1. INTRODUCTION

Commercial pressures are increasing on organisations to maximise their plant utilisation, improve network performance and reduce their plant lifetime costs. Owners, Asset Managers and Operators of today’s electricity distribution networks face increasing challenges in health & safety as these demands for improved network performance and reduced operating costs grow. This is usually against the backdrop of a network where the age profile of installed plant is steadily worsening, sometimes approaching or exceeding the equipment in-service design life. This is further compounded by the fact that, in many organisations the available skilled resource to work on the switchgear has also been depleted in recent years.

Further, elderly switchgear was designed at a time when the standards did not recognise or acknowledge the risks or consequences of an internal arc fault and it was therefore not designed to withstand this type of fault.

An internal arc fault is essentially when there is a short-circuit or flashover inside the switchboard, resulting in an explosive release of energy in a very short time interval. This type of failure is significantly more dangerous when the switchgear is using mineral oil as a means of insulation and/or arc interruption, as is the case with most elderly distribution switchgear.

Modern switchgear is usually viewed as being safer than old switchgear, in that it must be designed and tested to comply with the latest standards for safety which now take into account the possibility of internal arc faults. The latest 62271-200 standard is very specific in that it requires switchgear to be designed and tested to withstand internal arc faults of a specific level and duration and protect operators on designated sides of the switchgear.

This paper highlights the issues in managing elderly oil-filled switchgear and explains the modes and consequences of failure of this equipment. It explains what happens when a ‘flashover’ occurs inside a switchboard and shows how the experiences of designing and testing switchgear to the latest standard for internal arc withstand can be successfully applied to existing switchboards to bring them in line with the latest requirements for internal arc safety.
2. SWITCHGEAR FUNCTION

To fully understand the risks and consequences of switchgear failure it is important to clarify what it does. The function of switchgear on any electricity distribution network is very important to ensure that energy can be safely distributed to the loads and that the required level of network protection and control is assured. This functionality must be maintained both for normal system operation and for situations where equipment failure or human intervention has resulted in a short circuit fault releasing a considerable amount of energy in a very short time.

Listed below are the key functional requirements for switchgear. (Circuit Breakers)

- To make and break normal load currents.
- To operate continuously up to the normal rating of the switchgear.
- To withstand the passage of ‘through fault’ current for sufficient time to allow the downstream protection to operate.
- To safely switch on to fault, handling the energies involved,
- To safely interrupt fault current thereby removing the faulted equipment from the source of electrical supply.
- To be a Point of Isolation and Earthing for work to be done,

Switchgear must not only be designed and certified to ensure that it is capable of fulfilling this function; it must also be maintained in good condition. Should the switchgear fail to fulfill one or more of the above functions this can result in an internal arc fault on the switchboard, which can be particularly dangerous if the switchgear is using mineral oil as either an interrupting or insulating medium.

3. OIL-FILLED SWITCHGEAR,

The use of oil as an insulating and arc extinguishing medium in high voltage switchgear has been employed since the earliest switchgear was designed at the end of the 19th century. It has been extensively developed over the past 100 years and generally has a proven record of reliability and performance. There are however, significant risks associated with the use of oil in electrical switchgear and these range from environmental to operational to financial and not least, safety.

It is important to recognise that, because of the energies involved, failure of an oil switch to work correctly, particularly under short circuit fault conditions can lead to a catastrophic explosion and subsequent oil fire.

FAILURES ARE RARE, BUT WHERE THEY INVOLVE THE IGNITION OF OIL THE RESULTS ARE USUALLY CATASTROPHIC.

An ignition of the oil often results in a rupture of the switch oil chamber, resulting in the ejection of burning oil and gas clouds, causing death or serious injury to persons and major damage to plant and buildings in the vicinity of the failed equipment.
It is important to note that modern day arc flash protective clothing would not necessarily provide safety for the operator in the event of a switchgear fault resulting in the explosive ignition of oil and the resultant fire.

