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Valuable information on maintaining critical infrastructure

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HIGH RESISTANCE GROUNDING - AVOIDING MISAPPLICATION OF TVSS AND UPS SYSTEMS

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High resistance grounding of 600 V power distribution systems is applied in hospitals, data centres and telecom facilities where supply availability is demanded. High resistance grounding provides service continuity during a ground fault. It also enhances electrical safety by preventing a ground fault from escalating into an arc flash incident.

However, care must be taken during electrical system design to ensure that transient voltage surge suppressor (TVSS) and uninterruptible power supply (UPS) systems are properly applied. Installation of a TVSS or UPS designed for a solidly grounded system into a high resistance grounded (HRG) system can lead to unintended failures that reduce service continuity. During ground fault, transient voltage surge suppressors can rupture; UPS systems can fail with subsequent loss of critical load; and the critical load can be exposed to risk if incompatible grounding exists between the UPS bypass and output.

CONCEPT OF HIGH RESISTANCE GROUNDING

Figure 1 shows a 600 V high resistance grounded system. A resistor is inserted between neutral and ground to limit ground fault current to 5 A or less. The 2006 Canadian Electrical Code addresses HRG in rules 10-1100 thru 10-1108.

The majority (approximately 80%) of electrical faults are of ground type. By maintaining service continuity during ground fault, HRG improves system availability for the majority of electrical faults as compared to a solidly grounded system. A ground fault can be safely traced while the circuit remains energized.

Fault isolation and repair can then be temporarily deferred to a time more convenient for facility operations.

A low-level arcing ground fault on a solidly grounded system can escalate into an arc flash incident. By limiting ground fault current, high resistance grounding prevents single ground faults from escalating into arc flashes, thereby improving electrical safety.

During a bolted ground fault on a 600 V system, the neutral voltage rises to 347 V above ground and the two unfaulted phases rise by a factor of 3 to 600 V above ground, as shown in Fig. 2.

TVSS and UPS for use on a HRG system must be designed to accommodate this voltage rise during ground fault.

TRANSIENT VOLTAGE SURGE SUPPRESSORS

A TVSS consists of metal oxide varistors (MOV) that exhibit high impedance when system voltages are normal and low impedance when transient voltages are applied. The low impedance diverts surge current away from the load and back to the source to protect the load against transient voltages. An MOV has a maximum continuous overvoltage (MCOV) rating.

In a solidly grounded 347/600 V system, MOVs connected line-to-ground must be able to withstand 347 V plus a margin of 20% continuously. Hence they require an MCOV rating of 420 V.

There have been instances where TVSS have ruptured in 600 V high resistance grounded distribution systems. Typically, a 600 V distribution system will be high resistance grounded through a 5 A, 347 V, 69 neutral grounding resistor.

Investigation of one such incident at

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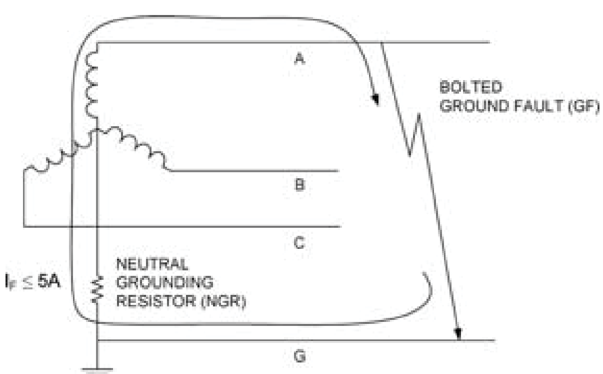

Fig. 1 High Resistance Grounding of a 600 V System

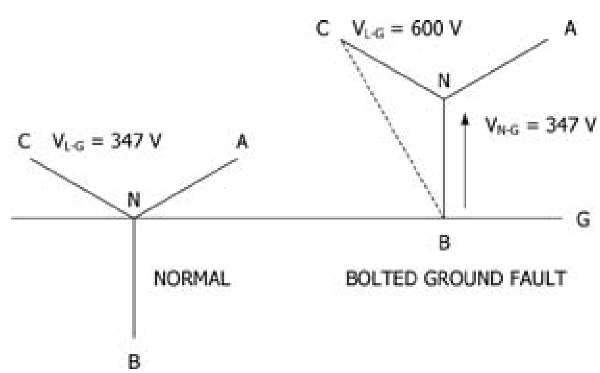

Fig. 2 Voltage Rise During Ground Fault on a HRG System

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a data centre in Ontario revealed that the TVSS failed during a ground fault when the metal oxide varistors (MOVs) connected between line-to-ground (L-G) were exposed to excessive voltage. The TVSS was rated for use on a 3-phase, 4-wire, 347/600 V solidly grounded wye system. It had been misapplied to the HRG system.

