White Paper

Switching the Neutral Conductor

ASCO Power Technologies®

Switching the Neutral Conductor

A Primer on Solid and Switched Neutral Transfer Switches

Automatic Transfer Switches (ATSs) are available with and without a dedicated pole to switch the neutral conductor of load circuits between Normal and Emergency power sources. This paper describes the function of switched neutral contacts together with considerations for their use. Although the examples shown herein describe options for three phase systems, the same concepts also extend to managing the neutral conductor in single phase systems.

SOLID NEUTRAL IN THREE-PHASE SYSTEMS

Three pole transfer switches are used to provide basic load switching operation for three-phase backup power applications. These switches transfer the three phase conductors between the Normal and Emergency power sources. In this application, the neutral conductor of the Emergency source is bonded to the neutral conductor of the Normal source using solid neutral plate mounted within the ATS, and the building ground serves the entire power system. In Figure 1, a three pole ATS is shown in a system that includes a single backup generator. Figure 2 shows a neutral plate used to connect the neutral conductors inside the ATS.

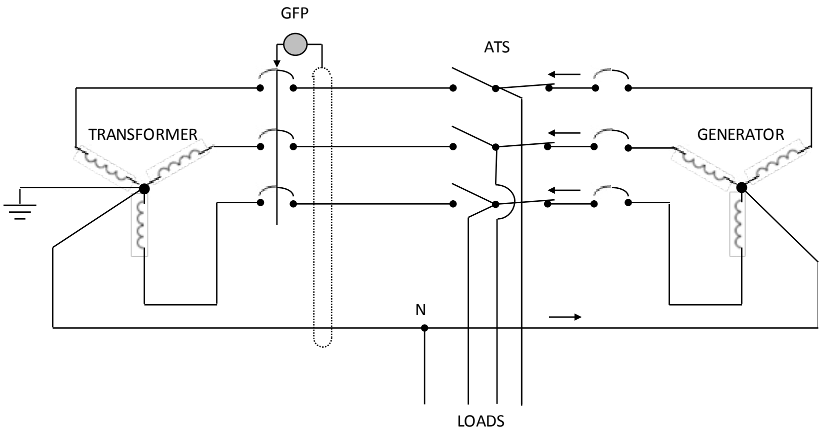

Figure 1:

A three pole ATS with a "solid neutral", connected to the Emergency source.

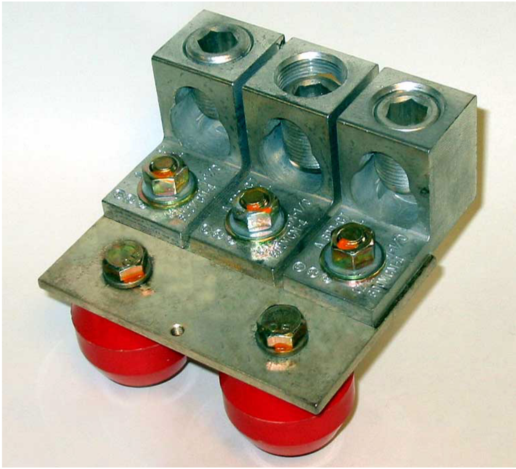

Figure 2:

A Neutral Plate with lugs for connecting the Normal, Emergency, and load neutral conductors.

APPLICATION OF SOLID AND SWITCHED NEUTRALS

The configuration shown in Figure 1 is routinely used in backup power systems. However, solid neutral switches cannot reliably route fault currents on systems with multiple grounds. In addition, they cannot ensure reliable ground fault sensing when power systems are so equipped. The two following scenarios illustrate key aspects of solid and switched neutral applications.

Cable Failure

A transfer switch should be located close to the loads it is switching. In some facilities, this can result in ATSs located far from a generator, service entrance, and/or grounding point. If one or more of the conductors becomes inoperable, perhaps because of a cable cut, the ATS would start the generator and transfer loads to the backup power system, as shown in Figure 3. This condition leaves the system ungrounded, which may energize the generator frame if a ground fault occurs, presenting an electrocution hazard to personnel. In addition, the condition could trigger a ground fault protection sensor on the Normal source to trip its circuit breaker and prevent the ATS from automatically re-transferring to Normal.

