Distribution Single-Phase Tripping and Reclosing: Overcoming Obstacles With Programmable Recloser Controls

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***Abstract*—Ever since the first ground-fault detection device was incorporated into a fault interrupting mechanism, limitations have existed as to how much sustained load unbalance could be tolerated for a given three-phase distribution feeder. All single-phase fault interruption will introduce some incremental unbalance if load is dropped. Therefore, projected peak load levels beyond the location of fault interrupting and sectionalizing devices have always been determining factors as to whether the protection device would isolate all phases or only the faulted ones. For example, fuses, being independent phase-interrupting devices, can only be used at locations where the load they interrupt will not cause unbalance greater than the pickup level of upline ground-fault detection equipment. Single-phase reclosers and sectionalizers must also be applied with similar consideration. Traditionally, if high load levels will be interrupted, three-phase circuit reclosers with gang-operated interrupters are used.**

With no choice but to use three-phase interruption on more heavily loaded feeder sections, utilities long ago accepted the fact that possibly two-thirds of the customers beyond these protection devices would have to endure unnecessary outages each time a single-phase fault occurred. However, the quest to improve reliability by minimizing the number of customers affected has renewed interest in single-phase fault interruption on three-phase distribution lines. With the relatively recent availability of microprocessor-based recloser controls designed to operate with three-phase, independent-pole-operated reclosers, utilities are taking a closer look at using single-phase fault interruption in nontraditional locations.

This paper will explore the possibilities opened when a programmable recloser control, monitoring current on all phases, is used to make independent trip and close decisions for each phase. Various challenges introduced with single-phase interrupting will be addressed and solutions offered.

I. INTRODUCTION

With an increased focus on service reliability, many utilities are looking at their distribution protection practices to determine if they can improve on the methods they have used historically for standard distribution protection. Although modern power distribution systems use single-phase protective devices such as fuses and reclosers liberally, these devices are typically found on laterals and taps off of the main three-phase feeder. 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 brought about by single-pole tripping, utilities are looking for solutions to these problems to minimize any detrimental effects. In the past, utilities have achieved single-pole tripping by using three single-phase hydraulic reclosers grouped together. Because these devices were purely per-phase protection, they could not overcome many of the difficulties associated with single-pole tripping and their use was limited. By taking advantage of today's microprocessor-based recloser controls and the versatile reclosers available, solutions to these problems can be found. Over the past five years, Alabama Power Company has begun implementing single-pole tripping with microprocessor-based recloser controls on distribution feeder circuits. The goal for this initiative is to improve reliability and service to customers. By isolating the smallest portion of the system possible to clear a fault, Alabama Power can minimize the number of customers affected, and the improvement to reliability numbers will be significant. Additionally, customer satisfaction will improve as customers on unfaulted phases no longer experience momentary outages for faults on other phases.

II. BENEFITS OF SINGLE-POLE TRIPPING

Single-line-to-ground faults are 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. For conservative estimates of reliability impact, Alabama Power has estimated that 60 percent of faults can be cleared with single-pole tripping, 25 percent involve two phases and 15 percent require three-pole tripping to clear. 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. With three-phase tripping devices, the number of customers seeing an outage, whether momentary or sustained, is the same regardless of the type of fault. Single-phase tripping schemes, however, can open only the phase(s) 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. Given that the vast majority of faults do not involve all three phases, single-pole tripping offers significant improvement to reliability numbers.

TABLE I
FAULT TYPE DISTRIBUTION

Fault Type	Frequency
Single Phase Involved	60%
Two Phases Involved	25%
Three Phases Involved or Three-Pole Tripping Required	15%

Reliability indices include several components to measure the level of service that a utility provides to its customers. Among these are SAIDI, SAIFI, and MAIFI, which the following text describes and defines:

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

$$\mathrm{SAIDI} = \frac{\text{Total Customer Interruption Durations}}{\text{Total Number of Customers Served}} \quad (1)$$

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

$$\mathrm{SAIFI} = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}} \quad (2)$$

MAIFI: Number of momentary interruptions per year.

$$\mathrm{MAIFI} = \frac{\text{Total Customer Momentary Interruptions}}{\text{Total Number of Customers}} \quad (3)$$

