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Internal Arc Risk Mitigation Tools for Enhanced Safety and Reliability

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Abstract

Low voltage switchgear and control gear assemblies complying with IEC 61439[1] standards ensure a high level of safety and reliability for its end users. However, a remote possibility of an internal arc fault still exists and hence it is essential to employ risk mitigation tools to enhance safety and reliability. Standard bodies like IEC, IEEE, NFPA etc. provide several methods for making the switchgear assembly more robust from an internal arc standpoint. These include IEC TR 61641[2], IEEE1584[3] and NFPA 70E[3] which are a set of available guides and standards. Besides compliance with these standards, several tools are available to mitigate the risk of an internal arc and its associated effects. Here we shall elaborate on the tools that can be used in combination, for reducing the risk associated with an internal arc fault event.

Keywords: Internal Arc, Low Voltage Switchgear and Control Gear, Risk Mitigation, Safety and Reliability, Standards

1. Introduction

An arc flash typically could be over in less than 5 cycles i.e., around 100 milliseconds. To put this into perspective, the human eye blinks in 300 to 400 milliseconds. Thus, an arc flash incident has the potential to cause extensive damage to personnel and property almost in the blink of an eye. A report published in the Industrial Safety and Hygiene News[4] estimated that, on average there are around 30000 arc flash incidents every year which include 7000 burn injuries, 2000 hospitalisations and 400 fatalities. It is important

however to note that a large percentage of the above can be cut down, by employing various risk mitigation techniques, which is the combined responsibility of the original equipment manufacturer and the end user. The risk of human life involved in an arc flash incident should compel the manufacturers and end users to realise the significance of using arc flash mitigation techniques and arc flash-resistant equipment design.

2. Internal Arc in LV Switchgear Assemblies

2.1 The Phenomenon, Causes and Effects

An internal arc inside an LV switchgear assembly refers to a short circuit fault taking place inside the assembly between two or more conductive paths having a potential difference. Both internal arc and bolted short circuit faults are classified as short circuit faults, but there is a significant difference in the phenomenon of both. While in a bolted short circuit fault, the electrical system undergoes a lot of mechanical and thermal stress, in the case of an internal arc, the sudden energy results in high pressure and sudden temperature rise making internal arc fault a highly dangerous event for both, the personnel and the equipment safety as compared to bolted short circuit fault.

During an internal arc fault, due to the sudden release of energy and heat, copper expands, due to ablation/

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vapourisation, to 67000 times itsoriginal volume, leading to a rapid explosion.

As a first step to understanding risk mitigation, we need to first understand the causes and effects.

The following list covers some of the major causesand effects of internal arc faults inside a switchgear assembly:

Causes:

- Human error – Leftover tools and materials.
- Faulty workmanship – Loose joints.
- Use of inferior materials or inadequate design – poor quality conductors, supports or incorrectly sized busbars.
- Entry of rodents / small animals.
- Lack of regular maintenance.

Effects:

- High energy release.
- Sudden increase in temperature (can go up to 19000°C).
- Pressure rise up to 3atm.
- Flying shrapnel up to 1600km/ hr speeds.
- Shock waves and loud noise (may cause permanent ear damage).

It can be seen from the above that any non-compliance related to internal arc can have dire consequences for both personnel safety as well as for the smooth working of the overall business of any organisation.

Considering the catastrophic consequences, it becomes imperative to follow the "prevention is better than cure" approach and use appropriate risk mitigation techniques.

3. Compliance to Standards

3.1 IEC 61439

When it comes to the safety and reliability of low-voltage switchgear assemblies, we don't need to look much beyond the IEC 61439 set of standards applicable to low-voltage switchgear and control gear assemblies having a rated insulation voltage of <1000V. The constructional requirements provided in the IEC 61439 standards ensure that the assembly is already a pedestal higher than other non-compliant assemblies. IEC 61439 mandates certain requirements related to clearances, creepage distances, protection against access to hazardous parts, barriers and partition design, protection against fire and heat, temperature rise, short circuit and di-electric performance etc. which ensures significant robustness is pre-built into the switchgear assembly. Also, IEC 61439 explicitly states the forms of separation used inside switchboards. By opting for a higher form of separation inside the assembly, we are taking care of operator safety and preventing a fault in one area from affecting the functioning of another area within the assembly.

