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Dear Simon,

E.S. Cornwall Memorial Scholarship – First Quarterly Report – Reena Kwong

Please find enclosed my first quarterly report as part of the E.S. Cornwall Memorial Scholarship for the period 2nd March to 2nd June 2009 during my employment with National Grid.

During my initial three months of placement with National Grid, I have been able to experience some technical elements of the transmission planning required by a system operator in order to accommodate large volumes of renewable and conventional generation into their network. In particular, I have been able to obtain some insight into various types of transmission reinforcements which may be used in order to improve network capability for the integration of large volumes of generation, as well as performing system studies implementing these reinforcements to determine the extent of their impact on the network.

I welcome any feedback from all interested parties in relation to this report.

Kind Regards,
Reena

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Executive Summary

My proposed program under the E.S. Cornwall Memorial Scholarship is aimed at gaining international experience in the integration of wind farms into an electricity market. Specifically, exposure to the network planning required to be considered by the system operator/s in order to cater for large amounts of wind farm output is sought, as well as investigating the issues, and solutions to such issues, which may arise in the integration of wind farms in a market.

The period of my scholarship is from March 2009 to September 2010. My first placement is with National Grid, the system operator of Great Britain (GB), from March 2009 to March 2010. During my 12 month term with National Grid I will be involved in their Blueprint 2020/2030 Project. The Blueprint Project relates to a major review of National Grid's commercial framework and technical standards to accommodate large volumes of renewable, leading to the redrafting of their Security Standards.

This report is the first of six reports, and outlines my work experience within the first three months of employment, 2nd March to 2nd June 2009, with the Strategy Review Team in National Grid.

National Grid Strategy Review Team

Background

Due to the increasing awareness of Climate Change, there is particular interest for power systems to be able to operate effectively with high levels of renewable in order to decrease the amount of CO_2 emissions. In response to the Climate Change concerns, the Electricity Networks Strategy Group (ENSG) chaired by the Department of Energy and Climate Change (DECC) and the energy regulator Ofgem (Office of Gas and Electricity Markets) requested that an EU target of 15% of the UK's final energy demand be provided from all renewable sources by 2020. This requires significant contribution from the electricity, heat and transport sectors, as well as advances in energy efficiency. In terms of the renewable share of generation, the above target equates to an increase from 5% to 36% over the next 10 years. In addition to this, a significant portion of existing conventional and nuclear generation capacity will need to be replaced with new lower carbon generation over the same period.

Subsequently, National Grid established a Strategy Review Team within its Asset Management department designed to focus on developing different generation and demand backgrounds (scenarios) that would be consistent in achieving the above mentioned target for the year 2020 as well as an extension to the year 2030. The Strategy Review Team is also responsible for identifying and investigating reinforcements potentially required for each scenario; in particular, the large amounts of onshore and offshore wind generation as well as new nuclear generation that may account for the anticipated changes in generation mix between now and 2020.

As a result of preliminary system studies undertaken by the Strategy Review Team, three 'Gone Green' scenarios were developed and proposed to the ENSG (see Table 1). It can be noted that all three scenarios potentially achieve the 36% renewable generation target.

Electricity	Scenario 1	Scenario 2	Scenario 3
Wind Capacity **TWh**	**20.9GW E&W** **11.4GW Scotland** **= 98TWh**	**24.3GW E&W** **8GW Scotland** **=98TWh**	**25.7GW E&W** **6.6GW Scotland** **=98TWh**
Other Renewable TWh	**49TWh (Biomass, hydro, tidal, CHP, PV)**	**49TWh (Biomass, hydro, tidal, CHP, PV)**	**49TWh (Biomass, hydro, tidal, CHP, PV)**
Total Renewable	**147TWh**	**147TWh**	**147TWh**
Renewable %	**36%**	**36%**	**36%**

Table 1 - Scenarios Meeting 2020 UK Renewables Targets[1]

'Gone Green' Scenario Development

Generation Background

In determining the above table, an energy model (which has been rigorously reviewed for its plausibility) was developed analysing the possible contribution from the electricity, heat and transport sectors, and as a result the fuel mix (generation background) for the 'Gone Green' scenarios was determined and can be viewed below.

