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STATIC VAR COMPENSATION FOR THE SPS ELECTRICAL NETWORK

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Abstract

The electrical installations of the SPS pulsed electrical network consist of power converters for dipoles and quadrupoles, RF cavities and the north experimental area. Large pulsing loads like these can only be connected to the 18 kV electrical network if a Static Var Compensator takes care of reactive power compensation, voltage control and harmonic filtering. This paper explains the underlying principles of static var compensation and gives an overview of the existing two saturated reactor compensators. Finally, a project description is given for the planned installation of a third Static Var Compensator for the SPS pulsed network which will be based on Thyristor Controlled Reactor technology.

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1 INTRODUCTION

A Static Var Compensator (SVC) is a device which compensates for the reactive power of the load connected to a power system. Because of its fast response it can stabilize the busbar voltage even during fast changes of the load. An SVC is usually directly connected to a medium voltage power system.

In the past, many SVCs were based on the effect of self-saturation of the iron core of a so-called saturated reactor. Since the end of the seventies, thyristor controlled SVCs have been available on the market and for a few years one has been able to observe the development of new SVC technologies based on GTO or IGBT semiconductors. The aim of this development is to improve dynamic performance, flicker control and speed of reactive power regulation as well as the reduction of losses which form a major part of the operating costs of such an installation.

This paper explains the underlying principles of static var compensation and gives an overview of the existing two saturated reactor compensators of the SPS pulsed network. Finally, a project description is given for the planned installation of a third SVC based on Thyristor Controlled Reactor (TCR) technology.

2 WHAT ARE ACTIVE AND REACTIVE POWER?

A resistor *R* connected to a three-phase a.c. voltage source will see a current which is in phase with the voltage across this resistor. If an inductance *L* or a capacitance *C* is connected to the same source, the current will be 90° lagging or leading with respect to the voltage. Real power systems represent a combination of *R*, *L* and *C*, which means that voltage and current are usually not in phase. The angle between voltage and current is called the phase angle ϕ.

Apparent power *S* is the product of voltage (*U*) and current (*I*) and has the unit volt-ampere [VA].

$$S = \sqrt{3}\ UI \qquad \text{[VA]} \ . \tag{1}$$

Like voltage and current, apparent power can also be represented in a phasor diagram as a complex quantity. The real component of this phasor is called active power and the imaginary component is the reactive power. The cosine of the angle between active and apparent power is the power factor $\cos\phi$.

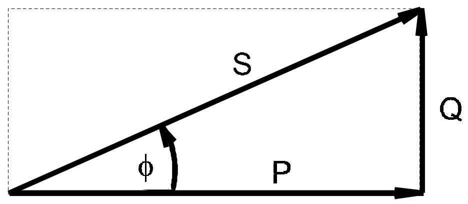

Fig. 1: Phasor diagram of active, reactive and apparent power.

Active power *P* is the product of the voltage and the in-phase (active) component of the current. The active power is measured in watts [W].

$$P = \sqrt{3}\, UI \cos\phi = S \cos\phi \qquad \text{[W]} \ . \tag{2}$$

Reactive power *Q* is the product of the voltage and the watt-less (reactive) component of the current. The unit of the reactive power is volt-ampere reactive [var]. According to IEC Publ. 27-1 the unit abbreviation ‘var’ should be written in lower-case letters, while all other power unit abbreviations are to be in capital letters.

$$Q = \sqrt{3}\, UI \sin\phi = S \sin\phi \qquad \text{[var]} \ . \tag{3}$$

Reactive power can be either positive or negative, depending on the sign of the phase angle ϕ. By definition, positive reactive power means power consumption and is characteristic for inductive loads such as power converters, reactances and motors. Negative reactive power indicates reactive power generation typical for generators or capacitor banks.

3 STATIC VAR COMPENSATORS (SVCs) IN ELECTRIC POWER SYSTEMS

3.1 Reactive power compensation

SVCs usually generate the reactive power which is consumed by the load, meaning that positive reactive power of the load is compensated for by negative reactive power of the SVC. It is desired to reduce the remaining reactive power as far as possible in order to reduce the equipment ratings and energy transmission losses.

