



Prevention of Negative-Sequence Element Misoperations During Unbalanced Conditions

Relay Work Group

July 12, 2012

Table of Contents

Introduction.....	3
Heavy Load on a Non-Transposed Line.....	3
Problem	3
Solution	5
Subharmonic Frequencies Excited by a Fault on a Series-Compensated Line.....	5
Problem	5
Solution	6
Standing Voltage and Current Unbalance Conditions	6
Problem	6
Solution	6
Tapped-Distribution Substation	7
Problem	7
Solution	7



Introduction

The WECC Relay Work Group (RWG) has recently reviewed several line protection misoperations caused by sensitive negative-sequence elements operating during unbalanced conditions. These reviews led to the decision to produce a white paper that describes these unbalanced conditions and methods to prevent protection misoperations during them. The paper describes the following situations:

- Heavy Load on a Non-Transposed Line
- Subharmonic Frequencies Excited by a Fault on a Series-Compensated Line
- Standing Voltage and Current Unbalanced Conditions
- Tapped-Distribution Substations

Transmission lines built on mountainous or rocky terrain may have very high tower- footing resistance. This situation, in conjunction with a lack of overhead shield wires, can result in low magnitude ground-fault current. Ground-fault protections for these lines require very sensitive settings that may make them susceptible to misoperation during unbalanced conditions.

This paper deals with sensitive negative-sequence directional-overcurrent elements applied to detect high-resistance ground faults on transmission lines.

Generally, the RWG recommends system modeling to prevent mis-operations during external faults and unbalanced conditions.

Although the mis-operations described below are associated with sensitive negative- sequence elements, sensitive zero-sequence elements may respond to some of these conditions in a similar manner.

Misoperations due to the first two conditions described below are more likely to occur during stressed system conditions when a mis-operation is least desirable.

Heavy Load on a Non-Transposed Line

Problem

This problem is associated with lines constructed without transpositions or lines not re-transposed after reconfiguration to accommodate the addition of a new substation.

Unequal mutual coupling associated with a non-transposed line causes different phase impedances that in turn cause unbalanced current. This unbalanced current has negative- and zero-sequence components. For most line configurations, load flow through a non-transposed line produces more negative-sequence than zero-sequence current.



Prevention of Negative-Sequence Element Misoperations During Unbalanced Conditions

The magnitude of negative-sequence current produced by the non-transposition depends on line configuration, line length, and magnitude of power flow. High load flow through a long non-transposed line may produce sufficient negative-sequence current to operate sensitively set negative-sequence overcurrent elements, including those used to supervise directional elements.

The protection at each line terminal measures the negative-sequence current produced by load flowing through the non-transposed line and that produced by other system unbalances. This current flows into one terminal and out the other terminal.

Unbalanced current flow through different phase impedances causes different voltage drops in each phase of the line that affects the magnitude and angle of the negative-sequence voltage at the terminal where negative-sequence current flows out of the line.

Consider first the terminal where negative-sequence current flows into the line. The protection at this terminal measures the negative-sequence voltages caused by external system unbalances including that produced by load flow through source non-transposed lines. Since the magnitude of this voltage is relatively small, Capacitor Voltage Transformer (CVT) error can have a significant impact on its accuracy. The protection at this terminal may measure a negative-sequence voltage that lags the negative-sequence current, which is indicative of a forward fault. If the magnitude of the negative-sequence current exceeds the setting of the negative-sequence overcurrent element and the setting of the directional element supervising current elements, then the forward directional-overcurrent element asserts.

Next, consider the other terminal where negative-sequence current flows out of the line. The protection at this terminal measures a negative-sequence voltage that is affected by the same external system unbalances as the power-sending terminal in addition to that produced by load flow through the non-transposed line. Load flow through a non-transposed line may cause a phase shift in the negative-sequence voltage at the receiving terminal. However, CVT errors may be a major contributor to the apparent phase shift in negative-sequence voltages detected by relays at the two-line terminals. The use of negative-sequence polarizing is based on the assumption that the polarizing negative-sequence voltages at each terminal are essentially in phase. Significant phase shift in the polarizing quantity, in conjunction with the operation of associated negative-sequence current elements, can result in operation of the forward directional-overcurrent element at the terminal where negative-sequence current flow is out of the line. In a permissive overreaching transfer trip (POTT) scheme, operation of forward directional-overcurrent elements at both line terminals during a non-fault condition results in incorrect tripping of the line.

Increased transmission line loading following removal of generators or lines due to either planned or forced outages increases the risk of mis-operations.



