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White Paper

Not all Low Voltage Switchgear is created equal

The must-have solution for power distribution systems

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Not all Low Voltage Switchgear is created equal: The must-have solution for power distribution systems

Introduction

Reliability and safety are the two most important criteria in the proper functioning of a power distribution system, but both can be compromised if an electrical fault occurs. By integrating the right low voltage switchgear, greater reliability and safer operation can be achieved in the power distribution system.

There are two basic types of electrical faults that could disrupt the power distribution system.

Bolted fault

In a bolted fault condition, the voltage at the fault location is essentially zero. The fault energy generated is dissipated throughout the power system, that is, no electric arcs are created.

Low-voltage metal-enclosed switchgear conforming to IEEE C37.20.1 ① is designed to withstand the mechanical forces generated by bolted faults on the load terminals until a power circuit breaker or other protective device can interrupt the flow of current. This capability is verified by short-circuit and short-time withstand tests on the equipment, and interruption tests on the power circuit breakers. Bolted faults typically cause little damage to the low-voltage switchgear, and can typically be quickly inspected before returning to service.

Arc fault

Unlike a bolted fault, the voltage at an arcing fault location is essentially the system voltage. For arcing faults initiated within the switchgear, the fault energy and the destructive forces are focused within that switchgear enclosure, and potentially any other close-coupled equipment.

An internal arc fault can be caused by one or more of the following:

- Insulation degradation & contamination
- Entrance of vermin into the equipment (e.g. rats, snakes)
- Conductive objects coming into contact with the energized bus (for example, tools left behind in the equipment)
- Any other unplanned condition that creates an electrical discharge path through air. (for example, transient voltage surges)

Arc temperatures can exceed 20,000 K, rapidly heating the air and vaporizing metal parts. The arc creates a cloud of ionized air, known as plasma, which has conductive properties similar to that of metals. The expanding plasma creates severe mechanical and thermal stress in the equipment which can rapidly burn through the enclosure, distort frame and structural members, and defeat door and other dead-front barrier latches, resulting in release of plasma, hazardous particulates, and flying debris from within the switchgear enclosure.

These arc faults, also known as arc flash events, occurring within the low-voltage switchgear can lead to serious injuries up to, and including death. The Occupational Safety and Health Administration (OSHA) currently does not have a strong mechanism for reporting and documenting frequency of arc flash injuries, but in a recent study of arc flash accidents, "one large utility has discovered an average of one arc-flash injury every 18 months for the past 54 years." (IEEE 1584, clause10.3 ②). Minimizing arc faults in the switchgear is of utmost importance to enabling a safe environment. Additionally, arc flash events can result in prolonged downtime and severe equipment damage.

Traditional solution

NFPA 70E ④ under 130.7 mandates that personnel working in close proximity to electrical hazards will use personal protective equipment (PPE) to protect workers from injuries in the event of an arc flash. But, PPE only provides protection from the thermal effects of the arc flash and shock hazards. It does not protect the person from physical harm, for example the direct impact of the pressure wave or being struck by flying debris. The requirement for PPE is dependent on the hazard or risk category which is governed by Table 130.7 (C) (15) (a), or an incident energy analysis.

PPE is typically not preferred by end users for a number of reasons. First, it is bulky, hot and restrictive and leads to loss of dexterity. Second, the time required to suit up is typically many times greater than the actual maintenance activity. Third, training is required to effectively utilize the PPE. And finally, it is difficult to enforce PPE discipline.

Preferred alternative solution

Arc Resistant Low Voltage Switchgear is designed to provide an additional degree of protection for personnel performing normal operating duties in proximity to the energized equipment during an arcing fault. Such duties include opening or closing breakers, closed-door breaker racking, reading instruments, or other activities that do not require cover removal or opening doors, other than auxiliary/instrument compartment doors. A typical arc resistant equipment design accomplishes the additional protection by channeling the plasma and pressure away from the personnel, usually up through the top of the gear.

