Deregulated generation markets, open access to transmission, regional differences in production costs, permitting delays and investment uncertainty have led to increased utilization of existing transmission facilities. Increased utilization places additional focus on economic means to increase transfer capability and maintaining adequate system reliability of aging transmission infrastructure. For a major Northern California utility, the capacity and reliability of aging transmission equipment was of concern. The first major concern was the reliability of vintage series compensation on the Pacific AC Intertie, a vital, two-circuit 500 kV link between the Pacific Northwest and Southern California constituting the backbone of the utility transmission system spanning northern and central California.

**Replacement of series capacitors**
Series compensation was installed about 30 years ago. Typical compensation levels were 70 percent and current ratings were 1800 amperes on eleven remaining old capacitor banks. All old capacitor banks were protected with spark gaps. Increased transfer capacity, both continuous and emergency overload, was desired. Rather than replacing these capacitor banks on an in-kind basis, however, an analysis was made to determine the optimum replacement solution. This analysis took into account the bank ratings, compensation levels, impact on transfer level economics, number of segments, protection criteria and overall replacement economics to determine the optimum replacement strategy.
The study concluded that the new banks should consist of the following:

- Increased continuous rating of 2667 A
- Emergency overload rating of 4000 A
- Same line compensation level but equally split between the two half line lengths
- Gapless protection
- Fewer segments
- Redundant control and protection system
- New mid-line location at Gates

All in all, a total of 11 ABB series capacitors have been commissioned between 1998 and 2006: at Round Mountain (four), Table Mountain (two), Gates (four), and Midway (one). Time scales were coordinated, to minimize series capacitor outages. On top of this, two more ABB series capacitors have been in operation since 1986, one at Tesla, and one at Table Mountain.

**Upgrading**

Additionally, an ageing Series Capacitor at Vaca Dixon was upgraded and re-commissioned in 2004. In this procedure, the old control system was replaced by the state-of-the-art ABB MACH 2 control and protection system. A new current measurement system and fiber optic platform was also installed, as well as interface to the existing MOV, spark gap and bypass switches.

The purpose of all the series capacitors is to increase the dynamic stability of this heavily utilized 500 kV system, so raising the availability and power transmission capacity of the grid. Thereby, the replacing of the series capacitors will contribute importantly to alleviation of the lack of power which might otherwise cause trouble in many cases.

**Series capacitor schemes**

All 11 series capacitors supplied since 1998 are gapless. In the event of faults in the transmission system, the main protection of the series capacitors is achieved by means of metal-oxide varistors (MOVs) in parallel with the series capacitor. In cases of internal faults, i.e. faults located inside series-compensated line segments, the series capacitor is bypassed by closing a bypass switch. After the fault has been cleared, the series capacitor is re-inserted into operation by opening the bypass switch.
The main circuit design is the same for all, with the following exceptions:

- All except Gates and Round Mountain North have one segment only. At Gates and Round Mountain North, each series capacitor has two segments.
- The bypass switch closes in 20 ms at Gates and Midway. In all others, the switch has a closing time of 50 ms.

The current rating is 2667 A for steady-state conditions and 4000 A for 30 minutes emergency overload. The capacitors have internal fuses.

The series capacitor control and protection is implemented by the ABB MACH 2 microprocessor based system. Optical current transformers (OCTs) are used for current measurements. Optical fiber links are used for signal transmission to and from the EHV series capacitor platforms. The fiber optics have built-in redundancy.

This ABB series capacitor system provides the following features:

- No relay protection or electronics needed on the platforms.
- No auxiliary power supply or battery required on the platforms.
- OCTs are powered solely by light generated at ground potential.
- Bank supervision, diagnostics and logging functions are included to give full control and overview of installations.
- Continuous self monitoring is employed, thereby extending maintenance intervals and reducing maintenance costs.
- Full redundancy of the control and protection system to ensure extremely high reliability and availability.

### Main technical data of the series capacitors

<table>
<thead>
<tr>
<th></th>
<th>Rated power, Mvar (3-phase)</th>
<th>MOV rating, MJ (3-phase)</th>
<th>Reactance ohm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gates North</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>584</td>
<td>693</td>
<td>27.4</td>
</tr>
<tr>
<td>II</td>
<td>584</td>
<td>621</td>
<td>27.4</td>
</tr>
<tr>
<td><strong>Gates South</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>545</td>
<td>495</td>
<td>25.6</td>
</tr>
<tr>
<td>IV</td>
<td>545</td>
<td>457</td>
<td>25.6</td>
</tr>
<tr>
<td><strong>Midway</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>504</td>
<td>432</td>
<td>23.6</td>
</tr>
<tr>
<td><strong>Vaca Dixon</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Upgrading of existing series capacitor)</td>
<td>384</td>
<td>213</td>
<td>18</td>
</tr>
</tbody>
</table>

(In the upgraded Vaca Dixon series capacitor, the original spark gap scheme has been preserved.)
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