Applications and Discussions of Arc Flash Protection Relay as a Main Busbar Protection in MV Switchboards

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Abstract:

Minimizing the operational personnel's injury and the damage to the power equipment when an arc flash fault occurs in a MV switchboard has always been a major concern to the utilities protection engineers. This paper summarized the last 10 years application and operational experiences of arc protection in MV switchboards of substations in China. The different aspects of power distribution configuration and applications are discussed in relation to the arc protection. Key protection issues, such as recommendations of current and light settings, reliability of the light sensors, selectivity of the arc protection relays, the pros and cons of the arc protection relays in comparison with the traditional busbar differential protection relays, etc. are also discussed. Finally, two successful arc protection operations are reported and discussed. The paper concludes that as an alternative protection to the busbar differential protection, the arc protection relay can be cost effectively and widely used in the MV switchboards of substations with high speed, flexibility, reliability and selectivity. Particularly the arc protection relays are suitable for retrofitting of existing MV switchboards of the substations where no busbar main protection has been installed in almost all the MV switchboard of the substations in China.

Keywords:

Arc protection relay, MV Switchboards, Busbar main protection, Point light sensor, Loop light sensor,

1. Arc Protection Technology and its Background

The arc protection relays has been developed and in operations in the power distribution MV switchboards since late 80s and/or early 90s of last centenary. This arc protection technology was introduced into China market as a standing alone relay in 2004. The following is a summary of arc protection technology background and development both in overseas and China.

1.1 European and US Standard Relating to Arc Flash Protection

The arc flash fault of MV switchboard has always been one of the major concerns of power utilities protection engineers since the starting of electric network in 1890. Due to its great threats to the lives of operational personnel and serious damages to the electric installations, The European IEC Standard Committee revised its standard IEC60298 in 1981, which describes the causes of arc flash fault, its measures and its testing procedures [1]. Mr. Ralph Lee, a fellow of IEEE, conducted a comprehensive study on the arc fault of MV switchboard in 1987 which provided a theoretical base for arc protection relay development in the late 80s [2]. In the same year of 1987, the American IEEE [3] and the Canadian EEMAC [4] also published their standards for metal-enclosed switchgear and Controlgear for MV switchboards including arc fault preventions. By 2003 the new IEC62271-200 [5] has replaced the IEC60298 become the new standard for the MV switchgear and controlgear with more restrict measures for arc fault prevention. In 2004, American National Fire Protection Association (NFPA) developed a standard as part of the National Electrical Code (NEC) to further regulate the operational safety and fire prevention due to the arc flash fault at MV and LV switchboards [6].

1.2 Chinese Standards Relating to the Arc Flash Protection

The impedance busbar differential protection schemes have been fitted in the MV switchboard as the main busbar protection in many developed countries since 1930s. However, there are almost none busbar main protection schemes so far for the MV switchboards of the substations in China. The possible main reasons for no main busbar protection might be: 1) complicity of busbar differential protection scheme design, setting calculation, installation, commissioning, operation and maintenance; 2) system reliability are more important than personnel safety in the network operation in the early days in China; and 3) the Chinese electrical protection design code [7] for the protection relaying and control device of electric installation has never request a main busbar protection as a must for MV switchboards in substations. After 10 years of promoting the arc protection technology in China, the Standardization Administration of the People's Republic of China (SAC) and the China Electricity Council (CEC) have formed working groups separately to write up the draft standards for arc flash protection equipment. Both the Chinese National Standard

(GB) and the Chinese Electrical Industrial Standard (DL) for Specification of Arc Flash Protection Equipment [8][9] are expected to be published in 2015. This is a certainly big step forward towards electrical personnel safety and reliability for MV and LV power distribution switchboard installations in China.

1.3 Principle of Arc Protection Relays

The arc protection can be arranged just using arc sensors without current check. However, for stabilities, it is practical and often to use current check in the MV distribution switchboards in China due to the operational and maintenance procedures. The principle operation of arc protection relays is shown in Fig 1.3A. This logic diagram covers all phase to phase arc flash faults.