Figure 3 shows the typical connections and Table 3 shows the typical ratings of MOVs in TVSS units designed for a 600 V, 3-phase, 4-wire, solidly grounded system. L-L mode MOVs are shown dotted because they are often omitted. (Between any two phases are two L-N MOVs in series and two L-G MOVs in series, each pair providing line-to-line protection).

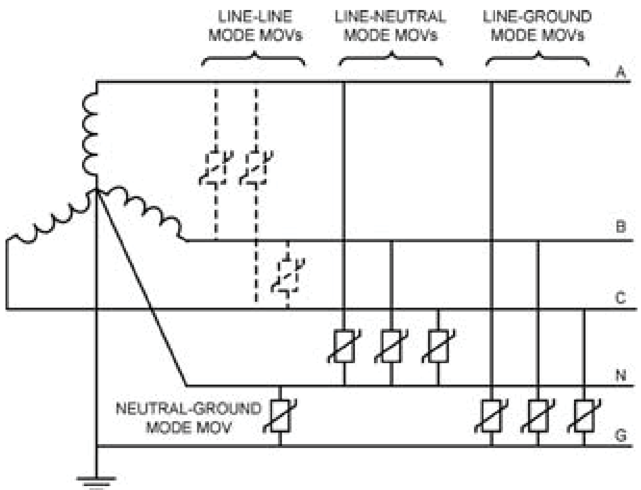

Fig. 3 TVSS for Solidly Grounded System

TYPICAL MCOV RATINGS FOR A 347/600 V, 3-PH, 4-W SYSTEM

Mode	L-N	L-G	L-L	N-G
MCOV	420 V	420 V	840 V	420 V

Table 3

An MCOV of 420 V is sufficient for MOVs connected L-G on a solidly grounded 347/600 V system. Continuous L-G voltage does not exceed 347 V ± 10%. On a HRG system, however, L-G voltage rises to 600 V (i.e., to rated line voltage) during a bolted ground fault. At this voltage, an MOV with an MCOV of 420 V will be stressed and eventually fail. That is why the MCOV of an MOV connected in L-G mode on a HRG system must be rated higher than the system line voltage. Figure 4 shows the typical connections and Table 4 shows the typical ratings of MOVs in TVSS units designed for a 600 V, 3-phase, 3-wire, HRG system.

600 V HRG systems are 3-wire. The neutral is not distributed because it becomes energized during ground fault. Hence, there is no need for L-N or N-G protection modes on a TVSS used on a 600 V HRG system.

HRG systems do not exhibit the 600% overvoltage phenomenon above ground that can occur in ungrounded systems during intermittent arcing ground faults. The let-through current of a neutral grounding resistor (NGR) is always chosen to

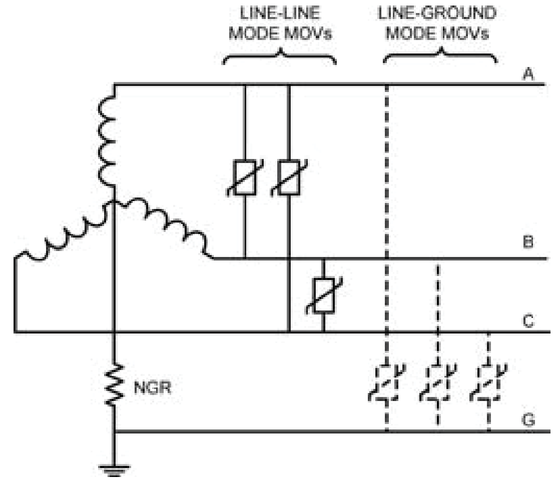

Fig. 4 TVSS for High Resistance Grounded System

TYPICAL MCOV RATINGS FOR A 600 V 3-PH, 3-W HRG SYSTEMS

Mode	L-G	L-L
MCOV	750	750

Table 4

be higher than the capacitive system charging current. This ensures that the continuous L-G voltage during a ground fault will not exceed 600 V on a 600 V system.