PPE requirements can be greatly reduced by utilizing equipment which has been tested and labeled as "Arc Resistant." This can lower the hazard risk category to the minimum, and thus operators could significantly reduce the PPE required for the operations mentioned.

Arc resistant testing
C37.20.7, IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults, establishes performance levels known as "Accessibility Types." There are two predominant Accessibility Types on the market, Type 2A and Type 2B. Type 2A describes equipment which is evaluated to criteria for providing additional personnel safety on the front, sides and rear of the gear with all doors and covers securely in place. Type 2B rated equipment preserves the arc resistant performance, even while control or instrument compartment doors/covers are open – thus maintaining protection for an operator inspecting or adjusting monitoring and control devices within that control compartment.

There are many caveats to this testing guide, but for simplicity, the following generally applies.

- The test is performed at rated maximum voltage of the equipment.
- The rated arcing current is specified by the manufacturer and is maintained constant throughout the duration of the test. The preferred value of the arcing current is the rated short-time current of the equipment.
- Arcs are initiated which emulate all likely locations of arcing faults that could occur under actual service conditions.

Arc initiation and location
During validation (design) testing, the manufacturer uses bare metal wire for arc initiation. For low-voltage distribution equipment, 1kV and below, this arc initiator wire is required to be fine-stranded, 10 AWG copper wire. The fault is initiated by placing the wire directly on the conductors of all three phases at various points in the equipment; namely the main and section bus, cable lugs, and primary disconnects within the breaker compartment. If the conductors are insulated, then at breaks or transitions of the insulation medium, openings must be made to connect the wire directly to the three phase conductors at these locations.

Environmental simulation
Operating personnel are simulated by use of cotton cloth patches ("indicators") positioned horizontally and vertically along the front, sides and rear of the switchgear. These indicators ignite at approximately the same energy level as would cause second degree burns to humans. The equipment room (aisle widths, proximity to walls and other obstructions, ceiling height, etc.) is simulated per the NFPA 70, National Electric Code (NEC) [3], or the manufacturer's specifications. These application considerations are documented by the manufacturer as minimum conditions for the end-use equipment room.

Arcing duration
The maximum time period during which the equipment experiences the internal arc fault and meets the testing criteria is the rated arcing duration. The preferred rated arcing duration is 0.5 seconds; with the minimum recommended is 0.1 seconds. The rated arcing duration is documented on the equipment nameplate. The upstream supply equipment must be coordinated to prevent the arcing current from being maintained longer than the marked rated duration.

Assessment
After the test, the equipment must meet all the following criteria:

1. Properly latched or secured doors and covers do not open.
2. No fragmentation of the enclosure occurs.
3. Arcing does not cause holes in the freely accessible front, sides or rear of the enclosure.
4. No indicators ignite.
5. All equipment grounding connections remain effective.

A comment on arc duration
A typical arc duration rating of 0.5 seconds does not necessarily tell us the period of time the arc was sustained at a certain fault location inside the switchgear. This sustained arcing duration is the single most important factor in predicting the severity of the event. The longer the arc is sustained, there will be more resultant plasma, and corresponding pressure buildup, erosion of conductors and other ferrous materials, damage to insulators, and energy emitted. These may also result in secondary arcing events in other equipment locations.

Design options in arc resistant low-voltage switchgear
Low-voltage switchgear manufacturers typically offer a wide array of optional features. The one which is of particular relevance for this discussion is insulated/isolated bus and the effect it has on arc resistant switchgear performance.

Insulated bus: There are various constructions that accomplish bus insulation. One method may have each individual phase bus bar covered with a plastic insulating sleeve with a dielectric withstand capability of 2.2kV, and rated for flame-resistance. Other insulation methods include epoxy coating, heat shrink tubing, and insulation tape. There is little to no air gap between the conductor and the insulation. In most cases, the insulating material has been third-party certified for performance, in addition to specific application performance testing by the equipment manufacturer.

