INNOVATIVE POWER FLOW REGULATING TAP-CHANGER CONTROL INSTALLED ON MULTIPLE PHASE-SHIFTING TRANSFORMERS

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ABSTRACT

This paper describes the development and installation of a power flow regulating tap-changer control that has been installed on multiple phase-shifting transformers (PSTs) on the AEP system. These transformers are also known as phase angle regulating (PAR) transformers because they control the phase angle across a networked transmission system branch circuit to regulate the real power flow in that branch of the transmission grid. PSTs regulate the phase angle by inserting a quadrature voltage into each phase by action of a tap-changer mechanism. AEP installed the PSTs to optimize power flow on existing transmission assets until planned transmission system upgrades are complete.

Historically, most PST installations have been manually controlled because the regulated quantity, power flow, is only indirectly controlled by the position of the tap changer. The actual change in power for each tap step is a function of system conditions so it is easily possible that an automatic control will hunt (control action overshoots the regulation dead band which causes the tap position to continually change). AEP desired a control that would provide automatic regulation to an operator set point. This requirement led to the development of a control with an adaptive bandwidth feature that learns system conditions to prevent the possibility of hunting. In addition to local and remote, automatic and manual control, the control includes automatic features such as one-button "take off bypass and put in service" and "put on bypass and remove from service" automatic switching sequences to ensure proper switching sequences and operator safety. The first of five units was energized in the summer of 2006 and the most recent was energized in the summer of 2007. All installations are operating satisfactorily.

INTRODUCTION

American Electric Power (AEP) is applying 138 kV, 150 MVA phase-shifting transformers (PSTs) on the ERCOT transmission grid to help optimize power flow. The simplified equation (neglecting losses and shunt admittances) for the power flow through a transmission line is shown as (1) [1].

$$P = \frac{E_S \bullet E_R}{X_L} \sin \delta \qquad (1)$$

Where:

- E_S is the sending end voltage
- E_R is the receiving end voltage
- X_L is the series reactance of the transmission line
- δ is the angle between the two voltages

Examination of this equation reveals that power flow is largely a function of the angle between the two voltages. If the angle across the line can be regulated, the power flow through the line can be regulated. By introducing an angle that is additive (advance), power flow can be increased. By introducing an angle that is subtractive (retard), the power flow can be reduced.

PSTs typically introduce this phase shift by injecting a quadrature voltage into each phase between the source and load bushings. For example, a voltage in phase with V_{BC} or V_{CB} would be combined with V_A to produce a phase shift between the S1 and L1 terminals of the transformer. Figure 1 shows a diagram of the PSTs that AEP is using.

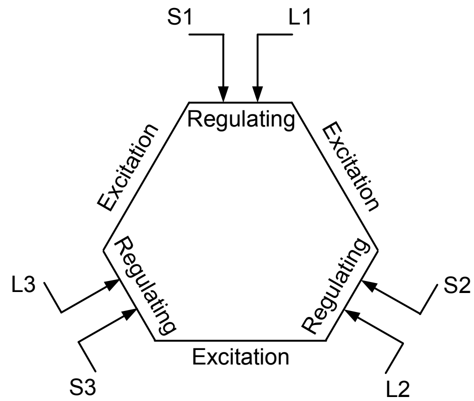

Figure 1 Delta/Hex Phase-Shifting Transformer

The three excitation windings and the three regulating windings are connected in a delta/hexagonal configuration. There are two three-phase tap-changer mechanisms—one for the source terminals and one for the load terminals. Each tap-changer mechanism moves its three 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. Each tap changer is moved alternately such that their tap step maintains a symmetrical distance from the midpoint of the regulating windings. The manufacturer specifies that no more than one step off of symmetrical positions is allowed to maintain the health of the transformer.

Historically, most PST installations have been manually controlled because the regulated quantity, power flow, is only indirectly controlled by the position of the tap changer. AEP desired a control that would provide automatic regulation to an operator set point. In addition to local and remote, automatic and manual control, the control was required to include automatic features such as one-button "take off bypass and put in service" and "put on bypass and remove from service" automatic switching sequences to ensure proper switching sequences and operator safety. The original tap-changer control that was supplied with the PST did not meet these requirements.

The scope of the project included: development of a power flow regulating tap-changer control that exceeded AEP's requirements and satisfied the transformer OEM's requirements to ensure that the warranty of the transformer would not be voided, development of a complete design documentation package including detailed logic diagrams and an instruction manual, and on-site testing and commissioning support.

BACKGROUND AND GENERAL INFORMATION

AEP installed three, 138 kV, 150 MVA PSTs in South Texas in the Electric Reliability Council of Texas (ERCOT) region in 2006. At each location, AEP Texas Central Company (TCC) studied the system needs and requirements due to unique system problems. In each case, a PST provided the best solution. The PST, in conjunction with other system upgrades, was determined to be the most economical solution to rectify the existing system problems. Reference [1] discusses the application of these PSTs in more detail.

These PSTs provide AEP, as the transmission owner, a cost-effective means to support free market generation while preventing overloads on the transmission grid. Since the original three PSTs have been installed, AEP has installed a fourth in 2007 and is planning to install a fifth in 2008.

Figure 2 shows the arrangement of the PST installations in AEP's substations. The PST includes a bypass circuit breaker to allow the PST to be removed from service. The source side of the installation is connected to the previous line circuit breaker(s) and the line relaying is moved to the new load side and bypass circuit breaker. A source-side Motor Operated Disconnect (MOD) switch is included to isolate the PST when it is removed from service. This disconnect switch is rated to interrupt the transformer magnetizing current. When switching, the parallel paths are opened by a circuit breaker.

