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Limiting Arc Exposure in the 480V Systems of Nuclear Power Plants

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1. Introduction

A high energy arcing fault (HEAF) occurred in medium-voltage switchgears (SWGR) in worldwide nuclear power plants (NPPs) recently. HEAF events are not common in nuclear power plants but the operating experience illustrate that HEAFs can present a potential threat to the safe operation of NPPs. As a result, the nuclear power industry has placed a new emphasis on understanding and developing evaluation methods for these events. In this regard, review and study on the 480V distribution systems of NPP was performed to limit arc exposure in the systems. And arc fault mitigation methods were also proposed.

2. Protection design of the 480V load centers in NPPs

The 480 V low voltage system (Fig. 1) is fed from the 13.8kV and 4.16 kV medium voltage system through the distribution transformers. The secondary of the transformer is connected to a 480V load center bus by incoming breaker. The incoming circuit breaker is air circuit breaker (ACB) type and equipped with static type direct trip device which has long-time(LT) and short-time (ST) protection elements. The long-time element protects overcurrent and the short time element protects short circuit fault at the load center bus and backup the short circuit fault at the branch feeders. The branch feeders also protected by ACB. The motor feeder ACB has long time element(LT) and instantaneous element(IT). The long-time element protects overcurrent and the instantaneous element protects short circuit fault at the motor feeder and motor circuit. The IT element is not activated by motor starting current.

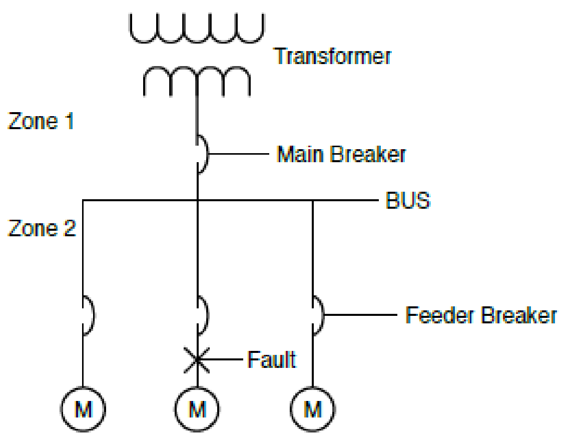

Fig. 1 480 V load center

3. Protection coordination

Load centers(LCs) and motor control centers(MCCs) works with a protection system to limit fault stress on the bus by reducing the time it takes to clear the fault while maintaining system coordination between downstream branch circuit breakers and upstream incoming feeder breakers. The best way to limit fault stress is to clear the fault in the shortest time. However, clearing the fault in the shortest time could sacrifice coordination and lead to broader power outages.

Coordination assures that continuity of service is maximized during any overcurrent and short circuit current fault. The upstream circuit breaker nearest the fault will open to clear the fault while all other circuit breakers in the system remain closed, which provides continuity of service to the unaffected parts of the system. However, if the fault is not cleared quickly due to the coordination time the stress caused by the high energy generated during a fault, it may damage equipment or personal. Fault conditions can cause thermal and mechanical stresses on the electrical system. Thermal stress is a result of the energy dissipated in the system during a fault and can be expressed as let-through energy (I^2t). Mechanical stress is the result of peak current that causes high magnetic forces that can bend bus bars, whip conductors and break insulators.

