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PROGRESS REPORT: STATIC VAR COMPENSATOR PROJECT FOR THE SPS ELECTRICAL NETWORK

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Abstract

This paper gives a progress report on the Static Var Compensator project BEF2 for the SPS electrical network. Following a market survey and a call for tenders, a contract has been awarded to ABB Sweden and the project is now in the phase of detailed performance studies, system design and ordering of the main electrical components. This progress report describes the electrical design, summarises the results of the harmonic filter design studies, discusses the interfacing of the control- and communication system and explains the mechanical layout of the Static Var Compensator and as well as the project co-ordination with the feeding BE substation renovation project. Finally, the project planning is presented and critical paths are evaluated.

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1 INTRODUCTION

After 25 years of pulsed operation, the two existing Saturated Reactor compensators BEF1 and BEF3 are now approaching the end of their life time and are in need of an overall renovation program. To facilitate the renovation of the Saturated Reactors and to have a redundant supply group for the operation of SPS as an injector for LHC, a third Static Var Compensator (SVC) will be installed on the 18 kV SPS pulsed network. The new SVC will also accommodate for the load increase due to the LHC injection tunnels TI2 and TI8. [1]

In February 2000 a call for tenders for the supply and installation of a 150 Mvar 18 kV Static Var Compensator has been issued and subsequently a contract has been awarded to ABB Power Systems in Sweden.

Following several months of intensive design studies and technical discussions between ABB Power Systems and CERN, the main design of the SVC is now defined and most of the major components on order.

This progress report describes the electrical design, summarises the results of the harmonic filter design studies, discusses the interfacing of the control- and communication system and explains the mechanical layout of the Static Var Compensator as well as the project co-ordination with the feeding BE substation renovation project. Finally, the project planning is presented and critical paths are evaluated.

2 PROJECT OVERVIEW

2.1 Static Var Compensator 150 Mvar 18 kV

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. Due to the large amplitudes and short rise times of the pulsing power, fast acting Static Var Compensators are necessary for the operation of the SPS.

Fig. 1 shows the single-line diagram of the SPS pulsed network. It consists of three transformers 400/18 kV 90 MVA of which transformer EHT1 and EHT3 each are connected to a Static Var Compensator based on Saturated Reactors. The new Static Var Compensator BEF2 will be connected to the transformer EHT2.

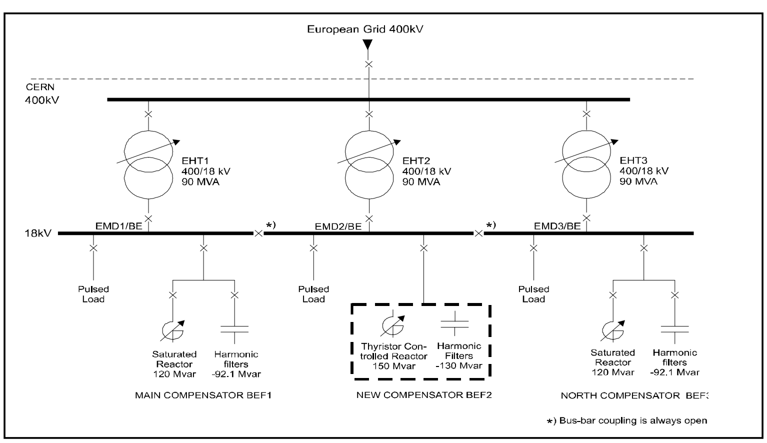

Fig. 1: Simplified layout of the SPS pulsed network

The whole installation will be located in Prevessin, close to the existing 400 kV substation. After the installation and the successful test run of the new SVC, it is planned to commence the renovation of the existing SVC's.

2.2 Civil Engineering

The Static Var Compensator project requires extensive civil engineering works for which CERN ST-CE is responsible.

The civil engineering works comprise the construction of a 150 m cable duct between the BE substation and the SVC yard as well as the construction of a concrete platform of about 2500 m^2.

About 4000 m^3 of soil need to be removed for the construction of the platform. This soil will be used to construct an earth wall behind the SVC yard in order to reduce the cost for civil engineering works and to limit noise emission to the outside.

