

# **VOLTAGE AND POWER QUALITY CONTROL IN WIND POWER APPLICATIONS BY MEANS OF DYNAMIC COMPENSATION.**

by

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## **ABSTRACT**

Wind power, as a rule, does not contribute to voltage regulation in grids. Also, wind power very often is a source of voltage fluctuations and flicker. Furthermore, care must be taken to upkeep availability of networks more or less dependent on wind power by preventing the voltage from collapsing in conjunction with faults occurring in the grid.

The paper treats the above characteristics of AC grids powered by asynchronous wind generation as well as proposes measures for safeguarding of acceptable power quality and availability of the said grids. The measures proposed are based on dynamic compensation of reactive power, by means of thyristor as well as IGBT (Insulated Gate Bipolar Transistor) technology.

## **1. INTRODUCTION**

After decades of deliberations, wind power is starting to play more than just a symbolic role in an increasing number of countries' energy balances. Worldwide, some 10000 MW of wind power is in operation today. It is expected that by the end of 2002, this figure will have increased to 20000 MW.

One example: ten years ago wind power was but of marginal importance in Germany. Today, with more than 3000 MW in operation, the country is Europe's most important user of wind power. In France, up to 500 MW are expected to be in operation by the year 2005.

In Denmark, more than 1000 MW of wind power is now contributing about 5% of the country's electric energy balance. By the year 2005, there will be 1500 MW in operation. In a long perspective, there is political consensus that about half of the country's power balance is to be based on wind.

### **Installations fast emerging**

Now emerging are sea based wind power farms, where large amounts of wind power generation (typically tens of MW up to more than a hundred) is located out in the sea and where the power is landed through powerful underwater cables. The first wind power farm off the Danish coast, rated 150 MW, is to be commissioned in 2002. AC transmission will turn out to be an economically and technically attractive option in many cases, and dynamic reactive power compensation will then be a natural part of the scheme.

The dominating kind of wind power generators are asynchronous, this since they are robust and cost effective. Induction generators, however, do not contribute to regulation of grid voltage nor frequency, and they are substantial absorbers of reactive power. Ideally, they need to be connected to very stiff grids in order not to influence power quality in a detrimental way. This is not the case in reality, however. Quite on the contrary, wind power is usually connected far out in the grid, on subtransmission or distribution levels, i.e in the majority of cases on 10-30 kV, and rarely above 60 kV, and where the grid was not originally designed to transfer power from the system extremities back into the grid.

### Voltage control: a growing concern

Often, voltage regulation problems arise as a consequence of grids being made dependent on wind power, a matter of growing concern as wind power gets more important in the power balance. The problem is aggravated as traditional primary power such as thermal generation gets lower priority in the power supply balance, which is often the case due to political and environmental considerations.

To a certain degree, voltage control problems caused by deficit of reactive power in the grid can be, and is, remedied by installation of fixed or mechanically switched shunt capacitors. This will not help on voltage fluctuations, however, caused by varying output of wind generators. Regular voltage flicker is part of the picture, as well, caused by such phenomena as turbulent wind impact and so-called tower shadow effects. On top of this comes concerns for voltage collapses due to grid faults, as well as for fast appearing overvoltages associated with sudden islanding of wind power fed parts of distribution grids containing shunt capacitors for reactive power support.

## 2. SOME BASIC MECHANISMS

Distribution networks (and indeed also in some cases, subtransmission networks) receiving infeed from wind power have two distinct characteristics, both influencing voltage stability in the network in question: number one: resistance is usually a significant part of the line impedance, and number two: the network was usually not designed originally to receive and carry this power from wind generation (Fig.1).

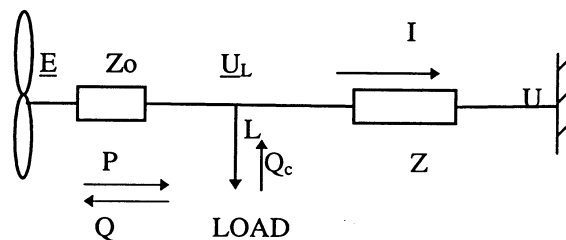


Fig. 1: Wind power infeed into radial feeder network.

The situation is aggravated by the fact that the majority of wind farms are based on asynchronous generation, consuming reactive power instead of contributing, as in the case of the more common, synchronous generation. Furthermore, the consumption of reactive power of asynchronous wind generators fluctuates, periodically as well as stochastically, which imposes still more disturbance on the grid voltage.

The relationship between voltage gradient and the flow of active and reactive power on a radial distribution feeder can be expressed as follows:

$$\Delta U = (RP - XQ) / U \quad (1)$$

Here,  $\Delta V$  is the voltage gradient over the feeder due to the infeed of active power  $P$  and consumption of reactive power  $Q$  of the wind mill.  $R$  and  $X$  are feeder resistance and reactance, respectively.

