Review of opportunities for gas turbine generators in the changing electricity system of the United Kingdom

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Introduction

In line with national and international recognition that global warming is the result of human activity[1] , in recent years renewable generation technology is increasingly replacing fossil fuelled generation. For practical and economic reasons this results in an increased use of power electronics to connect these new energy sources to the grid network, with a consequential reduction in the amount of synchronous generation connected to the grid.

The effect of this change is twofold, firstly a reduction in network fault levels, with synchronous generation typically contributing about three times their rating to the local network whereas the newer technologies contributing little more than their own rating. Secondly, the stored energy (or inertia) of the network is also reduced, with synchronous generation typically contributing between about three and five times rating whereas, in the event of system disturbances, the newer technologies only contribution is small, due to the decoupling effects of the interfacing convertors. These same observations apply with respect to HVDC submarine links which, although extremely useful with respect interconnecting the grid networks of adjacent land masses, i.e. Great Britain to Ireland and Great Britain to Continental Europe, due to their high capital costs they tend to be fully utilised in either one direction or the other, with little evidence to date of their potential to provide fast support to a distressed grid being utilised.

The net effect of the above is a continuing reduction of the resilience of the grid network to system disturbances. The awareness of this (increasing) network characteristic is demonstrated by recent work undertaken by the UK's national grid's Electricity System Operator (ESO) into the System Operability looking forward to circa 2030[2]. This continuing work includes assessment of the adverse impact of declining short circuit levels on the performance of electrical protection systems and on the operation of the electronic power convertors. This same work also investigates the effects of reductions in synchronous generation on the interdependency of system voltage and frequency, with increasing volatility being evident as the proportion of synchronous plant reduces.

Additionally, operational experience has highlighted issues with existing Loss of Mains (LoM) protection on embedded generation, with a fast tracked programme of replacement[3] of existing LoM protection being undertaken. This action recognises that more rapid deviations in local network frequency and voltage waveform shifts in the event of grid faults will otherwise result in significant loss of generation capacity to the grid.

The major system frequency disturbance on the UK electricity system on the 9th August 2019 highlights the potential problems of operating a large interconnected AC system with a significant proportion of asynchronous generation such as wind turbines and solar PV. National Grid have identified a need for fast-response generation and storage devices, such as gas-turbine generation, in the UK grid system to maintain security of supply.

Noting this National Grid have set targets of being able to operate a "Zero Carbon" transmission system by 2025. The challenges and opportunities that this offers will be explained and some worst-case scenarios in a system with extensive wind and solar generation capacity will be shown in this presentation

1 https://climate.nasa.gov/evidence/ The current warming trend is of particular significance because most of it is extremely likely (greater than 95 percent probability) to be the result of human activity since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia.
2 https://www.nationalgrideso.com/insights/system-operability-framework-sof The System Operability Framework (SOF) takes a holistic view of the changing energy landscape to assess the future operation of Britain's electricity networks. The SOF combines insight from the Future Energy Scenarios with a programme of technical assessments to identify medium-term and long-term requirements for operability.
3 http://www.energynetworks.org/electricity/engineering/accelerated-loss-of-mains-change-programme.html, also for easier detail https://www.locogen.com/services/asset-management/accelerated-loss-of-mains-change-programme

9th August 2019 System Event

On the 9th August 2019 at 15:00 there was a series of event on the National Grid Transmission system which resulted the loss of 1,240MW of demand via under frequency load shedding relay operation.

The events that occurred were as follows;

- Fault on the Eton Socon – Wymondley 400kV overhead line
- Loss of 737MW of generation at Hornsea off-shore wind farm
- Loss of 641MW of generation at Little Barford Unit 1 combined cycle gas turbine
- Loss of 150MW of distributed generation via vector shift relays
- Loss of 350MW of distributed generation via RoCoF relays
- Frequency fell to below 48.8Hz at which point under frequency load shedding was initiated, resulting in the loss of 930MW of demand.
    - This demand included demand that was not connected to DNO under frequency relays, these being Railway supplies and Ipswich Hospital
    - The load at Newcastle Airport was incorrectly disconnected by under frequency relays

The events of the 9th August will be discussed in detail below.

