# IMPROVING MEDIUM VOLTAGE SWITCHGEAR PROTECTION IN DISTRIBUTION NETWORKS

Juha ARVOLA
Arcteq Relays Ltd – Finland
juha.arvola@arcteq.fi

Samuel DAHL
Arcteq Relays Ltd – Finland
samuel.dahl@arcteq.fi

Tero VIRTALA
Arcteq Relays Ltd – Finland
tero.virtala@arcteq.fi

## *ABSTRACT*

*Medium voltage switchgears have been traditionally protected by overcurrent and earth-fault relays. Today also arc protection functionality has been widely utilized providing fast acting protection against internal arcing faults. Modern protection IEDs are capable of integrating above functions along with several additional functions for monitoring, control and diagnostics. The new IED technology introduces also enhanced measurement technology for more sensitive protection. This paper discusses improved protection methods against internal arc faults, emphasizing monitoring technologies that enable preventive protection. A new protection IED is introduced, incorporating a cable end differential protection algorithm along with traditional overcurrent, earth fault and arc protection functions. This cable end differential protection function utilizes measured phase currents and measured zero-sequence current and calculates a differential current over the cable end.*

## INTRODUCTION

C. The rapid increase of temperature expands the volume of the air causing a pressure wave which in turn leads further to a potentially damaging sound wave as well. The extreme temperatures cause switchgear components to vaporize within milliseconds. High pressure leads to opening of switchgear doors, releasing extreme energy to exposed personnel, should they be in the area during the arcing fault. In addition to direct light, temperature and pressure effect other danger factors include release of toxic gases and burning shrapnel.

Arcing faults are typically caused by human errors resulting in equipment failures or aging equipment failing to operate according to specification. Some more common equipment failures are switchgear power cable connections and circuit breaker racking mechanisms. In some operational environments animals, such as rodents and snakes are known to cause arc faults when entering or nesting electrical equipment.

Most of the arc-flash faults start as single phase to ground fault and then develop into three phase faults [1]. This is why an early detection of the arc fault and consequent fast fault isolation is critical.

## EARLY DETECTION OF DEVELOPING FAULTS

Arcing faults can be categorized into sudden faults which can be caused by e.g. direct human interaction or component failure in a switching operation, and slowly developing faults, caused by e.g. degrading insulation or loose joint. In the following, both of these fault types are discussed

The most common fault location of developing internal arcing fault is the incoming or outgoing cable compartment [1]. Based on this fact it is of an outmost importance to enhance the protection and monitoring of the cables.

### Technologies for online monitoring of switchgear

There is a compendium of solutions available in the market for on-line monitoring of the switchgear for preventive measures. The most commonly deployed technologies are partial discharge (PD) monitoring and thermal monitoring. Feasibility of using other types of sensors for preventive monitoring are continuously researched.

### Switchgear thermal monitoring

Switchgear thermal monitoring has been widely deployed in electrical power distribution systems to detect hot-spots and consequently potential failure locations. Use of infrared cameras has been the most commonly utilized method for hot-spot detection. Infrared cameras however provide only a momentary thermal image at the time of photographing. Some potential failure locations are difficult to reach during normal operation of the switchgear even with aid of viewing windows specifically made to switchgear doors. Introducing a continuous and accurate real-time thermal monitoring method by installing temperature sensors in switchgear strategic locations brings in evident benefits.

The main challenge of successful introduction of real time thermal monitoring has been the required electromagnetic immunity for installations in electrical substations. Stringent electromagnetic compatibility requirements have made many of the existing technologies like wireless systems inapplicable for substations. Another challenge has been the number of required sensors in the switchgear, making systems complex and costly.

The number of sensors can be kept lower when concentrating on the most probable failure spot, the cable end [1]. Other strategic locations may be added, such as busbar joints and breaker connections.

## Fiber optical sensors for switchgear thermal monitoring

Use of fiber sensors in switchgear temperature measuring provides a method inherently immune to interferences. As temperature measurement requires direct connection to energized parts a high temperature withstand of the sensing probe and fiber itself should be carefully evaluated. Fragile nature and cleanliness concerns of common fiber optic sensors have made use of common fiber optics challenging in terms of robust installation.

Polymer Optical Fibers (POF) have been used in European automobiles for over a decade and have been deployed in vehicles that have endured the harsh climate conditions found across the globe.

