UPGRADING GENERATOR PROTECTION WITH DIGITAL MULTIFUNCTION RELAY TECHNOLOGY

Murty V.V.S. Yalla
Beckwith Electric Co. Inc.
Largo, FL USA

George Punnoose
Easun Reyrolle Ltd.
Hosur, TN

ABSTRACT

The introduction of Digital Signal Processor technology enabled multiple protection functions to be integrated into a common protection platform, which allowed all generator protection functions to be implemented in a single multifunction relay at low cost. Included are discussions on application and performance differences between multifunction protection systems and single function static and electromechanical relaying devices. This paper describes why owners of older generators should consider upgrading protection on their generators. It details the deficiencies of older protection schemes and proposes protection upgrade using digital multifunction relay technology.

INTRODUCTION

Generator protective relaying technology has evolved from discrete electromechanical relays and static relays to digital multifunction protection systems. Most protection schemes in use today are either discrete electromechanical or static relay types, which have a long history of providing reliable protection. However, with the introduction of digital multifunction protection systems, generator protection engineers are incorporating this technology into their protection schemes. Protection engineers are now applying multifunction protection systems to generators for upgrading or augmenting existing protection and for new protection [1].

Two types of upgrades are being used. The first uses multifunction protection systems to replace older discrete component electromechanical protection schemes. The second type of upgrade uses multifunction generator protection system to add protection functions that are not on older machines. In most cases, new generators are being protected with some combination of dual multifunction generator protection or single, multifunction generator protection combined with other generator protection schemes.

Digital technology offers several additional features, which could not be obtained in one package with earlier technology. These features include the following: metering of voltages, currents, power, and other measurements; event recording and oscillography; remote setting and monitoring through communications; user configurability of tripping schemes; reduced panel space and wiring; low burden on the vts and cts and continuous self-checking.

The following sections of the paper describe reasons why older generators need to upgrade their protection, typical application of a multifunction relay for generator protection, and additional features offered by digital multifunction relays.

GENERATOR PROTECTION UPGRADE USING DIGITAL MULTIFUNCTION RELAYS

Digital Multifunction Relays are an ideal choice for a cost-effective method to implement a generator protection upgrade program. The following are some of the important reasons why older generator protection systems are upgraded using digital multifunction relays.

1. Reduction in relay testing and maintenance workload

With continued down sizing of personnel in the electric utility industry, fewer people are available for testing and maintaining protection systems. Lack of self-checking features on electromechanical and static relays requires periodic testing of these relays. Upgrading generator protection with digital multifunction relays which have built-in continuous self-checking capability will reduce testing and maintenance workload.

2. Improved protection

Several protective functions implemented using older technology, especially electromechanical relays, are not sensitive enough to provide proper protection for faults and abnormal conditions on the generator. The following are some of these functions:

Negative Sequence Overcurrent Protection

When negative sequence current flows in the stator winding,, it will induce double frequency current in the rotor surface. A majority of this induced ac current at double the frequency will flow on the rotor surface due to the skin effect, which results in rotor surface heating. When the negative sequence current increases beyond the generator's continuous unbalance current capability, the rotor temperature increases. If the generator is not tripped, a rotor failure can result. The rotor thermal limit is expressed as follows:

$I_2^2 t = K$ where:

I_2 is the negative sequence current in pu
t is the time in seconds and
K is a constant, which depends on generator size and design.

The table below (from ANSI standard C50.13 [2]) shows the continuous unbalance capability of a generator:

Type of Generator	**Permissible Negative Sequence Current (% of stator rating)**
Salient Pole Machine	
With connected amortisseur windings	10
With non-connected amortisseur windings	5
Cylindrical Rotor	
Indirectly cooled	10
Directly cooled to 960 MVA	8
961 to 1200 MVA	6
1201 to 1500 MVA	5

It can be seen from this table that the continuous negative sequence current capability of the generator is in the range of 5% to 10% of the generator rating. During an open conductor or open generator breaker pole condition, the negative sequence current can be in the range of 10% to 30% of the generator rating. Other protective relays on the generator or on the system will not usually detect this condition and the only protection is the negative sequence overcurrent relay. When older generators are protected by electromechanical relays, these relays can only be set to a minimum pickup of 60% of the generator rating. In order to prevent generator damage, digital or static relays must be applied whose pickup can be set down to 3%. Upgrading older generators with digital multifunction relays will provide sensitivity required for proper protection of the generator from unbalance currents. Figure 1 shows inverse time overcurrent characteristic implemented on a digital multifunction relay.

Loss of Field Protection

When a synchronous generator loses its excitation, it will run at higher than synchronous speed and operate as an induction generator delivering real power to the system. However, at the same time it obtains its excitation from the system, becoming a large reactive drain on the system. This large reactive drain causes problems for the generator, adjacent machines, and the power system. Also, the slip induced eddy currents in the field winding, rotor body, wedges, and retaining rings cause heating. The high reactive current drawn by the generator from the system can overload the stator winding causing the stator temperature to increase. A loss of field condition which is not detected quickly can have a devastating impact on the power system by causing both a loss of reactive support as well as creating a substantial reactive power drain for a single event. This type of condition can trigger an area wide voltage collapse and trip transmission lines if there is not a sufficient source of reactive power available.

