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Pylons and Power

Cyfeillion y Ddaear Cymru
Friends of the Earth Cymru

Summary

Friends of the Earth Cymru considers that potentially very significant reductions in the cost of under-ground electricity transmission links to the proposed wind farms in mid Wales could be made. These potential savings would be such that under-grounding much or all of the cable links would be a viable option when compared to the relatively lower cost of an over-ground link using large and highly visual pylons and sub-stations. The capital and life-time costs of an under-ground link could be reduced from around the £600 million estimated by National Grid in their initial consultation to £300-390 million depending on wind farm capacity, configuration and whether new energy storage technology was included.

Using load-duration data from a group of wind farms in southern Scotland, we estimate that the proposed wind farms in mid Wales would be likely to generate around 95 per cent of their annual electricity production at below 66 per cent of their maximum output. The 'security of supply' regulations require two circuits in the link, each of which could carry the maximum output of all the wind farms, to avoid lost production if there is a fault in one or other of the circuits. We estimate that most of the year such a high capacity link would be carrying less than one seventh of the electricity it could carry, and so the link capacity could be halved with minimal loss of electricity production. Any over-specification of the link capacity required, be it HVDC or AC under-grounding, could result in multi-hundred million pounds of unnecessary costs. The capacity of the links required by the security of supply regulations should therefore be reviewed. An energy storage facility at or near the upland sub-station could also minimise production losses during a fault, and would bring wider system benefits in terms of routine demand-responsive supply to the grid and power quality improvements.

Given the relatively high costs for the placing underground of transmission links, we suggest that cost reductions of the order estimated could facilitate a decision to place underground much or all of the transmission links. We request that National Grid put forward more detailed undergrounding options (including storage) for public, political and industry consideration and further consultation

1 Introduction

Friends of the Earth Cymru has based this report on the National Grid's document '*Connection of On-shore wind farms in mid Wales' Strategic Optioneering Report Issue 1 March 2011*' and also drew on information contained in '*SP Energy Networks - Mid Wales Connections, Initial Strategic Optioneering Report (Version H1) March 2011*'.

Friends of the Earth Cymru supports placing underground much or all of the cabling to the proposed wind farms in rural Wales. Some 870 MW of schemes are currently proposed for connection in mid Wales.

Undergrounding is a more expensive option than overhead pylons though recent advances in technology and reliability, and the security of supply standards required, may tip the balance in specific cases. Part undergrounding may be an acceptable compromise in some instances.

Here, Friends of the Earth Cymru makes the case for further consideration of undergrounding most if not all of the transmission links to proposed wind farms in rural Wales, with a focus on current proposals in mid Wales.

2 Grid capacity and supply security considerations

Friends of the Earth Cymru suggests that the regulations for specifying transmission link security and quality and hence capacity (NETS SQSS) appear to be excessive, given that National Grid also has a remit to provide cost-effective services and to have regard for wider aspects such as visual impact. The link capacity requirement could be considered excessive because a relatively small percentage of energy produced by wind farms annually is generated at higher outputs (e.g. it may be that less than 10 % of annual production would be generated at above 66 % of installed capacity, or above what one circuit might carry). Consequently, an outage of one or other circuits of a two-circuit 'link' (of combined capacity just exceeding the installed capacity of the wind farms) may not result in a significant reduction in power transmission, depending on the reliability of the technology and duration of the outage. An outage would not adversely affect the distribution network to consumers as the link would be to the main grid. However, the NETS SQSS capacity requirements require two circuits both exceeding the installed capacity of the wind farms. This results in very high link costs, particularly for undergrounding options.

The high voltage direct current (HVDC) option is specified in the mid Wales Optioneering report at 2 GW (2 x 1 GW circuits). Yet this 2 GW link, estimated to cost in excess of £600 million, would connect about 700-870 MW of schemes at most which would generate on average about 210-260 MW over a typical year (assuming a 30% capacity factor). So the 2 GW HVDC link capacity option would be at least seven times greater than the average output of the wind farms.