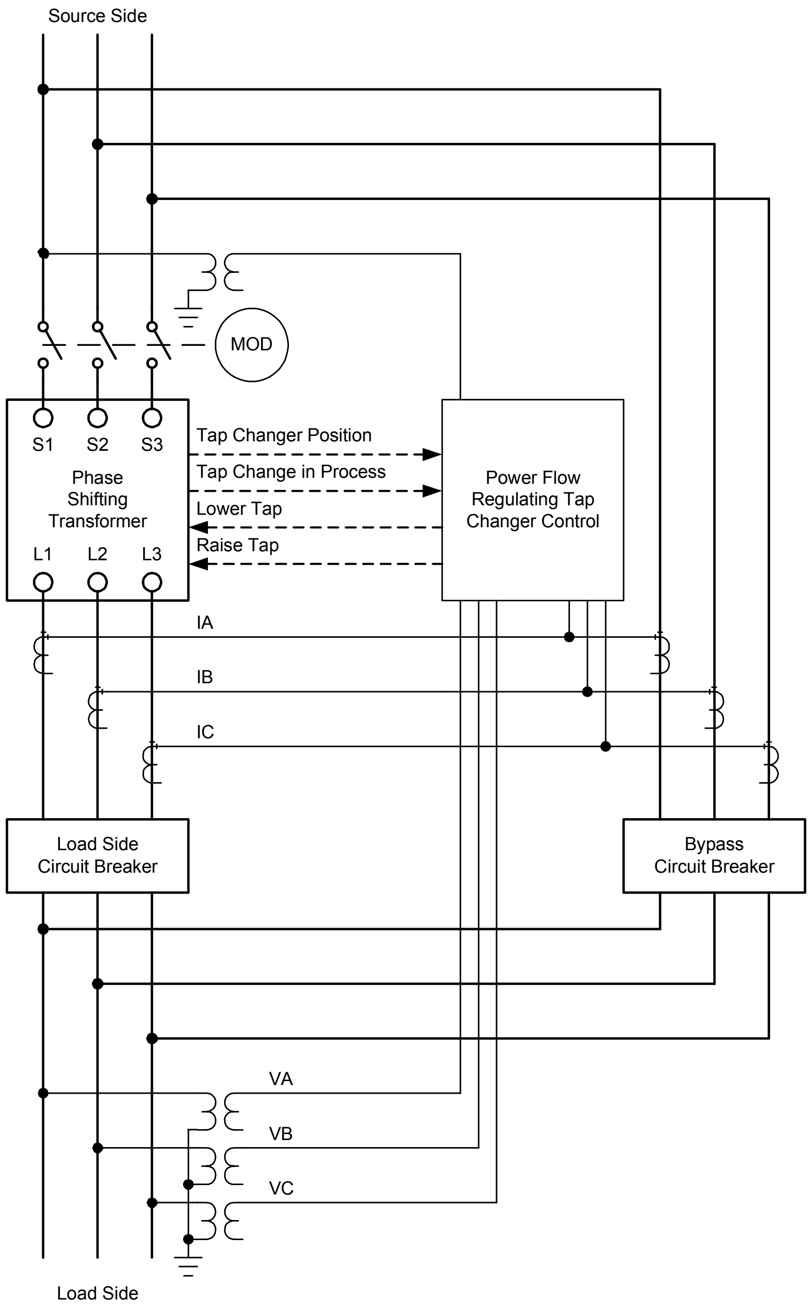

Figure 2 AEP PST Installation

Sensing connections are connected between the instrument transformers on the power system and the controller as shown in Figure 2. These include:

- Three-phase voltage and current at the load-side terminals of the PST.
- Single-phase voltage at the source-side terminals of the PST for voltage angle confirmation of neutral status.

From these parameters, it measures:

- Apparent power (S).
- Real power (P).
- The power factor (PF) (ratio of P/S).

Control signals are connected between the tap-changer mechanism and the controller. These include:

- Output contacts for raise and lower pulses to the motor circuits.
- Input contacts for motor running status.
- Binary Coded Decimal (BCD) tap-changer position signals.
- Alarm contacts from the tap-changer mechanism.

PST Control Challenges

A discrete step-regulating device typically includes a desired operational set point and a +/– bandwidth above and below the set point. Because the regulated parameter will change in discrete steps, it is not possible to always operate at exactly the operational set point. The +/– bandwidth defines the allowable range around the operational set point before a step change is initiated to bring the regulated parameter back closer to the desired operational set point. If the regulated parameter is within the band limits, no automatic tap changes are required. When the regulated parameter is outside of the band limits for a user-settable period of time, the automatic regulating device will initiate a tap step change in the direction required to bring the regulated parameter back to within the band limits.

Traditional transformers include tap changers for the purposes of regulating the voltage at the secondary of the transformer. In these applications, there is a direct and linear relationship between the tap step parameter (transformation ratio) and the regulated parameter (secondary voltage). In the case of a PST, the tap step parameter is degrees of phase angle shift and the regulated parameter is real power, P.