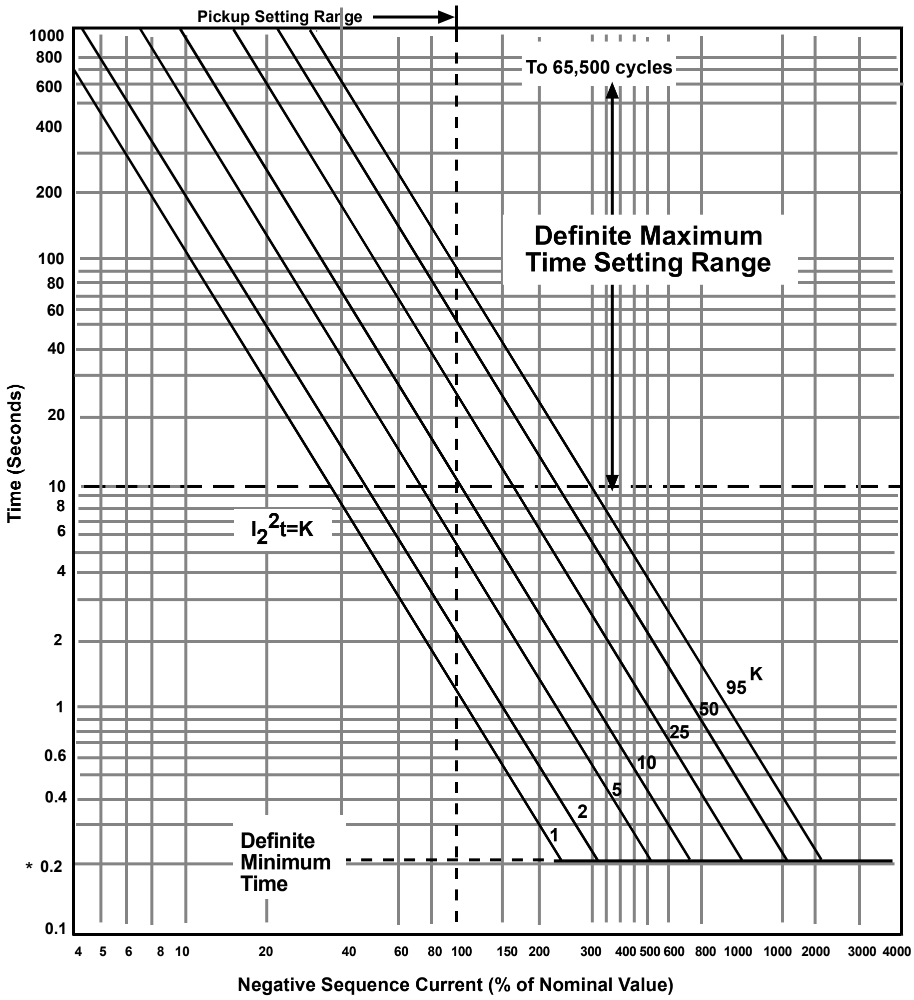


Figure 1 Negative Sequence Inverse Time Overcurrent Protection

The loss of excitation protection should reliably detect the loss of excitation condition without responding to load swings, system faults, and other transients, which do not cause the machine to become unstable. The most widely applied method for detecting generator loss of field is the use of offset mho relay to sense the variation of impedance as viewed from the generator terminals. Traditionally, this protection is provided by a single zone offset mho electromechanical or static relay. The offset is set at one half of the direct axis transient reactance (X'_d), and the diameter is set at direct axis synchronous reactance X_d. When the machine impedance is greater than 1.0 pu (in some cases up to 2.0 pu), the circle diameter becomes very large. This may result in misoperations during stable power swings.

Digital multifunction relays incorporate two-zone offset mho characteristic. The first zone can be set with a diameter of 1.0 pu and a short time delay which provides fast protection when the loss of field condition occurs during heavy load. The second zone is set with a diameter of X_d and a longer time delay to provide protection during light load conditions while preventing misoperation during power swings. Two possible setting characteristics with multifunction relays are shown in figures 2(a) and 2(b). The multifunction relay also has a voltage control feature to provide additional security. This feature, when enabled, can block the relay if the generator voltage is above a specified value. Another advantage of the digital technology is that the relay characteristic does not change with operating frequency, which is the case with electromechanical relays. During power swing conditions, the generator frequency changes, and if the relay characteristic changes with frequency, it is possible to have relay misoperations.

