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Application Note

AC Generator Stator Protection Using the Basler BE1-11*g* Relaying System

Generators are subject to insulation failures (faults). Abnormal operating conditions, such as over/under voltage and frequency, field failure and loss of prime mover can lead to eventual insulation failure and thermal damage. These conditions, if not detected and interrupted in a timely manner, can cause severe damage resulting in failure of the generator. The total cost of this failure not only includes the repair or purchase cost of a new generator, but also the costs involved with replacing the lost power for the duration of the outage.

Generators are a major component of the electric power system and the protection requirements require careful consideration. The complexion of generator protection may be based on machine size, although it is difficult, because the desired protection may be determined more by the importance of the generator to the power system than by the size of the machine. Considerations should focus on particular protection functions and the application of settings. These should be in accordance with relevant guides and standards, generator manufacturers' recommendations and electric utility requirements. The interconnecting configuration typically applied to large generators is a unit generator-transformer with a generator breaker on either the high side or low side of a step-up transformer (Figure 1). The generator in this configuration is usually wye-connected and high-impedance grounded through a distribution transformer. Selection of generator protection for this type of configuration should be made so that the generator protection is coordinated with the utility system's protection and to allow the generator controls to take corrective actions before tripping.

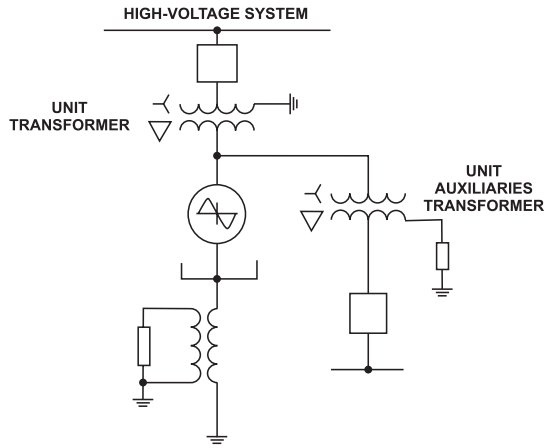

Figure 1 - Unit Generator-Transformer Configuration with Generator Breaker on High Side of a Transformer. (Reference IEEE Std. C37.102 – 2006)

Generator Stator Protection

A basic requirement for any ac generator is protection against stator phase and ground faults. Although a stator phase fault seldom occurs, it is a serious fault if it does because of the high current encountered and potential damage to the windings, shaft and couplings. High-speed phase differential (87) relaying is normally used for fault protection of generator stator windings. It detects three-phase, phase-to-phase, and double-phase-to-ground faults and quickly separates the generator from the utility system and removes the machine field and prime mover in a timely manner, thus minimizing damage. A single-phase-to-ground fault is not normally detected by differential relaying unless a generator neutral is either solidly or low-impedance (resistance) grounded.

To detect stator ground faults in high-impedance grounded generators, a neutral unbalance overvoltage element (59N) used in conjunction with a 3rd harmonic neutral undervoltage element (27-3rd) is the "tried and true" method for providing 100% stator ground fault protection (Figure 2). The 59N element is designed to operate on voltages of fundamental frequency (60Hz) while the 27-3rd element is designed for operation on the 3rd harmonic voltage (180Hz) component present

at the terminals of nearly every generator to varying degrees and occurs due to the nonsinusoidal nature of rotor flux. The magnitude varies based on differences in design and manufacture. As a result, stator ground faults from the machine terminals to about 90% of the stator winding are reliably detected by the 59N element. In the last 10% of the stator winding, ground faults are reliably detected upon "loss" of the 3rd harmonic voltage by the 27-3rd undervoltage element. The 27-3rd or 27TN must be blocked to avoid false tripping during generators' startup or shutdown. Phase over and under voltage elements (27/59P) or frequency (81) elements can be used to supervise the operation of the 27TN (see Figure 3 for an example).

