Performance of Relaying During Wide-Area Stressed Conditions
Highlights of the IEEE PSRC Working Group C12 Report

George J. Bartok for IEEE PES-PSRC Working Group C12

Abstract

Protective relay operations during wide-area disturbances have often contributed to the spread of the disturbance instead of preventing the disturbance propagation [1], [2]. The paper highlights various points discussed in an IEEE Power Systems Relaying Committee working group report on the performance of protective relays during wide-area stressed power systems conditions [1].

Causes of Wide-Area Disturbances

The report (available on the IEEE Power Systems Relaying Committee Website, www.pes-psrc.org) begins with a detailed description of causes of wide-area disturbances such as voltage or angular instability, voltage excursions and frequency excursions. The report also discusses higher equipment loading and high power transfers which could also lead to a wide-area disturbance.

Protective Relay Performance

The IEEE PSRC report focuses on the behavior of protection functions during dynamic operating conditions that are not generally considered during the normal relay setting process and provides solutions to prevent such undesirable relay performance during system-wide disturbances. Several salient points are discussed for the following protection schemes:

- Transmission line protection
- Transformer protection
- Generator protection
- Bus protection
- Shunt reactor/ capacitor protection
- Feeder protection
- Motor protection
- Load Shedding

Since most of the modern relay schemes are microprocessor relays, phasor measurements are affected by inputs at off-nominal frequencies. Frequency tracking/compensating schemes used in these relays may lag or may not track the fast changing system frequency. The impact of the frequency deviation from nominal is discussed for each type of protection. For example, distance relay algorithms or operating principles make use of memory polarization. Memory polarization uses several cycles of pre-fault voltages to ensure correct relay operation for faults that cause voltages to dip below a threshold or for faults on series compensated lines resulting in voltage inversion. The longer the memory duration, the higher is the risk of undesired tripping during off nominal frequency operation. The behavior of legacy systems (electromechanical or solid-state relays) under off-nominal frequency is dictated by their designs.

Transmission Line Relays

Angular instability causes large power swings leading to undervoltage and overcurrent situations in the system. Distance relays are prone to respond to unstable swings resulting in unwanted tripping at undesirable locations in the system resulting in severe generation-load imbalance. It may be desirable to block tripping at some locations and to permit tripping at some other locations in order to maintain system stability. Detailed analysis is required to properly apply the OOS tripping/ blocking logic.

High power transfers and heavy loading during system stressed conditions may result in load impedance encroaching into the impedance characteristics of overreaching distance relays resulting in undesired line tripping and worsening the overall system stability. Voltage stability problems may also result in load impedances encroaching into the relay-tripping region due to the reduction in system voltages during heavy loads. Modern relays are equipped with load encroachment logic to prevent operation due to loads.

Other transmission line protections such as current differential or phase comparison relay schemes make decisions by comparing currents at two (or three) line terminals. These relays are generally not affected during system stressed conditions. However, since these schemes are communication dependent, excessive asymmetric channel delays caused by network switching may result in undesired tripping.

System restoration through proper selection of automatic reclosing is important in improving system stability. Since a majority of faults on transmission lines are transient in nature, high speed tripping and reclosing aids in preventing system instability. However, it may not be desirable to reclose onto a permanent three-phase fault at some locations that may adversely impact system stability.

Protection issues related to parallel lines, series compensated lines and three terminals lines are discussed in detail in the report.

Transformer Protection

Overvoltages during system stressed conditions may result in excessive fifth harmonic current that may operate differential relays not equipped with fifth harmonic restraint. Excessive loading of transformers may also result in the operation of overcurrent relays set at levels with less overload margin. Supervisory control, based on transformer loading, top oil temperature and the winding temperature, is mentioned in the report as an alternate option to prevent tripping during temporary overload situations.

Generator Protection

Generators are protected against overloads, abnormal frequency and abnormal voltage. Improper coordination of protective relays has resulted in tripping of generators during system disturbances. Prolonged depressed voltages could result in the tripping of critical plant auxiliaries, resulting in generator shut downs.

By properly coordinating the generator protection devices with the regulating and control systems, making use of allowable short time operation outside of rated safety limits, unnecessary tripping during system disturbances can be avoided.

Voltage restrained overcurrent protection and/or distance relays used as backup may operate during low voltage and overload conditions. These should be coordinated with transmission line relays and associated breaker failure relay times. The operation of ground backup overcurrent relays in generator step-up transformer neutrals should also be reviewed to ensure that they would not trip the generator unnecessarily.

Furthermore, generator under-frequency protective relays should be coordinated with under-frequency load shedding relays to prevent undesired tripping of generators during a system disturbance. Loss-of-field relays may operate incorrectly during stable power swings or during an under-excited condition. Loss-of-field relay operation during a recoverable power swing can be prevented by properly selecting the setting based on several power swing scenarios. The setting should also coordinate with minimum excitation limiters to fully utilize the generator capability during a disturbance.