Para 7.5.9 page 49 (Connection of on-shore wind farms in mid Wales Strategic Optioneering Report by Scottish Power) states:

'The capacity of the HVDC solution is assumed to be 2 GW. This level of capacity is required to meet the requirements of the NETS SQSS which requires two circuits each capable of carrying the generating output of the wind farms. To carry 870 MW an HVDC system of 1 GW would be sufficient. As two circuits are required a total HVDC capacity of 2 GW is required for each of the HVDC options considered.'

Note : HVDC converter stations and cable systems are delivered in standard sizes ranging from 500 MW, 750 MW, 1 GW, 2 GW etc. In this case 2 x 1GW converters and cables are sufficient.

Much depends on how the SQSS regulations are interpreted, given that the generating output of wind farms could mostly be carried by a circuit of somewhat lower capacity than the installed capacity of the wind farms. Considering the enormous sums of money involved, the 2 GW specification cited could be excessive and hence incur unnecessary costs for the HVDC undergrounding. Similarly, the costs for installing alternating current (AC) underground cables (e.g. 2 x 1 GW circuits) would also be high and presumably even pylon capacity may be over-specified to a degree that significantly changes the scale, height, cost and visual impact of that proposed option.

Consequently, we have made some broad calculations on underground transmission links comprising significantly less capacity than ostensibly would be required by NETS SQSS regulations. The calculations assess the effect of circuit outages on annual power transmission, production curtailment and overall link costs. We have also assessed the possible inclusion of an electricity/energy storage facility near the wind farms or at the proposed upland sub-stations. Storage could help reduce any significant curtailment of production during circuit outages. Storage may also routinely provide highly useful demand-responsive output (e.g. during afternoon peak demand), back-up services (including black start) and power quality improvements (e.g. smoothing, reactive/active power provision) for management of the National Grid.

We also note the ENA 'security of supply' conditions (a and b below) regarding distribution networks which might in principle be applied to direct transmission links between National Grid and wind farm developers in mid Wales. Perhaps the wind farm developers may request a level of security which could be in their broader interests, and National Grid may be happy to offer a level of security which has system benefits for the wider grid.

The Initial Strategic Optioneering Report (Version H1) March 2011 report states that:

3.7 Security of Supply – Distribution networks in the UK are generally designed according to the security standard defined within the ENA Engineering Recommendation P2/6 “Security of Supply”. The basic principle of P2/6 is based on the need to provide greater levels of supply security as the size of the group load increases. Network security is created by a combination of plant redundancy and load transfer capability.

In other words, for large load groups, it should be possible to maintain supplies to customers following an outage of any single item of plant or to restore supplies by transferring the load into another load group by network switching.

3.8 However, the standard does not apply to individual (large) customers if:

(a) the customer requests a security different from that defined in P2/6 (either better or worse) and
(b) it is possible to provide the level of security that the customer requests

3 Power production by wind turbines at different wind speeds

The analysis below is based on a report entitled: The sufficiency of transmission capacity to accommodate wind farms and manage security of supply (K.R.W. Bell, University of Strathclyde, 2006). The report studies the time distribution of electricity generated, amongst other things, of a total of 99 MW of wind farms dispersed around southern Scotland over a two year period (from April 2003 to March 2005). So this report, particularly Figure 3 on page 6, may be a relatively good proxy for the proposed dispersed schemes in mid-

Wales (i.e. schemes dispersed in hilly areas of Britain). The wind regime in mid Wales may be stronger or weaker than the winds in southern Scotland.

Figure 3 of this report appears to indicate that only about 4% of this southern Scotland region's wind farms annual power production is generated at over 66% of the wind farms' total installed capacity (see Annex 1). Similarly, only about 1.68% of power is produced at over 72% of installed capacity, and virtually no power is generated at over 90% of installed capacity (though spikes lasting less than 30 minutes may have occurred). The output was measured in time periods of 30 minutes. Regarding the 90% figure, presumably while some wind turbines may turn off (for self protection) during very high winds across the region, other turbines would still be generating at or near maximum output but rarely exceeding 90% of capacity in a thirty minute period. This data suggests that a 66 MW transmission link to 100 MW of wind farms across a region in southern Scotland would still manage to deliver about 95% of the wind farms' annual output.