It is also foreseen to extent the cable duct from the SVC yard to the BE9 substation in order to have available a large cable duct between the BE and BE9 substations.

2.3 Supply of Primary Cooling Water

The primary cooling water, required for the cooling of the thyristor valve, will be taken from the existing SPS service gallery nearby.

The piping system will pass through the BE substation and will be installed in the new cable duct between the BE substation and the SVC yard. CERN ST-CV is in charge of these works.

2.4 Interfaces to the BE substation renovation project

The SVC project is closely linked to the BE substation renovation project. As mentioned above, the Static Var Compensator is supplied from the 18 kV BE substation. The operation of the SVC will be fully integrated into the substation control system which controls the different configurations of the SPS pulsed network and assures the proper interlocking and backup protection under all conditions [2]. The SVC protection system will be located in the safe room of the BE substation, as well as a touchscreen for SVC supervision.

3 ELECTRICAL DESIGN

3.1 General

The Static Var Compensator will consist of a Thyristor Controlled Reactor rated 150 Mvar and eight harmonic filters (F2, F3, F5, F7, F11, F13, HF1 and HF2) generating a total reactive power of -130 Mvar.

The SVC will be connected to the feeding 18 kV BE substation via a 5x3x500 mm^2 Cu cable. In the SVC yard, the SVC will be split into the following three groups:

- TCR, harmonic filters F2, F3, F5
- harmonic filters F7, F11, F13
- harmonic filters HF1, HF2

For the switching of the first group a 4000 A 72.5 kV circuit breaker will be used. In addition, an external earthing switch will be installed on the main busbar of this group. The second and third group will be switched using two 2500 A 24 kV withdrawable indoor circuit breakers which will be installed in one of the compartments of the pre-fabricated building. As will be explained later on in more detail, the filter HF2 will be equipped with a combined disconnect-/earthing switch in order to allow the disconnection of this filter in times of moderate network loading.

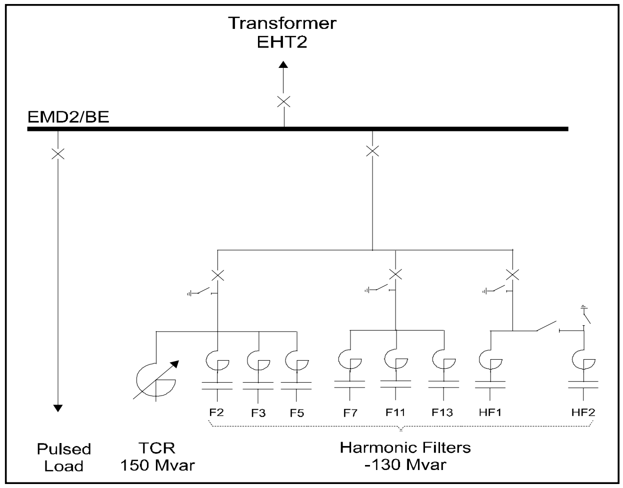

Fig. 2: SVC single-line diagram

3.2 Filter Design

3.2.1 Harmonic currents and filter design characteristics

The harmonic filters will be subjected to harmonic currents generated by the following three sources:

- the pulsing load,
- the TCR,
- the harmonic background distortion of the 400 kV system.

Considering the contributions of these three major sources of harmonics, the design of the harmonic filters is based on the harmonic currents as shown in table 1. The table shows all major characteristics of the harmonic filters.

Table 1

Harmonic filter design characteristics

Filter	Tuning	Type	Rated harmonic current [A]	Filter damping	Rated power [Mvar]
F2	2.0	C	90	3.8	13.6
F3	3.0	C	180	4.45	13.6
F5	5.0	LC	340	80	18.9
F7	6.95	LC	210	80	14.7
F11	10.95	LC	390	80	18.3
F13	12.95	LC	260	80	14.5
HF1	18.95	HP	270	9.8	18.2
HF2	20.95	HP	270	15	18.2

The filters F2 and F3 are designed as C-type filters in order to minimize the losses. These filters are applied to avoid instabilities due to the parallel resonance of the filter capacitors with the power system. Due to the increase in capacitive power of the new SVC BEF2, compared to the existing compensators BEF1 and BEF3, the natural resonance point is now at a lower frequency and close to the second harmonic. This aspect requires particular attention when designing the second harmonic filter in order to achieve the best compromise between a moderate filter impedance and a sufficient damping.