[1] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

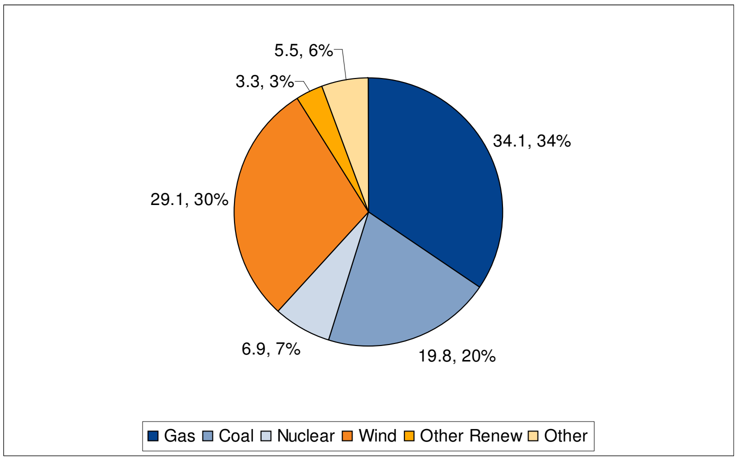

Figure 1 - Fuel Mix in 2020 ('Gone Green' Scenarios)[2]

The chart above also accounts for the following assumptions which were applied to the energy model to ensure both of the renewable energy and emissions targets are met, namely:

- plant closures,
- significant new renewable (including offshore and onshore wind, some tidal, wave, biomass and solar),
- intermittency of renewable generation and the requirement for back-up,
- significant new non-renewable (including nuclear, supercritical coal, gas),
- electricity demand remains flat due to reductions from energy efficiency measures and increases from heat pumps and cars, and
- demand side response

The combination of these factors produced a generation background for the system design studies for each year out to 2020. The generation background was also achieved by considering a 20% plant margin to meet the Average Cold Spell (ACS) peak electricity demand and take into account the risk of plant unavailability. In order to calculate the contribution from each plant type to meet demand over each year, a generation ranking order based on anticipated operational cost to the generator, was used to define the amount of contributable generation that will meet this peak electricity demand. As the most significant contributor to the renewable generation portfolio is wind generation (whose generation availability is intermittent) a larger plant margin of 40% was assigned to contributable wind generation in order to determine the remainder of contributable generation required from conventional plant to meet the ACS peak demand. This ranking order maximises renewable

[2] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

generation output followed by nuclear and newer fossil fuel plants with older fossil fuel plants, pumped storage and interconnectors providing the marginal plant.

In order to reflect the intermittent nature of wind output, development of the various generation backgrounds required a generic distribution curve. This generic distribution curve was developed for the technology and accounts for different output over seasons, and an appropriate wind generation diversity factor across the GB system. In order to dispatch the most economic generation without violating the transmission capacity limits, the output of wind generation at any time is determined by Monte Carlo sampling.

Demand Background

In order to develop the demand background for the 'Gone Green' scenarios, the demands of the residential, service, industry and transport sectors were analysed using an integrated energy model. This model considers the various types of demands within each sector, as well as considering allowances for economic growth, potential for energy efficiency savings and growth in new forms of demand (i.e. electric cars and heat pumps). Once this total electricity demand has been developed, demand met from embedded generation and the demand met from large scale generation is determined.

Preliminary System Studies

In order to identify transmission reinforcements and opportunities, understanding the current system performance is necessary. When performing system studies on the 'Gone Green' scenarios during the winter peak period, the Great Britain network was divided into critical boundaries in order to obtain power transfers across these boundaries which are dependent on the generation background (Figure 2). These boundaries are based on the generic boundaries specified in the GB Seven Year Statement[3]. To ensure the different scenarios in generation and demand background are accounted for, the generation and demand either side of a particular boundary are altered, therefore producing a range of power flows for different sensitivity studies based on an agreed methodology described in Appendix C of the GB Security and Quality of Supply Standard[4] (GB SQSS).