**FIG. 1**  RECENT FAILURE OF 11kV OIL SWITCHGEAR

One oil circuit breaker failed to operate correctly resulting in explosions and oil fires that consumed the entire 11kv substation and two adjacent Grid Transformers.

View of substation and Grid Transformers ablaze, shortly after the switchgear fault

View of interior of 11kv substation showing the 11kv switch-room after the resultant oil fire had been extinguished.
4. LEGISLATION

Each country has its own set of Laws, Regulations and Health & Safety Legislation, but in most countries it is a legal requirement for all owners and operators of electrical equipment to ensure that it is properly operated and maintained so as to prevent danger. The way in which this is achieved is by following the Regulations to comply with the Acts of Law. (see below)

In the United Kingdom for example, the Health and Safety at Work Act, the Management of Health and Safety at Work Regulations and the Electricity at Work Regulations apply. The HSAW Act contains requirements to the effect that anyone employing people should ensure their safety so far as is reasonably practicable. The Management Regulations require an employer (or self-employed person) to make an assessment of risks to employees or others, taking specialist advice where necessary. The level of detail in the assessment should be broadly proportionate to the risk, which means it needs to be fairly detailed in the case of oil-filled switchgear as the risk is one of death.

The EAW Regulations and the Provision & Use of Work Equipment Regulations, (PUWER), require electrical equipment for use at work to be constructed, maintained and operated in such a way as to prevent danger so far as is reasonably practicable. Equipment should also not be used where its strength and capability may be exceeded and it should be protected from excess.

FIG. 2  SAFETY AT WORK & THE LAW

With the increasing focus on the environment and safety and the increasing risk that elderly, (oil-filled) switchgear poses, it is likely that there will be initiatives put in place during the next few years by regulatory authorities, to remove this type of switchgear from electricity supply networks. Many proactive organisations already have these programmes in place.
5. RISK FACTORS WITH ELDERLY (oil–filled) SWITCHGEAR

Experience has shown that the ownership and operation of elderly high voltage switchgear often presents a number of factors that can increase the risk of ‘ownership’ and therefore contribute towards the potential failure of that equipment.

These factors include:

- Lack of knowledge of the equipment
- Network changes resulting in the switchgear being overstressed under certain operational conditions,
- Not being modified as per manufacturer's advice
- Having dependent manual operating switchgear, i.e. where the movement of the contacts is directly dependent on the movement of the handle by the operator
- Not being maintained or operated properly
- Being fitted with operating handles that are not anti-reflex type (high-voltage oil-switches and isolators only).
- Spares & Technical Support not being available for the switchgear

When a failure occurs in an 11kV switchboard that results in a breakdown of the insulation or a ‘flashover’, an arc is struck that increases the temperature at the point of fault to as much as 20,000°C in less than 50ms. This results in an explosive over-pressure that can be very dangerous for operators, particularly if the failure has occurred inside or adjacent to an oil-filled chamber on the switchboard.

5.1 LACK OF KNOWLEDGE,

Switchgear is usually operated by trained staff often known as "Authorised Persons ". In the past these were generally works electrical engineers or supervisors but due to changing employment patterns this is often no longer the case. Some organisations may not have any "Authorised Persons" on their staff and may have chosen to contract out all operational work and maintenance of their switchgear.

As a result there may be no one in the organisation who fully understands the equipment, its construction and safe operation (particularly when it is the dependent manually-operated type) and either the need for maintenance or the correct maintenance procedures.

5.2 OVERSTRESSING OF SWITCHGEAR

Switchgear is described as being 'overstressed' when the fault energy of the electrical system at the switchgear location (i.e. from a short-circuit fault), exceeds the fault energy rating of the switchgear. This could be either the short circuit withstand rating of the switchgear, or the make & break duty rating of the switchgear.