3.2 Voltage control

A load current passing through the series impedances $R+jX$ of transmission lines, cables or transformers creates a voltage drop ΔU across this impedance, causing a voltage difference between the sending end and the receiving end of the transmission system. Without additional measures, the voltage at the receiving end is usually smaller than the voltage at the sending end. This voltage drop can be calculated approximately by applying the following equation:

$$\Delta U = U_s - U_r \bullet RI \cos \phi + XI \sin \phi \,. \tag{4}$$

From Eq. (4) it can be seen that any change in load current I will cause a change in busbar voltage. Very large cyclically varying loads, such as the SPS having a large reactive and active power swing and very short rise times of the pulse, will cause heavy disturbances of the 18 kV and 400 kV busbar voltages, making the operation of the accelerator impossible and disturbing other electrical loads connected to the power network.

Equation (4) also shows that the reactive power is an excellent means to control the voltage drop and therefore the busbar voltage. Modern SVCs are able to change their reactive power output within 100 ms, making them highly suitable for the voltage control of busbars feeding fast changing or pulsing loads such as electric arc furnaces, rolling mills or particle accelerators.

Without an SVC the 18 kV busbar of the SPS pulsed network would suffer periodic voltage variations of about 14% during each cycle of the SPS machine. An SVC reduces these variations to values smaller than 0.75%.

1.3 Harmonic filtering

Power electronic such as power converters, power supplies, converter-fed motors and the SVC itself cause a strong distortion of the sinusoidal wave shape of voltage and current. The Fourier analysis of a fundamental period reveals the presence of typical harmonic frequencies which are usually multiples of the 50 Hz fundamental frequency. The major distortion is normally caused by power converters and other power electronics which to a large extent generate 250, 350, 550, 650 Hz and HF harmonics.

In most cases, the capacitor banks of an SVC are tuned to these harmonic frequencies by adding specially adapted filter coils. Each filter has its resonance point at a certain harmonic frequency, thus representing a low-impedance path for currents of that particular frequency. As a result, these frequencies are eliminated and the busbar voltage remains undistorted and sinusoidal.

4 THE SPS PULSED NETWORK

As a general strategy at CERN, pulsing loads and stable (non-pulsing) loads are separated as far as possible to avoid disturbances of stable loads due to distortions caused by pulsing loads. For this reason, the terms *pulsing network* and *stable network* are used to characterize the type of load connected to it. Obviously, the networks themselves are not pulsing: It is only the electrical power which can pulse.

The SPS pulsed network supplies all pulsing loads associated with the SPS and the north experimental area. Because of the large amplitudes and short rise times of the pulsing power, fast acting SVCs are necessary for the operation of the SPS.

Figure 2 shows the simplified layout of the SPS pulsed network. It consists of three large 400/18 kV transformers of which transformers EHT1 and EHT3 are each connected to an SVC based on saturated reactors. For the transformer EHT2, the installation of a new a new SVC is planned and a call for tender is in preparation.