The 2006 CEC advises in Rule 133.2.1 that electrical equipment shall be suitable with respect to the maximum steady voltage (r.m.s. value for a.c.) likely to be applied, as well as overvoltages likely to occur. TVSS MOVs are not exempt.

The US 2005 National Electrical Code (NEC) requires in section 285.3(3) that the MCOV of a TVSS exceed the maximum continuous phase-to-ground voltage available at the point of application. Section 285.3(2) specifies that a TVSS used on a resistance grounded system be listed for use on this type of system.

It is anticipated that UL 1449, Transient Voltage Surge Suppressors, will be amended to add a listing for use on resistance grounded systems. When published, it is expected that the UL listing will remove some of the ambiguity in applying a TVSS to a HRG system. Until such a listing is available by UL, one must use what is known as a "delta-rated" TVSS, which is suitable for use on a HRG system.

MOVs in a delta-rated TVSS are typically connected in L-L and L-G mode, as shown in Fig. 4. L-G mode is shown dotted because some TVSS manufacturers offer delta-rated units with L-L mode MOVs only. Typical MCOV ratings are shown in Table 4.

It is not recommended that TVSSs be installed in ungrounded distribution systems due to the possibility of excessive phase-to-ground voltages that can occur during intermittent arcing ground faults.

UNINTERRUPTIBLE POWER SUPPLIES

3-phase 600 V UPS systems designed for use on solidly grounded power systems often employ MOV surge suppressors

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Resistance Grounding
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to protect the rectifier power electronic devices.

The phase-to-ground MCOV is typically insufficient for application on a HRG source. A typical UPS will include either a rectifier input autotransformer, or possibly no transformer at all.

Connecting this type of UPS to a HRG source can result in failure of the rectifier MOVs and loss of power to the critical load.

When purchasing a 3-phase UPS System, inform the UPS manufacturer whenever the UPS is to be fed from a HRG power source. The manufacturer will provide the UPS with a rectifier input isolation transformer to prevent the rectifier MOVs from being exposed to high phase-to-ground voltages during a ground fault on the upstream power source. Due to the possible presence of excessive phase-to-ground voltages on ungrounded systems, consideration should be given to converting ungrounded systems to HRG before installing a UPS.

Failure of Isolated Redundant UPS with a HRG System

A site in Ontario experienced a loss of power to the critical load on a UPS system that was connected to a HRG system.

The critical load was protected using dual 150 kVA rated UPS modules, connected in an isolated redundant configuration, as illustrated in Fig. 5. In this configuration the primary UPS is normally in service, while the secondary UPS is on "hot standby". Upon loss of the primary unit, the critical load is automatically transferred to the secondary module via the static bypass switch in less than 1/4 cycle.

Each UPS was factory supplied with an input autotransformer and MOVs that were connected on the 600 V side to provide transient voltage surge protection. The upstream power transformer supplying power to the UPS system was rated 750 kVA, 27.6 kV/600 V, delta-wye. The transformer secondary neutral was grounded via a 5 A, 69 ohm, 347 V HRG system to provide supply continuity during a single line-to-ground fault.

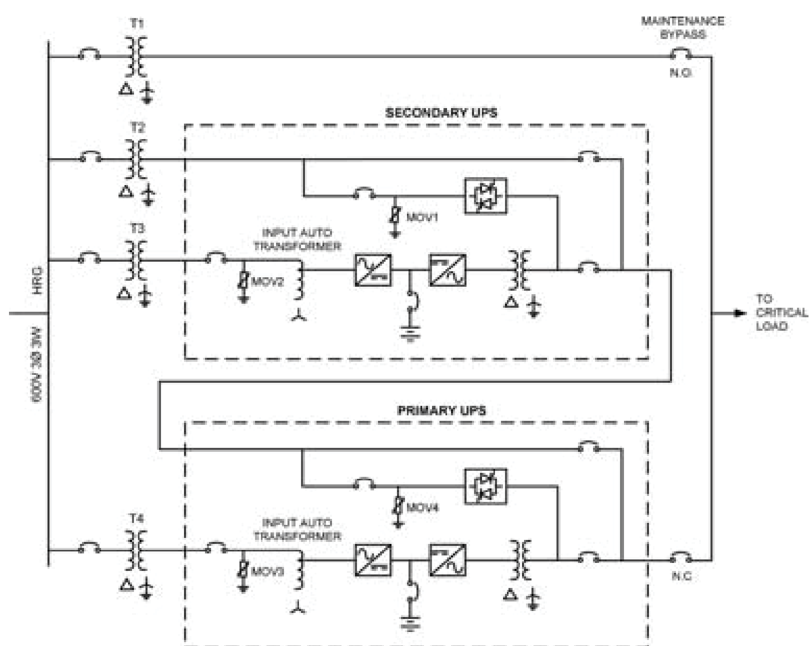

Fig. 5 Simplified One Line Diagram for Isolated Redundant UPS System. Isolation Transformers T1, T2, T3, and T4 were added on-site later to address the problem of UPS failure.