Solution

To prevent mis-operation of negative-sequence directional-overcurrent elements during high-power transfer through a non-transposed line, set associated negative-sequence current elements greater than the maximum negative-sequence current that will flow at the highest possible power transfer level. This should be easily achievable for most relatively well-grounded transmission systems.

However, in a transmission system operating in areas of high ground resistivity, it may not be possible to obtain the desired sensitivity and remain secure for all load conditions. In this case, one solution is to increase the positive-sequence restraint factor setting in the negative-sequence directional-element enabling circuit. This progressively reduces the sensitivity of the negative-sequence directional element as positive-sequence current (i.e., load) increases. This provides the desired sensitivity during normal system operation. A greater reduction in sensitivity will occur during a system contingency, such as the loss of a parallel line resulting in higher load.

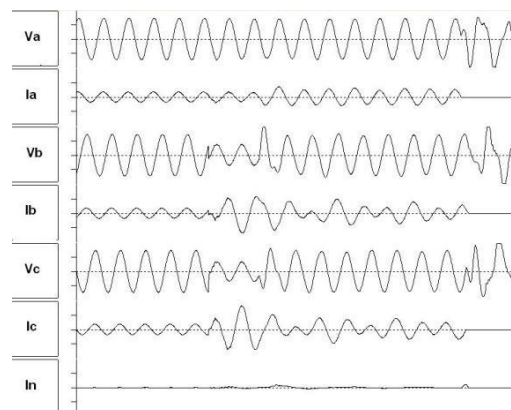
The RWG recommends accurate modeling to determine settings that are secure during maximum loading conditions.

Subharmonic Frequencies Excited by a Fault on a Series-Compensated Line

Problem

A fault on a series capacitor-compensated line can generate transient oscillations having a subharmonic frequency determined by the relative values of line series inductance and capacitance. These oscillations shown in the digital fault recorder (DFR) waveform below can appear on lines located adjacent to a faulted line. Because microprocessor relays may not completely filter out these subharmonic oscillations, there can be spurious operation of negative-sequence elements resulting in tripping of a non-faulted line.

DFR Output



Prevention of Negative-Sequence Element Misoperations During Unbalanced Conditions

Solution

In most power systems, the sensitivity of the protection can be set sufficiently high to override these oscillations. However, if there is a requirement to retain high sensitivity, one method to prevent misoperation is to delay the very sensitive negative-sequence directional-overcurrent element to ride through the transient oscillation period and rely on other elements to provide the desired protection operating speed.

The risk of a negative-sequence element operation increases with the outage of adjacent transmission lines due to fewer lines are available to absorb the effects of the transient oscillation.

The RWG recommends using power system modeling incorporating real-time digital simulator (RTDS) simulations for protection systems applied on series- compensated lines. The RTDS simulation must be of sufficient duration to check security during the transient oscillation period, typically lasting several seconds.

Standing Voltage and Current Unbalance Conditions

Problem

Instrument transformer inaccuracies or power system conditions can cause standing voltage and current unbalance conditions present at the relay. Causes of standing unbalance include:

- Defective instrument transformer
 - CVT capacitor failure
 - Current transformer secondary circuit
- Power system condition
 - Series capacitor unbalance
 - Unequal phase conductor lengths of underwater cable

A standing unbalanced condition can affect the performance of negative- sequence voltage-polarized directional elements that can adversely affect the security or dependability of line protection.

Solution

It is important to detect these unbalanced conditions in order to apply mitigation to prevent possible mis-operations. This can be done by programming microprocessor relays to initiate an alarm if current or voltage unbalance (e.g., 3I2 or 3V2) exceeds a selected threshold for a period of time (e.g., two minutes). Set 3I2 and 3V2 above normal unbalance.



Tapped-Distribution Substation

Problem

Transmission line tapped-distribution substations often use transformers with the high side connected in delta and the low-side connected in grounded wye. During a ground fault on the low side of the transformer, the delta-connected transformer windings trap zero-sequence currents so that they are not seen by the line protection. Thus, zero-sequence elements applied in the line protection will not detect a low-side ground fault. However, negative-sequence currents resulting from a low-side ground fault can result in mis-operation of line protection negative-sequence elements.

Solution

Negative-sequence overcurrent elements applied in line protection must be coordinated with low-side protection for any unbalanced low voltage fault.



Prevention of Negative-Sequence Element Misoperations During Unbalanced Conditions

WECC receives data used in its analyses from a wide variety of sources. WECC strives to source its data from reliable entities and undertakes reasonable efforts to validate the accuracy of the data used. WECC believes the data contained herein and used in its analyses is accurate and reliable. However, WECC disclaims any and all representations, guarantees, warranties, and liability for the information contained herein and any use thereof. Persons who use and rely on the information contained herein do so at their own risk.