A fine example to mention would be the clearance requirements of IEC 61439. It mandates maintaining a minimum of 14mm clearance between live parts for claiming an impulse voltage of 12kV.

Another example would be the mandatory glow wire test (suggested as per IEC 60695-2-11) where the current carrying parts like supports etc., need to be verified for a 960 °C glow wire test, which proves the material's capability to resist fire.

3.2 IEC TR 61641

In addition to IEC 61439, another document which ensures robustness in design is the IEC Technical Report (IEC TR 61641), which is a guide for testing under conditions of arcing due to internal fault.

IEC 61641 also mentions that although compliance with IEC 61439 standards ensures safe and reliable operation, a remote possibility of an arcing fault remains. In the case of the internal arc due to the reasons mentioned above, IEC 61641 acts as a guide for manufacturers, end users and testing laboratories.

In a nutshell, this TR provides details on the method to conduct an arc fault test inside a Low Voltage (LV) switchgear assembly and also lays out the passing criteria.

It classifies assemblies into various arcing classes like A, B, C and I depending on the satisfaction of certain conditions. Testing an assembly as per IEC 61641, as of the time of writing this paper, is a voluntary test done at the discretion of the manufacturer. However, compliance with both IEC 61439 and IEC TR 61641 will ensure a safe and reliable switchgear assembly.

3.3 IEEE 1584 and NFPA 70E

IEEE 1584 guide provides techniques for designers and facility operators to apply in determining the arc-flash hazard distance and the incident energy to which employees could be exposed during their work on or near electrical equipment.

NFPA 70E is a broader standard that addresses overall electrical safety in the workplace, including requirements for personnel safety including Personal Protective Equipment (PPE) levels and requirements, training, equipment labelling, safety program implementation etc.

An example of a warning label as required by NFPA 70E is given in Figure 1.

Figure 1. NFPA warning label.

By adhering to the guidelines provided in IEEE1584 and NFPA 70E, significant arc flash risk reduction can be achieved.

4. Internal Arc Risk Mitigation Techniques

Internal arc risk can be mitigated by using two main approaches, using inherent design methodology and using arc fault relays.

4.1 Inherent Design Methodology

Performing Design Failure Mode and Effect Analysis (DFMEA) and Fault Tree Analysis (FTA) is required to prevent design failures.

From an Original Equipment Manufacturer (OEM) perspective, it is essential to aggressively make use of the structured tools for risk analysis and mitigation during the design stage. This will help to identify and address potential failures that can result from an arc flash event. These could mainly include fish-bone diagrams, Failure Mode Effects and Analysis (FMEA) and FTA.

An example of how FTA is used to drill down the potential causes of the failure, in this example, the opening of the doors due to the arcing pressure is shown in Figure 2.

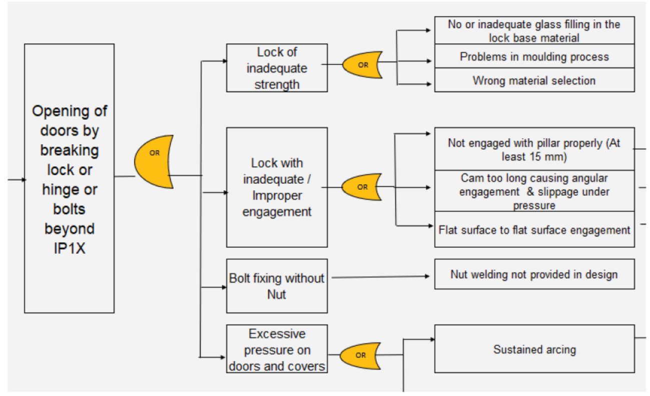

Figure 2. Fault tree analysis.