A point to note at this stage is that when the 'Gone Green' scenarios were developed and preliminary system studies incorporating potential new generation were performed, the

[3] The GB Seven Year Statement can be found on the National Grid website at: http://www.nationalgrid.com/uk/Electricity/SYS/
[4] The GB SQSS and its Review process can be found on the National Grid website at: http://www.nationalgrid.com/uk/Electricity/Codes/gbsqsscode/

Normal and Infrequent Loss Limits stated in the current GB SQSS were found to be inadequate. Currently, the GB transmission system is able to accept a normal loss of power infeed of up 1000 MW and an infrequent (i.e. up to four occurrences per year) loss of power infeed of up to 1320 MW. As there are connections of new generating plants with capacities of greater than 1320 MW being considered, the current standard in the GB SQSS will become inappropriate. Therefore, a review of the current GB SQSS in order to accommodate larger volumes of generation connections was proposed in February 2008. This review process is still taking place.

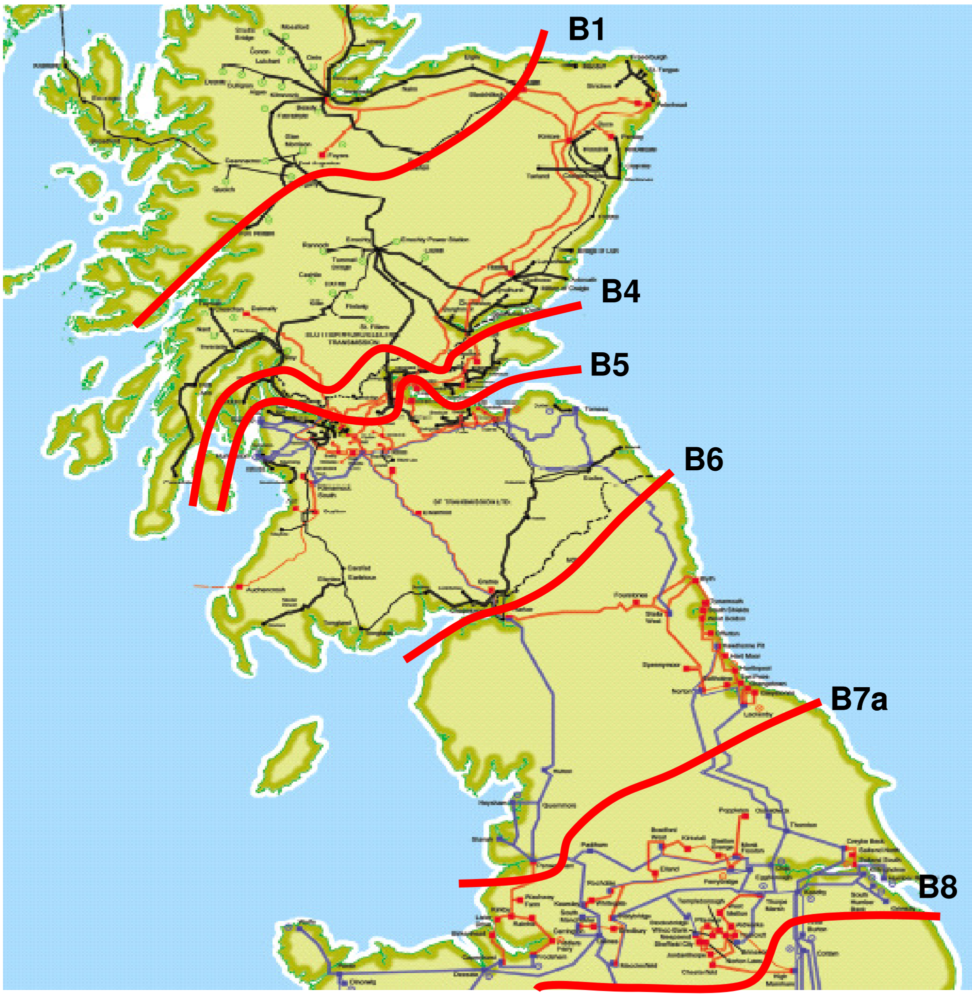

Figure 2 - System Boundaries used in the Gone Green Scenarios[5]