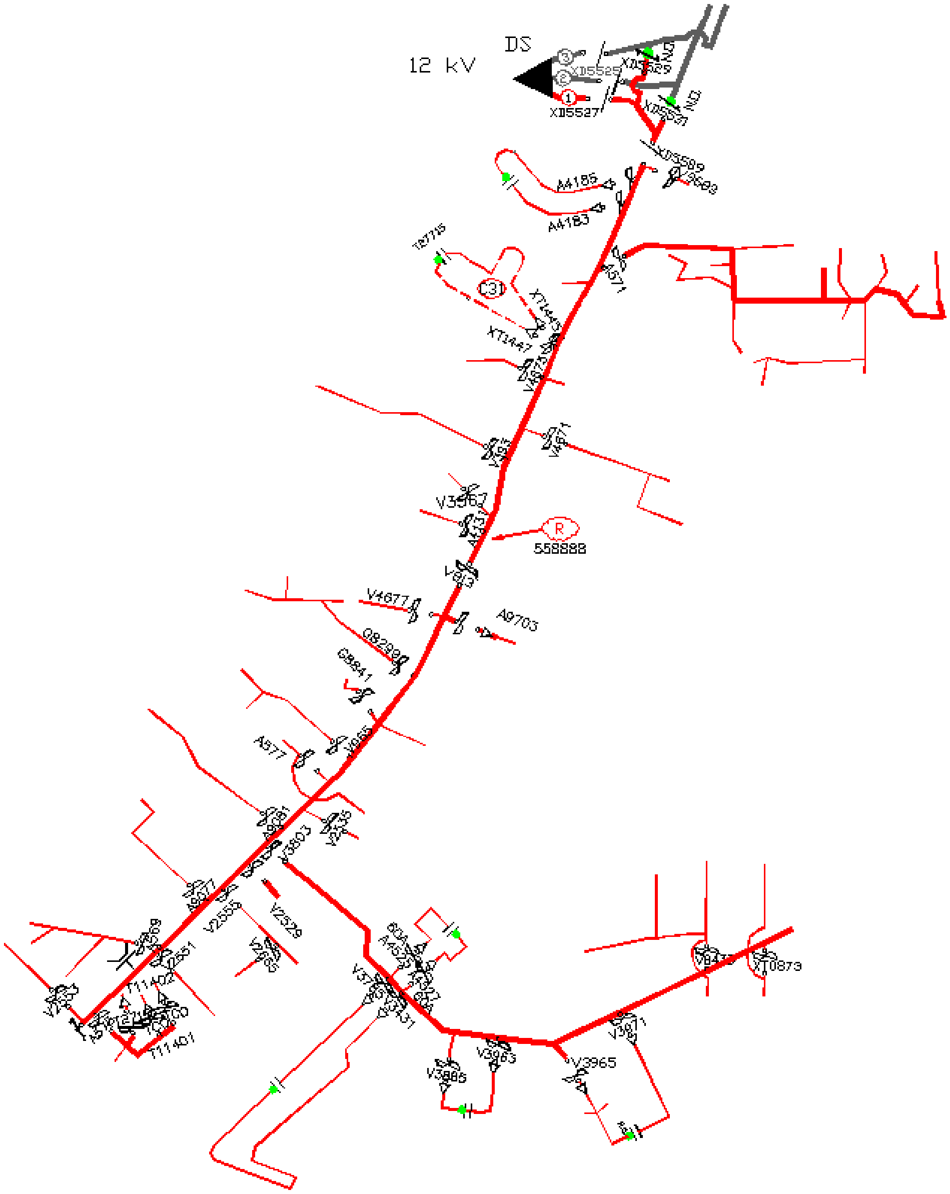

Fig. 1 Typical distribution circuit

Fig. 1 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 SAIDI would be affected by a change in the number of outages experienced. For a circuit with 1000 customers and five outages per year lasting an average of one hour each, we can calculate the system SAIDI contribution for this feeder as follows:

$$\text{SAIDI} = (5\ \text{Outages} \bullet 60\ \text{Min} \bullet 1000\ \text{customers}) / \text{Cust. Total}$$

$$\text{SAIDI} = 300{,}000 / \text{Cust. Total} \quad (4)$$

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:

$$\begin{aligned}
&\text{SAIDI} = 5\ \text{faults} \bullet 60\ \text{Mins} \bullet 1000\ \text{cust} \bullet 0.333 \bullet 60\% \\
&+ 5\ \text{faults} \bullet 60\ \text{Mins} \bullet 1000\ \text{cust} \bullet 0.667 \bullet 25\% \\
&+ 5\ \text{faults} \bullet 60\ \text{Mins} \bullet 1000\ \text{cust} \bullet 1 \bullet 15\% \\
&= 154965 / \text{Customer Total} \qquad (5) \\
&\text{Single Pole Trip SAIDI} = 154965 / 300000 \\
&= 51.65\% \\
&\text{Change} = 48.35\%\ \text{reduction}
\end{aligned}$$

As the results show, using a single-pole tripping scheme where possible can reduce a feeder's contribution to the system SAIDI by approximately 48 percent. The SAIFI and MAIFI numbers would follow similarly.