The reactive power consumption of an induction generator is a function of its loading and increases as the active power output increases. The power factor at rated load is usually in the range of 0,85-0,90, which means that the consumption of reactive power is typically about half of the active power generation.

The reactive power consumption corresponding to no load conditions usually is compensated for by means of fixed capacitors placed at the wind power plant. Any reactive power consumption in excess of that must be compensated by other means.

The simple expression (1) shows that the impact of the wind mill on the feeder voltage will be a rise or a drop along the feeder, depending on the X/R ratio. If P and Q were constant, the voltage gradient would be constant, as well, and could be compensated by means of fixed reactive power compensation. To some extent, as mentioned above, this is done, to achieve a no load power factor at the wind power plant usually between P.F.=0,95 and P.F.=1.

However, the active power as well as reactive power flow due to the wind power plant in reality also contains fluctuating components, giving rise to corresponding fluctuations of the feeder voltage. This is detrimental to power quality in the grid and needs to be remedied. This is where dynamic compensation comes in (SVC or Static Var Compensation, and SVC Light (VSC based)).

There are several types of fluctuations, differing in their impact on voltage quality as well as in their physical origin:

- Tower shadow effect (periodic,  $f \approx 1-2$  Hz).
- Wind turbulence (stochastic, average frequency  $f < 0,1$  Hz).
- Switching of windmills (single events per hour).

These phenomena, plus additionally others such as wind vertical gradients, contribute to voltage fluctuations or flicker, as illustrated in the IEC flicker curve, Fig. 2. According to the curve, a maximum of 3% voltage variations is allowed for a periodicity of one minute. For more frequently occurring variations, the permitted value decreases to below 0,3% for fast variations (flicker).

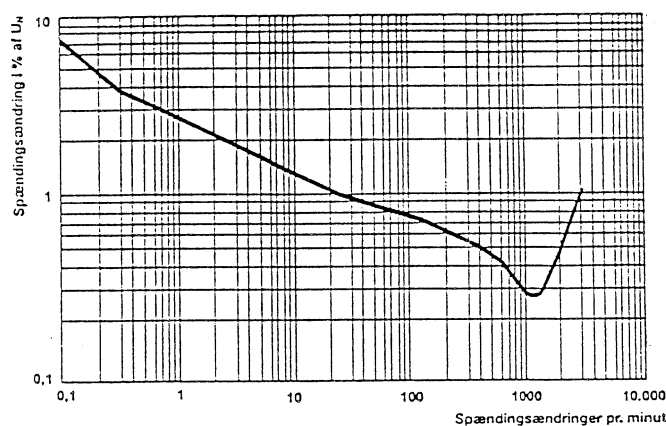


Fig. 2: Flicker threshold curve.

The tower shadow effect is caused by the periodical passing by of the wind turbine blades past the wind mill tower, twice each rotational cycle for two blade turbines, and three times a cycle for three blade turbines. This gives a dip in the mechanical torque at each passing, which is transferred to the generator shaft and subsequently felt as a dip in the output voltage. Due to the nature of this phenomenon, it is periodical and of a frequency usually in the order of magnitude of a couple of Hz.

Tower shadow effect tends to be aggravated in wind power farms consisting of several wind mills due to a tendency of the wind mills to operate in synchronism with each other, particularly in cases where the fault level of the grid is weak.

Voltage fluctuations caused by wind turbulence, as indicated by the expression, are due to stochastic as well as gusty impact of the wind on the turbine, which is transferred to the generator shaft. It is perceived in the grid as very low frequency variations in the voltage (order of magnitude 0,01 Hz).

The impact of wind turbulence on the mechanical input to the turbine is quite heavy, as the wind power transferred to the turbine is proportional to the cube of the wind velocity,

$$P_{in} = k v_{wind}^3 \quad (2)$$

Here, the coefficient k is dependant of the characteristics of the wind turbine as well as of air density [1].

As seen in (2), any fluctuating component in the wind impact will be reflected in an amplified way in the mechanical power transferred to the turbine shaft, and from there on to the output of the generator.

Windmill switching, finally, gives rise to voltage dips in the grid each time it happens. For wind mills of a certain rating, typically 0,5 MW or bigger feeding into distribution grids, its effect on the grid may be quite significant. Furthermore, as switching of wind mills may occur relatively frequently, i.e. up to several times an hour in grids heavily dependant of wind power, it may constitute a nuisance calling for effective counter-measures in order to upkeep voltage quality in the grid.

A typical illustration of wind speed and output active power as functions of time is given in Fig. 3.