Details of the system incident

Prior to the fault National Grid stated that they were carrying enough fast and sustained reserve to cover the largest single generation infeed to the system at 1000MW, Table 1 below shows the reserve that was being carried in the system.

Generation levels at the units tripped from the transmission system are shown in Table 2 below.

The detailed time line of the events is shown in Table 3 seen over page on page 16.

A graph of the power system frequency is shown in Figure 1 over page on page 16 which details the events of the 9th August was produced by National Grid in their event report.

Service	Provider type	Lower Frequency response held (MW)	
		Primary response	Secondary response
Dynamic – Generation (Mandatory response)	BM	284	325
Dynamic – Firm Frequency Response	BM & Non -BM	259	270
Dynamic – Enhanced Frequency Response	BM & Non -BM	227	227
Static – Firm Frequency Response	Non-BM	21	261
Static – Low Frequency Response through auction	Non-BM	31	31
Static Interconnectors	BM	200	200
Total		**1022**	**1314**

Table 1 Primary and Secondary Reserve on the 9th August

Power Plant	Generation Level Prior to Event	Generation Level Post Event
Little Barford ST1C	244MW	0MW
Little Barford GT1A and 1B	397MW	0MW
Hornsea Offshore wind farm	799MW	62MW

Table 2 Dispatched Generation lost during incident

Time	Event	MW Change
16:52	Frequency 50Hz with 1,000MW of Primary Reserve	
16:52:33.490	Blue Phase to earth fault on the Eaton Socon – Wymondley 400kV circuit cleared from both ends in 70ms	
16:52:33	Approximately 150MW of Distributed Generation tripped on vector shift	-150MW
16:52:33.835	Hornsea off shore wind farm reduced in power from 799MW to 62MW	-737MW
16:52:34	Little Barford ST1C tripped	-244MW
16:52:34	350MW of Distributed Generation tripped on RoCoF protection operation	-350MW
16:52:44	650MW of fast frequency response delivered	+650MW
16:53:04	Frequency stabilised follow delivery of a total of 900MW of reserve	+250MW
16:53:31	Little Barford GT1A tripped	-210MW
16:53:49	Frequency reaches 48.8Hz and under frequency load disconnection occurs tripping 931MW of load	+931MW
16:53:58	Little Barford GT1B tripped	-187MW
16:54:20	Control action restores frequency to 50Hz (1000MW of reserve plus 1200MW of instructed actions)	+1200MW
16:58 – 17:16	DNOs instructed to restore load confirmed at 17:37	

