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Arc Flash Hazard Mitigation Applied in Switchgear with Air Magnetic Circuit Breakers

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Abstract**:** The proposed paper covers the installation and testing of an Arc Protection System inside metalclad switchgear with air magnetic circuit breakers. The testing of the Arc Protection System on air magnetic circuit breakers at a High Current Test Lab came about as the result of the installation of the Arc Protection System at a large fossil power station on Staten Island, NY. Due to the close connection between the generator and the station auxiliary transformer and 4.16kV switchgear, conventional relay applications did not provide fast enough clearing times to protect personnel from severe injury and equipment from catastrophic damage from the large available fault currents.

I. INTRODUCTION

Overcurrent protection schemes rely on time delay to coordinate the upstream relay with the downstream relay. Minimum time delay required to accomplish this coordination can vary from 0.2 to 0.4 seconds which can introduce unacceptable levels of incident energy (cal/cm^2) in applications involving medium voltage metalclad switchgear. On medium voltage systems with high available fault current, bus differential relays are often applied to provide faster fault detection times in the order of 10 to 20 milliseconds. Both overcurrent and bus differential relays rely solely on current for detecting faults inside of switchgear with the latter method requiring large quantities of CT's and extensive wiring.

An Arc Protection System using inputs from CT's on the main breaker and an clear optic fiber detects and operates when both instantaneous overcurrent and a large amount of visible light occur as the result of an arc flash fault inside of the switchgear bus, feeder cable or breaker compartments. The Patented Solid State Arc Protection Relay utilizes a clear looped optic fiber to detect light and 1A or 5A current transformer inputs for peak current detection allowing it to operate in less than 2.5 milliseconds. The logical Anding of both the current and light eliminates the need to coordinate the Arc Protection Relay with other time or instantaneous overcurrent protective relays. This paper will also address the routing of the optic fiber loop and setting considerations that are required to adapt the Arc Protection Relay to installations involving air magnetic circuit breakers.

II. REDUCING EQUIPMENT DAMAGE AND IMPROVING PERSONNEL SAFETY

Interest in an arc protection relay was first generated in Europe because IEC Switchgear does not have insulated bus bars where as ANSI Switchgear has insulated bus bars. Flashovers between bus bars in IEC Switchgear due to rodents and bus bar contamination resulted in severe failure of switchgear compartments. In order to reduce the damage to IEC switchgear resulting from internal flashovers, a secure Arc Protection Relay was designed and developed over eight years ago.

While ANSI Switchgear is different from IEC switchgear in that the bus bars are insulated, flashovers have become a major concern as the result of NPFA 70E-2004 becoming the "Standard for Employee Safety in the Workplace". NPFA 70E-2004 adopted the IEEE Standard 1584-2002 as the recommended calculation method for determining incident energy (cal/cm^2) and it is used to determine the Personal Protective Equipment (PPE) that is needed at different levels of incident energy. IEEE Standard 1584-2002 "IEEE Guide for Performing Arc-Flash Hazard Calculations" incorporates further testing to establish calculation methods for determining incident energy at low and medium voltages. With OSHA regulations for Safety in the Workplace, NEC citing NFPA 70E as a guide to quantifying Arc-Flash Hazards and Insurance Companies becoming more concerned about personnel safety around energized electrical equipment, there is a need to do more than just "become compliant with these standards." That need is to mitigate personnel exposure to the flash hazard by using various means including:

1. Remotely locating control switches and instrumentation away from energized equipment.
2. Increasing the working distance by utilizing remote racking devices for circuit breakers.
3. Reducing the clearing time by using bus differential protection or zone selective interlocking.
4. Utilizing an Arc Protection System to reduce the detection time for flashovers to 2.5 milliseconds.
5. Only allowing maintenance to be performed on de-energized equipment.

While Arc Resistant Switchgear funnels the incident energy safely out of the switchgear, it is interesting to note that it does nothing to reduce the available incident energy or to reduce the Personal Protective Equipment (PPE) requirements.

