TOWARDS A EUROPEAN SUPERGRID

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Abstract – Europe has two choices for delivering a zero carbon power sector by 2050. Either It can travel to 2050 via an extension of current 2020 policy, with an emphasis on individual country action, and bilateral interconnection providing a patchwork of inter-country balancing of variable generation or it can travel along a new path which treats Europe's renewable energy as a continental resource, and sees interconnection as a critical part of delivering that zero-carbon energy to homes and businesses across the EU. The second option is the path towards a European Supergrid. It is argued in this paper that the Supergrid is technically and economically viable. However, new policies and a new regulatory framework is needed.

Keywords: Supergrid, HVDC

1 INTRODUCTION

In 2009 the European Union (EU) and the G8 Heads of Government committed their countries to an 80 % reduction in Green House Gas emissions by 2050. International consensus to reach this target requires the EU to achieve a "nearly zero-carbon power supply".

Providing zero-carbon power to homes and businesses across the EU will require an open market in electricity, underpinned by both upgraded and new trans-national transmission networks. This new transmission network will also support and balance variable sources of renewable energy generation to maintain security of supply and provide firm power across the EU.

Building this network in time to meet the 2050 challenge will require action today. The EC European Energy Infrastructure Package (EIP) is a necessary first step to a future coordination and optimization of network developments in the EU.

2 THE FRIENDS OF THE SUPERGRID

FOSG are a group of international companies sharing a mutual interest in promoting the concept of open markets in electricity transmission, trans-national interconnection and exploiting the resulting business opportunities. This development in interconnection has become known as "Supergrid".

Our definition of Supergrid is the following: "an electricity transmission system, mainly based on direct current, designed to facilitate large-scale sustainable power generation in remote areas for transmission to centers of consumption, one of whose fundamental attributes will be the enhancement of the market in electricity".

Supergrid is not an extension of existing or planned point to point HVDC (High Voltage Direct Current) interconnectors between particular EU Member States. On the contrary, the Supergrid will allow future generation to be built where resources are optimal and not constrained and transported to existing grids at key nodes. FOSG is presently the only representative body combining companies engaged in delivering the HVDC infrastructure and related technology with those which may develop, install, own and operate that infrastructure.

Moreover, and given the trajectory of European energy policy it is clear there is a need for a body like FOSG to:

- Make both the case for interconnection combined with delivery of offshore renewable energy (the first phase of the Supergrid will start in the North Sea).
- Identify the technology and logistical support available to deliver the Supergrid.
- Encourage the regulatory change needed to bring about trans-national connection at scale.

3 THE EXISTING POLICY AND REGULATORY FRAMEWORKS

Although the target for renewable energy set out in the new Directive for 2020 imposes significant challenges for several Member States, it is clear that the solutions needed to deliver 20% renewable energy across the EU will be essentially national. That is to say, the 2020 target will not, by itself, foster significant interconnection between member states.

The demand for extended interconnections should be driven by a clear 2050 Roadmap that gives concrete and pragmatic details on the necessary steps to the final goal of a European Supergrid. Lack of interconnection combined with significant renewable power can lead to the curtailment of that generation.

The target for 2050 decarburization is ambitious and the regulatory and policy measures in place at present are not sufficient. New European regulatory and policy frameworks need to set up stable and clear rules and procedures for the development of the Supergrid and the supply chain challenges that require to be overcome.

The Memorandum of Understanding signed on 3 December by the ten countries supporting the North Seas Countries Offshore Grid Development Initiative (NSCOGI) is an initiative that gives in our view a clear political support to the launching of the European Supergrid that we believe will start its first Phase in the North Sea and should then expand to cover the entire European Union. The initial developments in this region

will serve as an example to be followed by the other Member States while the Supergrid expands or starts also developing in other regions.
However, the current national grid connection regimes will not provide sufficient capacity to connect the significant amount of offshore wind plant planned by national governments as part of their strategies to meet the EU's 2020 targets. Further, current interconnection proposals make no provision either for the connection of marine renewable energy "en route", nor for the development of cross-border trade in electricity.
It is for these reasons that FOSG has developed its Phase 1 proposal, as an example of how the first leg of Supergrid could look like as part of the EU's energy and climate change goals, and at marginal cost - and maximum benefit – to the European consumer.

3.1 Supergrid Phase 1

The Supergrid will be built out in phases, initially connecting the current crop of offshore wind generators to existing grids. As a first step (Phase 1) SuperNodes could be built in the North Sea using 2015 technology to cluster offshore wind generation for bulk delivery.
Figure 1 is a possible design for Phase 1. This proposal recognizes that:

- The UK wants to connect a further 25GW of offshore wind to its already congested networks by 2020. A number of possible solutions have been considered to facilitate this including line up-ratings, offshore 'bootstraps' and offshore clustering.
- Germany plans to build 25GW of offshore wind generation by 2025/2030 and the existing grids in Northern Germany are already largely congested with on-shore wind generation.
- Norway wants to trade up to 25GW of hydro generation in markets where prices are higher.
- Belgium's Renewable Energy plans include at least 2GW of offshore wind generation.
- The Netherlands's Renewable Energy plans include at least 2GW of offshore wind generation. by 2020 (included in FOSG Phase 2 proposal).