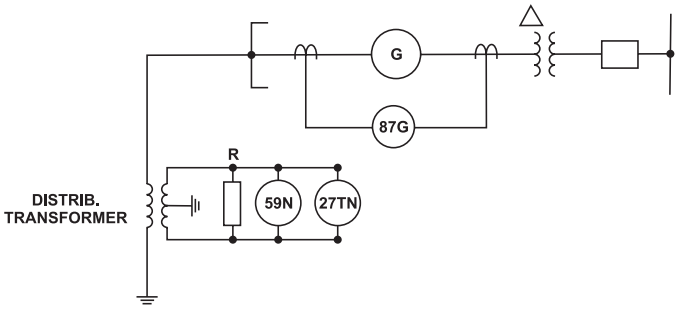

Figure 2 - Stator Phase and Ground Fault Protection in High-Impedance Grounded Generators

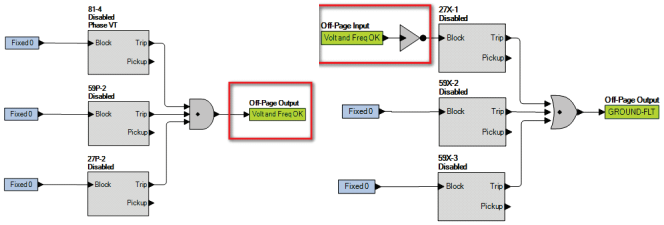

Figure 3 - The Use of 27/59 and 81 Elements to Supervise 27TN in BESTlogic™*Plus*

To detect stator ground faults in solidly or low-impedance grounded generators, neutral differential (87N) relaying, neutral directional (67N) relaying, or neutral overcurrent (50N/51N) relaying can be used (Figure 4). The 50N/51N is typically set to 5% of available ground fault current and must be coordinated with the system ground fault protections. The 67N compliments the operation of the 51N. It is set to trip for ground faults current flowing toward a generator with a shorter time delay and requires a use of zero-sequence voltage (3V0) polarization. The 87N is sometimes referred to as restricted earth fault (REF) relaying. The 87N is usually set faster than the 51N.

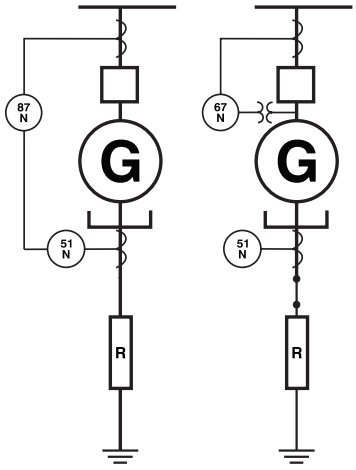

Figure 4 - Stator Ground Fault Protection in Low-Impedance Grounded Generators

Using the Basler BE1-11*g* for Complete Generator Stator Protection

The Basler BE1-11*g* is a multifunction relay that offers a full package of generator protection features. It can be used to detect all types of hazards to generators including stator phase and ground faults. It also comes in a non-drawout vertical case (S1 case) in addition to horizontal rack or panel mount cases (H1 case). The vertical case (S1 case) easily fits into a standard S1 case opening.

The protection functions discussed above for a generator stator protection are available in the BE1-11*g*. It offers phase (87), neutral (87N) differential, and polarization (67N) elements under current element in BESTCOMS*Plus*® (Figure 5). The 87 element in the BE1-11*g* is a three-phase percentage restrained current differential with dual slopes. Users can choose between using percentage differential or flux balance differential by Mode selection in BESTCOMS*Plus*. Harmonic restraint to improve security and transient monitor to detect the effects of CT saturation during a through fault are also included under this element. The 87N element detects an imbalance between the calculated neutral current (3I0) and the measured ground current (IG).

