Monitoring Neutral-Grounding Resistors—An Update

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Abstract—**Many of the problems associated with ungrounded and solidly grounded distribution and utilization systems are overcome with resistance grounding. Resistance grounding can limit point-of-fault damage, eliminate transient overvoltages, reduce the flash hazard, limit voltage exposure to personnel, and provide adequate tripping levels for selective ground-fault detection and coordination. Charging current, ground-fault detection, and ground-fault coordination are reviewed. Reasons for monitoring the neutral-grounding resistor (NGR) are presented. Problems associated with NGR monitoring are discussed and monitor design requirements are summarized. These design requirements, and two decades of experience, guided development of two generations of NGR monitors which detect both resistor faults and ground faults.**

This paper is an update to reference [1]

I. Charging Current

Each phase of a distribution system has capacitance to ground. Although a system may be ungrounded in that none of its current-carrying conductors are intentionally connected to ground, an ungrounded system has its neutral point established by distributed system capacitance as shown in Fig. 1. If capacitive reactance is balanced, voltages and currents are balanced as shown in the unfaulted phasor diagram where the magnitude of unfaulted phase-to-ground current is 1.0 A. If phase A is faulted to ground, voltage and current to ground in phases B and C increase in magnitude by 1.73. Fault current I_F is defined as the system charging current and its magnitude is three times the magnitude of the unfaulted phase-to-ground current.

Extensive damage can occur when an ungrounded power-distribution system experiences a transient-overvoltage condition caused by an intermittent ground fault. It is generally accepted that transient overvoltages can be eliminated using a neutral-grounding resistor (NGR) with a let-through current equal to or greater than the system charging current. Fig. 2 shows the same system as Fig. 1 with a 5.0-A NGR added. Voltages and currents in the unfaulted case are the same as in the ungrounded system. If phase A is faulted to ground, voltages and currents in phases B and C are also the same as in the ungrounded system; however, fault current is the vector sum of NGR current and system charging current.

If the system in Fig. 2 has three equal feeders, currents will be as shown in Fig. 3. Meters A_1 and A_3 on the unfaulted feeders each read 1.0 A—the charging current of their respective feeders. NGR current and fault current remain unchanged at 5.0 A and 5.8 A respectively. Meter A_2 on the faulted feeder will read 5.4 A—the vector sum of NGR current and the charging currents of the unfaulted feeders.

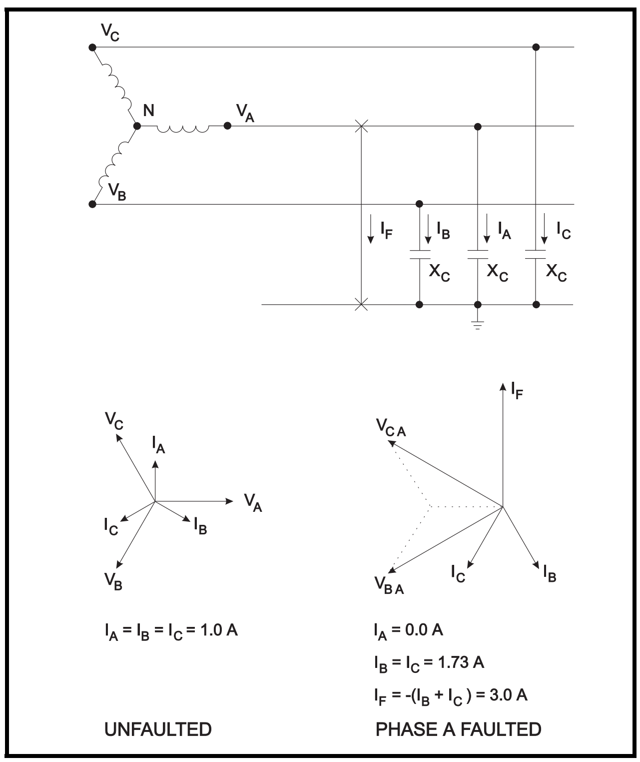

Figure 1. Ungrounded System.