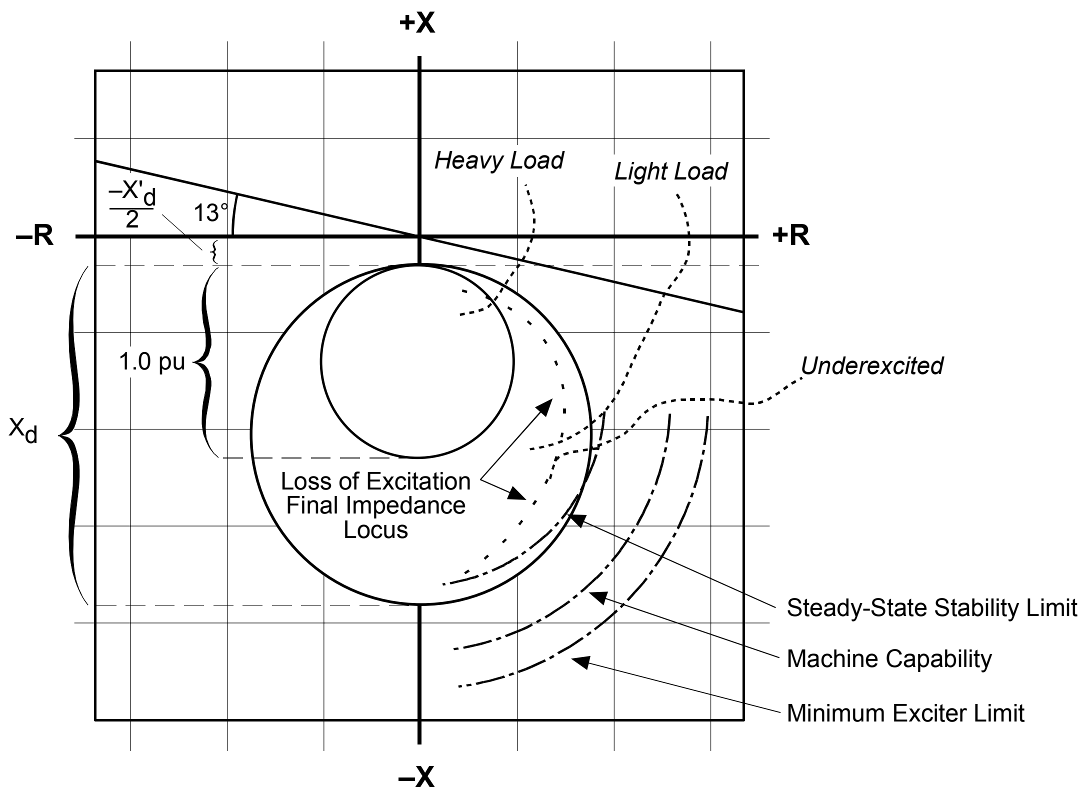


Figure 2 (a) Loss of Filed Protection Approach #1

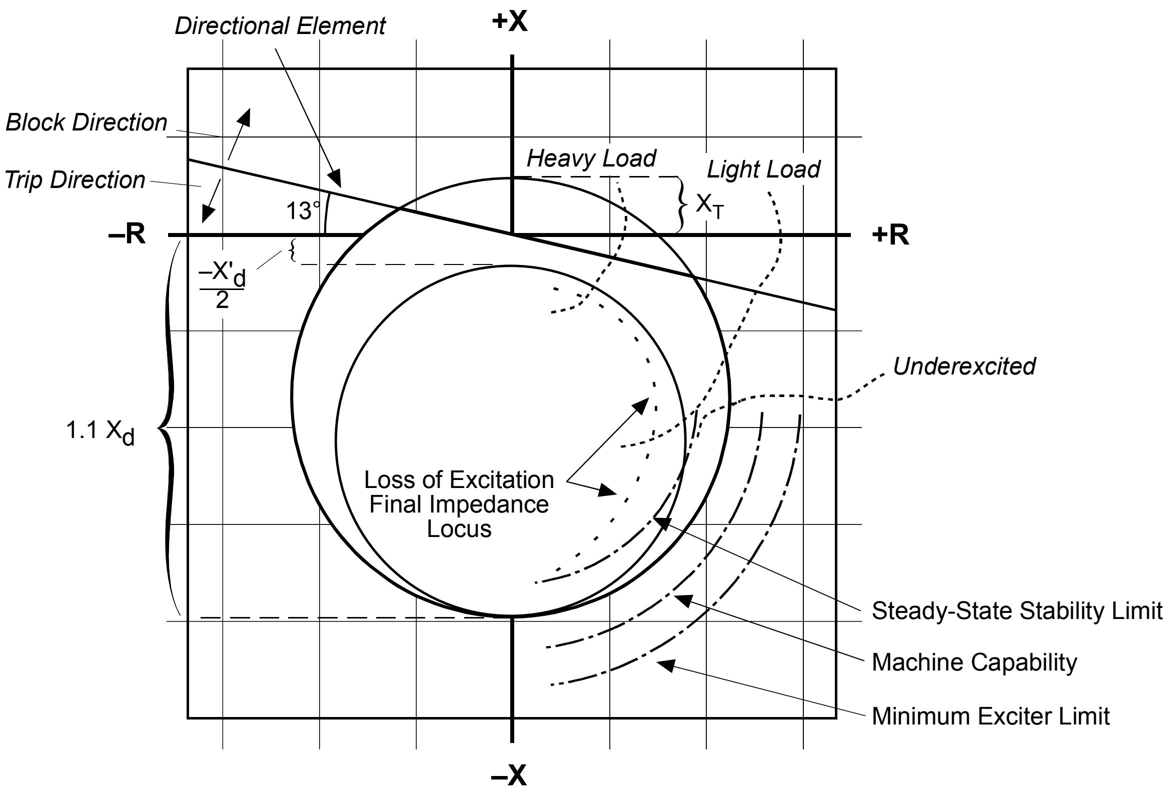


Figure 2 (b) Loss of Field Protection Approach #2

Overexcitation Protection

Overexcitation of a generator will typically occur when the V/Hz exceeds 1.05 pu on the generator base. During an overexcitation condition, saturation of the magnetic core of the generator or the connected transformer can occur, and stray flux will be induced into the non-laminated components which are not designed to carry flux. Damage can occur within seconds. It is general practice to provide V/Hz protection for generators and transformers from these excessive magnetic flux density levels. Damage due to overexcitation occurs most frequently when the unit is off-line prior to synchronization. Traditionally, definite time or inverse time relays are used to provide protection for this condition.

Modern digital relays provide protection using both definite time as well as inverse time elements to match the short-time overexcitation characteristics of a generator and its associated unit transformer and auxiliary transformer. The time integration feature of the volts/hertz protection is easily obtained and allows the heating and cooling characteristics of the generator and transformer to be simulated. The digital relays are designed to provide accurate V/Hz measurement over a wide frequency range (2 Hz to 120 Hz). This is especially required for gas turbine generators using converter start technology where the frequency can go very low. A typical protection characteristic implemented on a multifunction relay is shown in Figure 3.

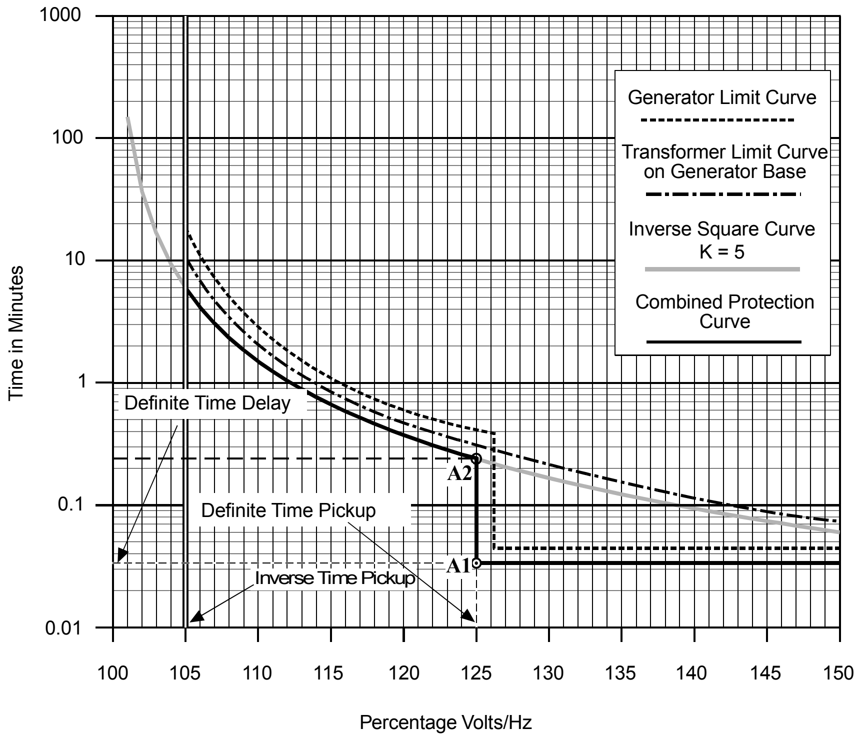


