Voltage Indicator
How Does it Work?
Application Note

SAFESIDE™ Permanent Electrical Safety Devices

This document relates to the following SafeSide™ family of voltage indicators (VI) products with operating voltages of 40-750VAC/30-1000VDC:

- **R-3W2**: Flashing Indication, CAT III/IV, UL Type 4X/12/ 13, Class 1 Division 2 Hazardous Locations
- **R-3W**: Flashing Indication, UL Type 4X/12/13
- **R-3W-SR**: Solid-ON Indication, UL Type 4X/12/13

Reference material: http://Info.graceport.com/pwa

Background:

Keeping personnel away from live voltage is foundational to electrical safety. Additionally, electrical safety demands a precise answer to the question, "Is voltage present?". Thru-panel voltage indicators go a long way in providing the very first answer to this all-important question, while a voltmeter provides personnel with a second, redundant answer.

From an electrical safety perspective, the ability to look at an electrical panel with a VI installed provides visibility of voltage from outside the enclosure without exposing personnel to the hazard. Not surprisingly, those using thru-panel voltage detection on their equipment have found this concept embraced by safety, electrical, and maintenance people at all levels of influence.

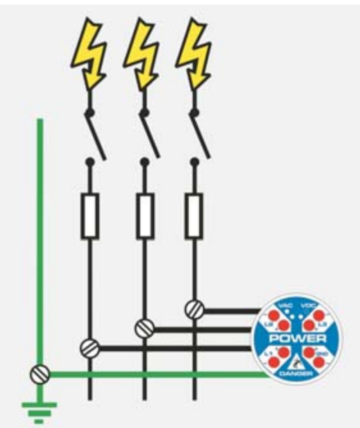

Fig. 1 Typical wiring diagram

Understanding how VIs function helps clarify many application questions that arise when applying this device into any type of power system. Most examples will use a 480VAC 3-Phase system (Fig. 1).

How it Works

A voltage indicator uses a high impedance voltage detection circuit per phase to sense and illuminate AC/DC voltage. The illumination of the LEDs occurs only when current passes through two of these voltage detection circuits. Envision four voltage detection circuits (L1, L2, L3, GND) "meeting" each other in the center of the VI. The amount of the current that flows through the voltage detection circuit depends upon the phase and ground voltages, which allows for multiple current paths passing through at least four LEDs. Each voltage detection circuit has two LEDs; one LED illuminates when the AC sine wave is positive and the other LED illuminates when the AC sine wave is negative (Fig. 2). For an LED to illuminate, current must pass through two of the voltage detection circuits, which causes four LEDs to illuminate. "Voltage when illuminated" means that if only one of the four LEDs illuminates, it still provides voltage indication to the worker. For DC systems only, one LED per voltage detection circuit will illuminate (Fig. 8).

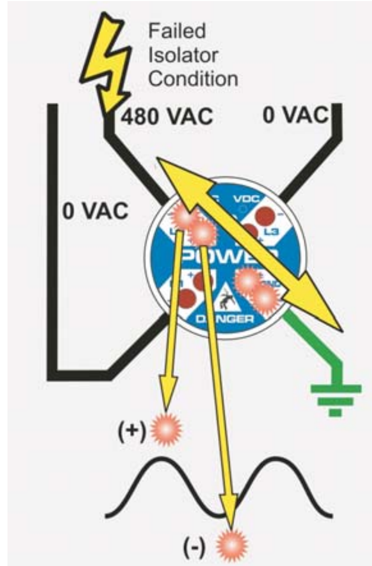

Fig. 2 Two LEDs illuminate on the top and bottom of the sine wave. One LED per leg illuminates for DC

When balanced voltages exist on each phase, the current flowing through each phase circuit is also equal (Fig. 3).

