

**GENERATOR PROTECTION USING  
MULTIFUNCTION DIGITAL RELAYS  
(ECNE 10/92)**

## **INTRODUCTION**

Protective relaying technology has evolved from single function electromechanical units to static units and now into the digital arena. The development of low cost microprocessor technology has made possible the multifunction digital relay where many relaying functions can be combined into a single unit. When applying such products, the major concern of the protection engineer is the redundancy and reliability of the system. In the past, the engineer applied many individual units. The failure of a single protective unit was not a major concern since there were other discrete relays in the protection system that would provide a backup to the unit that was out of service. If a multifunction relay is out of service, the consequences can be more severe since many protective functions may be incorporated into the unit. With proper planning, the multifunction digital relays can provide the level of redundancy that was available in the past and provide a better overall protective system. When applying single function relays, the cost of each protective function needs to be justified versus the added protection the relay provides. In many cases, typically on less critical generators, only minimal protection was applied in order to reduce costs. Today, with digital relays, these compromises do not need to be made. The multifunction relays provide a high level of protection at a very attractive cost. This allows the protection engineer to design a complete protection system with less concern about costs.

## **OVERVIEW**

A multifunction digital relay is a microprocessor-based unit that uses Digital Signal Processing technology in order to provide multiple protective relaying functions for generator protection in one unit. Since many functions are incorporated into one package, much less panel space and wiring is required than would be if individual relays were used (as illustrated in Figure 1).

The multifunction digital relay can protect a generator from voltage, frequency, reverse power, overcurrent, loss-of-field, and overexcitation (V/Hz) disturbances, while also providing loss-of-VT-fuse detection, and breaker failure/flashover protection. A second multifunction digital relay could provide voltage, frequency, overcurrent, directional power, and directional overcurrent protection. With the addition of differential relays, the protection system could consist of only three or four relays.

When applying the multifunction digital relays for generator protection, the protection engineer must consider the amount of primary and backup protection desired. Then consideration can be given to determine if the relays are providing sufficient redundancy so that adequate protection remains when any one unit is out of service.

## **GENERATOR PROTECTION**

The generator protection system design should take into account the types of faults and abnormal operating conditions that could be present at the generating plant and provide means for detecting and acting upon these conditions. The extent of the protection system design will

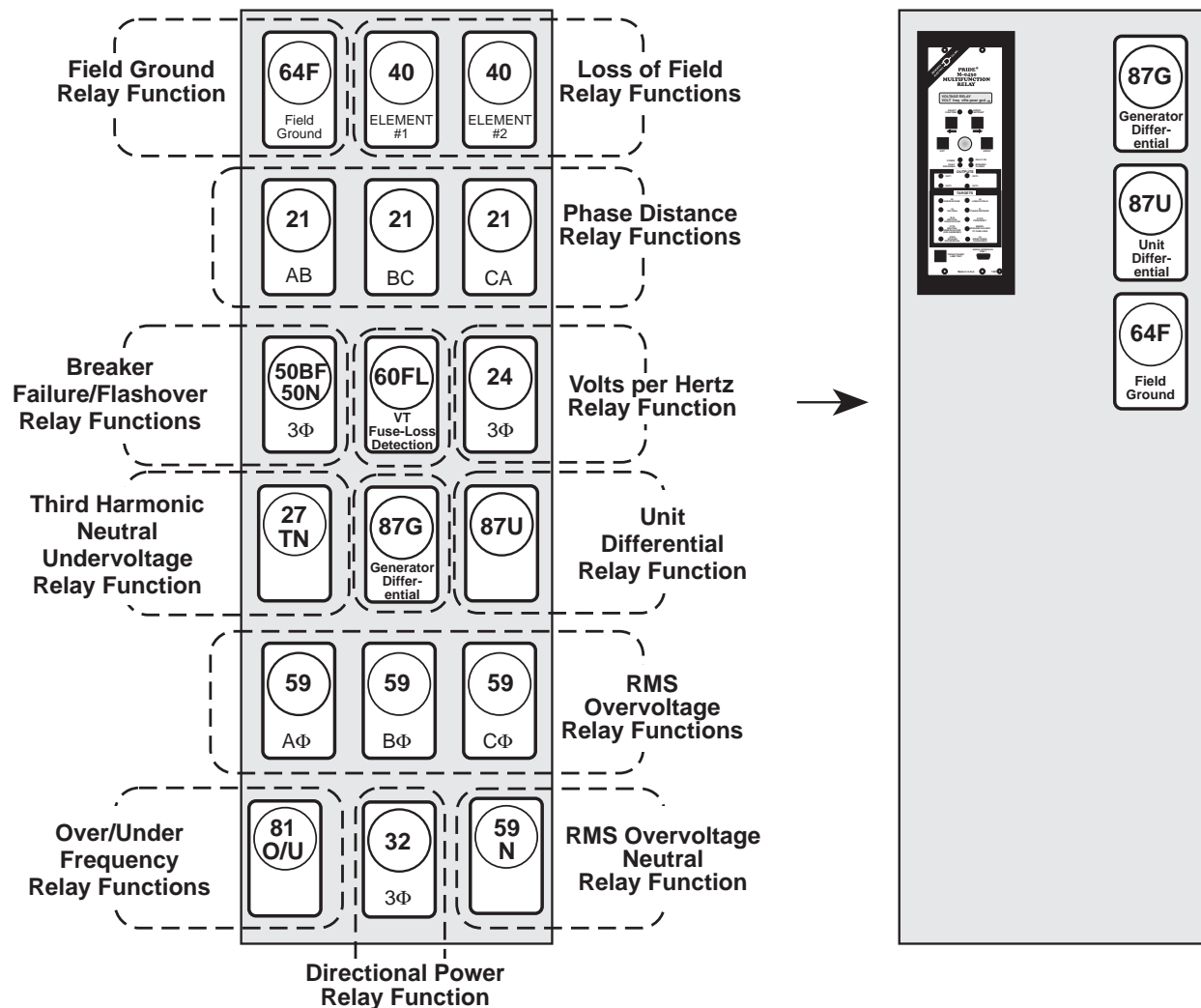


FIGURE 1 Discrete Relaying versus the Multifunction Digital Relay

depend on the size and relative value of the generating unit. Large critical units tend to have extensive protection systems with redundancy provided by having primary and backup protective functions.

Smaller, less critical units may have a subset of the primary protection provided for the larger unit with little, if any, backup protection. There can be no broad classifications of what size unit is to be designated as less critical, since the importance of a unit is always relative to the total utility capacity.

With the advent of multifunction relays, the trade-off of protection coverage versus cost has taken a marked turn toward more protection.