Out-of-step relays may operate during a disturbance due to their characteristics being modified by under-frequency or under voltage conditions even though the generator is not in an out-of-step condition. The relays are typically set to trip only if the swing is unstable and the settings may require extensive system transient studies.

Bus Protection

Since bus protection schemes are based on the differential principle, they are generally immune to severe system disturbances. Heavy current flows may result in false triggering of CT saturation detectors or directional schemes blocking operation of relays employing these principles.

Shunt Reactor/ Capacitor Protection.

Shunt capacitor bank protection may be sensitive to severe unbalance currents and harmonics present during a disturbance. Neutral unbalance detection schemes not adequately compensated for system unbalance or harmonics may operate under these conditions tripping the reactive support that is needed during the system disturbance.

Shunt reactor protection based on negative sequence current or voltage quantities may operate for other harmonics, such as the fifth, during a system disturbance.

Feeder Protection

Instantaneous and inverse time overcurrent relays or circuit reclosers are used for the protection of feeders. System disturbances resulting in voltage and frequency excursions may affect the connected load, resulting in an overcurrent operation. Uncontrolled tripping of feeders may result in a larger generation/load imbalance, aggravating the disturbance.

Motor Protection
System disturbances resulting in under-voltage and under-frequency conditions will have an impact on the performance of motors and associated relays. Under-voltage will result in higher currents and decreased torque, resulting in stalled motors or overcurrent conditions. An under-frequency condition may result in reduced cooling, operating thermal relays. It could also result in over fluxing, causing the V/Hz protection to operate. The report directs the reader to the IEEE "Guide for AC Motor Protection" [3] which provides information on impacts of abnormal power supply to motors and presents possible solutions.

Under-frequency Load Shedding
Under-frequency load shedding schemes are installed to prevent propagation of system disturbances. These relays may operate on either frequency, rate-of-change of frequency, or both and are set with a coordination time delay. Schemes are designed based on predetermined scenarios. This could result in either over tripping or under tripping of load during a different islanding scenario. The report suggests the use of adaptive schemes to achieve optimum shedding and restoration.

Improving Protection Performance
As protection systems should not contribute to the propagation of the disturbance, the impact of wide-area disturbances can be minimized and the number of disturbances decreased by improving the protection systems currently installed. This could be achieved by designing protection and control schemes for those disturbance conditions not considered in the initial design. However, experience has shown that some relays might have prevented further cascading by tripping on system conditions for which they were not designed. The report [1] describes in detail methods available to improve performance of relaying during wide-area stressed conditions to prevent further propagation of disturbances.

Protection Scheme Design
The design of protection schemes has a significant effect on the overall performance during wide-area disturbances and other abnormal system conditions [2]. One such design improvement could be to limit the use of memory voltage only during fault conditions to prevent operation of distance relays under off-nominal frequency excursion. Another design consideration discussed in the report is to implement voting logic on redundant protection schemes to improve security.

Hidden Failures
Self-diagnostic and input supervision features of modern relays improve the availability of the protection system.

Human Errors
Human errors have contributed significantly to the failure of protection functions. These include wiring and relay setting errors. Adequate testing and review processes can reduce human errors.

Conclusions

This paper highlights key points discussed in the IEEE PSRC Report "Performance of Relaying During Wide-Area Stressed Conditions". In addition to the salient points covered in this paper, the report also describes field experiences under stressed conditions citing various past power system disturbances around the world.

References

[1] Performance of Relaying During Wide-Area Stressed Conditions, IEEE Power System Relaying Committee, 2008 Report. Available: http://www.pes-psrc.org.

[2] NERC Recommendations to August 14, 2003 Blackout - Prevent and Mitigate the Impacts of Future Cascading Blackouts; www.NERC.com .

[3] Guide for AC Motor Protection, IEEE C37.96-2000.

Acknowledgment

This paper is based on the report created by IEEE Power System Relaying Committee Working Group C12 that can be found on the committee web site, http://www.pes-psrc.org. The authors acknowledge excellent contributions by WG members that made this paper possible: D. Novosel (chair); G. Bartok (vice-chair); A. Apostolov; M. Begovic; K. Behrendt; G. Benmouyal; M. Bloder; S. Brahma, G. Brunello; A. Buanno; F. Calero; M. Carpenter; J. De La Ree; A. Deronja; W. Elmore, J. Gardell, W. Hartmann; G. Henneberg, S. Horowitz; S. Imai; A. Johnson; B. Kasztenny; B. Kennedy; P. Kerrigan; S. Kim; C.W. Liu; V. Madani; P.Mysore; S. Saygin, M. Shah; J. Soehren; V. Terzija, D. Tziouvaras; M. Venkata; S.Ward; D. Ware; T. Wiedman; B. Wojszczyk