By using such risk mitigation tools, a detailed risk analysis can be performed.

4.2 Incorporating Design Features

4.2.1 Pressure relief mechanism

Use of spring-loaded flaps that would open in case of overpressure created during the initial portion of the arcing duration. Necessary calculations need to be performed as discussed later in the case study section.

4.2.2 Form of separation

Using the highest form of internal separation like form 4b, wherein each section of the assembly is compartmentalized and physically separated from the other section, keeping the fault and its effects restricted to the location of the fault.

Figure 3. Compartmentalised assembly with Form 4b separation.

4.2.3 Insulating material

Using high-quality insulating material having a comparative tracking index (CTI) > 600V

4.2.4 Clearances

Maintaining higher clearances than the standard requirements for e.g. 25 or 30 mm.

4.2.5 Sleeving

Use of high-quality polyolefinsleeve with FR capability for busbars, to prevent arc travel and restrike.

4.2.6 Locking arrangement

Use of high-strength locking arrangement which prevents doors and covers from opening and causing harm to the operating personnel. Necessary calculations need to be performed as discussed later in the case study section.

4.3 Using Arc Flash Relay

Using an arc flash relay sensor as a method of active arc flash protection can also help limit the amount of destruction caused by an arc flash incident.

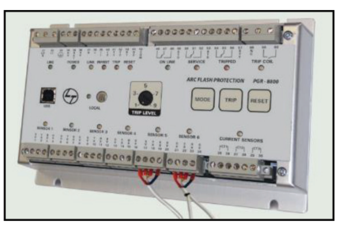

Figure 4. Arc flash relay unit.

A typical installation with an arc flash relay consists of fibre optic sensors or point sensors placed strategically inside the switchgear assembly. Refer Figure 6. These sensors will detect the light from the arc and generate the tripping signal. Also, to avoid nuisance tripping, CTs can be used to measure the current flowing at the time of the fault.

Figure 5. Installation with arc flash relay unit and sensors.

During the condition of high-intensity light combined with high fault current, the relay will generate the tripping signal (generally during a very short period of 2ms) and the tripping device like ACB shall operate and interrupt the fault, thereby reducing the extent of damage. Although the use of a mitigation device adds to the overall cost of the project, it becomes an indispensable tool for handling such arc flash events, which may end up becoming a catastrophic event, leading to disruption of business and associated monetary loss as well.

5. Case-Study

Internal arc design and testing of LV switchgear and control gear assembly for 85kA, 0.5s at 415V as per IEC TR 61641. To comply with our switchgear assembly to IEC TR 61641, the following process flow was adopted:

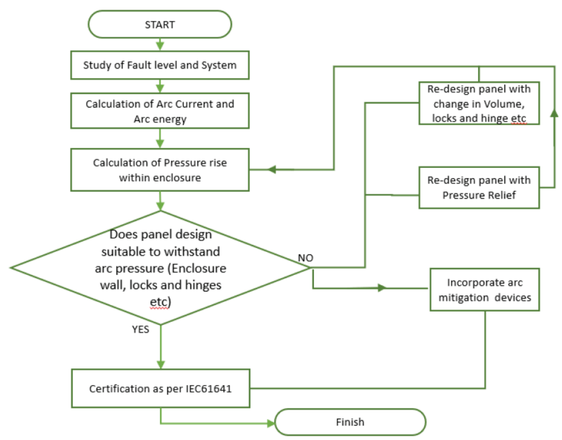

Figure 6. Process flow: Internal arc fault compliance.