III. 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. Some of these concerns are described in the following text.

A. 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 recloser controls that monitor all three phases and can direct tripping and closing 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.

1. The first mode, 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. You cannot use this mode when sustained single phasing of three-phase loads or sustained load unbalance is unacceptable.
2. The second mode, Single-Pole Tripping/Three-Pole Lockout (SPT3PLO), allows for 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.
3. The final mode, 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 you must avoid even short intervals of single-phasing of three-phase load.

With a recloser control that offers flexible logic programming, variations and enhancements beyond these basic operating modes are possible. Additionally, with this ability, you can make the control adapt to system conditions. This allows the control to change the operation as necessary and maximize opportunities to take advantage of single-pole tripping, while avoiding problems when you require three-pole tripping only.

B. Ground-Fault Sensitivity

In the past, when individual single-phase hydraulic reclosers have been grouped together to achieve single-pole tripping for feeder faults, the trip value of the phase recloser limited the sensitivity for ground faults. The single-phase hydraulic recloser is an individual phase-sensing element, so load carrying capability determines the sensitivity of the element. Often, the required sensitivity of the overcurrent element dictates the loadability of the feeder or the placement and type of the protective devices used. With three-phase protection, we typically use ground time-overcurrent elements operating from the residual of the phase currents to improve protection by increasing sensitivity. While individual hydraulic reclosers provide the desired phase selectivity, because they do not offer the sensitivity of a ground-sensing protection element, we might be unable to use these where the required loading and restricted earth fault detection are in conflict.

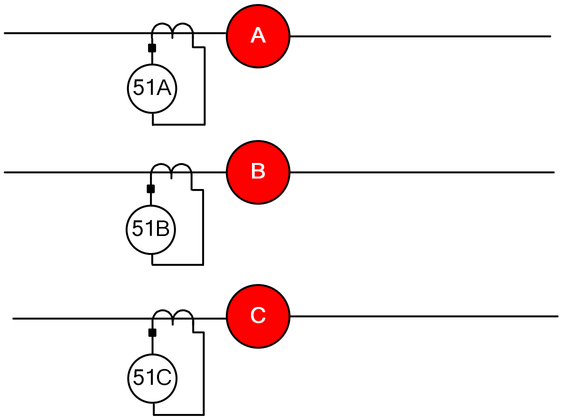

Fig. 2 Traditional independent reclosers

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.

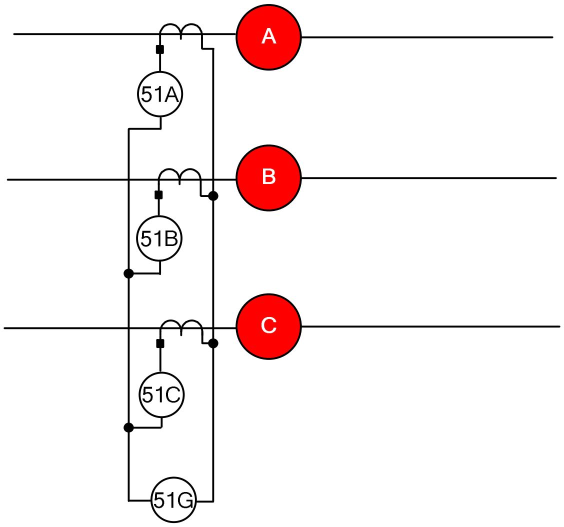

Fig. 3 Single-pole tripping recloser with common control

C. Load Unbalance Following Single- or Two-Pole Trip

Fig. 4 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. Normally, 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 tripping recloser 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 and 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, weather, etc., we must consider the worst-case loading conditions when setting the ground protection.