Equation (1) defines the relationship between phase angle and power flow. Examination of (1) shows that the change in power (ΔP) for each tap step is a function of system parameters. The transfer impedance, X, will typically be dominated by the line impedance, which is constant. But, the system source impedances will also affect the function. The angle δ affects the function as a sine function and therefore is not linear across the range of possible system load angles. The voltages E_S and E_R will be relatively constant in a normally operating power system. Based upon this review, it is expected that the ΔP for each tap step will vary somewhat from installation to installation and from time to time based upon system operating parameters.

The selection of a bandwidth setting must be balanced to provide optimal operation. Setting the bandwidth too low can result in excessive numbers of operations. It can also result in hunting. Hunting occurs when a tap step results in a ΔP that is near to or even greater than the total bandwidth. For each tap step, the ΔP can overshoot the band and the regulator will soon attempt to step in the opposite direction. Selection of a high bandwidth will reduce the possibility of excessive operations and hunting; but result in poor regulation around the desired set point. The control that was developed includes a method for adapting the bandwidth based upon measured ΔP.

PST CONTROL FEATURES

The power flow regulating tap-changer control that AEP had developed includes the following protection monitoring and control features:

- Local and remote manual control to raise and lower the tap position.
- Interface to SCADA RTU via DNP3 protocol
- Automatic tap-changer control to maintain power flow at a set point +/– the bandwidth.
- Adaptive bandwidth logic to optimize regulation while preventing hunting.
- Automatic regulation to keep loading below the PST's maximum automatic limit.
- Inverse timing overload element that allows maximum use of the available capacity and automatic reduction of loading to relieve overload before PST is damaged.
- Automatic suspend-automatic-operation functions to prevent operation during times where the tap changer can be damaged or if there are abnormal operating conditions.
- One-button automatic sequence to run tap changer position to neutral.
- One-button automatic sequence to put PST in service.
- One-button automatic sequence to remove PST from service.
- Local annunciation and remote communication of status and alarm conditions.
- Local and remote indication of tap-changer position, power flow conditions, and motor operational parameters.

Figure 3 shows the local user interface for the control. All control and indication functions can be accessed locally via this control panel or remotely via a DNP3 SCADA link.

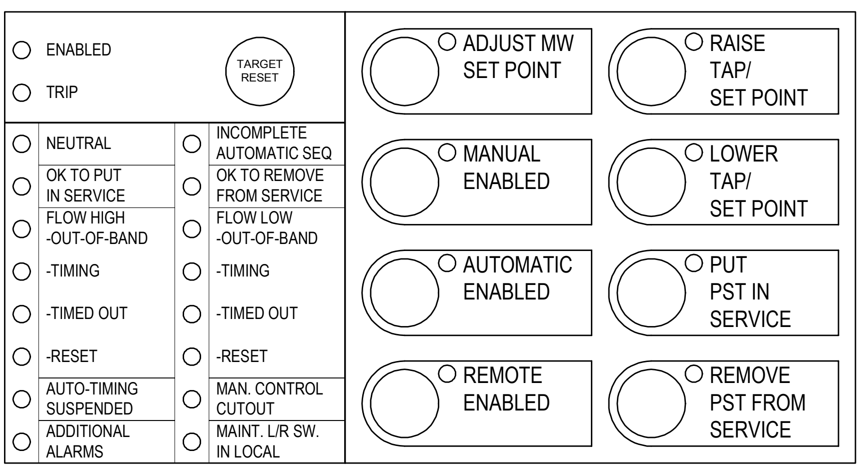

Figure 3 User Interface

POWER FLOW REGULATION

Regulation Set Point Logic

System operators can enter a set point to which the control will attempt to regulate the power flow when automatic control is enabled. The regulation set point is adjusted by system operators based upon operating criteria given by system planning engineers. The power flow set point, in MW, can be adjusted locally and remotely to any forward or reverse value within the maximum automatic control limit setting. The value is signed such that a positive set point indicates power flowing out of the load bushings of the PST and a negative set point indicates power flowing into the load bushings of the PST.

The +/– bandwidth is the amount of power above or below the regulation set point that the power is allowed to vary. The total bandwidth is two times the +/– bandwidth amount. As long as the power flow through the PST is inside the upper and lower limit, no tap changes will be required.

Ideally, the +/– bandwidth should be the same as the ΔP that will result from one tap step. If this is the case, each time the power flow reaches the edge of the bandwidth, one tap step will bring the power flow back exactly to the set point.

Adaptive Bandwidth Logic

The adaptive bandwidth function stores in memory registers the absolute value of the ΔP from the most recent eight tap changes as shown in Figure 4. The adaptive +/– bandwidth is calculated as the average ΔP of the most recent tap changes. A user setting is provided to determine how many values are to be averaged in adjusting the +/– bandwidth. A multiplier setting is included to easily reduce the bandwidth to improve regulation or widen the bandwidth if the number of operations becomes excessive. A user setting is provided to define an initial +/– bandwidth that the control will use until the ΔP from actual tap change operations has been recorded. The memory registers are preset to the user setting for initial +/– bandwidth when the control is toggled from manual to automatic.

From the set point and bandwidth, the control calculates the upper and lower band limits. Or, to prevent operation above the user maximum automatic regulation set point, the control calculates the band limits from the MVA rating and the measured power factor of the load flow through the PST.