The UPS system suffered a serious failure resulting in a total loss of power to the critical load. The primary module, its internal static bypass and the secondary module all failed.

Follow up investigation revealed that the factory installed MOVs were inadequate for application on the HRG system. The MOVs had a maximum MCOV of 420 V. Under normal operating conditions, the applied voltage to all MOVs is 347 V (line-to-ground), well within the MCOV. Under a phase-to-ground fault condition, the voltage of the faulted phase went to zero, while the voltage of other two phases increased to 600 V, thus overly stressing the MOVs. In this case, MOV3 connected to the primary module exploded, producing plasma material that shorted MOV4 on the static bypass. This occurred because the printed circuit boards for MOV3 and MOV4 were physically located just three inches apart, with no adequate barrier separating them.

To solve this problem, four delta-wye input isolation transformers, T1 thru T4, were installed as shown in Fig 5. The secondary neutral of each transformer was solidly grounded to ensure that the applied voltage across each MOV would not rise during a ground fault on the primary side 600V HRG system. The internal UPS inverter output transformers had always been solidly grounded. With the addition of transformers T1 thru T4, the UPS rectifier and bypass input sources became solidly grounded also. Additionally, a mechanical barrier was added between the circuit boards holding MOV3 and MOV4 as well as those of MOV1 and MOV2.

Compatible Grounding Between UPS Input and Output

Large UPS systems usually feature separate bypass and rectifier input power sources for added redundancy. A small data centre in Ontario had such a UPS, rated 300 kVA, 600V, 3-phase. Both the rectifier and bypass input power sources were HRG. The UPS was factory supplied with an internal rectifier input isolation transformer. At site, the UPS inverter output isolation transformer was solidly grounded. The UPS vendor was not informed that the building was high resistance grounded.

The first indication of a problem was the persistent appearance of a "Bypass Unavailable Alarm". Investigation revealed a ground fault in the building HVAC system that was fed from the same power transformer as the UPS bypass input.

The ground fault shifted the bypass neutral voltage above ground by 347 V, whereas the solidly grounded the inverter output neutral remained at ground potential. The neutral voltage difference between the bypass and output created the "Bypass Unavailable Alarm". The alarm cleared once the ground fault was located and repaired.

Further investigation revealed another grounding scheme issue. If a ground fault were to occur on the solidly grounded critical load, the UPS as designed would instantly transfer the load to bypass via the static bypass switch. The critical load would then remain parked on the HRG bypass. The neutral voltage difference between bypass and solidly grounded inverter would prevent re-transfer, posing an unacceptable risk of downtime.

It is recommended that the bypass and inverter output sources be grounded the same way, either solidly grounded or HRG. Typically, if the building 600 V distribution system is HRG, then the 600 V UPS inverter output should also be HRG.

This way, a ground fault in the critical load would produce an alarm and not transfer to bypass. The faulted component in the critical load will not experience an unscheduled shutdown as would occur in a solidly grounded system.

If the critical load must be solidly grounded, then the UPS input and bypass sources should be isolated from the upstream HRG system and solidly grounded via delta-wye isolation transformers.