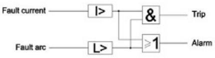

Fig 1.3A Logic Diagram of Arc Protection for Phase Faults

For all different neutral earthing systems, the following more comprehensive protection logic scheme, shown in Fig. 1.3B, is also presented for further studies and development.

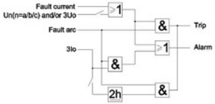

Fig 1.3B Logic Diagram of Arc Protection for All Phase and Earth Faults

This protection scheme covers all possible phase to phase and phase to earth faults under different neutral earthing systems in China. Further detailed discussions are described in section 2 of this paper.

1.4 Comparison between Arc Protection and Busbar Differential Protection

Can the arc protection become an alternative main busbar protection to the traditional busbar differential protection? With this question in mind, we have created a comparison table between the arc protection and the busbar differential protection shown in Table 1.4 below. The key aspects of the protection features are discussed and described in this table. As the modern numerical relays, both relays are all subject to pass the entire protection type testing requirement to the relevant IEC/GB standards, such as electrical insulation tests, environmental tests, and EMC/EMI tests, etc. Other functions, such as events logging, fault recording and waveform storage, time synchronizing, standard communication protocols etc. are all assumed to be achievable and not discussed in this table.

	Bus Arc Protection	Bus Diff. Protection
Op. Principle	Arc flash light sensing with or without current and/or voltage check to detection all phase to phase and phase to earth fault	Current differential to detection all phase to phase and phase to earth fault within the bus zone defined
Op. Speed	Typically less than 15 ms at 2 times In Typically less than 8 ms with no current and/or voltage check	Typically between 20ms to 45ms at 2 time In
Stability	Due to its unique operational principle, the arc protection relay can be very stable with very low current and/or voltage setting	Must remain stable during all external faults; Complex setting calculations; Be immune from mal-operation
Selectivity	Can selectively trip out the some or all outgoing feeders, incoming feeders, CBs within the zone; CB fail protection	Always trip out all CBs within the zone; CB fail protection
Flexibility	Full logic programming for all busbar configuration and operations; Covering all possible panels and installations of CB	Limited numbers of panels and protection zones depending on the design of the barbar protection device and engineering
Reliability	Full fiber optical sensors and links for the protection, control and communication signaling Fault locations	Copper twisted wires are used between the master and slave units No fault locations
Other functions	Those arc protection relays are particularly suitable for retrofit MV switchboard projects, where no main busbar protection were installed; The existing protection design and scheme will not be effected by this retrofitting; This protection scheme is cost effective including all CTs and/or VTs and sensors (1X)	It is almost impossible for retrofitting MV switchboard projects to add the busbar differential protection relays into the existing switchboards. This is mainly due to the additional PL class CTs must be installed to complete the schemes ; More expensive including all CTs and/or VTs (1.5x)

Table 1.4 Comparisons between the Arc Protection and the Busbar Differential Protection

1.5 The Key Reasons of Recommending Arc Protection Relays in MV switchboards in China

The following are the key reasons for recommending the arc protection relays to be installed or retrofit in as the busbar main protection schemes in MV switchboards.

- Minimizing and/or avoiding the injury or loses of human lives by arc flash fault within the MV switchboards.
- Minimizing and/or avoiding loses or damages to the MV switchboards by arc flash fault within.
- Reducing the insulation damages to the secondary windings of the power transformers due to the fast tripping of the busbar faults by installing the arc flash protection relays as the main busbar protection schemes.
- Minimizing the indirect cost of property damage due to the fast production process recovery by fast busbar fault clearances.

2. Arc Protection Relay in Different Neutral Earthed Systems

2.1 Neutral Insulated System

Most of the MV distribution systems in China are neutral insulated system. This earthing arrangement allows the power supply to be continued for two hours while a phase to earth fault occurs. The arc protection systems installed so far for this case are only detecting and operating on a phase to phase fault within the switchgear compartments. As 80% of MV switchboards busbar faults start as a phase to earth fault and quickly developed into a phase to phase fault. In order to detect an earlier phase to earth fault, the zero sequence voltage can be considered as one of detection methods. Further studies, development and tests are required to add this as a function for earlier warning of a phase to earth fault at busbar, the fault can be cleared after two hours delay without developing into a phase to phase busbar fault.