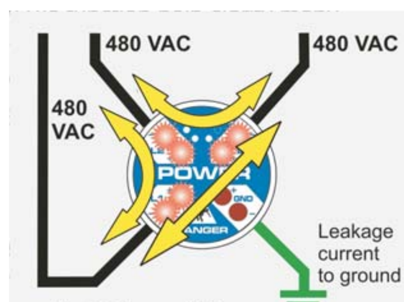

Fig. 3 Balanced Voltage No illumination on GND LEDs

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Because these currents are shared equally between the phases, in this case no current flows to ground and therefore the GND LEDs are not illuminated. This is the normal operating mode for most VI installations, and for large VI installations (50+ units), this means that the accumulation of ground currents will not adversely affect ground fault detection systems.

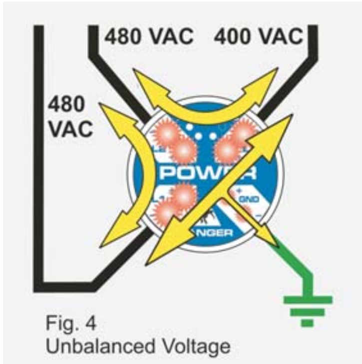


Fig. 4
Unbalanced Voltage

With the LEDs off, the nominal leakage current of 60µA has a negligible impact on the overall ground current to the electrical system.

When a voltage imbalance between phases exists, the GND LEDs will illuminate (Fig. 4). Under this condition, the current flow to ground is proportional to the percent of voltage imbalance as calculated below:

V1: Voltage L1
V2: Voltage L2
V3: Voltage L3
VX: Largest difference either L1, L2 or L3
AV: Average Voltage: (V1+V2+V3)/3
(480+480+400)/3=453
Percent Unbalance: (AV-VX)/AV
(453-400)/453=11%

With an imbalance less than 1%, the GND LEDs remain off. Somewhere between 1% and 15% the GND LEDs start becoming visible (around 60µA) and become fully illuminated above 15%. Under a single phasing condition, the maximum current flow in the ground leg is 600µA at 480VAC (Fig 2). With a phase loss condition, the current flow in GND is approximately 193µA. An electrically noisy environment also causes the GND LEDs to illuminate by inducing voltages at various frequencies into the ground leg. The GND LEDs will almost always be on when VIs are installed in close proximity to energized drives or high powered solid state devices.

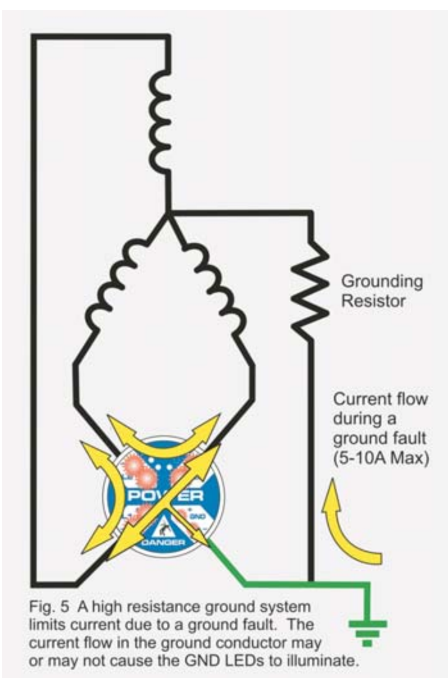


Fig. 5 A high resistance ground system limits current due to a ground fault. The current flow in the ground conductor may or may not cause the GND LEDs to illuminate.

High Resistance Ground System (HRG)

HRG systems limit the current flow from a ground fault somewhere in the electrical system through a grounding resistor connected to the transformer neutral. In many cases, the current flow in the ground system illuminates the GND LEDs (Fig. 5). However, other factors also cause the GND LEDs to illuminate, so when a VI is installed on a HRG system, illuminated LEDs do not necessarily mean a ground fault exists in the system.