In order to put the generator protection problem in perspective, a short discussion on protection schemes is warranted. The “IEEE Guide for AC Generator Protection” ANSI C37.102 [1] is one of the premier documents available to the protection engineer for guidance in generator protection system design. In addition, there are several protective relaying texts available. A sample one-line protection scheme, from reference [1], for a unit-connected generator is shown in Figure 2. In this paper, discussions are limited to faults or abnormal conditions that are primarily detected by sensing the generator terminal voltages and currents. These fault types and disturbance conditions are classified as:

- Phase Faults
- Ground Faults
- Loss of Excitation
- Overexcitation
- Overvoltage
- Unbalanced Currents
- Abnormal Frequencies
- Motoring
- Dead Machine Energization
- Breaker Failures
- System Faults

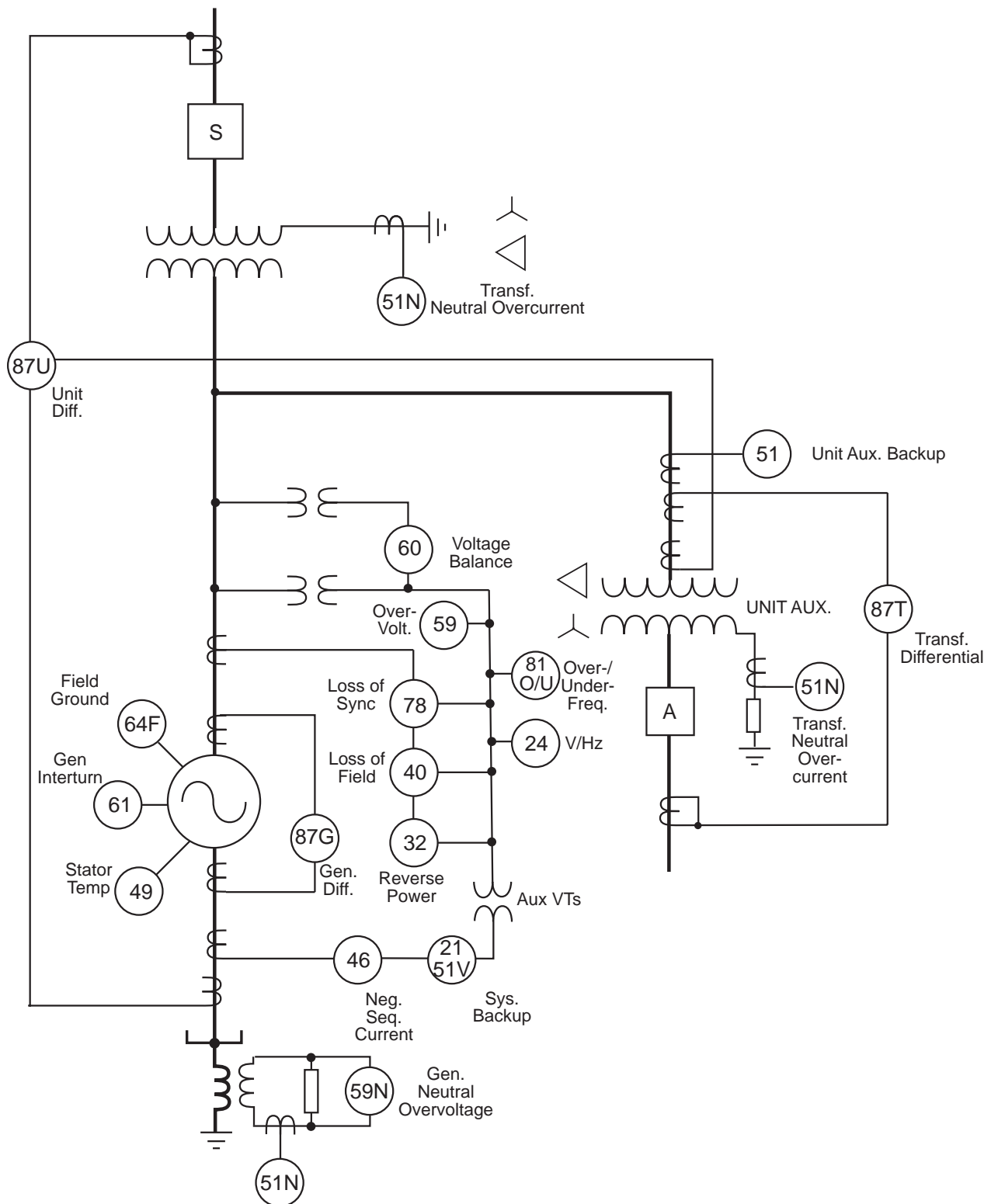
In addition to the above faults and disturbance conditions, several other conditions should be considered. Examples of these are: loss of synchronism, overload, interturn faults, stator and rotor thermal protection, and field ground. This paper does not cover these topics.

The numbers used in Figure 2 represent a shorthand notation defined by the ANSI/IEEE Standard C37.2-1979 to identify specific relaying functions. The guide to the use of these numbers and their definitions is found in reference [4].

## **PRIMARY AND BACKUP PROTECTION**

For each fault type listed above, there may be primary and backup protection applied to detect the fault and protect the generator.

The “primary protection” is the protective function designed as the “first choice” for detection of a designated fault type in the protection zone. This protection trips the appropriate breakers



**FIGURE 2 Unit Generator-Transformer Configuration**

to clear faults in the protected zone only. The primary protection is typically the fastest protective function for detecting the designated fault type.

“Backup protection” is a form of protection that operates independently of the primary protective function. The backup protection may duplicate the primary protection or may be intended to operate only if the primary protection fails or is temporarily out of service. Backup protection may trip breakers outside the protected zone. Backup protection may be slower to operate than the primary protection so that the primary protection has the first chance to operate.

## **GENERATOR PROTECTION APPLICATIONS**

### **PHASE FAULT PROTECTION**

Phase faults in a generator stator winding can cause thermal damage to insulation, windings, and the core, and mechanical torsional shock to shafts and couplings. Trapped flux within the machine can cause fault current to flow for many seconds after the generator is tripped and the field is disconnected.

#### **Primary Protection**

Primary protection for generator phase-to-phase faults is best provided by a differential relay (function 87). Differential relaying will detect phase-to-phase faults, three-phase faults, and double-phase-to-ground faults. With low-impedance grounding of the generator, some single-phase-to-ground faults can also be detected. (Turn-to-turn faults in the same phase cannot be detected, since the current entering and leaving the winding will be the same.)

#### **Backup Protection**

Backup protection for phase-to-phase and three-phase faults in the generator, unit transformer, and connected system can be provided by a unit-connected differential relay (87U), or a phase distance relay (21). A definite time delay can provide coordination with all relays that the phase distance relay setting over-reaches.