Figure 3 Definite and Inverse Time Volts/Hz Protection Characteristics

Rotor Earth Fault Protection

The field circuit of a generator is ungrounded, and a single ground on the field circuit generally will not affect the operation of the generator. However, the probability of a second ground fault occurring is greater due to the deterioration of the field insulation and establishing ground reference by the first ground. The second field ground short-circuits a portion of the field winding. This causes damage to the winding and produces rotor iron heating. The field winding short-circuit also produces unbalanced air gap fluxes and unbalanced magnetic forces which result in machine vibration.

The tripping practices for field ground condition vary by the user. Some users trip the generator while others alarm. Traditionally, two methods are applied in the industry. In the first method, a dc voltage is applied to measure the insulation resistance. In the second method, 50/60 Hz ac signal is injected to measure the insulation resistance. The digital multifunction relays use low frequency square-wave injection principle to measure the field insulation resistance. Figure 4 illustrates the measurement technique. A square wave signal is injected into the field circuit of the generator. The return signal, which is proportional to the field insulation resistance, is measured. The injection frequency (0.1 Hz to 1 Hz) should be selected based on the rotor capacitance. This method provides reliable insulation resistance measurement. The measurement technique can also detect a break in the measurement circuit or brush lift condition. This can be programmed to send an alarm to the operator indicating that the rotor earth fault protection is off-line.