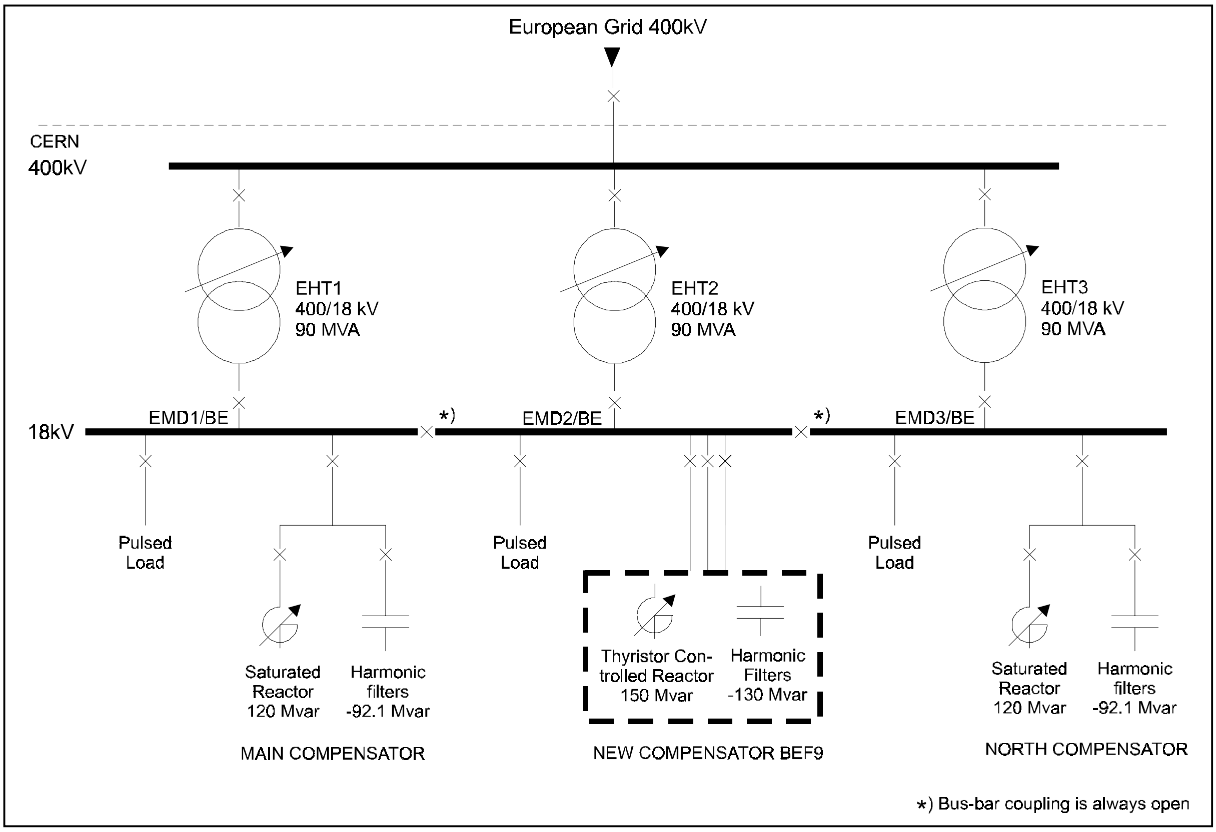

Fig. 2: Simplified layout of the SPS pulsed network.

5 THE TWO EXISITNG SATURATED REACTOR COMPENSATORS FOR SPS

Since the beginning of SPS operation, two large SVCs have been stabilizing the 18 kV busbar voltage of the SPS pulsed network. These two SVCs are of the saturated reactor type which use the linear voltage–current characteristic above the saturation knee of the iron core to stabilize the 18 kV busbar voltage. Each SVC consists of a 120 Mvar saturated reactor combined with – 92.5 Mvar of harmonic filters, tuned to the harmonic frequencies 100, 150, 250, 350, 550, 650, 850 Hz and HF.

Because of its inherent response, the saturated reactor follows the cycle of the pulsing load in order to keep the voltage variations at the 18 kV busbar as low as 0.3% (slow changes) and 0.75% (fast changes). As mentioned above, the voltage variation would be about 14% without SVC. The total harmonic distortion of the 18 kV busbar voltage is reduced from about 20% (without SVC) to 0.5% (with SVC).

Figure 3 shows a recording of the active power of EMD1/BE over one 450 GeV cycle of the SPS. One can clearly see the steep rise and fall times of the power pulse which would normally cause a pulsing voltage variation at the 18 kV busbar.

A recording of the reactive power is shown in Fig. 4. Without compensation, the pulsing reactive power would cause very strong pulsing voltage variations at the 18 kV level. The reactive power consumed by the load (2) is compensated for by the reactive power generated by the SVC (3). As a result, the remaining reactive power (1) supplied by the 400 kV network via the transformer EHT1 is very small. This remaining reactive power (1) is the function $-(K_1P^2 + K_2P)$ of the active power P in order to perfectly stabilize the 18 kV busbar voltage.

One can also see that the response time of the SVC is extremely short, enabling it to follow even steep changes in load active and reactive power.