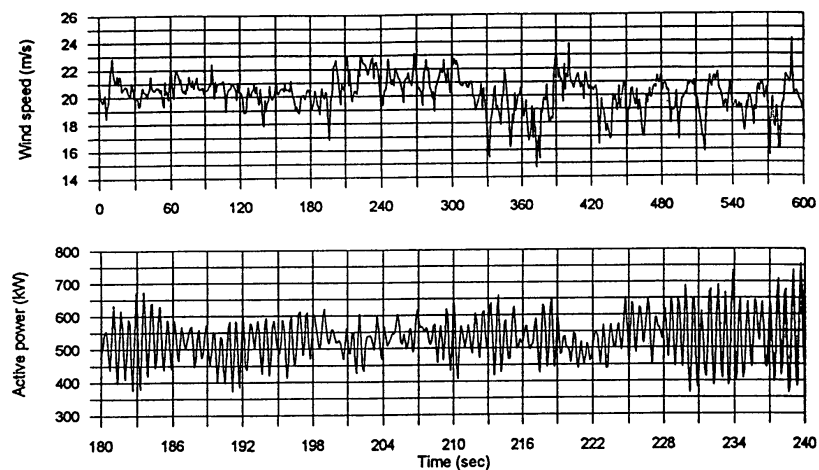


Fig. 3: Wind speed and output power fluctuations.

### 3. GRID IMPACT

The use of asynchronous generation for wind power applications is attractive due to the robustness and in a relative sense low cost of this type of devices. With this kind of generation, however, fluctuations in mechanical input to the turbine are transmitted over the turbine shaft to the generator and subsequently appear as power fluctuations at the output. Why this is so can be understood by examining of the characteristics of the asynchronous (induction) machine. By running the machine at over-synchronous speed, i.e. with a negative slip, it acquires a generator character, with the wind turbine acting as the prime mover and the electrical counter torque  $M_{el}$  set up in the stator connected to the grid at the voltage U:

$$M_{el} = kRU^2 s / (R^2 + X^2s^2) \quad (3)$$

Here,  $s$  denotes the over-synchronous slip, and  $R$  and  $X$  denote rotor impedance. As can be seen, the induced torque, and thereby also the power, is a strong function of the machine's slip, i.e. the relationship between stator and rotor frequency. The stator frequency is locked to the grid frequency, i.e. 50 Hz or 60 Hz. The rotor frequency is given by the wind impact, and consequently,  $s$  becomes a function of the wind speed, and, as per (3), so does  $M_{el}$ .

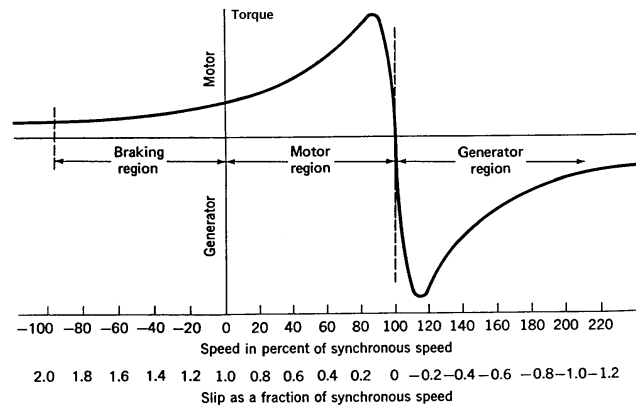


Fig. 4: Induction generator characteristics.

The characteristic shape of the torque to slip curve of an induction generator can be seen in Fig.4. Additionally, as is evident from (3), the curve shape is strongly dependant of the grid voltage to which the generator is connected. As will be treated later, this is of importance for the dynamic behaviour of wind power plants.

#### Impact on power quality

As can be expected, the severity of impact on power quality from wind power operation is dependant on the strenght, i.e. the fault level of the grid to which a wind mill or indeed a whole wind farm is connected. There are several rules of thumb quoted in literature aiding in the assessment of whether wind power plants to be connected to grids can be expected to cause detriment to power quality.

As far as the impact from switching of wind power plants is concerned, the following applies [3]:

$$S_N \leq S_{SC} / 50 \tag{4}$$

Here,  $S_N$  denotes the rated power of the wind power plant.  $S_{SC}$  is the short circuit level of the grid. The expression indicates that if the rated power of the wind power plant exceeds 2% of the fault level of the grid, measures should be taken to minimize the impact on power quality of the grid caused by switching of wind power plants.

In cases of wind power plants with overall ratings exceeding tens of MVA (an increasingly common case, in fact), it can be seen from (4) that even with points of common coupling located at subtransmission level (grid voltages 50 kV – 150 kV), dynamic compensation of reactive power will be required in many cases, in order to avoid unacceptable voltage fluctuations in conjunction with switching of the wind power plant.

In a more general sense, the amount of voltage fluctuations or flicker that can be tolerated without applying of countermeasures is dependant on the periodicity of the same. The relationship is governed by the flicker threshold curve shown in Fig. 2 above. As can be seen, in the case of flicker caused by tower shadow effect, the inflicted amplitude of voltage fluctuations should not be allowed to exceed 0,5%. If any higher, countermeasures in the way of dynamic compensation (SVC, SVC Light) should be applied.

