Wind Power in the local Grid, Problems and solutions

By
Christer Liljegren
CLEPS AB/ Gotlands Energiverk AB
+46(0)498274316
e-mail:ch.liljegren.cleps@gotlandica.se

Introduction

The aim of this paper is to give an overview about the subjects that Gotlands Energiverk AB (GEAB), as owner of the network, has been studing and are considered to be the most important impacts for the grid operator. Some solution that has been implemented describes, but the aim has not to go in to details. One of the most important experiences is to have roles and clear responsibility border for the different parts in a deregulated marked. In Sweden the owners of windmills mostly are independent producers.

History

The electrical system was built from the village Slite in North part of the island. The reason for this was that the limestone industry was the first and the biggest consumer. Even today this Cement industry is the biggest consumer and consumes nearly 30% of the electrical energy on Gotland. In the early 20-century a Power plant which used coal and also oil diesel motors were built. On the countryside small diesel generators were built for very local consumptions. In 1930 they began to connect the small power units to the system in Slite with overhead lines. In this year we get an electrical system on Gotland with central production of power.
Next step was 1954 when the first HVDC link in the world, got in operation between the mainland and Gotland. The rated power of this link was 15 MW. Later on, they upgraded this to 30 MW.
The grid was built up for the consumption that consisted on small loads in the countryside. In 1970 the consumers began to use electrical power for heating and the consumption increased a lot at remote places. In 1983, the old HVDC link was taken out of operation and a new one replaced it with 150 MW rated power. A few years later a redundant HVDC link was built.

In the beginning, the power company was responsible for the lighting from the electrical lamps, not for the electrical power. After the development of metering equipments it was easier to measure the electric energy and could be paid for kWh. The power company, utility, was responsibility for the power and the quality to the costume's.

Description of the electrical system.

The network consists on approx. 300 km 70 kV lines, 100 km 30 kV lines and 2.000 km 10 kV lines. Normally there is no local production except the Wind Power. The HVDC-Link transfers power from the mainland and regulates the frequency on the island. In order to keep the voltage stability there are also synchronous generators that play an important role for the function of the system. The energy turnover in the system is about 850 GWh and the peak load approx. 160 MW and the minimum load is around 40 MW. About 36.000 customers are connected.

During the last years there has been a large increase of wind power generation. The wind power capacity was, in 1984, 3 MW and became 15 MW in 1994. Today, there are 155 windmills with total installed power of 80 MW producing about 180 GWh.

Gotland electrical system

- •Peak load 160 MW
- •Min load 40 MW
- •850 GWH consumption
- •HVDC-links from mainland 2*150 MW
- •6 Gasturbins, total 160 MW
- •300 km 70 kV lines
- •100 km 30 kV lines
- •2100 km 10 kV lines and cables
- •2500 km low voltages lines and cables
- •2300 transformers

Fig 1: Overview for the Gotland electrical system

However, with the existing infrastructure, which was planned accordingly to the consumption, the system could not receive the increasing production in the south of the Island. While in the north a strong network foreseen to feed the largest consumers (Visby and Slite) existed, a weaker system in the south, designed to feed much smaller loads, became a ‘bottleneck’ for the wind power generation.

In the southern part of the island, where the peak load is only about 17 MW, there is about 60 MW wind power capacity installed. In the southernmost area Näs, and outskirts, where the peak load is less than 0,5 MW, approx. 40 of the 80 MW wind power capacity is installed.

This unbalance between load and production, makes the system very difficult from a technical point of view. For example the short circuit power is very low in relation to all connected equipments, compared with a normal distribution system. The system is rather unstable when the rotating mass in the system is very low, compared with a system that is fed from synchronous generators. The solutions to the island’s power transmission problems were met with installation of the first HVDC-Light plant.

