Benefits and Design Aspects of Sao Joao do Piaui 500kV Series Capacitors

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Abstract-- In summer of 2003 the Sao Joao do Piaui Series Compensation System located in the Brazilian Maranhao-Bahia 500kV ac-network has been ordered and designed for delivery, erection and commissioning. The power demand of the growing Brazilian industries requires an economical solution for an increase of power transfer capability with the existing lines. Fixed series compensation has been found as the appropriate choice not only to enable the desired power increase but also to stabilize the interconnected networks by reducing the connecting line impedance. Starting of commercial operation of two capacitors located in two serial lines is scheduled for August 2004. This paper will give an overview of the design philosophy of the capacitor system and for the choice of the component rating.

Index Terms-- FSC-Fixed Series Capacitor; BCS-Banco de Capacitor Serie; MOV-Metal Oxide Varistor, Spark Gap, Dynamic Stability, PSCAD/EMTDC

I. INTRODUCTION

The Sao Joao do Piaui Series Compensation System has been developed for an increase of power transfer through the Sobradinho-Boa Esperança lines in the Maranhao-Bahia 500kV ac-network (Fig. 1), keeping the system stable during transmission line outages. The ac-network at Presidente Dutra is coupled through this corridor to the Sobradinho power plant by two serial lines with connection in Sao Joao do Piaui substation (Fig. 2). As a future extension the corridor will be expanded by adding a new parallel line SJP-SOB and a new corridor connecting Sao Joao do Piaui and Coletora (now Colinas) to use additional hydropower of the Tocantins and Maranhao area. As well short circuit power will increase in the adjacent substation. These additions, that will take place until Year 2008, and their impact on the final component ratings are considered in the design of both discussed series capacitors.

Fig. 1. Location of FSC Sao Joao do Piaui (Brazil)

The FSC system consists of two capacitors (BCS1, BCS2), one in each of the serial lines located in Sao Joao do Piaui substation entering from Sobradinho and Boa Esperança. Both have an identical design but have different impedances with respect to different line lengths at the same compensation...

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degree of 70%. In the following the data for BCS1 will be explicitly given and BCS2 data are given in parentheses. The most economical design has been found for a gap protected MOV scheme with an MOV total energy capability of 72MJ (80MJ for BCS2) per phase. External faults are covered by the installed metal oxide varistors (MOV) without bypassing the capacitor. In case of internal faults, the capacitor is immediately bypassed by the gap and locked out by a switch. Future ac system configurations have been investigated during the final design to find the necessary energy requirements of the MOV. The calculations are based on a PSCAD/EMTDC model of the ac-system corridor with both different actual and future ac-system configuration stages including the detailed representation of the capacitors and their control and protection features.

II. SINGLE LINE AND MAIN DATA

The fault calculation is the basis for the type of protection for the series capacitor bank. For FSC Sao Joao do Piauí, a MOV and Gap protected series capacitor has been found to be the most economical solution that meets all ac-system fault requirements. The single line diagram comprising the main components is shown in Fig. 3. The capacitive reactance is 52.68 ohms (47.54 ohms for BCS2) corresponding to 50.21 µF (47.69 µF for BCS2). The degree of compensation is 70% of line impedance. The nominal continuous current both capacitor banks are designed for is 1750 A rms with temporary overload currents up to 2625 A rms for 10 min.

A. Component Ratings

For a cost and performance optimized design, various studies with different system conditions have been carried out. To determine the component ratings under worst case conditions, not only steady state voltage and current stresses need to be examined but also the transient stresses during severe ac-system faults have to be investigated in detail.

1) Capacitors

The series capacitor consists of one segment representing a H-configuration. Four stacks constitute such a configuration. The total number of installed capacitor units is 660 for BCS1 (484MVA) and 600 for BCS2 (437MVA) in all three phases. They are of outdoor type with internal fuses. The 733 kVAR capacitor unit has a rated voltage of 8.4 kV rms with a nominal current of 88 A rms.

2) Metal Oxide Varistor MOV

Due to the overload conditions after an ac system fault, the rated voltage of the MOV has been chosen to 153 kV rms for BCS1 and 143 kV rms for BCS2. To determine the number of MOV housings which have to be installed on the platform, ac-system fault calculations have been carried out. Different ac-system configurations as well as different fault types and point on wave fault inceptions need to be considered for the design, to establish the proper operation of the capacitor system also for future stages of the growing ac-network.

There are two different types of faults which have to be considered for the design of the number of MOV housings:

External Faults:

External faults are those occurring outside the series compensated line terminated by breakers. The MOV must be designed to withstand external faults without damages, as the series capacitor will not be bypassed during external faults. This type of fault leads to the highest dissipated energy of the MOV. The highest energy consumption for the MOV has been found to be 58MJ for BCS1 and 59MJ for BCS2 per phase considering a three phase ac-fault with unsuccessful line reclosing.

Fig. 4 shows the energy dissipation of the MOV until first fault clearing. The energy dissipation for an unsuccessful reclosure into an existing fault can be calculated using these simulations by doubling the energies given here.

Internal Faults:

Internal faults are those occurring within the series compensated line terminated by breakers. If an internal fault is detected, the series capacitor is allowed to be bypassed by the triggered spark gap. This type of fault leads to the maximum overvoltage stress of MOV and capacitor. As soon as the instantaneous value of the MOV current exceeds 7 kA for
BCS1 and 11 kA for BCS2 the protection issues a signal to trigger the gap within 1 msec.