The Phase 1 design addresses these immediate issues while providing a staging post for the future.

In this proposal, to be assessed, optimized and adapted in a process coordinated by the Single Planer (see definition under further point), energy from wind generation clusters off the east coast of the UK, is collected at SuperNodes at Firth of Forth, Dogger Bank/Hornsea and Norfolk Bank which are connected together and interconnected with the German and Belgian North Sea clusters and Norwegian Hydro Power. The grid then delivers this power to the existing grids at terminals at Glasgow, Hull and Zeebrugge and SuperNodes at London and Southern Germany (or North Rhine Westphalia). The final design will consider together the foreseen installed capacity on- and offshore, the enhancement of system flexibility (from market integration and management point of view), the global environment impact and the costs.

Figure 1: Supergrid phase 1.

The design is based on connecting 23,000 MW of offshore wind from the Firth-of-Forth, Dogger-Hornsea, Norfolk Bank, German and Belgian Offshore clusters using technology expected to be available between 2015 and 2020.

3.1.1 Financing the First Phase of the Supergrid

Project costs are recovered from an agreed or regulated tariff. Two models are considered:

1. User pays – where the Transmission Use of System (TUOS) Charge is paid by the direct users of the system, and;
2. Socialized Cost model - where the costs are recovered through the electricity retail tariff in the connected countries.

Note that for the tariff calculation we have only taken into account those countries physically connected to the first phase of the Supergrid. However, the countries benefitting from such new interconnections would certainly go beyond the ones physically interconnected – a fact that should be recognized by the regulatory authorities.

Transmission Use of System - TUOS

Although the Base Case model for the use of system assumes 23 GW of wind alone connected at a 40% capacity factor (or capacity utilization), the operator should be incentivized to increase this factor by allowing other users to trade on the network and by providing ancillary services such as spinning reserve and voltage support. This will reduce the required Transmission Use of System (TUOS) charge.
For this reason both 40% and 90% capacity factors are used in the analysis.
The main assumptions in the TUOS calculation are:
Project Finance:

- Capex = €28,000 million (2010 value)
- 30 % Return on Equity
- 23 GW of Wind at 40% Capacity Factor must carry the cost
- 6 year build out with 40 years of operation

Capacity Factor:

- 40% - if the wind alone trades on the system
- 90% - when wind and other energy/service providers use the network

The calculated TUOS for different values of Debt/Equity and capacity factor are shown in Table 2:

Capacity Factor	Gearing	TUOS (€/MWh)
40%	70/30	46.7
	75/25	43.8
	80/20	40.8
	85/15	37.8
	90/10	34.8
90%	70/30	20.8
	75/25	19.5
	80/20	18.1
	85/15	16.8
	90/10	15.5

Table 1: Transmission use of system charge.

In summary, the transmission charge for phase 1 of the Supergrid could vary from 4.67 cents to as low as 1.55 cents per kilowatt- hour (c/kWh), depending on gearing and utilization. The challenge to the regulators is to provide an environment that leads to high gearing values while incentivizing the grid operator to increase the capacity factor/utilization.

Socialized Cost Model

In this variation the costs are recovered by adding a Supergrid component to the national retail tariffs in the connected countries of Germany, UK, Norway and Belgium. Table 2 summarizes the electric energy consumption in these countries (IEA 2008):

Country	Consumption (GWh / annum)
Germany	617,132
Belgium	95,527
UK	400,388
Norway	128,806
Total Energy	1,241,853

Table 2: Annual consumption (IEA 2008 statistics) in connected countries.

Table 3 presents the calculation of the increased tariff in the countries connected to Phase 1 in order to recover the project costs over 40 years based on 2008 statistics published by IEA. The result is that in Germany, UK, Belgium and Norway an increase in the retail tariff of 0.23 cents per kWh would be required to pay for Phase 1.

Income	2,820,720,000	€ / annum
Total Energy	1,241,853	GWh / annum
Cost	2.27	€ / MWh
Tariff	0.23	€c / kWh

Table 3: Socialized tariff calculation.