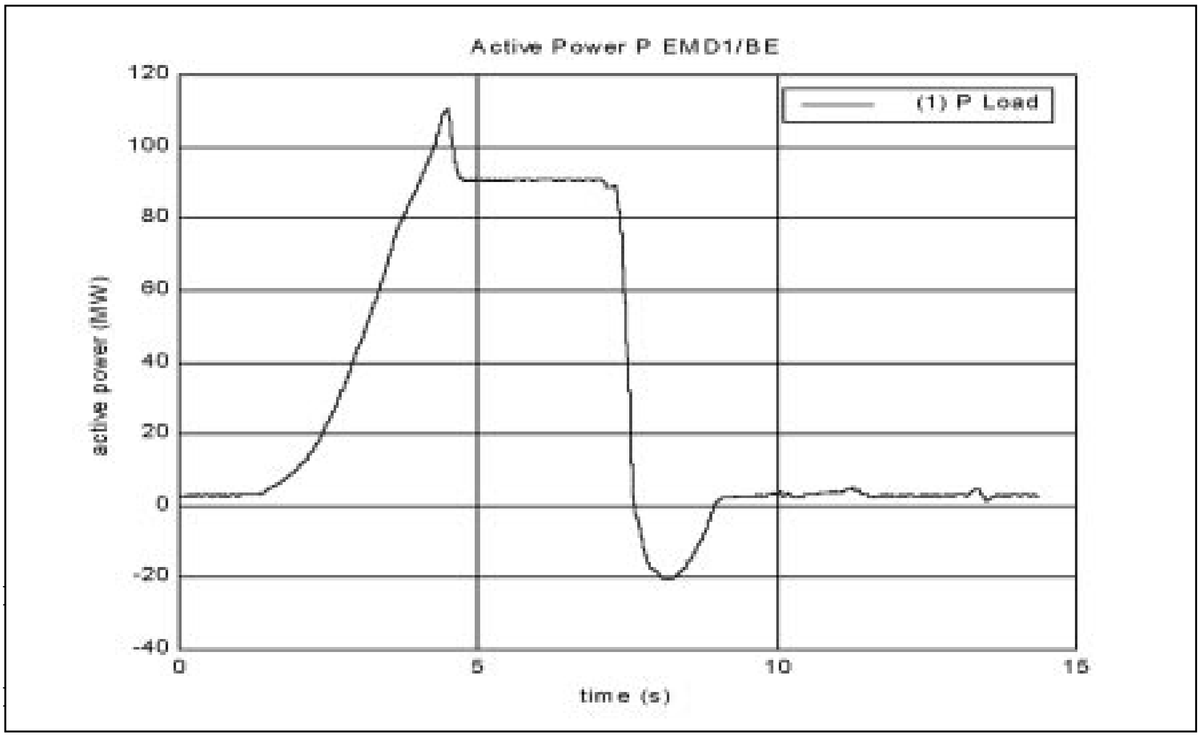

Fig. 3: Active power of the pulsing load at 450 GeV.

