

## SAPEI HVDC CONVERTERS

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### 1. INTRODUCTION

SA.PE.I (SARdegna PENinsula Italy) is a new HVDC link under construction that will interconnect between the Sardinian network and main land Italy. Since back in the 1960's the networks was already connected by the SACOI scheme. Today SACOI is considered to have limited capacity and parts that are reaching its economical life time. The new link will on Sardinia be located in Fiume Santo in the north western part, close to the the SACOI terminal, and in fact use the same sea electrode station, while the main land station will be located in Latina, south of Rome. The selection of station locations was primarily based on AC network aspects, both sub-stations could connect to the SAPEI link without any AC network reinforcements.

### 2. TRANSMISSION CAPACITY AND SYSTEM CONFIGURATION

#### 2.1. *Transmission capacity*

The transmission is a bipolar (two 12-pulse monopoles) HVDC-link with a rated power capacity in either direction of  $2 \times 500$  MW and with a minimum power of  $2 \times 50$  MW.

The power capacity is referred to the rectifier d.c. terminals (pole to neutral). The maximum ambient temperature used for this rating is 40°C.

If one of the poles trips or is stopped, it is possible to operate the other pole by using the other cable as return conductor or using the electrode stations for ground return of the dc current.

The nominal d.c. voltage, pole to neutral, in the transmission is 506 kV and the nominal direct current is 998A.

#### 2.2. *Operation modes*

The HVDC transmission is designed and rated for the following operation modes:

- a. bipolar mode utilizing the electrode cables and sea electrodes of both terminals as grounding points.
- b. monopolar mode with ground (sea) return utilizing the electrode cables and sea electrodes of both terminals.
- c. monopolar mode with metallic return utilizing the d.c. cable of the other pole as return path with the electrode cables and sea electrodes of one terminal, Latina, as grounding point.

## SAPEI HVDC CONVERTERS

### ***Bipolar operation***

The operation is considered bipolar if both poles are in operation. Depending on the conditions of each pole, the operation is balanced bipolar or unbalanced bipolar. In order to be considered balanced bipolar, the d.c. voltage references of both poles have to be of the same magnitude and of opposite polarity, and the power levels of both poles have to be the same, even though the actual d.c. voltage and currents may differ due to tolerances and OLTC( On Load Tap Changer) position. If any of the above condition is not satisfied, the operation is considered unbalanced.

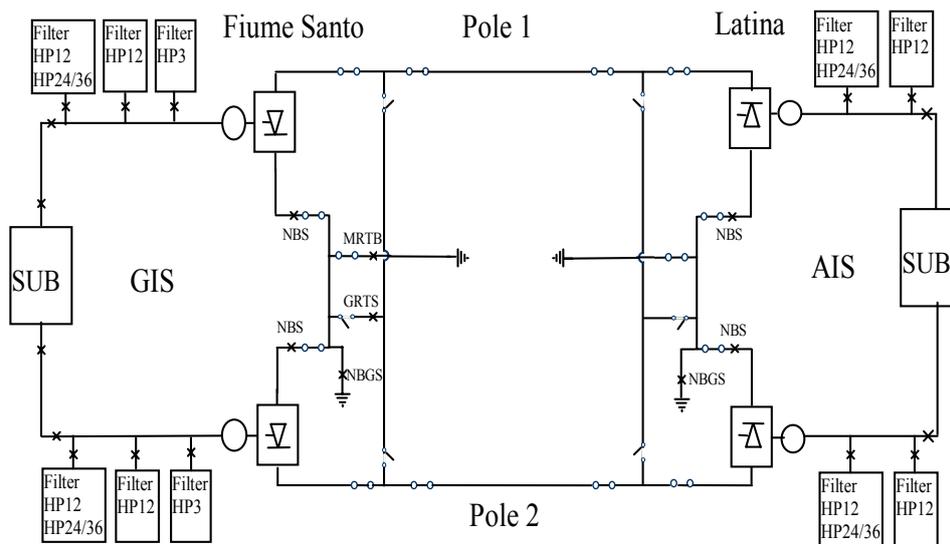
### ***Monopolar operation***

The operation is considered monopolar if only one converter pole is in operation in each converter station. Depending on how the neutral sides of the converters are tied together for the return current, the operation can be either monopolar with ground return or monopolar with metallic (cable from other pole) return. In the former, both neutrals are grounded and the return current will flow through the ground, while in metallic return, the return current is carried by one of the cables, and the ground reference is given by the electrode connection in Latina, i.e. Latina is the directly grounded station in monopolar mode with metallic return.