These funding proposals involve only the countries directly interconnected in the first phase. However, taking into account that the Supergrid phase 1 will already benefit European consumers from other countries, even if not directly connected and since the Supergrid will eventually interconnect the entire EU, the EC could also envisage setting up a European Network Fund. This Fund could be funded by a fixed and equal additional tariff charged to all European consumers. This fund would be drawn down as necessary to fund the various Phases of the grid development. The Master Plan 2050 shall help determine how the European Network Fund is to be set up and used. The rules for the use of such a Fund should fall under the responsibility of the EC and the European Regulator (ACER if that is the case).

We also suggests to the EC that the European Investment Bank is involved as the guarantee institution for the investors willing to participate in the Supergrid.

3.1.2 Technology for Phase 1

A key concept for the Supergrid Phase 1 is the SuperNode (Figure 2). From a technical perspective a SuperNode interconnects a number of DC links together with wind parks via a small islanded AC network (node). The term islanded means, that the small AC network is not connected to other AC networks but only fed by the connected DC links and the wind parks.

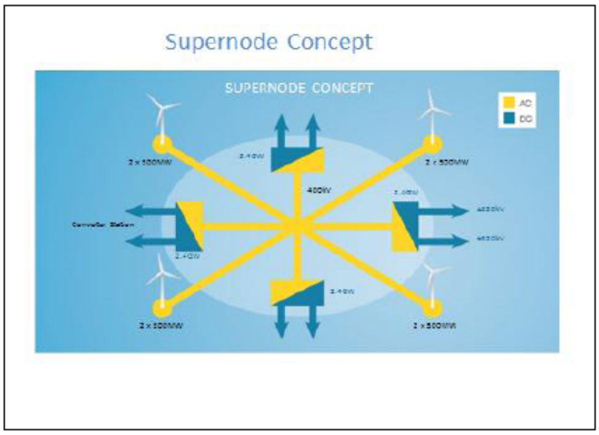

Figure 2: SuperNode Concept.

It is an important advantage of this concept that it is largely based on technology existing today. As of today there is much experience with DC links interconnecting two AC systems. Most of the existing DC links are equipped with Line Commutated Converters (LCC) based on thyristor technology. However, there is quite a number of HVDC links operating or under construction, which are based on Voltage Sourced Converter technology (VSC). The development needed to build SuperNodes is mainly in the field of control and protection for the islanded AC network, which includes frequency control as well as fault detection and fault clearing strategies. The preferred DC transmission technology for building SuperNodes is VSC. This is because a VSC transmission system can generate and maintain the AC voltage at the node with respect to amplitude and frequency, a feature also referred to as black start capability. As long as there are VSC systems providing sufficient short circuit power available at the AC node, LCC based HVDC transmission can also be connected. The concept of VSC transmission controlling islanded AC networks will be demonstrated by the first HVDC connected wind parks in the North Sea which are currently under construction.

There are also some disadvantages associated with the concept of SuperNode including the number of AC/DC and DC/AC conversions necessary. The power converters needed are costly; require relatively expensive space on offshore platforms and cause extra power losses. Eliminating some of the power converters requires HVDC links to be interconnected on the DC side forming HVDC multi-terminal systems or grids. There are only very few HVDC systems having three LCC terminals today which are operated under specific conditions. In general, larger multi-terminal systems have to be considered a new field of technology with the first projects being already under discussion.

The most important step needed to develop HVDC grids further is the aspect of interoperability of different individual projects and technologies of different manufacturers. Interoperability requires standardization of the basic principles of design and operation of HVDC grids. As a starting point for the standardization of HVDC grids some fundamental planning criteria need to be defined, probably leading towards different types of HVDC grids (e.g. transmission and distribution HVDC networks, sometimes also referred to as "local" and "inter area" grids). Key questions indentifying such planning criteria include:

- What applications should be covered? (e.g.: radial or meshed topologies, transmission distances, character and requirements of the AC systems to be connected)
- What operating conditions should be covered? (e.g.: system contingencies, future expandability, communication for control and protection)
- What are typical performance requirements? (e.g.: reliability, power losses, time to detect and clear faults)

Based on the fundamental planning criteria, important questions to be answered with respect to HVDC grid standardization include:

- Standardization of DC voltage levels.
- Concepts for interconnecting local and inter area DC grids
- DC grid topologies.
- Control and protection principles.
- Fault behavior.
- Typical block sizes for converter stations.

A number of key network components need to be developed and competitive supply chains need to be established. Investors should be provided with clear guidelines on how to specify the equipment for a multi vendor HVDC grid. Such guidelines are normally summarized in functional specifications which are needed for, e.g.:

- AC/DC Converters.
- Cables.
- DC Overhead Lines.
- DC Chopper.
- Charging Resistors.
- DC/DC Converters.
- DC Circuit Breakers.
- Communication for network control and protection.