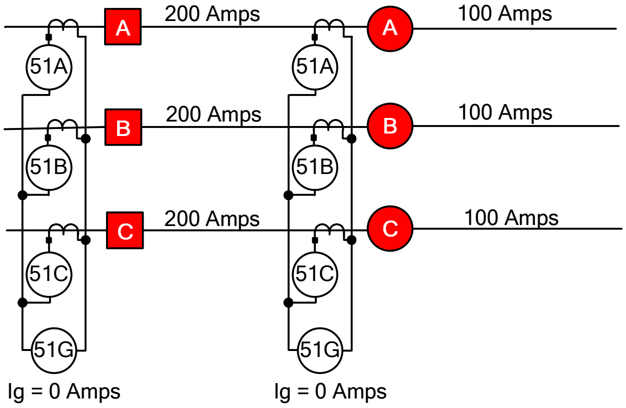

Fig. 4 Typical feeder with balanced load

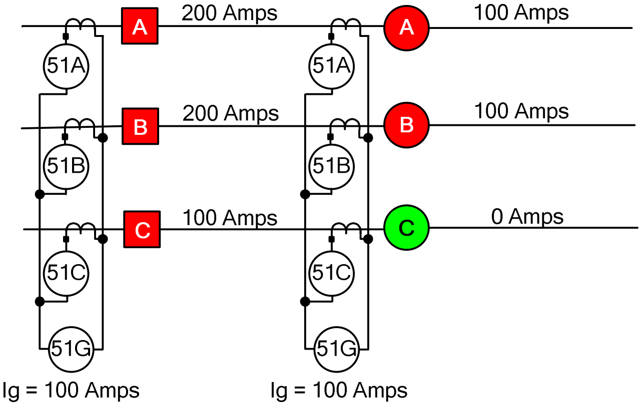

Fig. 5 Unbalance resulting from single-pole trip

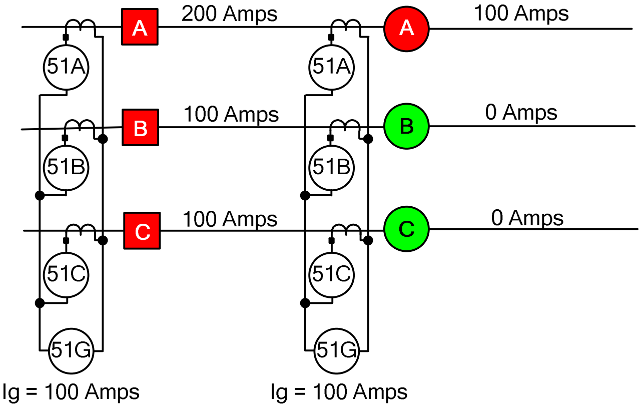

Fig. 6 Unbalance resulting from two-pole trip

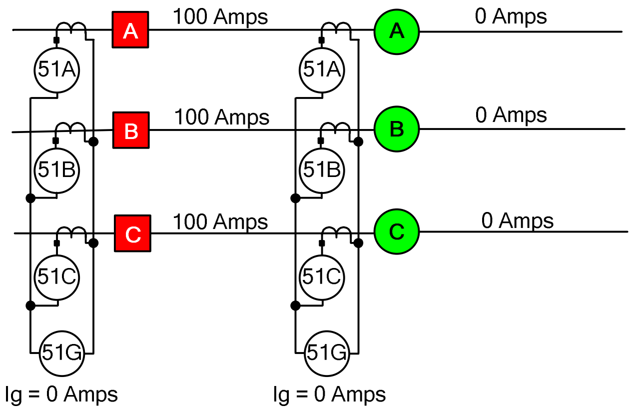

Fig. 7 Unbalance from three-pole trip

D. Possible Solutions

1) Raise Pickup

An obvious solution 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 recloser control and configure it to adapt the overcurrent pickup to system conditions. With the recloser control metering loading values as well as monitoring 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.

To illustrate this scenario, consider the case of a feeder with a maximum expected phase current of 600 A primary. Typical phase-overcurrent settings would need to carry this loading along with a margin to allow for emergency loading conditions. If we consider a 25 percent margin acceptable, we would set the phase overcurrent to 600 • 1.25 = 750 A primary. With traditional per-phase protection, this setting would limit the sensitivity for ground faults to the 750 A pickup. If a ground-overcurrent element is available, we can set the pickup to accommodate a typical unbalance of 15 percent (750 • 15% = 112.5 A). This is a substantial increase in sensitivity for ground faults.

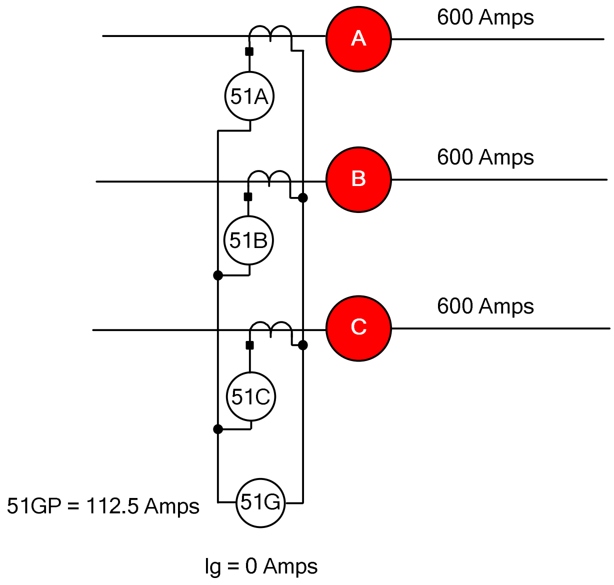

Fig. 8 Balanced operation

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. For the example given, considering the three-phase current angles to be separated by 120 degrees, the ground current for a single-phase open condition with the maximum expected load would be:

$$\begin{aligned} Ig &= 3I0 = Ia + Ib + Ic \\ Ig &= 600\angle 0 + 600\angle 240 + 0 \qquad (6) \\ Ig &= 600\angle -60 \end{aligned}$$

