Introduction:

Southern California Edison Co. has embarked on replacing several 500 kV series capacitors on its 500 kV transmission system. Some of these series capacitors were installed in late sixties and early seventies when the Pacific AC and DC inter-ties and the Eastern 500 kV transmission system was developed [1]. The series capacitors have been in service for 30 plus years and have practically outlived their economic useful life.

The series capacitors used the then prevalent spark gap protective bypass technology. The spark gap technology has required high maintenance and frequent testing to ensure the precise gap settings for voltage spark over protection thus resulting in higher maintenance costs and equipment outages. Maintenance and operational costs have also increased considerably as the equipment has aged and availability of the spare parts for replacement has diminished. The capacitor cans also have relatively higher losses.

With the modern technological developments and advancements in the field of capacitor cans and thyristors, SCE was faced with a challenge to choose one of the several alternative technologies for the new replacement series capacitor protection. SCE could replace the existing series capacitors with the old spark gap technology, use the metal oxide bypass protective technology which was developed around early eighties or could push the technological bar and go in for “Thyristor Protected Series Capacitors”. Considering all facts and economics, SCE decided in 1998 to proceed with the new “Thyristor Protected Series Capacitors” technology. Since then two such series capacitor banks have been already installed and are operating satisfactorily at SCE’s Vincent substation. Additional five banks are programmed for replacement in next four to five years.

This paper presents the new “Thyristor Protected Series Capacitors”, installed at Vincent substation.

Power System Configuration and Characteristics:

Southern California Edison Co. receives a significant share of its power demand from Pacific Northwest and Arizona-New Mexico-Nevada area to meet the high power demand of its 4.5 plus million customers. Several SCE owned resources were also located in Nevada (Mohave power plant), Arizona (Palo Verde power plant) and New Mexico (Four Corners). SCE also imports significant amount of inexpensive power from northwest (BPA, Canada), which is transmitted to California by the AC and the DC Pacific power transmission system. Since the distances between these power plants and the loads in Southern California Edison area are very large, the 500 kV transmission system to northwest and to east of California is mostly series compensated. The power transmission system was built in the sixties. Vincent substation is the north gateway for SCE and connects to the Pacific Gas and Electric transmission system. The SCE system works together with the Los Angeles Department of Power transmission system and are joint owners with them for the High Voltage DC line.

The AC Pacific Inter-ties have three Midway - Vincent 500 kV lines which are 105 - 112 miles long, and have 70 percent nominal series compensation. The total line impedance of these lines ranges between 65 to 70 Ohms. Series capacitor banks are located at each end at Vincent and Midway substation. These lines are part of the Pacific AC Inter-tie which inter-connects the Pacific Northwest US to Southwest US and their reliability is of extreme importance. The lines run and operate in parallel to the +/-500 kV HVDC line. The AC Pacific Inter-ties have a total capacity of 4800 MW. Each 500 kV line between Midway and Vincent is rated 3500 Amperes for N-2 outage conditions. The System is designed to operate for loss of a corridor that is two out of three lines, between Midway and Vincent substations.
Figure 1 above shows the 500 kV lines between Midway and Vincent and some other eastern substations.

**Series Capacitor Ratings and Requirements on Midway-Vincent lines:**

There are six Series Capacitor banks installed on three 500 kV lines between Midway and Vincent substations. Southern California Edison owns five of these six capacitor banks. The sixth one is owned by Pacific Gas & Electric Co. Each capacitor bank has nominal 24 ohms capacitive impedance. The series capacitor banks are rated for continuous current rating of 2400 Amps, and emergency half hour rating of 3500 Amps for half hour. The series capacitor banks are rated to ride over a maximum swing current of 4800 Amps without bypassing.

The capacitor banks have been designed to withstand a maximum short circuit duty of 40 kA on Symmetrical basis. Although, the short circuit duty is presently less, the banks have been designed for maximum anticipated short circuit duty. The typical fault clearing times used by SCE are 5 cycles for primary fault clearing protection and 15 cycles for secondary back up protection based on 60 Hz. The voltage protection presently on the series capacitor is provided by spark-over gaps which are set at 3.5 per unit voltage. Because of the technological limitations at the time, the series capacitor banks were installed, the voltage across each spark-gap had to be limited to between 50 to 60 kV maximum. This required that each series capacitor bank be segmented in four equal segments.