[5] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

Potential Wind Generation and Transmission Reinforcements

The quantity of renewable generation required to meet the EU renewable target is quite large. The most likely technology of renewable generation is wind with a predicted installed capacity of approximately 30 GW by the year 2020[6]. This number consists of both on-shore and off-shore wind technologies. On-shore wind technology is the more developed of the two and the installation of wind generation in the earlier years (up to 2015) has been biased towards on-shore wind generation, mainly in Scotland. Off-shore wind generation has been taken into account in the latter years leading to 2020, mainly in the English and Welsh waters as identified by The Crown Estates in Figure 3 below.

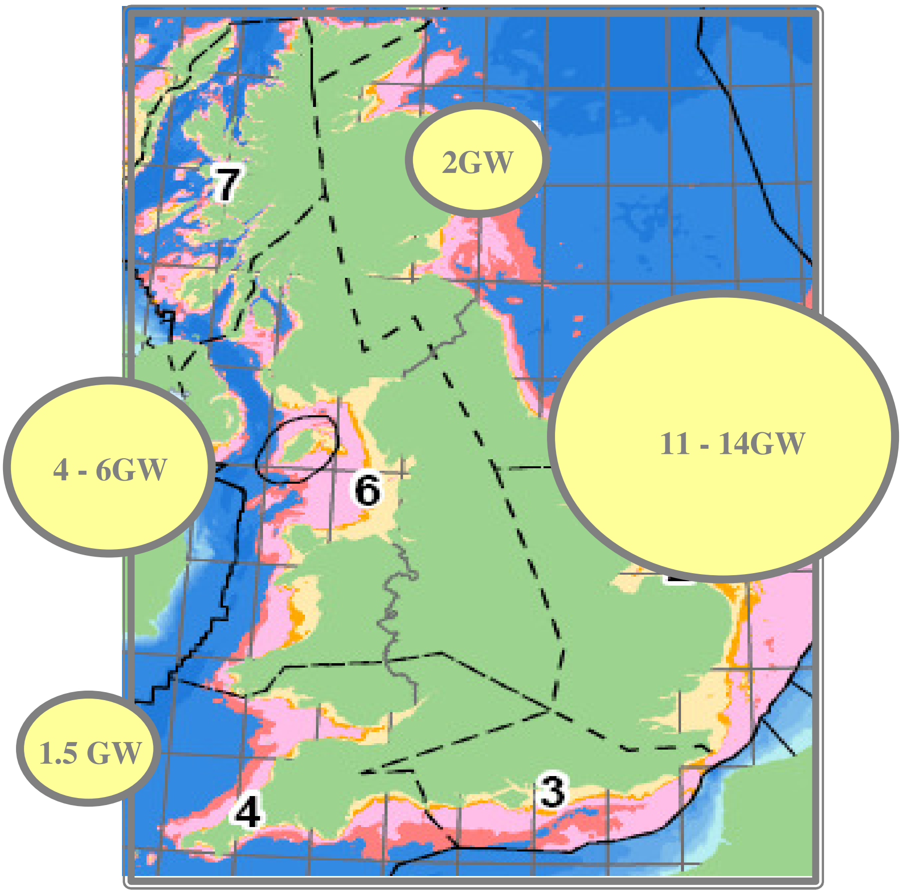

Figure 3 - Location of Potential Off-Shore Wind Farm Capacity[7]

Approximately 60% of on-shore wind capacity is expected to be installed in Scotland by 2015, therefore reinforcement in the B1 and B4 boundaries (Figure 2) is necessary due to increased power transfers (north to south) identified between the Scottish and English

[6] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf
[7] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

networks. Due to the location and size of potential off-shore wind generation shown in Figure 3, further transmission reinforcement is also required from the B5 through to B8 boundaries.