2.2 Neutral Impedance (Peterson Coil or Arc-suppression Coil) Earthed System

Large amount of the MV distribution systems in China are also installed with arc-suppression coil through the transformer neutral to limit the fault current down to a level with no arcing on the outgoing feeders. The same as the Neutral insulated system, the arc protection systems installed are only detecting and operating on a phase to phase fault inside the switchgear compartments. Similarly as the neutral insulated system, the zero sequence fault detection method can be employed for earlier warning of a phase to earth fault at busbar without tripping for two hours.

2.3 Neutral Resistance Earthed System

Due to the rapid urbanization in China, large metropolitan cities, such as Beijing, Shanghai, etc., are also more and more using neutral resistance earthed method. This method allows the earth fault to be detected and tripped instantaneously or with a time delay. Depending on the resistance value to be employed, the fault current can be limited at desired levels. In these cases, Sensitive Earth Fault (SEF) detection and/or zero sequence voltage earth fault detection can be considered as the current and/or voltage check for the arc protection to detection the busbar phase to earth fault and trip the incoming CB. In this way, all busbar faults are monitored and checked at lower settings with a possible faster fault clearance time.

3. Arc Protection Relay in Different Power Distribution Systems

3.1 Single Busbar with Two Incoming Feeders and a Bustie

The most commonly used busbar arrangement in the 220/35kV, 110/10kV and 35/10kV substations of the Chinese power utilities and/or industrial plants is two incoming feeder with a bustie CB. A typical arc protection application diagram is shown below in Fig 3.1.

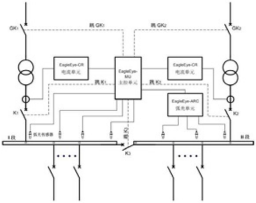

Fig. 3.1 Single Busbar with Two Incoming Feeders and a Bustie

Please note that often other power sources, such as small hydro power stations, might be connected to the outgoing feeders of the utilities substations. In this case, when a busbar fault occurs, the current of the outgoing feeders must also be measured and tripped out for the complete arc busbar protection scheme.

3.2 Single Busbar with Two Incoming Feeders and no Bustie

Single busbar with two incoming feeders and no bustie is the commonly used busbar arrangement for the power distribution systems of the thermal and/or gas power stations. The typical arc protection application scheme is shown in Fig. 3.2 below.

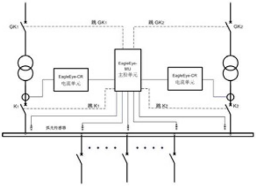

Fig. 3.2 Single Busbar with Two Incoming Feeders and no Bustie

3.3 Three or More Single Busbars with Busties

For the power distribution systems of the hydro power stations, the busbars are usually arranged in a way backing up each other from at least two sources for more secure power supply in case of one supply is failed. Additional current check is required for the protection scheme with remote signaling. A typical application diagram is shown in Fig 3.3 below.

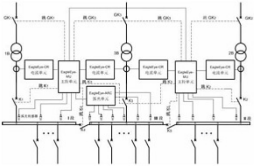

Fig. 3.3 Three or More Single Busbars with Busties

3.4 Single Busbar with Single Incoming Feeder

This arc protection scheme is typically designed for the solar and/or wind power plants. The schematic diagram is shown in the Fig 3.4 below.

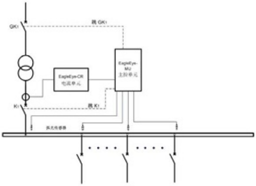

Fig. 3.4 Single Busbar with a Single Incoming Feeder

3.5 Single Busbar with All Feeders Tripping

For more selectivity, additional arc sensors can be placed in the cable compartment of the outgoing feeder panels. This arrangement allows the arc protection scheme to trip and open the outgoing feeder once the arc occurs in the cable compartment. If the arc persists in the other compartments of the switchgear and the incoming current still exceeds the current setting, the incoming feeder will be tripped and opened to clear the busbar fault. The schematic diagram is shown in the Fig. 3.5 below.