III. REDUCING THE ARC FLASH TIME

An arc flash in metalclad switchgear caused by high available fault currents will rapidly generate a large amount of light in the area of flashover. Since metalclad switchgear by definition has barriers between the breaker, bus, cable and instrument compartments the light intensity maybe confined to the faulted compartment or reflected through openings caused by severe damage to the compartments and the barriers that separate them. In addition to traveling rapidly, light travels in a straight path unless reflected off surfaces that subsequently disperse it in other directions including around corners

If a high available fault current is detected without the corresponding detection of light, the fault is downstream from the switchgear. If a large quantity of light is detected without the detection of current greater than the full load rating of the main bus, the light source is from something other than a flashover in the switchgear. In either case, no action is taken by the Arc Protection Relay. If the current is above the bus rating and a larger amount of light than normal background light is detected, the Arc Protection Relay activates the trip outputs. The Relay has two galvanically isolated, high speed IGBT semiconductor outputs, and a relay output.

The total fault clearing time when using the high speed outputs is 2.5 milliseconds plus the operating time of the upstream circuit breaker. Vacuum circuit breakers operate times can vary depending on the manufacturer but are typically 3 cycles or 5 cycles. For air magnetic circuit breakers the operate time is typically 5 cycles. For older oil circuit breakers, the operate time is typically 8 cycles. For both vacuum and oil circuit breakers the fault current from downstream faults is interrupted by contacts that are contained in a confined medium from which no light escapes. In the case of the air magnetic circuit breakers, the fault current is interrupted by the breaker main contacts and is dissipated into the arc chute. The arc current is extinguished when the alternating current crosses the zero point of the sine wave. As the arc current travels up the arc chute, both ionized gases and light are dispersed.

IV FUNCTION OF THE ARC PROTECTION RELAY

The Arc Protection Relay uses a high quality glass fiber with a clear plastic outer sheath that can be routed up to 200 feet throughout the switchgear. The optic fiber has a minimum bending radius of 50mm. Although the optic fiber is non-conducting, it should not be placed in contact with the high voltage bus because hot surfaces can melt the fiber and the build up of any contaminants on the fiber over time could become conductive. Contaminant build up on the surface of the optic fiber is not a problem as light only needs to be exposed to two and a half inches of the optic fiber in order for it to be transmitted to the Arc Protection Relay. The optic fiber is looped back to the Arc Protection Relay which detects the light from either end. The advantage of having the optic fiber looped back to the arc protection relay is in the ability of the relay to periodically check the continuity of the optic fiber by sending a test pulse through the fiber loop. A failure to detect the test pulse results in an Internal Relay Failure (IRF) alarm. Damage to the optic fiber in one place does not prevent the Arc Protection Relay from operating during a flashover as the light will travel in a radial direction back to at least one of the fiber optic inputs of the Arc Protection Relay. Furthermore, damage to the optic fiber during a flashover does not hinder performance either since light is more easily transmitted through the ends of the optic fiber than it is through the side walls.

The light captured by the optic fiber is amplified and compared to a pre-selected reference. Once the light exceeds the set reference level, a light signal is activated. When an automatic reference level has been selected, the relay forms the reference level based on the background light intensity measured by the optic fiber. When a manual reference level has been selected, the relay forms the reference level based on the value set by a potentiometer (Light Ref. Level Adj.) on the front panel. The automatic mode should be selected when changes to background light are gradual or slow-changing. The manual mode should be selected when changes to background light are rapid or unpredictable.

In normal service, the optical arc flash system is supervised by single-phase fault detectors (ANSI Device 50) by placing the Trip Condition key switch on the front panel in the IL & Light position. With the Trip Condition key switch in the IL & Light position, both the optical and overcurrent functions must be activated before a trip output signal is issued.
If tripping is to be activated by light only, the overcurrent signal can be set constantly active by means of the Trip Condition key switch on the front panel. When a trip signal is delivered, the trip outputs are set in the activated state until the RESET pushbutton on the front panel is pushed or a reset signal is applied to the RESET input on the back of the relay.