The protection zone depends on the relay reach, CT placement, and directional setting. When neutral-side CTs are used, the protection includes the generator, and protection will be available when the generator is both on- and off-line. When line-side CTs are used, the protected area depends on the relay offset: the relay can be set to look towards the generator, towards the system, or in both directions. When set to look towards the system, proper setting of the offset will provide some coverage for generator winding faults.

The voltage restrained or controlled Inverse Time Overcurrent relay (51V) and Directional Overcurrent (67) functions can also be used as supplemental backup protection. The negative sequence overcurrent function (46) can also be used as backup for uncleared system phase-to-

phase faults; this function will also protect the generator and associated equipment from unbalanced conditions and faults.

## **GROUND-FAULT PROTECTION**

One of the main causes of ground faults is insulation failure. The zero sequence impedance of a generator is usually lower than the positive or negative sequence impedance, and hence, for a solidly grounded generator, the single phase to ground-fault current is greater than the three-phase fault current. To limit the ground-fault current, generators are usually grounded through an impedance.

Since, on an impedance grounded generator, the fault-current available for sensing a phase-to-ground fault can be very small compared to phase-to-phase faults, depending on the location of the fault and the method of grounding the generator, separate ground-fault protection is usually provided.

### **High-Impedance-Grounded Generator**

With high-impedance-grounded generators, the generator ground-fault current may not cause severe damage to the generator, but a subsequent ground fault on a different phase will result in a phase-to-phase fault which can cause serious damage. An overvoltage relay (device 59N) connected across the grounding impedance to sense zero-sequence voltage can detect faults to within 5%–10% of the stator neutral (90%–95% of the stator winding). In order to detect faults within the area not protected by this relay, an undervoltage relay sensitive to the decrease in the third-harmonic voltage at the neutral (device 27TN) can be used to protect the final 10%–30% of the neutral end of the stator. There are several additional schemes for 100% stator ground fault protection discussed in reference [1].

### **Low-Impedance-Grounded Generator**

For low-impedance-grounded generators, phase differential protection (87) may provide coverage for ground faults, depending on the fault level and differential relay sensitivity.

A differential relay, responsive to zero sequence current, connected across the terminals of the generator and the neutral can provide higher sensitivity and fast operation. One of the requirements of zero sequence differential protection is that the line-side CTs and neutral CT have the same ratio; otherwise, an auxiliary CT with matching ratio must be used.

When a zero sequence source is present on the system (several generators are bussed together and connected to the load through a single transformer), a ground directional differential relay (87GD) can be applied. The 87GD function can work with a wide range of CT mismatch and without requiring the use of an auxiliary CT. It operates on the product of the triple zero sequence current, the neutral current, and the cosine of the angle between the two. The relay is relatively insensitive to ratio errors and CT saturation.

The multifunction digital relays eliminate the need for an auxiliary CT by providing an internal CT correction factor (entered by the user) in case of CT ratio mismatch. The zero sequence current is computed internally using line-side CTs, and hence, there is no requirement to provide a separate zero-sequence-current input.

### **Backup Ground-Fault Protection**

Backup protection for ground faults with either type of generator grounding can be provided by an Inverse Time Overcurrent relay (device 51N) in conjunction with an Instantaneous Overcurrent relay (device 50N) applied at the generator neutral to detect zero sequence unbalance current which flows during ground faults.

## **LOSS-OF-FIELD (EXCITATION) PROTECTION**

Loss of excitation on a synchronous machine can be caused by operator error, excitation system failure, a short in the field leads, accidental tripping of the field breakers, or flashover of the exciter commutator. When the machine loses its excitation, the rotor accelerates and the synchronous machine operates as an induction generator. As a result, the machine draws inductive reactive power from the system instead of supplying it to the system. Also heavy currents are induced in the rotor teeth and wedges and can cause thermal damage to the machine if the machine continues to operate. Loss of excitation protection is a backup to the proper operation of the excitation system, as such additional backup is not typically applied.

A two-element offset mho relay is used to protect against loss of field. Properly set, this will detect a loss of field from full load down to almost no load. It is applicable to any type and size of generator, including hydro, gas turbine, steam, and diesel. Several additional features, such as a directional element (directional control), an undervoltage element (voltage control), and an over frequency element (frequency control) provide security against misoperation.

## **OVEREXCITATION PROTECTION**

When the ratio of the voltage to frequency (volts/Hz) exceeds 1.05 pu for a generator, severe overheating can occur due to saturation of the magnetic core of the generator and the subsequent inducement of stray flux in components not designed to carry flux. Such overexcitation most often occurs during start-up or shutdown while the unit is operating at reduced frequencies, or during a complete load rejection which leaves transmission lines connected to the generating station. Failure in the excitation system can also cause overexcitation. Similar problems can occur with the connected transformer.

A Volts/Hz relay (24), with an inverse time characteristic that matches the capabilities of the protected equipment and with definite time setpoints, is used to protect the generator from overexcitation. Together, these functions can closely match the protection curve of a generator and/or unit transformer.



An overvoltage relay function can provide partial backup, but will not be effective at reduced operating frequencies.

## **OVERVOLTAGE PROTECTION**

Generator overvoltage may occur during a load rejection or excitation control failure. In case of hydrogenerators, upon load rejection the generator may speed up and the voltage can reach high levels without necessarily exceeding the generator's V/Hz limit. The overvoltage relay (59) is used to protect the generator from this condition.

## **UNBALANCED CURRENTS**

Unbalanced faults and other system conditions can cause unbalanced three-phase currents in the generator. The negative sequence components of these currents cause double-frequency currents in the rotor that can lead to severe overheating and damage. The negative sequence overcurrent function (46) is provided to protect the unit before the specified limit for the machine is reached. As established by the ANSI standards, limits are expressed as  $I_2^2 t = K$ , where  $I_2$  is the negative sequence current in multiples of the tap setting,  $t$  is the operating time of the negative sequence relay element in seconds, and  $K$  (the time dial setting) is a constant established by the machine design.

The multifunction relay provides the Negative Sequence Overcurrent function with a tap setting variable from 1 A to 5 A and a pickup setting variable from 5% to 100%. Also, the value of  $K$  can vary from 1 to 95, making this function suitable for any generator size.

A minimum delay, for this function, set at 12 cycles is used to avoid nuisance tripping. The relays can also provide maximum delay that can be set by the user to reduce the tripping times for modest imbalances. An important feature that helps protect the generator from damage due to recurring imbalances is a linear reset characteristic: when  $I_2$  decreases below the pickup value, the trip timer resets to zero linearly to emulate cooling characteristics of the machine.