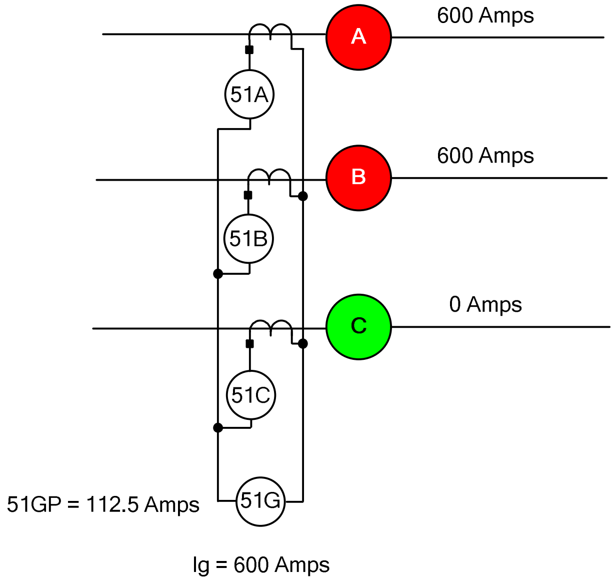

Fig. 9 Unbalance resulting from a single-pole open

Because the 600 A ground current is more than five times the pickup of the ground element, the ground-overcurrent element would trip for this condition. Because the control has a status indication from each of the recloser poles, we can use these elements to supervise the ground overcurrent element. We would use this logic to prevent operation of the ground element if all three poles are not closed.

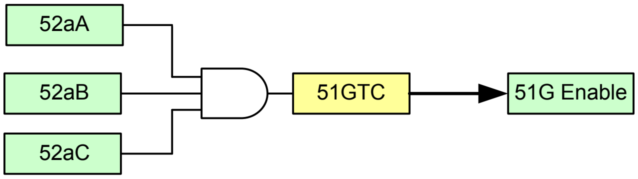

Fig. 10 Ground enable logic

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.

Because we can set the ground element significantly lower than the phase elements, 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 particular phase involved would be tripped regardless of whether the particular 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.

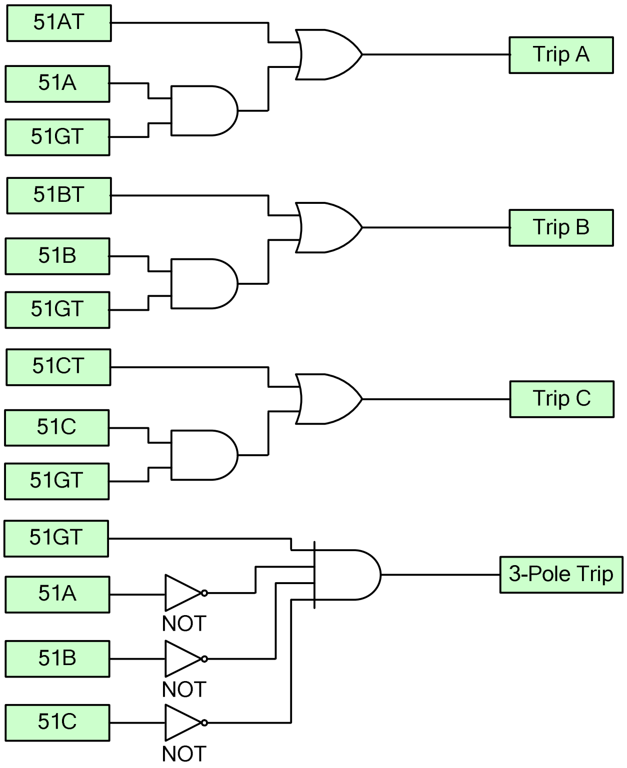

Fig. 11 Phase trip selection logic for ground faults

2) 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. The currents the elements detect on the involved phases may be different, so the maximum time-overcurrent element upline may not be timing for corresponding currents with the single-phase downline devices involved. Once the first single-phase device trips downline, the maximum phase-overcurrent element may see a lower current corresponding to the second single-phase overcurrent element that might remain timing. Because the current that the three-phase device uses initially was higher prior to the first single-phase element tripping, the time overcurrent element in the three-phase device will have advanced further than for the current corresponding to the fault on the remaining phase and will in effect have a head start. 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 single-pole tripping device is using independent overcurrent elements for each phase, so the first overcurrent element corresponding to the initial faulted phase will begin timing along with the upline three-phase device. Once the fault evolves, the second phase will begin timing from the reset position. The three-phase device, however, will continue timing without regard to another phase being involved. 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 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 for this would be for the fault to evolve just prior to the first involved phase clearing. This would require 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 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 so that we can 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.

