Advantages of DC Use in Wind Farms: State of the Art and Relevant Experiences

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Abstract
In this article a review of the advantages of direct current use (DC) in wind farms in order to enhance their capability to withstand grid incidences and contribute to power system operation will be presented. A state of the art of the different High Voltage Direct Current (HVDC) technologies will be exposed and their application to wind power production discussed. Finally, the diverse existing experiences in this field will be reviewed.

Keywords:
Direct current (DC), Wind Farm Configuration, Power Electronics, Wind Power Grid Integration, Hydrogen.

I. INTRODUCTION

CURRENTLY a major part of the energy used in developed countries is obtained from fossil fuels such as oil, coal and gas. More specifically, in Europe, they sum up as much as an 80% of the total primary energy consumption [1]. This figure can be taken as a good rough approximate for most developed countries. Regrettably the extensive usance of fossil resources poses several problems.

The first drawback is an environmental one; it is not only that most fossil fuels release polluting particles and gasses during their burning (which perhaps could be prevented from reaching the atmosphere by the right use of appropriate filters) but also that unavoidably they produce CO_2 which provokes the green house effect. Despite the efforts devoted to investigate diverse CO_2 sequestration techniques no satisfactory results have been obtained yet, constituting a major hindrance for a sustainable fossil fuels use.

Another difficulty comes from the fact that the vast majority of known oil and gas reserves are concentrated in a few countries. As is well known this stimulates conflicts and fights for the control of these precious resources and -on those countries that lack of them- an external dependence to cover their energy needs. That is the case of the EU whose economic stability has sometimes been blackmailed by the threat of an increase in prices of commodities.

Finally, attention must be brought to the fact that due to their nature, fossil resources are not renewable, and will sometime come to an end. Most of the studies on this issue agree that this will happen more in the longer than in the shorter term, however many of them also state that a previous problem may come from the stresses on prices that could appear prior to their total exhaustion.

For all these reasons, a global change is being promoted towards a more sustainable use of energy. On this way several international agreements, such as the Kyoto protocol, have been established and the exploit of renewable energies encouraged.

The EU may be considered as holder of a leading position regarding the compromise with environment. As a matter of fact, in the treaty for a European Constitution [2] it is stated:

"(…) the Union shall (…) contribute to (…) the sustainable development of the Earth."

Several studies and regulations have been developed to advance in this direction. On the "*Green book for Security of supply*" [3] the European Commission analyzed separately the two sides of the electricity supply problem: that of demand and production. Regarding the latter, the green book pointed out that the higher potential was that of renewable sources and therefore should constitute a preferential option in the European energetic strategy.

Following this indication the EU set the directive 2001/77/CE where a target 12% of national brut energy consumption coming from renewable sources and a 22,1 % of electricity was fixed.

This favorable institutional support has produced a dramatic increase in the penetration of electricity coming from renewable sources in power systems. The most astonishing progression has been that of wind energy. Spain constitutes a good example of this evolution having placed itself as second European country in installed wind power capacity with more than 10.000 MW.

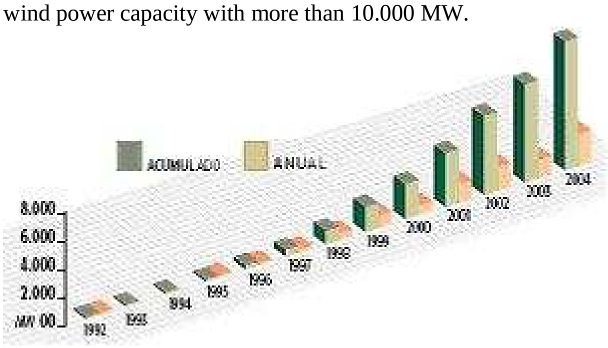

Fig 1. Wind Power Installed capacity in Spain yearly and cumulative. (Source: Asociación Empresarial Eólica)