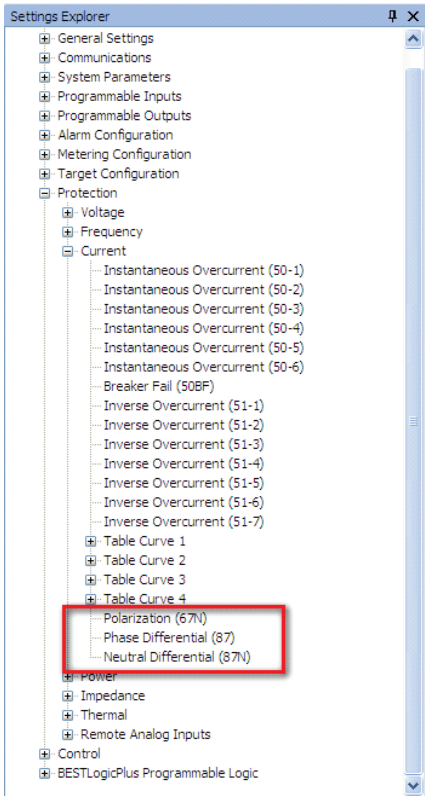

Figure 5 - Current Element in BESTCOMS*Plus*®

The 59N and 27TN elements of the BE1-11*g* can be found through BESTCOMS*Plus* under voltage element either over or undervoltage (Figure 6). They are user selectable through a drop-down list under 59X or 27X functions. Note that the third harmonic voltage should be measured with a generator in operation because the third harmonic voltage levels vary from generator to generator and also depend on a generator loading. The settings of the 27TN should be adjusted accordingly. To obtain third harmonic voltage data, the BE1-11g offers class B power quality measurement performance that includes harmonic voltages up to the 15th harmonic. This data can be viewed using BESTCOMS*Plus*, through the front panel HMI, and through the web page interface (BESTnet™*Plus*).

The BE1-11*g* also offers the backup impedance (21) element that can be used for backup generator stator protection. Further, the out-of-step (78OOS) element is also included in the BE1-11*g*.

Out-of-Step or pole slipping is a loss of synchronism of a generator relative to the system. This condition is electrically similar to a three-phase fault. It causes high current and forces on the generator windings and high levels of transient shaft torques. The 78OOS element in the BE1-11*g* uses impedance techniques to sense this condition. The element sees an apparent load impedance swing as impedance moves from zone to zone. The use of a single blinder scheme can be implemented in the BE1-11*g* to minimize the probability of tripping on recoverable swings.

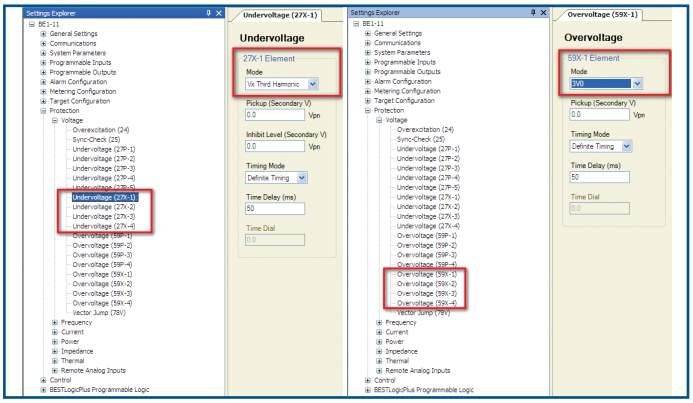

Figure 6 - Voltage Elements in BESTCOMS*Plus*

The need for 78OOS protection must be determined by a system stability study normally conducted by the utility to which the generator is connected. Utility interconnection agreements and power pool agreements may affect the need for this protection.

The backup impedance (21) element is primarily used for generator external fault protection to protect a generator from supplying prolonged fault current to faults on the power system to which the generator is connected. It is also used to provide backup for generator internal protection. The 21 element is an impedance based function that uses calculated impedance of a fault to determine a fault distance. Users set up a zone of reach (in ohms) using a mho circle. If the calculated impedance falls within the zone, it picks up. The zone of protection is usually set to include a generator step-up transformer and reach into the power system. Time delay can be used to delay tripping and must be coordinated with the system protective relaying.