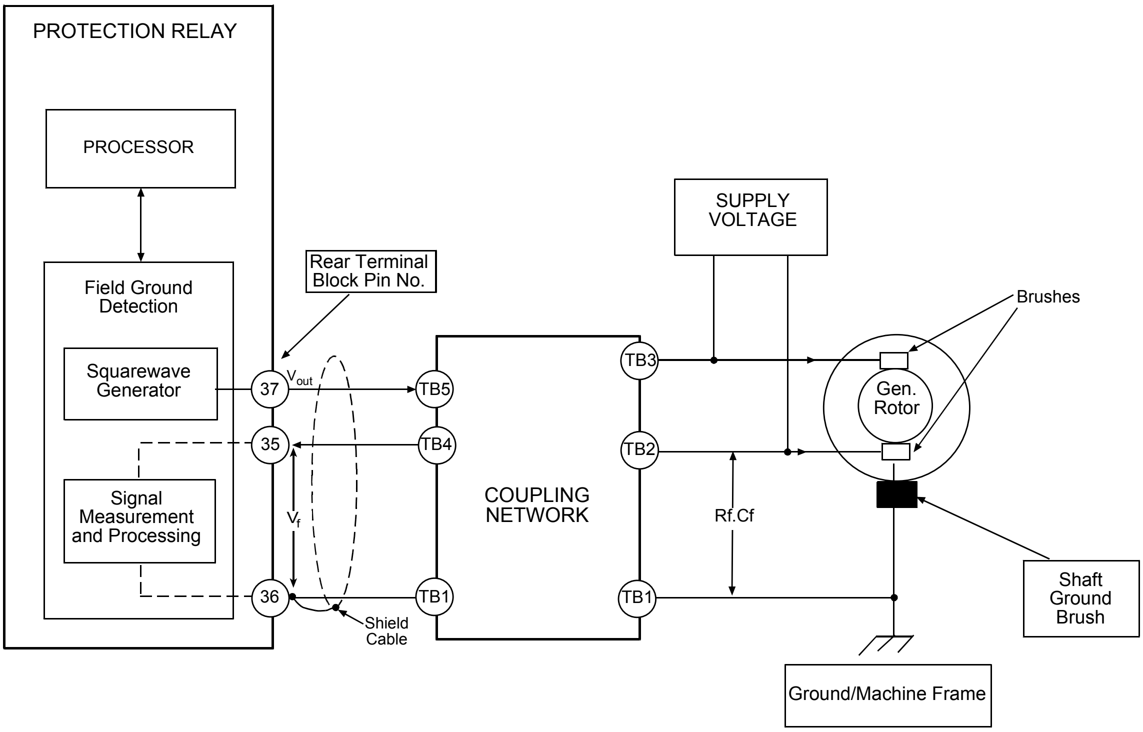


Figure 4 Block Diagram of Rotor Earth Fault Protection Implementation

3. Additional protective functions

Some of the protection functions were not applied on the older generators because they were not perceived as a problem. In some cases they were only applied on very large generating units. The following are these protection functions:

Inadvertent (Accidental) Generator Energizing

In recent years accidental energizing of synchronous generators has been a particular problem within the industry. Several machines were destroyed when they were accidentally energized while off-line. Several utilities are applying special protection schemes to provide protection for inadvertent energizing. When a generator is accidentally energized while on a turning gear, it acts like an induction motor and draws high current from the system. The machine can be damaged in a very short time (few seconds). One of the main causes for accidental energizing of generators is operator error.

Conventional relays provide limited protection for inadvertent energizing, and dedicated protection schemes should be applied. Digital multifunction relays provide an economic upgrade to add inadvertent protection to the old generators. The logic shown in figure 5 uses overcurrent and undervoltage elements to implement inadvertent energizing protection. An undervoltage element with adjustable pickup and dropout time delays supervises an instantaneous overcurrent relay. The undervoltage detectors automatically arm the overcurrent tripping when the generator is taken off line. The under voltage detector will disable the overcurrent relay when the machine is online.

