CASE STUDY

American Electric Power (AEP)—South Texas, United States

Innovative Phase-Angle Control Helps AEP Optimize Power Flow on Transmission Grid

AEP (American Electric Power) has installed 138 kV, 150 MVA phase-shifting transformers (PSTs) on the ERCOT (Electric Reliability Council of Texas) transmission grid. Three units went into service in 2006, one in 2007, and at least one installation is planned for 2008. These transformers were selected to help optimize power flow from existing transmission system assets until future 345 kV line construction projects can be completed. The delta/hex PSTs deployed in South Texas are a new, single-tank design that promises to be much more economical than previous designs.

These specialized transformers require a protection system that is redundant, sensitive, and secure for all types of faults, including turn-to-turn faults in the transformer and its surrounding buswork. In addition, a flexible, automated PST control is required. AEP selected a combination of conventional protection concepts and a completely new differential protection system that compensates for the variable phase-angle shift introduced by operation of the PST. Traditional percentage-restrained transformer differential protection could not be used because of the continuously variable phase shift across a PST. The protection system incorporates a series of relays from Schweitzer Engineering Laboratories (SEL), Pullman, Washington.

Initially, the original transformer manufacturer was to provide the PST controls per AEP specifications. However, because automated controls were required, the customer decided that a device with extensive programmability was needed to provide the desired "one-pushbutton-in-service" and "one-pushbutton-out-of-service" capabilities. AEP commissioned SEL to engineer, configure, and program this control system.

Figure 1—First of several PSTs under assembly

While SEL is perhaps best known for their prowess on the protection side of power systems, the company also provides innovative products and services for the control side, including engineering, programming, installation, and training. SEL developed the power flow regulating tap-changer control to meet the AEP project requirements.

"PSTs, also called phase shifters or PAR (phase-angle regulating) transformers, are becoming more popular," says SEL's Michael Thompson, "because they are considered FACTS devices, or flexible ac transmission system devices. There is a lot of interest in getting more power down existing lines, which requires advanced power-flow regulation."

Thompson adds that while PSTs are becoming a more common tool to optimize transmission assets, until now the controls have often been operated manually. "SEL has been able to automate the control technology to enable the system operator to simply input a megawatt set point, allowing the tap-changer control to automatically regulate according to the operator's requirements," he says.

Regulating the Angle and Flow

Because power flow through a transmission line is largely a function of the angle between two voltages, if the angle across the line can be regulated, the power flow can also be regulated. Power can be increased by introducing a phase angle that is additive (advance). Conversely, by introducing an angle that is subtractive (retard), the power can be reduced.

PSTs typically inject a quadature voltage into each phase between the source and the load bushings to induce phase shifting. Traditional PST designs require two transformer cores to accomplish this task. However, a new type of single-tank PST has emerged. This new design promises to improve the economic viability of deploying such devices on the transmission grid.

On the delta/hex PST, the three excitation windings and three regulating windings are connected in a delta/hex configuration. Two three-phase tap-changers are installed: one for the source terminals and one for the load terminals. Each tap-changer mechanism moves its terminals up and down the regulating winding to create the phase shift across the transformer. When the two tap-changers pass each other, the transformer shifts from advance to retard operation.

"AEP's PST control system is based on the SEL-451 Protection, Automation, and Control System as the core for a transformer tap-changer control," Thompson explains. "In addition to controlling power flow, the tap-changer control provides automatic detection of improper tap operation sequences and overload conditions. Included are alarms and remedial action schemes that will alert key personnel and take proper actions if a problem occurs."

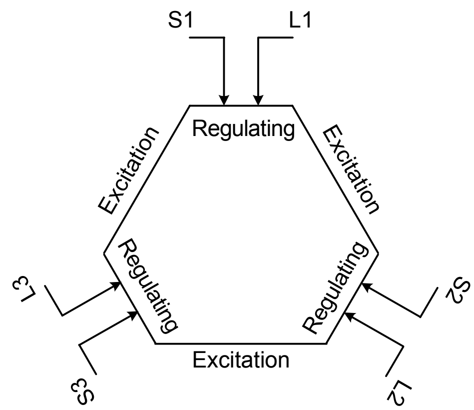

Figure 2—Delta/hex configuration has two tap-changers

An Automated Control System

SEL engineers designed and installed the first of the PST control systems within a few weeks of AEP's request. After testing the system with the AEP Protection and Control group, engineers from their Operations group added new specifications to take advantage of the PST overload capabilities without undue risk of thermal damage.

In addition to the automated control system, Thompson explained, "The design documentation was an important deliverable in this project. We wrote a comprehensive instruction manual so others can understand how the tap-changer control works."

The primary PST control device is an SEL-451 connected to an SEL-2100 Logic Processor. The SEL-451 receives information on the open/close status of the bypass, load, and source breakers via the communications links through the logic processor. The programming prevents invalid switching sequences that can result in a trip or damage to the PST.

"For example, there are three different ways for the control to check to see if the PST is on neutral or not," Thompson explains. "If you try to bypass a transformer that is not on neutral, you are going to get some tremendously high circulating currents, so high it would look like a fault. It is necessary to be absolutely sure that it is on neutral before you start any automatic procedures to put the transformer in or out of service."

The control provides information through AEP's SCADA system to the operations center. Electronic information is available inside the local area network at each of the substations, so the control can automatically make appropriate decisions as to when to provide a bypass and when to place the unit in service. If the operator (dispatcher) starts to place the unit in service and it fails, a routine check will send a warning, for example, if the dispatcher starts to put the unit in service and it fails, the control returns a message "incomplete automatic sequence" and aborts the process.