The technical aspects of future European HVDC grids are subject of a European Study Group "Technical Guidelines for HVDC Grids" hosted by the German Electrotechnical Commission VDE/DKE. The Study Group includes European manufacturers of HVDC systems, European Transmission System Operators (TSO) and Universities. CENELEC TC 8X and ENTSO-E are regularly informed about the results of work and exchange of information has been agreed with Cigré B4. Functional Specifications for the components needed for the first multivendor HVDC systems in Europe shall be prepared by End of 2011.

3.2 Supergrid Phase 2

Figure 3 shows how phase 1 of the supergrid could evolve to a supergrid phase 2. By 2050, the supergrid should cover the entire EU (Figure 4).

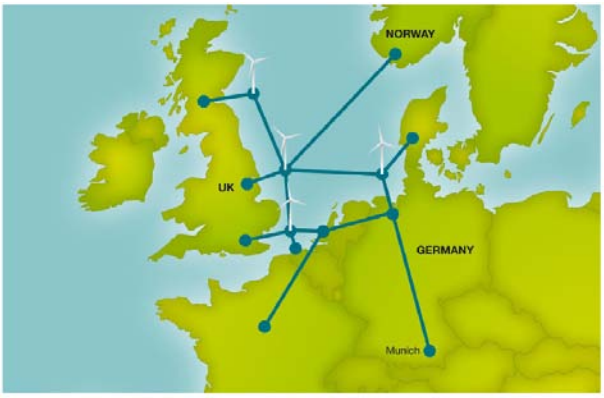

Figure 3: Supergrid phase 2.

Figure 4: 2050 Supergrid should cover the EU.

4 THE NEW POLICY AND REGULATORY FRAMEWORK FOR THE SUPERGRID

In order to help the process of developing a stable regulatory framework for the European Supergrid, FOSG proposes the implementation of the following general principles that should evolve with more detail:

- A single planner;
- A single grid code;
- A single European regulator.

A Single Planner: considering the formal powers recently given to ENTSO-E under the third legislative package, FOSG believes that such a role should fall to ENTSO-E but ensuring entrepreneurial insight. The involvement of the concerned industry is essential since the entire supply chain should be ready when the investments on the first phase of the Supergrid start by 2015. The mandate to ENTSO-E should come from the EC and ACER and should also focus on developing a Master Plan 2050. This Master Plan shall identify the sources of future power and shall design an integrated grid to connect them to the key nodes of AC networks while optimizing security, redundancy and the single market. Such a plan, despite giving a general overview of the entire EU, should also be divided into steps or phases and should therefore start focusing in more detail in the North Sea considering that offshore wind investments are already taking place there. This goes fully in line with the EC proposal to consider the North Sea as part of one of the priority corridors. Moreover, as regards the network operation of the first phase of the Supergrid that as mentioned before will start in the North Sea. ENTSO-E should also commence considering establishing an ISO (Independent System Operator) among the TSOs of the North Sea region involved. This ISO would then enlarge its operational powers to involve the other TSOs while the Supergrid enlarges to the rest of the EU. The EC and ACER should also help setting up the rules that should govern such new ISO for the Supergrid.

A single Grid Code for the Supergrid: Standardization and interoperability are major steps forward to achieve the efficient and timely realization of the Supergrid. Such a new Grid Code should be proposed by ENTSO-E with the agreement of the EC and ACER and after consultation with all the interested stakeholders. The new Grid Code will need to start focusing on offshore wind investments.

A Single European Regulator: considering that ACER will formally start its mandate in March 2011 and even though it cannot be considered formally as a European regulator, FOSG believes that ACER can, if the will of the existing 27 regulators is such, act as a Single regulator. Otherwise, ACER should be given enlarged powers compared to those considered in the third package. If such powers cannot be given to ACER under the present legal basis, the EC should then consider the need for a new proposal to the Council and EP.

The Supergrid shall be a European network and not the sum of interconnections between Member States. It should be designed taking into account the entire EU and therefore its regulatory framework should also be European.

5 CONCLUSIONS

Delivering a zero-carbon power sector across the EU by 2050 will require the opening of national electricity markets to interconnection, competition and cross-border trade. In addition, it will see power generation based on unabated fossil fuels replaced by renewable energy, principally marine wind energy in northern Europe and solar energy in the south combined with hydro and biomass principally from the East and North and carbon capture and storage. For this to be achieved a Supergrid is necessary. A supergrid is a new and up to date grid system which, when combined with Smart technologies and solar energy in the Mediterranean area will deliver a secure, competitive and sustainable energy system for the European consumer.

A Supergrid is the route to freedom from third countries' energy dependency, to an internal market and to a zero carbon future for Europe.

FOSG fully supports the EC intention to propose introducing permitting procedures applying to projects of European interest. This will certainly facilitate the construction of the new European Supergrid and ensure energy independence and economic stability in our regions. We also look forward to the new instrument replacing the TEN-E which will be crucial for further developments of European smart energy networks.