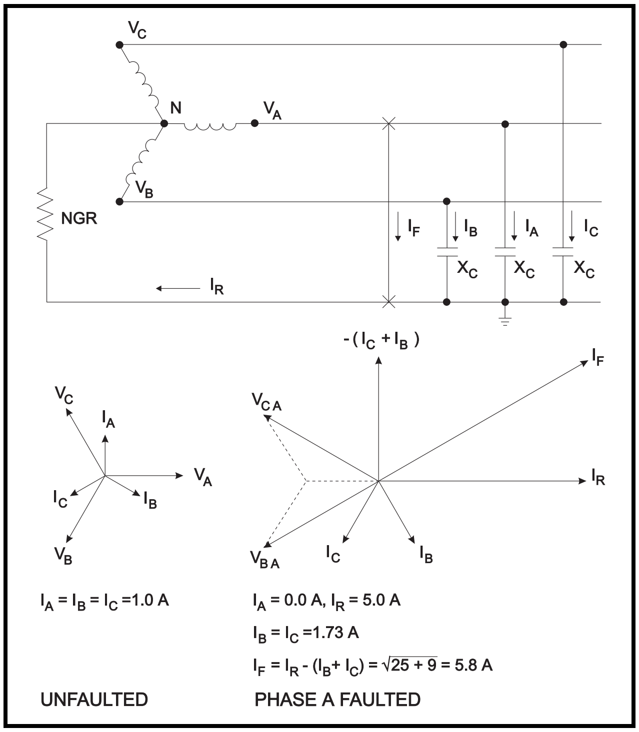

Figure 2. Resistance-Grounded System.

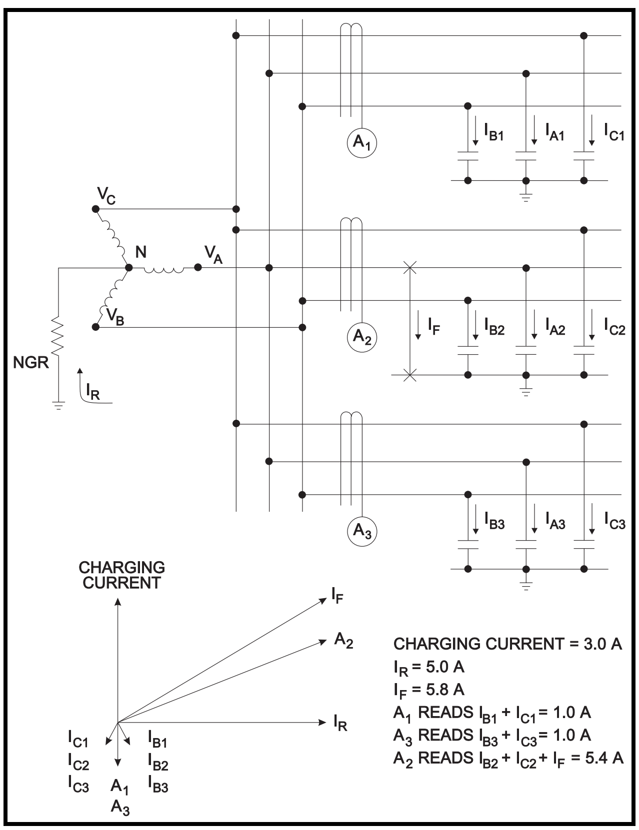

Figure 3. Resistance-Grounded System with One Faulted Feeder.

II. Selective Ground-Fault Coordination

Selective ground-fault coordination is achieved if sympathetic tripping cannot occur and only the faulted feeder is removed from the system. It has just been shown that a ground-fault detector on an unfaulted feeder observes the feeder's charging current when a ground fault occurs elsewhere in the system. Consequently, sympathetic tripping can occur on an unfaulted feeder if the operating value of the feeder's ground-fault relay is less than the feeder's charging current. Sympathetic tripping cannot occur, regardless of the relative feeder sizes, if an operating value above the charging current of the largest feeder is used for all ground-fault relays in the system. To provide a margin, selective ground-fault coordination is usually achieved with time discrimination and an operating value above the system charging current. Back-up protection is accomplished either by time-delayed operation of an upstream device or by a zone-selective interlock that blocks the upstream device from tripping for a pre-selected time.