**Ratings of the Existing Series Capacitor Banks:**

The nominal system voltage rating of the series capacitor banks is 525 kV. The maximum rated continuous voltage is 550 kV and the series capacitors are mounted on platforms insulated for 1800 kV BIL. With a full load of 2400 amperes, the rated voltage across the series capacitor bank (all four segments) is 57.6 kV. There are four segments in each bank, with rated voltage of 14.4 kV and spark over gaps set at 50.4 kV (3.5 per unit). The spark gaps can be adjusted between 2.5 per unit to 4.5 per unit. The maximum transient voltage across the by pass switch can reach up to 210 to 215 kV. Each capacitor bank is rated for 400 MVAR approximately.

**Problems with Existing Series Capacitors Technology:**

The series capacitor banks used spark gaps and therefore, multiple segments in each capacitor bank. Reinsertion of these segments was always a challenge as insertion of each segment creates DC offsets and results in exceeding the over voltage limits. Also, adequate time has to be allowed for the plasma to cool off for successful reinsertion, the segments were inserted at least three cycles after the fault clearing time generally assumed to be five cycles. Several reinsertions attempts had to be made before all four segments of a series capacitor bank would reinsert for full capacitor bank operation. This also required higher gap setting design range of from 2.5 per unit to 4.5 per unit on each capacitor segment. Because of the reinsertion problems and to avoid delaying the reinsertion of capacitor banks, the spark gap protective setting of 3.5 per unit has been selected. Later series capacitor bank installations have used dual-gap schemes, nonlinear resistors, metal oxide resistors to reduce the problem of re-insertion [2,3,4]. The main spark-gap protection which is a triggered vacuum gap does provide a very fast bypass when the voltage exceeds the setting and the spark-gap is triggered.

The metal oxide bypass protection technology developed around late seventies and early eighties became more prevalent and then it became difficult to obtain spare parts for the spark-gaps which are one of the very high maintenance items.

Also, since these capacitor banks were installed in late sixties, the seismic standards at that time were not developed and the series capacitors were designed to a relatively lower seismic withstand level.

**Reasons for Replacement:**

SCE is replacing these series capacitors for several reasons. The capacitor cans used are thirty plus years old using paper film technology with high dielectric losses. The new capacitor cans will reduce the losses significantly. The new capacitor cans are also much lighter and comparatively, lot more MVARS can be packed in one capacitor can. The control and protective system is old and is requiring excessive maintenance. As discussed above, it has very poor reinsertion performance which can degrade the reliability of the AC Pacific interties. The protective level is also very high requiring much higher dielectric withstand capability, and with modern technologies which can provide superior reinsertion performance, can be reduced to 2.0–2.5 instead of 2.5 to 4.5 per unit levels. Reducing the series capacitor bypass level also helps in reducing the transient SSR torques on the nearby generating machines.

Since the technology is thirty plus years old the system requires spare parts which are hard to obtain. The series capacitor banks were designed for a much lower seismic withstand and some of them were damaged in the January, 94 Sylmar earthquake.

**Series Capacitor Replacement project at SCE:**

The project included replacing five SCE owned series capacitor banks out six series capacitor banks on Pacific AC Inter-tie between Midway and Vincent.

substations. In addition, SCE owns several other series capacitor banks on the eastern transmission system, most of which were installed around the same time. Since all these capacitor banks were getting old and requiring high maintenance, SCE embarked on a major series capacitor replacement program starting 1996-97 to replace seven series capacitor banks. Also, the capacitor banks are installed at the substations. Most of the substations, where these series capacitor banks were to be installed, have relatively high short circuit duty thus imposing the need of higher energy withstand capability for metal oxide protected series capacitors.

Search for New Technology:

Contacts were made with several manufacturers to assess the technical performance of the series capacitor available technologies. Also, SCE was interested in getting a technology, which could be enhanced and modified to obtain additional benefits of Thyristor Controls in future. SCE did have experience with a research project done jointly with EPRI, and several other utilities of installing a NGH device, which uses thyristors to selectively bypass the series capacitor bank every half cycle if the half cycle exceeded the 8.33 millisecond time. This device has been in operation for last 14 years and had worked satisfactorily [5,6]. The thyristors fire only when the conditions are abnormal that is when there are sub-synchronous currents present in the line currents. Since the thyristors fire only for short durations, they do not require water-cooling and the device has a simple design. SCE started seeking a similar technology such as the NGH device at Lugo substation. This NGH device filters out the sub synchronous currents from the 500 kV line and avoids any electro-mechanical sub synchronous resonance interaction with the machine mass-spring system.