Table 3 Details of incident on the 9th August

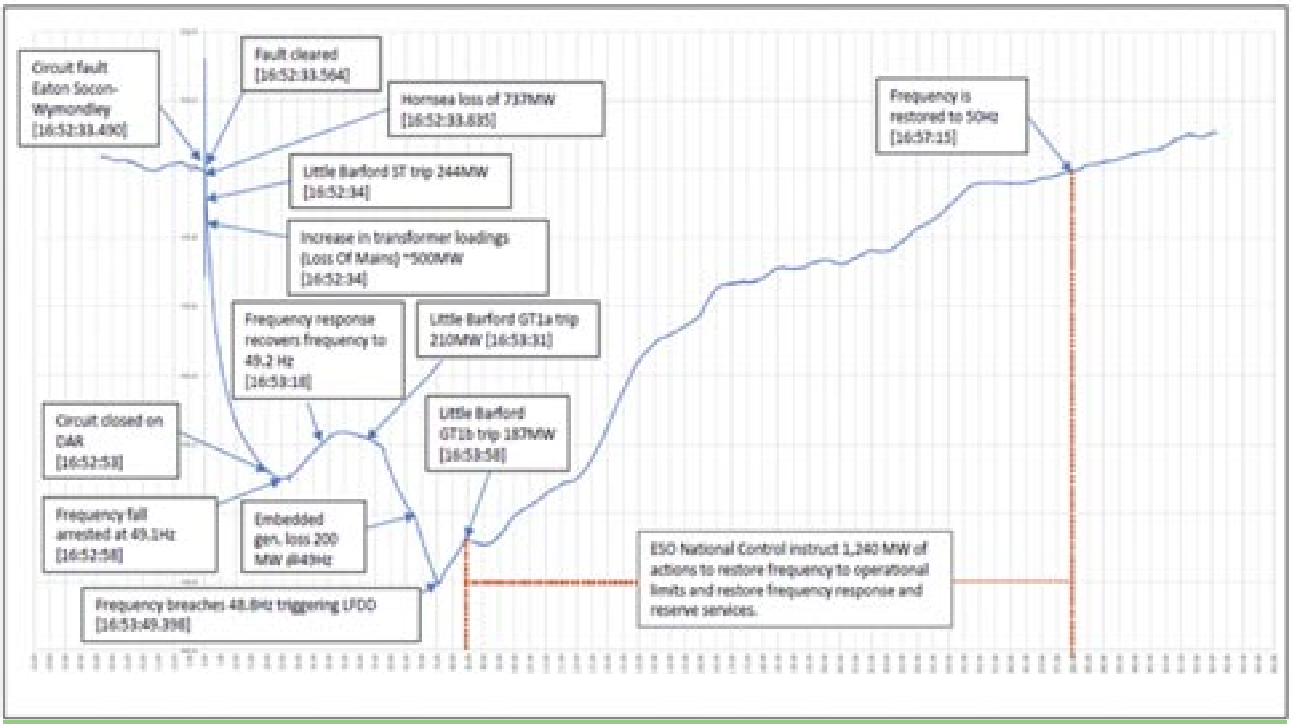

Figure 1 Graph of the system frequency on the 9th August

During the incident there was distributed generation lost via vector shift relays which is understood to be a regular occurrence for National Grid when there is a fault on the transmission, details of the generation that has been lost following a transmission fault are shown in Table 4 below. The level of generation infeed to the system lost on the 9th August as a result of the operation of Vector Shift protection was 150MW and was not excessive compared to other such events.

The operation of the under-frequency demand disconnection scheme curtailed the system frequency fall and as a result prevented a much larger event, the major issues of note from the event were the disconnection of the following;

- Railway facilities and trains
- Ipswich Hospital
- Newcastle Airport

Newcastle Airport

It was reported that the feeder supplying Newcastle Airport was disconnected by the operation of the under-frequency demand disconnection protection owned by Northern Power Grid. At the time the site was not covered by the Electricity Supply Emergency Code (ESEC) but following the event it has now been register by this scheme and hence removed from the under-frequency protection scheme.

Conclusions of the 9th August Event

- The operation of the protection on the National Grid and DNO system operated successfully to clear the faulted circuits and to secure the system.
- Protection on some trains operated at a frequency that was not requested by the DNO and result in travel disruptions.

Date	Faulted Circuit	Generation tripped by Vector Shift Relays
18 March 2016	Grain Bus Coupler	470MW
20 March 2016	Grain – Kingsnorth	200MW
22 May 2016	Langage – Landulph	380MW
21 May 2017	Littlebrook Reserve Busbar	200MW
8 June 2017	Cottam – Eaton Socon – Rye House	240MW
10 July 2017	Bramford – Sizewell	300MW
17 July 2017	Kensal Green Reserve Busbar	400MW
27 December 2017	Hinckley Point – Melksham	205MW
16 January 2018	Alverdiscott – Indian Queens – Taunton	290MW
18 January 2018	Burwell – Walpole	315MW
9 August 2019	Eaton Socon – Wymondley	150MW

Table 4 Distributed Generation lost as a result of the operation of Vector Shift relays

Railway infrastructure

The Distribution Network Operator confirmed that none of the Rail network load lost was as a result of the operation of their under-frequency demand disconnection protection. It was reported that the Class 700 and 717 trains tripped via their own protection scheme as a result of the under-frequency event, this caused delays to trains following the affected units which resulted in the closure of London King Cross and St Pancras Stations.