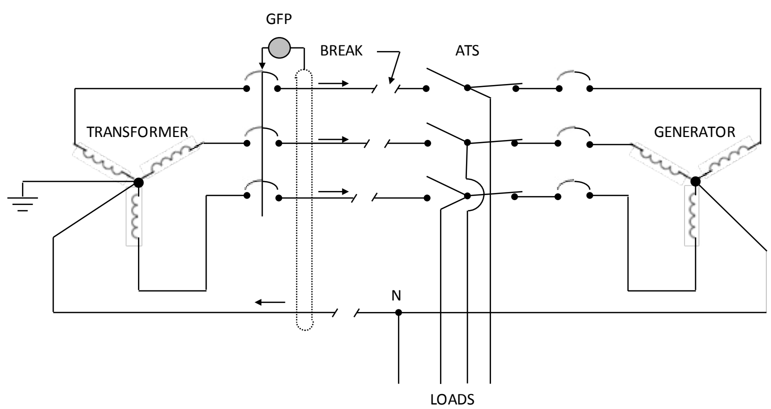

Figure 3: An inoperable cable could leave the Emergency system without a neutral and/or ground.

Adding a separately derived ground to the Emergency system provides a solution. If a cable became inoperable, the load would transfer to the Emergency system, and would be served by its dedicated ground. Under normal conditions, however, the lack of a means for disconnecting the Normal-side neutral would leave the entire power system served by two ground points, possibly at different potentials.

In order to avoid problems associated with a solid neutral connecting two ground points, the respective grounding systems must be isolated. This can be accomplished by switching the load neutral to either the Normal or Emergency source using an extra pole, as shown in Figure 4 below. This arrangement will isolate the Normal neutral if a cable becomes inoperable on the Normal side of the power system. A four pole switch is shown in Figure 5.

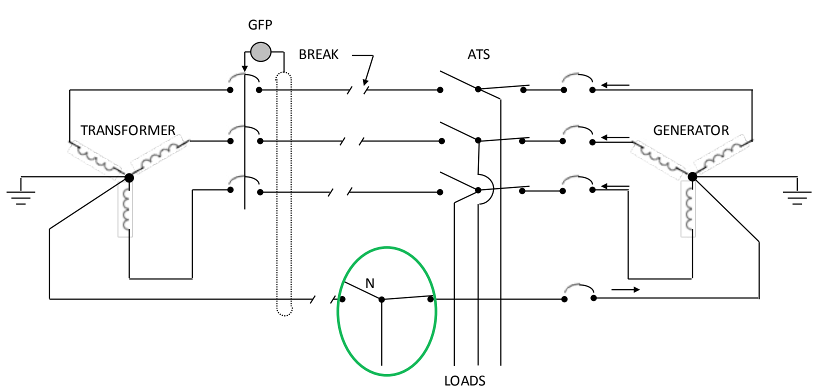

Figure 4: A four pole transfer switch provides a dedicated pole for connecting the load neutral to either the Normal or Emergency neutral conductor, thus isolating the neutral for each system.

Figure 5:

An ASCO four pole, 1000 Amp, transfer switch in a Type 1 enclosure.

Improper Ground Fault Sensing

Ground faults are currents that flow from a phase conductor to ground. These can occur as arcs across air gaps, which generate heat due to their high impedance. Because ground fault currents often occur at levels that are insufficient to trip a circuit's overcurrent protection device, the fault can persist and cause severe damage to the affected equipment, and can result in a fire. In addition, they can present an electrocution hazard to people that could come in contact with energized equipment surfaces.

Article 230.95 of the National Electrical Code® requires ground fault protection on solidly grounded systems having line-to-ground voltages of 150 to 1000 volts, rated 1000 Amps or more. Ground fault sensing systems use current transformers to measure the current flow along the phase and neutral conductors of a circuit. Under normal conditions, the vector sum of the current flowing on the phase and neutral conductors equals zero, as shown in Figure 6. When a ground fault occurs, some portion of the current flows to the power source by a different path, as shown in Figure 7. When this occurs, the sum of the currents passing through the ground fault sensing system does not equal zero and the ground fault protection system should trip a circuit breaker to interrupt current flow.