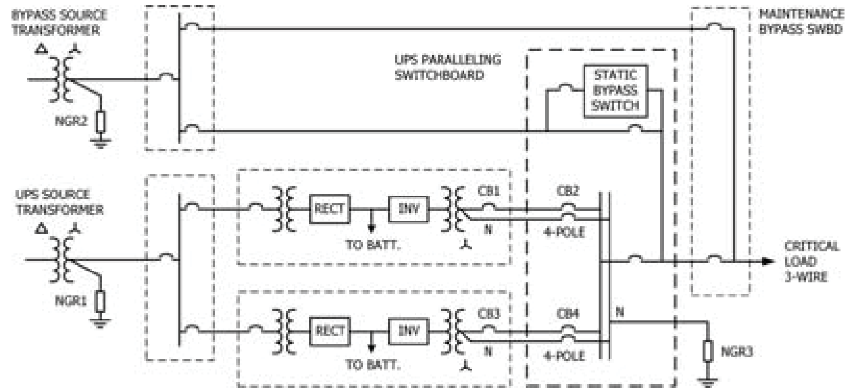

Fig. 7 High Resistance Grounding of a Parallel UPS System

Fig. 6 shows how to properly configure a UPS for an HRG system. NGRs are added at the UPS rectifier input, bypass input and inverter output (NGR1, NGR2 and NGR3). The UPS vendor can accommodate high resistance grounding when advised up front.

Ground alarm relays are required for each NGR to provide alarm indication upon ground fault.

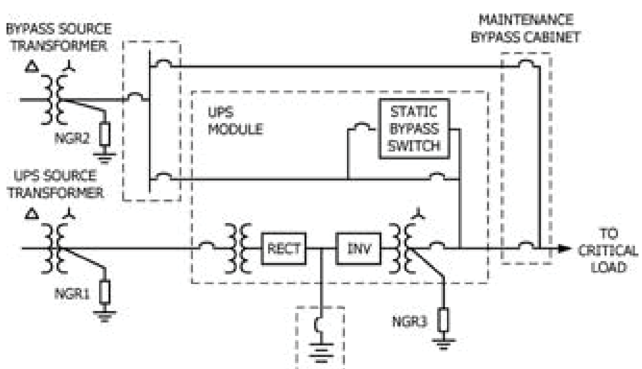

Fig. 6 Grounding of UPS Bypass Input and Inverter Output

High Resistance Grounding of Parallel UPS Systems

Parallel UPS modules increase the redundancy and capacity of a UPS system. Parallel UPS systems have traditionally been solidly grounded. They must share a common output neutral bus to facilitate single-point grounding, Significant circulating currents flow in the shared neutral; hence UPS manufacturers recommend a full capacity neutral cable.

A recent trend has been to use HRG UPS systems to increase critical bus availability upon ground fault.

For an HRG system, UPS vendors adapt the traditional solid grounding scheme by connecting a neutral grounding resistor (rated 2-5 A) between the output neutral bus and ground, shown as NGR3 in Fig. 7. The neutral bus becomes energized during a ground fault. When isolating a module for maintenance, the neutral must be disconnected along with the phase conductors. Neutral switching is typically done with 4-pole module output isolation breakers, CB2 and CB4 in Fig. 7. A UPS service technician must remember that opening the UPS internal 3-pole breakers CB1 or CB3 alone will not isolate the UPS module from the bus.

It is suggested that UPS manufacturers consider using the grounding scheme widely used on parallel HRG generators, proposed in Fig. 8. This scheme uses an artificial neutral zigzag grounding transformer to access the system neutral for single point grounding, thereby eliminating the shared output neutral and 4-pole breakers. Switchgear construction would be simplified, and a UPS service technician would no longer be concerned about isolating the neutral when disconnecting a module from the critical bus.

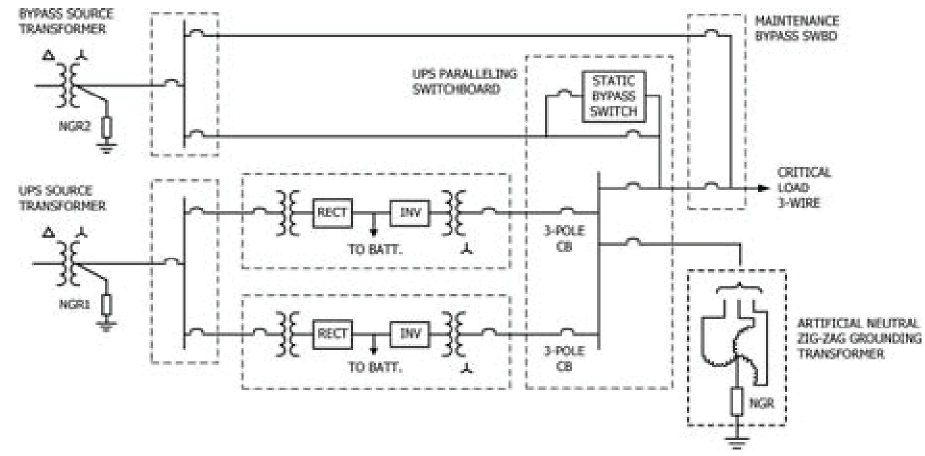

Fig. 8 Proposed Method for High Resistance Grounding of Parallel UPS Systems

Double Ground Fault in HRG UPS Systems

When a ground fault occurs on an HRG system, it should not be left in place indefinitely, but rather repaired within 24 hours or as soon as is practical.