Close-in faults effects can complicate the settings of the 21 element. In the BE1-11*g*, memory voltage is incorporated into the reach equation for low voltages that occur during close-in faults. The source setting is used to determine which BUS (VT-CT connection) current values are used in the reach equation. The BE1-11*g* offers only one source that is BUS1 but with dual

current inputs, users can choose either CT1 or CT2 for the BUS. The 21 element also does Wye-Delta compensation to the voltages and currents before calculating impedance.

For thermal protection of generator stator windings, the 49RTD available in the BE1-11*g* can be used for this protection. The BE1-11*g* must be connected with a remote RTD module that is connected to a resistance temperature detector embedded in a generator stator slot. The relay communicates with the remote RTD module over RS485 or Ethernet providing RTDs information to the BE1-11*g*. The 49RTD element uses temperature reading from the remote RTD module to alarm or trip when the temperature reaches a set value. The BE1-11*g* has user settings for a variety of RTD types.

The BE1-11*g* can accept up to two remote RTD modules. The remote RTD module not only provides RTDs inputs to the relay, it can also be used to provide analog input and output signals (4-20 mA or 0-10 Vdc signals). Each remote RTD module has four analog inputs and four analog outputs.

Figure 7 shows a generator application with all protection features available in the BE1-11*g*.

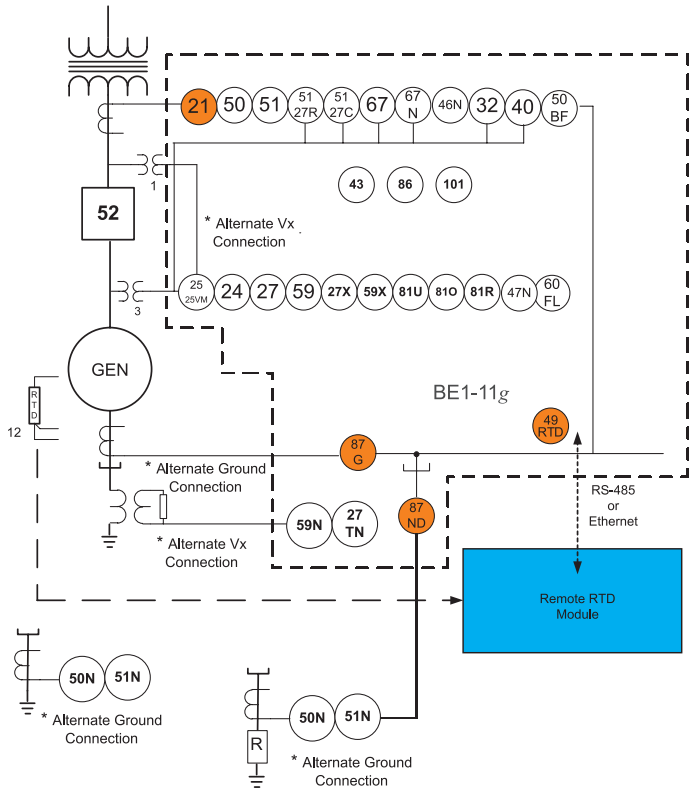

Figure 7 - BE1-11*g* Generator Application

Physical inputs and outputs on the BE1-11*g* have been expanded to seven physical inputs and eight physical outputs plus one alarm output contact. The front panel HMI of the BE1-11*g* incorporates users' defined LEDs and labels seen on the right hand side of the front panel shown in Figure 8. Virtual switch (43) buttons were added to the front panel HMI of the BE1-11*g* for easier access along with access through BESTCOMS*Plus*.Figure