Internal arc is a very uncertain and complex phenomenon which cannot be accurately predicted. However, a mathematical approach can be made to understand its effect. Most of the electrical arc energy gets converted into tremendous pressure inside the enclosure which can expressed:

$$dP = \frac{(K_{ad} \times K_p \times P_{el} \times dt)}{Vol}$$

where Kad = adiabatic constants, Kp = energy transfer Co-efficient,

Pel = Electrical Arc Power, dt= arc durationVol= Volume of the enclosure

Pel = Electrical Arc Power which is the productof arc voltage and arc current

Pressure rise for the given volume is compared for different fault levels as shown in Figure 7

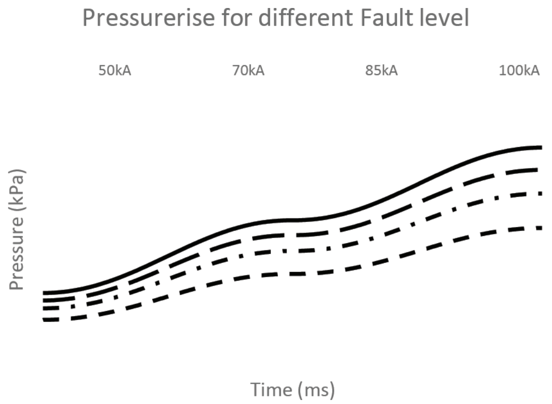

Figure 7. Pressure rises for different fault levels.

Now, considering the pressure rise-time characteristics for 85kA, 415V, as shown below in Figure 8. P2 is calculated to pressure rise in the enclosure for 85kA for the arcing duration of t2. This P2 was compared with the maximum pressure withstand capacity of locks i.e. P1 having tensile strength of 60-70kgf. This was found inadequate to withstand the pressure generated in the panel due to 85kA.

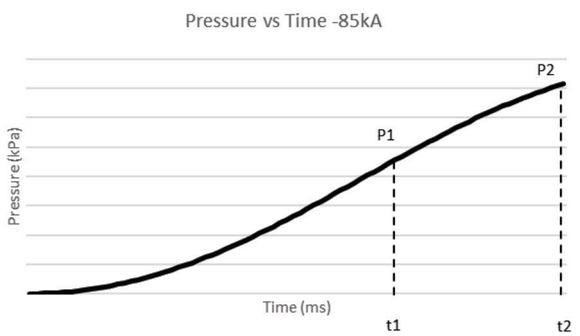

Figure 8. Pressure rise vs time for 85kA internal arc fault.

Therefore, a new lock was designed with an improved tensile strength of 120-140kgf.

To comply with the IEC61641 and to limit the effect of hot gases due to arcing, the pressure generated due to arcing should be released from the enclosure as fast as possible i.e. within a fraction of a second. This can be possible with the use of a pressure relief mechanism.

The design of pressure relief was done considering the following factors:

1. Weight of the flap
2. The backpressure required to open the flap must be less than P1, which will release the pressure before it impacts the locks and hinges, avoiding the possibility of any cracks in the locks and hinges
3. Location of flaps

By using pressure relief, pressure rise within the panel has been reduced to a large extent and the same is shown below.

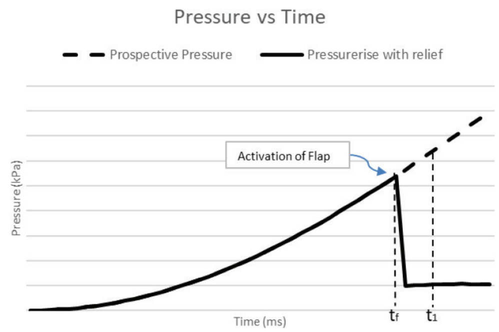

Figure 9. Pressure rise vs time for 85kA with pressure relief.

With the help of the above process flow and after performing the necessary calculations, other specifications/ features were incorporated into the design:

1. Form 4b internal separation to restrict the arc effects within the compartment.

Figure 10. Form 4b separation.

2. Higher than 25mm clearance between live parts to reduce arcing current.
3. Sleeved busbars

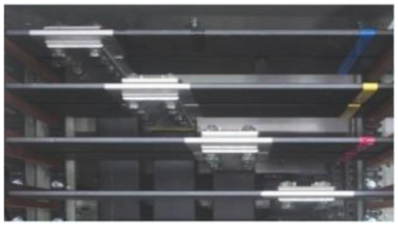

Figure 11. Sleeved busbars with > 25mm clearance.

