Unlocking the potential of smaller loads for response services requires communication with those loads, which has not been available in the past. Such a participation of loads in frequency response services is termed demand-side response. The quantity of demand side response available depends on the flexibility of the load and the access to control the load. In the future communication with smaller loads such as households will be via smart meters. Increased flexibility in demand is expected with an increase in heat pumps [36] and electric vehicles. Electric vehicles have been predicted to be able to provide 6% of the daily balancing requirement for the year 2020 [37]. [38] studied the primary frequency response from electric vehicles in the Great Britain power system. The performance of the frequency response depended on the vehicle charging scheme. They also found that it may be sufficient for parts of the electric vehicle fleet to participate in the primary response. The use of smart meters to provide primary frequency response via domestic load control has been investigated by [39] for the UK for 2020. They reported that 1GW of controllable loads would be required for the 2020 scenario, due to large amounts of converter connected generation. They further mention that the time delay in frequency measurement at the household side is critical when using demand-side management for primary frequency response. Benefits and challenges for demand side management have been analyzed by [40]. The main benefits include a reduction in the necessary generation margin, improved efficiency in network investments and the ability to balance a system with a high penetration of intermittent generation. Challenges were the necessary ICT infrastructure, the need for an increased understanding of possible benefits of demand side management and its competitiveness with other approaches.

V. CONCLUSION

The current work has found that the response requirements of the future GB system are predicted to increase [6]. Gas and renewable generation will increase as well as the capacity of interconnectors and nuclear. Loads will comprise increasing amounts of electrical heat pumps and electric vehicles. Gas generation has always played an important part in balancing the system. Hydro generation and plants run on biomass can also contribute to the frequency response of the system. Major research effort has gone into the frequency support by wind plants. Due to the high cost of keeping a reserve wind generation is most fit for over-frequency and short-term (inertial and perhaps primary) under-frequency support. New interconnectors are required to be able to provide mandatory frequency response. Further system support may be available through the rollout of smart meters. Using this technology, loads such as heat pumps and electric vehicles could reduce the demand levels during under-frequency events.

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