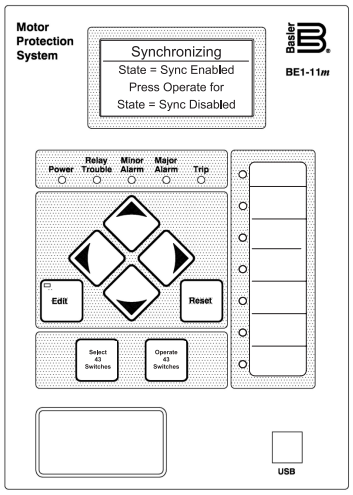

Figure 8 - BE1-11*g* Enhanced Front Panel HMI

Better Programming via Easy Graphical Interface

A national reliability study showed that nearly all multifunction relay misoperations are caused by incorrect programming. Basler's intuitive settings software helps solve this problem. All BE1-11 relays can be programmed using any Boolean function with drag-and-drop elements, inputs, outputs and the like from the BESTlogic*Plus* programmable logic (a part of BESTCOMS*Plus*, included with each relay at no charge), shown in Figure 9. Basler Electric also provides pre-built templates for most protection applications in BESTspace™. The views or templates can be customized and saved according to your company's standard. Logic documentation is provided, as well as logic printing and settings export capabilities.

Figure 9 shows a part of the BESTspace logic for high-impedance grounded generator with sequential trip that can be used with the BE1-11*g*. Each element can be chosen from the BESTlogicPlus toolbox by dragging and dropping them onto the programming page. Click and hold to connect a line between the two elements. Users can use the Comment Box located in the Toolbox to add a comment and save the new logic as an integral part

of the BESTCOMS*Plus* file. Users can also save it in the Logic Library for later use in similar applications. When complete, upload the new logic and settings to the BE1-11*g* via the BESTCOMS*Plus* program.

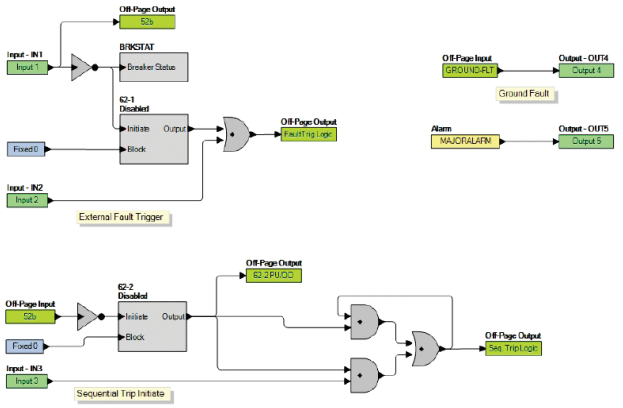

Figure 9 - A Sample of High-Impedance Grounded Generator Protection Logic in BESTspace

The BE1-11 Series Settings Check

All BE1-11 series relays have summary pages that quickly show if the GUI programming logic has elements connected but not set, or elements set but not connected in logic. Figure 10 shows an example where there is more work to be done before uploading the final programming to the relay.

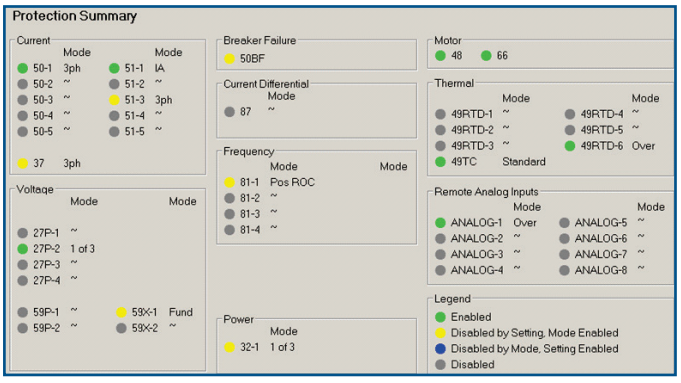

Figure 10 - Protection Summary for Settings Check

For more information

For further assistance with product orders or questions, contact Basler Electric Technical Support at 618-654-2341.

For additional information about the BE1-11 Protection System including more application notes, product bulletins, and instruction manuals, visit www.basler.com, contact your Application Engineer, or contact Technical Support at 618-654-2341.

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