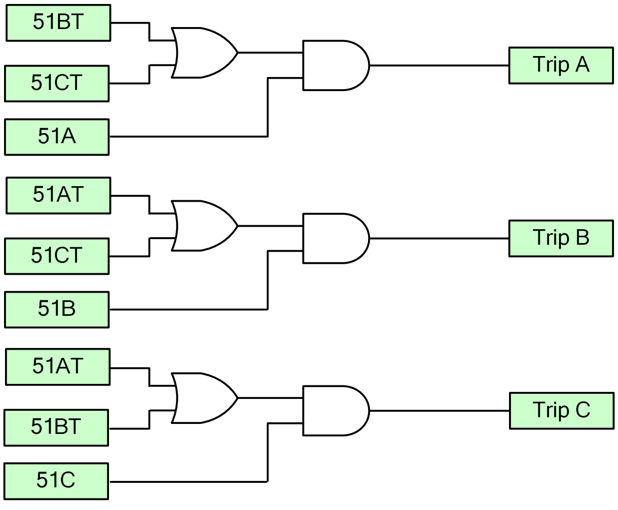

Fig. 12 Multiple phase fault trip selection

3) *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 of the event, 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.

IV. FIELD EXPERIENCE

Alabama Power Company began applying microprocessor controls with reclosers capable of single-phase operation in 2004. Some highlights of the original scheme were the following:

- 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

After approximately four years of field experience with these units and gaining a better understanding of some of the obstacles discussed previously, Alabama Power began to consider ways to enhance single-phase operation modes. The problems the utility specifically targeted were as follows:

1. Disabling the ground element for pole-open conditions meant that the phase element became the only element that could consistently provide sensitive protection for restricted faults. The ground element could only be considered as a bonus element for more sensitive protection during three-pole closed conditions only. This limited the locations where the units could be applied because phase elements had to have lower settings than those necessary for a three-phase-only unit.
2. Disabling the ground element for pole-open conditions also meant that phase elements would have to coordinate with upline ground curves. Any coordination advantage gained by having the ground element active would be lost once a phase opened and the ground curve was disabled. This could lead to miscoordination and unnecessary tripping of the upline device.
3. Single-phase tripping limited the application of these devices to lightly loaded feeders and taps because of the possibility of tripping the upline ground protection device.
4. Single-phase tripping along with independent reclose counters meant that evolving faults and staggered close shots could lead to upline maximum-phase time-overcurrent devices seeing more trip shots than the four shots traditionally used with reclosers. Alabama Power uses electromechanical disk emulation in its microprocessor feeder protection relays, so every downline trip sequence the feeder relay sees adds to the accumulated time in the phase time-overcurrent element. Miscoordination is much more likely with independent reclosing counts downline. This was not a new problem, as single-phase hydraulics coordinating with microprocessor relays present the same challenge. However, with a programmable microprocessor-based recloser control, Alabama Power had a solution not available with single-phase hydraulics.

A. *Solutions Implemented*

To address the four concerns listed previously, we modified three distinct areas of the original protection and control logic in the standard single-phase capable, microprocessor-based recloser control. The first and most fundamental change was related to the operating mode of the recloser. Prior to the enhancement, we determined the most suitable recloser operating mode based on location, peak loading, etc. This operating mode was selected using a configuration setting, and the recloser would then continuously operate in this mode. The driving factor in whether Alabama Power could select single-phase tripping was whether peak load levels could possibly 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. Loading at many of these sites was low enough during a majority of time to operate in single-phase mode. However, peak loading dictated the operating mode because we had to avoid any possibility for misoperation of the feeder ground relay resulting from excessive unbalance.

To overcome this obstacle, we incorporated a relatively simple logic scheme to switch between single-phase operation mode and three-phase mode depending on load (see Fig. 13). 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 setpoint for five minutes, the control switches to the three-phase trip and lockout mode. After load falls below the setpoint for the same time period, the unit returns to the single-phase mode selected at the time of configuration (either SPTSPLO or SPTPLO).