The SAPEI project are implemented in two consecutive phases. The first phase finishes with implementation of one single-pole connection in the direction of current from the continent towards Sardinia, with return of current through ground sea, using the new cathode in Latina and the anode of the existing SACOI connection, upgraded to 2500 A.

In case of outage of the Pole 1 cable and in order to operate Pole 1 converter station with Pole 2 cable keeping the correct current direction through the anode in Sardinia, a Cross Cable between the poles is installed.

The simplified Single Line Diagram is shown below:



### **SAPEI HVDC CONVERTERS**

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The basic control mode is constant power control

1. Normal angle operation ( $\gamma=17^\circ$ ). This is the normal operation mode and it will be possible to operate either in bipolar operation (100 – 1000 MW) and monopolar operation (50 – 500 MW), ground return and metallic return.
2. Increase gamma operation ( $\gamma=19^\circ$ ). This increased gamma operation mode will be possible to operate either in bipolar operation (100 - 1000 MW) and monopolar operation (50 - 500 MW), ground return or metallic return.
3. Operation during restoration. Operation mode used for restoration of the Sardinian network after blackout (40 - 300 MW). Monopole operation, ground return or metallic return.
4. Operation at Overload. Operations using the inherent overload capability at low ambient temperature, using redundant cooling or short time overload capability.

### **3. MAIN CIRCUITS ARRANGEMENT**

For SAPEI the target has been to apply the simplest and most straight forward main circuit arrangements, considering the specified requirements. The base for the design has also been to use proven solutions, typical for a transmission of this size and to attain similarity between the two stations when differences are not prescribed.

The converter stations are configured as bipolar schemes (two 12-pulse monopoles). At both stations, Y and  $\Delta$  connected single-phase three-winding transformers will feed the 12-pulse thyristor valves.

The converter valves are divided in three quadruple valve units that are fed from the respective three single-phase transformers.

The demands on harmonic filtering and reactive power support have resulted in similar filter solutions in the two stations, with the addition of two HP3 filter banks in Fiume Santo.

The bipolar scheme is equipped with d.c switches to enable change over from bipolar operation to monopolar operation with ground or metallic return and back again.

### **4. LAYOUT**

The objective of the station design has been to keep the two stations equal where possible. Due to high level of salt and industrial pollution in Fiume Santo a GIS solution is provided, and a.c. filter banks are installed indoor. In Latina the a.c. filters are located outdoors and the stations is fed from a normal AIS.

The pole DC side, including the air smoothing reactor, is located indoor in both stations. On the contrary, the neutral buses and equipment will be placed outdoors in both stations.

The converter transformers are situated close to the valve hall with the valve side bushings protruding into the valve hall wall. This minimizes the d.c. insulation exposure to the outdoor environment and reduces the risk for bushing flashovers. In the valve hall the valves are suspended from the ceiling of the building and have the high voltage terminal at the upper end.

## **SAPEI HVDC CONVERTERS**

## **5. LOSSES**

The equipment has been optimized with respect to the loss requirements.

The no-load losses are calculated to about 0.5 MW and at rated power the total operating losses are not above 3.5 MW per converter station and pole.

The total losses are below 0.7 % of rated power, which is a fairly low figure, but still in the range to be expected from a modern converter station.

## **6. RELIABILITY AND AVAILABILITY**

In order to reach the best possible predicted reliability and availability the design utilizes a high degree of duplication to eliminate outages due to failures or necessary maintenance. Essentially all sub or auxiliary systems that are of importance to the transmission of power are provided with redundancy.