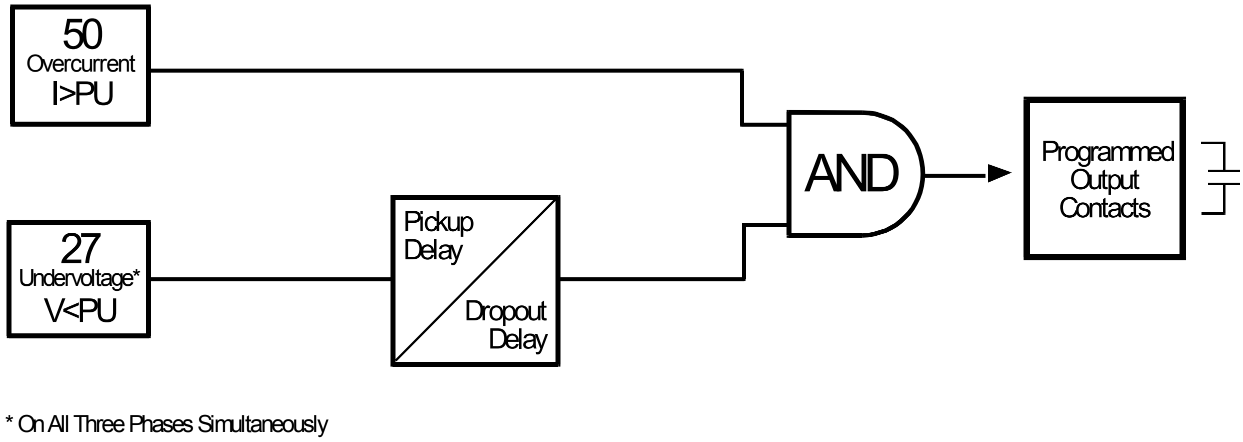


Figure 5 Inadvertent energizing protection logic

100% Stator Ground Fault Protection

Most medium to large generators are grounded through a distribution transformer with a secondary resistor. Using this grounding method, a single line-to-ground fault is generally limited to 3 to 25 primary amperes. Ground fault protection for these generators is provided by overvoltage relay (59N) connected at the secondary of the grounding transformer. However, this relay will provide protection for only 90%-95% of the stator winding as shown in figure 6. Many utilities have upgraded ground fault protection to provide 100% stator winding coverage. One such method uses third harmonic undervoltage (27TN) implemented as part of a multifunction relay. When the generator is operating normally, a third harmonic voltage is present at the neutral of the generator. When the generator experiences a stator ground fault near the neutral end of the stator winding, the third harmonic voltage reduces. This can be used as a measure to detect ground faults near the neutral as shown in figure 6.