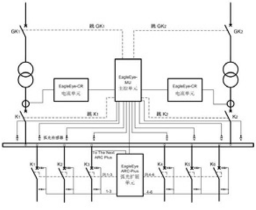

Fig 3.5 Single Busbar with All feeders Tripping

3.6 Double Busbars with Busties

This is a special application of arc protection with double busbars and busties. A typical application of a railway track substation with double busbars and busties arrangement is shown in the Fig. 3.6 below.

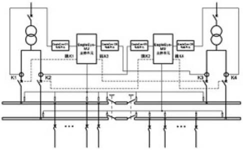

Fig 3.6 Double Busbars with Busties

4. Key Application Issues

4.1 CT and VT selections

In most cases, existing and/or commonly used P class CTs for the overcurrent and earth fault protection relay can be used and/or selected effectively for the arc protection relay. The relay can be connected in series with the existing feeder protection relay. The burden of CTs nowadays is usually acceptable with modern numerical relays. When the connection cables from the CT to the relays are long, the overall burden of the relays and wires are necessary to be evaluated and checked. In some cases, such as fault current is very limited, the detection of unbalanced zero sequence voltage by connecting the VT in open delta format at the busbar becomes necessary.

4.2 Current and Light Setting Recommendations

The current check is usually recommended to be set at 1.2 – 1.3 times of power transformer rated current in a utility substation. When motors are connected in the outgoing feeders, the current setting of the arc protection relay should be considered to be above the maximum start-up current of the motor.

The light density should normally be set in between 20kLux to 40kLux depending the sensitivity of the light sensor selected and the site light conditions.

4.3 Speed of Operations

The arc flash protection can be operated with or without current check. In the case of without current check, the operational time of the relay can be between 1ms to 7ms depending on the what kind of tripping output relays are used. With the current check, the operational time of the relay can be between 3ms to 10ms at 2xIn current setting. Therefore, arc protection relay can be considered as a main protection due to its speed of operations.

4.4 Reliability of the Light Sensors and Channels

There are two kinds of the light sensors on the market. One is photodiode type and the other is the fiber light sensor. The photodiode type is detecting the light and converting the light signal to the electrical signal at the point of sensing. The disadvantage of this type sensor is the secondary LV electrical protection wires are running through the HV compartment.
The fiber optical light sensor can be a point sensor or a loop sensor. The point sensor is detecting the light at the tip of the sensing point and sending the light signal through fiber optical cable back to the relay device. The loop sensor is detecting the light alone the fiber optical cable, which is running through the switchboard compartment to be monitored. The advantage of fiber optical point sensor is identification of fault location and immune to the electromagnetic field interference. The fiber optical loop sensor is cost effective but difficult to allocate the fault unless the loop is carefully designed in a segregated way. A fiber typically optical point light sensor is shown in Fig. 4.4 below.

Fig. 4.4 A Fiber Optical Point Light Sensor

Extra care must be taken at the termination of the fiber light cable into the relay devices during the installation and commissioning of the relays to avoid unwanted tripping and alarm signaling.

UV fiber optical sensor is also under developing, testing and trial. Although the field experiences are limited, study shows that arc fault initiated from the UV, then developed into the visible light. The detection of UV light sensor might make the earlier detection of arc flash and allows the relay becoming more stable from other visible light sources.

4.5 Selectivity of the Arc Protection Relays

In most cases, one arc sensor is installed in each busbar compartment of the switchgear. The disadvantages of this arrangement is that if the arc flash initiated from the CB or cable compartments, the arc flash will not be detected and cleared until it developed into the busbar compartment.

In order to increase the selectivity of the protection, arc sensors can be placed separately into the cable compartment and the CB compartment. Once the arc flash fault initiated from the cable compartment, without current check, the arc protection relay can directly trip and open this outgoing feeder itself in a shortest possible time, at the same time, the incoming feeder current and other light sensors placed in the CB and busbar compartments are continuously monitor the arc development. If the current and the arc are still both detectable and are above the settings, the incoming CB will be tripped and opened to clear the fault. In order to reduce the cost of arc protection relay, the loop sensor might be carefully designed and arranged in combination of the point sensor to achieve same selectivity with less possible cost.