An estimate of the amount of flicker to be expected from a wind power farm can be done by means of the following expression:

$$P_{lt} = \sqrt{n} c S_N / S_{SC} \quad (5)$$

Here,  $P_{lt}$  denotes the long term flicker level, while  $n$  is the number of (identical) wind mills in the wind farm in question and  $c$  is a flicker coefficient characteristic to each particular wind mill.

The coefficient  $c$  increases with wind velocity and can reach values up to 60 for individual wind mills [2,3]. In cases of clusters of wind mills connected to the same point in the grid,  $c$  is reduced in proportion to the number of mills in the cluster [3].

The long term flicker level should be  $P_{lt}(95) \leq 1$ , measured over a week. To achieve this,  $P_{st}(99) \leq 0,35$  (short term flicker level) from each individual wind mill should not be exceeded [4].

### **Dynamic fault mitigation**

The usefulness of dynamic compensation for mitigation of voltage fluctuations caused by the utilization of wind power has been mentioned in this paper. Other essential benefits of this approach are encountered in conjunction with fault situations in the grid, where SVC helps to preserve or restore dynamic voltage stability of the system. There are two cases particularly worth highlighting in this context, both intimately linked to the use of wind power: fast arising overvoltages caused by sudden islanding, and potential voltage collapses due to cumulating deficit of reactive power.

### **Sudden islanding**

If a wind powered section of a network is isolated ("islanded") from the rest of the grid, the wind mills will continue to produce active power, causing unacceptable values of voltage and / or frequency. In such a case, the wind mills are to brake and trip automatically. This, however, cannot happen instantaneously. Consequently, until tripping has been performed, there is an overvoltage danger [5].

Immediately following upon the occurrence of the islanding condition, the system voltage will rise so as to create a balance between the reactive power production in the grid and the consumption of reactive power of the wind mill(s). The time it takes to reach this balance depends on the electric time constants of the generator(s), i.e. a few cycles.

The worst possible case is when there is a combination of maximum wind power production and a minimum of load in the islanded network, as well as fixed reactive power compensation corresponding to full compensation of the wind mill(s) at rated output power.

To prevent unacceptable overvoltages, it is essential that any production of reactive power in the network is very quickly absorbed or interrupted. This can only be achieved by means of dynamic compensation, i.e. SVC.

### **Voltage collapse**

If there is a fault somewhere in the grid causing depression of the system voltage, the slip of connected windmills will increase according to expression (3). With increasing slip, the stator current and thereby reactive power consumption of the windmills will increase. This accumulating deficit of reactive power in the grid will cause additional voltage depression, and so on.

If the system voltage decreases to such an extent that the corresponding pullout torque of the windmill generators falls below the mechanical infeed torque (Fig. 4), the windmill(s) will start to accelerate, until

they are tripped. In the meantime, voltage collapse may occur due to excessive consumption of reactive power.

To prevent voltage collapse from occurring, fast support of reactive power is required. This can readily be achieved by means of a properly sized and located SVC. This SVC can be rated to advantage for a high dynamic yield during a short time and a lower yield for steady-state operation, a concept which will prove very cost-effective.

#### 4. DYNAMIC COMPENSATION: SOME SALIENT FEATURES

Two kinds of dynamic compensation of reactive power have been mentioned in this paper: SVC (Static Var Compensator) and SVC Light. The former type is based on thyristor controlled reactors and thyristor switched capacitors, whereas the latter kind is VSC (Voltage Source Converter) based. As will be commented upon, both types have their particular merits and applications in conjunction with wind power fed AC grids, and both will be highlighted below.

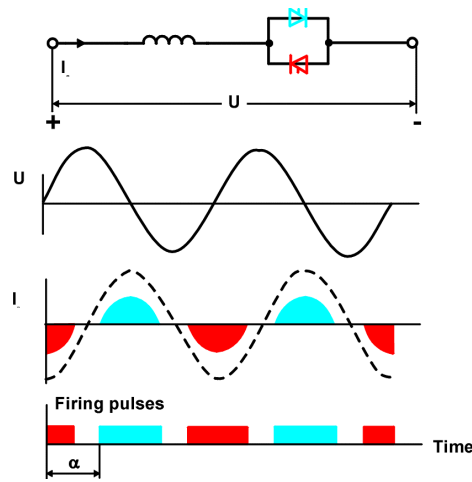


Fig. 5a: Operating principle of TCR.

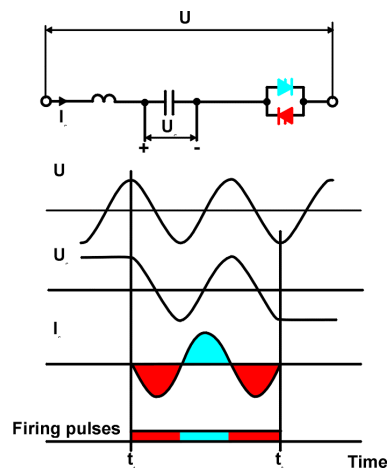


Fig. 5b: Operating principle of TSC.