Description of HVDC light

The HVDC light system consists of two converter stations connected by 70 km double + / - 80 kV DC cable. The converters are connected via reactors to the 80 kV AC bus which is fed from the 75 kV system. The transformers are equipped with tap changers to be able to reduce the voltage on the Converter side to reduce no load and low load losses. This is a special feature of this installation introduced, since the wind power seldom operates at peak production, and sometimes does not produce at all. This makes it very important to keep the no load and low load losses as low as possible, as they had a much bigger influence on the economy than the peak load losses.

The HVDC light is equipped with voltage source converters with pulse width modulation (PWM) using IGBT: s. With PWM just about any phase angle or amplitude is possible by changing the PWM pattern, which can be done almost instantaneously. As this allows independent control of both the active and reactive power, a PWM voltage sourced converter comes close to being the almost ideal transmission network component. From the system’s point of view it acts as a motor or generator without mass and is able to control active and reactive power almost instantaneously. This makes the operation characteristics more software than hardware dependent.

Simplified Gotland Network

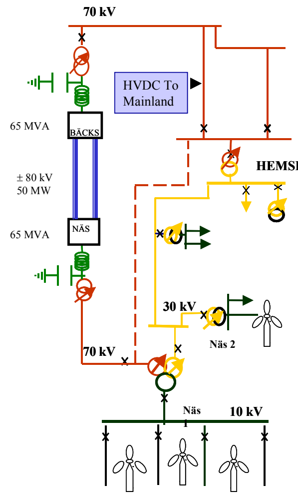

Fig 2: Simplified Gotland Network

Grid technical aspects

For a successful expansion of the wind power, the electric system must be adjusted to be able to regulate and keep an acceptable voltage quality. In relation with the increasing expansion of the wind power production, GEAB has co-operated with Vattenfall to ensure a safe supply with good voltage quality. The work has given rise to many new ways of looking at the network problems such as short circuit currents, flicker and power flows, among others. In order to solve these problems, some new methods have been developed, some of which have been published in conferences. The essential aspects to study are:

- **Flicker**
- **Transient phenomena** where faults have been dominating. The study of fault events have shown that the selective plans must be re-worked in the case of large proportions of wind power production with asynchronous generators.
- **Stability** in the system with voltage control equipments.
- **Power flows**, reactive power demands, as well as voltage levels in the system.
- Calculation of **losses** in the system with wind power generation. A method to obtain accurate estimations of losses, which later on is used for economical evaluations.
- Instantaneous frequency control with production sources such as gas turbines, but also diesel power plants and gas turbines.
- **Harmonics**

Flicker

Flicker is the perturbation of the human eye produced on the lighting by voltage variations. This can be a consequence of variable electrical loads and generations.

Conventional windmills have different way for emission of flicker. One ‘slow’ that is due to wind gusts. Repeated starts and connections and disconnections of capacitors are a source of ‘fast’ flicker. But most of the flicker from wind turbines comes from the so-called 3P effect, which originates power and voltage fluctuation at the blade-tower passing frequency, which gives rise to power fluctuations around, typically, 1-2 Hz.

The most typical frequencies of the voltage fluctuations generated by conventional wind turbines are around 1 and 8Hz, which are, casually, those for which the human eye is most sensitive.

There are a number of standards and recommendations that set limits for allowed flicker levels. However, these are often obtained from statistics and assumptions and do not guarantee disturbance free voltage. GEAB has not used the IEC norm for Flicker (Pst Plt…) during planning for installations of wind power. Instead, the amplitude of the power fluctuation for different frequencies and limits for the different voltage fluctuation were used. This method is safer and gives more information than the statistic value that IEC use.

An extensive simulation work was carried out to evaluate flicker levels before and after HVDC-light installation, and to develop a flicker controller that reduces the flicker specially in the range of 1-3 Hz. GEAB has noticed that several windmills can go in to “synchronous” operation, during specific conditions that depend on the grid. When we have this flicker controller that phenomena disappear and we cannot note this “synchronous” operation.

Transient phenomena

The studies have shown that a very important aspect is the asynchronous generators behaviour during faults in the grid. The sub-transient current increases with more asynchronous generators. If the fault is longer than aprox. 200 ms, the generators take reactive power from the grid, the voltage dip in the coupling point be bigger and the fault current thought the fault, becomes lower than without wind power. If the grid is protected with over current relay, the selective plans must take care about these phenomena.

