

Condition Monitoring in Low Voltage Circuit Breaker Technology

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Keywords: condition, temperature, monitoring, circuit breaker, maintenance

Abstract

Overheating is the single biggest cause of failure in switchgear. Modern circuit protection is provided by digital overcurrent relays which are operated by current, not heat so abnormal heating caused by loose connection bolts, ventilation failure or worn contacts is usually left undetected by conventional circuit breakers. This can lead to pre-mature failure of switchgear and also constitutes a potential fire hazard. Thermal imaging can help prevent this but is only valid for that 'snapshot' in time. Continuous condition monitoring of the temperature of switchgear can substantially minimise down time of the installation and reduce the risk of fire.

1 Introduction

The overcurrent protection system used in low voltage distribution (lower than 1000v ac rms) often plays 'second fiddle' to its bigger relations in medium and high voltage networks.

However in terms of volume of protection devices it is one of the largest areas and if problems were to occur, the impact to the customer is the greatest.

Two of the important protective devices utilised to protect modern low voltage distribution systems is the Moulded Case Circuit Breaker (MCCB) and Air Circuit Breaker (ACB)

Similar to other types of protection, these two areas have evolved to utilise microprocessors for overcurrent protection and all the well-known benefits that these provide.

Overheating of circuit breakers can cause fire or explosion by igniting flammable materials. This can cause death, injury and considerable financial loss as documented by the Health and Safety Executive (HSE) [1].

If a circuit breaker was to 'over-heat' due to a loose connection, contact erosion or ventilation issues the traditional thermal magnetic circuit breaker would self-protect itself and the installation.

However microprocessor based circuit breakers detect "current not heat" so the situation can arise where the load current is well within an acceptable threshold but an overheating situation can still occur resulting in a potential fire hazard.

Recent developments within microprocessor circuit breakers provide the option of monitoring the temperature of the contacts or terminals, continuously.

If an abnormal condition was to occur this information can be communicated to the Building Management System (BMS) to allow the facility manager, to plan for preventative maintenance before a critical power outage or even a fire hazard was to occur.

Over the past decade the use of thermal imaging has helped greatly in this respect, however this only provides a "snap shot" in time and does not protect the low voltage distribution system 24/7.

The demand of critical installation such as data-centres, demand maximum power availability and minimum downtime.

This paper will explain in detail the technology used, real life applications and end user benefits gained from the introduction of such technology in low voltage switchgear.

The paper will also reference several case studies to illustrate the potential problems that have occurred and the solutions now available to improve the overcurrent protection model in low voltage distribution.

2 Maintenance

It is widely accepted by all switchgear manufacturers that overheating is one of the greatest risks that could result in premature ageing of switchgear, thus reducing the average Mean Time Between Failure (M.T.B.F.). At worst it can constitute a potential fire hazard, for both the circuit breaker and installation itself.

Circuit breakers can be installed for many years, with often little or no maintenance compared to other equipment in low voltage distribution.

The lack of maintenance is usually the result of oversight, lack of knowledge of the equipment or pressures to avoid

plant shutdowns. Whatever the situation it will lead to a situation where switchgear has been neglected (this is particularly true of low voltage devices, according to the Health & Safety Executive).

The result is that routine servicing such as contact refurbishment and verification of contact engagement may not have been carried out for many years and deterioration due to corrosion may also have occurred [2].

After the transformer the incoming circuit breaker, often an Air Circuit Breaker is one of the most important pieces of equipment. It is the 'gatekeeper' to the low voltage distribution network, but often receives less attention than other building services equipment such as Lighting, HVAC (Heating Ventilation Air Conditioning) & Security. If the incoming ACB should fail then all other equipment is redundant.

If the system uses standby power through a Generator or U.P.S. (Uninterruptible Power Supply) then again it is normally the ACB that supplies this power.

Condition monitoring of circuit breakers, particularly 'incoming' circuit breakers can greatly improve the reliability of the low voltage network.

3 Circuit Breaker Design

The majority of ACBs used are draw-out type. This provides easier access to the ACB and additional isolation which maintenance procedures may require. This requires the facilities use of 'isolating contacts' for the interconnection between body and chassis.