Ipswich Hospital

It was noted that the hospital's own protection operated at the same time as the fault on the Eaton Socon – Wymondley circuit and that half of the hospital load was lost for 14 seconds

- The demand disconnected via DNO under frequency relays was restored in 40 minutes, which is extremely fast for such an event
- National Grid stated in their report that the level of generation disconnected via Vector Shift relays was as expected. A fault, such as a busbar fault, could trip the largest generator, it is recommended that National Grid cover the additional risk of the generation "behind" vector shift relays. It is also recommend that when calculating the level of reserve held on the system in future that the risk level should be largest plant risk plus the level of generation that could be disconnected by Vector Shift relays, Table 4 shows this risk could be as high as 470MW.

Challenges and Opportunities for Gas Turbines in the Future

Challenges

The National Grid Electricity System Operator (ESO) has published the road map to operating a Zero Carbon Grid by the year 2025, this is not just a major challenge to the System Operator but also to all fossil fuel generators. The ESO has stated that this will mean the system demand will be supplied by renewable generation, nuclear power and interconnector circuits from other Grid Operators in Europe.

The location of the renewable generation currently connected to the electricity system in England, Wales and Scotland is shown in figure 2 below. This figure also shows the transmission constraints that are currently active on the system operated by the ESO.

It should be noted that these challenges also offer opportunities for gas turbine generators in the Ancillary Service and Capacity Markets, which are detailed below in Figure 2.

Opportunities

The area of opportunity that are available for gas turbine generators are increasing but their electrical generation utilisation levels may be low in the peaking market, but for the ancillary service market these opportunities offer much larger utilisation figures, from voltage support, system stabilisation and system inertia contracts.

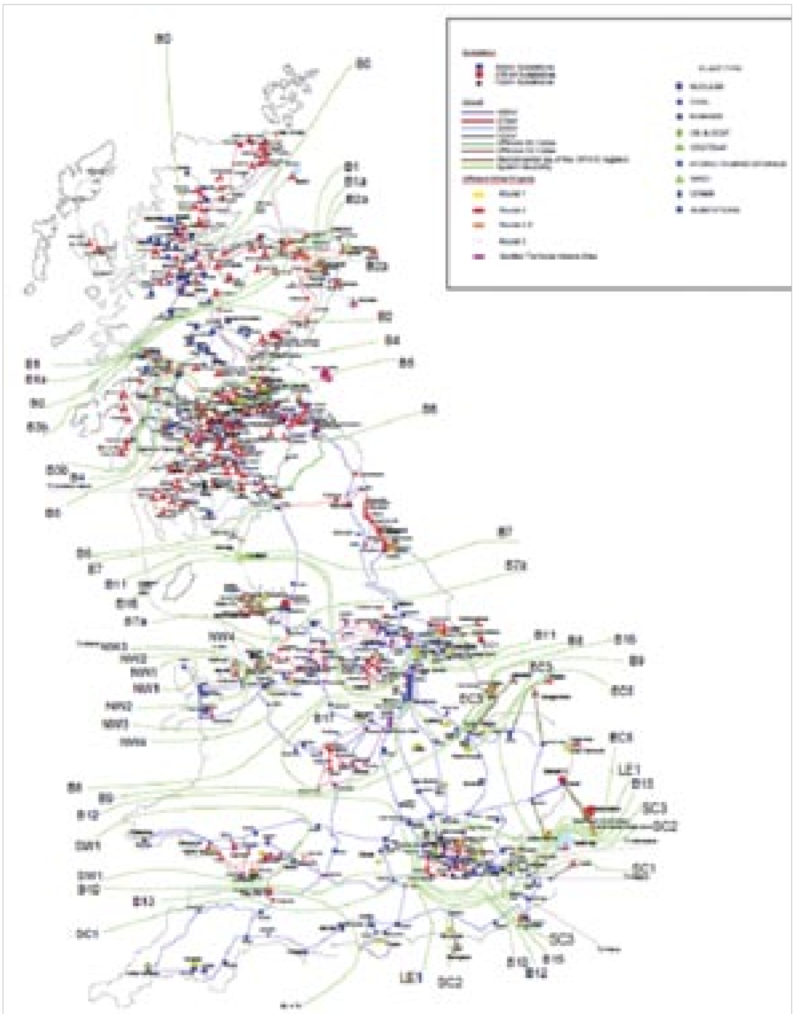

Figure 2 Locations of renewable generation and transmission constraints on the system