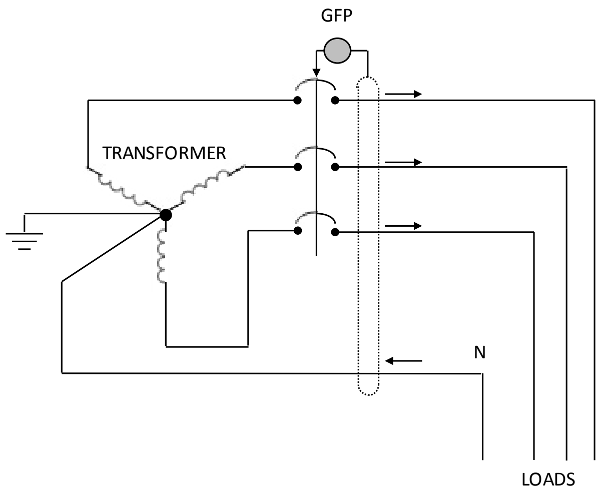

Figure 6:

Under normal operating conditions, the sum of currents measured by the ground fault sensing system should be zero.

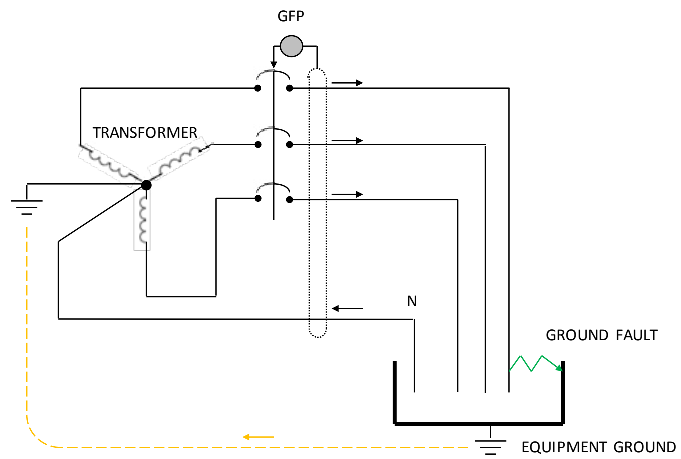

Figure 7:

When ground faults occur, the sum of the currents on the phase and neutral conductors does not equal zero, triggering ground fault protection.

A problem arises when a standby system with a separate ground is added to a ground fault-protected power system. As shown in Figure 8, fault paths to each ground become available. Because the system solidly connects the neutral conductors, a portion of the ground fault current can return to the on-line power source through the neutral of the off-line source. This condition could prevent the ground fault sensing system from detecting a current imbalance and from tripping circuit interruption.

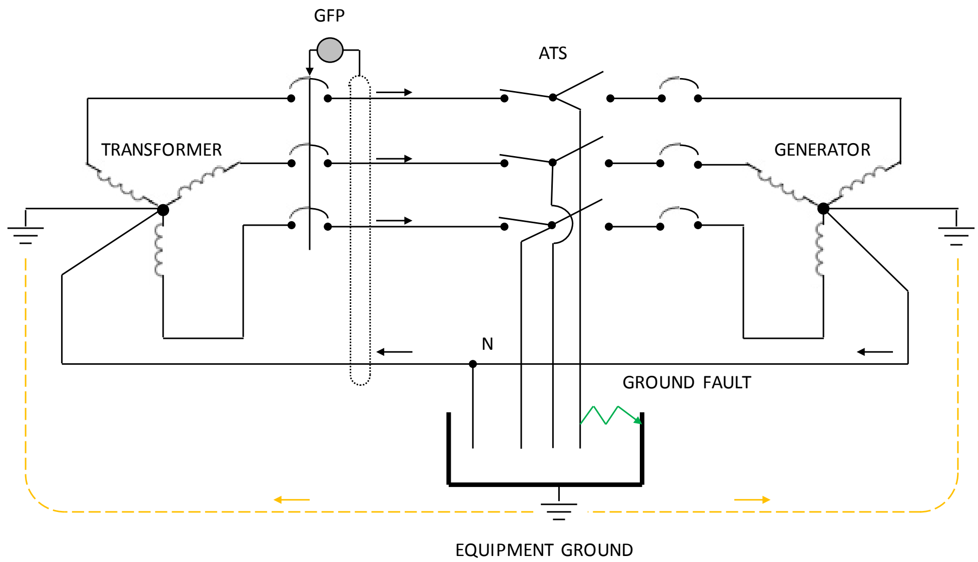

Figure 8: If two grounds were used with an un-switched neutral, a ground fault might remain undetected.