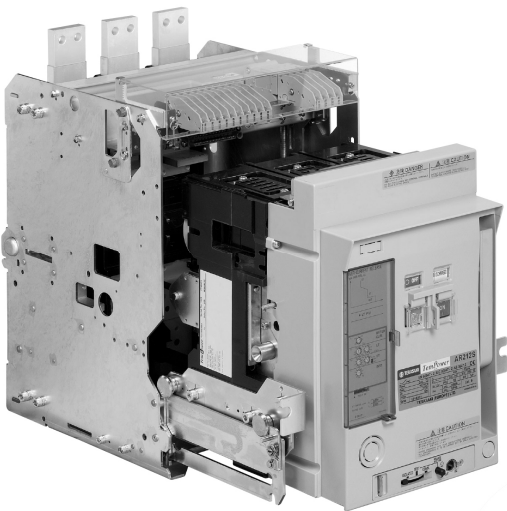


Figure 1
Draw-out ACB

As the name suggests, the interrupting medium of the ACB is air and therefore sufficient space is required between the contacts to ensure effective arc extinction. Generally, due to space requirements, the majority of ACBs use one contact break per pole to interrupt any short circuit.

However, a few modern circuit breaker manufacturers have introduced a 'DoubleBreak' contact system (figure two). This provides the opportunity to further elongate the arc to ensure even faster interruption of the short circuit.

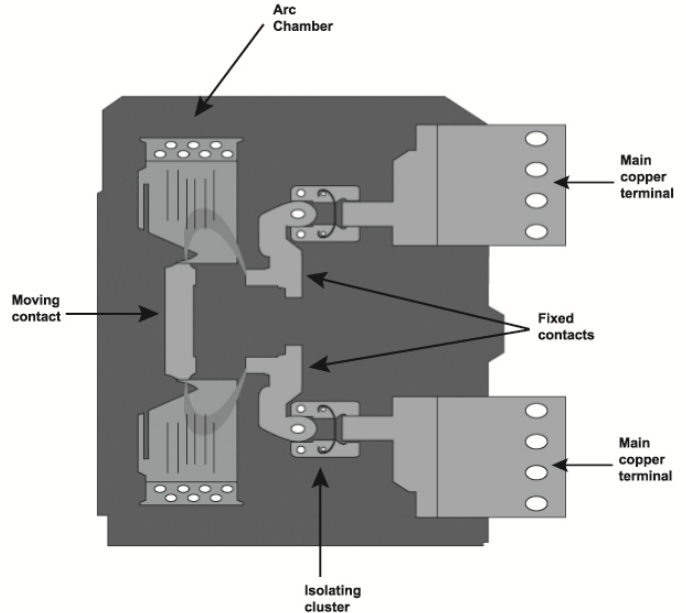


Figure 2
ACB with Double Break System

An additional benefit of this contact design is that the arc energy is 'shared' between two sets of contacts so any contact surface erosion is greatly reduced, minimising build up of contact resistance and thus increasing its operational life.

Whilst the ACB is the mechanical device that opens the contacts, the signal to do so normally comes from an integral protection relay.

Unlike Moulded Case Circuit Breakers (MCCB) that sometimes have the option of being thermal magnetic or electronic, all protection relays on ACBs are electronic/microprocessor based, due to its larger current rating.

In a thermal magnetic MCCB, the internal bimetallic element responds to the true 'r.m.s.' heating effect as a result of I^2R losses. However an electronic MCCB or ACB protection relay responds to 'current' not 'temperature'. The electronic protection devices would 'model' an inverse tripping curve proportional to the current.

It does not detect anything that would result in an over-temperature situation, while a normal load current was being applied.

