

SVC LIGHT: A POWERFUL MEANS FOR DYNAMIC VOLTAGE AND POWER QUALITY CONTROL IN INDUSTRY AND DISTRIBUTION.

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INTRODUCTION

Modern society relies heavily upon electricity. With deregulation and privatization, electricity has become a commodity as well as a means for competition. Power quality, as a consequence, is coming into focus to an extent hitherto unseen. Disturbances emanating from any particular load will travel far, and, unless properly remedied, spread over the grid to neighbouring facilities. A traditional way to deal with the problem of poor or insufficient quality of power distribution is to reinforce the grid by building of new lines, installing new and bigger transformers, or moving the point of common coupling to a higher voltage level.

Such measures, however, are expensive and time-consuming, if they are at all permitted. A simple, straightforward and cost-effective way of power quality improvement in such cases is to install equipment especially developed for the purpose in immediate vicinity of the source(s) of disturbance. As an additional, very useful benefit, improved process economy will often be attained as well, and as a matter of fact enable the said investment to turn out a profitable measure.

With SVC Light, VSC (Voltage Source Converter) and IGBT (Insulated Gate Bipolar Transistor) technologies have been brought together to offer possibilities hitherto unseen for power quality improvement in industry and power distribution. The paper highlights the SVC Light technology as well as focusses on a couple of important applications: mitigation of arc furnace flicker, and dynamic voltage control of wind powered grids.

VOLTAGE FLICKER

An electric arc furnace is a heavy consumer of active as well as reactive power. Also, the physical process inside the furnace (electric melting) is erratic in its nature, with one or several electrodes striking electric arcs between furnace and scrap. As a consequence, the consumption especially of reactive power becomes strongly fluctuating in a stochastic manner (Figure 1).

The voltage drop caused by reactive power flowing through circuit reactances in the electrodes, electrode arms and furnace transformer therefore becomes fluctuating in an erratic way, as well. This is most clearly visualized in the flickering light of incandescent lamps fed from the polluted grid.

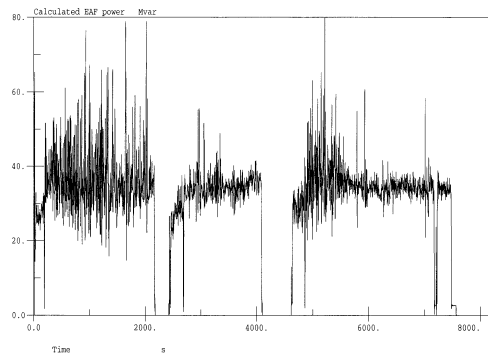


Figure 1: Reactive power consumption of an EAF.

The International Union of Electroheat (UIE) in cooperation with IEC has defined a quantity for expressing flicker severity, P_{st} . According to this terminology, $P_{st} = 1$ means that in a group of people, half can observe light flicker that the group is being exposed to.

In the case of wind power, the flow of active as well as reactive power associated with the use of asynchronous generators also contains fluctuating components which give rise to corresponding voltage fluctuations in the grid (Figure 2). Such fluctuations have several different causes:

- 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 and flicker.

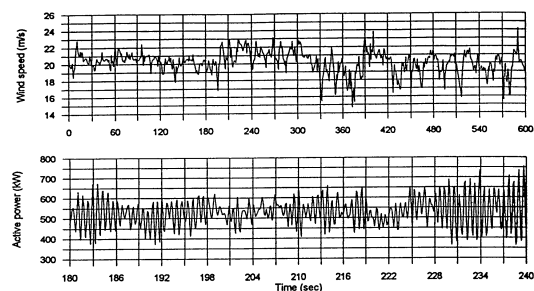


Figure 2: Wind speed and output power fluctuations.

SVC LIGHT

To parry the rapidly fluctuating consumption of reactive power, 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.

The function of the VSC 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 (Figure 3). 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. An offsetting capacitor bank is 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. The response time is limited mainly by the switching frequency and the size of the reactor.