Actually, in this country the first "*Renewable Energies Promotion Plan*" [4] pointed as an objective 8.140 MW to be installed by 2010. This number has gone under two reviews ever since being increased to 13.000 MW and 20.000 MW successively. However when coming to develop the plan it was found that, if no modifications were introduced in the wind turbines, stability problems in the power system could appear. [5]

In many other countries too, Wind Energy development has aroused worries in Transmission System Operators (TSOs) till now disregarded. The major concern deals with the mentioned threat for system dynamic stability that this form of generation could pose. In this sense several European TSOs are passing new regulations aimed at strengthening wind farms response in case of grid disturbances. One of the first aspects considered is Wind Turbines (WT) reaction to voltage sags. Other limitations include restrictions on wind farms

(WF) production due to grid capacity or caps on simultaneous generation percentage.

In order to overcome these reluctances and fortify WTs availability one possible solution could be the joint use of direct current (DC) and hydrogen in wind farms. DC would disconnect frequency and voltage from the grid and WF, strengthening WF reaction to faults. Storage would contribute to smoothing the WF production profile and exploiting at a maximum the evacuation capacity. Besides, storage systems would near WF operation to traditional power plants and enable wind energy to take part in the system regulation. Finally, future offshore WF development demands solutions to long cable distance transmission which could include DC use.

For all these reasons, Spanish National Renewable Energy Centre (CENER) and Public University of Navarra (UPNA) have started a joint research on direct current WF definition. The project is financed by the National R&D plan from Spanish Science and Technology Ministry.

In the following paper a summary of diverse DC transmission technologies is presented and diverse international experiences on this field summarized.

II. MAIN DC USE ADVANTAGES IN WIND FARMS

As it has already been said, direct current (DC) has several advantages against alternating current when coming to talk about its use in wind farms (WF).

- **DC could enhance WF fault withstand capability**.

DC uncouples the electrical system within the WF and the electrical grid. Thus it could strengthen WF response to grid incidences. If well designed, the AC/DC converter could act as a perturbation muffler and keep WF on line in case of voltage sags or other grid perturbations ([6] and [7]).

Besides, if using the appropriate inverter technology, reactive power production during faults could be regulated contributing to grid fast recovery [8].

- **DC could enable a better WF and WT control**.

Concentrating DC/AC conversion in the substation allows a control over the WF P-Q working point [9]. As stated above, this represents obvious advantages during grid incidences, but also in normal operation mode. Reactive power control contributes to grid voltage control, decreases losses and therefore reduces costs and increases reliability.

In addition, whatever the generation technology chosen (DC machines, power electronics rectifiers…) WT running in a DC environment can vary their speed more or less easily. This implies a better resource usage and higher global WF performance.

- **DC could constitute the only transmission option in some offshore WF**

In offshore WF long cable transmission distances may appear. As is well known very long distance AC cables constitute a technical impossible as capacitive losses represent a bottleneck and deter its utilization above certain threshold. This could be well the situation in some offshore WF. In this case DC would stand as an alternative to take into account.

In addition, even if the distance is not so long, the same capacitive effect implies that DC transmission would decrease losses.

Finally a structural advantage must also be hinted, DC does not induce currents in the cable armature. As a consequence, stronger steel armored cables can be set up, which are quite appropriate for underwater lying.

- **DC use could increase performance and save components in Hydrogen production system**

Most storage systems work on DC. And, particularly, when coming to talk about Hydrogen, it seems that the most suitable means to produce it seems to be by electrolysis. This process too runs on DC. Thus in AC Wind Farms a rectifier is needed. In DC Wind Farms this component could be dispensed and therefore an increase in performance and decrease in cost attained.

III. STATE OF THE ART OF DC TRANSMISSION

HVDC links date back to about 50 years ago. Then, both in Sweden and USSR, a research effort was conducted on DC technology which resulted in the mercury arc valve. In the ‘60s the power electronics components development (particularly Thyristor) overcame this solution and following links were established based on this new device. However, Thyristor still presented the disadvantage of being a line commutated component which, as will be explained below, has limitations on reactive power control and others.