Basic diagrams of one phase of a thyristor-controlled reactor (TCR) and a thyristor-switched capacitor (TSC) are shown in Fig. 5a and 5b. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated.

A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor which also serves to de-tune the circuit to avoid parallel resonance with the network. The thyristor switch acts to connect or disconnect the capacitor bank for an integral number of half-cycles of the applied voltage. The TSC is not phase controlled, which means it does not generate any harmonic distortion.

A complete SVC based on TCR and TSC may be designed in a variety of ways, to satisfy a number of criteria and requirements in its operation in the grid. Two very common design types, both having each their specific merits, are shown in Fig. 6a and 6b.

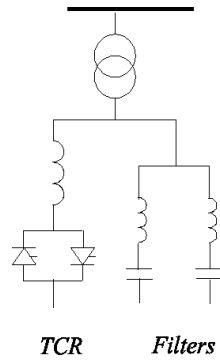


Fig. 6a: TCR / FC configuration.

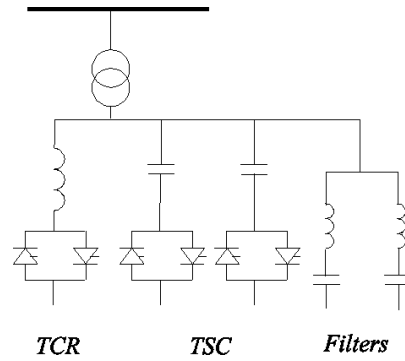


Fig. 6b: TCR / TSC configuration

### SVC characteristics

A typical terminal voltage versus output current of an SVC is shown in Fig. 7. Usually, the terminal voltage is allowed to vary in proportion to the compensating current, in accordance to a set slope.

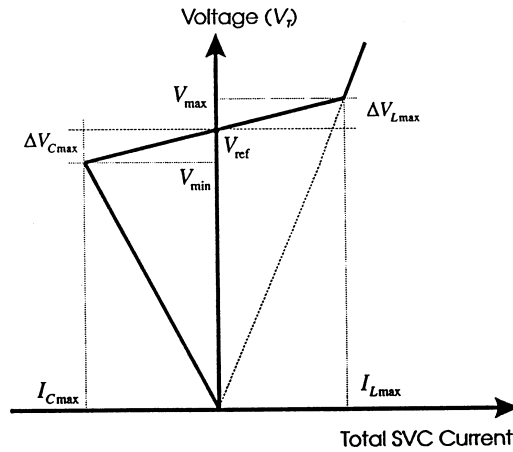


Fig. 7: V-I characteristics of SVC

The voltage at which the SVC neither generates nor absorbs reactive power is the reference voltage  $V_{ref}$ . This reference voltage can be adjusted within some certain range. The slope of the characteristic represents a change in voltage with the compensator current and can therefore be seen as a slope reactance  $X_{SL}$ . The SVC response to a voltage variation will then be given by

$$V_T = V_{ref} + X_{SL} I_{SVC} \quad (6)$$

The SVC of TCR / TSC type is very useful as a means for dynamic voltage control in a number of situations such as mitigation of voltage fluctuations which are not too rapid and preventing of voltage collapses in conjunction with grid faults as discussed above. Its dynamic response is limited by the maximum switching frequency of ordinary grid commutated power thyristors, i.e. 100 Hz.

### SVC control

The main objective of the control system is to determine the SVC susceptance needed in the point of connection to the power system, in order to keep the system voltage close to some desired value, cfm. eq. (6). This function is realised by measuring the system voltage and comparing it with the set (reference) value. In case of a discrepancy between the two values, the controller orders changes in the susceptance until equilibrium is attained.



The controller operation results in a susceptance order from the voltage regulator which is converted into firing orders for each thyristor. The overall active SVC susceptance is given by the sum of susceptances of the harmonic filters, the continuously controllable TCR, and the TSC if switched into operation. The control system also includes supervision of currents and voltages in different branches. In case of need, protective actions are taken.

### **Thyristor valves**

The thyristor valves consist of single-phase assemblies (Fig. 8). The thyristors are electrically fired. The energy for firing is taken from snubber circuits, also being part of the valve assembly. The order for firing the thyristors is communicated via optical light guides from the valve control unit located at ground potential.

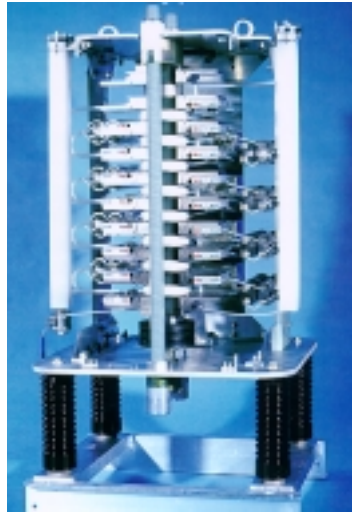


Fig. 8: Thyristor valve of BCT design.