4 Sources of Overheating

There are a number of sources that can contribute towards the overheating effect of any circuit breaker; all of which can occur while it is carrying its normal full load current. If left undetected, this could result in the circuit breaker having a reduced life span or at worst a fire hazard. Possible sources are:

i. Connections/Terminals

If any of the copper connections onto the main ACB terminals (Fig. 1) are not at the correct torque, this can lead to a potential hot spot in the installation. Equipment close to machinery which have reasonable vibration such as generators, pumps, motors and compressors can also lead to a situation where over a long period of time an over-temperature could result.

ii. Contacts

The fixed and moving contacts of any circuit breaker can be prone to contact erosion over a period of time, depending on the application. If for example the circuit breaker is switching an inductive load such as a motor, this will induce some localised arcing and small contact erosion. Over a number of cycles this can lead to an uneven contact surface, thus increasing contact resistance as shown at points ① in Fig. 3. If the circuit breaker has been subject to some lower magnitude faults over its lifetime, i.e. ground faults, this too can result in an increase in temperature at the contact point, which will transfer to the terminals. Pictures of new and slightly worn contacts are shown in Fig. 4 & 5 respectively.

iii. Isolating Clusters

All draw-out ACBs utilise isolator clusters, these too can be subject to contact erosion. On a fault condition, the current passes from the connections, through the clusters, then contacts.

The isolating clusters are spring loaded and are therefore subject to some degree of slight arcing that can lead to increased contact resistance, at points ② in Fig. 3.

It is not the first time where the draw out body has been replaced to reduce an overheating problem, only to discover that the over temperature was due not to the ‘contacts’ but the “isolating clusters”. Pictures of new and slightly worn isolating clusters are shown in Fig. 6 & 7 respectively.

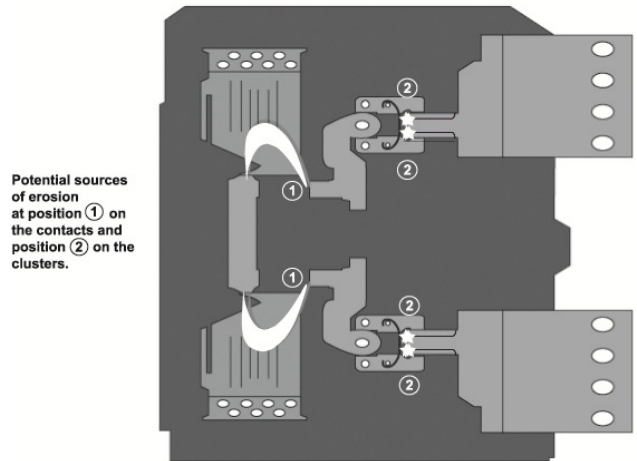


Figure 3
Potential Source of erosion

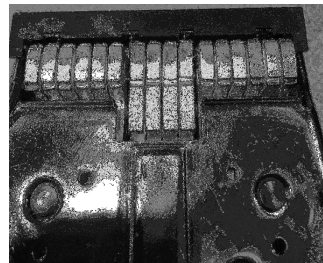


Figure 4
New Contacts

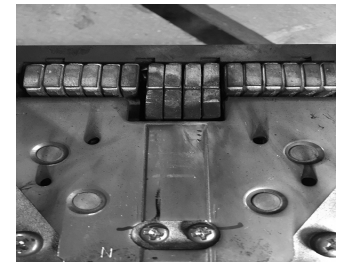


Figure 5
Contacts after earth fault

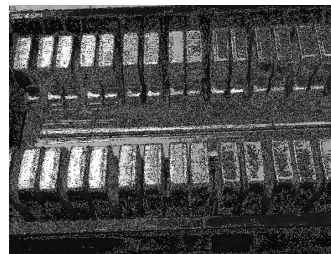


Figure 6
New Isolating cluster

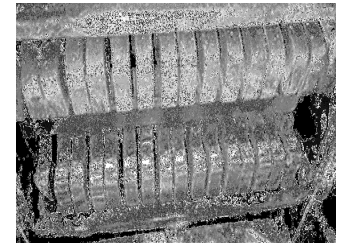


Figure 7
Cluster after earth fault

iv. Poor Ventilation

All circuit breakers are installed in switchboards and these will have some degree of ventilation if the Internal Protection (I.P.) rating is anything from IP31 to IP43. These types of switchboards would have several louvers to facilitate some degree of air flow in the enclosure. For higher IP ratings, some designs may use fans to provide forced air cooling for switchgear equipment.