Adding an additional pole to switch the neutral isolates the two systems. This provides only a single ground path, as shown on Figure 9, and facilitates accurate ground fault sensing on the Normal side of the power system. It also ensures that accurate ground fault sensing on the Emergency side, if a sensing system is provided there.

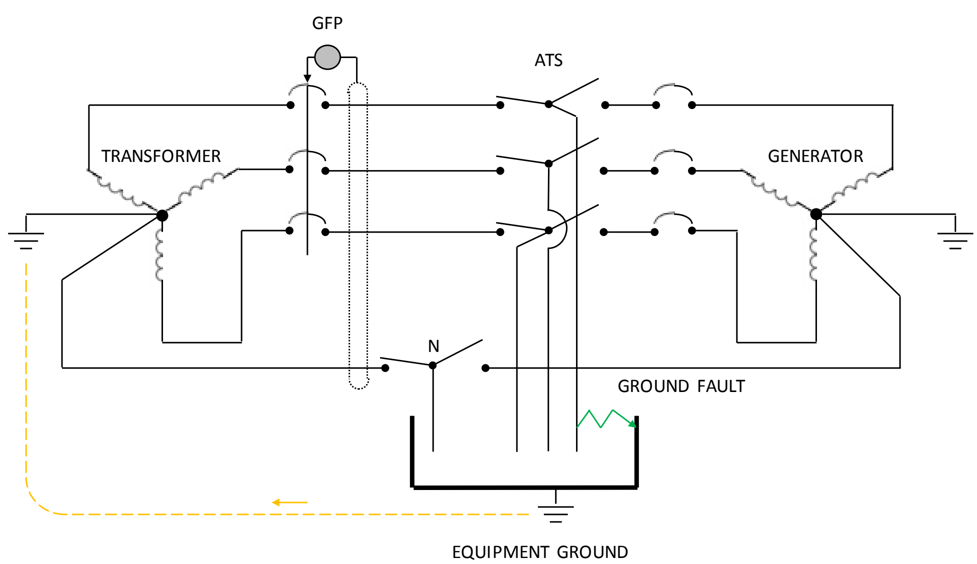

Figure 9: Providing a switched neutral isolates the respective neutrals to provide a single return path for ground fault current.

NEUTRAL SWITCHING EFFECTS

Conventional ATSs utilize a momentary open transition, where the energized contacts open before the contacts for the alternate source close. This "break-before-make" sequence interrupts current flow on the phase and neutral conductors, typically for duration of 100 milliseconds.

During transfer, the neutral pole would disconnect first because its presumably lower voltage would result in an arc duration that is shorter than on the phase contacts. This could lead to momentary loss of neutral, which could produce voltage differences between phase conductors if imbalanced loads are present. For simplicity, the following diagrams show how imbalanced loads impact line voltages when a neutral is removed from a split phase system.

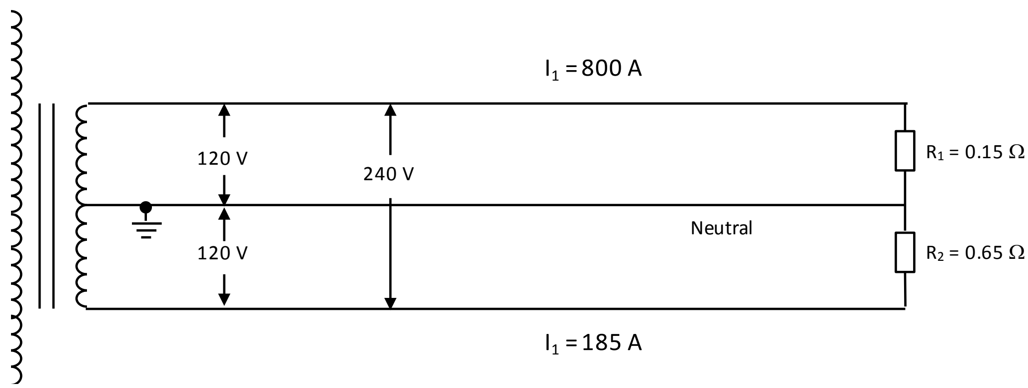

Figure 10: Voltage on each phase is equal when the neutral is present.

