ADVANCEMENTS IN ARC PROTECTION

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ABSTRACT

This paper discusses aspects of arc protection in switchgear, and presents advancements in the most efficient arc protection technology, based on optical detection of arc flash. This technology can be divided into three parts:

1) *detection of arc light and overcurrent (sensors, current transformers)*
2) *protection logic and system for selective operation (relay or stand-alone device)*
3) *fast operation of primary equipment (circuit breaker, fuse, quenching device)*

This paper presents new research results and technological development in all of these fields.

INTRODUCTION

Arcing fault is rare but the most devastating type of fault in MV and LV switchgear. It may cause safety hazard to personnel through radiation, thermal convection, arc blast and flying particles, and toxic impact. The economic consequences are often very significant. Direct damage to equipment causes often only a fraction of the total costs. Indirect costs due to long interruption of processes can be quite substantial, not to forget the possible medical and legal expenses, if there are humans involved.

Arc fault prevention through good design and careful maintenance is naturally the primary target. However, accidents occur, and therefore there are a number of technologies for mitigation of arc fault impacts. Personal protective equipment, arc containment, reduction of arcing current, and reduction of arcing time are some of the most common approaches. Often the most feasible and effective mitigation option is to reduce the arcing time by fast protection. Different protection approaches have been widely compared in a number of scientific papers. The fastest possible protection is achieved by using optical detection of arc flash.

In this paper, advancements in detection of the arc light are presented. The characteristics of arc-flash light have been analyzed, and several types of fiber sensors have been tested.

If arc fault detection is based only on light, there is a risk of nuisance tripping. This is why in most cases the protection is based on dual-sensing principle, i.e. detection of light and overcurrent. New achievements in integration of overcurrent detection into circuit-breakers are presented. Results of the performance of this technology can be shown.

For maximal protection and minimal damage, arc elimination technology can be applied. The technology and its performance are presented in this paper. Because arc quenching technology has been criticized for causing high current, the risks related to this issue and mitigation options are discussed.

OPTICAL DETECTION OF ARC FAULT

Literature survey

There is a strong correlation between arc fault current and light [1]. An arcing fault can thus be detected immediately by detecting the light. Understanding of the arc light characteristics is a requirement for reliable detection of arc light, and for distinguishing the arc light from the light coming from other sources. In this research, both literature survey and laboratory measurements have been used for spectroscopic investigation.

A number of arc fault detection methods have been examined in the literature. According to the studies, the fastest possible detection is achieved by using optical detection of arc flash. These investigations have contained the UV range, the visible light, and the range of the infrared radiation [2], [3], [4], [5], [6]. The disadvantage of all these methods is the coupling of other radiation sources in the sensor which can cause nuisance tripping. In reference [6] the sensitivity has been reduced by implementing optical filters in the sensors. This work has been used as basis for other investigations.

Laboratory tests of fiber optical sensors

One of the fundamental laboratory tests was to identify the spectrum of arc light. The spectrum is needed to be able to choose optical sensing technology for arc-flash light detection. These tests were defined for different copper electrodes, busbars, and standard switchgears. The currents were changed in a range from 1 to 65 kA. All measurements indicate that wavelengths in dependency on material from 330-530 and 770-870 nm are the critical areas. Figure 1 presents the measured characteristics of arc spectrum.

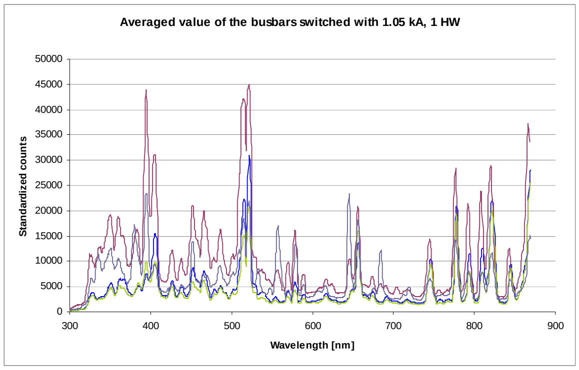

Figure 1. Measured characteristics of arc spectrum on busbars with small distance and different materials.

The results for the uncritical area of range 530-770 nm for different busbars are in line with measurements from [6]. An optimal optical fiber should be sensitive in the critical range and not sensitive in the uncritical range. A specific filtering of the uncritical range of wavelengths has lead to an improvement of the sensitivity, so that the radiation from other sources will not activate the sensor.
The transmittance characteristics of various types of optical fibers have been tested. Figure 2 illustrates the impact of the filtering of the uncritical range.

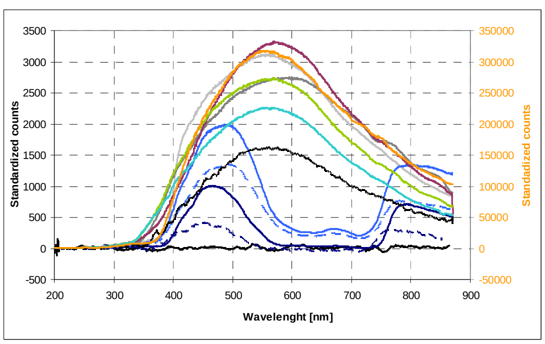

Figure 2. Received signals of the tested fiber optic sensors.

