An increased focus on service reliability causes many utilities to look at their distribution protection practices. Although modern power distribution systems use single-phase protective devices, utilities have been reluctant to consider single-pole tripping on the main three-phase line for a variety of reasons, including a desire to protect three-phase loads, difficulty coordinating devices along the feeder, and loss of sensitivity of the protective devices for low-magnitude faults. Each of these concerns is valid, but because of the obvious benefits to reliability, utilities are looking for solutions to these problems. Over the past several years, the industry has begun implementing single-pole tripping with microprocessor-based recloser controls on distribution feeder circuits.

**Distribution Single-Phase Tripping and Reclosing**

**Overcoming Obstacles**

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1. **“Boulder”, CO, USA**

2. **Typical distribution circuit**
**Benefits of Single Pole Tripping**

A single-line-to-ground fault is the most common type of fault on distribution systems. Some studies show that only two to three percent of distribution faults are three-phase faults. Conservative estimates of reliability indicate that 60 percent of faults can be cleared with single-pole tripping. When we consider phase selectivity for tripping to clear a fault, there are obvious benefits to isolating only the affected phase(s) over tripping a three-pole device for all faults. Single-phase tripping schemes open only the phase involved in the fault and can reduce outage numbers by two-thirds for line-to-ground faults and one-third for faults involving two phases.

Reliability indices include several components to measure the level of service that a utility provides to its customers. These indices include the following:

**SAIDI:** Minutes per year an average customer does not have electric power.

\[
SAIDI = \frac{Total\ Customer\ Interruption\ Duration}{Total\ Number\ of\ Customers\ Served} \]

**SAIFI:** Number of interruptions per year that an average customer experiences.

\[
SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} \]

**MAIFI:** Number of momentary interruptions per year.

\[
MAIFI = \frac{Total\ Number\ of\ Customers}{Total\ Customer\ Momentary\ Interruptions} \]

Figure 2 shows a typical distribution circuit with a midpoint three-phase tripping recloser. Given that the total number of customers is fixed and that the outage time would be similar for three-pole or single-pole tripping, the system would be affected by a change in the number of outages experienced. For a circuit with 1,000 customers and five outages per year lasting an average of one hour each, we can calculate the reduction in outage time by tripping single pole single-phase hydraulic reclosers grouped together.

\[
SAIDI = \frac{5 \text{ Outages} \times 60 \text{ Min} \times 1,000 \text{ Customers} \times 0.333 \times 60}{300,000 \text{ Cust. Total}} = 0.5165 \text{ Min. Cust. Total} \]

By tripping single pole as opposed to three pole only, we can reduce the number of customers affected to only the phases involved in the fault. If we assume that 60 percent of the faults involve only one phase, 25 percent involve two phases, and 15 percent are three phase or require three-phase tripping, we can calculate the expected impact to the system SAIDI contribution from this feeder by single-pole tripping as follows:

\[
SAIDI = 5 \text{ Faults} \times 60 \text{ Min} \times 1,000 \text{ Cust} \times 0.333 \times 60 + 5 \text{ Faults} \times 60 \text{ Min} \times 1,000 \text{ Cust} \times 0.667 \times 25 + 5 \text{ Faults} \times 60 \text{ Min} \times 1,000 \text{ Cust} \times 1 \times 15 = 154,965 \text{ Cust. Total} = 51.65 \text{ Min. Cust. Total} \]

Change = 48.35% reduction - (The SAIFI and MAIFI numbers would follow similarly)

**Single-Pole Tripping Concerns and Solutions**

Although single-pole tripping holds obvious benefits over fixed three-pole tripping, there are some concerns that we must address to see the advantages without sacrificing protection.

**Tripping/Reclosing Modes**

With traditional independent reclosers used for single-pole tripping, each unit operates independently of the others for tripping and reclosing. Because of this fixed mode operation, their use is limited to locations that can always accommodate single-pole tripping. Microprocessor-based recloser controls that monitor all three phases and can direct tripping and clearing from a central unit allow flexibility in the trip/close modes. Three basic operation modes are possible when we use the common control along with single-phase trip/close capable reclosers.

- **Single-pole tripping/single-pole lockout (SPTSPLO)** allows tripping, reclosing, and lockout of each phase independently of each other. This mode results in the lowest outage impact for a single-phase fault. This mode cannot be used when sustained single-phasing of three-phase loads or sustained load unbalance is unacceptable.

- **Single-pole tripping/three-pole lockout (SPT3PLO)** allows an independent pole tripping and reclosing, but if a pole trips to lockout, the other poles open and lock out as well. Use this mode when the system cannot tolerate extended periods of unbalance current resulting from an unbalanced lockout condition.

- **Three-pole tripping/three-pole lockout (3PT3PLO)** allows the recloser and control to operate as a traditional three-phase recloser. In this mode, the recloser trips, recloses, and locks out all three phases as necessary to clear any type of fault. Use this mode when load levels prohibit any incremental load unbalance that a momentary single-phase interruption would cause and when even short intervals of single-phasing of three-phase load must be avoided.