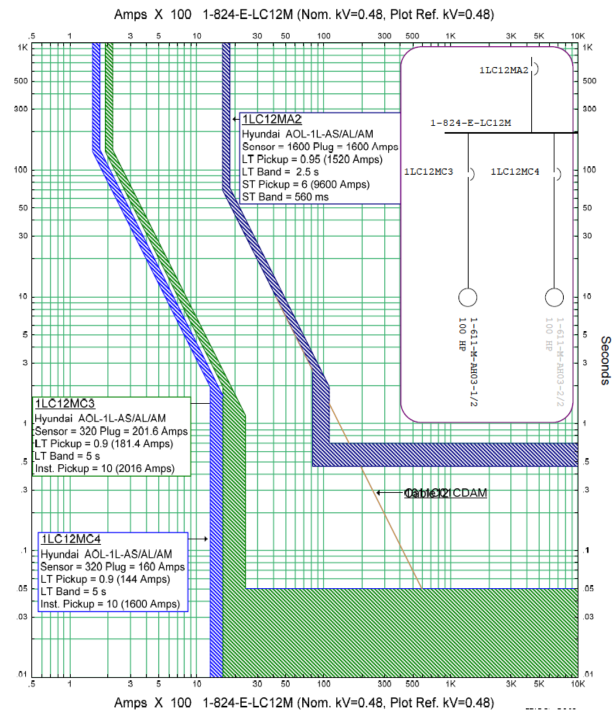

Fig. 2 480 V load center relay coordination curve

Fig. 2 show the ACB coordination curves for a 480 V load center's incoming circuit breaker and branch circuit breakers [1]. Incoming feeder breaker's frame rating is 2,000 A and sensor rating is 1,600 A. The LT trip element of the incoming feeder breaker is set at 1,520 A and ST trip element is set at 9,600 A with time delay 560 ms. The branch circuits are motor feeders. The IT trip elements are set at 2,016 A and 1,600 A respectively with no time delay that means instantaneous trip. The maximum pickup time of instantaneous relay is 40 ms. Therefore, if short circuit fault occurs at the LC bus, the short circuit current (30~40 kA) continues about 560 ms before the trip of the incoming ACB. when short circuit current is less than 8 kA, it takes more longer (2.5 ~ 20 seconds) time to trip. In that case obviously the bus and incoming breaker can't withstand the short circuit current.

4. Arc flash and released energy

Electric arcs produce some of the highest temperatures known to occur on earth-up to 35,000 °F [2]. The intense heat from arc causes the sudden expansion of air. This results in a blast with very strong air pressure. It can completely destroy metal panels and equipment and cause serious physical injury to people in the affected area. Some important definitions of arc flash and related issues can be found in IEEE 1584-2002 IEEE Guide for Performing Arc-Flash Hazard Calculations [3]. Because they release large amounts of energy and heat over a very short period of time, arc-flash events have become the focus of studies to improve safety for operations and maintenance personnel and minimize damage to switchgear panels and equipment [4]. The typical 480 LC of the NPPs shown in Fig.2 is exposed to the arc flash hazard due to the long coordination time.

5. Arc flash mitigation methods

According to Webster's dictionary, mitigation is defined as, "to make milder, less severe or less violent". When applied to electrical system safety, arc flash mitigation involves taking steps to minimize the level of **hazard** and/or the **risk** associated with an arc-flash event. The most effective arc flash mitigation methods look to incorporate "safety by design". Though not as effective as substitution or elimination, the goal of engineering practice is to reduce the degree of hazard. Administrative controls and warnings are less effective because they rely on workers following proper procedures and safe work practices. The arc flash mitigation can be achieved by reducing arc flash energy to a level where permitted tasks can be performed, or locating the worker so that he/she is not subject to harm. [5]. Why is a circuit breaker or fuse always considered in the arc flash analysis? Because arcing time is the key determining factor for arc flash energy. Per the equations in IEEE Std. 1584-2002, arc flash incident energy varies linearly with time. If the duration of the arcing fault doubles, the available energy doubles; halve the duration and you cut the energy in half.

6. Zone selective interlocking method

Zone selective interlocking (ZSI) allows electronic trip devices to communicate with each other so that a short circuit or ground fault will be isolated and cleared by the nearest upstream circuit breaker with no intentional time delay. Devices in all other areas of the system (including upstream) remain closed to maintain service to unaffected loads. Without ZSI, the bus fault is cleared by incoming breaker but with the intentional delay due to the coordination with downstream breakers. (see Fig.2). With ZSI, the upstream breaker closest to the fault will ignore its preset short-time and/or ground fault delays and clear the fault with no intentional delay. Zone-selective interlocking eliminates intentional delay, without sacrificing coordination, resulting in faster tripping times. This limits fault stress by reducing the amount of let-through energy the system is subjected to during an overcurrent [6].

7. Conclusions

Switchgear bus protection is made by bus differential relay (device no. 87B) in the medium voltage systems. However, it is not recommended in the low voltage systems. That because there are too many branch feeders and no spaces to install dedicated CT for the differential relay. But, now days digital type protective trip devices (relays) are provided for low voltage LCs and MCCs which are equipped with communication function. In that sense, ZSI method is recommended for the low voltage LCs and MCCs of the nuclear power plants in Korea.

ACKNOWLEDGMENT

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