If any of the small ventilation areas become ‘clogged’ with dust or even blocked this will increase the thermal stress on components. If left undetected, this will result in overheating of switchgear.

5 Thermal Imaging

Infrared Thermography is a useful technique to find problems early.

Before an electrical component burns up, it heats up. Infrared scanning of electrical components can help detect loose connections and defective equipment as part of a preventative maintenance regime, as shown in Fig. 8. In this picture the MCCB on the left is operating at a higher temperature than the device on the right.

If the switchboard is fitted with inspection windows then this non contact method of analysis is useful. However the majority of switchboards are not fitted with such facilities usually due to cost. This means in practice the door of the switchboard needs to be opened and the equipment ‘live’ and carrying current to ensure a proper reading is taken.

From a Health and Safety point of view this is regarded as working while live and therefore substantial risk assessments need to be carried out before this work can be arranged, which can cause disruption.

Another issue with thermal imaging is that it is a “snapshot” in time. If an overheating problem was to occur in between the thermal imaging period which could be anywhere from one to five years as an example, then the problem would be left undetected and may pose a potential fire hazard.

Thermal Imaging is a useful technique but does **not** provide the ideal scenario of 24/7 monitoring.

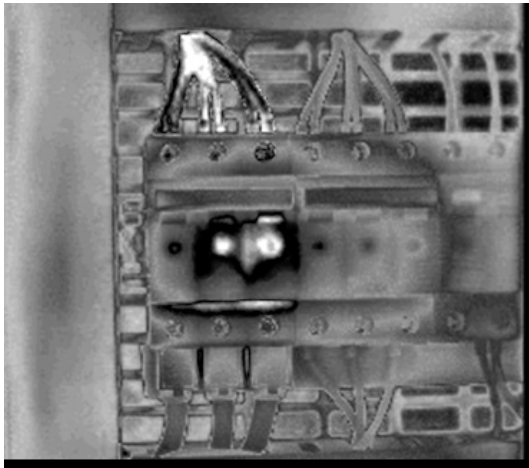


Figure 8
Switchgear under thermal imaging

6 Contact Temperature Monitoring

It is now possible for modern ACBs to be fitted with the option of continuous contact temperature monitoring.

The status and wear of the contacts is determined by the temperature measurement using NTC (negative temperature co-efficient) thermistors. Self-diagnosis is achieved by direct

measurement of physical properties. Each phase of the circuit breaker contact is fitted with its own thermistor.

The thermistor will analyse all the three phases continuously every ten milliseconds.

The thermistors used are in a glass encapsulated package, diode outline, with axial tinned Dumet (Copper-Clad Ni-Fe) wire.

The temperature response to contact resistance (wear) of the ACB contact temperature monitor is shown in figure 9.

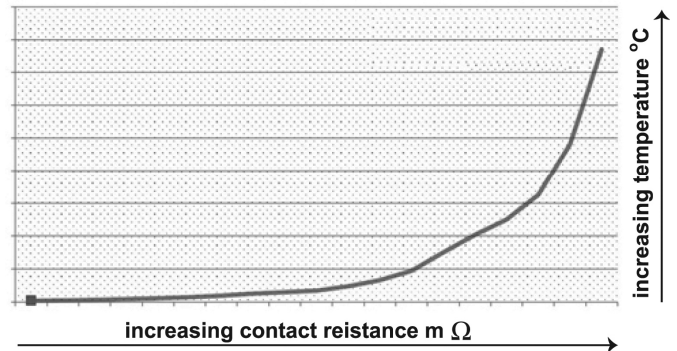


Figure 9
ACB Contact Temperature vs Resistance

It is important to distinguish between direct, continuous measurement and contact wear indications based on algorithmic modelling. The latter are inherently less accurate and therefore more likely to result in false alarms or under-protection. Continuous monitoring of the contact temperature provides valuable input for preventative and predictive maintenance programs. [3]



Figure 10
Protection Relay with Contact Temperature Monitor

Should an abnormal temperature occur the relay will generate an Over Heat (OH) alarm on the integrated LCD window, close a volt-free output contact and deliver an alarm message to the Modbus network, figure 10.