With a recloser control that offers flexible logic programming, variations and enhancements beyond these basic operating modes are possible. A microprocessor-based control can adapt to system conditions. This allows changing the operation as necessary and maximizing opportunities to take advantage of single-pole tripping, while avoiding problems when three-pole tripping is required.

**Ground Fault Sensitivity**

In the past, when individual single-phase hydraulic reclosers were grouped together to achieve single-pole tripping for feeder faults, the trip value of the phase recloser limited the sensitivity for ground faults. While individual hydraulic reclosers provide the desired phase selectivity, they do not offer the sensitivity of a ground-sensing protection element.
Logic functions provide tripping for faults below phase pickup.

A microprocessor-based common control operating three independent tripping/closing recloser poles offers improved functionality. With a common protective device, the control can modify operation and protection according to conditions on all three phases. Additionally, the common control can calculate or measure a ground residual current value from the three phases. An overcurrent element operating on this value offers improved sensitivity for ground faults compared to the phase protection element. This protection is not possible with independent single-phase units. Providing this improved sensitivity offers a solution to the loadability versus sensitivity problem described previously. Typically, we can set the ground overcurrent element as low as 10 to 15 percent of the phase value. This is a considerable improvement in detecting low-magnitude ground faults. It is important to note that this setting depends on the presence of typical load unbalance (Figure 6b).

Load Unbalance Following Single or Two-Pole Trip

Figure 3a shows an elementary diagram of a feeder with normal load currents on each phase. Typically, there will be some load unbalance present, and this will show up as a low-level ground current. Usually, we can set ground elements to easily accommodate this normal unbalance and provide sensitivity for low-magnitude downline faults. During times when one or two poles are open, however, even with only normal load current flowing in the closed poles, the unbalance of the circuit will appear as significant ground current. We must set ground protection locally at the single-pole trip point and on any protective devices upline to accommodate this unbalance current. Depending on load levels, this ground current due to a pole-open condition can be large compared to the typical unbalance. Protection sensitivity may have to be sacrificed to allow single-pole tripping. Since loading can vary substantially on a feeder depending on various factors, such as season, time of day, and weather, we must consider the worst-case loading conditions when setting the ground protection (Figures 3a/b and 4a/b).

Possible Solutions

Raise Pickup: An obvious solution to the problems presented above would be to raise the pickup setting of the ground element that detects the unbalance current. We would need to increase the pickup above the anticipated unbalance current, but we may be unable to do this where fault levels are lower than the possible current unbalance. If we use a fixed higher setting, we can accommodate the problem of the unbalance current, but the sensitivity advantage of the ground element is compromised or lost. We can take advantage of the logic capabilities of the microprocessor-based recloser control and configure it to adapt the overcurrent pickup to system conditions. With the recloser control metering loading values as well as monitoring the status of each pole of the recloser, we can modify the ground overcurrent setting as necessary in the control to avoid tripping for unbalance conditions. For operations where all poles are closed, this setting allows the overcurrent element sensitivity to be at a maximum. We can adjust it as necessary for changing conditions.

If one or two phases open either for a fault or other condition, we will see ground current in the recloser control resulting from the unbalance. The resulting unbalance current is the 3I0 current, which we can calculate by summing the phase currents. Because the ground current can be significantly larger than the pickup of the ground element, it would trip for this condition. Because the control has a status indication from each of the recloser poles, we can use this to supervise the ground overcurrent element. We would use this logic (Figure 8) to prevent operation of the ground element if all three poles are not closed.

We must consider disabling the ground element for this condition when performing coordination studies. Any upline device must be set to coordinate with the downline device, considering that the ground curve is not active in the downline device. We would lose the overcurrent sensitivity advantage of the ground element for this condition.

There may be instances where we need tripping for faults that are below phase pickup. Logic functions were designed to allow the recloser to trip all three phases for faults that are below phase pickup but are detected by the ground element. With the ground element enabled (all three poles closed), unbalanced faults would typically have an asserted phase overcurrent element and ground overcurrent element. For these instances, the phase involved would be tripped regardless of whether that phase element or the ground element timed out first. For low-magnitude faults where the faulted phase cannot be determined (ground element timed out, no phase element picked up), we trip all three poles to ensure the fault is cleared (Figure 7).

Coordination With Upline Three-Phase Devices: Coordination between a single-pole tripping recloser and an upline three-phase device can present problems. Often, the three-phase tripping device will use a maximum phase overcurrent element in which the time-overcurrent element uses the highest phase current that the relay detects. For multiphase faults, the upline maximum phase overcurrent element will be timing against multiple single-phase overcurrent elements. After clearing one fault, the upstream timer may be close to operation for the remaining (reduced) fault current. This may lead to a potential miscoordination between devices if sufficient margin does not exist between the overcurrent elements involved.