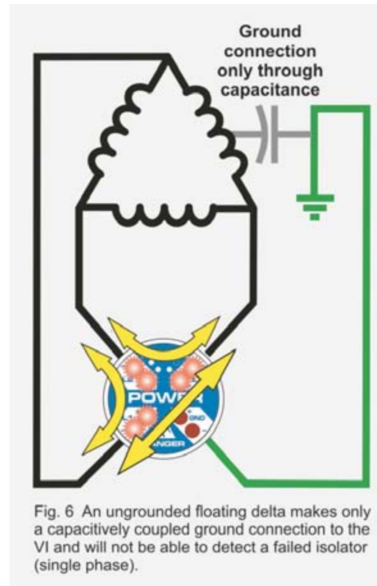


Fig. 6 An ungrounded floating delta makes only a capacitively coupled ground connection to the VI and will not be able to detect a failed isolator (single phase).

Ungrounded Systems

A VI has reduced functionality when installed into an ungrounded or floating power system. Because only a capacitive connection and no hardwired connection exists between ground and the incoming transformer, the VI will not be able to detect a single phase isolator failure (Fig. 6). There may be cases where enough capacitive coupling exists to provide a ground connection for the VI to function normally (Note comments below for verifying the ground connection).

A Safe Ground Reference Point Required

From an electrical safety perspective, LED illumination means that voltage exists. Voltage does not discriminate, so neither does a VI! A safe ground reference for the GND leg of the VI ensures that the VI illuminates in an isolator failure or single phase condition occurs (Fig. 2 & 7). Without a

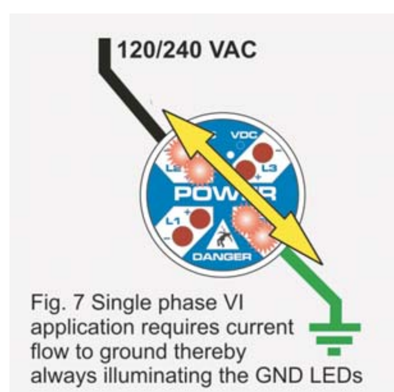


Fig. 7 Single phase VI application requires current flow to ground thereby always illuminating the GND LEDs

ground connection, there would be no path to complete the LED illumination circuit. If the GND LEDs do not illuminate after installation, pulling a fuse or disconnecting one VI lead wire should allow current flow to ground thereby testing the integrity of the ground connection.

Short Circuit Current Rating (SCCR)

SCCR ratings apply to only current-carrying devices and not to VIs. This rating determines how much current can flow through the given electrical enclosure (or system) without permanently damaging any of the devices within the enclosure.

By nature, a VI is always short circuited between phases, but because of its high impedance circuitry, the short circuit current is below a 1.0mA all the time. Therefore, no condition exists where the current flow through the device causes permanent damage to the device. The VI high surge immunity and CAT IV/III rating protects it from a voltage surge during a fault condition.

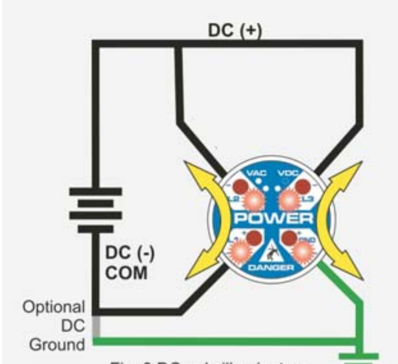


Fig. 8 DC only illuminates one LED per leg on the VI.

Over-current Protection

VIs should normally be installed without fuses unless required by local codes and authorities. For a more detailed discussion on this issue, please refer to *VoltageVision_FusingDocument.pdf.* These reasons are summarized as follows:

- High Impedance: VIs are C-UL-US Listed (file E256847, CCN: NKCR-Auxiliary Devices) for use in a UL 508A industrial control panels or UL 845 motor control centers. UL performed a single component evaluation test that insures the VI would not experience a catastrophic failure due to a component failure, thereby causing a direct short circuit between phases. The UL test showed that a single component failure draws no more than 3.7mA current at 750VAC applied to the device.