4. High-strength metallic locks and door hinges.

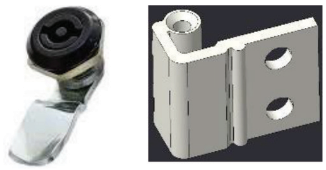

Figure 12. High-strength locks and hinges.

5. Adequate Flap opening area located centrally on the top plate.

In addition to accommodating the above design features, a detailed DFMEA and FTA were performed before the test to understand and counteract any probable failures.

No arc fault relay was used in this case.

A typical result sample obtained during one of the test shots is depicted below:

Test	Current				Recovery Voltage	
	Let – through kA peak	Duration of burning (t_b) ms.	Joule Integral $A^2s \times 10^3$	Arc Energy kJ	Per Phase V rms	Average Between Phases V rms
Internal Fault (Repetition)	18.347 37.313 22.323	10.49 8.207 6.408	1052 4315 1523	1046 4021 1232	252.2 252.2 252.1	436.8
Observations during test						
No visible disturbance						
Pressure release flap operated.						

Figure 13(a). Arcing current, duration and energy during 85kA, 0.5s test.

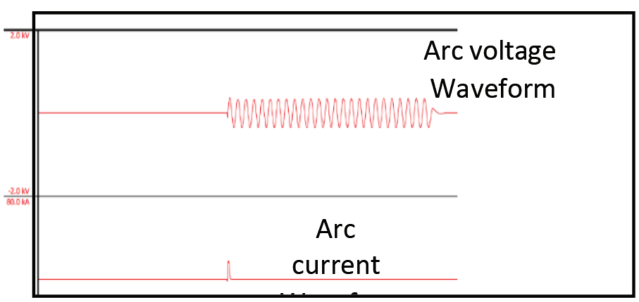

Figure 13(b). Arcing current and voltage waveform.

As per IEC 61641, if the arc is self-extinguished in less than half the intended set duration, the same test is repeated. If in case it again extinguishes within the first half duration, the test is deemed as passed, while satisfying the following passing criteria laid out in IEC 61641:

1. Correctly secured doors and covers do not open. Minimum IP1X protection to be maintained.
2. No parts of the ASSEMBLY are ejected which have a mass of more than 60g.
3. Arcing does not cause holes to develop in the external parts of the enclosure.
4. The indicators do not ignite.

Figure 14. Internal arc test set up with indicators.

1. The protective circuit should remain effective.
2. The ASSEMBLY is capable of confining the arc to the area where it was initiated. Effects of hot gases and sooting to adjacent units other than the unit are acceptable.
3. Capable of emergency operation i.e. verification by a dielectric test with a test voltage of 1,5 times the rated operational voltage for 1 minute.

In this case, the arc was self-extinguished at around 10ms. The initial pressure built up was released by the spring-loaded flaps, while the inherent design features helped in the quick quenching of the arc.

The assembly passed the internal arc test with arcing class 'C' (satisfying all 7 criteria) for an internal arc fault rating of 85kA and duration of 0.5s.

6. Conclusion

In conclusion, we can say that even though arc fault testing is not a mandatory test for an IEC 61439-certified assembly, it is imperative to provide emphasis on the internal arc risk mitigation techniques discussed above. This will ensure robust, reliable and most importantly safe operation of the assembly. Using risk mitigation methods like FMEA and FTA is an indispensable part of the entire process. Additionally, creating robust designs, performing arc flash pressure rise calculations and using arc mitigation devices like arc fault relays will also boost the safety of the assembly and prevent the arc from causing extensive damage to life and property.

When it comes to internal arc risk mitigation, there is no one tool to overcome the risk. Instead, a combination of multiple tools and processes can help provide a holistic view of the challenges involved. This can help in successfully mitigating that risk and creating a safe working environment for the end-user.

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