**Fig. 4. External Fault MOV Energy BCS1 and BCS2**

The highest voltage has been found to occur for a three phase internal fault directly at the terminals of the capacitor. This voltage is, however, limited to a protective level of 283 kV = 2.17 pu for BCS1 and 262 kV = 2.22 pu for BCS2 by the MOV, resulting in a MOV current of 15 kA (14 kA respectively.

**Fig. 5. Capacitor Voltage Rating BCS1 and BCS2**

Considering single pole closing in case of internal faults it must be considered that an internal fault might occur that is not detected by the fast bypass feature of the protection system. However this fault will be detected by monitoring of dissipated MOV energy and a bypass is initiated after the external MOV energy setting value has been exceeded. This leads to the final MOV energy rating for the two series capacitor banks. Fig. 6 shows the corresponding internal fault energies the MOV has to withstand. As stated above the graphs for BCS1 only the first closing; unsuccessful reclosing is not shown. 15% spare energy has been added for the final rating of the MOV.
3) Spark Gap

The spark gap has to protect the MOV against overload in case of internal faults. The protection fires the gap within 1 msec as soon as a threshold value of 7 kA (11 kA for BCS2) is exceeded. It is absolutely necessary that the gap bypasses the MOV as soon as possible because of the high rate of rise energy dissipation in MOV during internal faults. The gap consists of two housings installed on top of each other. The main trigger circuit is located in the lower housing while the upper one is passive. It fires successively after the lower gap has been triggered. The flashover voltage can be adjusted from 255 to 310 kV peak (235 to 290 kV peak for BCS2). The thermal fault current carrying capability is 40 kA rms.

4) Damping Circuit

The damping circuit is designed to discharge the capacitor in case of an internal fault when the voltage across the capacitor reaches the protective level. For both capacitors the same components and their ratings are chosen. It is located in series to the capacitor racks and is always stressed by line current. As an advantage this arrangement assures there is no voltage on the bypass disconnector when the capacitor is bypassed by the bypass switch: It can be opened or closed with zero voltage even if the bypass switch carries nominal ac line current. The inductive impedance of the damping reactor has been considered in the rating for the capacitor to achieve the precise line compensation rating of 70%. To limit the peak value current of the discharging capacitor, a reactor of 400 µH has been chosen for both series capacitors. This results in a discharge frequency of about 1100 Hz. The appropriate damping is achieved by a resistor of 4 ohms located in parallel to the damping reactor. To avoid a steady state current drain in the resistor, a small spark gap is also included in series with the resistor: The small gap fires for voltages exceeding the overload requirements of the capacitor. Therefore the resistor need not be rated for steady state conditions. The impulse energy rating of the resistor is sufficient for a duty cycle of two consecutive discharges.

5) Bypass Switch

The 550kV SF6-bypass switch is designed as three single-phase units, one for each phase with a rated voltage of 245kV across the open switch coils and a closing time of 50 ms. It consists of porcelain insulator columns with a hydraulic opening mechanism. The switch is used for insertion and disconnection of the bank. In case of internal faults, it also closes so the spark gap current commutates to the switch releasing the gap from further current stress. Initiated by the protection system it also closes if the rated MOV energy is exceeded. Due to this requirements the switch is designed for high frequency capacitor discharges as well as power frequency currents and dynamic short circuit currents up to 40 kA rms.
III. LAYOUT CONSIDERATIONS

The SC components are installed on a platform which is connected to the high potential of the ac-transmission line. This design leads to the lowest creepage distances and flashover voltages across the components. The platform itself is built up on reinforced structures of porcelain insulators to provide an appropriate line to earth creepage distance with a height of 6 meters. The capacitor is built up in two segments with four stacks in an “H”-connection to detect unbalances. The damping circuit resistor is located within the damping reactor coil. The two spark gap housings are installed on top of each other to save platform space. The MOV housings including the spares per phase are built up in two stacks. The bypass switch is not installed on the platform but located beneath the platform on the ground. Due to the optimized design the platform size is only 14m x 9m and has a total weight of about 40 tons. Fig. 8 show the platform layout and associated bypass switch for one phase.

IV. CONCLUSION

Sao Joao do Piaui series capacitor project consists of two series capacitor installations connected in series on two different lines entering Sao Joao do Piaui substation. The design of the components has been carried out by intensive studies to find an optimized solution for power transfer increase and stabilization of the existing network. The details of the component design are discussed in this paper. The layout as well as the single line diagram is object of discussion. With a nominal power rating of 484 MVA for BCS1 and 437 MVA for BCS2 the Sao Joao do Piaui series capacitors will provide stable and increased power transfer through the Maranhao-Bahia 550kV ac system corridor.

V. REFERENCES


VI. BIOGRAPHY

Lutz Kirschner, Senior Project Engineer, MIEEE, received his Diploma in Electrical Engineering 1992 from the university of Aachen, Germany. He joined SIEMENS company in the HVDC Department as a system design engineer. He was involved with technical and commercial design of HVDC converter stations. Since 1995 he is responsible for Fixed and Thyristor Controlled Series Capacitor design and was busy in several series capacitor projects carrying out the basic design studies. He is working on the design of Thyristor Protected Series Capacitor systems (TPSC) and FACTS devices. In the FSC Sao Joao do Piaui project he carried out the Final Basic Design Studies comprising the transient fault calculation and main component ratings. His special fields are time domain digital simulations and system studies. Since 1998 he is a member of IEEE.

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