To overcome the network capability deficiencies identified within the current GB transmission system, some of the reinforcement methods which have been considered include:

- reconductoring circuits,
- upgrading circuits to higher voltage and,
- constructing new circuits

It has been recognised that these more 'traditional' approaches are subject to environmental scrutiny which can delay the transmission reinforcement and subsequently delay the integration of increased generation capacity required to meet the UK targets. Another barrier to the above mentioned reinforcement methods is the fact that some transmission circuits are not of considerable age, and therefore obtaining the necessary consents for reconductoring (or the likes) may be more difficult to approve.

New Technologies Considered

Another identified approach to minimise environmental concerns and enhance or fully utilise the existing network assets is to employ previously unused technologies such as series compensation and HVDC developments in sub-sea cables. Consideration has also been given to the lead time and any planning consents required to implement these newer technologies.

Series Compensation

Some of the technical advantages of using series compensation to increase network capability include better voltage stability, higher power transfers across long AC transmission lines and improvement of transient stability by reducing transmission line reactances by approximately 35%.

High Voltage Direct Current

Some advantages of the High Voltage Direct Current (HVDC) technology include lower losses, improved stability of the AC network the HVDC links are connected to, and no capacitive charging therefore eliminating the restrictions on cable lengths.

Currently, the GB transmission companies are in discussions with manufacturers of these technologies which have been successfully integrated into networks in Europe, India and China.

Work Experience

North Wales Strategic Plan

In order to produce an effective plan of an improved network that will accommodate larger volumes of renewable or conventional generation, the transmission areas of the existing network requiring improvement need to be identified through analysis and a better understanding of the network's capability.

Once results of the initial studies on the 'Gone Green' scenarios were produced to Ofgem, National Grid were, for the 2009/2010 financial year, given approval from the regulator to conduct further investigation and analysis on the transmission reinforcements proposed to confirm the original results.

My work to date has specifically included performing thermal capability DC studies in National Grid's in-house power system studies application ELLA, on the existing North Wales transmission network where it has been proposed to integrate up to 6.5 GW of generation by the year 2020 (Table 2); an increase of 115%.

	Network Boundary	**Current**	**2015/16**	**2020/21**	**2025/26**	**2030/31**
Forecast generation (GW)	ALL	3	3	6	9.3	9.3
Generation accommodated in zone (GW)	NW1	1.3	1.3	5.5	5.5	5.5
	NW2	3	4	6	7.2	7.2
	NW 3	3.7	6.5	6.5	7.7	7.7
	NW4	3.8	6.5	6.5	10	10

Table 2 - North Wales Future Requirements

As mentioned previously, in order to calculate power transfers within the GB system, the network is divided into boundaries. Figure 3 represents the network boundaries created for the North Wales region.

It can be seen from Table 2, a further 4 GW of generation (made up of nuclear, wind and interconnection with Scotland and Ireland) is to be connected into the North Wales network boundary NW1 by 2020. This is a clear example of where the review of some sections of the GB SQSS is required in order to accommodate larger capacities of generation connections.

