

RELIABLE ARC FLASH DAMAGE MITIGATING SYSTEM IN MV SWITCHGEAR

Young Woo JEONG
 LSIS Co., Ltd. – Republic of Korea
 ywjeong@lsis.com

Hyun Wook LEE
 LSIS Co., Ltd. – Republic of Korea
 hwleea@lsis.com

Seog Won LEE
 LSIS Co., Ltd. – Republic of Korea
 seakwonl@lsis.com

Kil Young AHN
 LSIS Co., Ltd. – Republic of Korea
 kyahn@lsis.com

Young Geun KIM
 LSIS Co., Ltd. – Republic of Korea
 youngk@lsis.com

ABSTRACT

The arc flash in switchgear is the most severe condition and the conventional protection system is inadequate for this accident. So many arc flash damage mitigating systems have developed and are being adopted to switchgears and controlgears more and more recently.

We developed a reliable arc flash protection system (APS) for MV switchgear. The system consists of arc protection module for conventional digital multifunction protection relay and the protection relay which has only arc detection function, arc eliminator which make 3 phase short and earth in very short time and arc light sensors.

Several APS makers devised their system with different criteria and detailed structure. And it is very rarely but if it occurs, the mal-operation of APS bring about big damage. APS has many factors to consider should be prepared and revealed by the manufacturers themselves before the establishment of a good standard.

This APS has not only the equivalent arc mitigation property of other manufacturers but also has distinguished reliable properties. During the development process, we adopted a special communication protocol for the APS to avoid the mal-operation and patented several functions were applied to enhance the reliability and consumer

convenience. It has a reliable arc detection algorithm, a prevention scheme of mal-operation, good safe structural function for maintenance and can be re-used. With many tests at company lab and independent test high-power lab, reliability of the APS had revealed. We launched this reliable APS and several customers adopted the system. Up to now the systems are under operation and show good performance. With this system, LSIS carried out several turn-key project and the results were successful. Also these actual adoption gave us some technical insights of the field and points to improve. In this paper the unique characteristics and reliability of general functions of the APS will be explicated. Essential technical difficulty for arc eliminator will be discussed.

INTRODUCTION

The temperature of an electrical arc can reach up to 20,000 K and the energy of the arc is converted into heat, pressure and radiation. An electrical arc is transited into four steps compression/expansion/emission/thermal and reach its maximum pressure within 10~15ms after the ignition of the arc. So it looks like an explosion.

When arc flash accident occurs in the switchgear, typically it has a power of about 8~60MW. And arc flash is eliminated after 4~7 cycles for instantaneous operation and

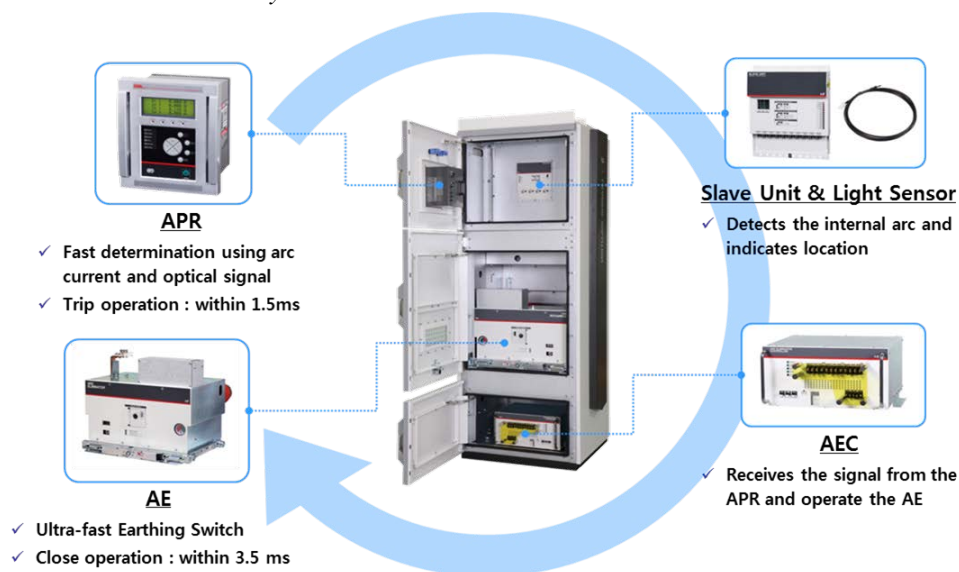


Figure 1 The composition of LSISAPS

300ms for delayed operation with time coordination with the combination of conventional protective relay and circuit breaker. These are insufficient to protect people and facilities.