Between thyristors, heat sinks are located. The heat sinks are connected to a water piping system. The cooling media is a low conductivity mixture of water and glycol. The TCR and TSC valves each comprise a number of thyristors in series, to obtain the voltage blocking capability needed for the valves.

### **Bi-Directional Control Thyristors**

Of course, high power thyristors are normally able to conduct in one direction only. This is no serious limitation in most applications of the technology. In the case of SVC, however, thyristors conducting in both directions of the current cycle would definitely offer possibilities for savings in costs as well as space. This has now become a reality. In the most recent SVCs supplied, the thyristor valves are equipped with so-called Bi-Directional Control Thyristors (BCT). In such devices, two thyristors are actually integrated into one wafer with separate gate contacts.

The two component thyristors in the BCT function completely independently of each other under static and dynamic operating conditions. Each component thyristor in the BCT has a performance equal to that of a separate conventional device of the same current carrying capability.

The valves comprise only one thyristor stack in each phase instead of two, which of course enables considerable compacting of the valve design.

### **SVC Light**

With the advent of continuously controllable semiconductor devices capable of high power handling, voltage source converters with highly dynamic properties have become feasible far into the tens of MVA

range. With the SVC Light concept, the VSC (Voltage Source Converter) and IGBT (Insulated Gate Bipolar Transistor) technologies have been brought together to create a tool offering possibilities hitherto unseen for power quality improvement in industry and power distribution.

This opens up for completely new options of power quality control in areas so far unattainable or only partly manageable, such as active filtering and far-reaching mitigation of voltage flicker in subtransmission and distribution grids. The SVC Light technology is being implemented at present for flicker mitigation at a couple of different locations within European electric power industry.

SVC Light is a flicker mitigating device. It achieves this by attacking the root of the problem, the erratic flow of reactive power through the supply grid down into the loads. The reactive power consumption is measured, and corresponding amounts are generated in the SVC Light and injected into the system, thereby decreasing the net reactive power flow to an absolute minimum. As an immediate consequence, voltage flicker is decreased to a minimum, as well.

To parry the rapidly fluctuating consumption of reactive power of wind mills, an equally rapid compensating device is required. This is brought about with state of the art power electronics based on IGBT (Insulated gate bipolar transistor) technology. With the advent of such continuously controllable semiconductor devices capable of high power handling, VSC (Voltage Source Converters) with highly dynamic properties have become feasible far into the tens of MVA range.

### Voltage Source Converters

The function of the VSC in this context is a fully controllable voltage source matching the bus voltage in phase and frequency, and with an amplitude which can be continuously and rapidly controlled, so as to be used as the tool for reactive power control (Fig. 9).

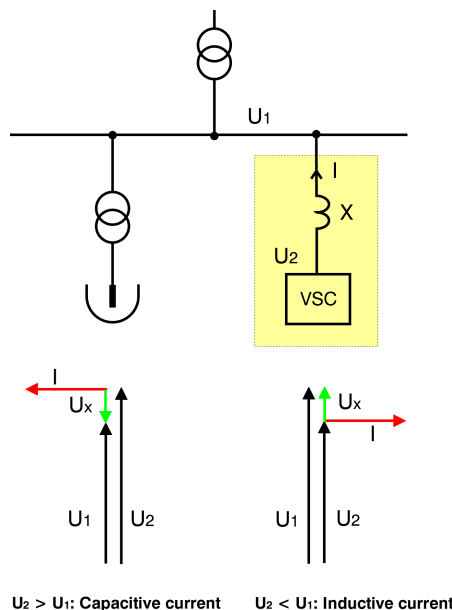


Fig. 9: VSC: a controllable voltage source.

The output of the VSC is connected to the AC system by means of a small reactor. By control of the VSC voltage ( $U_2$ ) in relation to the bus voltage ( $U_1$ ), the VSC will appear as a generator or absorber of reactive power, depending on the relationship between the voltages. To this controlled reactive power branch, an offsetting capacitor bank is usually added in parallel, enabling the overall control range of the SVC Light to be capacitive. The reactive power supplied to the network can be controlled very fast. This is done only

by changing the switching pattern in the converter slightly. The response time is limited mainly by the switching frequency and the size of the reactor.

The controllability of IGBTs also facilitates series connection of devices with safeguarded voltage sharing across each IGBT. This enables SVC Light to be directly connected to voltages in the tens of kilovolts range. Thanks to this, it becomes unnecessary to parallel converters in order to achieve the power ratings needed for wind power farms in the order of tens of MVA or larger.

### Pulse Width Modulation

The input of the Voltage Source Converter is connected to a capacitor, which is acting as a DC voltage source. At the output, the converter is creating a variable AC voltage. This is done by connecting the positive pole or the negative pole of the capacitor directly to any of the converter outputs. In converters that utilise Pulse Width Modulation (PWM), the input DC voltage is normally kept constant. Output voltages such as a sinusoidal AC voltage can be created. The amplitude, the frequency and the phase of the AC voltage can be controlled by changing the switching pattern.