Isolated bus: Again, various designs exist, but the basic premise is that insulating barriers are placed between and enclose each phase bus bar. There is an intentional and significant air gap between the conductors and the barriers. Some manufacturers use a combination of insulation and isolation. Likewise, in most cases the insulating material has been third-party certified for performance, in addition to specific application performance testing by the equipment manufacturer.

Comparison of bare bus to insulated/isolated bus

Several simulations were conducted according to the arc resistant testing guide, IEEE C37.20.7 [5]. Various arc initiation locations and electrical ratings were evaluated with bare bus and insulated/isolated bus.

To compare the simulations, sustained arc duration and total energy emitted must be considered. Total energy is measured in Watts-second (Ws) and is calculated by numeric integration of the voltage and current over the time interval per Simpson's rule. This is performed over the duration of sustained arc.

The first simulated arc fault was created at the top of the switchgear assembly's vertical riser bus, constructed with 7" phase-to-phase spacing. The fault location was the farthest distance away from the current source. Table 1 lists the simulation parameters and results.

	Simulation	
Input parameters	**1(A)**	**1(B)**
Open circuit voltage (Vac)	508	508
Available symmetric current (kA)	85	100
Time (msec)	500	500
Construction of bus-bars	insulated/isolated	insulated/isolated
Performance parameters		
Arc duration time (msec)	16.8	18.7 (11% increase)
Total energy (Ws) (in millions)	0.301	0.373 (24% increase)

Table 1

Analysis of Simulations 1(A) & 1(B) indicates there is only a slight increase in arcing duration and total energy when the available symmetric current is increased from 85kA to 100kA while keeping the rest of the input parameters constant. This is important for predictive purposes.

Now consider Table 2. This comparison is similar to 1(A) vs. 1 (B), but conducted at 635V. We would expect the same trend in these 635V simulations as in 1(A) and 1(B) at 508V.

	Simulation		
Input parameters	**1(C)**	**1(D)-Predicted**	**1(D)**
Open circuit voltage (Vac)	635	635	635
Available symmetric current (kA)	85	100	100
Time (msec)	500	500	500
Construction of bus-bars	insulated/ isolated	bare bus	bare bus
Performance parameters			
Arc duration time (msec)	14.1	15.7 (11% increase)	518
Total energy (Ws) (in millions)	0.165	0.204 (24% increase)	20.33

Table 2

However, Simulation 1(D) (bare bus condition) sustained the arc 33 times longer than expected. The total energy generated in the bare bus condition was 100 times greater than predicted by calculation. See column 1(D)-Predicted.

The second simulated arc fault was created across the three phases at the line side (source) cable connections with 7" phase-to-phase spacing. This assembly is located in the rear of switchgear assembly, adjacent to the vertical riser bus and main through bus. This area is commonly known as the cable compartment.

Table 3 lists the simulation parameters and results.

	Simulation			
Input parameters	**2(A)**	**2(B)**	**2(C)**	**2(D)**
Open circuit voltage (Vac)	508	508	635	635
Available symmetric current (kA)	100	100	85	85
Time (msec)	500	500	500	500
Construction of bus-bars	insulated/ isolated	bare bus	insulated/ isolated	bare bus
Performance parameters				
Arc duration time (msec)	23.4	131	15.2	517
Total energy (Ws) (in millions)	0.314	2.697	0.340	16.27

Table 3

Simulations 2(A) & 2(B) were performed at the same voltage and current levels to compare the two bus bar constructions. The arcing duration in the bare bus condition increased 5.6 times over the insulated/isolated bus. An increase of 8.6 times the total energy generated was observed.

Similar results were observed in Simulations 2(C) & 2(D) performed at 635V. The total energy generated in the bare bus construction was 48 times greater than the energy generated in insulated/ isolated bus. The arc sustained 34 times longer. The damage to the equipment was considerable.

