Coping with Single-Phase Load Diversity Using Adaptive Relay Settings

1. Introduction

Setting ground overcurrent elements on the typical distribution circuit is a straightforward task. The ground element setting must be sensitive enough to operate for the coordination point with the lowest ground (earth) fault current. However, for circuits with large single-phase load diversity, a large zero-sequence current (or $3I_0$), will be seen in the neutral due to this imbalance. The ground element pickup setting must also be high enough that the relay does not trip for this level of zero-sequence current. The amount of $3I_0$ present will change for different system conditions, such as summer peak versus winter peak.

Typical relaying practices for a circuit that has large single-phase load diversity involve making some tradeoffs on the reliability of the protection system. Generally, sensitivity (and therefore dependability) is lowered so the relay allows the maximum expected zero-sequence current in the neutral (maintaining security).

This application note introduces the idea of adaptive relay settings to provide better ground overcurrent protection for circuits with large single-phase load diversity. The normal settings of the relay use a ground element with maximum sensitivity for fault conditions. As system conditions change and the load diversity increases, the relay adapts by decreasing the sensitivity of the ground pickup, preventing a false operation by allowing more $3I_0$ to flow. Adaptive relay settings provide a cost-effective method of improving the protection of distribution feeders, by automatically maintaining both dependability and security as system conditions change.

2. Current practices

For circuits with large single-phase load diversity, there are three philosophies used for setting ground relay elements:

1. Disable the ground element: This allows the maximum amount of $3I_0$ present during load diversity. However, the method provides minimum protection. Only the phase elements will operate for a ground fault, and, due to load allowance requirements, they may not have the sensitivity to see all phase-to-ground faults. This method greatly lowers the dependability of the protection system to maintain security.
2. Lower the ground element sensitivity to allow the maximum amount of $3I_0$ expected. This maintains some ground protection for all system conditions and doesn't require constant correction of the relay settings. However, the sensitivity of the ground relay is not ideal, especially when load diversity is small. Like disabling the ground element, this method also lowers the dependability of the protection relay to maintain security, but not as radically.

3. Change the ground element sensitivity for specific system conditions. This method is used when load diversity increases greatly for a long period of time, such as seasonal load peaks. Protection is maximized as much as feasible, but relay settings must be changed several times a year. This method only lowers the dependability of the protection system when absolutely required, and maintains security.

All three of these methods are in common use. From a pure protection standpoint, changing the ground pickup settings for system conditions is the best method. This method provides the best system reliability, by only lowering dependability when required. The drawback is the cost involved. With electro-mechanical relays, field changes of settings are required. Numerical relays generally require remote control, auxiliary relays, and operator action to change settings groups.

3. New application concept

Adaptive relay settings allow a protection relay to automatically, and independently, change settings as the system operating conditions change. The Siemens SIPROTEC 4 overcurrent relays (7SJ61, 7SJ62, and 7SJ63), using the PLC programming capability in the Continuous Function Chart (CFC), can adapt relay settings automatically. For this application, a relay will adapt the ground element sensitivity as the amount of zero-sequence current changes due to increasing single-phase load diversity.

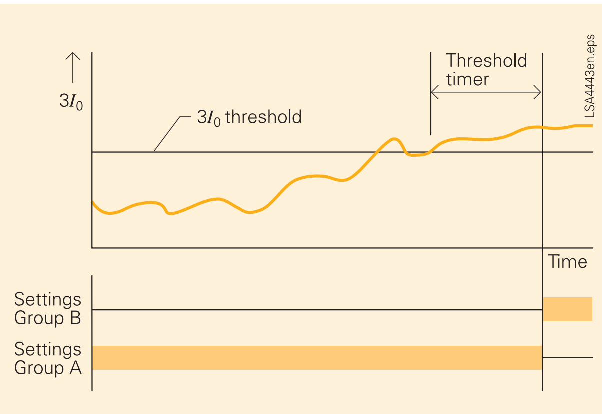

Fig. 1 Adapting ground element settings

To adapt the ground element settings, the relay is programmed to change settings groups as the measured zero-sequence current changes over time. As the amount of $3I_0$ increases, and remains above a pre-determined threshold value, the relay changes settings groups from one with maximum ground element sensitivity, to one that provides less sensitivity for higher phase diversity.

When the amount of $3I_0$ decreases, and remains below the predetermined threshold, the relay returns to the normal settings group. This concept is illustrated in Fig. 1.

Definition of the elements shown in Fig. 1:

- Settings Group A
  The "normal" settings group. The ground element pickup setting is set with maximum sensitivity to operate for a fault at the circuit reach point, while allowing the amount of $3I_0$ present during normal single-phase load diversity conditions.
- Settings Group B
  The alternate settings group. The ground element is set to allow the amount of $3I_0$ present during the maximum single-phase load diversity condition.
- $3I_0$ Current Threshold
  The level of zero-sequence current that indicates a change in single-phase load diversity of the circuit. The value of this threshold must be large enough to indicate that the load diversity is actually changing, but less than the pickup setting of the ground element for Settings Group A.
- Threshold Timer
  This time delay is used to ensure a larger load diversity exists, and that the diversity is not a transient condition. The increase in single-phase load diversity, as indicated by the amount of $3I_0$, must the load diversity settings group. The timer must be set long enough to ensure the load diversity has increased to new level, and has not just temporarily increased due to a the addition of a large, transient, single phase current draw condition. The timer must also be set so the relay can differentiate between fault conditions and changes in single-phase load diversity.
- Reset Timer
  This is the time necessary to indicate a decrease in the single-phase load diversity. The single-phase load diversity, as indicated by the amount of $3I_0$, must stay below the $3I_0$ Current Threshold for this length of time to return the relay to the original settings group. This timer must be set long enough to ensure the single-phase load diversity has actually returned to normal condition.