## **ABNORMAL FREQUENCY PROTECTION**

### **Over Frequency Protection**

Full or partial load rejection can lead to overspeed of the generator, and hence, over frequency operation. In general, over frequency operation does not pose any serious problems and control action can be taken to reduce the generator speed and frequency to normal without tripping the generator. Generators are shipped with overspeed detectors. An over frequency relay can be used to supplement this overspeed equipment. The multifunction relays provide a two-setpoint over frequency relay (device 81O) that can be set to alarm or trip on an over frequency condition.

## **Under Frequency Protection**

Overloading of a generator, perhaps due to loss of system generation and insufficient load shedding, can lead to prolonged operation of the generator at reduced frequencies. This can cause particular problems for gas or steam turbine generators, which are susceptible to damage from operation outside of their normal frequency band.

The turbine is usually considered to be more restrictive than the generator at reduced frequencies because of possible mechanical resonance in the many stages of the turbine blades. If the generator speed is close to the natural frequency of any of the blades, there will be an increase in vibration. Cumulative damage to the blades due to this vibration can lead to cracking of the blade structure.

While load-shedding is the primary protection against generator overloading, under frequency relays (device 81U) should be used to provide additional protection.

## **ANTI-MOTORING PROTECTION**

If the power input to the prime mover is removed while the generator is still on line, the generator will act as a synchronous motor and drive—and possibly damage—the prime mover. The percent of rated power required to motor varies depending on the type of prime mover, from 0.2% of rated power for a hydro-turbine with the blades above the tail-race water level, to up to 50% for a gas turbine. On large steam units, primary protection is often provided by oil pressure, valve limit switches on the main steam valve, and steam flow indications.

A power relay (device 32), set to look into the generator, is used to detect motoring. The power relay may be either primary or backup protection or both.

## **DEAD MACHINE ENERGIZATION PROTECTION**

If a dead machine is accidentally energized (energized while on turning gear), it will start and behave as an induction motor. During the period when the machine is accelerating, very high currents are induced in the rotor and the machine may be damaged very quickly. While some commonly used relays may react to the problem, including loss-of-excitation relays, reverse power relays, and system backup relays, several factors make them of limited usefulness. First, available current and voltage may be below the relay pickup levels. Second, some of these relays will be inoperative during maintenance if the VTs are disconnected. Finally, even if these relays do detect the event, their time delays may be too great to avoid damage to the generator. Because of these problems, dedicated dead machine protection is often advisable.

Protection against dead machine energization can be provided by a distance relay (device 21) set to look into the generator. This relay must have a very short time delay in order to adequately protect the generator. Because of this requirement, the same 21 device may not be useful for system fault backup protection.

Protection against dead-machine energization can also be provided with a directional overcurrent relay connected at the machine terminals and set to operate for currents flowing into the machine.

## **BREAKER FAILURE PROTECTION**

### **Failure to Trip**

Backup protection must be provided for the case where a breaker fails to operate when required to trip (breaker failure). This protection consists of a current detector, in conjunction with a timer initiated by any of the protective relays in the generator zone. Should the detector show that the breaker has not opened by the time the specified time delay has passed, the breaker failure relay will initiate tripping of the backup breakers.

### **Breaker Flashover**

Breaker flashover is a form of breaker failure which can cause severe damage to the generator due to inadvertent energization. The risk of flashover is greatest just prior to synchronizing or just after the generator is removed from service.

The breaker flashover condition (one or two poles) can be detected by a negative sequence or ground overcurrent relay, but the time delay associated with these relays is very long. An instantaneous overcurrent relay connected at the neutral of the generator step-up transformer can provide fast detection of breaker flashover and can be used to provide an additional breaker failure initiate signal to the breaker failure function.

## **SYSTEM FAULT BACKUP**

In many cases, the protection package designed for the generating unit will include relaying functions that will detect system faults.

### **Phase Faults**

The phase-distance function can be used to provide backup protection for system faults. As a backup for system faults, it can easily coordinate with existing line relays of the distance type. The voltage-restrained/controlled overcurrent function (51V) can also be used for this backup function.

The voltage-restrained/controlled overcurrent relay will restrain operation under emergency overload conditions and still provide adequate sensitivity for fault detection. Depending on the step-up transformer configuration, the relays, sensing current and voltage on the generator bus, traditionally require a set of auxiliary phase shifting transformers in order to receive the proper voltage. In the multifunction digital relay, these transformers can be eliminated with the appropriate phase shift being accomplished in software.

## **Ground Faults**

With unit-connected generators, backup for system ground faults can be accomplished with a time overcurrent (51) relay connected in the neutral of the step-up transformer primary. When the generator is directly connected to the system, the 51 device is connected to a current transformer in the generator neutral.

The summary of the generator protection by fault type is shown in Table 1. The protection for each fault type is shown as primary and backup. In some cases, the primary and backup protection are accomplished by redundant relay types (i.e., overvoltage). In other cases, no backup protection is indicated since the protection shown is backup protection for line relays or for the excitation control system (i.e., loss of field).

## **DESIGNING PROTECTION SYSTEMS USING MULTIFUNCTION DIGITAL RELAYS**

When planning the protection for a generator, the engineer must develop a protection philosophy that represents the extent to which the system will cover the various fault types, many of which are shown in Table 1.

When this is decided, the level of backup relaying that is to be employed can be determined. Looking at the twelve conditions in Table 1, if one primary and one backup (where applicable) is chosen for each fault type, the system would consist of between twenty and thirty relays. Many of these devices would be three-phase devices, otherwise additional single phase devices are required and the count becomes much larger.

The cost of this system for relays, panel space, wiring and auxiliary equipment is prohibitive for even very large units. For this reason, systems designed in the past seldom contained this level of protection.

Today, with the use of multifunction digital relays, the equivalent system may contain four or five individual relays with commensurate reduction in panel space, wiring and other costs. Therefore, a very high level of protection becomes affordable, however the reliability issue becomes of more concern. If a multifunction relay is out of service, the protection system design should continue to provide a reasonable level of protection.

Table 2 contains a function list for two multifunction generator protection relays that are currently available. The relays incorporate sixteen or twelve protective functions in one package.

PROTECTIVE SCHEME		
FAULT CONDITIONS	PRIMARY	BACKUP
<b>Phase Faults</b> (phase to phase; 3-phase)	87G	21, 51V 87U, 46
<b>Ground Faults</b> (phase to ground) High Impedance Grounding Low Impedance Grounding	59N, 27TN 87GD	50N/51N, 27/59 50N/51N
<b>Loss of Excitation</b>	40	
<b>Overvoltage</b>	59	59
<b>Overexcitation</b>	24	59
<b>Unbalanced Currents</b>	46	
<b>Abnormal Frequency</b>	81O/U	81O/U
<b>Anti-Motoring</b>	32	32
<b>Dead Machine Energization</b>	67	
<b>Breaker Failure</b> Fails to Trip Pole Flashover	50 BF 50N (transformer high side neutral)	46
<b>System Backup</b> Phase Faults Ground Faults	21, 51V 51N (transformer high side neutral)	46
<b>Field Ground</b>	64F	

NOTE: VT Fuse Loss (60FL) detection is provided as a part of the multifunction relays.