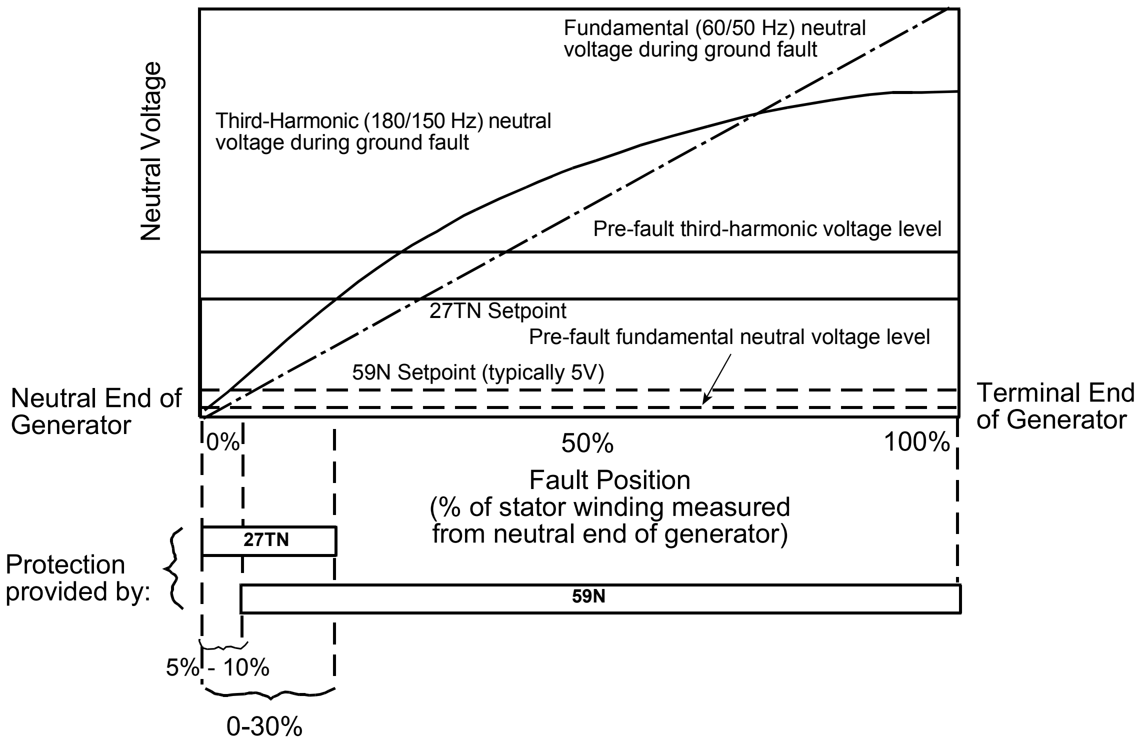


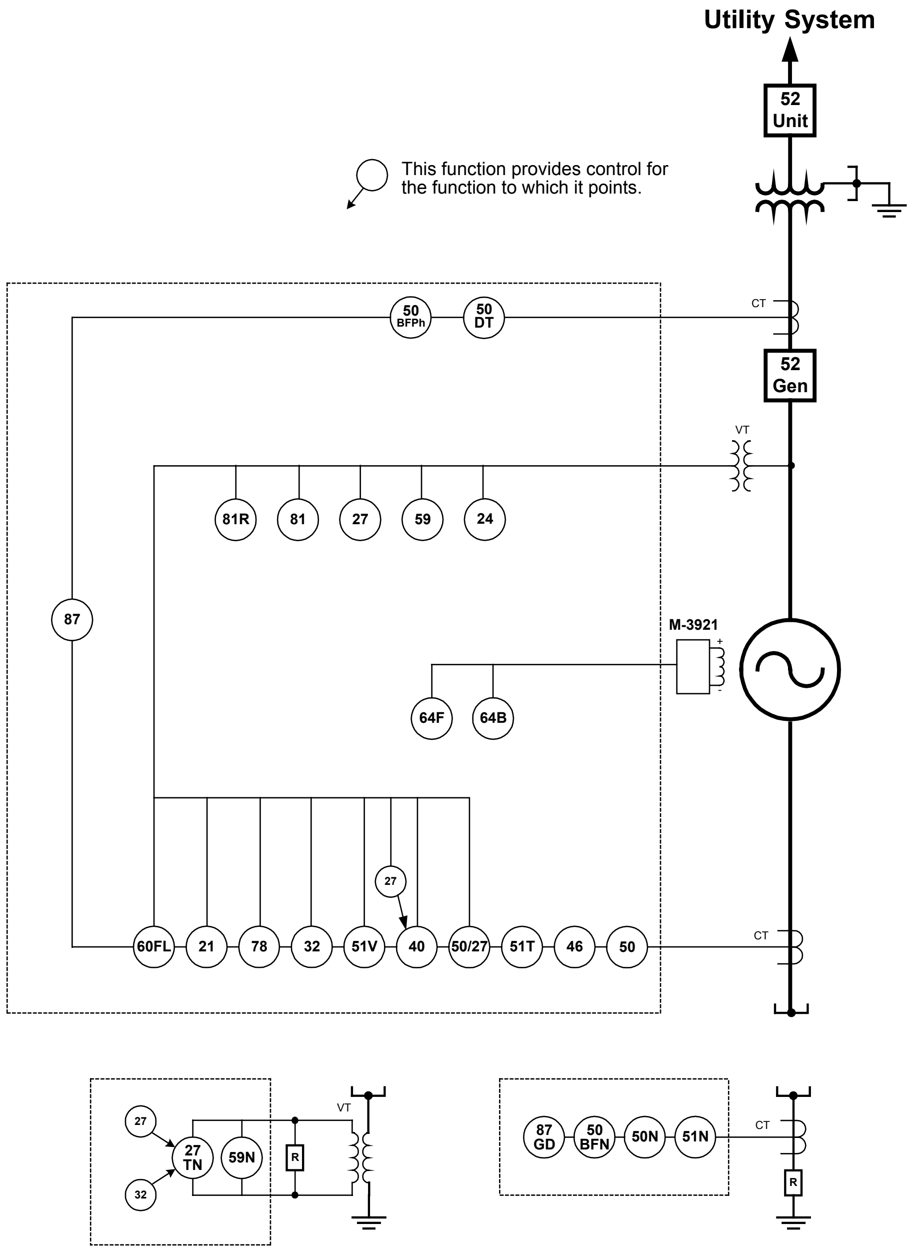
Figure 6 100% Stator Ground Fault Protection

4. Faster fault diagnosis and reduced down time

With the help of sequence of events and oscillographic recordings, faults and other system related problems can be quickly diagnosed. If the problem is not identified within the generator, it can be quickly brought back on-line saving the utility from purchasing the lost power from a neighboring utility. With out the help of these recordings it may take a lengthy investigation to determine the problem.

TYPICAL APPLICATION OF A MULTIFUNCTION RELAY FOR GENERATOR PROTECTION

The following one line diagram (Figure 7) shows a typical application of digital multifunction relay (M-3425) applied for generator protection. A detailed discussion of different protective relay functions and their application to various types of generators can be found elsewhere [3,4].



High-impedance Grounding with Third Harmonic 100% Ground Fault Protection

Low-impedance Grounding with Overcurrent Stator Ground Fault Protection

Figure 7 Typical Generator Protection One-line Diagram

The following protection functions are included in the multifunction protective relay:

1. Generator Phase Differential (87G) or split phase differential (50DT)
2. Stator Ground (59N) or 87GD/51N (for low impedance grounding)
3. 100 percent Stator Ground, third harmonic neutral undervoltage (27TN)
4. Current Unbalance/Negative Sequence (46)
5. Dual zone Loss of field (40)
6. Overexcitation (24)
7. Undervoltage (27)
8. Overvoltage (59)
9. Underfrequency (81U)
10. Overfrequency (81O)
11. Directional Power with low forward power (32)
12. Stator thermal Protection (51T)
13. Breaker failure / Breaker flashover (50BF-Ph/50BFN)
14. System Backup: voltage controlled/restrained overcurrent (51V) and dual zone phase distance (21)
15. VT fuse loss (60)
16. Out-of-Step (78)
17. Rotor Earth fault (64F/64B)

There are several thousand digital multifunction relays in service and one such model (M-3425) is shown in Figure 8.