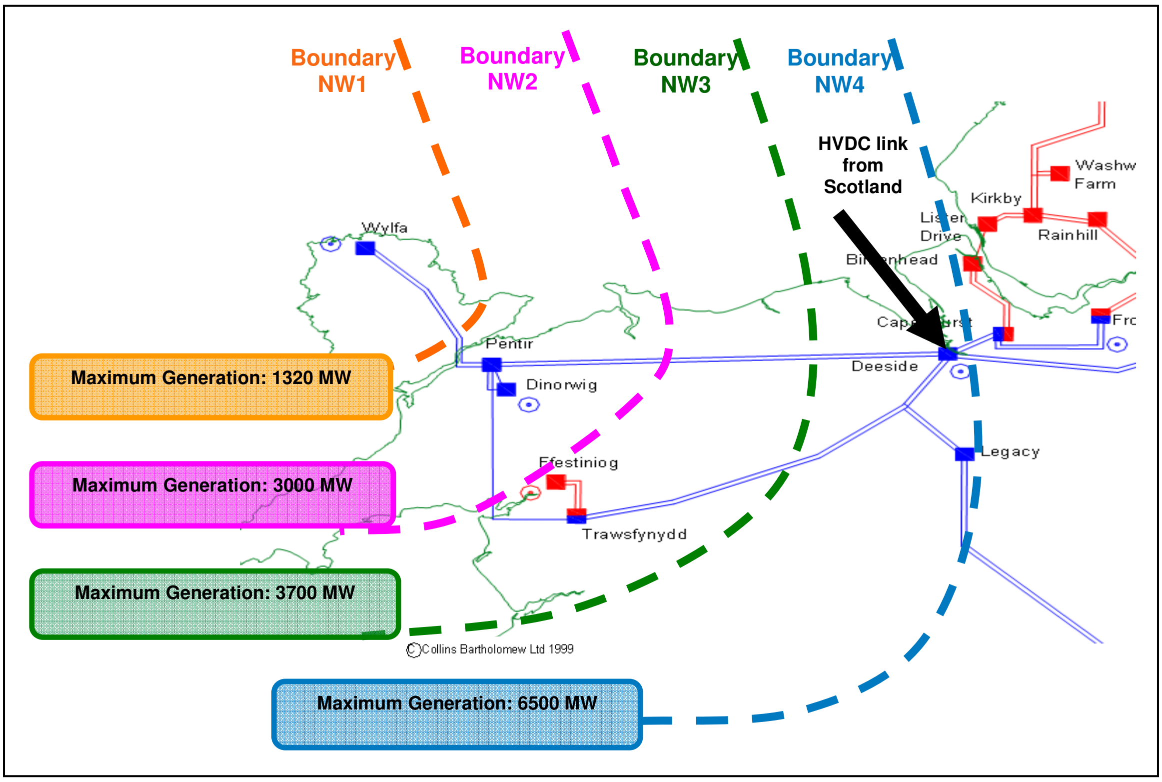

Figure 4 - North Wales Boundaries and Current Capacity Limits[8]

Subsequent studies were then undertaken incorporating different scenarios of identified potential transmission reinforcements in weaker parts of the network to investigate at what level of extra generation a particular reinforcement is required (Figure 5).

Specifically, the proposed reinforcements I have modelled and investigated within the North Wales region include:

- thermal uprating of existing transmission lines and/or cables
- additional transmission circuits

[8] GB Seven Year Statement – May 2008; http://www.nationalgrid.com/uk/Electricity/SYS/; and Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

- the impact of 'teed' connection points
- the incorporation of HVDC links
- the addition and use of quadrature boosters

In addition to the above reinforcements; the operation of pump storage generators, variability of HVDC interconnector flow, as well as consideration of the cyclic rating of transmission lines were also incorporated into numerous system studies. These studies provided an indication as to the extent of the impact that each proposed reinforcement has on the thermal capability of the North Wales network.