The filters F5, F7, F11 and F13 are normal LC filters without damping resistors. Some of the filter reactors might apply damping rings to achieve the specified filter damping.

The SVC will normally operate with all harmonic filters in operation. To reduce SVC losses in times of moderate network loading, the HF harmonic filter is split into two portions HF1 and HF2, allowing the disconnection of 18.2 Mvar of the filter HF2. In exceptional circumstances it could be possible to operate the SVC with 112 Mvar of filters (18.2 Mvar of HF2 are switched off) in combination with the 18.5 Mvar capacitor bank of the Auxiliary Compensator. The 18.2 Mvar rating of the HF2 filter also allows the re-use of the Auxiliary Compensator filter components when renovating one of the existing SVC's BEF1 or BEF3.

The design studies have shown that the impedance of the cable feeding the HF1/HF2 filter group is critical to the harmonic performance of these filters. For this reason the SVC layout aims to minimise the length of the feeding cable for this filter group.

3.2.2 Harmonic filter performance

The harmonic performance of the filters has been studied and verified by computations performed independently by ABB Power Systems and CERN. One major objective of the filter design was to achieve a performance similar to the existing saturated reactor compensators BEF1 and BEF3 [3].

As explained in paragraph 3.2.1, three configurations have been considered in the calculations:

- configuration A: SVC with all filters in operation (standard configuration)
- configuration B: filter HF2 switched off (configuration for moderate network loading)
- configuration C: filter HF2 switched off and capacitor bank of the Auxiliary Compensator BB3 switched on (exceptional configuration)

Figure 3 shows the impedance diagram for the standard configuration with all filters in service:

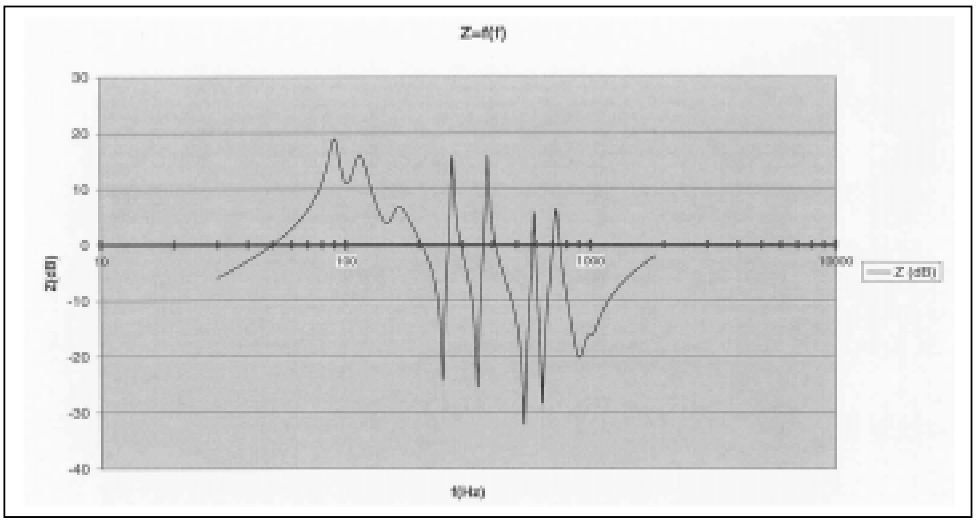

Fig. 3: Impedance diagram (all harmonic filters in service)

Based on the rated harmonic currents as explained above, the remaining Total Harmonic Distortion THD(U) at the 18 kV busbar will be about 0.5%. The harmonic performance of the SVC achieved for each individual harmonic is shown in table 2. Each individual harmonic is kept below 0.3%.