Arc flash make a damage to the installed electric power equipment and economic loss by outage of electricity and sometimes injure human. Conventionally to protect human life from arc flash accidents, the switchgear mechanically rigid, having compartment and arc flow vent is used. However fundamentally switchgear itself cannot prevent the damage of the equipment, and it is a passive method that has a burden of enlarging the switchboard and increasing the price.

In order to actively and effectively eliminate arc flash accidents in the switchboard, global makers develop and sell APS, and the adoption to switchboard has been continuously extended and proved effective. Mostly APS make decision with a strong light and large current of arc flash. When arc flash happen, the APS divert the fault current to high speed earthing switch with galvanic contact then cut off the current with circuit breaker. For APS, speed and reliability are very important. In this paper, we introduce the effective APS of LSIS and some technical issues for its performance.

COMPOSITION OF APS

The arc energy is proportional to the magnitude of the voltage, the current and the holding time. Since the magnitude of the fault voltage and current cannot be controlled, the holding time must be minimized in order to reduce the arc energy. The temperature and pressure caused by the arc reach the maximum value within 10 ~ 15 ms after ignition of the arc, so that the damage can be minimized by extinguishing the arc before that. The APS introduced in this paper eliminate the arc within 5ms and its configuration is as follows.

In order to detect and remove arc flash at high speed, an arc protection relay and an arc bypass switch (arc eliminator) are essential. Arc relays detect arc flash light and fault currents at the same time and respond only to 'AND' conditions for faster detecting than conventional relays. Determination of the arc fault within 1.5ms and issue an operation command to breaker and arc eliminator.

Arc Light Sensor

There are two types of optical sensors that detect arc flash: a point sensor that receives light only from the lens located at the end of the sensor, and a loop sensor that receives light from the surface of the sensor and transmits it to the arc protection relay. Each sensor has advantages and disadvantages. Point sensor can detect the location of an accident, but many sensors need to be installed. Loop sensor can detect light of several sections with one sensor, but accident location is unknown. The point sensor is equipped with a diffusion lens that can receive light evenly at a very wide angle of incidence (over 180 °) at the end, and the transmission of light is carried out by plastic optical fiber. The loop sensor has a transparent outer jacket

of the optical fiber, and arc protection relay has a function to monitor whether the loop sensor is normal connection status or not in real time. And these optical fibre sensors have good electro-magnetic susceptibility.



Figure 2 Point Sensor and Loop Sensor

Arc Protection Relay (APR)

We developed two kinds of APR, one is a high-speed dedicated APR which has only arc detection function and the other is light sensor added conventional digital multifunction protection relay. These relays differ in their operating time due to the protection function and processing sequence, and dedicated relays are usually used in combination with arc eliminators to perform improved arc flash protection.

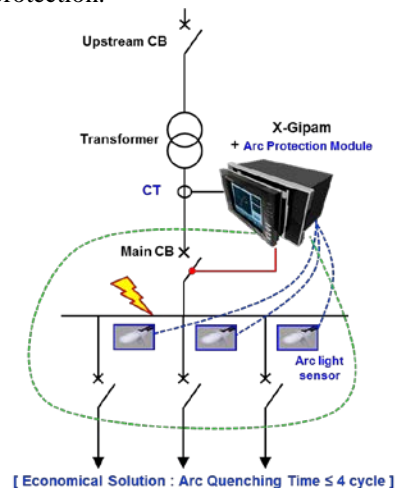


Figure 3 Multifunction APR

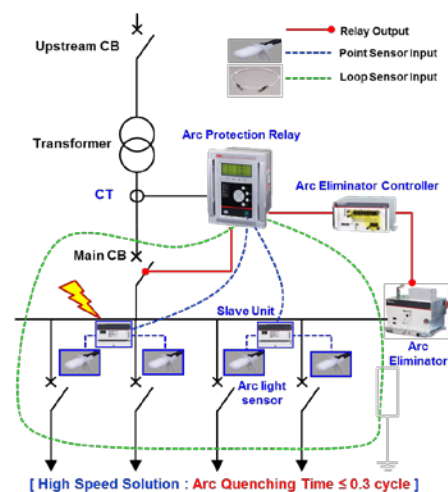


Figure 4 High Speed Dedicated APR

Conventional protection relays judge the accident by signal processing of Discrete Fourier Transform (DFT) for the current signal for 1/2 ~ 1 cycle to prevent erroneous operation. However, APR utilize the instantaneous value of the current signal. In this case, to avoid the possibility of erroneous operation the APR decide as arc flash accident only when both the optical signal and the current signal exceed the set value. In order to improve the fault detection speed and reliability, a unique signal processing technology of LSIS patent is applied. The APR of this paper outputs the signal less than 1.5ms from the instant when arc flash exceed the set light and current level. In addition, the reliability of APR has been proven by customer experience in recent 3 years.