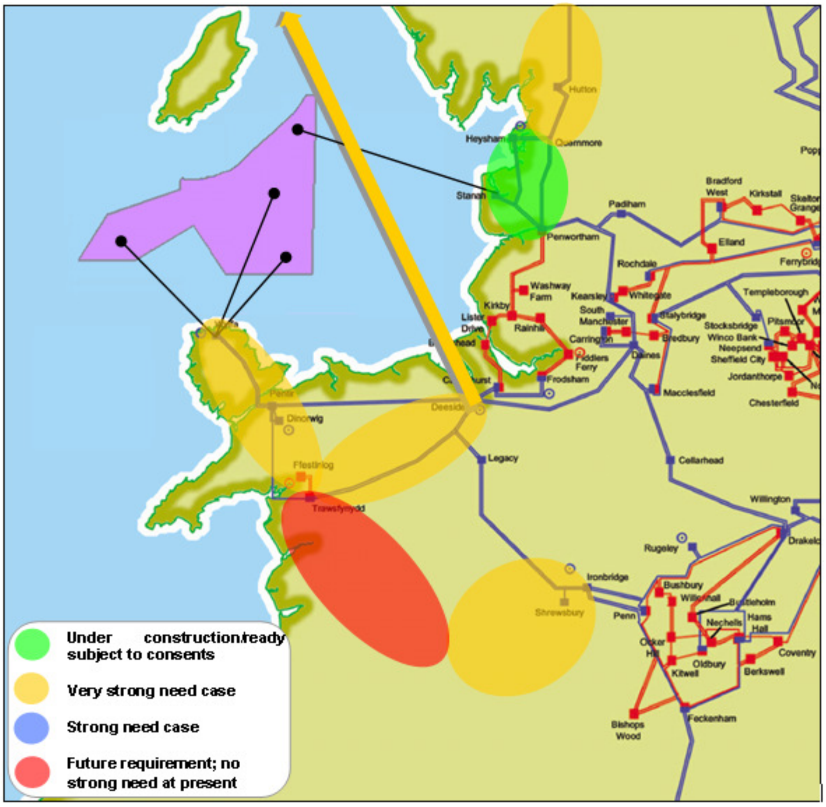

Figure 5 - Areas requiring Reinforcements identified in North Wales - 2020[9]

Continued monitoring on the development of the project in realising the above mentioned potential reinforcements (that are required to meet the renewable targets within the specified timeframe) will be important, as a number of external variables need to be met. In particular, the planning consent process which facilitates network development may cause some concerns in order for the reinforcements to be delivered to the required timescales. However, while it is an extremely challenging target, it is believed that the scenarios described are capable of being delivered.

[9] Our Electricity Transmission Network – A Vision for 2020; http://www.ensg.gov.uk/assets/1696-01-ensg_vision2020.pdf

Manufacturer's Seminar on HVDC and Series Compensation

As there are proposals for HVDC links and series compensation reinforcements in the North Wales strategic plan, I was fortunate enough to attend a seminar presented by a manufacturer of these two technologies to National Grid staff.

The 3-day workshop was extremely informative, providing details on the basics, applications, modelling and performance of HVDC links and series compensation technologies. In addition to these, example system studies were performed in Power Factory on both technologies which were very insightful.

Future Direction

In the coming months at National Grid, I will be completing the DC power system studies on the North Wales region in order to confirm the preliminary studies. Once the studies are completed, recommendations will then be made by National Grid to the ENSG working group on the methods to move forward with the project.

While approval is being sought from the ENSG working group, National Grid will continue to investigate modelling of the proposed HVDC links and series compensation technologies into the power system analysis package Power Factory. This will be a major project as the implications of integrating series compensation and HVDC links in Power Factory are unknown as this tool has not been widely used at National Grid in the past.

I will be involved in this project as well as continuing to perform power system studies in Power Factory on the North Wales region with more emphasis in studying the voltage stability around the region with the proposed transmission reinforcements to accommodate increased volumes of generation. Also, with the aide of Power Factory, I will be able to investigate in more detail the effects of series compensation and HVDC implementation into a network in order to facilitate large amounts of renewable generation. It has already been noted that series compensation does have potential to introduce electrical resonance into a system under certain conditions and therefore affecting generator performance. Hence, once the series compensation model has been implemented as part of National Grid's network in Power Factory, further analysis on this issue can be undertaken.

As I continue with more detailed analyses on a network that is being designed to integrate larger volumes of generation, I feel I will be more exposed to network issues which may arise during the process of such integrations. Therefore, I plan to gain awareness in the types of issues arising, and also evaluate techniques associated with the methods of rectification. In addition to this, I will also gain exposure to the necessary planning consents and pre-construction works involved for different types of reinforcements, which in turn, will also provide me with an insight on the timeframe such projects require in order to be delivered.

I mentioned previously that National Grid specifically established the Strategy Review Team to focus on the potential changes required to the GB network in order to accommodate larger volumes of renewable and conventional generation to achieve the renewable and emissions targets by 2020. In order to manage the large amounts of workload necessary in the strategic development of such a large project in the required timeframe, National Grid are currently considering a restructure of the Strategy Review Team to facilitate the co-ordination of smaller, more specialist teams to undertake the reinforcement proposals and system design studies in earnest. This restructure may lead to my involvement in other specialist areas where further knowledge on the project can be obtained.