Voltage Support

National Grid have identified several areas where they require additional voltage support, one of these being the Mersey Ring. This area has become an area of interest following the closure of Fiddlers Ferry power station. The Mersey Ring is supplied via two double circuit overhead lines, one from Penwortham in the north (Penwortham – Washway Farm – Kirkby 1 and2) and the other from Connah's Quay in the south (Capenhurst – Connah's Quay 1 and 2), this shown in Figure 3 opposite.

National Grid system Operator (ESO) will be coming to the market for other voltage support contracts, these are due early next year.

Network Stability

National Grid ESO have recently issued the Network Stability RFI document for Scotland in with they are looking for devices to be added to the system to add;

- Inertia,
- Voltage support
- Additional Fault infeed, and
- Network Stability Damping

Currently the ESO are not specifying that these devices will be synchronous machines, but at present all the requirements cannot met with power electronics, hence this is an opportunity for the connection of synchronous machines, this could be either a synchronous condenser or a synchronous generator. This is the first of many such requests from the ESO as they have specified in the Road Map document that other areas will require the same system support, the areas of concern are shown in Figure 4 below.

Black Start

National Grid ESO has again issued an RFI for Black Start generators, this service in the past was served by large coal fired power stations, but following their closure there are very few power stations left on the system that can fulfil this service. Following the closure of Fiddlers Ferry there are no power stations current offering this service in the North West of England.

Conclusions

There are a number of challenges ahead for conventional synchronous generators with the National Grid ESO targets of being Carbon Neutral by

2025. The ESO want to be able to operate the transmission system with only renewable and nuclear generation on the system. This will also give opportunities for fast starting gas turbine in the Capacity Market plus new markets for synchronous generators to operate in the Ancillary Service Market, which is very likely to increase, with additional services being sort in the following areas:

- System Inertia
- Additional System Fault Level
- Stability Damping
- Voltage Support
- Black Start

All the services including those of Peaking Plant services could be met using Gas Turbine generators with a clutch. There would be benefits in having an electrical generator with a flywheel, with alternator rated higher than the turbine. This would give advantages in all the above ancillary services called for by the Electricity System Operator. ■

This Paper was presented at the IPowerE Conference 26-27 November 2019.