If the load-duration figures are similar to what would pertain in mid Wales, then a 1 GW HVDC link (2 x 500 MW circuits) could probably transmit most of the annual production of 870 MW of wind farms even if one or other circuits has an outage totalling several weeks per year. When both 500 MW circuits are working then all the power generated could be transmitted (less link losses). During an outage on one circuit, the other 500 MW circuit could still transmit most of the electricity generated. 500 MW is equivalent to 58% of the installed capacity of an 870 MW wind farm scenario (including 1% converter losses). The annual energy generation above 58% of installed capacity is about 8% of the annual yield.

Consequently, during one circuit outage, the link could not transmit about 8% of the electricity which could have been generated given typical wind conditions. Consequently, the curtailment of power, assuming four weeks of outage on one circuit or other per year, would result in a loss of only about 0.62% (8% x 4/52) of typical annual generation. If outages were two weeks or eight weeks the curtailment losses would be 0.31% or 1.24% respectively. So the possible scale of generation losses would probably be of similar order to that of routine transmission losses (estimated by National Grid to be about 0.6% for AC circuits and 2-4% for HVDC). Much would depend on the reliability of the latest hardware and the wind conditions during the outages.

A 700 MW scenario would obviously lose even less production as one 500 MW circuit is equivalent to 72% of installed capacity, above which only 1.68% of power is generated. So assuming a total of 4 week per year outage on one or other circuits then annual lost production would be about 0.13% (1.68% x 4/52) of average annual output.

4 Costs of curtailed output in comparison to link costs

An 870 MW wind farm scenario would generate 2.29 TWh per annum so 8% losses (above 58% of installed capacity) would amount to about 185 GWh/y (for a full year of lost production). For a 700 MW scenario, generating 1.84 TWh/y, a loss of 1.68% would be about 31 GWh/y.

In the 870 MW windfarm scenario the value of the curtailed production for every four week circuit outage per year could be (assuming £85 per MWh of lost production) about £1.2 million per year. This would total about £30 million over 25 years. In the 700 MW windfarm scenario the value of the curtailed production for every four week circuit outage per year could be about £0.203 million per year. This would total about £5.07 million over 25 years.

The costs of a 2 GW HVDC underground link are estimated in the National Grid's Strategic Optioneering Report to comprise £460 million capital costs (£350m HVDC and £110m other) and about £150 million 'lifetime costs' (maintenance, converter losses, etc) amounting to some £610 million. We assume that a 1 GW link might have a capital cost of about half that to install (assuming costs are proportionate), with possibly marginally less lifetime costs (say reducing to £130m), totalling £360 million (i.e. £230m + £130m).

The overall saving, including curtailment losses over a 25 year period, may be in the order of £220 million on total link costs of £610 million for an 870 MW scenario. A saving of about £245 million in a 700 MW scenario may be possible. The actual costs could be about £365-390 million for a 1 GW link (2 x 500 MW circuits).

Such figures suggest a significant saving could be made by specifying a 1 GW link requirement (2 x 500 MW circuits) instead of a 2 GW link. A 700 MW scenario could potentially comprise 2 x 350 MW circuits with a large capacity storage facility possibly enabling additional capital and life time savings.

5 Storage to reduce curtailment

Integrating an electricity storage facility into the transmission link could help reduce curtailment during circuit outages. Even if the storage facility cost as much or more than the value of the avoided loss of production (i.e. up to £30m over 25 years in the 870 MW scenario) there would still be significant additional system benefits which would be profitable (e.g. demand-responsive power, smoothing) that could justify the investment.

Some commercial storage technologies are available for wind energy storage including ABB's DynaPeaQ lithium-ion battery technology and Prudent Power's Vanadium Flow Cell system. Several storage schemes at wind farms are in operation globally.