Special efforts were made to safeguard Sardinia from the failure of the entire bipole, which was one of the main drivers in terms of requirements for flexibility of operation and reliability of equipment (see also short circuit tests on transformers).

A significant contribution to the high figures on reliability and availability is achieved by redundancy in the control equipment. Different schemes are applied, such as duplication of functions or distribution into separate blocks. Duplication, the main method to achieve redundancy, is used for all important control and protection functions. Switch over to a redundant part is initiated automatically on faults or manually. Switch over between systems can be performed with the station on line with normally non or, in the worst case, just a minor disturbance to the power conversion. The redundancy also means that maintenance or repair can be performed on line with the faulty system in a standby position, while the technically sound system is taking the active control actions.

The predicted energy availability, not considering scheduled unavailability, for the two converter stations and poles together is in the order of 99.5 %. The forced outage rate is estimated to not be above 3 outages per pole and per year and not above 0.1 bipolar outages per year. The predicted values are in agreement with the operational experiences from recent HVDC systems delivered by ABB and are also substantiated by the statistics of the different utilities and CIGRÉ

## **7. MAINTENANCE**

To reach the goal of high reliability and short time for both planned and unplanned outages, a thoroughly tested system of reliable equipment is necessary. Together with well planned and performed preventive maintenance, the time for and number of outages can be kept to a minimum.

Modern thyristor valves require a minimum of maintenance. Valve maintenance is concentrated to a short period every second year with a pole shut down.

If a forced outage occurs, the identification of the cause, tracing of faulty units and replacement, need to be done expeditiously and with precision in order to minimize the outage time and the risk for repetition. This is accomplished by a comprehensive monitoring system, a built in on line documentation system well suited for fault tracing and efficient tools to verify a faulty unit.

## **SAPEI HVDC CONVERTERS**

## **8. AUDIBLE NOISE**

The preliminary investigation of the predicted sound levels for the Latina and Fiume Santo HVDC converter stations shows that the required max sound level limits at the station perimeter wall will be met.

In order to limit the noise from the stations the acoustical aspects has been considered in the design of each station. To secure that maximum required noise levels will not be exceeded certain noise attenuation measures have been implemented in both stations.

## **9. QUALITY PROGRAM**

ABB has developed an effective and efficient quality assurance program that is third party certified according to ISO 9001 and that complies with other applicable standards. The know-how acquired by long experience with HVDC projects of different nature and good technical resources ensures reliable products in compliance with the specifications.