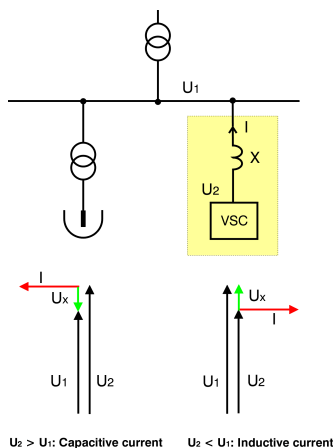


Figure 3: VSC: a controllable voltage source.

The converter valve

The converter topology for SVC Light is a three level configuration (Figure 4). 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 Pulse-Width Modulation (PWM), the converter will create a very smooth phase current, with low harmonic content.

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. This enables SVC Light to be directly connected to

voltages in the tens of kilovolts range. IGBT furthermore has low switching losses and can be used at high switching frequencies. Devices are available with both high power handling capability and high reliability, making them suitable for high power converters. It thus becomes unnecessary to parallel converters in order to attain the power ratings needed for arc furnace or wind mill compensation (typically tens of MVA).

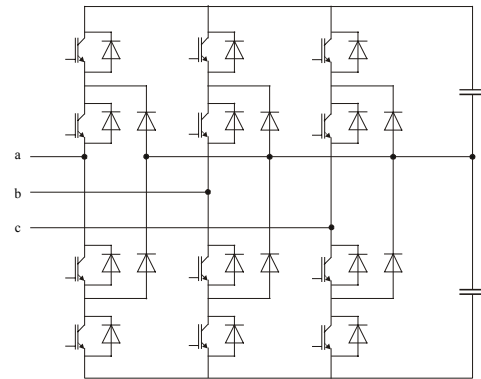


Fig. 4: Three-level converter.

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.

The three-level converter used is a Neutral Point Clamped (NPC) configuration. This configuration includes four IGBT valves and two diode valves in every phase leg. 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. Water cooling of the IGBT valves gives a compact converter design and high current capability. In one particular case the valves have been designed to handle approximately 1300 Arms phase current continuously and at transient conditions 1700 Arms (Figure 5).



Figure 5: Photograph of SVC Light valve.

Control and protection system

The control and protection system of SVC Light is based on industrial standard PC hardware (operating system Windows NT) to facilitate an open system easily integrated into existing systems and externally accessed directly if desired. The strategy of building the control and protection system based on open interfaces assures that future improvements in the fast developing field of electronics can be used. The system consists basically of three units, the Main Computer, the I/O rack, and the VCU (Valve Control Unit), Figure 6. Communication between the units is performed via industrial standard type busses.

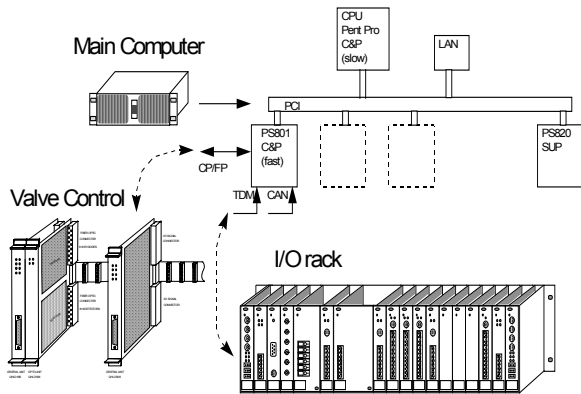


Figure 6: Control system for SVC Light.

The system is operated from an OWS (Operator Work Station), which can be a standard PC. The MMI (Man Machine Interface) is the world's most used graphic control package for Windows NT - InTouch. InTouch is a flexible software, in which customer adopted MMI can easily be designed.

UDDEHOLM TOOLING SVC LIGHT

Uddeholm Tooling at Hagfors in mid Sweden is a steel producer with its metallurgical process based on scrap melting in an electric arc furnace (EAF) and subsequent refining in a ladle furnace (LF). The EAF is rated at 31,5 MVA with a 20% overload capability, whereas the LF is rated at 6 MVA plus a 30% overload capability. Both furnaces are fed from a 132 kV grid via an intermediate voltage of 10,5 kV (Figure 7).

The feeding grid is relatively weak, with a fault level at the P.C.C. of about 1000 MVA. This is quite insufficient to enable operation of the two furnaces while upkeeping reasonable power quality in the grid.