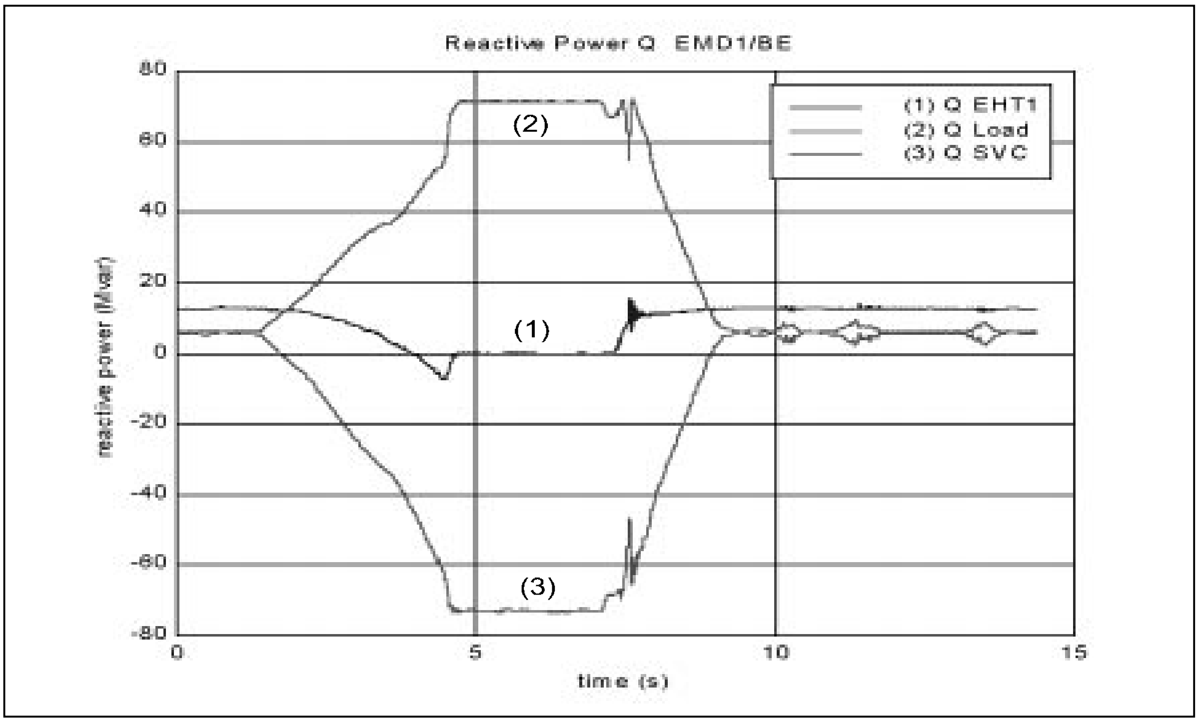

Fig. 4: Reactive power of pulsing load and SVC at 450 GeV.

6 THE NEW PROJECT OF A THIRD STATIC VAR COMPENSATOR

After 25 years of pulsed operation, both saturated reactors are now approaching the end of their lifetime and are in need of an overall renovation programme. To facilitate this renovation and to have a redundant supply group for the operation of SPS as an injector for LHC, a third SVC will be installed on the 18 kV side of the transformer EHT2/BE. To give a better understanding of the project, Fig. 5 shows a photo of a similar SVC installation: One can see the Thyristor Controlled Reactors (TCR) in the top left corner and the harmonic filters in the foreground.