Particularly when oil switchgear is operated under fault conditions that are in excess of its rating envelope, it may be unable to cope with the resulting electrical, thermal and electro-magnetic stresses and this can lead to a catastrophic failure.
Such failures with oil-filled switchgear are invariably accompanied by a rapid release of energy and subsequent rupture of the oil tank, burning gas clouds and oil mist that envelop anyone near the switchgear and these have usually resulted in death or serious burn injuries.

Where the fault rating of the switchgear is less than the system potential fault energy levels, the following action should be taken immediately, regardless of the type of operating mechanism:

(a) Reduce the fault energy levels, if possible, for example:- operating transformers as single feeders to switchboards and not in parallel with other transformers. This will invariably result in a less secure network, where larger sections may be isolated following a cable fault. These changes should be made as soon as possible to reduce the fault energy level to as low as practicable. -- If this can't be done then...

(b) Prohibit all live operation and disable automatic tripping of the switchgear. This action will necessitate re-adjustment of electrical protection further back towards the source of supply in order that the electrical protection at the switchgear can be made non-operative. The re-adjustment is needed to ensure adequate levels of electrical protection for the system.

(c) Prevent access by persons to the switchgear whilst it is live.

(d) The switchgear should only be maintained with the switchboard de-energised and in accordance with manufacturer’s advice by trained personnel. Particular attention should be paid to insulating oil, solid insulation, contact assemblies, operating mechanisms, seals and gaskets, as applicable.

(e) Longer-term measures that can be taken to reduce fault energy levels include fitting reactors or network re-configuration. These measures may be used to reduce fault energy levels to values less than the fault energy ratings of switchgear. Such actions are normally only a solution for high-voltage installations. It should be noted these measures will not overcome the problems associated with switchgear that has no fault energy rating.

Where the actions (a) and/or (e) above reduce the fault energy levels below the rating of the switchgear then electrical protection and live operation can be restored, after necessary measures (e.g. interlocks) have been provided to prevent the rating being exceeded at any time. In addition to these immediate actions, arrangements should be made to replace the overstressed switchgear as soon as possible.

This does not necessarily mean that the entire switchboard has to be replaced. In some cases, for example with the Reyrolle type LMT oil switchgear, a higher fault rating for the switchboard can be easily achieved by replacing the oil circuit breakers, i.e. Retrofitting the circuit breakers with RPS Switchgear’s Vacuum units.

5.3 SWITCHGEAR REVISION STATUS

Manufacturers and other operational bodies may have, over the years, issued improvement notices covering details of modifications or upgrades to existing equipment, which should be carried out on oil-filled switchgear to ensure that the switchgear is to the latest standard..

However, in most cases, owners or operators are unaware of the need to carry out these modifications. As a result the equipment may be incapable of performing its duty satisfactorily.
5.4 DEPENDENT MANUALLY-OPERATED SWITCHGEAR (DMO)

The operating mechanisms of most switchgear, i.e. independent manual, dependent power, independent power and stored energy, do not, in themselves result in any particular risks.

However where switchgear is dependent manually operated (DMO), the operator closes or opens the switchgear by moving a lever or handle by hand. DMO levers/handles are fitted to both medium and low-voltage switchgear. These types of operating mechanism are particularly dangerous as the movement of the contacts is totally dependent upon the speed and actions of the person operating the levers/handles.

Any hesitancy on the part of the operator is likely to lead to a serious and potentially fatal failure of the switchgear, e.g. operators may not realise that they have failed to close the circuit breaker completely, and release the operating lever/handle thus drawing an arc within the oil tank which can result in catastrophic failure.

5.5 INADEQUATE MAINTENANCE

It is not unusual to find that elderly oil-filled switchgear has been neglected, due to the largely quiescent nature of its duty and because of the factors mentioned earlier.

Routine servicing such as oil changing, lubrication, contact refurbishment and verification of contact engagement has often not been carried out for many years. Deterioration due to corrosion and moisture ingress may also have occurred.

This is usually the result of maintenance budget limitations, oversight, lack of knowledge of the equipment, or pressures to keep the equipment, and hence the plant, in operation. In many cases the expertise in handling and maintenance techniques for insulating oil is lacking.