III. Tripping Ratio And NGR Selection

Tripping ratio is defined as the ratio of prospective ground-fault current to the operating value of the ground-fault protection. An adequate tripping ratio ensures that sufficient ground-fault current is available for detection when a ground fault occurs. Reference [2] shows that a tripping ratio of at least 7 is necessary to detect a two-phase-to-ground fault. It can be argued that this type of fault should be cleared by overcurrent devices and that ground-fault detection does not require a tripping ratio of 7. On the other hand, a higher tripping ratio is required to provide machine-winding ground-fault protection. Reference [3] states that the generally accepted protection philosophy is based on protecting 90 percent of a wye-connected winding, and that the probability of a ground fault on the last 10 percent nearest the neutral is small. A tripping ratio of 10 is required to meet this protection philosophy; however, tripping ratios of 5 are common.

If the operating value of the ground-fault relays is greater than the system charging current, and if a tripping ratio of 5 is selected to ensure adequate tripping levels and machine-winding ground-fault protection, the let-through current of the NGR must be greater than 5 times the system charging current. Charging current is a function of system voltage and can be measured on an existing system or estimated from tables. Typically, charging current will be 0.5 A per 1000 kVA on low-voltage systems and 1.0 A per 1000 kVA on medium-voltage systems. Consequently, 5-A, 15-A, and 25-A grounding resistors are common.

Low-current and high-current NGR's are also used. Low-current NGR's have application where the energy available to a ground fault, or where the voltage drop in the ground return, must be limited. High-current NGR's are used in larger systems; however, designers comfortable with solidly grounded systems often choose NGR's with the let-through currents much larger than necessary for either system stability or selective coordination.

IV. NGR Selection For Alarm-Only Systems

Some electrical codes allow continued operation of a system when one phase is faulted to ground. There may be restrictions on system voltage and ground-fault current, and there may be a requirement to locate and isolate the fault as quickly as practical.

For an alarm-only system, choose an NGR with a let-through current larger than the system charging current. The pickup current of ground-fault devices is usually set at or below 50 percent of the NGR let-through current.

V. NGR Monitoring Considerations

The preceding sections outline a method for NGR sizing for low- and medium-voltage installations. Other requirements can influence NGR sizing; however, where resistance grounding is used, ground-fault protection, coordination, and annunciation systems depend on the integrity of the NGR. If the NGR fails, these systems become inoperative. In addition, an open NGR causes the system to become ungrounded and exposure to transient overvoltages is possible.

Ground-wire monitoring has been used for many years to ensure the integrity of the grounding circuit external to the NGR; however, little attention has been focused on the NGR itself. Electrical codes are beginning to recognize the importance of NGR monitoring; however, design requirements have not been established to prevent NGR monitors from creating additional hazards.

One approach to establish design requirements is to examine various designs for conceptual problems or hazards. The use of a potential transformer as an NGR monitor is an ideal candidate for this approach. For example, some installations simply connect the primary of a potential transformer across the NGR and connect the secondary to a time-delay relay. This is a voltage-based ground-fault detector and it does not monitor the NGR. Rather, it monitors the neutral voltage and it will not operate until a ground fault occurs regardless of the condition of the NGR. If the NGR is open when a ground fault occurs, ground-fault relays will not operate and the neutral voltage will be sustained until the time-delay relay operates and trips the breaker. A ferroresonance hazard exists with this technique. If the NGR opens, the system is grounded through the potential transformer and its inductance can interact with system capacitance to form a series RLC resonant circuit. References [4] and [5] discuss ferroresonance with respect to ungrounded systems.

A further problem with potential-transformer installations becomes obvious when a ground fault through a rectifier element is considered. The transformer winding provides a low-resistance path to direct current which can saturate the transformer and affect relay operation or burn the winding open. This same problem exists in installations that use neutral-grounding transformers. In both cases, direct current is not limited by the NGR and ground-fault voltage can be higher than anticipated.