In case of large metropolitan city, such as Beijing and Shanghai, resistance earthed systems are employed due to large numbers of underground cables are laid. It is recommended that the master tripping function should be used to completely eliminate possible discharge of capacitive fault current back into the busbar to re-ignite the arcing. In this way all the CB connected to the busbar will be tripped and opened.

5. Successful Operations and Field Experiences of Arc Protection Installed

5.1 Southern Grid Guangdo Dajing 110/10kV Substation

The 10kV switchboard of the substation was installed with RIZNER arc protection relay consisted of one main unit, two current units and each busbar compartment fitted with one arc optical light point sensor.

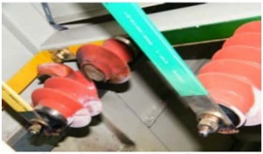

Fig. 5.1A Surge Arrestor of Phase A Failure

On the 22 April 2010, at 08:16 in the morning, the incoming feeder CB501 of secondary side of the main power transformer No. 1 was tripped and opened by the arc protection relay.

After site investigation and fault analysis by protection engineers, it was concluded that the surge arrestor of phase A of 10kV PT panel was exploded by possible lighting re-strikes or induced high transient switching voltages, although the feeder OC/EF protection was operated correctly. The photo of damaged surge arrester is shown in Fig 5.1A. This causes a phase to phase busbar fault by arc flash fault cross over busbar of PT panel. The Photo of damaged panel is shown in Fig. 5.1B. The arc protection relay was correctly tripped and opened the CB501 within an overall time of 50ms cleared the fault.

Fig. 5.1B The Phase to Phase Busbar Fault

The current setting of the relay was at 1.3 time of rated transformer nominal current. The light density setting was at 30K Lux. The arc flash protection relay acted correctly as the main busbar protection relay with very fast operation. The damage to the switchgear of the substation was minimized and the recovery of power supply to the customer was achieved in a shortest possible time.

5.2 State Grid Zhejiang Longshi 110/35kV Substation

Fig. 5.2A State Grid Zhejiang Longshi 110/35kV Substation

The 35kV switchboard of the substation was installed with RIZNER arc protection relay which consisted of one main unit, five current units and one arc optical light sensor for each busbar compartments. The substation of Longshi 110/35kV is shown in Fig 5.2A.

The 35kV busbar operational configuration is as such that busbar 1 and busbar 2 were running in parallel with bustie CB closed. Both outgoing feeders 3528 and 3530 on the busbar 2 were connected with small hydro power stations.

On the 17 June 2011, at around 15:30 in the afternoon, an earth fault was occurred at the phase A of PT panel on the busbar 2. At 15:31:37 the earth fault was developed into a phase A to phase B fault. The arc protection relay detected an arc flash light above 50kLux and with a fault current of 14.6A at busbar 2 incoming feeder. The relay tripped and opened busbar 2 incoming CB and the bustie CB, at the same time the outgoing feeders' CBs 3528 and 3530 were also tripped correctly. The overall fault clearance time from the time of detecting the phase A to phase B fault to the tripping signal issued was 150ms.

Fig. 5.2B PT Insulation Breakdown Failure

After the site investigation and fault analysis by protection engineers, it was concluded that the PT insulation breakdown was the cause of the phase A to the ground fault, and the quickly developed into a phase to phase fault. The tripping logic was correct designed and the current setting of 1.2 times of In at 6A with an arc flash light setting of 50kLux were acceptable. The arc protection relay was operated fast and correct to minimize the fault damages.

6. Conclusions

To minimize the lost and/or injure of human lives and the damage of power utilities' property, the main protection of MV busbar is highly recommended as part of the standard design code in China. This will be in line with the international practice and relevant IEEE/IEC standards and coming up Chinese GB and DL standards.

As an alternative to the busbar differential protection, the busbar arc protection scheme has its distinct advantages, particularly in retrofitting of MV switchboard projects.

Simplicity, sensitivity, high speed, flexibility, reliability and selectivity are key features of arc protection relays. Several typical applications are discussed and summarized.

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