Where oil-filled switchgear has been neglected, it is difficult for owners & operators to assess the actual fault capability of the switchgear in the state in which it is found.

In on-site evaluation tests carried out by Reyrolle on elderly oil switchgear, it was found that on more than 50% of oil switchgear thought to be in good condition, the circuit breakers had faults or were operating outside of their design envelope and in some cases would have failed to operate correctly under system fault conditions.
6. DESIGNING FOR INTERNAL ARC WITHSTAND SAFETY,

It must be acknowledged that the chance of an internal arc fault occurring on well designed switchgear is extremely low, particularly when the primary conductors in the bus-bar, current transformer and cable box chambers are totally encapsulated as with the RPS range of LMVP switchgear.

However, the latest standard 62271-200, requires that design of switchgear must be able to withstand and safely vent an internal arc to ensure safety for personnel in the vicinity of the switchboard. Therefore special attention must be paid in the design to the strength of all chambers, strength and fixing of doors, the control of the arc, the design of venting arrangements and operational interfaces The latest standard is more exacting than the earlier IEC298 standard, it focuses on operator safety and it requires the switchgear to meet specific requirements that **must** be complied with for the equipment to be classed as certified.

<table>
<thead>
<tr>
<th>TESTING INTERNAL ARC TO IEC 60298</th>
<th>TESTING INTERNAL ARC TO IEC 62271-200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of test conditions by agreement between Manufacturer and Operator</td>
<td>Test according to defined conditions of the standard, must be complied with.</td>
</tr>
<tr>
<td>Any room height, distances</td>
<td>Defined test arrangement, room height &amp; distances</td>
</tr>
<tr>
<td>Any points for arc initiation</td>
<td>Defined points for arc initiation</td>
</tr>
<tr>
<td>Defined acceptance criteria can be applied</td>
<td>Defined acceptance criteria <strong>must</strong> be applied</td>
</tr>
<tr>
<td>Feeding directions freely selectable</td>
<td>Defined fault feeding direction</td>
</tr>
<tr>
<td>Description of test results</td>
<td>Test passed / not passed</td>
</tr>
</tbody>
</table>

6.1 PPE AND INTERNAL ARC SAFETY

It should be noted that the standard acknowledges the use of additional protective devices such as high-speed arc protection, the application of personal protective equipment, the provision of information/training to users and the use of remote racking/operation as being methods of reducing the risk. These should not be used however, as substitutes for good design, type certification and compliance with the standards.

For new equipment, through the specification and design of internal arc classified switchgear, where the energy and emissions resulting from and internal arc are safely contained and then suitably vented away from personnel in the vicinity, ‘safe working’ for switchgear operation and presence in the vicinity of the switchgear can be effectively managed without the need for excessive PPE.
6.2 THE FOUR PHASES OF AN INTERNAL ARC FAULT

To design switchgear that is capable of safely dealing with an Internal Arc Fault, it is important to understand what happens when a fault occurs. An arc fault is usually caused by the failure of the switchboard insulation systems or the failure of a circuit breaker to interrupt the flow of current. This results in an extremely dynamic situation involving many thousands of amps with an explosive release of energy in a very short space of time.

The duration of say, a 1 second internal arc fault can be subdivided into four distinct phases:-

PHASE 1:- COMPRESSION.

This phase begins when the arc ignites and ends when the maximum pressure in the faulted compartment is reached. The air in the ‘enclosed’ compartment will be heated depending on the level of arc energy. Because the pressure relief devices are closed initially, the pressure in the compartment raises directly proportional to the arc fault current and the length of the arc, (arc voltage) and indirectly proportional to the volume of the chamber in which the fault occurs. The duration of this compression phase and the maximum pressure reached depends on arc energy (arc fault current and arc voltage), the volume of the faulted chamber and also other factors such as the arc position, the design of the pressure relief vents and also any air circulation openings in the chamber.