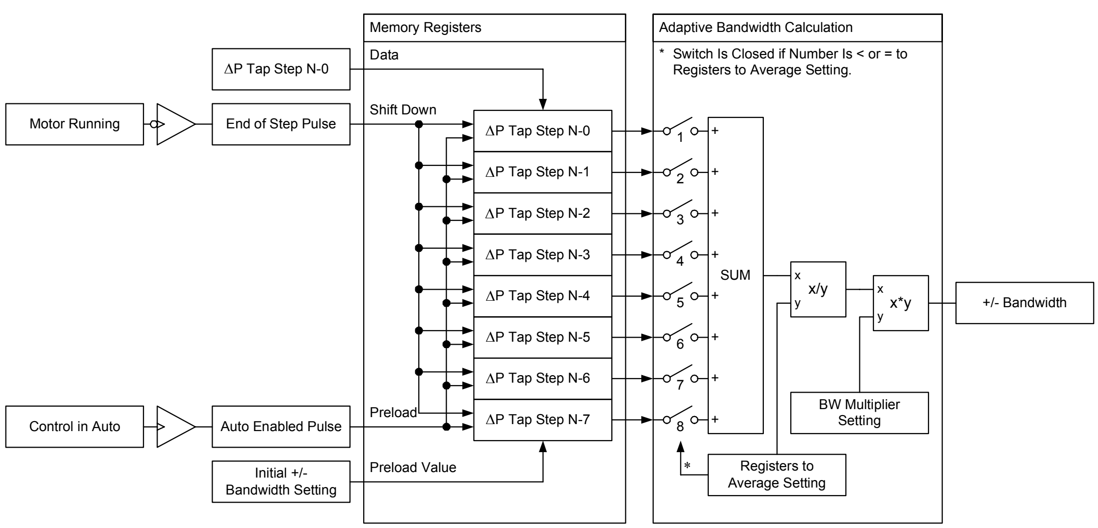

Figure 4 Adaptive Bandwidth Function

Integrating Timers Logic

Integrating timers are used to initiate tap changes. If automatic control is enabled, once the measured real power flow goes out-of-band high, or out-of-band low, for a set time delay, a tap change will be initiated in the correct direction to move the power flow back closer to the set point. The timers are integrating timers that count up when the power flow is out-of-band and count down when the power flow is in band.

Refer to Figure 5 for the following discussion. One way to understand the characteristics of an integrating timer is to envision a clock hand that moves clockwise or counter clockwise depending upon which input is asserted. When the hand is against the Reset stop, the timer is reset. If the hand is moved clockwise more than it is moved counterclockwise, it will eventually reach the Expired stop. When it does, the expired output asserts. An integrating timer is superior for this type of application where the parameter to be timed can be right on the edge of the band limit and the input continuously sets and resets. An integrating timer will eventually time out and initiate a tap change if the aggregate time that the power flow is out-of-band is greater than the time that the power flow is in-band.

Eight LEDs are provided to indicate the status of the two timers and the measured power flow relative to the band limits. See Figure 3.

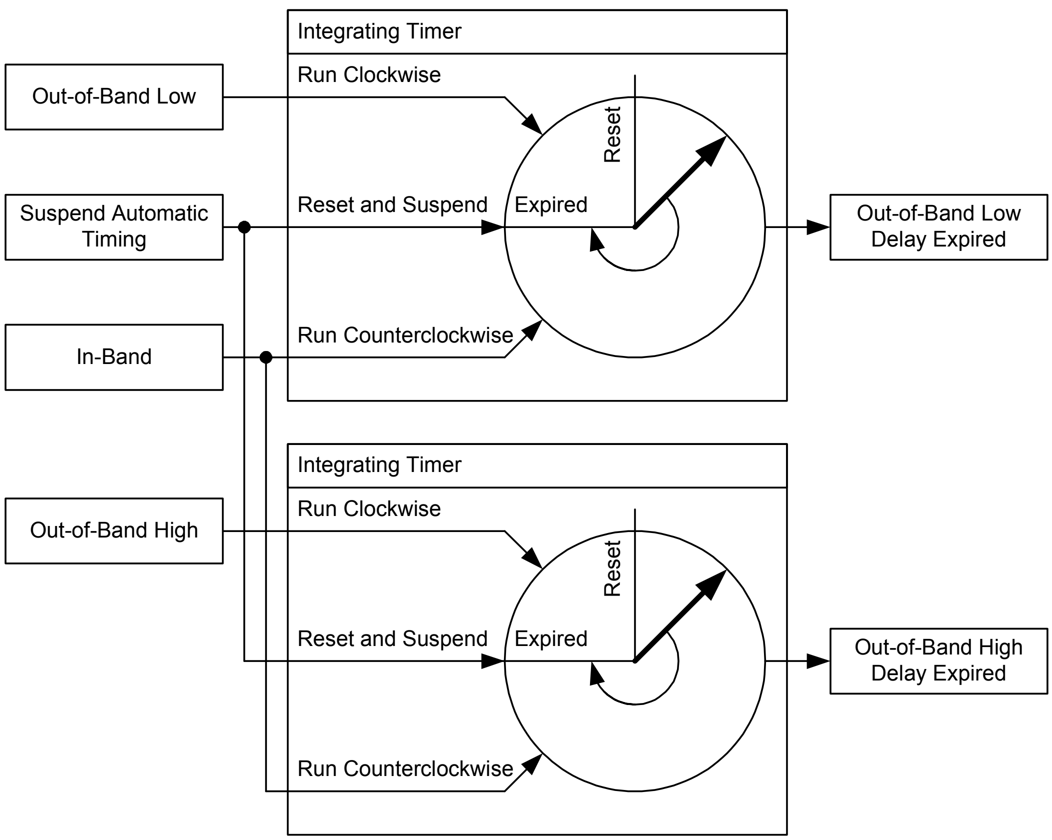

Figure 5 Integrating Timers

AUTOMATIC CONTROL MONITORING FUNCTIONS

Abnormal operating conditions can result in the regulator attempting to adjust the power flow improperly, which will result in the tap changer continuing to change taps until it reaches one of its extreme positions.