The storage facility in this instance would have to have a very large storage capacity to capture more than a few hours' worth of electricity at any one period of stronger winds in an outage period which may last days. Consequently, such a storage system would be expensive. However, the benefits of having a very large facility available to the National Grid would then also be large, in terms of technical aspects (demand-response, power smoothing and power quality) and hence potentially valuable.

In terms of storage capacity and power rating, flow cells are highly scalable in terms of power output and storage duration (though would be stretching today's technology). The DynaPeaQ technology is capable of scaling to 50 MW for an hour or more. ABB's DynaPeaQ system could well complement HVDC Light transmission links as is this case in the 1 GW Norway-Denmark link.

For example, an installation of up to about 50 MW/1 hour+ scale may store, for later transmission, some of electricity that would otherwise have to have been curtailed if one of the 500 MW circuits was not available. In the 870 MW scenario the wind farms could then be generating at about 550 MW (averaging 63% of cumulative capacity) for an hour, or whatever the storage capacity installed were, and much or all the energy generated could be stored for later transmission (i.e. when windfarm output fell below 500 MW and transmission capacity became available).

There would be some electricity losses in the HVDC converters in both sub-station and greater losses in the storage facility (flow cells have a round-trip efficiency of about 70%). So some power generated just above 550 MW output would be used in the DC converters in the sub-station and in charging the storage facility anyway. Assuming converter losses of 1% of output, then about 5 MW of production would be used in the converters when transmitting around 500 MW. The storage facility may consume about 7 MW while charging and discharging (batteries, capacitors and or flow cells). So, with a 50 MW/one hour+ storage facility the windfarm output could rise to 562 MW (500 + 50 + 5 + 7) and still transmit (eventually) all the power that would have been transmitted with no outages for one hour+. As 562 MW is 64% of 870 MW then about 5% of production may be lost during the outage (see Annex 1) for short duration outages at least. Assuming four weeks of outage per year on one circuit or other then down towards just 0.38% (5% x 4/52) of annual production might only be curtailed and lost if sufficient storage were incorporated.

In a 700 MW installed capacity scenario, one 500 MW circuit could transmit 72% of maximum power production and the addition of a 50 MW/one hour+ storage facility would enable the transmission of 80% of maximum power production for as long as the storage capacity would allow. Energy produced above 72% and 80% of maximum power amounts to just 1.7% and 0.5% of annual energy production (see Annex 1) so little production may be lost even if there were strong wind conditions during the outage. Assuming four weeks of outage per year on one or other of the circuits then lost production would amount to 0.2% of annual production without a storage facility and possibly down towards 0.04% of annual production with a storage facility.

Anything like 50 MW of storage capacity would also bring system benefits and cost savings to the grid in terms of the routine delivery of wind-generated electricity at peak daily consumer demand times (particularly the evening peak hours) and in terms of grid stability. Such profitable and valuable services should be factored into the cost-benefit analysis of incorporating storage.

The DynaPeaQ facility could presumably help optimise the three underground 132 kV AC links from the wind farms. The Scottish Power report states:

3.6.1 If there is an instantaneous change in power flow (for example as a result of a wind farm disconnecting itself from the network or a circuit or transformer being switched out) this will cause an instantaneous step change in voltage. Plant and equipment can be sensitive to sudden changes in voltage, therefore events that cause instantaneous changes in power flow are avoided as much as possible (for example, the wind farm ramps up and down its export in a “slow” and controlled manner). Therefore, voltage step change is considered as part of the design process.

The area footprint of the transmitting or 'up-land' HVDC converter station and any integrated or dispersed large-scale storage facilities would depend on the capacity of link circuits and the storage specified. The height of the buildings may depend on the transmission voltage (e.g. 150 kW or 320 kV). However, HVDC sub-stations are highly compact and visually less intrusive than AC equivalents. The appearance for the most part could be dark green sheds with relatively little high-voltage equipment visible. The potential for tree screening would be dependent on site location, etc. With some innovative design the facilities could be made to look for the most part like farm sheds with a road access.