Evolving faults present a similar problem. Consider the case where a fault evolves from a single phase to ground to phase to phase to ground. The fault current the three-phase device detects changes phases, but does not go away when the first downline device operates, so the upline device con-
3 **Reclosers**

**a** Typical feeder with balanced load

**b** Unbalance resulting from single-pole trip

4 **Reclosers**

**a** Unbalance resulting from two-pole trip

**b** Unbalance from three-pole trip

5 **Balanced & unbalanced process**

**a** Balanced operation

**b** Unbalance resulting from a single-pole open

6 **Reclosers**

**a** Traditional independent reclosers

**b** Single-pole tripping recloser with common control

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Coordination with upstream protection must be considered during open pole conditions.

Single-pole control using measurement of all three phases simplifies scheme logic.
continues to time with a head start of the time between onset of the initial fault and the time the second phase became involved. The worst-case scenario is for the fault to evolve just prior to the first involved phase clearing. This requires that the upline overcurrent device be set at a minimum of two times the operate time of the downline device. Different fault current magnitudes between the phases could further complicate the situation just described.

Using a microprocessor-based recloser control, we can design a solution to aid with both of these potential difficulties. Because the recloser control monitors currents on all three phases, we can design logic to trip all phases in the process of timing when the first time-overcurrent element expires. Using this logic, the upline device only has to coordinate with the fastest operating element in the downline recloser. Operating in this manner does have the drawback of potentially affecting coordination with other downline devices, because the tripping times on additional phases may not correspond to the current seen on the respective phase (Figure 9).

**Single-Pole Reclosing:** Another complication to properly coordinating a maximum time-overcurrent element with a single-pole tripping device is reclosing. As discussed previously, because the upline device is seeing the highest current of the three phases while the single-pole tripping device times individually on each phase for potentially different magnitudes of current, we must take additional care to provide a sufficient margin. The onset of the fault may not have occurred simultaneously on the phases involved, so there can be a discrepancy in operating times of the individual phase overcurrents even for the same fault magnitudes. These are valid concerns for the initial trip, but when reclosing is added to the coordination equation, the problem can be magnified as the reclosing sequence moves along. If the single-pole tripping device operates independently for both tripping and reclosing, the reclose counter at the single-pole tripping device can become unsynchronized between phases, resulting in numerous operations that the upline three-phase device must coordinate with. If the upline device is an electromechanical induction disk type or induction disk emulating microprocessor type, we must account for disk buildup or ratcheting that may occur during the reclose operation sequence.

**Field Experience**

One electric utility began applying microprocessor-based controls with reclosers capable of single-phase operation in 2004. Some highlights of the original scheme include:

- Configurable for one of three operation modes:
  - Single-phase trip/single-phase lockout
  - Single-phase trip/three-phase lockout
  - Three-phase trip/three-phase lockout
- Ground protection elements available, but elements would be disabled for an open pole
- For faults where the ground element asserted without phase-element assertion, all phases of the recloser were tripped
- For single-phase mode, reclosing counters were independent

**Problems Identified**

After approximately four years of field experience with...
A simple logic scheme switched between single and three-phase mode.

To address the four concerns listed, three distinct areas of the original protection and control logic in the standard single-phase-capable, microprocessor-based recloser control were modified. The first and most fundamental change was related to the operating mode of the recloser. Prior to the enhancement, the most suitable recloser operating mode based on location, peak loading, etc. was determined. This operating mode was selected using a configuration setting, and the recloser would then continuously operate in this mode. The driving factor in whether single-phase tripping was selected was whether peak load levels could lead to excessive upline unbalance during single-phase fault interruption by the recloser. In general, if opening one or two recloser phases would lead to unbalance at the feeder relay in excess of 50 percent of the feeder ground relay pickup, single-phase operation would not be selected. This greatly limited the deployment of these units for single-phase operation, as peak loading dictated the operating mode to avoid any possibility for misoperation of the feeder ground relay resulting from excessive unbalance. To overcome this obstacle, a relatively simple logic scheme was created to switch between the single-phase operation mode and three-phase mode depending on load (Figure 10). This scheme uses a spare three-phase overcurrent element to monitor load current and time the occurrence of load exceeding or dropping below a user setting. If load remains above the set point for five minutes, the control switches to the three-phase trip and lockout mode. After load falls below the set point for the same time period, the unit returns to the single-phase mode selected at the time of configuration (either SPTSPLO or SPTPLO).

This enhancement allows the use of single-phase fault interruption in areas never before possible. In one division of the utility service area, as many as 85 percent of the presently deployed units now operating in the three-phase mode could be converted to this new scheme.

Determining the load level for switching from single-phase operation to three-phase mode can be achieved through monitoring of the feeder breaker current at the substation and a known distribution of load between the total feeder and the section under the recloser.

Figure 11 shows logic that simply commands the shot counter of a particular phase to advance if its shot counter was less than the count of another phase.

## Solutions Implemented

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