PHASE 2:- EXPANSION.

The second phase is when maximum pressure peak is reached and the pressure relief system operates to relieve the pressure. In this phase on the RPS switchgear design, the compressed plasma/gas is ejected from the faulted chamber through specially designed non-return venting devices into an intermediate expansion volume on top of the switchboard.

PHASE 3:- EMISSION.

In this phase the air in the chamber will be heated further and ejected via the open pressure relief flaps. In this stage the remaining air in the compartment will reach the arc temperature. In this stage almost all of the air in the compartment is expelled.

PHASE 4:- THERMAL OR ‘BURN-THROUGH’

The fourth phase will obviously last up to the end of arc current duration. In this stage the many thousands of degrees of the arc energy is concentrated on the materials inside the faulted compartment. This is the phase which is commonly known as ‘burn-through’ where conductors, switching devices, metal parts of the enclosure as well as any insulating materials will be melted and vapourised. The damage caused in this phase will be proportional to the length of time the protection takes to clear the fault, the level of arc fault current and the thermal characteristic of material used in the switchgear construction, such as Aluminium which will produce an exothermic reaction, adding to the energy and the subsequent damage.

The Compression & Expansion phases occur within the first 10-20ms of the fault inception.
PASSING THE INTERNAL ARC WITHSTAND TEST

To achieve certification the switchgear panels are tested at an accredited Test Station. The panels are inserted into a Test Cell which surrounds the switchgear on three sides. Indicator panels that contain cotton pads are then placed around the switchgear vertically at a distance of 300mm from the sides of the switchgear and also horizontally at a height of 2m on all tested sides.

The criteria for successfully passing the tests are:- (extract from EN 62271-200)

**Criterion No. 1**

Correctly secured doors and covers do not open. Deformations are accepted, provided that no part comes as far as the position of the indicators or the walls (whichever is the closest) in every side. The switchgear and controlgear do not need to comply with its IP code after the test.

**Criterion No. 2**

– No fragmentation of the enclosure occurs within the time specified for the test.
– Projections of small parts, up to an individual mass of 60 g, are accepted.

**Criterion No. 3**

Arcing does not cause holes in the accessible sides up to a height of 2 m.

**Criterion No. 4**

Indicators do not ignite due to the effect of hot gases. Should they start to burn during the test, the assessment criterion may be regarded as having been met, if proof is established of the fact that the ignition was caused by glowing particles rather than hot gases. Pictures taken by high-speed cameras, video or any other suitable means can be used by the test laboratory to establish evidence. Indicators ignited as a result of paint or stickers burning are also excluded.

**Criterion No. 5**

The enclosure remains connected to its earthing point. Visual inspection is generally sufficient to assess compliance. In case of doubt, the continuity of the earthing connection shall be checked (refer to 6.6, point b)).
6.3 CERTIFICATION FOR INTERNAL ARC FAULT

RPS Switchgear has certified its LMVP switchgear product for IAW to 62271-200 and this can be provided in any of the following A-FLR, 25kA, 1s solutions to suit customers specific site safety requirements:-

1. Internal Arc by-products can be safely ducted out of the switch-room in any direction, without using any temperature control.

2. Internal Arc by-products can be safely ducted out of the switch-room in any direction at a much reduced temperature, using our unique temperature control unit, (TCU). This can reduce the exhaust outlet by as much as 1,000°C.

3. For situations where it is not possible or practical to duct outside the switch-room, the Internal Arc by-products can be safely ducted into the switch-room in any direction at a much reduced temperature, using our unique temperature control unit, (TCU). This can reduce the exhaust outlet into the room by as much as 1,000°C.

All the above solutions are available with substation roof heights down to 2.8m.