Figures 1 and 2 show the electrical wave forms of Simulations 2(C) and 2(D), respectively. On each figure, point "a" denotes the arc initiation and the arc extinguishes at point "b". It can be seen that the arc was sustained significantly longer in the bare bus construction. It is important to note that the only difference in these simulations was the bus contruction – insulated/isolated vs. bare.

Additional simulations were conducted on the main through bus. The results summarized in Table 4 show the same trend that bare bus construction arcs significantly longer and generates more plasma than insulated/isolated bus.

	Simulation			
Input parameters	3(A)	3(B)	3(C)	3(D)
Open circuit voltage (Vac)	508	508	635	635
Available symmetric current (kA)	85	100	85	100
Time (msec)	500	500	500	500
Construction of bus-bars	insulated/ isolated	insulated/ isolated	insulated/ isolated	bare bus
Performance parameters				
Arc duration time (msec)	24.1	9.32	7.08	518
Total Energy (Ws) (in millions)	0.167	0.131	0.135	17.83

Table 4

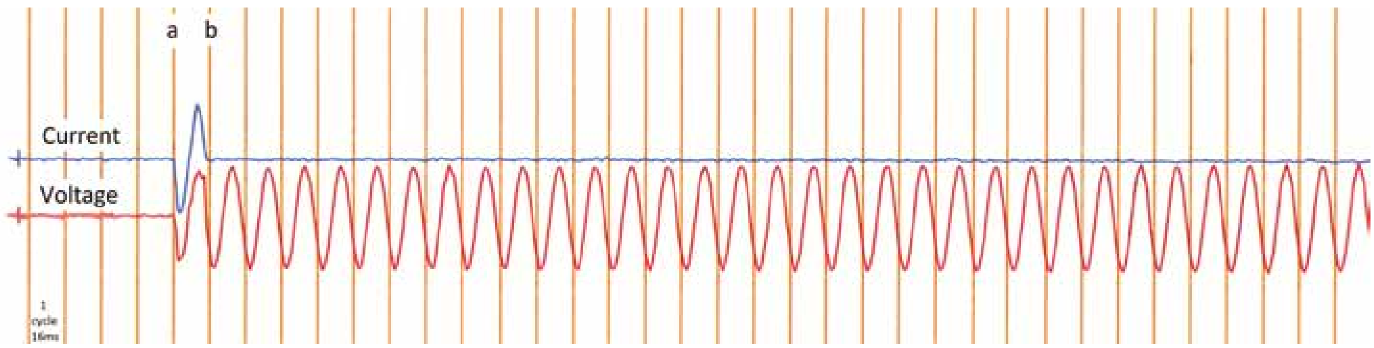

Figure 1: Insulated/isolated bus performance 2(C)

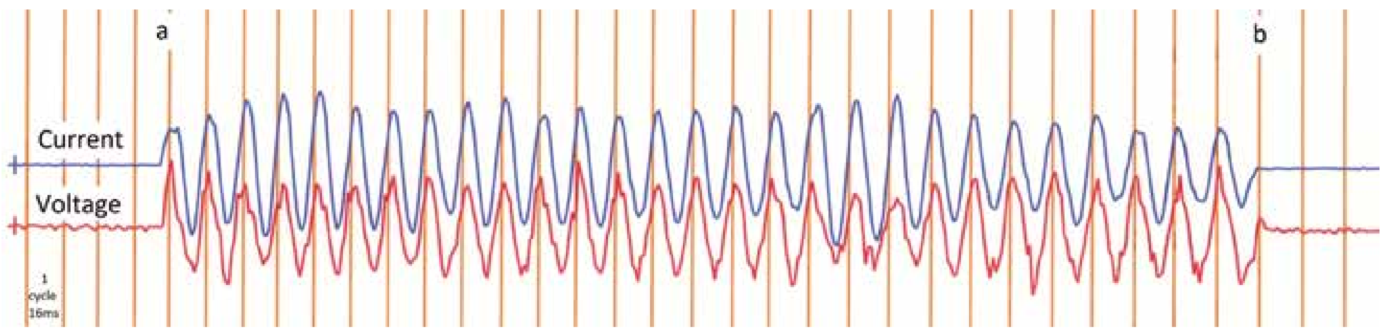

Figure 2: Bare bus performance 2(D)