- Electrical Integrity: The potted construction adds additional electrical strength to the VI.

- Surge Rated: The VI known as part number R-3W2 carries a CAT III (1000V) and CAT IV (600V) surge rating for reliability.

- Integral Lead Wires: The integral potted 18AWG UL listed 1000V rated lead wires will not vibrate loose causing a short circuit to ground. Since the failure mode of the VI is 3.7mA, these wires should not fail due to a device failure.

- Wire Protection: An optional NTW conduit adapter (R-3W-DR6) provides physical protection to the wires.

In conclusion, over-current protection only protects the VI's lead wires from shorting to ground or another bare conductor. If this happens, most likely the current will vaporize the lead wire causing limited damage to the enclosure. Since the lead wire insulation is flame-rated and UL-listed, it is designed to not sustain a flame.

Higher Voltage Range Applications

Please contact the factory if your application requires a higher continuous or intermittent operating voltage. Higher operating voltages product more heat, so the ability to operate at a higher voltage depends upon the ambient temperature of the installation. Voltage divider networks provide another solution to higher operating voltages, but at these voltage levels, resistor sizes and power dissipation becomes a factor. Series input resistors combined with internal circuitry of the VI creates a more efficient voltage divider (Fig 9.)

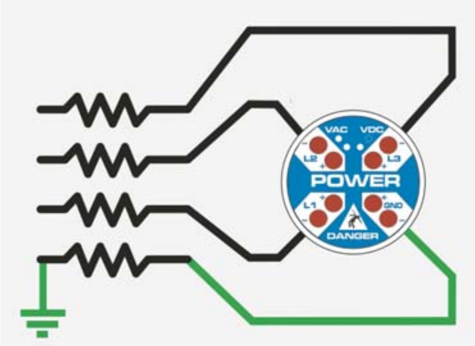


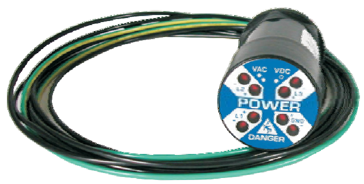
Fig. 9 Voltage divider with VI. Call factory for sizing

Phil Allen is the President and Owner of Grace Engineered Products, the leading innovator of thru-door electrical safety devices. He holds US Patents on a power receptacle design, and continues to consider new and more efficient ways of bringing electrical safety to the forefront. Phil did is undergraduate work at California State University, San Luis Obispo and is a 1984 graduate with a BSIE.

Grace Engineered Products is a member of the Rockwell Encompass Partner program, and is best known for its GracePort® line of custom-made data port interfaces. In addition to the GracePort® line, the company provides a well-established line of products – SafeSide™ voltage indicators and voltage portals - that make pre-verifying electrical isolation through enclosure doors safe and easy. Their focus is on NFPA 70E guidelines and making companies electrically safe.