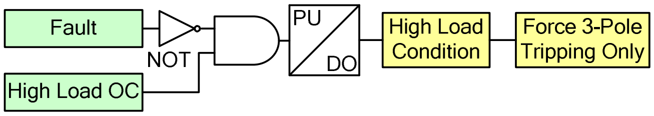

Fig. 13 Load-based tripping decision logic

We expect this enhancement to allow use of single-phase fault interruption in areas never before possible. We have estimated in one division of the Alabama Power service area that as many as 85 percent of the presently deployed units now operating in the three-phase mode could be converted to this new scheme. Once configured with the new settings, these units will begin to improve reliability during periods where loading allows them to operate in a single-phase fault interrupting mode.

The following is an example of one method for determining the load level for switching from single-phase operation to three-phase mode. The data given are from an actual feeder.

Monitoring of the feeder breaker current at the substation occurs remotely and recording of demand current occurs at regular intervals. We took the weekly peak demand values for each phase from these recordings and averaged these values. We determined that the average for the heaviest loaded phase was 277 amps and that the average unbalance was approximately 80 amps. SCADA does not monitor the current for the downline recloser, so we estimated weekly peak loading for the recloser using the measured peaks for the total feeder and a known distribution of load between the total feeder and the section under the recloser. The estimated average load level for the recloser is 140 amps.

With knowledge of the average load currents and feeder unbalance, we can determine a threshold for switching operation modes. If two phases of the recloser opened during an average load period, the additional ground current the feeder ground relay at the substation sees would be approximately 140 amps. The worst-case unbalance would then be approximately 220 amps, if we assume that the full 80 amps of average feeder unbalance we determine from the load measurements is to be added to the single-phase loading of 140 amps resulting from the recloser. In reality, we would expect the unbalance to be lower because some of the 80 amps of ground current from the load measurements come from load unbalance beyond the recloser. However, assuming worst case will provide more margin for error or system changes.

The pickup setting for the feeder ground relay at the substation is 240 amps. For our worst-case average unbalance of 220 amps resulting from two open recloser poles, the ground current would be nearing the relay pickup point. For this feeder, the recloser control was programmed to switch to three-phase operation mode whenever the recloser load reached 130 amps on any phase. Table 2 shows the calculated weekly peak loading for the recloser and the weeks in which we can expect the recloser to operate in a single-phase trip and reclose mode. Based on these estimates, the recloser will operate in single-phase mode full-time for approximately 18 weeks out of the year. In addition, for the remaining 34 weeks where we expect peak loading to exceed 130 amps, the unit will still switch to single-phase mode periodically when demand is below 130 amps.

TABLE II
WEEKLY PEAK LOAD

Weekly Peak Load (amps)	**Operation Mode**	**Weekly Peak Load (amps)**	**Operation Mode**
179.0	3P	162.8	3P
177.5	3P	165.0	3P
155.9	3P	166.7	3P
153.7	3P	131.5	3P
154.7	3P	130.6	3P
133.9	3P	88.8	1P
143.8	3P	134.5	3P
129.4	1P	91.5	1P
139.6	3P	94.2	1P
120.4	1P	125.5	1P
101.1	1P	109.5	1P
96.3	1P	96.6	1P
130.3	3P	122.8	1P
121.3	1P	84.2	1P
106.2	1P	135.4	3P
121.6	1P	145.3	3P

Weekly Peak Load (amps)	Operation Mode	Weekly Peak Load (amps)	Operation Mode
140.5	3P	163.1	3P
114.3	1P	165.5	3P
157.7	3P	155.9	3P
136.0	3P	164.9	3P
177.5	3P	162.8	3P
116.4	1P	168.8	3P
144.1	3P	166.4	3P
168.5	3P	184.1	3P
150.4	3P	178.1	3P
125.2	1P	185.3	3P

In addition to solving the concern of tripping upline ground devices on induced unbalance, the method just discussed also allowed for a change in how we operated the recloser ground element. Without the concern of load unbalance affecting the recloser's ground element, we decided to leave the ground element in service regardless of operation mode or the status of each phase interrupter. We could now set the minimum trip level (pickup) of the phase overcurrent elements to carry more load because they did not have to also sense restricted ground faults.

The final modification Alabama Power chose was to synchronize the shot counters. As discussed previously, out-of-sync shot counters were a potential problem because upline phase elements could be exposed to more trip shots than expected. Any three-phase (maximum-phase) TOC element upline operating with a definite or inverse-time reset characteristic (electromechanical reset emulation) could easily advance unnecessarily to the point of tripping for the right fault combination.

We introduced logic that simply commanded the shot counter of a particular phase to advance if its shot counter was less than the count of another phase. Fig. 14 illustrates a generic representation of this logic.