6 Triple HVDC circuit option

The wind farm capacity and Grid security requirements will determine configuration, circuit number and hence capital and lifetime costs. Numerous HVDC cable sizes are available including 350 MW and lower.

It is worth considering a triple 250 MW link to identify any security benefits or cost reductions. It appears that little energy is generated annually above 90% of installed capacity in windfarms dispersed over a region. For the 870 MW scenario 90% would be about 785 MW above which very little electricity would be produced (i.e. 870 x 90% = 783 MW). Consequently, it may be more cost-effective or otherwise beneficial to install a 750 MW HVDC link comprising three 250 MW circuits (3 x 250 MW) assuming a manufacturer makes 250 MW cables. Much depends of the reliability of different aspects of a HVDC system (e.g. cables and converters). Three circuits could mean more to go wrong but the capital cost could be proportionately cheaper. Also if there were two concurrent circuit outages there would still be one 250 MW link available (about the average output of the wind farms), which presumably satisfies the NETS SQSS 'infrequent infeed loss' risk.

The Optioneering Report states:

3.13 Paragraph 2.6.4 of the NETS SQSS requires that following the concurrent fault outage of any two transmission circuits the loss of power infeed shall not exceed the infrequent infeed loss risk. At present, the infrequent infeed loss risk is set at 1320 MW, increasing to 1800 MW from April 1, 2014. Given the level of generation capacity being connected (circa 870 MW), two transmission circuits are therefore sufficient.

Even without a storage facility a 750 MW link would be able to transmit 87% (757.5/870 = 0.87) of installed capacity and assuming no outages (including 7.5 MW converter losses), so annual losses due to curtailment would be very low. With one circuit outage the remaining 500 MW available would have similar losses as the outage scenario described above (around 0.6% of annual production lost per four weeks of outage per year). Adding in a storage facility of about 50 MW/1 hour+, such a 750 MW link with all three circuits working would be able to transmit 812 MW cumulative output (i.e. 93% of the installed capacity of the 870 MW scenario) which is more than the 90% level, above which little energy is produced from a dispersed system.

A triple circuit option could lose two circuits to outages, presumably very infrequently, and still be able to transmit 250-300 MW (assuming up to 50 MW flow cell facility). As the average output of 870 MW of wind farms would be about 260 MW then even the infrequent loss of two circuits would not necessarily result in significant loss of production assuming at least one of the circuits is quickly brought back into operation.

For a 700 MW windfarm scenario a 750 MW triple circuit even without storage would be able to transmit all energy produced when there are no outages. There would probably be little lost production annually even with outages of one or infrequently two circuits. Loss of one 250 MW circuit would leave 500 MW of link available and much of the electricity generated could still be transmitted (505 MW is 72% of 700 MW and with a storage facility 562 MW is 80% of 700 MW). As above, production above 72% and 80% of maximum power amounts to just 1.7% and 0.5% of annual energy production (see Annex 1). So, little production would be lost even if there were strong wind conditions during the outage. Assuming four weeks of outage per year of one or other of the circuits then lost production would amount to 0.13% of annual production without a storage facility and possibly down towards 0.04% of annual production with a storage facility.

The capital cost of a 750 MW HVDC three circuit link may be about £170 million (extrapolating from £460 for 2 GW assuming costs scale directly). Assuming the same slightly reduced lifetime costs of £130 million as above, then overall link costs may be about £300 million with very little curtailment costs.

Note that an 800 MW HVDC link with a 90 km length of undergrounding is currently being installed in northern Germany from some offshore wind farms.

The reliability assessment of the latest products would influence the choice of cable and converter configuration. HVDC cables can also be located on pylons in places as or if required by specific route constraints etc.

7 AC Undergrounding and overgrounding

A similar type of analysis could be undertaken for AC underground links to either 870 MW or 700 MW of wind farms using link capacities of 1 GW and 750 MW with or without storage. A similar scale of transmission link savings and infrastructure works (capital and lifetime) may or may not be available.