The drawing below shows the arrangement of RPS’s latest 62271-200 Internal Arc certified switchgear. (Single panel shown)

FIG. 3 RPS’s INTERNAL ARC CERTIFIED SWITCHGEAR
During the testing the temperatures and pressures within the various compartments of the switchboard were measured to evaluate the internal arc withstand design and the temperatures were monitored at various positions around the switchgear where an operator might stand. These temperatures were used to verify the temperature profile around the switchboard during the internal faults and further demonstrate the effectiveness of the internal arc design. The illustration below shows the 4 x panel switchboard that was tested in both the Ducted version and also in the Vented version, fitted with a Temperature Control Unit. The maximum temperatures recorded around the switchgear are also shown for each of the configurations tested.

**FIG. 4(a) TEMPERATURE PROFILE FOR DUCTED ARC CONTAINMENT**
(25kA, 1s Internal Arc Fault Test, A-FLR Ducted out of Switchroom)

**FIG. 4(b) TEMPERATURE PROFILE FOR VENTED ARC CONTAINMENT**
(25kA, 1s Internal Arc Fault Test, A-FLR Vented into Switchroom)
7. **CB RETROFIT & INTERNAL ARC SAFETY ENHANCEMENTS FOR EXISTING SWITCHBOARDS.**

7.1 **OIL CIRCUIT BREAKER REPLACEMENT**

It is not always practical or cost effective to completely replace the entire switchboard. One very effective, proven alternative option for the replacement of elderly oil-filled switchgear is to replace only the oil-filled circuit breaker trucks with modern vacuum equivalent units. This removes the oil from the switchboard and, as previously discussed, provides a significant increase in safety and reliability.

This process is known as ‘Retrofit’ and, because only the circuit breaker is being changed, the implementation does not involve any lengthy outages or work on the high voltage cables which would be the case of course if the entire switchboard was being replaced. The principle of switchgear Retrofit was developed many years ago and became very popular and universally accepted in the last two decades of the 20th century.

The important aspect of Retrofit is that it replaces only the ‘dynamic’ parts of the switchboard, i.e. the parts that wear out. R.P.S. Switchgear has been replacing the Reyrolle LMT oil circuit breakers with their vacuum truck for almost 40 years now, with more than 5,000 units in service worldwide.

(Retrofit has also been designed for the E Mail ‘J’ Series switchgear and more than 400 of these units have been completed to date.)

The advantages of a properly designed Switchgear Retrofit as an asset replacement option are listed below:-

- The RPS switchgear vacuum truck is a direct replacement, with all critical dimensions and operational features being the same as the original LMT breakers. This not only ensures that the retrofit circuit breaker will be an ‘easy fit’, it also minimises operator training.

- Usually only an individual circuit outage is required to complete the work, (busbars remain ‘live’)

- Full SCADA capability is achieved with the switchgear by retrofitting,

- The removal of oil significantly improves safety in the substation as previously discussed,

- Less than 1 day per circuit is required to complete the work, therefore minimal system disruption & minimal involvement is required by customers site staff

- Retrofitting can allow the Short Circuit Withstand Rating of switchboard to be increased. Typically the rating of an existing switchboard can be increased from 250MVA to 500MVA. (Type Certification evidence is available from RPS to support this)

- Retrofitting replaces the Oil Circuit Breaker with long life, low maintenance unit. Maintenance costs are reduced and the switching performance of the new vacuum circuit breaker is significantly better than the original oil breaker, (20,000 normal operations & up to 100 fault clearances.)
• The replacement VCB uses either the existing secondary isolating contacts or a new high integrity plug & socket connection,

• Retrofit is very cost effective compared with Switchboard replacement when the total cost of switchboard replacement is considered, often less than 25% of the cost of replacing the entire switchboard.