## **10. EQUIPMENT DESIGN**

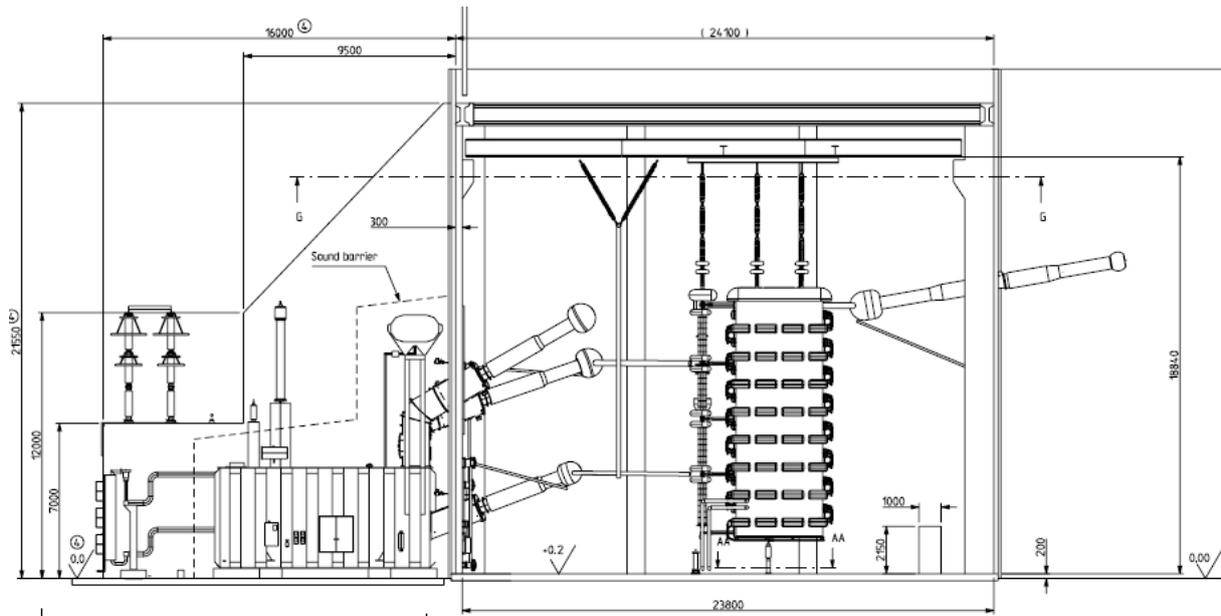
### ***10.1 Thyristor valves***

The valves are of an indoor, air insulated and water cooled design, comprising a minimum number of components.

The thyristor valves are of a quadruple valve design, i.e. four series connected single valves are provided in one mechanical unit. The valve structure is suspended which gives a superior mechanical design at all static and dynamic conditions. Identical valves will be used in both stations. They are designed with series connected thyristors of type YST 60. A thyristor of this type has been used also for the Italy Greece HVDC Link.

Each single valve unit consists of 8 series connected thyristor modules with 8 intermediate reactors. Each thyristor module consists of 9 series connected thyristors and voltage dividing circuits. Consequently each single valve consists of 72 thyristor levels, where 3 of these thyristors are redundant.

The cross-section connection between the converter valve and the converter transformer is shown below:



## 10.2 Converter Transformer

For the SAPEI HVDC Link transformers of single phase, three windings type are selected. There are three transformers per pole or 12-pulse converter. The layout is arranged with de d.c. side bushings protruding into the valve hall.

The transformer ratings for are summarized below:

Rated power per 1-phase 3 winding converter transformer unit	194 MVA
Transformer ratio (Phase-to-phase voltage on the line side / Phase-to-phase voltage on the valve side)	400 kV/ 207.7 kV
Rated frequency	50 Hz
Tap changer range	+ 14 / -6 * 1.25 %
Transportation weight	230 ton

The same design of the transformer are used in both stations, the only difference is that a cable interface is provided in Fiume Santo while in Latina traditional bushings are used.

The transformers have been optimized with respect to the losses. The measurement of the estimated losses shows that the transformer losses requirements are below the required values of 120 kW no-load losses and 360 kW load losses.

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### **10.3 Smoothing Reactor**

Each pole will be equipped with an air insulated smoothing reactor.

### **10.4 AC Filters**

The ac filter design for the SA.PE.I. 1000 MW  $\pm$ 500 kV HVDC Link has a total installed Mvar of 410 and 494 Mvar at Latina and Fiume Santo converter stations respectively.

For Latina converter station the filters are subdivided in:

- 2 $\times$ 108.8 Mvar banks, Z1. Each bank with two branches one branch consisting of a high-pass filter tuned to 12<sup>th</sup> harmonic the second branch with a double tuned high pass filter tuned to 24<sup>th</sup> and 36<sup>th</sup> harmonics.
- 2 $\times$ 96.2 Mvar banks, Z2. Each with a high-pass filter tuned to 12<sup>th</sup> harmonic.

For Fiume Santo the filters are subdivided in:

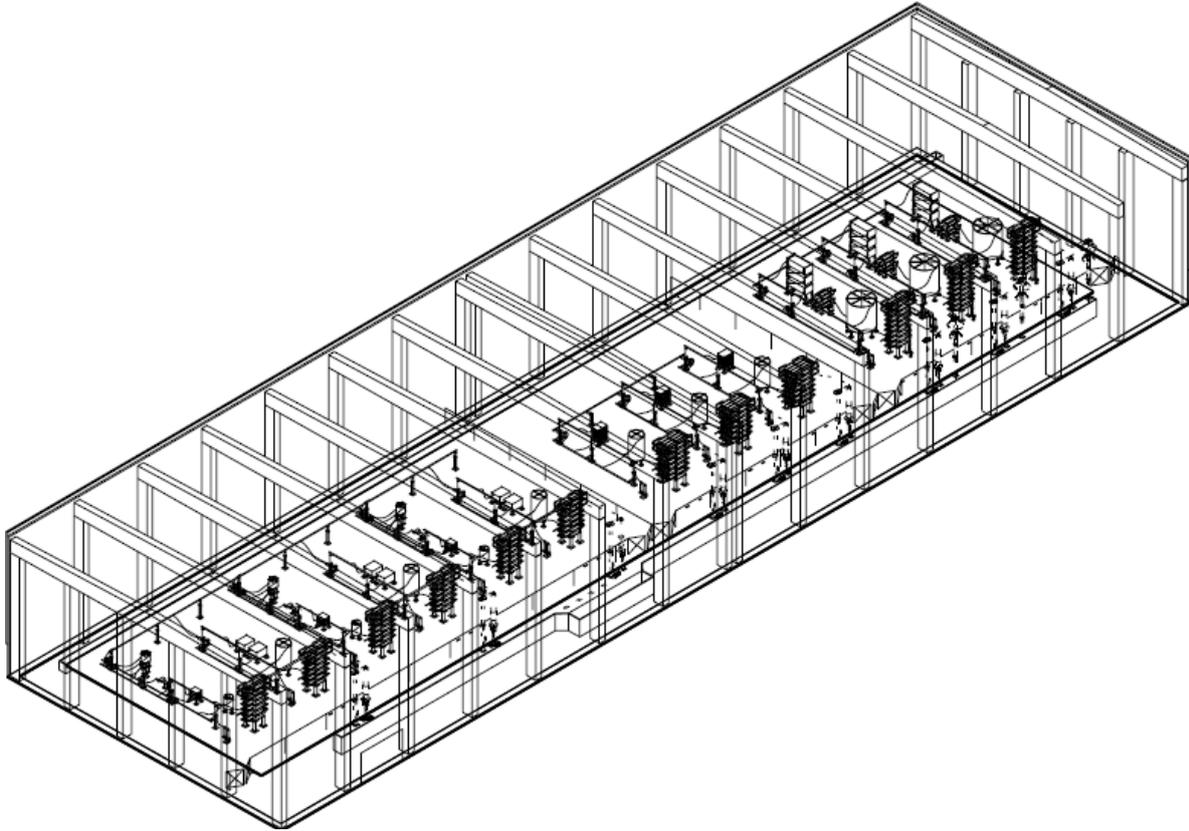
- 2 $\times$ 90.7 Mvar banks, Z1. Each bank with two branches one branch consisting of a high-pass filter tuned to 12<sup>th</sup> harmonic the second branch with a double tuned high pass filter tuned to 24<sup>th</sup> and 36<sup>th</sup> harmonics.
- 2 $\times$ 90.7 Mvar banks, Z2. Each with a high-pass filter tuned to 12<sup>th</sup> harmonic.
- 2 $\times$ 65.6 Mvar banks, Z3. Each with a high-pass filter tuned to 3<sup>rd</sup> harmonic.

The filter banks are symmetrically located at the respective converter feeder.

The design complies with requirements of a maximum:

- Individual harmonic voltage distortion of 1 % and 0.5 % for odd and even order harmonics respectively,
- Total, effective, harmonic distortion of 1.5 %, and
- Telephone harmonic form factor (THFF) of 0.9 %.

The a.c. filter layout in Fiume Santo is shown below:



### ***10.5 High frequency filters***

#### Fiume Santo:

The Fiume Santo converter station is fed by an approximately 0.3 km long AC-cable and there are no outdoor bus-work in the station. This arrangement will sufficiently eliminate any RI-noise.

#### Latina:

In order to meet the RI requirements in the whole frequency range a RI Filter consisting of a 100 nF capacitor with tuning unit and a 1mH inductance with tuning unit will be installed in each pole.