Figure 3(a) & 3(b) shows the arc duration and total energy of the discussed simulations plotted on the same scale. It can be seen in all cases that the insulated/isolated bus construction has considerably shorter arc duration and lower total energy emitted.

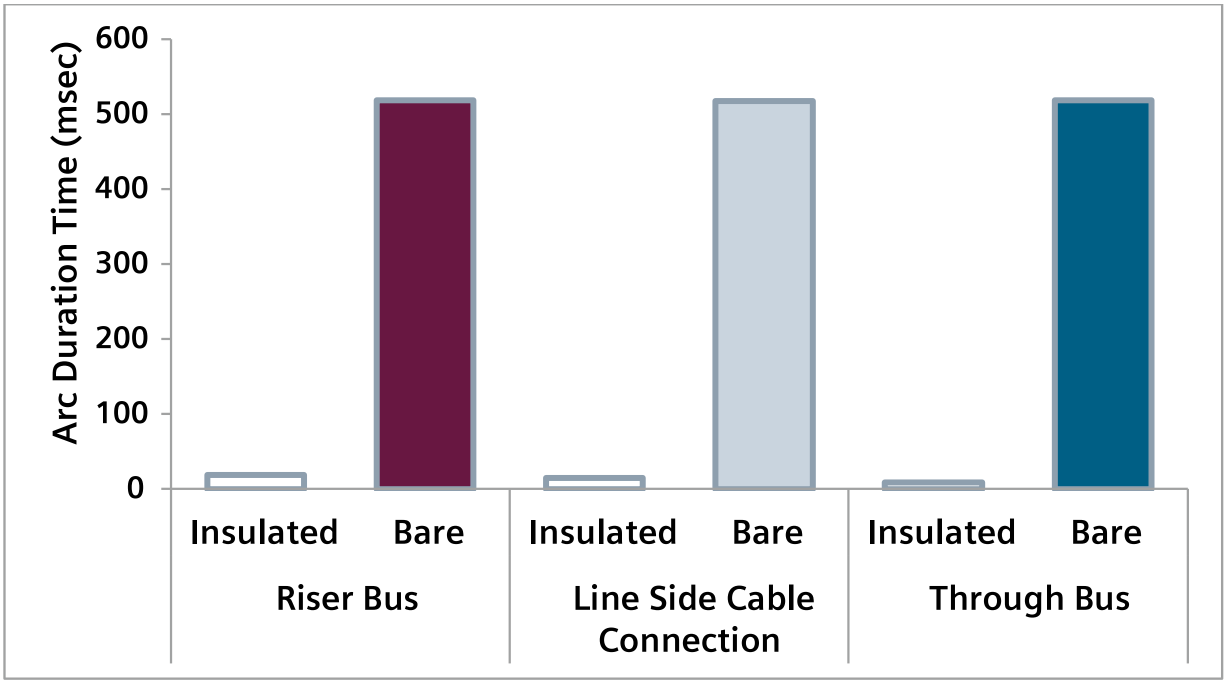

Figure 3(a): Summary of Simulations: (Arc Duration)