This information will allow the facility manager to plan for any necessary maintenance.

The implementation of condition monitoring techniques such as this can be equally applied to older installations as well as new build.

The increase in end customers considering retrofit solutions to replace ageing switchgear, can also take advantage of new solutions such as this when considering to replace and ‘upgrade’ their protection and switchgear.

7 Condition & Monitoring

Case Studies & Applications

7.1 Data Centre

The load factor of an installation is the average load divided by the peak load (over a given period). Datacentres have a high load factor compared to residential, commercial or industrial installations. Electrical equipment in an installation with a high load factor has a higher-than-normal risk of overheating. A thermal protection system which is integrated with circuit breakers is a good investment for mission-critical electrical installations. [3].

Terasaki recently installed 16 ACBs and MCCBs incorporating over temperature solutions for a multi-national blue chip manufacturer – datacentre in Merseyside, UK:



Figure 11
Datacentre with ACBs/MCCBs

In addition to the ACBs, all the MCCBs installed also used the terminal temperature monitoring solution on the plug-in MCCB. All the circuit breakers installed were also connected to the B.M.S. The data gathered by the MCCBs and ACBs was able to be communicated, to help with predictive maintenance plans in the future.

7.2 Chemical Factory

Following a recent fire at a major chemical plant in Osaka, Japan, the engineers diagnosed the source of the fault as a loose cable connection on the line side of a 400A electronic MCCB.

In addition to changing the maintenance schedules the chemical plant wanted to reduce the risk of a potential similar failure. They required electronic devices to achieve their co-ordinated protection so could not use thermal magnetic MCCBs in this instance.

They approached several manufacturers and requested if an option of thermal temperature monitoring could be developed. The idea was simple in that a visual indication was required based on terminal temperature – green for health, amber for planned maintenance to take place and red for immediate action. In addition a volt free contact was available for the Building Management System (BMS).

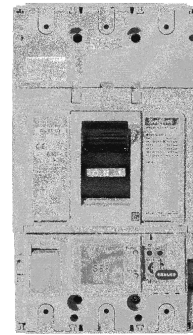


Figure 12
MCCB with Measurement & Data Communication

7.3 Installations with Corrosive Atmosphere

Sulfur rich environments are common at industrial facilities such as petroleum and chemical plants, refineries, paper and pulp recycling plants, sewer and wastewater plants. Such atmosphere produced by various chemical technologies causes a serious corrosion problem for many metals used in electrical apparatus.

Degradation of power contacts in corrosive atmosphere leads to significant increase of the contact resistance and consequently to a rise in temperature, and eventually to the failure. In electrical apparatus, both base metal copper and silver plating heavily corrode in environment containing sulfuric gases. In addition, expansive growth of silver filaments (whiskers) has been often found on primary current conductors of circuit breakers. [4]

Condition-based maintenance supported by on-line circuit breaker condition monitoring and temperature control of current-carrying path in switchgear during operation can effectively protect electrical apparatus from the failure. [4].

8 Summary

Low voltage switchgear is one of the areas that is perhaps overlooked when carrying out maintenance schedules in any installation. This is often due to pressures to avoid plant shutdown.

By neglecting routine maintenance this can lead to unplanned outages and any increased temperature of switching devices can also lead to a potential fire hazard. The information gathered by the circuit breaker on over temperature situations can help the facility manager develop predictive maintenance plans and minimise down time of the installation.

The Institute of Fire Protection Officers (IFPO) have also recognised that this unique innovation of continuous condition monitoring, of the temperature of switchgear can help reduce the risk of fire.

So if you prefer your switchgear not to 'run hot' then condition monitoring techniques, such as contact temperature monitoring should be considered.

References

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- [2] Health and Safety Executive, Keeping Electrical Switchgear Safe, HSG230
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