POF fibers have been designed for in-field terminations eliminating all optical connectors altogether on the sensing probe. A simple disposable cutting tool can be provided that allows the fiber to be cut to length in the field by anyone. Cleanliness concerns are also eliminated as contaminated ends can simply be cut-off, exposing a new fiber termination.

Of all the available technologies the Polymer optical fiber sensors are prone to provide the optimal solution to continuous temperature measurement of the switchgear.

Simple installation of the sensors keeps the overall cost of real time temperature monitoring in a feasible level. Further, when fiber optic sensors can be integrated to the protection and control IEDs the investment can be kept in an attractive level and efficient and simple continuous temperature monitoring can be established with low initial investment.

## Protection IED with enhanced measurement accuracy

New protection IEDs with more accurate measurement technology are now available. These modern IEDs are able to reach even class 0.2S power and energy measurement according to IEC 60687 standard using standard protection CT cards. This on the other hand means that current and voltage measurement errors even in low current magnitudes are in range of 0.1-0.2%. With such precise measurement the protection IEDs can perform more accurately throughout and especially in sensitive protection algorithms such as the new differential protection of cable ends introduced in next chapters. Another significant advantage of the new type of IEDs is the elimination of separate measurement devices.

## The new differential protection of cable ends

This chapter introduces an algorithm to obtain a highly sensitive cable end differential (CED) protection function.

Figure 1 shows required connections of CED function. The function utilized measured 3-phase currents to derive calculated residual current. This derived value is compared to neutral current measured using core balance current transformer.

CED function utilizes biased differential characteristics with settable sensitivity and two separate set knee-points.

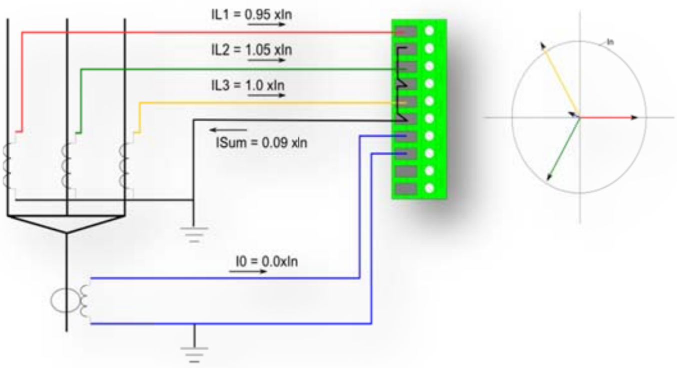


**Figure 1:** The measurements of the proposed differential protection with natural unbalances present.

When calculating the residual current from phase currents the natural unbalance may be in total around 10% using CTs of 5P class, being one of the most common CT accuracy classes in use. Figure 1 illustrates the natural unbalances that may be present in the system due to CT inaccuracy. Figure 2 illustrates the differential current measured by CED function respectively. Figure 2 demonstrates that the measured differential current in normal conditions is very close to differential trip characteristic. Therefore sensitive setting of CED function is not possible with natural measurement inaccuracies present in the system.

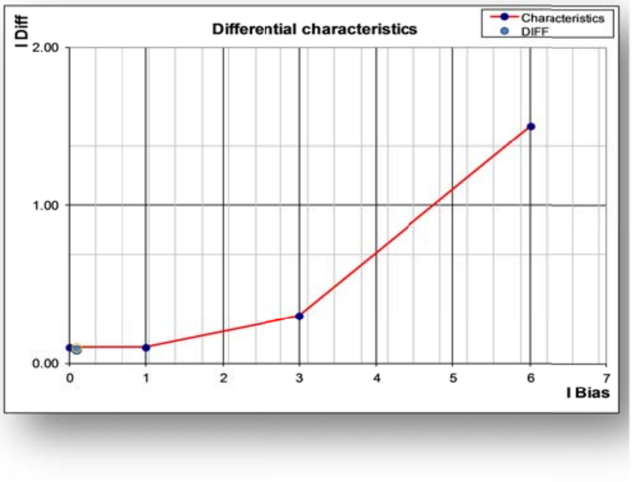


**Figure 2:** Natural unbalance in the phase current measurement due to CT error as seen in CED bias characterics.

## Natural unbalance compensation in CED function

When the phase current measurement natural unbalance is compensated in the above situation the differential settings may be set more sensitive and the natural unbalance does not affect into the calculation. This method of natural differential current compensation leads to a very sensitive cable end function.