Table 2
Harmonic performance (all harmonic filters in service)

NODE RESULTS (CONFIGURATION 1)

Node	Un /kV			f /Hz	U /V	u /%	phi /D
EMD2/BE				100.0	0.26	0.002	-75.9
	18.00			150.0	0.08	0.001	232.9
				250.0	16.86	0.162	5.7
				350.0	20.45	0.197	54.6
				550.0	31.56	0.304	70.9
				650.0	24.13	0.232	71.7
				850.0	13.86	0.133	-46.9
				950.0	10.41	0.100	34.6
				1150.0	18.22	0.175	75.7
				1250.0	21.53	0.207	78.6
				1450.0	26.91	0.259	81.4
				1550.0	30.55	0.294	81.7
				1750.0	16.04	0.154	81.7
				1850.0	11.63	0.112	81.7

3.2.3 Tolerances and their influence on filter performance

The influence of variations of boundary conditions and tolerances of components have also been evaluated. These variations consider the worst-case combinations of the following parameters:

- tolerance of system voltage and frequency
- component tolerances,
- variations of ambient temperature (range between minim and maximum ambient temperature),
- influence of capacitor unit fuse failures up to trip level.

The computations have also shown that neither the transformer tap changer nor the choice of the feeding transformer (different transformer impedances of EHT1, EHT2 and EHT3) have a significant influence on the harmonic performance of the SVC.

The influence of the worst-case combination of all parameters is shown in figure 4.

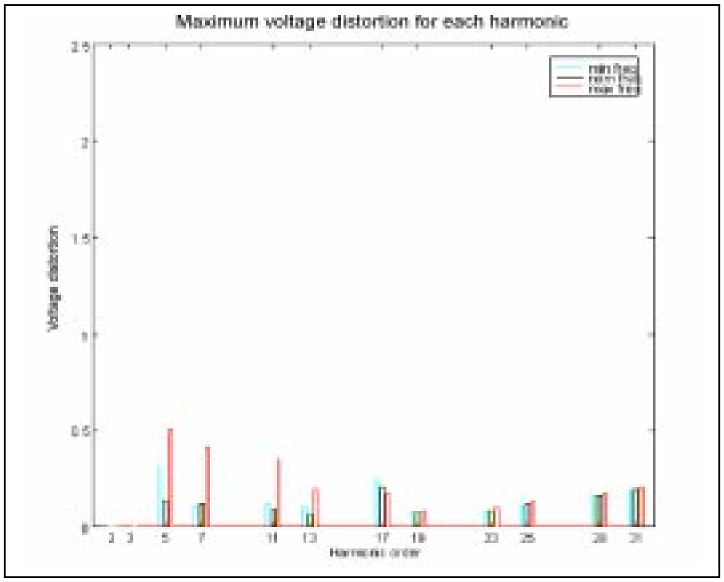

Fig. 4: Harmonic performance for the for the worst-case combination of all parameters [4]

It can be concluded that the SVC will fulfil the specified performance requirements even under the worst-case combination of all boundary conditions. Nevertheless it is recommended to replace defective capacitor during the annual winter shut-down in order to always assure an optimum SVC performance.

3.3 TCR reactor coils and thyristor valves

The TCR has a rating of 150 Mvar. The TCR coils are connected in delta where each TCR branch includes a thyristor valve and two reactor coils. The reactor coils are located on each side of the thyristor valve to limit fault currents in the valve and eliminate the risk for steep-front voltage surges.

The TCR reactor coils are of the air core type, the reactors for each phase are placed side by side. The reactors are of the low loss type and, as also for the harmonic filters, the capitalized losses will be evaluated during commissioning.

The thyristor valves consist of single-phase assemblies. Each valve comprises two stacks of anti-parallel connected thyristors. For the thyristor valve 4" thyristors will be used. The voltage rating of these thyristors is 6.5 kV, requiring the series connection of 10 thyristor levels per stack. The thermal rating of the valve is such that after a long period of maximum continuous TCR current the thyristor junction temperature is around 90°C which is well below the normal design value of 110°C. The maximum allowed thyristor junction temperature is 125°C.