Tap Step Wrong Direction Logic

One such abnormal operating condition that can result in a drive-to-extreme operation is if a problem occurs in the tap-changer control circuits, which causes a tap lower or raise operation to have the opposite effect. In this case, for example, if the power flow goes out-of-band high, the regulator will attempt to correct by adjusting the tap to lower the power flow. Due to a problem, this only causes the power flow to increase instead of decrease, which takes it even further out-of-band. The cycle will continue until the tap changer is at its extreme position. The control includes logic to measure the ΔP and suspend operation if it is not as expected.

Line-Open Logic

Another condition that can result in the tap changer running to an extreme position is if the line were opened—either inadvertently or for a fault condition. In this case, the regulator will sense the power flow going to zero, which may be out of its band limits. Tap changes will not result in moving the operating point off of zero, so the control will continue to call for tap changes until the tap changer reaches its extreme position. Then, when the path is restored, the power flow will likely be extremely over the rating of the PST.

The detect-line-open function asserts when the instantaneous real power flow is less than one percent of the maximum automatic regulation set point and the ΔP from the most recent tap change is also less than one percent of the maximum automatic regulation set point. When the line opens, the real power will go to near zero. If this is out-of-band, the control will initiate a tap step. For this condition, the ΔP will also be zero. The integrating timers will be reset and suspended from timing and further tap steps will be blocked. Once power flow is reestablished, the timers are allowed to time again. For this condition, the tap position will only change by one step before being stopped.

Maximum Operations per Hour Logic

In the event that the control does begin hunting, it can operate many times in a short period of time. This can result in excessive wear on the mechanism and disturbances to the power system. This is unlikely to occur if the adaptive bandwidth function is used; however, this function can be disabled. A maximum operations per hour function increments a counter each time a tap change operation ends. Every 10 minutes, the counter register is decremented by 1/6th of the maximum operations per hour setting. If the counter register reaches the maximum number of operations per hour allowed, the integrating timers are suspended until the next 10-minute interval occurs and decrements the counter register.

Additional Suspend Automatic Operation Logic

The control includes several other features to prevent damage to the transformer and/or tap-changer mechanism while in service. These include suspending automatic timing if:

- A VT fuse failure is detected making the measurement of real power and other quantities unreliable.
- The line circuit breaker automatic recloser is in cycle.
- An alarm contact indicates that there is a failure in the tap-changer mechanism.
- The local remote switch at the tap-changer mechanism is in local.
- The PST has been tripped due to a fault.

- The positions of the two tap-changer mechanisms do not meet required symmetry criteria.
- Phase current is above a level that will damage the tap-changer switching mechanism.

Automatic Run-to-Neutral Control

There are several operating scenarios where it is desirable to automatically run the PST tap changer to its neutral position. For example, this operation is necessary when putting the unit on bypass. Another example is when the PST is in an overload condition and must be run to neutral to relieve the overload. The automatic run-to-neutral control function initiates tap changes in the appropriate direction until it reaches neutral. The logic requires input from the tap changer to determine if the tap position is in advance or retard to initiate tap changes in the correct direction.

The control reads the status of a BCD signal to determine the tap position. The status of each digit is multiplied by that digit's value to convert the BCD signal to a decimal number. Figure 6 shows the source-side tap-changer position signal as an example. During the transition between positions, all of the BCD contacts deassert causing the tap position to read zero. This is not a valid state; so, when the reading equals zero, the register retains the previous valid reading so that the displayed effective tap position is not invalid. Since the tap-changer position could become stuck in between positions and read zero indefinitely, at the end of a tap step operation, the register is forced to update and show the true state.

The ability to determine that the PST is on neutral (no phase shift across the PST) is important when closing the bypass circuit breaker. If the bypass breaker is closed when the PST is not on neutral, extremely high circulating currents occur, which can damage the transformer, tap-changer mechanism, and the circuit breakers, switches, and bus work in the parallel loop circuit. The neutral indication incongruent alarm function uses three methods to determine that the PST is on neutral:

- Neutral contact closes when the tap changer is on neutral.
- Tap step position indicates the position is on neutral.
- Measure the voltage angle difference between the source bus and load bus and if the angle is less than a half tap step, the PST is on neutral.

If any of these methods do not agree for a user-settable time delay, a neutral status incongruent alarm is set. The delay is required to account for small variations in the time between each of the logic conditions asserting. When this alarm is set, the Neutral LED on the front of the control blinks to indicate that it is unknown if the tap changer is on neutral or not. See Figure 3.