In SVC Light, the VSC uses a switching frequency greater than 1 kHz. The AC voltage across the reactor at full reactive power is only a small fraction of the AC voltage, typically 15 %. This makes SVC Light close to an ideal tool for fast reactive power compensation.

### IGBT

For SVC Light the IGBT has been chosen as the most appropriate power device. IGBT allows connecting in series, thanks to low delay times for turn-on and turn-off. It has low switching losses and can thus be used at high switching frequencies. Nowadays, devices are available with both high power handling capability and high reliability, making them suitable for high power converters.

As only a very small power is needed to control the IGBT, the power needed for gate control can be taken from the main circuit. This is highly advantageous in high voltage converters, where series connecting of many devices is used. In addition to this, every IGBT position is equipped with an over-voltage monitoring system. This system makes it possible to detect if any IGBT position behaves in an unnormal way already during the delivery test. If this would happen, such devices will be exchanged.

### The converter valve

The converter topology for SVC Light is a three level configuration. In a three-level converter the output of each phase can be connected to either the positive pole, the midpoint or the negative pole of the capacitor. The DC side of the converter is floating, or in other words, insulated relative to ground. Using PWM, the converter will create a very smooth phase current, with low harmonic content. The three-level topology also gives low switching losses. This means high converter efficiency and high current capability.

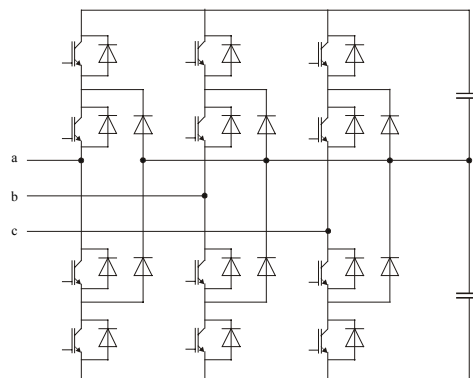


Fig. 10: 3-level converter.

The three-level converter used is a so called Neutral Point Clamped (NPC) configuration (Fig. 10). This configuration includes four IGBT valves and two diode valves in every phase leg. The DC capacitor in this case is divided into two series connected capacitors. Every IGBT / diode valve has to withstand the blocking voltage corresponding to one of the capacitors. The different valves are built by stacking the devices on top of each other (between coolers) and by applying an external pressure to the stack.



Fig. 11: SVC Light valve

The IGBT valves are water cooled, which gives a compact converter design and high current capability. Besides customer benefits, a compact design also has another advantage. This means that the loop inductance between the IGBT valves and the DC capacitors can be kept low, which is beneficial from a loss point of view. In one existing installation the valves are designed to handle approximately 1300 Arms phase current continuously and 1700 Arms at transient conditions (Fig. 11).

A typical voltage-current characteristic of an SVC Light is shown in Fig. 12. It is worth noticing that the SVC Light is capable of yielding a high reactive input to the grid more or less unimpeded by possible low grid voltages.

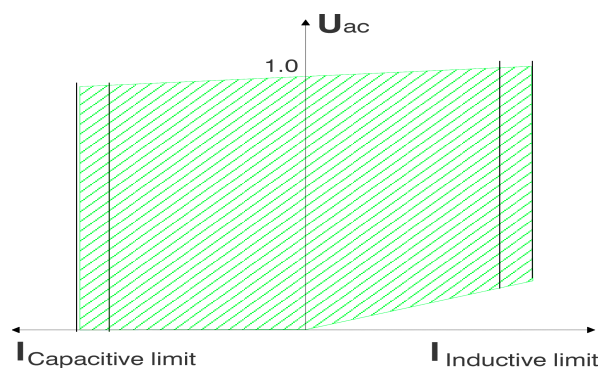


Fig. 12: SVC Light voltage/current characteristic

### 5. DYNAMIC VOLTAGE CONTROL SCHEME

As mentioned previously in this paper, if there is a fault somewhere in the grid causing depression of the system voltage, the slip of connected windmills will increase. With increasing slip, the reactive power consumption of the windmills will increase.

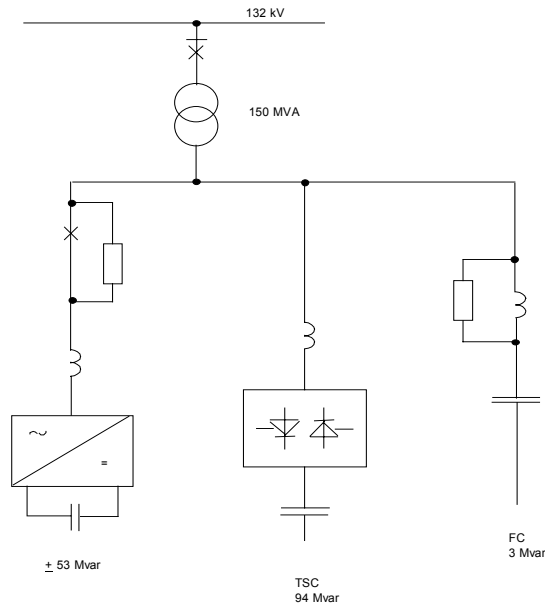


Fig. 13: Combined SVC Light and short-time rated TSC.