8 Summary of link option analysis

Friends of the Earth Cymru considers that when comparing transmission costs and visual impacts with NETS SQSS security standards, a lower capacity link may well be appropriate for the wind farms proposed in mid-Wales than the capacity specified in the consultation. The possibility of significantly reduced capital costs could facilitate the choice of undergrounding much or all of the transmission links. Furthermore, the link would be direct from the wind farms to the National Grid 400 kV system so consumer network security would not be directly affected and also a potentially significant storage capacity would be available to the National Grid.

The cost savings made by reducing the HVDC link capacity from 2 GW to 1 GW (2 x 500 MW circuits) or 750 MW (3 x 250 MW circuits) or other configuration (e.g. 2 x 350 MW or 1 x 1 GW) with or without storage facilities could be considerable. If the capital costs are anything like proportionate then the hardware and installation costs could fall from £460 million to £230 million or even £170 million. Assuming lifetime costs fall to some degree (£150m to £130 m) then the overall transmission costs would fall from about £610 million to £390 million or possibly down to £300 million for a HVDC system. The actual capital costs including curtailment losses could be about £365-390 million for a 1 GW link (2 x 500 MW circuits) or possibly £300 million for a 700 - 750 MW link. Production losses due to curtailment following circuit outages might range from very low up to about £1.2 million per year or £30 million over 25 years (assuming up to 4 weeks outage one or other circuit per year) and would depend on the reliability of the latest commercial hardware.

Some of this potential production loss may be avoided by the installation of a storage facility (such as ABB's DynaPeaQ system or vanadium flow cells). While very costly to install, a storage facility could routinely earn profits by supplying power on demand at peak daily consumer times and provide valuable wider system benefits such as Grid power quality (smoothing, active and reactive power and black start capability).

So the savings for a sufficient and cost-effective HVDC link may be in the order of £220-300 million (excluding storage facility and its benefits). Possibly a similarly significant scale of savings might be made using a 700 MW, 750 MW or 1 GW transmission capacity of AC underground and AC overground links. If this is the case then Friends of the Earth Cymru advises that more detailed undergrounding proposals and scenario options are drawn up for wider stakeholder consideration (i.e. public, political and industry consideration).

This paper was drafted by Neil Crumpton, energy advisor to Friends of the Earth Cymru (who was staff energy campaigner for the group and a representative on the WAG stakeholder group advising on the TAN 8 policy in 2004 along with representatives from CPRW, CNP, CCW, WDA and other bodies).

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Annex 1

Output calculations for 99 MW of wind farms in the southern Scotland region of period April 2003 - March 2005

From Fig 3 page 6 of the report 'The sufficiency of transmission capacity to accommodate wind farms and manage security of supply' by K.R.W. Bell at the University of Strathclyde: http://www.labplan.ufsc.br/congressos/cigre06/DATA/C1_112.PDF

The percentage of electricity generated above a certain level of output (or transmission capacity) over the two year period is calculated by dividing the area of the small triangular shape bounded by the graph line and above the % power output level, by the total area under the curve (i.e. divided by 3000 units). This energy would be the curtailed production in the event of a fault reducing the transmission capacity. Note that it is not the total energy generated by the wind farm at the higher outputs in stronger winds because most of the electricity would still transmitted by the working circuit.

The total area under the curve of Fig 3 = 3,000 approx (about 80 x 75 / 2 or 78 x 77 / 2). This area is equivalent to the total electricity generated over the period (power x time).