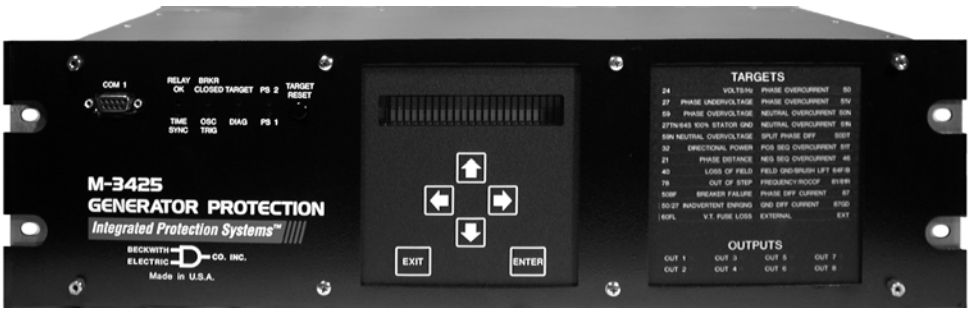


Figure 8 Digital Multifunction Relay (Beckwith Model M-3425)

In addition to the above protective relay functions, the following additional features are also offered by the M-3425 digital multifunction generator protection system:

Oscillography and event recording
The capability of storing analog data and internal and external sequence of events allows the user to quickly analyze incidents and reduce downtime.

Time Synchronization
This allows a user to better coordinate information from the generator protection package with information from other parts of the system. The relay synchronizes the time using IRIG-B time code input signal.

Metering
Depending on the display capability and accuracy, the protection package may displace or supplement traditional metering. The metering capability may also allow easier testing and commissioning of the relay and its associated wiring.

Monitoring
Monitoring of external inputs/outputs enhances security and reduces costs. Voltage transformer circuits can be monitored. When the vt signal is lost, functions can be inhibited and/or alarms can be issued.

Communications
Local and remote communication capabilities allow easy input of settings and changes, as well as access to event data. With the proper interface protocol, the generator package can be integrated with other intelligent devices in the power plant via a distributed control system.

Self-Monitoring and Diagnostics
Self-monitoring software in the multifunction relay allows detection of a failure of a major piece of hardware or software module. Consequently, the multifunction relay outputs can be disabled and an alarm generated, signaling the failure. With electromechanical or static relays, the failures are only detected during routine maintenance testing. The generator will be left without protection until the relay failures are detected and a new relay is put into service.

Programmable Logic
With all the information brought to the multifunction relay, programmable logic permits configuration of the logic related to protection and control functions. This will considerably reduce the external circuitry.

CONCLUSION

The paper identifies areas of generator protection which can benefit by upgrading to digital multifunction protection technology. In addition to protection, other added benefits of digital technology are outlined. Digital multifunction relay technology provides a cost-effective method to upgrade older generator protection systems to present industry standards. Concerns of reliability and availability can be addressed by applying a fully redundant protection scheme utilizing two independent multifunction protection relays.

REFERENCES

1. Murty V.V.S. Yalla (Chairman), etal, “Application of Multifunction Generator Protection Systems,” Working group J11 of the Rotating Machinery Protection Subcommittee, Power System Relaying Committee. IEEE Transactions on Power Delivery, Vol. 14, No. 4, October 1999, pp.1285-1294.

2. ANSI C50.13-1987, “American National Standard for Cylindrical Rotor Synchronous Generators.”

3. IEEE Tutorial on the Protection of Synchronous Generators, “IEEE Power Engineering Society, Catalog No. 95 TP 102, 1995.

4. IEEE Standard C37.102-1995 “IEEE Guide for AC Generator Protection”

BIOGRAPHY

Murty V.V.S. Yalla obtained his B.Tech from J.N.T.U Kakinada in 1981, M.Tech from I.I.T. Kanpur in 1983 and Ph.D. from UNB, Canada in 1988 all in Electrical Engineering. In 1989, he joined Beckwith Electric Co., Inc. in Largo, Florida, USA where he is currently the Vice President of Research & Development and Engineering. He is author/co-author of 4 patents and published several papers in international journals. He is a Senior Member of the IEEE and a member of the Power System Relaying Committee. He is presently the chairman of the working group J4, the revision of IEEE C37.102 Standard “Guide for AC Generator Protection.”

George Punnoose A graduate in Electrical & Electronics Engineering from university of Kerala . Have 18 years of professional experience in the field of protective relays and systems. Member of various national and international professional bodies. Present interest is on Digital Data communication and Substation integration solutions.