The natural unbalance is compensated during the system start-up when relay is on-line and measuring the phase currents. When compensation command is triggered the CED function compensates the internally derived residual current to zero making the derived residual current directly proportional to measured neutral current (by core balance CT) thus resulting to zero differential current at system start-up. This compensation does not impact any normal earth-fault settings but only the CED algorithm.

If in the cable end should occur any starting faults the cable end differential catches the difference in between of the ingoing and outgoing residual currents and the resulting signal can be used for alarming or tripping purpose for the feeder with failing cable end. The sensitivity of the algorithm and settings can be freely user settable. Figure 3 illustrates measured currents in an unbalance condition due to failure in cable end. Figure 4 illustrates the corresponding differential current measured by CED algorithm.

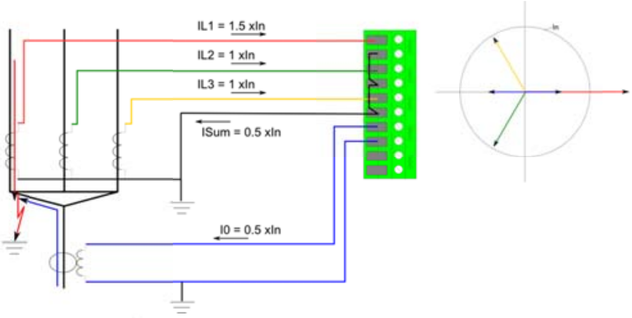


**Figure 3:** The measurements of a cable end fault.

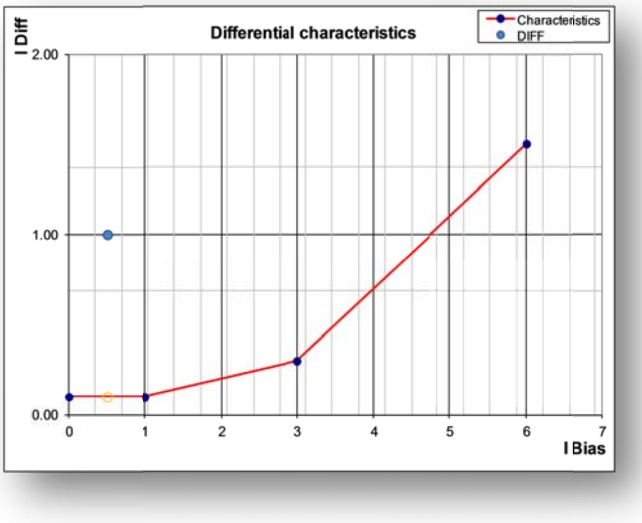


**Figure 4** The calculated unbalance indicating a phase-to-earth fault.

## Application of CED in distribution networks

Use of cable end differential protection algorithm leads in improved preventive protection of medium voltage switchgear in different types of networks. Sensitive differential protection is well applicable in unearthed distribution networks and low resistance earthed networks as the earth-fault currents are typically present in magnitudes of hundreds of amperes.

Use of CED in compensated (petersen coil) distribution networks for preventive purposes is also a potential application. Typical earth-fault currents in compensated networks are in range of 2-15 amperes and parallel resistance is adding about 10 amperes. The CED algorithm can reach sensitivities of less than 1% and therefore it can be applied to compensated networks as well. However, at the time of writing the paper more practical field tests are needed to prove the use of algorithm in compensated networks. The same applies to high-resistance earthed networks.

## FAST ACTING ARC PROTECTION

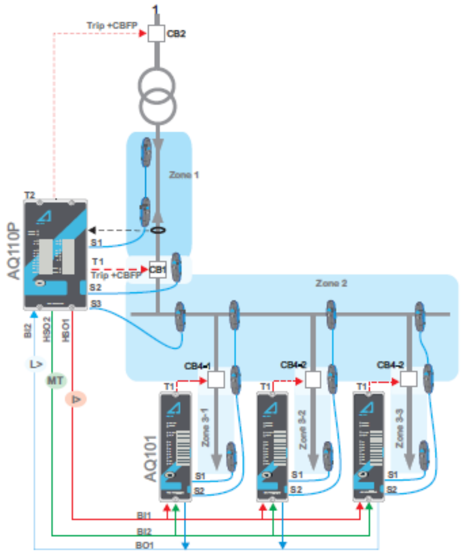
As not all the internal arcing faults are predictable by means of improved monitoring and above explained new protection algorithms a fast acting reactive method for arc fault mitigation is necessary. The best known and most efficient protection to mitigate the drastic consequences of internal arc faults is the arc protection using light sensors in the switchgear. Most typically this protection by light is combined by simultaneous sensing of orvercurrent and/or earth-fault for more dependable protection.