**TABLE 1 Generator Protection Summary**

FUNCTION	DESCRIPTION	Relay Type 1	Relay Type 2
<b>21</b>	Phase Distance (Mho characteristic)	—	✓
<b>24</b>	Volts/Hz (inverse time)	—	✓
<b>27</b>	RMS Undervoltage, 3-Phase	✓	—
<b>27N</b>	RMS Undervoltage, Neutral Circuit or Zero Sequence	✓	—
<b>27TN</b>	Third-Harmonic Undervoltage, Neutral Circuit	—	✓
<b>32</b>	Directional Power, 3-Phase	✓	✓
<b>40</b>	Loss of Field	—	✓
<b>46</b>	Negative Sequence Overcurrent	✓	—
<b>50</b>	Instantaneous Overcurrent, 3-Phase	✓	—
<b>50BF/50N</b>	Breaker Failure/Breaker Flashover	—	✓
<b>50N</b>	Instantaneous Overcurrent, Neutral	✓	—
<b>51V</b>	Inverse Time Overcurrent, 3-Phase, with Voltage Control or Voltage Restraint	✓	—
<b>51N</b>	Inverse Time Overcurrent, Neutral	✓	—
<b>59</b>	RMS Overvoltage, 3-phase	✓	✓
<b>59N</b>	RMS Overvoltage, Neutral Circuit or Zero Sequence	✓	✓
<b>59I</b>	Peak Overvoltage	✓	—
<b>60FL</b>	VT Fuse Loss	✓	✓
<b>67</b>	Phase Directional Overcurrent	✓	—
<b>79</b>	Reconnect Time Delay	✓	—
<b>81O</b>	Over Frequency	✓	✓
<b>81U</b>	Under Frequency	✓	✓
<b>87GD</b>	Ground (zero sequence) Differential	—	✓
<b>Total Number of Devices</b>		<b>16</b>	<b>12</b>

**TABLE 2 Generator Protection Functions**

## **SAMPLE SCHEME: MULTIFUNCTION RELAY TYPE I**

A sample protection scheme using relay type 1 from Table 2 is shown in Table 3 and Figure 3. The system consists of four separate devices.

- 87G – Three-phase generator differential relay
- 87U – Three-phase unit-connected differential relay
- 64F – Field ground relay
- Multifunction Digital Relay Type 1

The system described provides primary protection for nine of the twelve fault conditions listed, and provides backup protection for four fault conditions.

This protection system could be visualized as useful for a small generator or in a situation where the multifunction relay was added to an existing installation to upgrade incomplete protection. The primary and backup for phase faults is provided by separate relays. In fact, the 51V and 87U provide redundant backup to the 87G. The primary and backup ground fault protection is provided by the same device (multifunction relay). To solve this problem, a separate ground overcurrent relay (50N/51N) or a redundant ground overvoltage relay (59N) could be added.

## **SAMPLE PROTECTION SCHEME: MULTIFUNCTION RELAY TYPE 2**

A protection scheme using multifunction digital relay type 2, from Table 2, is shown in Table 4 and Figure 4. This system contains five separate devices:

- 87G – Three-phase generator differential
- 87U – Three-phase unit-connected differential
- 64F – Field ground relay
- 46 – Negative sequence overcurrent relay
- Multifunction Digital Relay Type 2

In this scheme, primary protection is provided for eleven of the twelve fault conditions. Backup protection for phase faults is provided by two separate units. Backup protection for ground faults could be obtained by adding a separate ground relay to the scheme.

Utilizing neutral side CT's for the multifunction digital relay, the 21 function can be used as a system backup which will also provide backup for generator faults.

This design is applicable for small- to medium-sized units. This scheme provides very comprehensive primary protection and could also be used as an upgrade to back up an existing protective scheme.

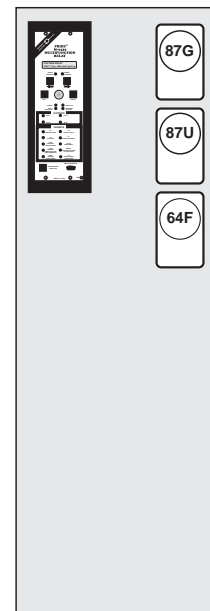
PROTECTIVE SCHEME		
FAULT CONDITIONS	PRIMARY	BACKUP
<b>Phase Faults</b> (phase to phase; 3-phase)	87G	51V, 50 87U 46
<b>Ground Faults</b> (phase to ground) High Impedance Grounding	59N	50N/51N, 27/59
<b>Loss of Excitation</b>		
<b>Overvoltage</b>	59	
<b>Overexcitation</b>		59 (partial protection)
<b>Unbalanced Currents</b>	46	
<b>Abnormal Frequency</b>	81O/U	
<b>Anti-Motoring</b>	32	
<b>Dead Machine Energization</b>	67	
<b>Breaker Failure</b> Fails to Trip Pole Flashover		46
<b>System Backup</b> Phase Faults Ground Faults	51V	
<b>Field Ground</b>	64F	

NOTE: VT Fuse Loss (60FL) detection is provided as a part of the multifunction relay.

  Provided by others.