The TCR unit is designed for continuous operation at system voltage up to 1.06 p.u. However, the TCR unit is fully controllable up to 1.25 p.u. A current limiting control function assures that in such a case no TCR overload occurs. At voltages above 1.25 p.u. protective overvoltage firing occurs.

3.4 SVC control system

Several possible variants of the control system have been simulated in the initial computer studies. The best performance has been achieved using a control system based on a conventional PI regulator for voltage control, combined with feedforward paths of the measured values of the active and reactive power of the load. To avoid oscillations of the TCR controls, filters have been added in the feedforward paths of the active and reactive power [5]. Comprehensive dynamic computer studies are still ongoing and the final design of the control system is scheduled to be defined in March 2001.

The heart of the control system is the MACH2 system which is built up around an industrial high-performance PC operating under WindowsNT. The MACH2 system consists of the independent systems A and B to assure a complete redundancy.

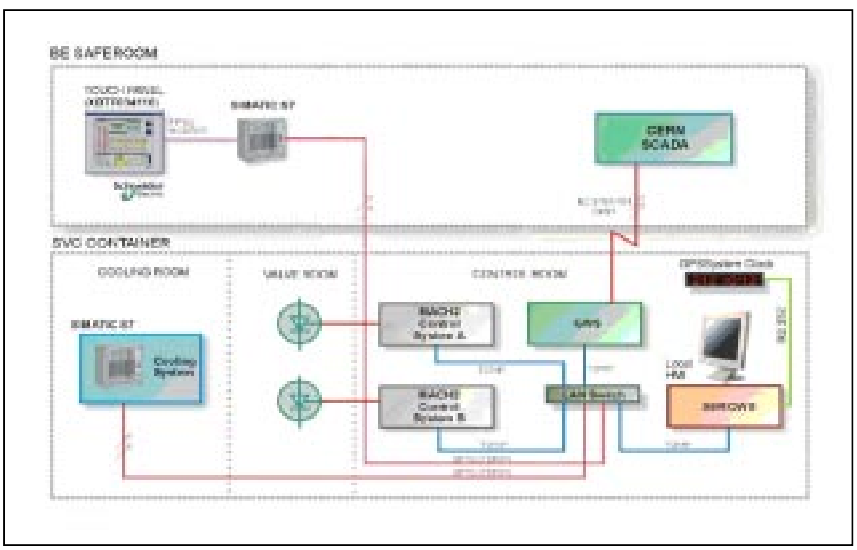

Fig. 5: Communication block diagram of the SVC control system [4]

4 MECHANICAL DESIGN

The harmonic filters and the TCR reactors will be an outdoor installation. A pre-fabricated building will be positioned in the front part of the SVC yard. This building will consist of four individual compartments, housing the thyristor valves, the cooling plant, the SVC control system and two small switchboards for the harmonic filters.

The TCR reactors will be installed directly behind the pre-fabricated building, the required delta connections will be done via aluminium busbars. The harmonic filters F2, F3 and F5 will be installed in a separate compartment, but connected to the same main busbar as the TCR.

On the right hand side of the SVC yard there will be one compartment with the filters HF1 and HF2 and another one containing the filters F7, F11 and F13.

All major components such as capacitor banks, filter reactors and filter resistors will be single-phase units. Hereby the three phases will be arranged side by side, the single-phase filter resistors will be installed on top of the single-phase capacitor banks.

All earthing and disconnecting switches will be arranged such that they can be operated from outside the high voltage compartment. A mechanical interlocking system assures that the high voltage installation is only accessible when the equipment is switched off and properly grounded.