If a ground fault was ignored and another ground fault was to occur on a different feeder and phase, then a phase-to-ground-to-phase fault would result, and both feeders would trip on overcurrent. If a double ground fault were to occur simultaneously on the bypass input and critical load (on different phases), there would be no immediate tripping of either faulted feeder because the two busses are isolated from each other via the static bypass switch. However, if an uninterrupted transfer to bypass were to be attempted, either automatically because of UPS failure or manually by an operator, then the critical load may be put at risk. A phase-to-ground-to-phase fault would occur during the moment the two sources were paralleled via the static bypass switch.

As an added precaution, it is recommended that the UPS system be interlocked with the GF alarm relays of the bypass source and critical load to prevent transfer whenever ground faults appear simultaneously on both busses.

GROUND FAULT MONITORING

A ground fault alarm panel is recommended for each high resistance grounded system to provide alarm indication when a ground fault occurs. This alarm should be monitored by a building management system (BMS) or similar monitoring system so that maintenance personnel can be notified and the alarm logged with a time-and-date stamp.

Furthermore, it is recommended that each feeder of each switchboard in the HRG system be monitored for ground fault.

This practice makes locating ground faults quicker and easier.

Feeder ground fault detection requires a separate zero sequence current sensor at each monitoring point. Residually connected phase current transformers (CT) commonly used in electronic-trip circuit breakers for ground fault sensing on solidly grounded systems are not sensitive enough to detect 1-5 A of ground fault current found in a HRG system.

Multi-feeder ground fault relays are commercially available for installation in switchboards to permit individual feeder monitoring for ground faults. It is recommended that these relays also be wired into the BMS for alarm logging and maintenance notification.

Circuit breakers with ground fault protection are often specified on 600 V solidly grounded systems for feeders 300 A and larger. The trip unit provides long-time, short time, instantaneous and ground fault protection (LSIG). Although LSIG breakers are not sensitive enough to sense single ground faults on an HRG system, they can still serve a useful purpose by providing coordinated ground fault tripping in the unlikely event of a double ground fault. The fault current of a phase-to-ground-to-phase fault is not limited by the NGR, hence will be high enough for sensing by the LSIG trip unit. If one or both of the ground faults is arcing type (not bolted), the LSIG trip units will provide coordinated ground fault protection such that only one feeder may have to trip. If both ground faults are bolted, then both feeder breakers will trip on instantaneous or short-time trip.

CONCLUSIONS

While high resistance grounding offers excellent protection against arcing ground faults and unscheduled shutdown from ground faults, care must be taken when applying to transient voltage surge suppressors and uninterruptible power supplies.

Transient voltage surge suppressors should be rated for use on HRG systems. Three-wire “delta-rated” TVSS are suitable for use on 600 V HRG systems because the L-G MOVs are rated to withstand the voltage rise that occurs during ground fault. TVSS designed for a 3-phase, 4-wire solidly grounded system are not suitable for a HRG system.

A UPS system intended for a HRG power system should have an internal rectifier input isolation transformer instead of an autotransformer to prevent MOV failure at the rectifier during a ground fault on the input power source.

The UPS 600 V input and output power systems must be grounded the same way, either HRG or solidly grounded.

Mixing the two grounding methods puts the critical load at risk during ground fault. If the critical load is to be solidly grounded yet the UPS is to be fed from a HRG source, then a delta-wye isolation transformer is required at the UPS input to decouple the UPS system from the HRG source. A UPS can be connected to a HRG source only when the critical load can also be HRG.

When parallel three-phase UPS modules with a shared output neutral conductor are high resistance grounded, a switched neutral (typically 4-pole breaker) is required at the output of each module for maintenance isolation purposes. The critical bus neutral becomes energized during ground fault.

It is suggested that UPS manufacturers consider using an artificial neutral zigzag grounding transformer and NGR to high resistance ground a parallel UPS system. This method is widely used to high resistance ground parallel generators and eliminates the need for a switched neutral at the output of each module.