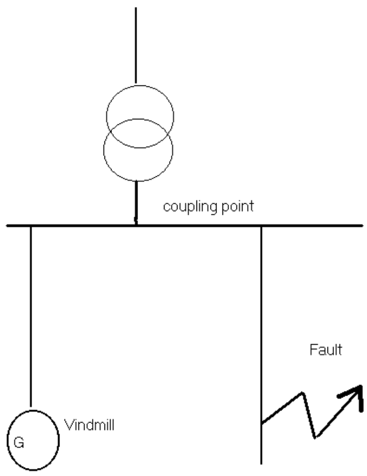

Fig 3.

We have to calculate the sub-transient fault current and also calculate the fault current in longer term for have right settings for the relay protection. It is quite complicated to obtain the different fault conditions and so far GEAB, with help from Vattenfall, has used computer models for dynamic studies, SIMPOW.

The studies and measurements have shown that the normal synchronous generator controls the voltage too slow for avoiding these phenomena, that begins to be a problem when the installed asynchronous generators rated power in total is around 1/10 of the short circuit power in the coupling point. That was the reason for GEAB to launch the HVDC-Light project. On Gotland it is more complicated to deal with the transient phenomena due to the response from the HVDC-Link to the mainland, that has quite different behaviour from HVDC-Light and also a normal synchronous generator. All this together produces an impact on the voltage dip during faults. It is important that the voltage dip does not disturb the customer’s voltage, or at last not more than they can accept.

Validations

One goal for GEAB is to maintain voltage quality for the customer after a big expansion with wind power. Therefore, GEAB has chosen four fault cases to be simulated in computer-models with the whole system representation. These cases the simulations compares with a system model without wind power.
The first fault case was Garda: In that case it was possible to perform a real three-phase fault, by closing a 10 kV breaker to simulate a solid three-phase short circuit. When we did that, we took measurements in voltage in 10 different points.
The sequence was only to close the breaker and let the over current protection trip the breaker again. The fault time was not longer than 50 ms, but it showed the response from different equipment. The power responses from some windmills, the synchronous generators, HVDC link and, of course, from HVDC-Light, were measured.

The synchronous generators are only showing the physical response and not much from the controllers due to the short fault-time. The same happens with the wind power but we can notice that the trend is similar to the computer simulations. HVDC-Light voltage-control is slower than the simulations. The reason was that the gain in the voltage controller was set on a lower value on the site, in order to get a more stable and safe operation.
Although the test worked well, the voltage dip was bigger in most of the places than the simulations showed. Continued work goes on to optimize the HVDC-light voltage control, aiming to achieve same or better results than the computer simulations.