In Figure 10 above, the Phase-to-Neutral voltages across both loads each equal 120V. However, removing the neutral isolates each phase, as shown in Figure 11 below.

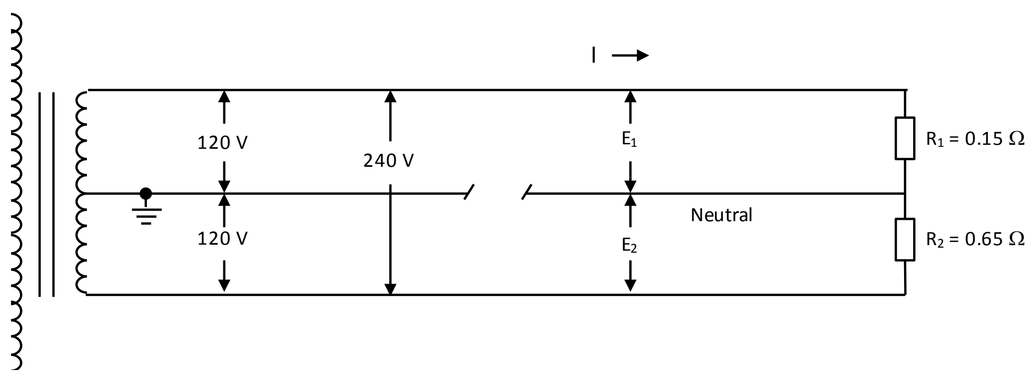

Figure 11: Breaking the neutral results in different voltages on each phase when different amounts of load are present.

Using the resistance of each load, the following equations indicate the voltages that would occur while the neutral is disconnected:

$$I = \frac{E}{R} = \frac{240\ V}{0.15+0.65\ \Omega} = 300\ A$$

$$E_1 = 300A \times 0.15\Omega = 45\ V$$

$$E_2 = 300A \times 0.65\Omega = 195\ V$$

In the example above, a nominal 240/120V single phase circuit could experience voltages between 45V and 195V during switching of the neutral conductor. Voltages exceeding these values could occur in other applications. Overvoltages can potentially damage load equipment, and voltage variations can affect the operation of sensitive loads.

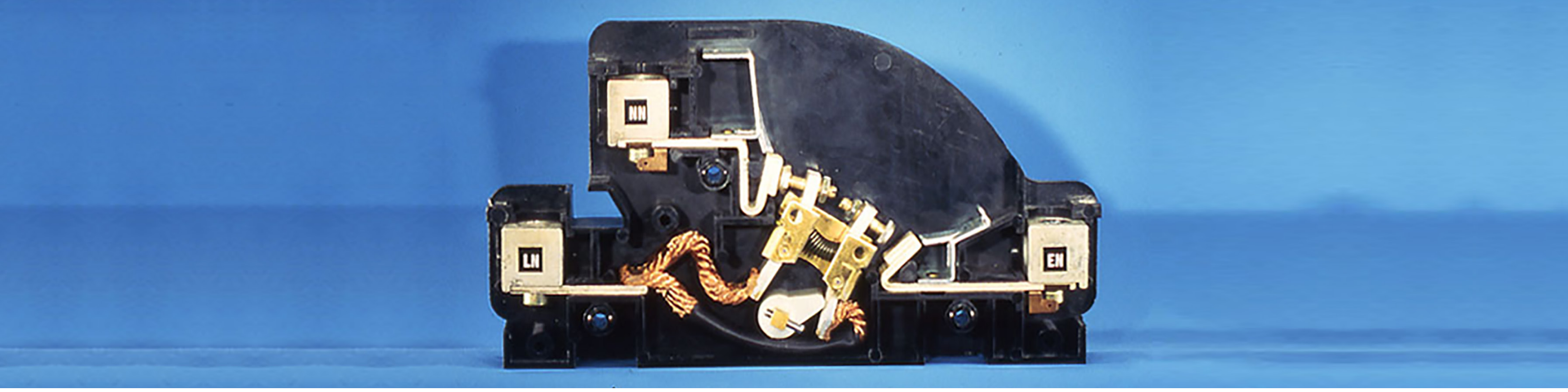

Figure 12: A contactor designed for overlapping netural switching.