Although a bigger problem with neutral-grounding transformers and reactors than with small potential transformers, the inrush that occurs at the onset of a ground fault should be considered. Transformer inrush can be 12 to 14 times full-load current for 0.1 second and can result in excessive ground-fault voltage.

Adjustable-speed drives and solid-state starters are found in increasing numbers in industrial systems. Non-triplen harmonic voltages that result cause harmonic currents to flow in the ground conductor if harmonic voltages or capacitive reactances are not balanced. Triplen harmonics are in phase and where triplen harmonic voltages are present, current at these frequencies will flow in the ground conductor and the NGR. An NGR monitor must either be set above the operating harmonic level or not be affected by harmonics.

The ideal monitor is a non-contact device; however, practical solutions involve elements connected in parallel with the NGR. Elements connected to the NGR are subject to line-to-neutral ground-fault voltages and must be evaluated in all failure modes. Resistors and inductors fail open, although turn-to-turn shorting can occur during failure. Capacitors can fail in open or in short. Any capacitive or inductive coupling technique should be investigated with respect to ferroresonance and excessive ground-fault voltage. Coupling devices must not transfer hazardous voltages to associated monitoring equipment.

Atmospheric electrical conditions, such as the presence of charged clouds, can affect an electrical substation feeding overhead lines. An NGR monitor used in this application must be immune to these conditions.

Monitoring the NGR should include monitoring the NGR connections to the neutral and to the ground bus. Fig. 4 shows a typical application of an NGR monitor with a sensing resistor connected to the neutral. The NGR monitor measures changes in NGR resistance, current in the neutral, and neutral-to-ground voltage. The NGR monitor coordinates these three measurements and operates output contacts when an NGR fault or a ground fault is detected. The output contacts can be used to trip the main breaker or to operate annunciation devices.

The measurements made by an NGR monitor can be useful when evaluating system problems. An analog signal can be used to provide local earth-leakage-current metering. An NGR monitor with a communications interface can allow data access with a local PC or with a network.