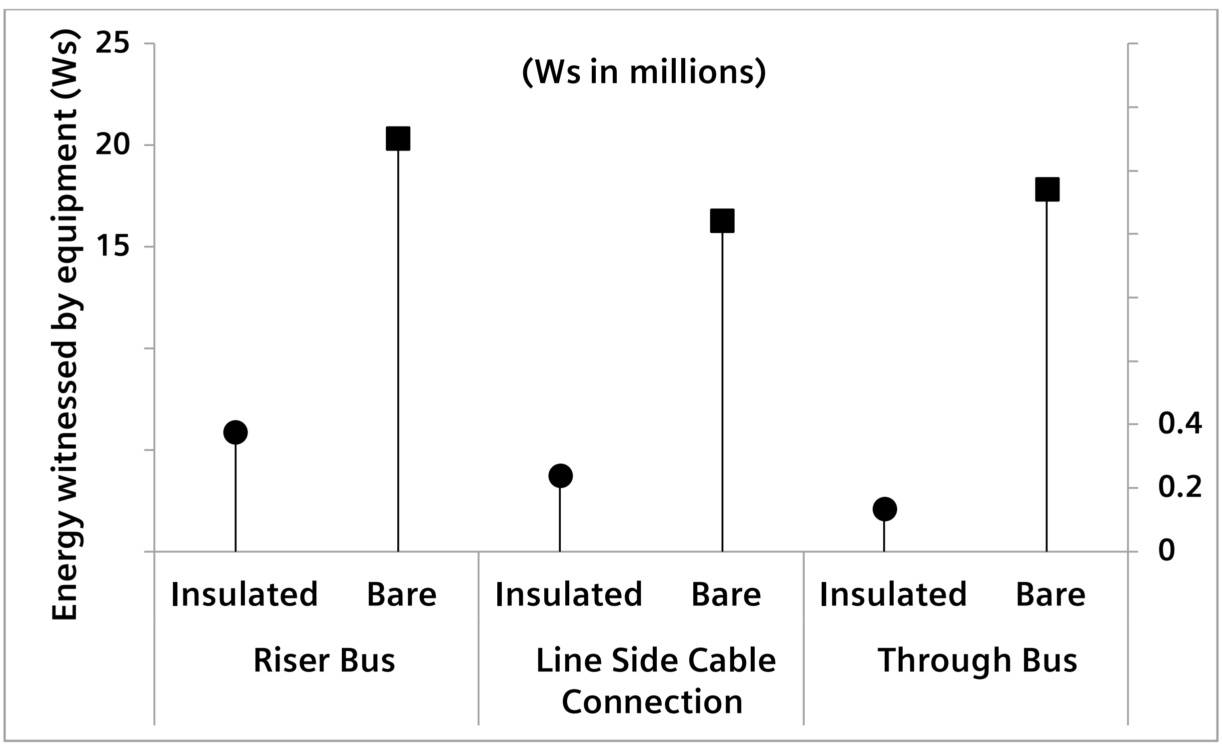

Figure 3(b): Summary of Simulations: (Total Energy)

Conclusion

Based on the simulations, it is evident that insulated/isolated bus significantly reduces the sustained arcing duration when compared to bare bus construction. Minimizing arcing duration reduces the total amount of energy generated inside the equipment, which in turn will result in less damage.

Insulated/isolated bus also reduces the possibility of creating arcing faults specifically if vermin enter the switchgear, they are less likely to make contact with multiple phases and/or ground, and if a ferrous object is resting on or falls onto live parts.

Thus, insulated/isolated bus is strongly recommended for all low voltage switchgear. And, to maintain the highest safety and reliability in your power distribution system, arc resistant switchgear should be selected with insulated/isolated bus construction because "not all low voltage switchgear is created equal".

References

① IEEE Std C37.20.1, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear

② IEEE Std 1584, IEEE Guide for Performing Arc-Flash Hazard Calculations

③ NFPA 70 National Electric Code 2014 Edition

④ NFPA 70E Standard for Electrical Safety in the Workplace 2012 Edition

⑤ IEEE C37.20.7, Guide for Testing Metal-Enclosed Switchgear Rated Up to 38kV for Internal Arcing Faults

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