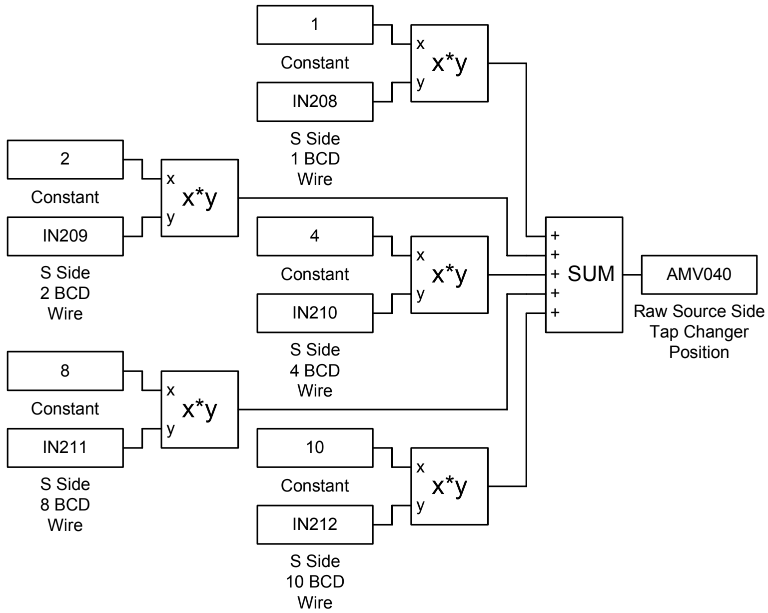

Figure 6 Measure Tap Position Logic

OVERLOAD ALARMS

Inverse Timing Overload Element

Operating above nameplate rating for an extended period of time can prematurely age the PST. The maximum automatic regulation set point can be set above the continuous rating. System conditions can occur where the PST has reached its extreme position and is still in overload, or the operators may overload the PST with the control in manual.

The overload characteristic of the PST has an inverse characteristic. It can withstand a high level of overload for a short period of time and a low level of overload for a longer period of time. The overload alarm function includes an integrating timer that uses an inverse time characteristic. The characteristic of the inverse timing overcurrent element is based upon the standard form described in [2] with modification to allow better matching of the timing characteristic to the overload versus time characteristic of the PST. The operator can select summer and winter ratings, which shifts the curve to match the operating limits as appropriate.

Once the element has timed out, the control can take action to relieve the overload to prevent permanent damage to the PST. When the overload element times out, the automatic regulation band limits are adjusted to below the active continuous rating (summer or winter). This will cause the control, if in automatic, to reduce loading to below the continuous rating allowing the overload element to reset. Once the integrating timer has reset, the user set point is automatically re-enabled. If that level is above the continuous rating, the control will increase loading back to the operator regulation set point and the overload timer will start timing again. The operators have indication of time remaining to time-out and time remaining to reset so that they know how much time they have to relieve the overload condition before the control will take remedial action to protect itself.

If system conditions are such that the PST, even at maximum tap position cannot reduce the overload condition, it will be necessary to relieve the overload of the transformer by running it to neutral. Logic is included to initiate an automatic run-to-neutral operation if the overload is not relieved within a settable time delay.

Overcurrent Overload Element

A second overload protection system that measures the current in the individual phases is also included. The tap-changer switching contacts can be damaged if the switching current is above a certain level. An overcurrent function will suspend automatic timing and assert the manual control cutout when any phase current is above this user-settable threshold. The overcurrent cutout function can also trip the motor circuit to prevent damage to the contacts if the tap-changer motor is running and an overcurrent condition is detected. This function also provides an alarm when the loading is within one tap step of reaching the overcurrent cutout limit. The alarm threshold is based upon the most recent ΔP measured and the measured power factor.

This overcurrent threshold also starts an integrating timer that will remove the PST from service if the overcurrent condition persists for longer than a user-settable delay. For the AEP PSTs, that time is 15 minutes. Since the tap changer is blocked from operation above this level, the PST cannot reduce the overload by its own operation. Thus, expiration of this timer will sequentially open the load-side breaker and close the bypass breaker to relieve the overload condition.

AUTOMATIC SWITCHING SEQUENCE LOGIC

The control includes logic to automatically put the PST in service and to automatically remove the PST from service. Before the automatic put-in-service sequence can be initiated, several preconditions must be satisfied:

- The PST MOD must be open.
- The load-side circuit breaker must be open.
- The bypass circuit breaker must be closed.
- At least one source-side circuit breaker must be closed.

A status LED on the front panel of the device provides local indication that these preconditions are asserted. See Figure 3 This status is also indicated remotely via SCADA. Figure 7 shows the flow chart for the process to place the PST in service. A similar process is used in reverse to remove the PST from service.

The power flow regulating tap changer uses serial communications links via a logic processor to send open and close commands to the circuit breaker control relays. To isolate the control outputs sent via the communications links, a pole of a test switch was wired to an input on the control. When the test switch is opened, the input deasserts. When this input is deasserted, open and close outputs are blocked from being transmitted to the logic processor.

DESIGN DOCUMENTATION

Detailed logic diagrams were developed to document the programming of the system. An instruction manual with detailed descriptions of each function and functional block diagrams helped make the detailed logic diagrams more readable. A three-ring binder that contained the printed instruction manual and all detailed logic diagrams was placed at each installation and the field operations offices. Each instruction manual also includes a CD ROM that contains electronic copies of all documentation and the device settings databases. If a device fails in the field and must be replaced, the settings files are readily available to program the replacement device and place it in service.