In the ‘90s IGBT apparition supposed another evolution in HVDC. Its fast commutation capability permitted Pulse Width Modulation (PWM) control implementation and a more suitable response to grid events. Anyhow, it still suffers constrains on power rating, losses, and higher costs than Thyristor based HVDC.

- **Line commutated Thyristor HVDC**

Line commutated devices need an external voltage signal to function. As a result they are not capable of energizing passive networks and require the presence of, at least, one generator to provide a voltage signal.

In addition, they are not capable of working in the four quadrants, as an unavoidable lag between line voltage and current appears [10].

However, they are a well proven technology and have higher power rating and lower losses and costs than other similar options.

- **VSC use in HVDC**

IGBT constitute fast line commutated devices. This lets them turn on and off independently of grid voltage signals. Thus a better control can be exercised over PQ and any point in the four quadrants reached. This has lead to defining them as Voltage Source Converters.

They are capable too of energizing passive networks even if no other generator is present. Finally harmonics reduction can be implemented by establishing specific firing pulse sequences.

However, the disadvantages of this technology compared to traditional HVDC are higher costs and losses and more limited power ranges. There seems to be installations with no rated power over 300 MW range [11]. Future trends hint a relatively fast cost and losses reduction though nowadays this is still to be achieved. Anyway, its specific characteristics suggest that this solution could be quite appropriate for the present project purpose.

- **Commercial available devices**

Some of the more widespread solutions are those of Siemens (with its HVDCPlus) and ABB (HVDCLight ®). There are also other companies such AREVA which propose another HVDC configuration consisting of hybrid HVDC and STATCOM to overcome traditional HVDC limitations[12].

IV. RELEVANT EXPERIENCIES

This team has carried out an extensive search on running installations which involved dc use and wind energy. However, only two relevant installations have been found: Tjæreborg (Denmark) and Visby (Sweden).

- **Tjæreborg:**

Fig 2 Tjæreborg situation. (Source: ABB)

In [13], [14] and [15] extensive information on Tjæreborg can be found. This wind farm is an experimental installation composed by four wind turbines with a total installed capacity of 6.5 MW. Two of them are a 2.0MW double fed induction generator, one 1.5 MW directly connected, and a 1.0 MW with full converter.

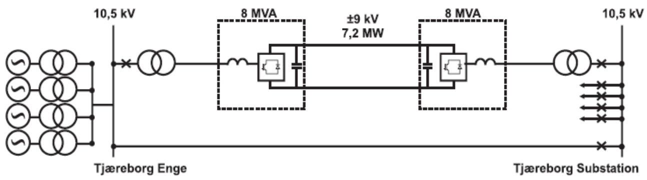

Fig 3 Tjæreborg electric layout. (Source: ABB)

The original wind farm was connected to AC Danish grid at 60 kV. A parallel DC cable was installed in 1999 and in December 2000 test and operation started. Results are available in cited bibliography.

- **Näs-Visby**

Fig 4 Gotland Island link. (Source: ABB)

In [16] information can be found about this HVDC experience in Gotland island, Sweden. A 70 km long, 50 MW rated DC cable was established in 1999 in order to connect Visby town with south wind farms in Näs.

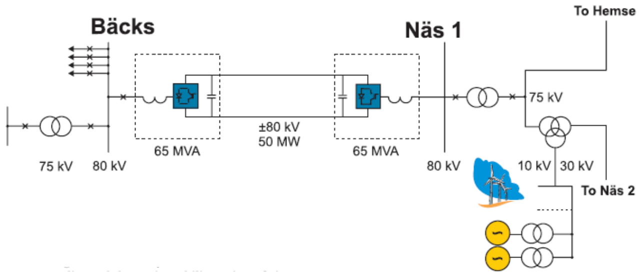

Fig 5 Gotland Island link. (Source: ABB)

- **Offshore experiences**

This team hasn't found any dc use experience in offshore WF. There was a proposal by ABB [17] though it hasn't been effectively implemented yet. And, as far as this team has came to know, Laesø offshore WF in Denmark is also planned to be built with a dc connection though hasn't been commissioned yet.