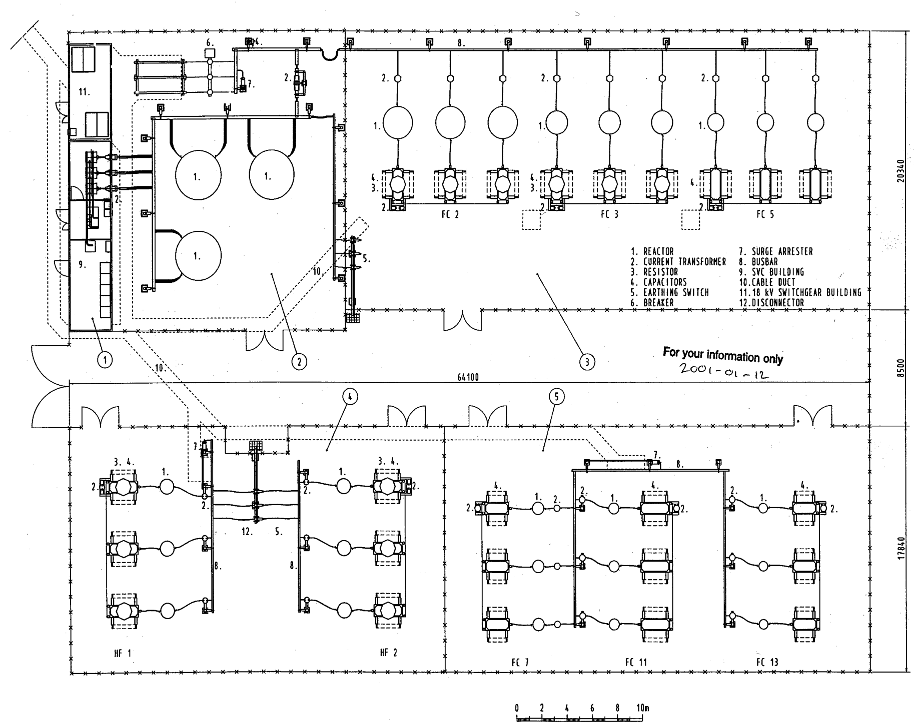

Fig. 6: Mechanical design of the Static Var Compensator [4]

5 PLANNING

The main deadlines for the SVC project are shown below:

Main electrical design	January 2001
Order of the main components	January 2001
Installation of the primary cooling water supply	March 2001

Civil engineering works (cable duct)	January – February 2001
Civil engineering works (concrete platform)	February – April 2001
Finish of system design and engineering studies	April 2001
Delivery of the major components	May 2001
Installation works	May – July 2001
Commissioning (without pulsing load)	July – October 2001
Commissioning (pulsing load tests)	October 2001
SVC ready for operation	November 2001

As per January 2001, the project is well within schedule and major difficulties regarding the planning are not expected. Nevertheless some remaining component parameters need to be defined very soon to issue or finalize all remaining orders of the main components.

The civil engineering works for the cable duct have started and will be finished in time. The most critical part of the civil engineering works is the construction of the concrete platform, it is imperative that the works are completed by the end of April 2001 in order to allow the commencement of the installation works beginning of May 2001.

6 SUMMARY

In this report a detailed description of the Static Var Compensator project has been given, the electrical design and results of the filter design studies have been explained as well as the mechanical layout of the installation. The interfaces to other CERN groups and services have been discussed and the project planning has been outlined.

It can be concluded that, based on detailed computer simulations, the optimum SVC design has been found yielding a performance comparable to the existing Static Var Compensators. Based on these design studies, the major components have been ordered for delivery just-in-time for the installation. Up to now, the project is advancing as planned and all major tasks are well within schedule in order to finish the commissioning tests as foreseen in October 2001.

REFERENCES

[1] K. Kahle, Static Var Compensation for the SPS electrical network, CERN-ST-2000-040, January 2000

[2] K. Kahle, Possible network configurations for the new BE substation, CERN/ST-EL/KK(2000-103)

[3] K. Kahle, Technical Specification for the supply and installation of a 150 Mvar, 18 kV Static Var Compensator, CERN IT-2738/ST, February 2000

[4] ABB Power Systems (S.-O. Nilsson, T. Larsson, H. Säfström, Levrinus a.o.), SVC design studies performed by ABB for CERN.

[5] The Royal Institute of Stockholm (Prof. ⊕. Ekström, M. M. de Oliveira), Study of a Static Var Compensator for the SPS pulsed network, January 2000

[6] 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)