In addition to optical characteristics, the fiber sensor should have the following qualities:

- ability to tolerate rather high temperature,
- mechanical toughness,
- chemical inertness,
- reasonable production costs.

With consideration of all characteristics the number of the sensor types could be reduced to three. However, further measurements indicated that the spectral distributions of arcing faults and switching arcs are very similar. Therefore an accurate distinction by the sensor system is not possible if only based on the spectrum of the light.
The impact of the distance between the sensor and the arc was tested. The measurements strongly indicate that the increased distance between the circuit breaker and the sensor is a good solution to reduce the risk of nuisance tripping.

ARC PROTECTION LOGIC AND SPEED

Protection logic and equipment

Figure 3 presents the general logic of arc protection. The first phase is the detection of the arc by optical sensors, and in most cases the detection is confirmed by information of overcurrent seen by current transformers. If the risk of optical sensor activation by external light is minimal, detection of light only is adequate condition for the operation of the protection. When the light detection is confirmed by overcurrent information, existing CT's required for normal overcurrent protection are used.

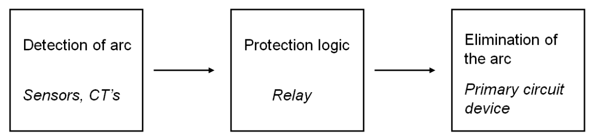

Figure 3. Logic of arc protection.

The detection information is processed by the protection relay. The relay may be just an arc protection option card in a normal numerical relay or a dedicated arc protection relay or a simpler stand-alone arc protection unit. The essential issues in the operation logic are the speed and the selectivity. The protection logic must be able to trip the correct primary circuit devices (circuit breakers, possibly arc quenching device) very rapidly.
Figures 4, 5, 6 and 7 present examples of arc protection components. Figure 6 presents a new generation arc protection central unit, providing improved user-interface, better operation speed, and various communication options.

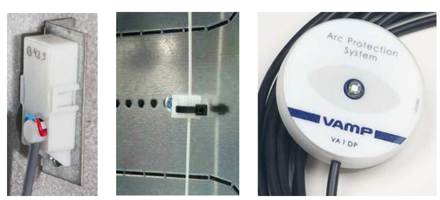

Figure 4. Point sensor, Fiber sensor and Personal sensor.

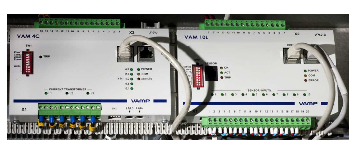

Figure 5. Current and light I/O units for collecting detection information.

Figure 6. Arc protection central unit and a numerical relay equipped with arc protection option.

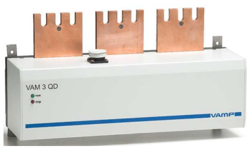

Figure 7. Arc quenching device (LV).

Speed of arc protection

The most effective means to reduce the energy released in an arc fault is the reduction of the arcing time. When applying optical detection based arc protection the arcing time consists of three components: arc detection time, operation time of the protection logic (relay) and the operation time of the primary device (CB or arc eliminator). As in normal protection, circuit breaker is the key component. In optical sensing based arc protection, most of the arcing time is caused by the operation time of the CB. This is illustrated in Figure 8.

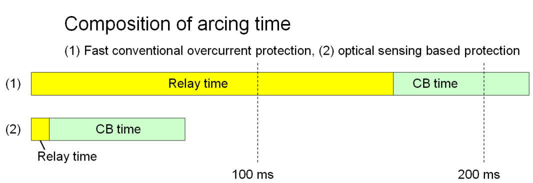

Figure 8. Composition of arcing time

In Figure 8 the relay time includes both arc detection time and the relay time. A short-circuit arc can be detected within 1 ms, and this applies to both detection of the light as well as the detection of the overcurrent. If the arc relay is equipped with semiconductor trip output, the total detection and tripping time may be ca. 1 ms. If the relay is equipped with conventional output relays, the relay time is a few ms longer. As Figure 8 clearly indicates, when minimizing the arcing time, the arc detection time can not be significantly reduced. However, the operation time of the primary device (CB, quenching device) can be improved.

Integration of the CB into the arc protection system

So far the arc protection systems have been separate from conventional circuit breakers. The interface to the breaker has only been the trip contact. A new invention is to integrate the current measurement of the LV CB to the arc protection system. This concept provides several advancements:

- No separate current I/O modules (collecting overcurrent detection information) are needed.
- No need to connect the normal CT's of the power system to the arc protection system which means less wiring.
- Significantly faster tripping of the CB.

The key issue in the invention is to utilize the current transformers that are integrated into the CB's. This way the time required by the triggering process of the CB can be reduced. In order to minimize tripping time, also the interface between the arc detection system and the CB was redesigned. The combination of the new interface and the CB technology has been tested, and the initial results verify tremendous performance advancement.