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 filter is rated at 14 Mvar and initially existing in the plant. The other is

rated at 8 Mvar and supplied as part of the SVC Light undertaking.

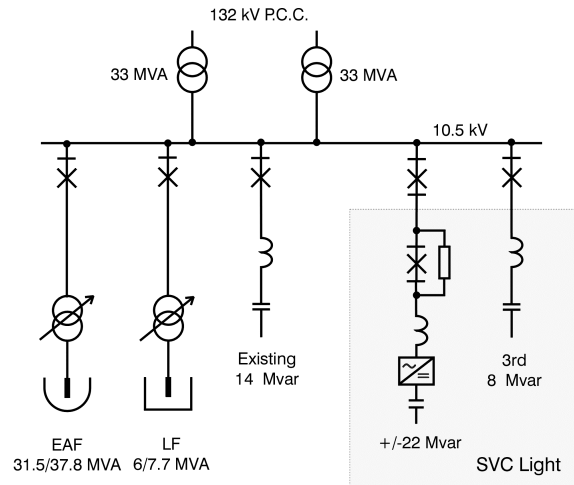


Figure 7: Single-line diagram of EAF feeding network and compensation.

Via its phase reactors, the VSC is connected to the furnace bus voltage of 10,5 kV. During energisation of the VSC, the DC capacitors are charged via charging resistors. While the DC capacitors are charged, the bypass switch is closed.

Preliminary flicker measurements

Field measurements have been performed in order to evaluate the performance of the SVC Light at Hagfors. Investigations show that the installed auxiliary current transformer in the EAF circuit is underrated, leading to saturation during bore down of the melt. This problem will be corrected, however at this stage no flicker measurements with a correct CT are available. The recordings and evaluation show flicker mitigation of 3.4 times. Mitigation is expected to increase to some 4.5 to 5.0 times when new auxiliary transformers have been installed.

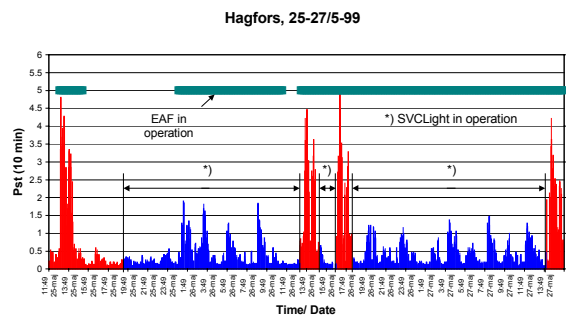


Figure 8: Flicker generation with/without SVC Light.

The flicker measurements have been performed according to the UIE/IEC method. The bar chart (Figure 8) shows flicker generation from the EAF with and

without SVC Light. The chart also shows when the furnace is in operation.

Improved furnace productivity

The dynamic voltage stabilisation at the furnace bus brought about by the SVC Light is also of benefit to process productivity and economy. This is due to the higher RMS value of the bus voltage during the process cycle, enabling a higher power yield of the furnace, and hence a shortened meltdown time for each basket of scrap. Likewise, specific energy as well as electrode consumption are decreased, which acts to decrease operating costs of the process.

The SVC Light at Hagfors was commissioned in 1999 (Figure 9).



Figure 9: Hagfors SVC Light

WIND POWER: REQUIRING VOLTAGE AND POWER QUALITY CONTROL

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. Now emerging are sea based wind power farms, where large amounts of wind power generation 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. On the

contrary, wind power is usually connected far out in the grid, at sub-transmission or distribution levels, where the grid was not originally designed to transfer power from the system extremities back into the grid.

Voltage control: of 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 primary power such as thermal generation gets lower priority in the power 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 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. This is where dynamic compensation comes in.

Plant characteristics

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.

The induced torque, and thereby also the power, is a strong function of the machine's slip, i.e. the relationship between the stator and rotor frequencies. 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. Consequently, the slip becomes a function of the wind speed, and likewise does the induced torque.