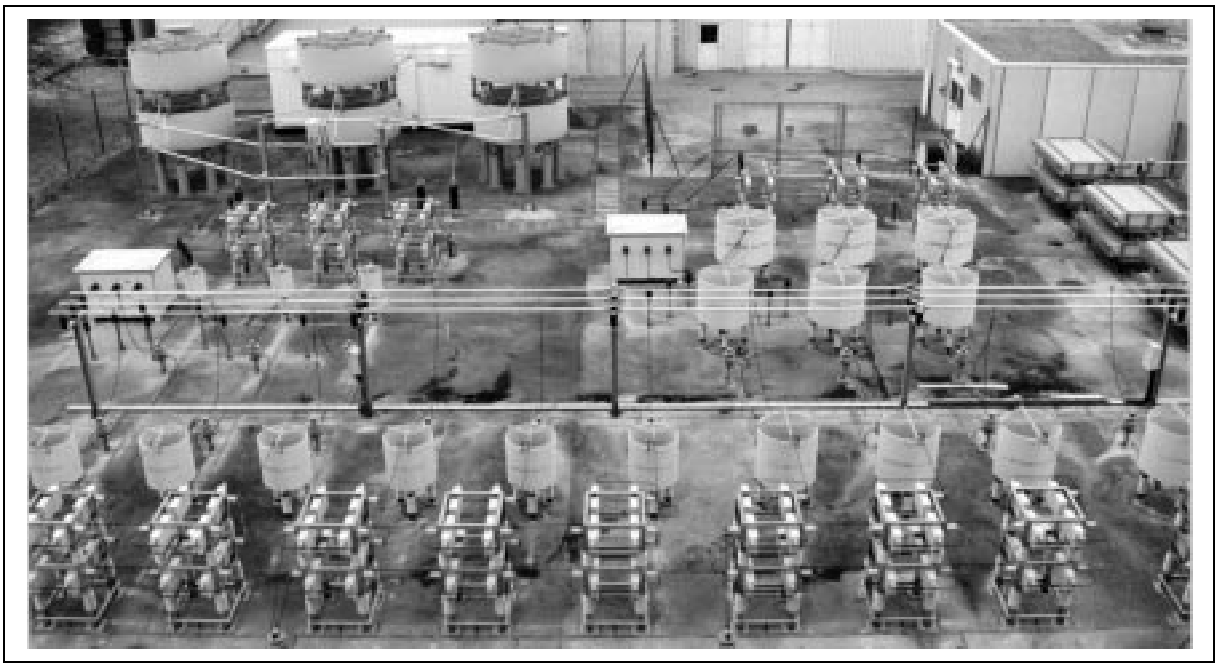

Fig. 5: Static Var Compensator based on Thyristor Controlled Reactor technology [2].

This new SVC will be based on modern TCR technology, which is in fact an electronically controlled source of reactive current. The fast acting control system of the TCR varies the firing angle of the thyristors and thus controls the reactive power output of the SVC. The response time of a TCR is less than 100 ms from zero to rated reactive power output.

The SVC will consist of a TCR rated at 150 Mvar and seven harmonic filters (100, 150, 250, 350, 550, 650 Hz and HF) generating a total reactive power of –130 Mvar. Computations have shown that the SVC will reduce the voltage variations on the 18 kV busbar to less than 0.3% (slow change) and 0.75% (fast change). The total harmonic distortion of the 18 kV busbar voltage will be kept below 0.5%.

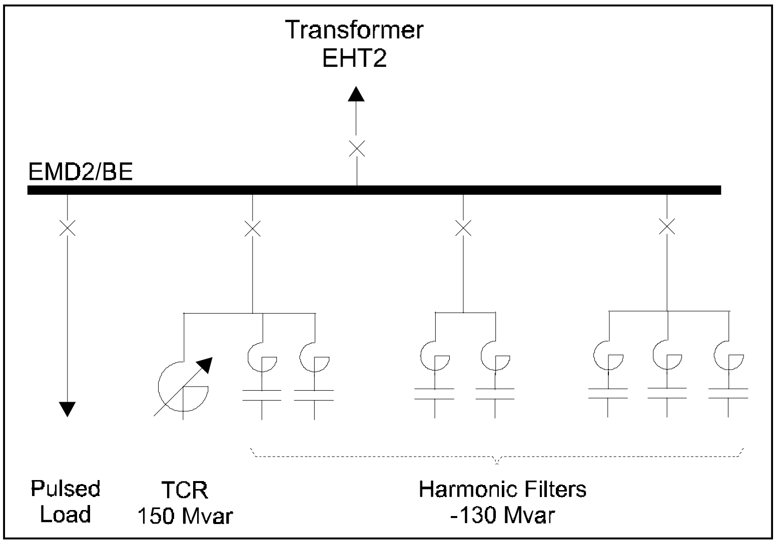

Fig. 6: General layout of the new Static Var Compensator BEF9.

The new SVC will be an outdoor installation covering a surface of about 2500 m^2. It will also include a prefabricated building for the high voltage thyristor valves and the SVC control system. The whole installation will be located in Prévessin, close to the existing 400 kV substation. This project is closely linked to the renovation of the BE substation and the renovation of the three transformers EHT1, EHT2 and EHT3. After the installation and the successful test run of the new SVC, the renovation of the existing saturated reactors will commence.

REFERENCES

[1] O. Bayard, J. Pedersen, The CERN 400 kV / 66 kV / 18 kV main substations and its associated compensators and filters, CERN ST/93–02(IE).

[2] Static Var Compensator 50 Mvar at CERN LEP PA2
(origin of the photo: http://nicewww.cern.ch/st/el/NetCtrl/net/network.htm).