The improved performance is illustrated in Figures 9 and 10, presenting test results. The tests were carried out by supplying the CB with overcurrent and triggering the arc flash detection by a flashlight.

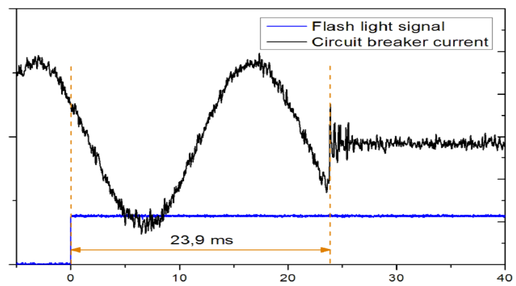

Figure 9. CB trip test, standard communication.

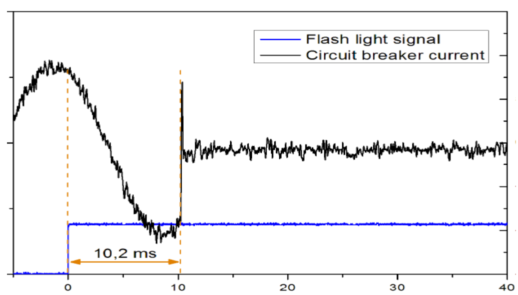

Figure 10. CB trip test, the new interface applied.

ARC QUENCHING

If minimal arcing time is required, the arc can be extinguished within a few milliseconds by an arc quenching device. In this case the arc protection relay sends a tripping command both to the arc quenching device and to the circuit breaker. When arcing time is limited to less than 5 ms the thermal impact of the arc is minimal, and the impact of the arc blast is drastically reduced.

The quenching device creates a bolted short-circuit on three phases parallel to the location of the arc fault. This reduces the voltage between the downstream busbars well below the minimum arc voltage and thus quenches the arc. The performance of the system is demonstrated by the oscillogram in Figure 11.

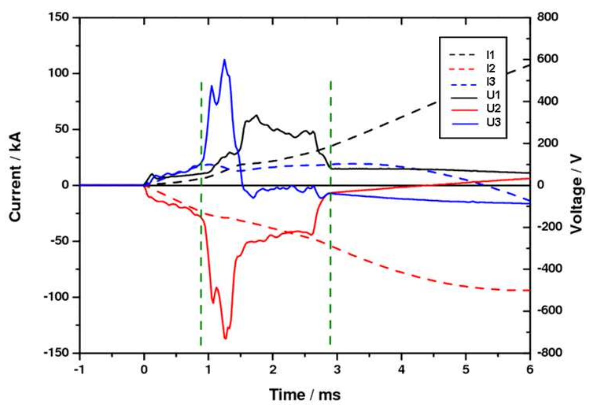

Figure 11. Oscillogram of current and voltage during arc flash extinction (3 phases, U_P = 440 V, I_{CC} =65 kA).

When arcing time is limited to ca. 2 ms as shown in the figure above the released energy is extremely low and both the thermal and the pressure impact is minimal. The short circuit is disconnected by the feeder circuit breaker within its respective clearing time.

On the other hand it has been discussed that in LV systems arc flash mitigation devices based on crowbar technology cause bolted fault currents which are often higher than the arcing current. In numerous tests in real power distribution boards with a prospective current of 65 kA using a quenching device it was found that the peak current of the initial arc reached about 90% of the maximum prospective value. However, there has been no evidence on actual increased stress or damage. On the contrary the bolted fault current of the quenching device together with the damping effect of connections between transformer and incoming breaker guarantees a fast non-delayed tripping of the incoming breaker. Moreover, the main stress of arc flash is characterised by the arc energy ∫uidt. Due to the short quenching time the arcing energy of the initial arc flash is drastically reduced in comparison to other mitigation methods.

In MV systems the arcing current is approximately equal to the bolted-fault current anyway [7], [8]. Thus the arc elimination system does not significantly increase the fault current level, and it will not increase the risk of damage due to high current and mechanical stress compared to situation where the arc is not eliminated by a short-circuit device. In MV systems an arc eliminator is in fact beneficial to transformers and motors, because the short circuit is eliminated faster by the circuit breaker than it would have been without arc elimination system. This is because the arc detection system will trip the circuit breaker faster than a normal protection relay sensing the overcurrent only.

CONCLUSIONS

Spectral analyses of arc-flash light have been carried out, and several fiber optic sensor types have been tested. A fiber type with better sensitivity has been developed. The new fiber is more sensitive to arcing faults and less sensitive to light from other sources.

A new type of arc protection central unit has been developed, providing improvements in performance, communications, and user interface.

A major achievement is the demonstrated integration of the LV circuit breaker into the arc protection system, including the use of CB's internal current measurement and new communication interface between the arc monitoring system and the CB, providing significantly reduced arcing time.

The most effective arc protection technology, utilizing arc quenching device, has been introduced. Its performance has been verified, and speculated risks related to this technology have been discussed.

ACKNOWLEDGMENTS

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