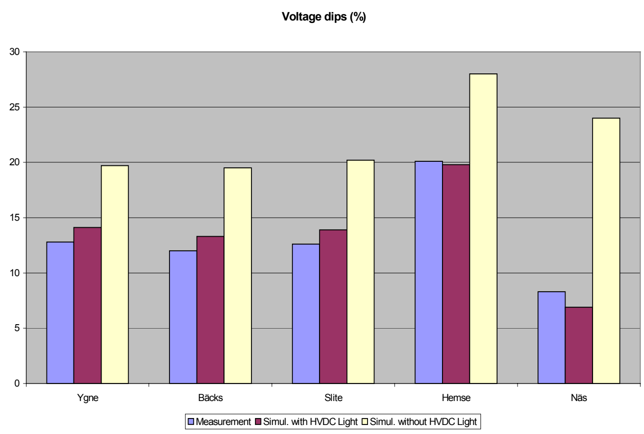

Table 1
Result from the test with short circuit in Garda

Power flows

As it is known, the wind power production depends strongly on the wind speed. On Gotland power variations around 50% in 10 minutes have been recorded. This variation produces voltage variations in the system that can affect the quality of the supply to the costumer. To control the voltage by tap changers can be difficult and also affects the maintenance cost for the transformers. To disconnect lines with only wind power production when stability problems exist is not an optimal solution either. Capacitor on-off switching is possible, but affects the voltage quality considerably. The most convenment method for solving voltage control problem with wind power is to use dynamic voltage control. This can be achieved by power electronics, such as SVC, together with intelligent controlling algorithms. The solution on Gotland has been the HVDC-Light.
There we can optimise the power flow against low losses and voltage level. An algorithm was designed for real time calculation and management of the reactive power set point in functions of the system loads and productions that is given at regular periods of time by the SCADA system. The algorithm using these data , calculates a reactive power set point for the HVDC-Light station every, aprox, 5 minutes. The time constants and gains for this slow voltage control must be coordinated with the tap changer controllers and synchronous machines voltage controllers, to avoid interaction and bad system performance. The interaction between dynamic voltage controllers in tap changer, synchronous machines, power electronics as SVC and other types of voltage control devices in system with large wind power penetration is an aspect that must be careful studied when setting control parameters since it determines the system voltage stability. The algorithm mentioned before is also used for real time calculation of active power set point in the HVDC-Light stations in functions of the system loads and productions, given by SCADA system. The main criteria are the total loss reduction, although operation limits as line maximum current etc. are considered.

Technical responsibility

The ownership for wind power is quite different for each case. Some consist on shareholders and some is private. There are also small and big companies that have done investment in wind power. On Gotland, most are independent ownerships.

GEAB as grid operator has the responsibility of the voltage quality to the costumers, and even the producers is a grid costumer.

Even when the wind power has such an impact on the power quality, GEAB has to handle this responsibility without being the owner to the plants. That is what GEAB set up technical requirements in the connection points. These requirements are defined in terms of current or power. There are also some function requirements as protection and dynamic functions. The windmills owners have the responsibility to present correct data and also follow the requirements set in a contract for grid connection. The ideas have come from influences from U.S. but mostly from U.K and the G59 guideline. These ideas have been accepted in the Swedish guidelines, AMP, for connecting small productions plants. When this method is used, the difficulty is to get definitions for all kinds of phenomena. AMP is based on IEC standards, that is not used on Gotland because this was not enough for all types of windmills. To use these methods the grid operator must have some information about the new plants technical construction and behaviour in different situations. Next step is to put up requirements for voltage control for the plants, to help up the stability. GEAB sees the demand for numerical models as a necessary requirement, that could be a condotion for connecting windpower parks to the Gotland grid

Future works

Due to the fact that there are more wind power installations to be connected on the electrical system, GEAB limits the maximum power to around 250 MW, as long as the technical aspects can be solved. There is a demand for wind power connections of more than 300 MW.
This situation means that the HVDC link to mainland has to manage frequency control with both directions of the power flow.

In 2002 Vattenfall is going to modify the HVDC link to the mainland in order to make it possible to change the power direction with continuous frequency control. The reason for this is to make it is possible to change the power direction without interrupting the power transmission or trip the production units, when the production exceeds the load. Today, with 80 MW wind power it can happen around 40 hours in a year. In 2003 with 150 MW wind power installed these can be around 500 hours in a year, and it will be necessary to automatically change power direction.

Other future works are to follow the development of technical solutions for wind power generations. The intension is to find relevant technical requirements for the connection, and the best solution for the system.

Finally, selective plans, relay protections and voltage control are important issues to continuously investigate as long the wind power installation still increases.

Conclusions

In this paper we have tried to go through the main difficulties that GEAB faced during the development of the wind power on Gotland. These experiences can be in common with other grid system. In summary the main issues are:

- Voltage stability with Transient aspects, Power flows and reactive power demands and co ordinations of voltage control in the system
- Fault situations and relay protections functions as well as the selective plans

In a deregulated electrical market it is important to clarify the responsibilities between the grid operator and the producers. That must be done so it is possible to avoid the difficulties.

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