4. Application examples

The load information shown in Table 1 is for a circuit with a summer peak. As shown, there is a significant increase in the load and the amount of $3I_0$ during the summer. It is desirable to use peak demand values for load information, or when possible, historical data for the amount of zero-sequence current. For this example, the minimum fault current that the ground element must operate for is 1.5 A_{sec}.

	Winter	Summer
Phase A Load	1.25 A_{sec}	2.38 A_{sec}
Phase B Load	1.54 A_{sec}	1.62 A_{sec}
Phase C Load	1.35 A_{sec}	1.42 A_{sec}
$3I_0$ Current	0.26 A_{sec}	0.87 A_{sec}

Table 1 Typical circuit load

Table 2 lists possible relay settings for the circuit load information from Table 1. The ground element pickup setting in Settings Group A is set to provide a desired reach sensitivity to the minimum ground reach point, while allowing some percentage of the normal amount of $3I_0$. For dependability, to ensure the ground element trips for all faults in the zone of protection, minimum reach is set in the range of 2/1 to 3/1. For security, the ground pickup should allow 120 % to 150 % of the normal amount of $3I_0$.

The ground element pickup setting for Settings Group B is set to maintain security by allowing some percentage of the expected amount of $3I_0$. A typical setting range is 120 % to 150 %. This setting is balanced against the desire to maintain some dependability by having some reach sensitivity to the minimum ground reach point.

The $3I_0$ Current Threshold is set at a level high enough to indicate a change in the single-phase load diversity, but still below the ground element pickup setting for Settings Group A. The $3I_0$ Current Threshold level, and the Threshold Timer, must also account for the rate of change of the zero-sequence current. If the threshold is too high, or the timer too long, the zero-sequence current may increase over the ground element pickup setting before a settings change occurs. Once the ground element is in pickup, no settings group change is possible, and the ground element will eventually trip.

The Reset Timer is set at a time long enough to ensure that the single-phase load diversity has actually decreased, to prevent the relay from "bouncing" between settings groups.

Element	Setting	Calculations
Setting Group A Ground element pickup	0.5 A_{sec}	Reach = 1.5/0.5 = 3.0 Allowance = 0.5/0.26 = 192 %
Ground element time dial	1.0	
Setting Group B Ground element pickup	1.1 A_{sec}	Reach = 1.5/1.1 = 1.36 Allowance = 1.1/0.87 = 126 %
Ground element time dial	1.0	
$3I_0$ current threshold	0.45 A_{sec}	
Threshold timer	30 min	
Reset timer	15 min	

Table 2 Example relay settings

5. Implementation of adaptive relay settings in a SIPROTEC 4 relay

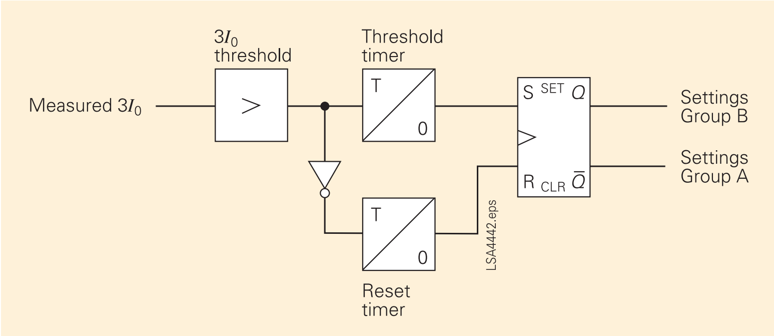

Fig. 2 Adaptive ground element logic

Implementation of the adaptive relay setting logic, using the SIPROTEC 4 7SJ61, 7SJ62, and 7SJ63 relays, is in the Continuous Function Chart (CFC) portion of the relay. This is a graphical programmable logic controller programming tool that permits the use of standard and advanced logic and control capabilities. Using the CFC, the logic of Fig. 2 is implemented in the relay.

The zero-sequence current measured by the relay is compared to the $3I_0$ Current Threshold in the "Measurement" plan of the CFC. The output of this comparison is used in the "Slow PLC" plan to start either the Threshold Timer or the Reset Timer. If the output of the comparison is logical 1, the Threshold Timer is started. Otherwise, the Reset Timer is started. When the Threshold Timer expires, a SR flip-flop is used to latch the ">Set Group Bit0" command. Asserting the ">Set Group Bit0" command changes the settings group from A to B. When the Reset Timer expires, the SR flip-flop is reset, deasserting the ">Set Group Bit0" command, and changing the settings group from B to A.

6. Summary

Adaptive relay settings provide a method for matching the reliability of the protection system to the actual system conditions. When looking at this example of single-phase load diversity, the protection engineer has typically had to give up some of the dependability of the protection system to maintain the security of the protection system. Adaptive relay settings give the relay the ability to maximize the dependability of the protection system, while not effecting security at all.

The idea of adaptive relay settings is a very powerful concept that can be extended to many applications. One possible application is to automatically change relay settings for temporary increases in circuit demand, such as during switching operations.

7. References

William D. Stevenson, Jr. Elements of Power System Analysis, 4th Ed., McGraw-Hill Book Company, New York, NY; 1982

Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill Book Company, New York, NY; 1986

DIGSI CFC Instruction Manual, Siemens Power Transmission and Distribution, Inc., Raleigh, NC; 1999

SIPROTEC Time-Overcurrent, Overload, And Motor Protective Relay with Bay Controller 7SJ61 V4.0/4.1 Instruction Manual, Siemens Power Transmission and Distribution, Inc., Raleigh, NC; 1999