**TABLE 3 Generator Protection – Type 1**





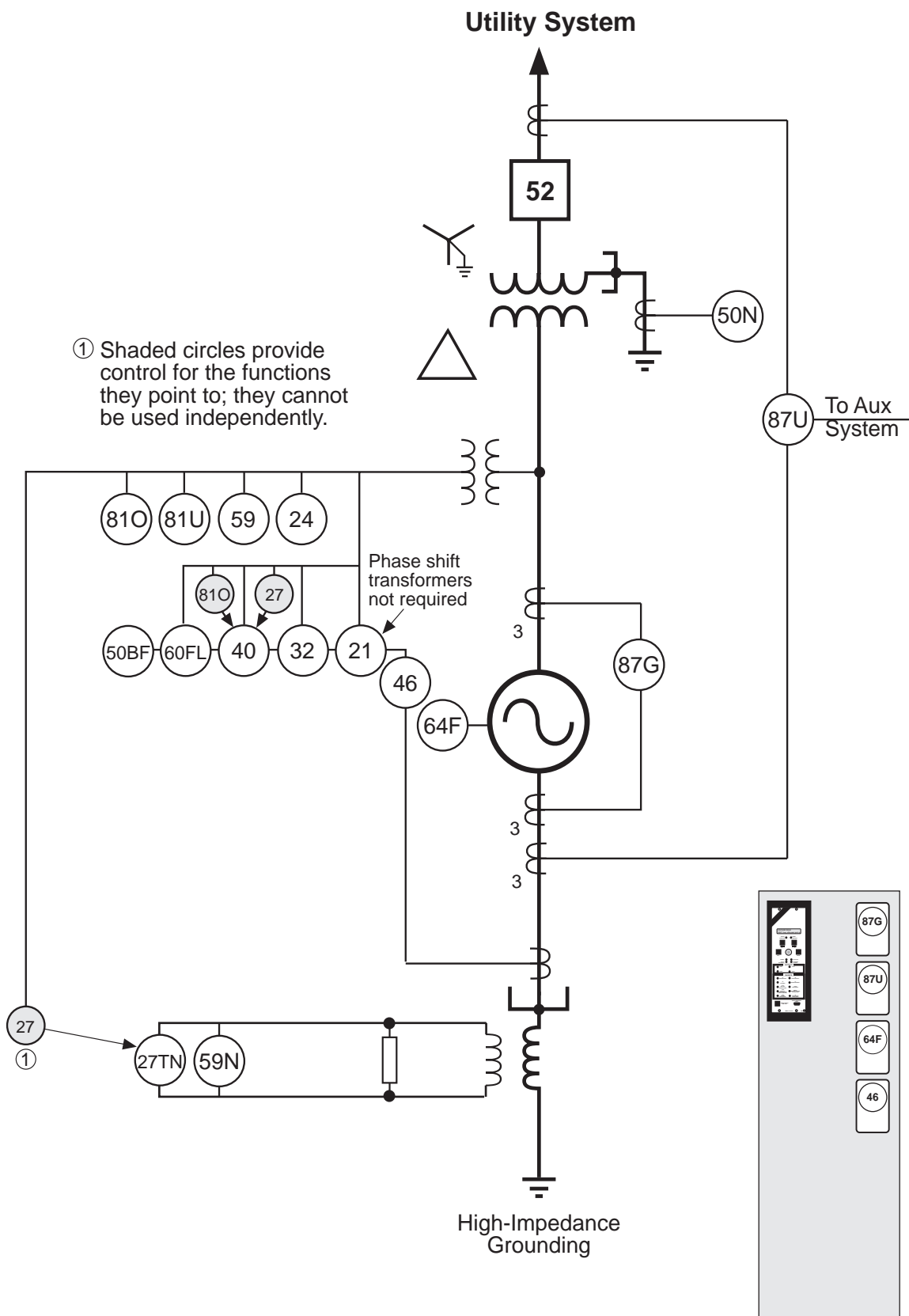
**FIGURE 3 Generator Protection Application Simplified One-Line Diagram – Type 1**

PROTECTIVE SCHEME		
FAULT CONDITIONS	PRIMARY	BACKUP
<b>Phase Faults</b> (phase to phase; 3-phase)	87G	21 87U
<b>Ground Faults</b> (phase to ground) High Impedance Grounding	59N, 27TN	
<b>Loss of Excitation</b>	40	
<b>Overvoltage</b>	59	
<b>Overexcitation</b>	24	
<b>Unbalanced Currents</b>	46	
<b>Abnormal Frequency</b>	81O/U	
<b>Anti-Motoring</b>	32	
<b>Dead Machine Energization</b>		
<b>Breaker Failure</b> Fails to Trip Pole Flashover	50BF 50N	
<b>System Backup</b> Phase Faults Ground Faults	21	
<b>Field Ground</b>	64F	

NOTE: VT Fuse Loss (60FL) detection is provided as a part of the multifunction relay.

  Provided by others.

**TABLE 4 Generator Protection – Type 2**



**FIGURE 4 Generator Protection Simplified One-Line Diagram – Type 2**

## **SAMPLE PROTECTION SCHEME: MULTIFUNCTION DIGITAL RELAYS TYPE 1 AND 2**

A protection scheme employing two multifunction relays is shown in Table 5 and Figure 5. The protection system consists of:

- 87G – Three-phase generator differential relay
- 87U – Three-phase unit-connected differential relay
- 64F – Field ground relay
- Multifunction Digital Relay Type 1
- Multifunction Digital Relay Type 2

In this example, primary protection is provided for all of the twelve fault types. Backup protection is provided for eight of the twelve fault types. With any one of the multifunction relays out of service, the protection reverts to one of the two previous examples (Figure 3 or 4).

The total protection system in this example would consist of the five relays listed above, wired into a single panel. The cost savings, relative to previously available technology, include reduced relay costs, reduced wiring, reduced design time, and reduced panel space.

Larger-sized units should be protected with this configuration. All the critical fault cases are covered by primary and backup protection and in some cases, supplementary backup as detailed in Table 5.

## **RETROFIT PROJECTS**

With the aging base of installed generating plants the process of modernization and upgrading the existing units has become a high priority. New insulation systems for the generators allow for higher efficiency and increased output capabilities of many older units. As a part of upgrading these systems the protection systems can easily be upgraded with the new digital relays. Due to extremely low burdens on the inputs the existing VT's and CT's are usually adequate. Many of the existing protective systems have become increasingly difficult to maintain. With the limited panel space and simple wiring required by the digital relays, the protection retrofit project can cost much less than in the past.

PROTECTIVE SCHEME		
FAULT CONDITIONS	PRIMARY	BACKUP
<b>Phase Faults</b> (phase to phase; 3-phase)	87G	21 50, 51V 87U 46
<b>Ground Faults</b> (phase to ground) High Impedance Grounding	59N, 27TN	50N/51N, 27/59
<b>Loss of Excitation</b>	40	
<b>Overvoltage</b>	59	59
<b>Overexcitation</b>	24	59
<b>Unbalanced Currents</b>	46	
<b>Abnormal Frequency</b>	81O/U	81O/U
<b>Anti-Motoring</b>	32	32
<b>Dead Machine Energization</b>	67	
<b>Breaker Failure</b> Fails to Trip Pole Flash Over	50 BF 50N	46
<b>System Backup</b> Phase Faults Ground Faults	21 51N	51V 46
<b>Field Ground</b>	64F	