24/7 Voltmeter

R-3W2 Voltage Indicator



UL TYPE 4X
TYPE 12
TYPE 13

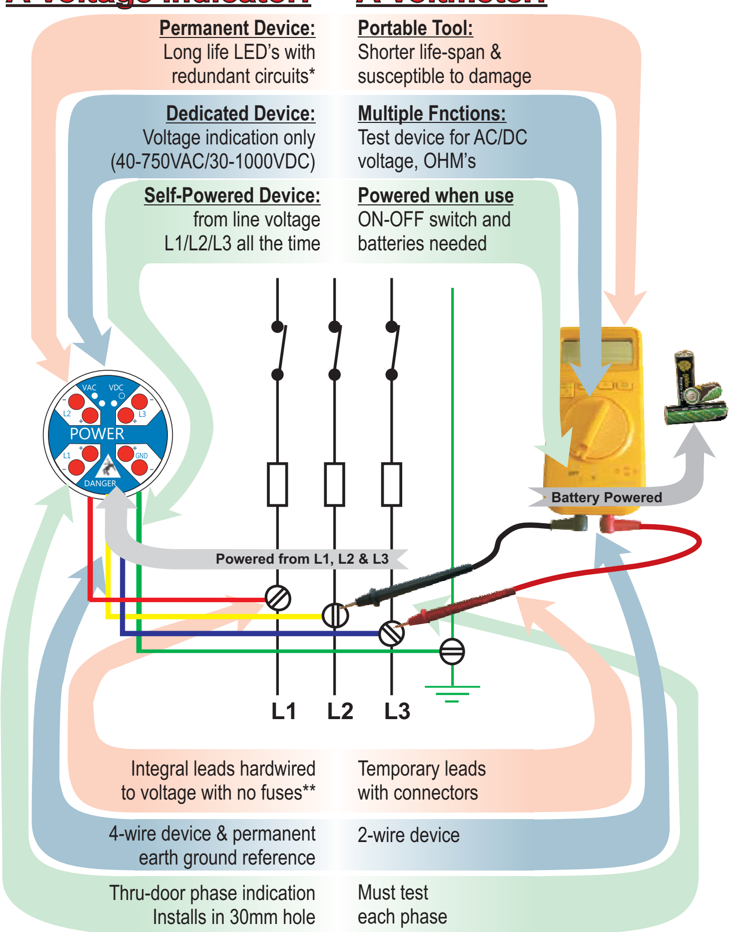
LISTED
IND. CONT. EQ.
HAZ. LOC. 42RV
46RD

CAT III 1000V
CAT IV 600V
DC or AC-rms to Ground
(Peak Impulse Transient 8000V
20 repetitions, 2 ohm source)

A Voltage Indicator:

- ...is permanent and less susceptible to damage.
- ...has reliability due to redundant circuits, surge immunity, long life LEDs and heavy duty construction.
- ...has one function: Indicating voltage.
- ...is powered from the line voltage only (no batteries)

A Voltage Indicator: A Voltmeter:



Warning: Before working on an electrical conductor, verify zero electrical energy with proper voltage testing instrument and the proper procedure as per NFPA 70E 120.1(5), 120.2 (F)(2)(f)(1-6), OSHA 1910.333(b)(2)(iv)(B).

Voltage Indicators (VI) Benefits

How the NFPA 70E Sample [1] Lockout/Tagout Procedure (LOTO) works with a VI.

Written LOTO procedures must be accessible to all employees. Each step that involves a VI must be included into the LOTO procedure. At a minimum, verify the proper operation of the VI before and after the work task.

NFPA 70E Annex G Reference	Key Concepts	Voltmeter Verification Only (No VI)	VI Safety & NFPA 70E Comments
6.1	Locate all electrical & stored energy sources	Voltmeter not used until 6.5	Provide 3-phase power system status, labels multiple power sources
6.2	Physically operate the isolator: disconnect power & relieve stored energy	Voltmeter not used	Indicates prescence of AC/DC voltage or stored energy.
6.3	Apply lockout device and an additional safety measure.		Provides continual information as an additional safety measure.
6.4	Attempt to operate the isolator		Indicates an isolator failure to operator.
6.5	Inspect voltage detector for damage		Need to inspect VI as part of LOTO procedure
6.6	Verify proper operation of voltage detector, then test for absence of voltage.	Repair if not functioning	Completed in 6.1. VI continually tests between L1-L2-L3-GND
6.7	Verify proper operation of voltage detector, after testing for absence of voltage.		See NOTE 2
6.8	Install grounding bars to eliminate induced voltages or stored energy		VI provides ongoing indication of stored energy or induced voltages.

[1] NFPA 70E, 2009 Edition, Annex G, 6.0-6.9

[2] The traditional "Live-Dead-Live" LOTO safety procedure with a voltmeter remains intact. These comments only describe the added safety benefits if a VI is employed in addition to existing LOTO procedure.