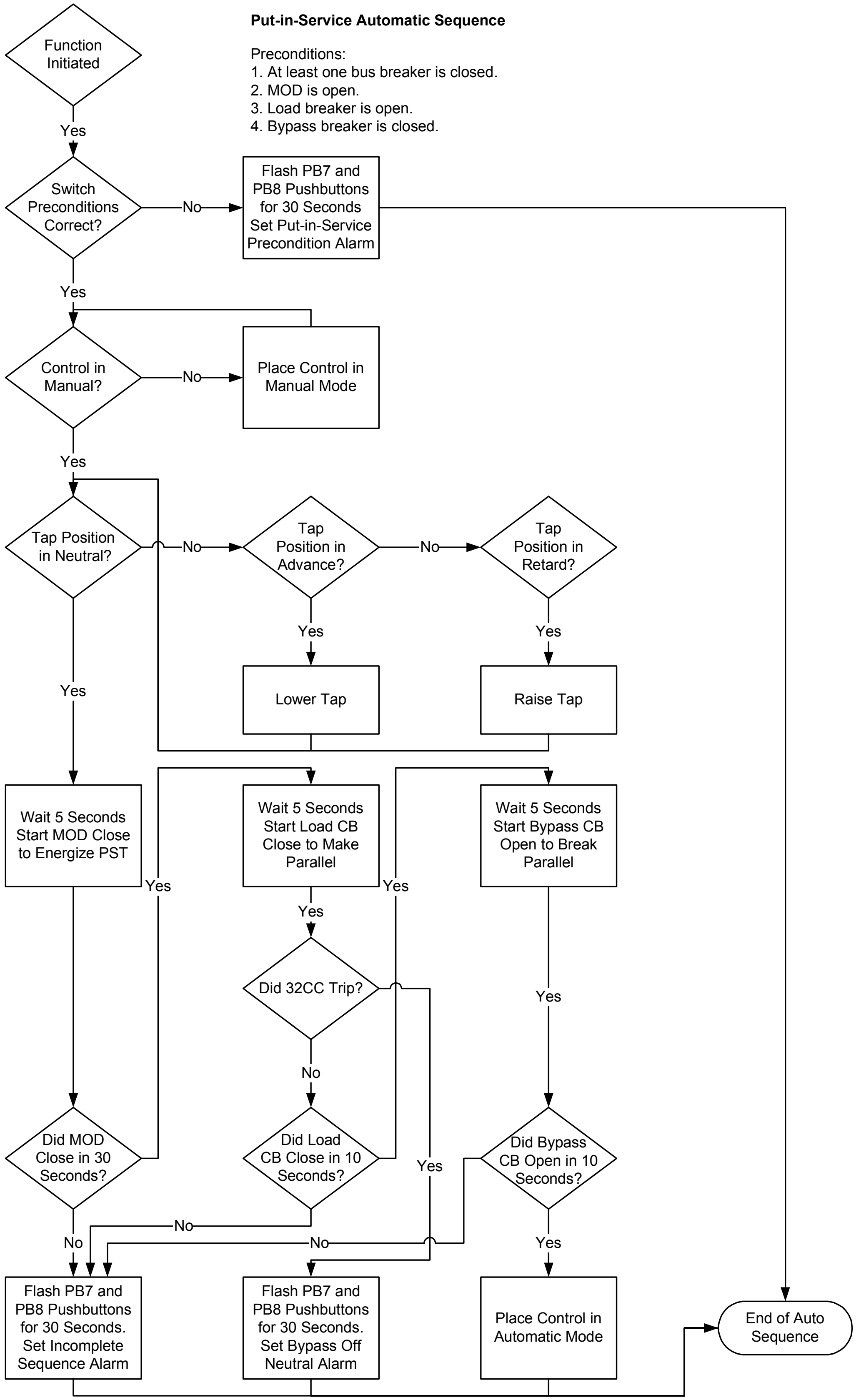

Figure 7 Automatic Put-In-Service Sequence Flow Chart

COMMISSIONING EXPERIENCE

Initial Development and Testing

The basic control was developed prior to the first on-site visit. At the first on-site visit, AEP engineers and the consultant developing the control met with a commissioning engineer from the PST OEM to discuss their requirements for using a different control than the one provided with the PST. The goal was to ensure that use of the new control would not void the PST warranty. This meeting resulted in several modifications to the control.

The basic control was also tested with the actual tap-changer mechanisms at this first on-site visit to determine timing of feedback signals from the tap-changer mechanisms and further modifications were made. A second visit was made to test the control prior to the final on-site visit to place the first PST in service. A further purpose of these visits was to train field engineers and technicians on the operation and check-out of the system so that they could commission the next installations on their own.

First Energization

The planning engineers had indicated that we should expect a ΔP of approximately 5 MW per tap step. So, the initial bandwidth setting was set at +/– 5 MW. The regulation set point was set to adjust line flow to 20 MW greater than the natural flow with the PST on neutral. We expected the control to take three to four steps to reach the regulation dead band.

When the control was placed on automatic, the control initiated a tap step and the actual ΔP was approximately 22 MW. This placed the real power flow inside the regulation dead band so the control stopped. The greater-than-expected ΔP may have been a result of the system topology at that time since all of the lines in the new substation were not yet in service.

This experience validated the need for an adaptive bandwidth function in the control of a PST. The control is set to average the ΔP from the most recent four tap steps in adjusting the adaptive bandwidth. Without an adaptive bandwidth function, the control would overshoot the dead band when the out-of-band timers initiated an adjustment under these conditions.