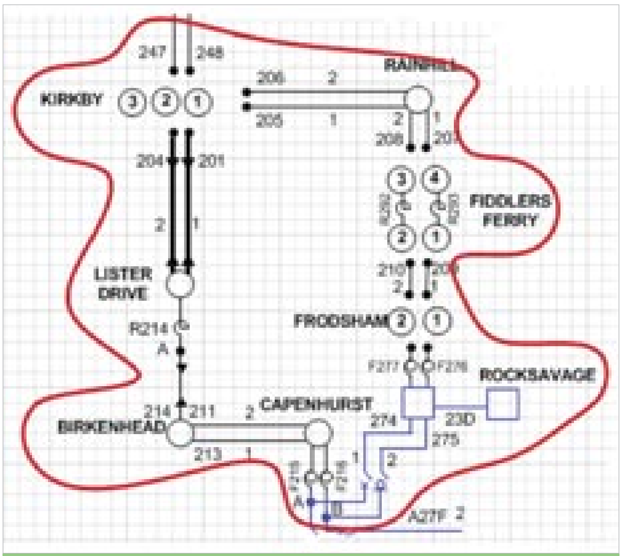

Figure 3 Mersey Ring Voltage Stability Constraint

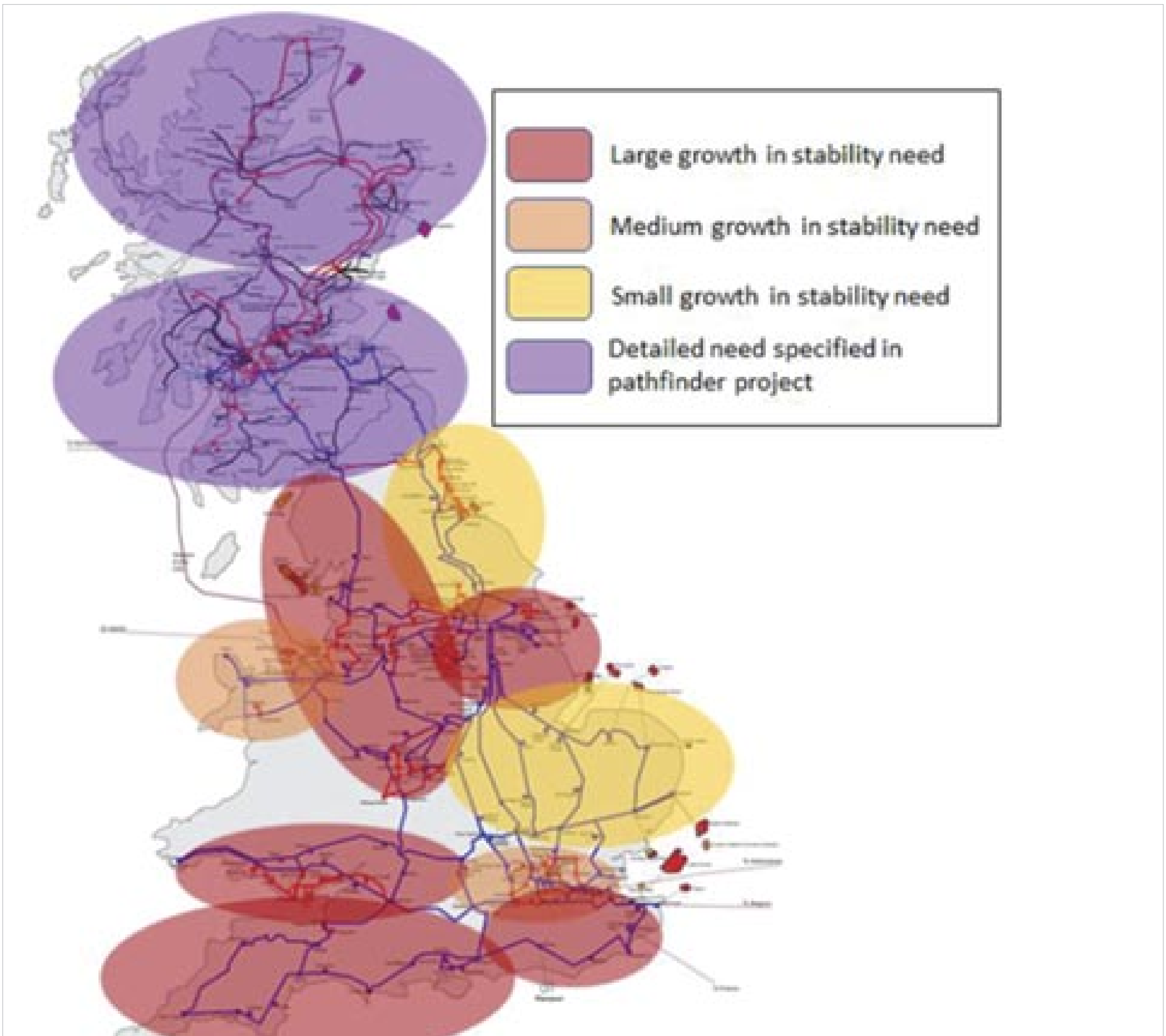

Figure 4 Network Stability needs on the Transmission System