The main advantage of the light and current based arc protection system is the operation speed and sensitivity. As the current condition is utilized only as a second tripping criteria with arc light the overcurrent can be set very sensitively, for example, 1.5 times the load current. Earth-fault settings can be set very sensitive as well. The protection zone is limited to internal arcing faults in the switchgear, and so there is no need to coordinate the protection, thus the tripping can be truly instantaneous resulting in detection and relay operate times of as low as 1-2ms. The total fault clearing time then depends on the type of circuit breaker(s) utilized to interrupt the fault feeding circuit.

Arc protection systems are cost effective to implement if compared to traditional busbar differential schemes. It is also important to note that busbar differential protection zone may not include the critical cable terminations due to current transformer locations. Arc light detection and protection provide effective switchgear and busbar protection for both medium voltage and low voltage systems. This kind of arc protection system can be very easily retrofitted into existing power systems.

## Types of arc protection systems

Arc protection systems may be implemented as dedicated arc protection systems or integrated in modern protection and control IEDs. Figure 4 illustrates typical dedicated arc protection system. Main advantage of dedicated arc protection system is its independence of other protection IEDs bringing an improved redundancy in the protection scheme. Figure 5 illustrates an integrated arc protection solution where. arc light sensors are integrated into modern protection and control IEDs. This type of integrated system reduces overall arc protection implementation cost by better utilization of modern protection and control IED capabilities.



Scheme Ia1.cdr

**Figure 5:** Dedicated arc protection system

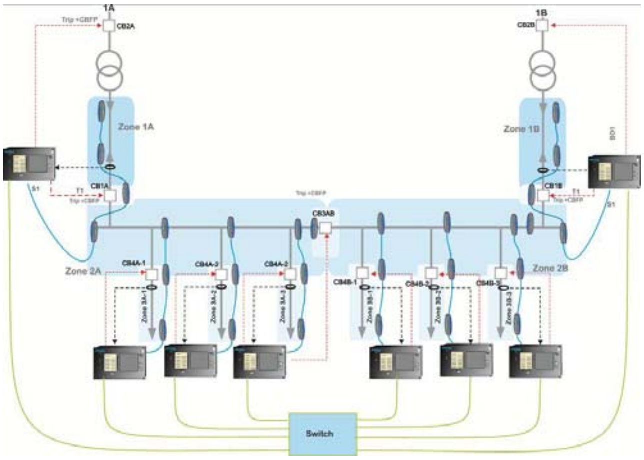


**Figure 5:** Arc protection integrated as a part of protection and control IED functions.

## CONCLUSIONS

The medium voltage switchgear protection can be improved applying modern protection and control IEDs capable of integrating functionality beyond the reactive protections. Proactive and preventive protection algorithms and functions can be added in these IEDs. Thermal monitoring of switchgear by adapting Polymer Optical Fiber technology leads to robust method for continuous thermal monitoring of e.g. cable joints. Deploying a novel cable end differential protection with natural unbalance compensation method provides a sensitive cable end preventive protection method for distribution networks. The cable end differential protection may be applied for alarming or tripping of starting cable end faults. Light and current based arc protection by either dedicated devices or integrated into same IED provides the fastest protection and mitigation against potentially devastating damages caused by arc faults. The new protection IEDs with improved measurement accuracies even up to class 0.2s according to IEC 60687 standard enable more sensitive protection and elimination of separate measurement devices.

## REFERENCES

[1] IEC 62271-200:2003: Standard for AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV

[2] S. Dahl, J. Arvola, T.Virtala 2010, “New standardized approach to arc flash protection”.

[3] S.Dahl 2011, “New Technologies Trends and Standards outlining the new generation of Arc Protection Schemes for Substations”, *Paper No.15 Eskom 2011 conference.*

[4] Arcteq Relays Ltd, Instruction manual AQ F215 - Feeder protection IED, REV1.0”, 2012”