Follow-Up Refinement

After about five months of operating experience with the PSTs, the control features were refined to better meet operational requirements. It was at that time that the inverse timing overload function was developed to allow operators to safely run the PST above nameplate during system contingencies. SCADA indications were also adjusted to give operators better information about the status of the control and the system that it is controlling.

When commissioning the revised overload logic, we used a relay test set to pick up the overcurrent overload element to verify SCADA indication. As mentioned earlier, when the overcurrent overload element times out, it takes the PST out of service by sequentially opening the load-side breaker and closing the bypass breaker. It was assumed that we had 15 minutes to verify SCADA indication and turn the test set off before this operation would occur. To be safe, the test switch that blocks control signals sent via the communications link was opened. This is described in the Automatic Switching Sequence Logic section of this paper.

When the test set was turned on, the control indicated a trip condition almost immediately. Investigation showed that the 15-minute timer had been inadvertently scaled as a 15-second timer. This experience proved the value of providing test switch functions on device outputs that do not go through hardware output contacts.

SUMMARY AND CONCLUSIONS

The following is a summary of some of the conclusions and lessons learned during the design and implementation of this new control system.

PSTs can help optimize existing transmission system assets by regulating the power flow across transmission system branches. The single tank, delta/hex transformer can be more economical than previous multitank designs, which promises to increase use of PSTs on the transmission grid.

Automatic control of a PST tap-changer mechanism presents some unique challenges. In the case of a PST, the tap step parameter is degrees of phase angle shift and the regulated parameter is real power, P. External factors, such as system voltages and the transfer impedance of the surrounding system, govern the actual ΔP that can occur for each tap step. These external factors can change depending upon system conditions and topology.

To optimize regulation and ensure that the automatic control does not hunt, an adaptive bandwidth function was developed that learns and adjusts its bandwidth setting based upon the actual measured ΔP from the most recent operations.

A microprocessor-based control can include reality checks, such as ΔP wrong direction, and detect line-open logic to prevent the control from running to its extreme limits due to an abnormal operating condition.

An inverse timing overload function based upon the PST's summer and winter overload characteristics can allow safe operation of the PST over name plate rating during system contingencies. Indication of time remaining to remedial action at the present level of overload gives operators useful information to determine actions to relieve the overload and allows optimum use of the PST to support the system.

It is advisable to provide test switch functionality for trip and close outputs even if they do not go through hardware output contacts.

An adequate design documentation package must be developed for a system such as this so that maintenance and operations personnel can support the system for the many years it will be in service.

Since PST controls are a new technology for AEP, initial specifications for the control system evolved over time and many discussions between the various stakeholders, including substation designers, standards engineers, field engineers and technicians, system planning engineers, the consultant, operators, and the equipment manufacturer. The original control had limited ability to be adapted to meet these evolving requirements. The control that was developed has been in service and operating to the satisfaction of AEP for over a year.

References

[1] M. Thompson, H. Miller, and J. Burger, "AEP Experience With Protection of Three Delta/Hex Phase Angle Regulating Transformers," proceedings of the 33rd Annual Western Protective Relay Conference, Spokane, WA, October 2006.

[2] IEEE Standard C37.112, 1996, Standard Inverse-Time Characteristic Equations for Overcurrent Relays.

Biographies

John Burger has a BSEE from Case Institute of Technology and a MSEE from Fairleigh Dickinson University. He is a Registered Professional Engineer in the states of Ohio and New Jersey. John has over 35 years experience in station and line relay protection and control. He has worked for AEP, primarily in the Protection and Control group, for the last 27 years. John is currently serving as a Staff Engineer in the Protection Metering Engineering and Standards Group with responsibilities for developing protection and control standards, application guides and supporting the relay setting project work. John has responsibility for workload management of the P&C group including the contractor support functions. He shares responsibility for ensuring that new devices to the AEP system are protected and controlled properly with Hank Miller. John has also worked as a Protection and Control Specialist, as part of the AEP Energy Services team, for the People's Republic of China on the Ertan 500 kV Transmission Project. John is a Senior Member of the IEEE, past chairman of the Columbus Chapter of the PES, a member of the IEEE Power System Relay Main Committee, Substation and Communications Subcommittees and chairman of working group H6. He is also currently serving as Chairman of the UCA International Users Group providing technical support for IEC 61850.

Henry Miller (Hank) has a BSEE and a BEE from The Ohio State University and a BA Degree in Philosophy from The Pontifical College Josephinum. He is a Registered Professional Engineer in the state of Ohio and holds a patent for a substation steel design. Hank has over 27 years of utility experience in station and line protection and control. Hank is currently working as a Staff Engineer in the Protection Metering Engineering and Standards Group with responsibilities for developing protection and control standards, application guides and supporting the relay setting project work. He shares responsibility for ensuring that new devices to the AEP system are protected and controlled properly with John Burger. Hank is a member of the IEEE.

Michael J. Thompson received his BS, magna cum laude, from Bradley University in 1981 and an MBA from Eastern Illinois University in 1991. He has broad experience in the field of power system operations and protection. Upon graduating, he served nearly 15 years at Central Illinois Public Service (now AMEREN), where he worked in distribution and substation field engineering before taking over responsibility for system protection engineering. Prior to joining Schweitzer Engineering Laboratories, Inc. in 2001, he was involved in the development of a number of numerical protective relays. He is a Senior Member of the IEEE and a main committee member of the IEEE, PES, Power System Relaying Committee. Michael is a registered Professional Engineer in the State of Washington and holds a number of patents associated with power system protection and control.