ADVANTAGES OF OVERLAPPING NEUTRAL CONTACTS

Temporal voltage effects associated with neutral switching may be avoided by utilizing a transfer switch equipped with overlapping neutral contacts, shown in Figure 12. Overlapping the neutral contacts also avoids load current interruptions, avoiding degradation of the neutral switching contacts. These contacts operate in a "make-before-break" sequence to momentarily connect the Normal and Emergency and emergency neutral conductors, but the phase conductors still provide load break operation. An overlapping neutral pole is circled in Figure 13 below. The contacts momentarily connect both conductors, typically for 100 milliseconds or less, to provide continuous service by a neutral conductor. The operating sequence is shown in Figure 14.

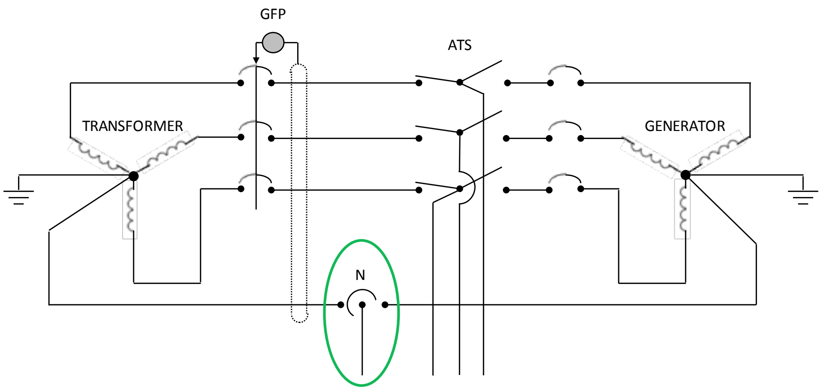

Figure 13: A four pole ATS equipped with overlapping neutral contacts.

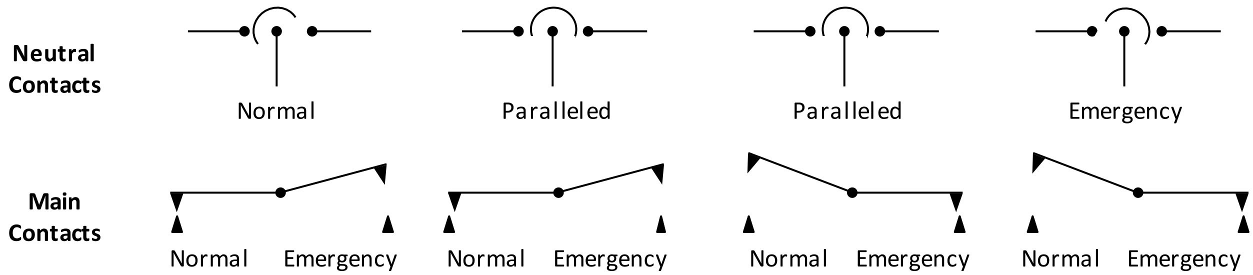

Figure 14: Sequence for switching from Normal to Emergency using overlapping neutral contacts.

SUMMARY

Transfer switches with solid neutrals provide reliable service for applications with single ground points. However, switching the neutral on separately derived power systems provides isolation that can improve reliability and safety. In addition, neutral isolation can promote reliable sensing of ground faults when ground fault protection systems are used. Equipping the neutral pole with overlapping contacts also avoids load current interruptions, maintaining the integrity of the neutral switching contacts. Overlapping neutral contacts also avoid voltage variances that could damage sensitive load equipment or impact its operation.

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