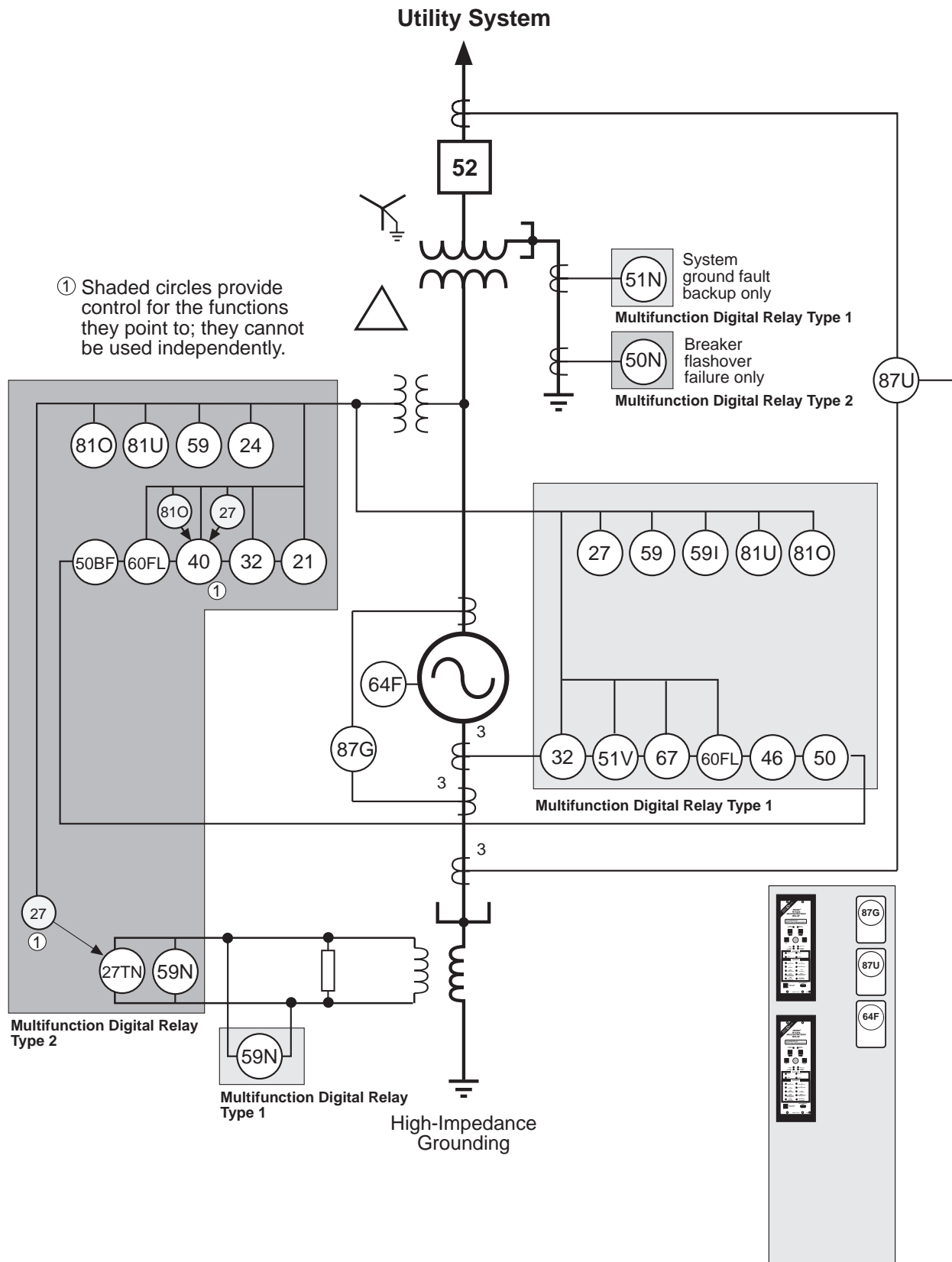
NOTE: VT Fuse Loss (60FL) detection is provided as a part of the multifunction relay.

  Provided by others.

  Provided by the Multifunction Digital Relay Type 1.

  Provided by the Multifunction Digital Relay Type 2.

**TABLE 5 Combined Generator Protection – Type 1 and 2**



**FIGURE 5 Combined Generator Protection Application Simplified One-Line Diagram – Type 1 and 2**

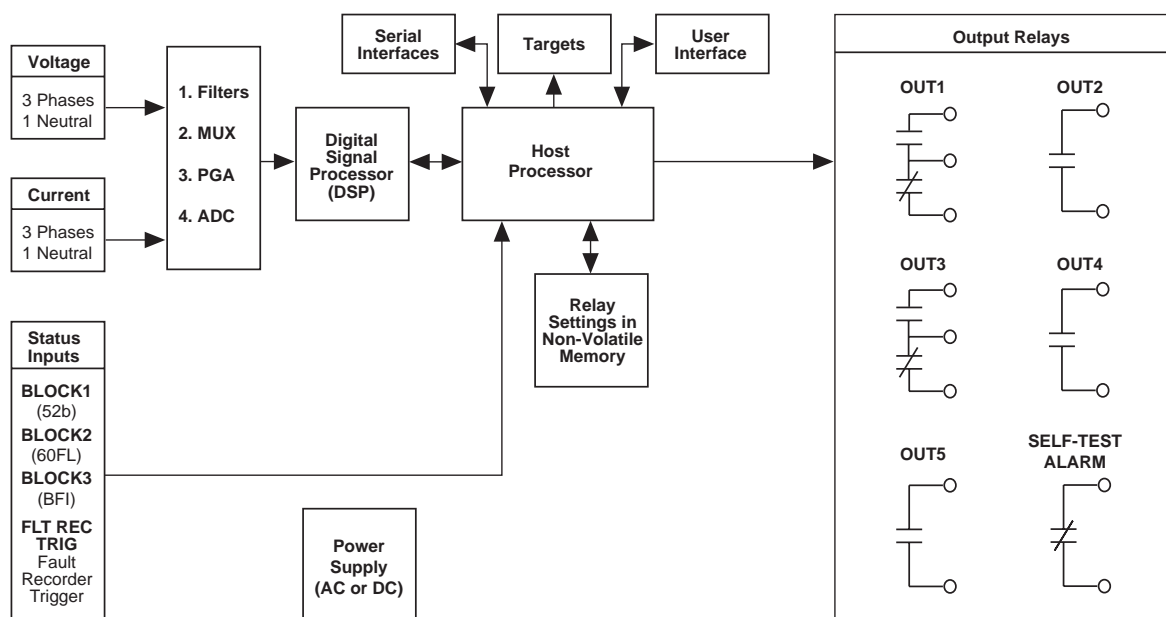
## **DIGITAL RELAYING HARDWARE/SOFTWARE DESCRIPTION**

The capability for a single unit to perform the multiple relaying functions discussed in this paper is derived from the advanced hardware and software products available today. The ability to perform sixteen separate relaying functions simultaneously, and provide response comparable to discrete relays, is mandatory. In addition, many non-relaying tasks are also simultaneously performed, such as self-tests, communications, man-machine interface operation, metering, fault data storage and targeting.