V. CONCLUSIONS AND FUTURE RESEARCHES

DC represents a promising option in Wind Power generation. It could prove to be a good solution to WF sensitivity to grid incidences and its combination with some storage system could suppose a definitive step ahead in the path to assimilate WF to traditional generation technologies.

However, up to date, there is not any park running under this philosophy. The components are commercially available though a research effort seems to be required to demonstrate the effective advantages of this technology, to balance what the profits and the costs are and find out which is the most suitable configuration. An intensive effort on converters development is also required too.

Another field to be explored consists in storage and DC WF integration. Hydrogen represents a good choice though its usage requires further development in order to define the system structure and quantify its advantages.

VI. REFERENCES

[1] I. d. L. Hierro and J. I. Pérez-Arriaga, "Informe Anual: Observatorio de energía y desarrollo sostenible en España," Universidad Pontificia de Comillas Cátedra BP de Desarrollo Sostenible, Madrid February 2005.
[2] E. Convention, "Treaty Establishing a Constitution for Europe ", 2005.
[3] E. Comission, "Green book for the Security of Supply ", 2000.
[4] T. y. C. Ministerio de Industria, "Plan de Fomento de las Energías Renovables," 1999.
[5] M. d. Economía, "Planificación de los Sectores de Electricidad y Gas 2002-2011," 2002.
[6] P. Cartwright, "Hybrid HVDC for the Supply of Power to Offshore Oil Platforms," in *CIGRÉ* Paris, 2004.
[7] Y. Jiang-Häfner, M. Hyttinen, and B. Pääjärvi, "On the short circuit contribution of HVDC Light," in *IEEE/PES T&D Asia Pacific*. Yokohama, Japan, 2002.
[8] S. G. Johansson, G. Asplund, E. Jansson, and R. Rudervall, "Power System Stability Benefits with VSC DC-Transmission Systems," in *CIGRÉ Conference*. Paris, 2004.
[9] N. Hörle, K. Eriksson, and A. Maeland, "Electrical supply for offshore installations made possible by use of VSC

technology," in *Cigré 2002 conference*. Paris (France), 2002.

[10] J. Arrillaga, *High Voltage Direct Current Transmission*, vol. 1, 2nd ed. Stevenage (U.K.), 1998.

[11] K. Eriksson, "HVDC Light (TM) and the development of Voltage Source Converters," in *IEEE/PES T&D Latin America*. Sao Paulo (Brazil), 2002.

[12] P. Cartwright, "The Integration of Large Scale Wind Power Generation into Transmission Networks using Power Electronics," in *CIGRE*. Paris, 2004.

[13] A.-K. Skytt, P. Homberg, and L.-E. Juhlin, "HVDC Light for connection of wind farms," presented at Second International Workshop on Transmission Networks for Offshore Wind Farms, Royal Institute of Technology, Stokholm, Sweden, 2001.

[14] K. SØbrink, P. L. SØrensen, E. Joncquel, and D. Woodford, "Feasibility Study Regarding Grid Integration of a 160 MW Offshore Wind Farm Using VSC Transmission," presented at European Wind Energy Conference (EWEC), Copenhagen, Dennmark, 2001.

[15] K. Eriksson, C. Liljegren, and K. Sobrink, "HVDC Light Experiences applicable for power transmission from offshore wind " in *ASME/AIAA Wind Energy Symposium*. Reno, NV, USA, 2004.

[16] L. C. Gunnar Bennstam, "HVDC Light® Grid Friendly and ecological technology," *ABB Review*, 2004.

[17] M. Dahlgren, H. Frank, M. Leijon, F. Owman, and L. Walfridsson, "Windformer (tm): Wind Power goes large scale " *ABB Review*, 2000.