Also we have the slave unit which enlarge the channel of light sensors. There are two types of slave unit, for point sensor and loop sensor respectively.



Figure 5 Slave Unit – Point and Loop Sensors

Arc Eliminator (AE)

The arc eliminator developed in this study is a switch that make 3 phase short and earth less than 3.5ms after receiving the operating signal of APR. With this operation, arc flash current is bypassed to arc eliminator which has a relatively low impedance and harmful arc flash in the air is removed. And then circuit breaker cut off the accident current.

Such high speed operation cannot be achieved by conventional hydraulic, pneumatic or spring mechanism. Only electromagnetic repulsive force or explosive can operate such high speed. LSIS AE applies an electromagnetic repulsive force mechanism to ensure double making shot at maximum current.

Electro-magnetic field analysis was performed to calculate the repulsive force. The optimum shape was derived by calculating the thousands of combinations of design variables with the equivalent circuit model analysis software. Also, arc eliminator controller for the storage of electrical energy and monitoring of arc eliminator status information has been developed and applied.



Figure 6 Equivalent Circuit Analysis S/W for Thomson Drive Mechanism (faster than FEM and similar accuracy)

The arc eliminator is equipped with the cradle structure for insertion and withdrawal in the switchgear. Insertion and withdrawal of the arc eliminator can be performed in case that the power line is even live; the contacts of the arc eliminator must be open.

Key performance requirements for arc eliminator are insulation, short time withstand current, short circuit making, closing speed, and mechanical strength. The specification of arc eliminator is shown on Table 1.

Table 1 Specification of developed AE

Voltage Rating	7.2/12 kV	25.8 kV
AC withstand	28 kV / 1 min	60 kV / 1 min
Imp. Withstand	75 kV BIL	150 kV BIL
Short-time withstand current	40 kA / 1 sec	
Making time	≤ 3.5 ms	
Electrical/Mechanical Endurance	2 shot / 10 shot	
Insulation Gas	SF ₆ Gas	
Opening method	Motor/Manual	

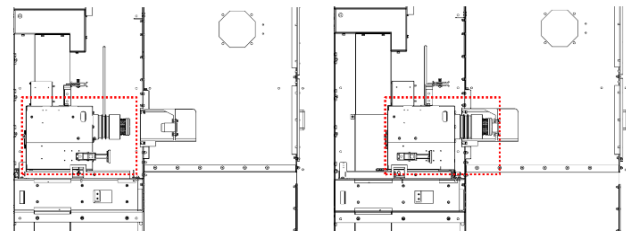


Figure 7 Withdrawal and insertion position of AE

TESTS TO VERIFY THE PERFORMANCE OF APS

The effectiveness of the developed system for arc flash removal in the switchboard was verified at the combination of dummy panel and APS adoption panel with actual arc flash accident. And also short time withstand current test and short-circuit making test are performed with unit AE.

At the test, fault current diverting was completed less than 5ms from arc generation and arc flash was disappeared. The panel was reusable after just small repairing. There was only some smoke and damage of spot. And high-power tests for unit AE showed good results.



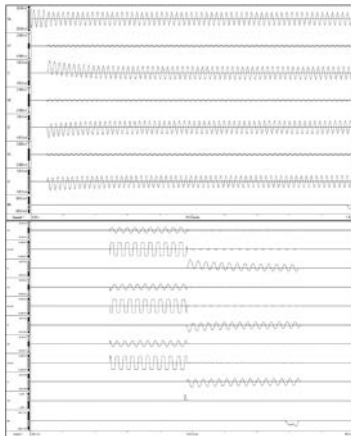


Figure 8 Short time withstand current and making test



Figure 9 Internal arc test with actual panel and APS

We found an important technical issue during the tests. It is that the electrical stresses for AE are different for unit AE making test and actual arc diverting test. At the initial stage of the development, we experienced only for actual arc fault test. At Figure 10, you can find the reason. For unit AE making test, same as other earthing switch, test current start from 0A for all three phases. But at arc eliminating test with actual panels, the fault current initiate with intentional bus bar and after about 5ms increased current of more than 50kAp flow into AE in an instant. So for AE, this situation is very severe condition and very difficult technical problem. For other general earthing switch, this situation is rarely occurring. We found the breakthrough with our patented idea for this technical and finally got the performance to making twice for 40kArms, 104kAp current.