"Through the SEL-451, the control provides automatic or manual control of tap-changer position and gives operators complete command of all tap-changer functions with automatic safeguards to prevent overload conditions," Thompson says. "Programming automatic sequences to run the tap-changer position to neutral and open and close breakers and motor operated disconnect (MOD) switches in the correct order enhances safety."

The tap-changer control maintains precise regulation of system power flow. Automatic control functions within the tap-changer control include a power-flow dead-band control with adaptive bandwidth.

Adaptive Bandwidth Control

Thompson notes that one of the problems with automatic control of a discrete step device such as the PST is "hunting." Hunting occurs when a tap step results in a change in power that is near or greater than the total bandwidth. For each tap step, the power change can overshoot the band, and the regulator will soon attempt to step in the opposite direction. Selecting a high bandwidth will reduce the possibility of excessive operations and hunting but result in poor regulation around the desired set point. The tap-changer control installed on the AEP transformers includes a method for adapting bandwidth based on measured power changes.

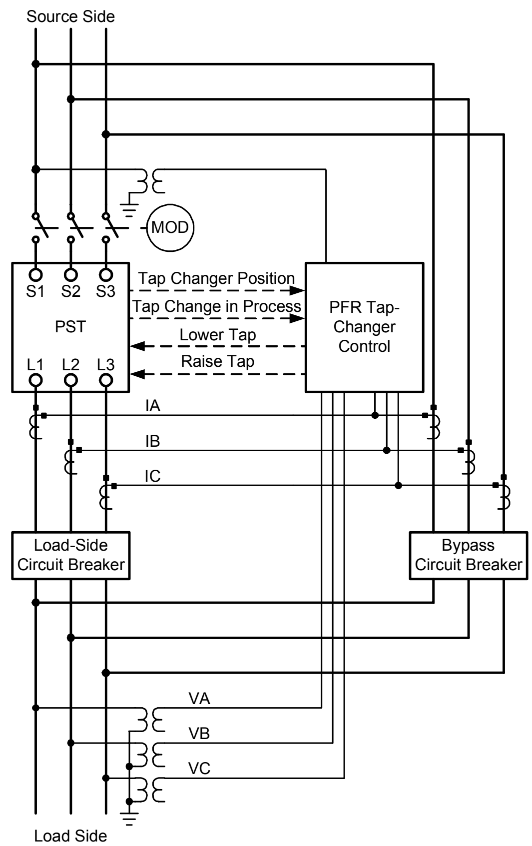

Figure 3—The tap-changer control measures real power flow from source to load and controls the tap-changer to regulate power flow when the bypass is open

"The adaptive bandwidth function is one of the powerful innovations incorporated into the SEL tap-changer control," Thompson says. "It stores the most recent eight tap changes in memory registers. So, in effect, it 'learns' with each step. From the operator set point and bandwidth, the control calculates the upper and lower band limits. To prevent operation above the user-settable maximum automatic regulation set point, the control also calculates band limits from the MVA rating and the measured power factor of the load through the PST and uses the more restrictive of the two limits. Without the adaptive bandwidth capability, the AEP controls would not have worked."

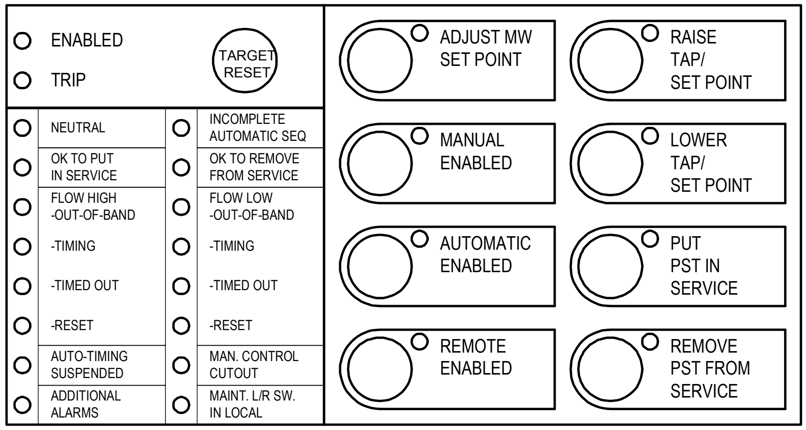

Figure 4—In addition to remote control via SCADA, the local user interface allows complete control and indication of PST functions

About AEP

Headquartered in Columbus, Ohio, AEP is one of the largest electric utilities in the United States, delivering electricity to more than 5 million customers in 11 states. AEP ranks among the nation's largest generators of electricity, owning nearly 38,000 megawatts of generating capacity in the United States. AEP also owns the nation's largest electricity transmission system, a nearly 39,000-mile network that includes more 765 kilovolt extra-high voltage transmission lines than all other U.S. transmission systems combined.

About SEL

SEL has been making electric power safer, more reliable, and more economical since 1984. This ISO 9001:2000-certified company serves the electric power industry worldwide through the design, manufacture, supply, and support of products and services for power system protection, control, and monitoring. For more information, visit www.selinc.com, or contact SEL by phone: +1 (509) 332-1890; fax: +1 (509) 332-7990; or mail: 2350 NE Hopkins Court, Pullman, WA 99163, USA.

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