To prevent voltage collapse from occurring, fast support of reactive power is required. This can be achieved by means of a properly sized and located SVC. This SVC can be rated to advantage for a high dynamic yield during a short time and a lower yield for steady-state operation, a concept which will prove very cost-effective (Figure 13).

Thus, in Figure 13, as a current example, an SVC Light rated at  $-50/+56$  Mvar at 132 kV is combined with a Thyristor-Switched Capacitor (TSC) rated at 94 Mvar, giving a total output of  $-50/+150$  Mvar. The purpose of the scheme is to yield dynamic var compensation of a large sea-based wind farm. The TSC will only operate in cases of potential voltage collapse until the wind farm can be tripped or until the fault has been cleared, i.e. only for a short while, and can therefore be rated in a very economical way.

#### **Hagfors SVC Light: powerful flicker mitigation**

Uddeholm Tooling at Hagfors in mid Sweden is a steel producer based on scrap melting and refining in an electric arc furnace (EAF) rated at 31,5/37,8 MVA and a ladle furnace (LF) rated at 6/7,7 MVA. Both furnaces are fed from a 132 kV grid via an intermediate voltage of 10,5 kV (Fig. 14). The feeding grid is relatively weak, with a fault level at the P.C.C. of about 1000 MVA. This is insufficient to enable operation of the two furnaces while upkeeping reasonable power quality in the grid. An SVC Light has been installed in the plant as a flicker mitigating device [6].

The SVC Light is rated at 0 - 44 Mvar of reactive power generation, continuously variable. This dynamic range is attained by means of a VSC rated at 22 MVA in parallel with two harmonic filters, one rated at 14 Mvar existing in the plant initially and one installed as part of the SVC Light undertaking, rated at 8 Mvar. Via its phase reactors, the VSC is connected directly to the furnace bus voltage of 10,5 kV.

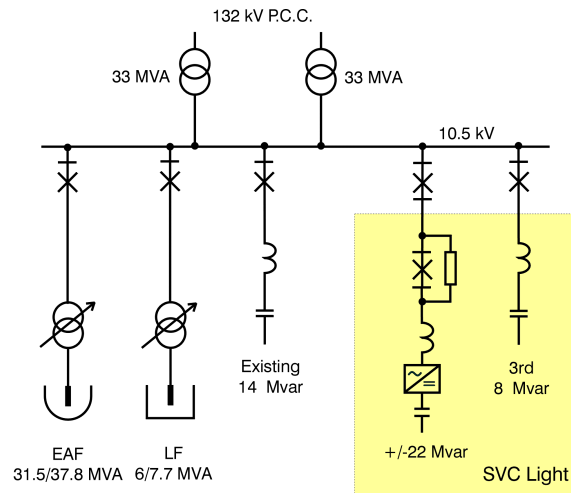


Fig. 14: Single-line diagram, Uddeholm Tooling.

The Hagfors SVC Light became operational in 1999 (Fig. 15). The residual flicker level at the 132 kV point of common coupling was aimed not to exceed  $P_{st}(95) = 1$  with the SVC Light in operation. This was based on simulations performed for the actual case. Measurements performed in the working installation have more than proved the flicker simulation results, with flicker reduction values exceeding 5,0.



Fig. 15: The Hagfors SVC Light.

## 6. CONCLUSION

Wind power is gaining rapid momentum in the world energy balance. With it, certain issues have to be addressed in order to upkeep reasonable power quality in subtransmission and distribution networks more or less dependent on wind power. Unless properly remedied, voltage fluctuations may otherwise proliferate and become a nuisance to grid users as well as operators.

Voltage stability in conjunction with faults in grids heavily dependant on wind power may furthermore be affected, unless proper preventive measures are taken. Likewise, rapidly appearing overvoltages caused by

sudden islanding of wind power generation facilities need to be prevented, lest the installations be seriously damaged.

Dynamic compensation of reactive power is an effective means of safeguarding power quality as well as voltage stability in such cases as well as in others. Such dynamic compensation can be implemented to advantage by means of thyristor-controlled reactors and thyristor-switched capacitors in parallel with the grid (SVC).

An optional way is by means of voltage source converter (VSC) based shunt compensation. Here, SVC Light combines VSC technology and IGBT (insulated gate bipolar transistor) technology to attain high dynamic response, a prerequisite for efficient flicker mitigation.

## 7. LITERATURE

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