### ***10.6 DC Switches***

There are an entire set of d.c. switches for changing from bipolar, isolating a faulty pole, operation to ground or metallic return and back again.

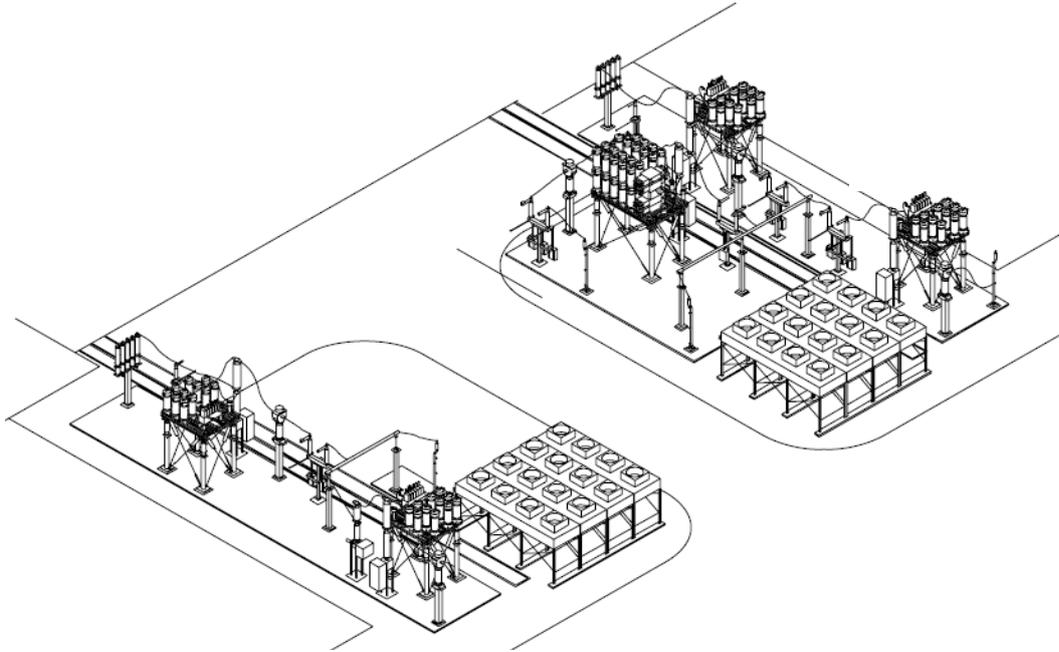
- Neutral Bus Switches, 2 per station
- Neutral Bus Ground Switch, 1 per station
- Ground Return Transfer Breaker, 1 in Fiume Santo
- Metallic Return Transfer Breaker, 1 in Fiume Santo

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The d.c. switches are designed with SF6-breakers. The d.c. switches are all equipped with an auxiliary circuit; a capacitor and inductance connected in parallel with the breaker. This circuit will start an oscillation and zero crossing of the d.c. current when the breaker opens and make it possible to completely commutate the current.

The d.c. neutral layout in Fiume Santo is shown below:



## 11. CONTROL SYSTEM

The control and protection system, MACH 2, has been specifically developed for HVDC.

The control and protection system is fully computerized and built with the state of the art electronics, microprocessors and digital signal processors, connected by high performance industrial standard buses and fiber optic communication links.

All major control functions for power transfer are made redundant as well as the measurement system for analogue and digital input signals.

The two 12-pulse converters are controlled and protected by dedicated sets of pole/block related control equipment. The operator interface is accomplished through an operator workstation (OWS).

The Remote Terminal provides an interface for remote control and supervision at the Dispatch Center.

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## **12. TESTING**

Comprehensive type tests in accordance with relevant and applicable IEC standards and in accordance with TERNA's technical specifications have been conducted for the SAPEI project.

The Converter Transformer Short Circuit test was successfully performed on Latina unit 1 in August in the Kema Laboratory in the Netherlands. The subsequent disassembly, active part inspection and new routine tests were successfully performed. No impact on the active part could be noticed and the repeated routine test was completed without problems.

The remaining converter transformer type tests were successfully performed on Latina unit 2.