Area above 58 % of installed capacity is 17 x (85-58) / 2 + 5 = 234.5

- then divide by 3000 to find % energy generated above that power output = 7.81 %

Area above 64 % of installed capacity is 14 x (85-64) / 2 + 5 = 152

- then divide by 3000 to find % energy generated above that power output = 5.07 %

Area above 66 % of installed capacity is 12 x (85-66) / 2 + 5 = 119

- then divide by 3000 to find % energy generated above that power output = 3.97 %

Area above 72 % of installed capacity is 7 x (85-72) / 2 + 5 = 50.5

- then divide by 3000 to find % energy generated above that power output = 1.68 %

Area above 80 % of installed capacity is 4 x (85-80) / 2 + 5 = 15

- then divide by 3000 to find % energy generated above that power output = 0.5 %

Area above 90 % of installed capacity is 0 x 0 = 0

- then divide by 3000 to find % energy generated above that power output = 0 %

Annex 2

http://www.geni.org/globalenergy/library/technical-articles/transmission/powergenworldwide.com/latest-development-in-hvdc-transmission/index.shtml

The HVDC Light transmission technology deploys a new IGBT (Insulated Gate Bipolar Transistor) semiconductor-based converter in combination with XLPE (cross-linked polyethylene) DC cable systems. This innovation complements the traditional bipolar semiconductor-based converter technology and has proved to be a state-of-the-art power system with increased controllability. HVDC Light is easy to install and offers a number of environmental benefits, including the use of underground or subsea power links, neutral electromagnetic fields, oil-free cables and compact converter stations. The technology also increases the reliability of power grids. The continuous development of HVDC Light has in the meantime increased the power range from tens of megawatts to 1200 MW at ±320 kV with cables.

HVDC Light has also opened up new applications for HVDC transmission, such as providing shore power supplies to islands and offshore oil & gas platforms, enabling city centre in-feeds and more recently the integration of offshore wind farms. In future, this technology is likely to play an important part in the development of DC grids. (multi-terminal DC connections)

Initially HVDC Light had around 3% losses per converter station, while in the latest generation it is now down to about 1%. Reliability requirements have been driven by dynamic performance, harmonic generation and the flexibility to accommodate changing grid conditions.

HVDC Light converters today are based on CTL (cascaded two-level) converter topology, eliminating the need for AC filters and enabling a more compact converter design with a low level of harmonics and audible noise. A special feature incorporated in HVDC Light is the IGBT module (StakPak), which incorporates a fail-safe short-circuit mode, allowing operations to continue, even after failure of an IGBT module, without auxiliary equipment. The latest generation of converter stations, comprising two 1000 MW and ±320 kV converters, has a footprint of 220 metres by 150 metres, which is substantially smaller than previous generations.

An important advantage of HVDC Light technology is that the power direction is changed by switching the direction of the current, and not by changing the polarity of the DC voltage. This facilitates the construction of multi-terminal HVDC Light systems. The terminals can be connected to different points in the same AC network or to different AC networks. The resulting DC grids can be radial, meshed or a combination of both.

Multi-terminal HVDC Light systems are particularly attractive for integration of large-scale renewable energy sources such as offshore wind farms and for reinforcement of interconnected regional AC grids.

Annex 3

http://www.abb.co.uk/industries/db0003db004333/f4fe0de96f60d23ac1257674004dbcb5.aspx

http://www.abb.co.uk/cawp/seitp202/4cd762575531f789c12577120036afda.aspx

DynaPeaQ®- SVC Light® with Energy Storage

DynaPeaQ provides a new dimension in developing smart grids. It allows a significant increase in renewable generation, maximizing C02-free generation. It provides cost-effective, environmentally attractive, and high quality services for existing networks.

The Energy Storage can receive and store power from wind turbines and surplus power from the grid. It can take the power delivered on a sunny day from photo-voltaic panels and put it into its
high capacity battery bank. Using modern electronics, DynaPeaQ feeds the grid with exactly the right amount of reactive and active power needed at each instant, independently of one another, and with a minimum of bulky filter arrangements. The system is based on SVC Light, combined with Li-ion battery storage. SVC Light is ABB's STATCOM concept, utilizing Voltage Source Converters (VSC) connected in shunt to the grid at the transmission level, as well as at the sub- transmission and distribution levels. State-of-the-art IGBTs (Insulated Gate Bipolar Transistors) are utilized as switching devices.

The Energy Storage's ability to store energy is highly scalable. At present, rated power and capacity are typically in the 20 MW range for tens of minutes, but the technology permits up to 50 MW for periods of 60 minutes and more