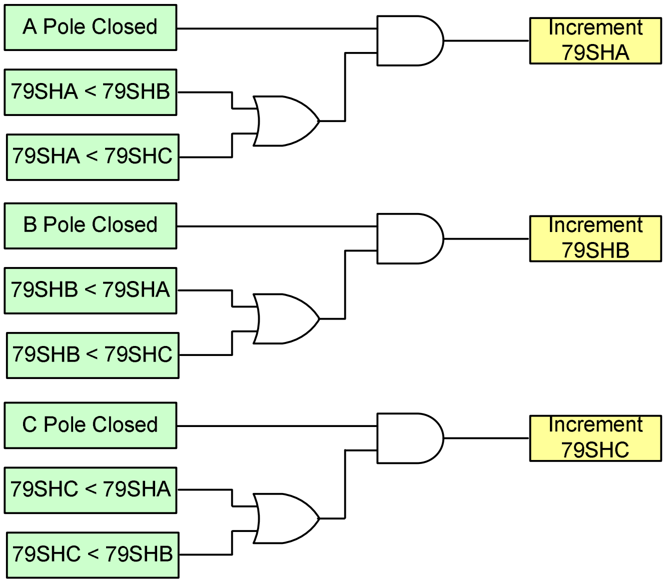

Fig. 14 Recloser shot counter synch logic

The only perceived disadvantage in synchronizing shot counters is that any phase becoming involved later in the fault will not have as many opportunities to clear as when using all of the traditional two to three reclose attempts. However, the synchronizing logic does not reduce the number of reclose attempts for the initial faulted phase. If any one phase completes a reclose sequence and another phase becomes involved late in the sequence (and locks out early as a result), this may actually be more desirable than the alternative. If the fault on the first phase is permanent, it is likely that phases becoming involved later in the sequence are part of the same permanent fault. When this is the case, a full set of reclose attempts on a phase joining the fault late in the sequence is unproductive.

V. CONCLUSIONS

Use of a single-pole tripping scheme for distribution protection has proven helpful in improving reliability. While implementing this new protection philosophy, we addressed a number of concerns and learned from the experience. Following is a summary of some of the important lessons learned:

1. Single-phase tripping and reclosing offers an excellent method of reducing unnecessary customer interruptions.
2. Traditional methods of single-phase fault interruption restricted the practice to more lightly loaded sections of distribution feeders because of the negative impact that unbalanced load interruption can have on upline ground-fault protection devices.
3. Single-phase fault interruption, even when performed from independent-pole reclosers with a modern protection and control unit commonly controlling the recloser, can lead to undesired trip operations on upline breakers as a result of phase or ground element miscoordination and/or excessive unbalance applied to the upline ground relay.

4. Simple solutions are possible with programmable, single-phase capable recloser controls that allow us to gain the benefit of single-phase tripping on feeders and feeder sections previously off limits to this practice.
5. Many feeders that experience peak loading which prohibits single-phase fault interruption are actually loaded at levels conducive to single-phase fault interruption for a large percentage of the time. In these cases, consider operating in a single-phase mode during times of lighter loading and automatically switching to three-phase mode as load increases.
6. When reclosing each phase independently can lead to miscoordination with upline maximum phase sensing time-overcurrent elements, consider synchronizing the shot counters in the recloser control to avoid potential coordination issues.
7. When possible, leave the ground element in service at all times within the single-phase capable recloser control. This maintains a consistent level of ground-fault sensitivity. Switching to a three-phase mode during periods of heavier loading can help facilitate this. By selecting the appropriate load point at which to change modes, resultant load unbalance following single-phase fault interruption will not reach a level high enough to cause false operation of either the local recloser's ground protection or any upline ground relays.

VI. BIOGRAPHIES

Robert Cheney began working at Alabama Power Company in 1978 as a field engineer. He is currently serving as a Senior Engineer in the Distribution Engineering Support department. Part of his duties in this role are the initiation and implementation of new operating practices made possible by using modern electronic controls now available on switches and reclosers. Robert graduated from Auburn University with a B.S. in Electrical Engineering and later received his M.S. degree in Electrical Engineering from the University of Alabama at Birmingham.

John Thorne has eight years experience at Alabama Power Company, serving in various distribution engineering positions. He has experience in construction, protection, and reliability at the company. He presently holds the position of Division Reliability Engineer for the Birmingham and Eastern Divisions. He received his B.S. degree in Electrical Engineering from Auburn University in 2004.

Greg Hataway received his B.S. in Electrical Engineering from the University of Alabama in 1991. He has broad experience in the field of power system operations and protection. Upon graduating, he served nearly 12 years at Alabama Electric Cooperative, where he worked in distribution, transmission, and substation protection before assuming the role of Superintendent of Technical Services at the cooperative. In this position he coordinated the utility's efforts in protection and power quality. He joined Schweitzer Engineering Laboratories, Inc. in 2002 as a Field Application Engineer in the Southeast Region.

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