**FIG. 5(a). R.P.S. VACUUM RETROFIT CIRCUIT BREAKERS INSTALLED IN REYROLLE LMT SWITCHGEAR**

**FIG. 5(b). R.P.S. VACUUM RETROFIT CIRCUIT BREAKERS INSTALLED IN E-MAIL ‘J’ SERIES SWITCHGEAR**
7.2 SAFETY IMPROVEMENTS IN EXISTING SUBSTATIONS

Removing the oil-filled circuit breakers is the first, very important step that will significantly improve safety in the substation. However, there are further improvements that can easily be applied to the existing Reyrolle LM type switchboards. RPS has used its experiences of designing its fully certified 62271-200 switchgear to apply retrofit modifications to existing switchboards. These modifications provide additional operator safety by upgrading the switchgear fixed portions towards the latest standards for Internal Arc withstand. (62271-200). They also provide a greater degree of protection for the operator when racking the switchgear into or out of the 'Service' position.

When the original LMT switchgear was designed by Reyrolle, there was no requirement or standard for switchgear Internal Arc withstand, so these switchboards are not equipped with any internal arc pressure relief or arc containment. In the event of a failure of the high voltage insulation or other fault leading to the inception of an arc, the operator would not be protected.

RPS Switchgear, (formerly Reyrolle), now offer the following safety improvements that can be easily retrofitted to existing Reyrolle LMT switchgear:-

- The existing LMT cubicle doors can be replaced with 25kA, 1 sec. Arc-proof front doors. The doors are the same units as used on the certified LMVP range. They strengthen the front of the existing switchboard and extend the existing cubicle forwards to allow the cubicle door to be closed when the breaker is in the ‘Bus-bar Earth’ position, which is not possible with the existing switchboard. (See below)

- These doors are equipped with a feature that allows the operator to rack the breaker into and out-of service and manually Open & Close the breaker through the arc-proof door. The operator therefore remains protected during these key operations. (See below)

- Removable ‘blast shields’ can be fitted to each end of the existing switchboard to ensure safety at the ends of the switchgear,

FIG. 6. ARC-PROOF FRONT DOOR KITS FITTED TO LMT SWITCHGEAR CUBICLES
The above features offer operator safety to the latest standards at the front of the switchboard for a 25kA, 1s internal arc fault within the circuit breaker compartment. The operator can carry out all racking operations and opening & closing operations from in front of a certified arc-proof front door.

In addition to the above the experiences of vent flap design and common expansion chambers learned on our new switchgear can also now be applied to existing LMT switchboards to bring them up to the latest safety standard with respect to Internal Arc withstand.

- The existing bus-bar chamber & current transformer chamber covers can be replaced with ‘pressure relief’ covers, allowing these chambers to vent safely to the rear of the switchboard,
- A ‘containment & deflector’ system can be fitted to the top of the switchboard to further ensure safety for the operator at the front and sides of the switchboard should an internal arc-fault occur,

**FIG. 7. LMT SWITCHGEAR FITTED WITH 3-SIDED ARC WITHSTAND KIT**

The pictures below show a 3 panel LMT switchboard that has been retrofitted with LMVP Vacuum Circuit Breakers being subjected to internal arc withstand tests. These tests verified that 3 sided safety can be achieved for an internal arc fault in any chamber on the existing switchboard with a substation ceiling height down to as low as 2.8m.
8. CONCLUSION

The increasing risks of ownership of ageing, (oil-filled) switchgear should not be ignored. The quiescent operating regime of most switchgear often makes the assessment of the true condition of the equipment difficult, but to perform its most important functions switchgear must be able to operate under short circuit conditions at the top of its design envelope. The chances of an internal arc failure are thankfully very small, but the consequences of such a failure are disproportionately high due to the energies involved and, as the age of the circuit breaker and its insulation and arc-interrupting systems approach the end of their design life the chances of such a failure will increase.

This paper concludes that the experiences of designing new switchgear to the latest arc-withstand standard can be successfully applied to existing switchboards to bring them in line with the latest safety requirements. Significant safety improvements can now be made by retrofitting key components to existing oil-filled switchboards to bring them in line with the latest 62271-200 standard for internal arc withstand safety, without having to implement costly switchboard replacement strategies.

9. ACKNOWLEDGEMENTS

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HSG230 -- Health & Safety Executive Guidance -- “Keeping electrical switchgear safe”