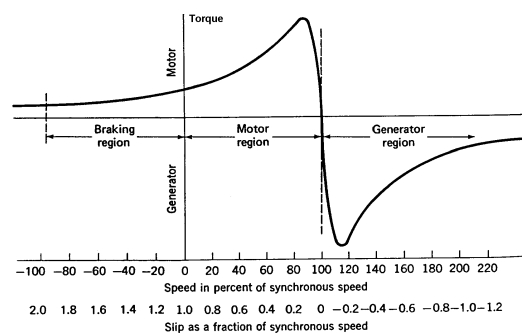


Figure 10: Induction generator characteristics.

The characteristic torque curve of an induction generator can be seen in Figure 10. Additionally, the curve shape is strongly dependant of the grid voltage to which the generator is connected. This is of importance for the dynamic behaviour of wind power plants.

Impact on power quality

The severity of impact on power quality from wind power operation is dependant on the fault level of the grid to which the wind mill or indeed wind farm is connected. There are 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. Thus, 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, 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 Figure 11. 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 by means of dynamic compensation should be applied.

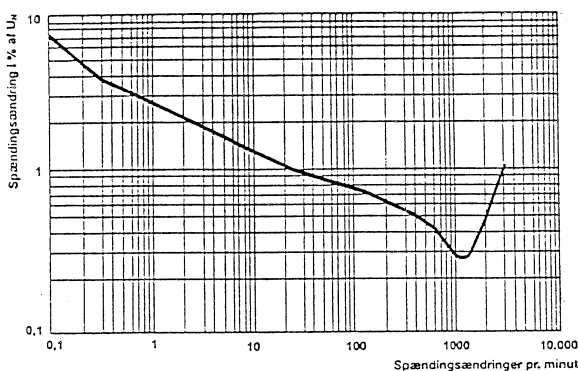


Figure 11: Flicker threshold curve.

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.

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.

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. 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 (Figure 10), the windmills 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 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 12).

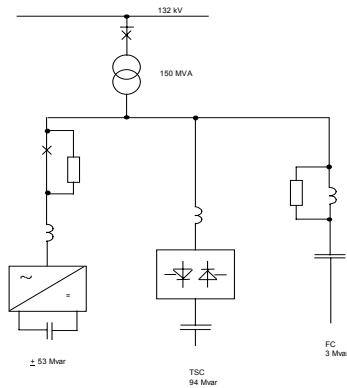


Figure 12: Combined SVC Light and short-time rated TSC.

Thus, in Figure 12, 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. A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor, Figure 13.

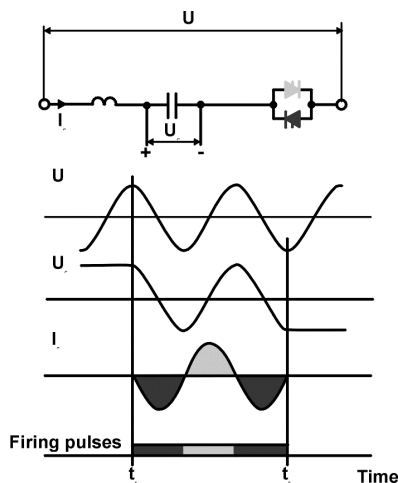


Figure 13: Operating principle of a TSC.

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.

The purpose of the scheme shown in Figure 12 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.

CONCLUSION

Voltage source converters far into the tens of MVA range based on IGBT technology are now a reality. Important applications for the technology are mitigation of voltage flicker from electric arc furnaces as well as from wind power farms connected to weak grids.

An SVC Light, i.e. IGBT based VSC equipment has been commissioned in a steel mill in Sweden. Flicker reduction close to a factor 3,5 has been measured in conjunction with the operation of an electric arc furnace, a result which is expected to improve further after planned modifications have been carried out in the plant.

Wind power is gaining rapid momentum in the world energy balance. With it, care has to be taken to keep up reasonable power quality in networks more or less dependant on wind power. Likewise, dynamic voltage stability must be safekept in conjunction with faults which can appear in the grid. SVC Light offers an effective means for achieving of this. Alternatively, a combination of SVC Light and traditional, thyristor based SVC may prove to be the most cost effective solution.

REFERENCES

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2. Grünbaum, R., 1999, "Enhancing of power quality in wind powered distribution", Power Delivery Europe-99, Madrid.