Since the program included replacement of six to seven series capacitor bank, which need to last next thirty years, a superior technology was most desirable. The specification was written and flexibility was included for the manufacturers to submit newer technological developments such as Thyristor Protected Series capacitors developments. The bids indicated that a TPSC could cost less than the metal oxide protective series capacitors thus providing superior performance and slightly lower costs.

Thyristor Protected Series Capacitor (TPSC)

The “Thyristor Protected Series Capacitor” technology is a new technology but very much similar to the technology used in the NGH device developed about 15 years ago. They use thyristors for protection, is simple does not require water cooling The Thyristor Protected Series Capacitors can be upgraded to a regular Thyristor Controlled Series Capacitors by addition of water cooling and some additional series reactors.

The first TPSC was installed at SCE Vincent substation on April 15, 2000. Figure 2 shows this installation. The second bank was completed on April 15, 2001. The third bank installation has been recently released and is due for completion by April 2003. There are four additional capacitor banks to be replaced under this program by year 2005-2006. SCE experience has been that TPSC can provide a superior technology at lesser cost.

Design Requirements & Environmental Conditions:

The new series capacitor banks are designed to withstand a maximum Ambient temperature of 50 degrees C, twenty four hour average temperature of 30 Degrees C, Minimum Ambient temperature of -10 Degrees C. The banks are designed to withstand a peak Solar Radiation of 100 Watts per square foot, wind blown dust, sand and precipitation. The series capacitor bank and all equipment are designed for outdoor installation. All the electronics at the platform is designed for outdoor installation, humidity of 0-100 percent non-condensing. The area has high seismic activity and the series capacitors are designed to meet the IEEE 693.

Thyristor Switch:

The Thyristor switch of the TPSC is the major new development and provides the new technology. It has been designed to operate as a single switch across the entire series capacitor bank thus eliminating multiple segments. Figure 3 shows the inside of a thyristor switch. with the thyristors stacked in different frames.

One Thyristor switch for the entire series capacitor bank reduces the problem of DC offset during re-insertion. The nominal voltage across the thyristor switch at series capacitor full load is 57.6 kV (24.0 Ohms
x 2400 Amperes). The maximum transient voltage during re-insertion can reach up to 184 kV. There are 42 thyristors in each string. The series capacitors are designed to stay in service for a swing current of 4800 amperes, which can subject the thyristors to a voltage of 115 kV (rms). The series capacitors have been designed to reinsert at currents of up to 3500 amperes.

Figure 3: Figure showing the inside of a Thyristor switch with the thyristors stacked in different frames.

The switch uses thyristors, which are five inches in diameter, with 7.5 kV voltage rating. The thyristors are light triggered thyristors. The light triggered thyristors minimize the electronics within the thyristor switch cubicle. Figure 4 shows a thyristor and the figure 5 shows the thyristors stacked in the frame and the connected light guide.

Figure 4: The five inch light fired thyristor used in the thyristor switches.

The Thyristor Switches are designed for fail-safe operation, are continuously monitored to detect failure of thyristors. Any failure would be immediately alarmed and the series capacitor would be bypassed. The thyristors are easily replaceable. The equipment is designed for outdoor installation.

Figure 5: Figure showing thyristors stacked in the frame with connected light guides.

Conclusions and Summary:

The Thyristor Protected Series Capacitors can provide fast, efficient series capacitor bypassing scheme. The thyristors can also reinsert series capacitors faster than the other conventional scheme. The thyristor protected series capacitors may also not be very sensitive to the short circuit duty as are the metal oxide protected series capacitors. In fact, for SCE project, the TPSC were found to be more economical compared to the metal oxide protective series capacitors. The TPSC can be designed for future upgrades to a fully operational Thyristor Controlled Series Capacitor.

The TPSC can be designed to provide sub-synchronous resonance protection similar to a NGH device installed at SCE’s Lugo substation. Appropriate control logic can also be used for intelligent insertion, reducing DC offsets and reducing transient over voltage stress.

The first series capacitor bank installation at Vincent substation was completed on April 15, 2000 and the second series capacitor bank was installed on April 15, 2001. The construction for the third series capacitor bank is in progress and will be completed by April 15, 2003.

The installation of the TPSC at SCE Vincent substation has advanced the series capacitor protection technology and has provided better performance at lower cost to SCE.
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Note/Disclaimer:

This paper represents the views of its authors and does not necessarily represent the views of Southern California Edison Co. or its parent organization Edison International.

References :


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