Following is a brief description of the hardware and software employed in the multifunction digital relays.

### **HARDWARE OVERVIEW**

Multifunction digital relays discussed in this paper are based on similar hardware platforms: a dual-microprocessor design, using a digital signal processing chip for analysis of the input waveforms, and a general purpose host microprocessor to control the outputs, the user interface and communications. A number of hardware and software self-tests are provided in order to ensure that the relay will not misoperate. A function block diagram of the relay is shown in Figure 6.



**FIGURE 6 Multifunction Relay Functional Diagram**

The relays provide for four voltage and four current inputs that are used to sense conditions on the generator. Several status inputs are used for functions such as programmable function blocking, breaker status, external breaker failure initiate, external fuse loss detection and a fault recorder trigger. Due to the nature of digital relays, the inputs are programmable as to their effect on the internal relaying functions. The relays also provide for five programmable outputs and an alarm/

self-test output. A loss of relay power or the failure of internal self-tests will cause this output to close.

The relay has an on-board man-machine interface (MMI) that can be used to program the relay's operation and settings and to view internal data. In addition, the user has available serial data interfaces that can be used for programming setpoints and data retrieval. Therefore the relays are fully operable from the local MMI or via remote connections to the serial interfaces.

The computational requirements for the relay are handled by a dual processor architecture. A digital signal processor (DSP) is used to convert the sampled analog signals into digital information. This replaces the analog hardware used by static devices to calculate information such as amplitude, frequency, phase angle, impedance, etc. The DSP passes this information to a host processor. The host processor compares this information to the relay settings, operates timers, and performs the relay decision logic tasks to determine when and if an output contact should be operated.

The host processor also is used to operate the MMI and serial interfaces. This is how the relay is set and transmits data to the users. In addition, fault data and target data is stored for interrogation by users for fault analysis.

## **SOFTWARE OVERVIEW**

The software for each processor is described briefly below.

### **DSP Processor Software**

The software for the DSP was developed to optimize execution speed and code length. The intermediate values in the calculations, which are sensitive to truncation and overflow errors, are maintained with double precision accuracy (32-bits).

The DSP acquires the digitized samples of the voltage and current signals from the ADC. The processor then calibrates the dc offset using ground channel reference and gain errors of all the channels using precomputed (in self-calibration programs) gain calibration coefficients from the EEPROM. These calibrated voltage and current samples are stored in the dual-ported RAM circular buffer for access by the fault recording software on the host processor. The processor then computes the fundamental RMS phasors of these signals. The phase angle inaccuracies due to sampling skew, CT, VT and anti-aliasing filters are calibrated from the fundamental frequency phasors. The calibrated phasors are then used to compute the fundamental frequency, real/reactive power, negative sequence current, volts per hertz, and phase impedances. The DSP also implements the inverse-time curves for the overcurrent, negative sequence overcurrent, and volts per hertz functions.

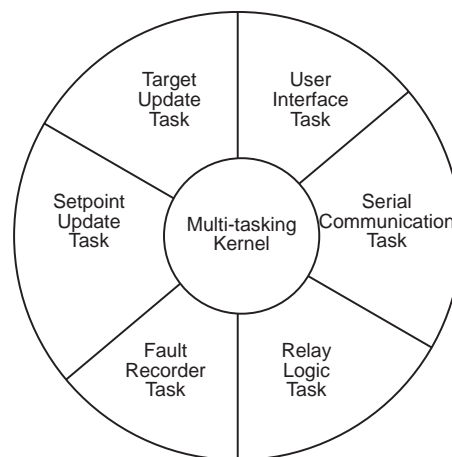
The DSP transfers the calculated parameters to the host processor for further processing.



## Host Processor Software

The organization of the host processor software is given in Figure 7. The multi-tasking kernel consists of a set of routines that allow functions to run concurrently. This is accomplished by giving each defined task-function a slice of the processor time and switching between tasks in a predetermined manner. This gives the illusion of simultaneous execution of functions due to the speed of executing all tasks.

The user interface task contains all the input formatting and output display routines for entering and reviewing setpoint and status information. The relay logic task performs the logic on the latest set of parameters available in the dual-ported RAM to determine the response to the latest input conditions.



**FIGURE 7 Organization of the Host Processor Software**

The setpoint update task updates setpoints in the RAM by reading stored values from the serial EEPROM and placing them in the RAM for quick access.

The serial communication task implements the communication protocol, for remote setting and status information, via serial ports.

The fault recorder task stores the sampled voltage and current data with time stamp in a circular buffer and transfers the latest fault data upon request through the serial link.

The target update task updates the trip targets.

## Self-Checking Functions

One of the major advantages of using the digital relay technology is its ability to check itself. The multifunction relay is equipped with over thirty different hardware and software failure checks which greatly improve the reliability. The following are the important self-checking functions included in the relay, some of which are executed continuously and the others on processor reset.

1. Watchdog timer reset.
2. DSP instruction/internal RAM check.
3. Dual-ported RAM read/write check.
4. ADC and PGA gain check.
5. Check sum verification of program ROM, calibration EEPROM and set point EEPROM.
6. DSP to host processor communication failure check.

When a self-check failure occurs, an alarm relay is activated and the processing stops to prevent misoperation of the relay.

### **Self-Calibration**

One of the interesting and novel design aspects of the multifunction relay is its self-calibration capability. Most of the existing static and microprocessor relays are designed with a number of trim pots to trim the signal offsets, gain and phase inaccuracies. This can be a time consuming process both during the factory calibration and during routine calibration by the customer. The multifunction relay does not have any user adjustable trim pots. The gain and phase angle errors are calibrated using precomputed calibration coefficients stored in the EEPROM.

The calibration coefficients are computed by a special calibration program. When the calibration mode is selected, the relay LCD display alerts the operator to connect the voltage inputs with 120 V and the current inputs with 5 A with zero phase angle between the signals. Then the relay computes the gain and phase angle errors and stores them in the EEPROM for use by the relay software.

## **CONCLUSION**

Multifunction digital relays are presently available that provide highly reliable protection for generators. These units utilize the latest digital signal processing technology to accomplish many relaying functions simultaneously. By appropriate use of multiple multifunction digital relays, or by using multifunction digital relays in combination with single-function relays, protection engineers can provide the reliability and security level needed for their specific applications.

Digital relays provide many extra features that are quickly becoming priority items. These include self-checking, digital fault recording, metering and remote communications. The self-calibration and special test programs included with the relays simplify test and checkout of installations using these devices.

## **REFERENCES**

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