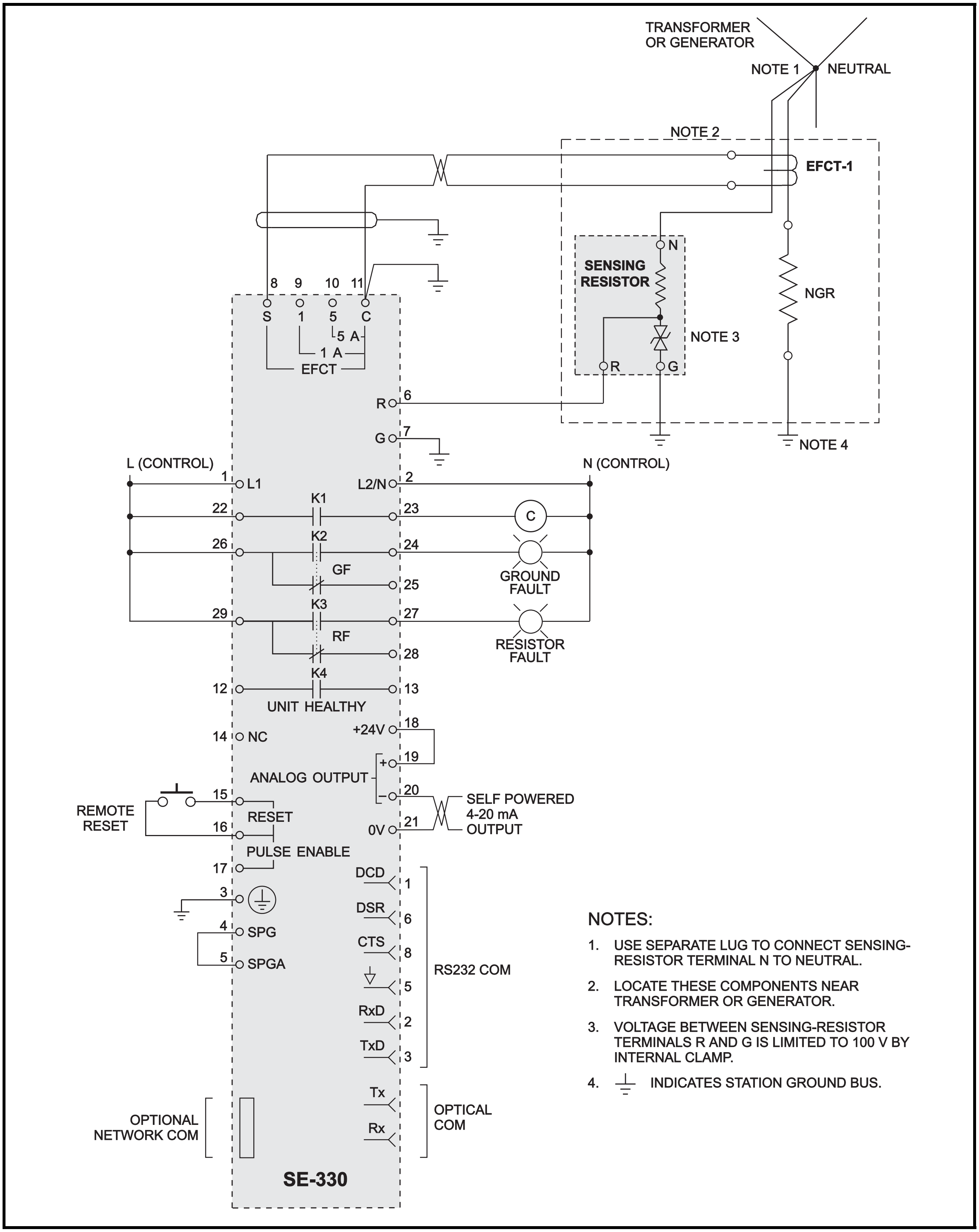

Figure 4. Typical NGR Monitor Application.

VI. NGR Monitor Design Requirements

NGR monitoring considerations can be summarized in terms of design requirements:

— The monitor must not create a hazard with respect to ferroresonance or ground-fault voltage.

— The monitor should not affect ground-fault coordination. If ground-fault protection is incorporated in the NGR monitor, operating values, sensitivity to harmonics, and coordination delays must be compatible with downstream devices.

— The monitor should be designed to operate in the undervoltage mode so that the output relay is energized when the monitor is not tripped. This is the fail-safe mode. Although the fail-safe mode is preferred, provision should be made for shunt-trip operation.

— The monitor must be capable of detecting an NGR failure that occurs subsequent to a ground fault, but prior to ground-fault tripping. Continuity through a fault must not be confused with NGR continuity.

— The monitor must be capable of detecting an NGR failure in an alarm-only system. Continuity through a fault must not be confused with NGR continuity.

VII. Summary

The background information presented here provided direction and guided the development of two generations of NGR monitors. Although inductive- and capacitive-coupling techniques were considered, a sensing-resistor approach was chosen to avoid problems with ferroresonance and excessive ground-fault voltage. A series of sensing resistors with increasing voltage ratings was developed to enable use of the same monitor on a wide range of low- and medium-voltage systems. The requirement to detect an NGR failure during a ground fault required neutral voltage to be measured. It also required the monitor to trip if neutral voltage is sustained above the product of the operating value of the ground-fault circuit and the resistance of the NGR. With the voltage-measuring circuit already incorporated, it followed that an NGR-resistance set point was not required and that an NGR-resistance trip level was sufficient. Further development allowed resistance calibration to individual NGR's. An NGR monitor provides protection against failures that previously rendered protection, coordination, and annunciation systems inoperative. The integration of ground-fault detection adds primary or back-up ground-fault protection.

References

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[3] J.R. Dunki-Jacobs, "The reality of high-resistance grounding," *IEEE Trans. Ind. Appl.,* vol. 1A-13, No. 5, September/October 1977.

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[5] R.H. Kaufmann, and M.N. Halberg, "System overvoltages—causes and protective measures," Chapter 5 of *Industrial Power Systems Handbook*, D. Beeman, Editor, New York, N.Y.: McGraw-Hill Book Company, Inc., 1955.