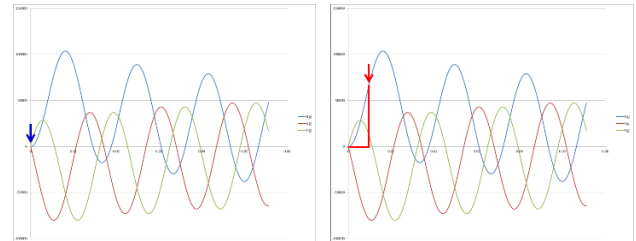


Figure 10 Different making time for general earthing switch and APS in actual panels

CUSTOMER APPLICATION OF LSIS APS

LSIS APS has been sold to customers in Korea since 2016 and has been in normal operation without any malfunctions or defects. Datacenter is major customer and we are expanding customers based on actual application results. In addition, due to the inconvenience of the absence of APS standard of IEC and IEEE / ANSI, we collaborated with related universities, research institutes and national institutions in Korea to establish the association specification. By this we induced the circulation of verified APS products in Korea. It is urgent to establish APS related standards of such as IEC, IEEE, and UL in the future.

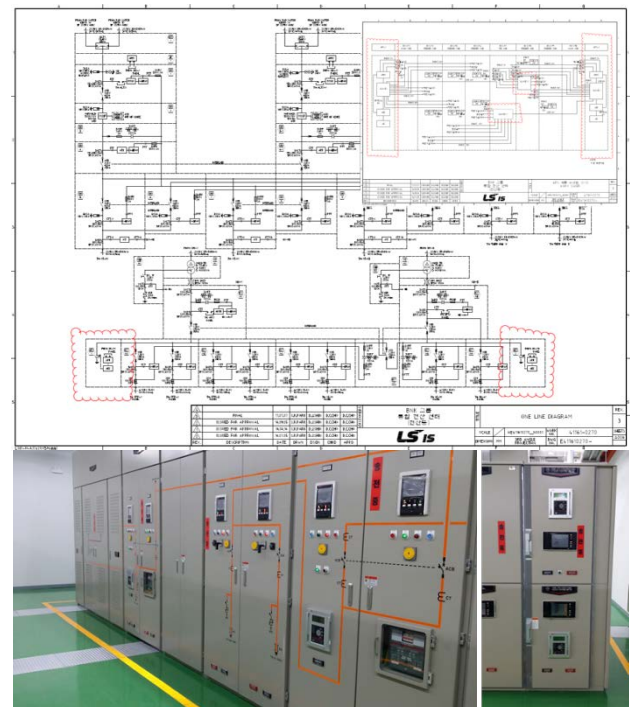


Figure 11 APS installed switchgear of customer

CONCLUSION

In this paper, we introduce APS which is reliable by judging the arc light and arc current by 'AND' condition, enabling accurate high-speed accident judgment and AE using optimized electro-magnetic repulsion mechanism through various analysis. The performance of the product was evaluated with the results of the tests. LSIS APS actively removed the arc accident in the switchboard.

This APS is installed and operated in a number of customers requiring safety and reliability, such as Data center in Korea, and it has been operating and showing excellent reliability until now. APS is a very important system that protects people and equipment and shortens power outage time, but reliability is very important because it can cause fatal problems if malfunctions occur. For this reliability issue, the 'Light & Current' algorithm is very good and the components should be tested and verified through function, EMC, environmental, durability and high power test.

Additionally we introduced an important issue about AE making at actual panels when arc fault happened. So it is apparent that unit AE making test cannot assure genuine performance at actual arc fault. AE should be tested in actual panel arc tests as APS. It is desirable that the international standards about APS should include this.

REFERENCES

- [1] M. Wactor, et al., 2001, "Strategies for mitigating the effects of internal arcing faults in medium voltage metal closed switchgear", Transmission and Distribution Conference and Exposition, Vol.1, 323-328
- [2] R. A. Wilson, et al., 2007, "Tripping with the Speed of Light: Arc Flash Protection", Protective Relay Engineers, 226-238
- [3] D. Gentsch et al., 2010, "New Ultra Fast Earthing Switch (UFES) device based on the vacuum switching principle", *XXIVth Int. Symp. On Discharges and Electrical Insulation in Vacuum - 2010*, 121-124.
- [4] Young-woo Jeong, 2011, "Solution for Internal Arc Flash Hazards in Air Insulated Switchgear", International Conference on Electricity Distribution, 385