The Arc Protection Relay can be furnished with Extension Units that allow the number of optic fibers to be increased, thus extending the Trip Condition key area to be protected and allowing localization of the fault by inspecting just the area covered by the optic fiber that detects the arc. A maximum of five extension units can be linked to each of the two RJ45 output ports. One Extension Unit handles two optic fiber loops and another Extension Unit handles up to eight radial lens sensors. The radial lens sensors are connected to the Extension Unit by coated optic fibers. The radial lens sensors allow the protected switchgear to be divided into smaller areas but have the disadvantage of not being periodically checked for continuity.

V. TESTING THE ARC PROTECTION SYSTEM ON AIR MAGNETIC BREAKERS.

In November 2006, the Arc Protection Relay was tested on two switchgear cubicles. One cubicle had a General Electric MagnaBlast 13.8-500-5H-1200 (15kV Class, 500MVA, 1200A) air magnetic (vertical lift) circuit breaker and the other cubicle had a Westinghouse 50DHP-250-1200 (5kV Class, 250MVA, 1200A) air magnetic circuit breaker. The purpose of the tests were to see what effect the arc chutes would have on the Arc Protection System when fault currents up to 20,000 amperes are interrupted by air magnetic circuit breakers.

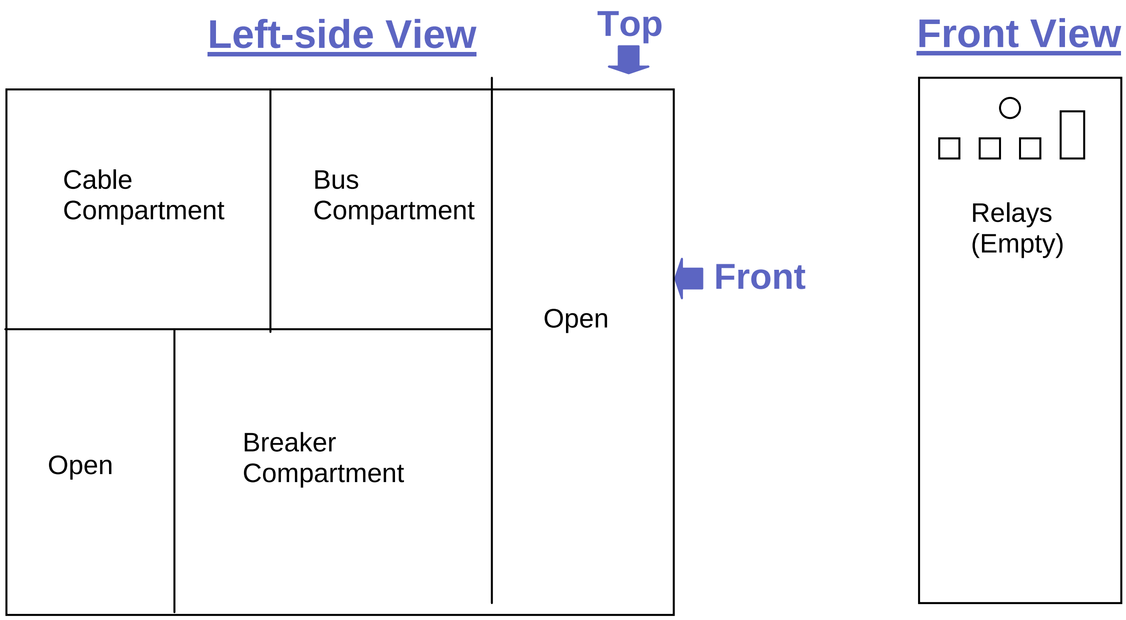

Figure 1: General Electric MagnaBlast Circuit Breaker

On the General Electric MagnaBlast circuit breaker, nine (9) Arc Protection Relays were tested simultaneously with the Relays setup into three groups of 3 to test different fiber optic routings and sensitivity settings at the same time. In each group of three, the Background Light Reference Level Adjustment of the units was set such that one unit each was tested at minimum, maximum and midway between minimum and maximum. Three sets of optic fiber were looped through the breaker and main bus compartments. The optic fiber sensor groups were laid out in three distinct patterns with some in a clear plastic ¼” OD hose for added protection.

1. Across the bottom of the structure away from the arc chutes
2. Along the side of the structure as it is installed in new switchgear allowing for easy removal of the breaker
3. Along the back of the structure also allowing for easy removal of the breaker

Another Arc Protection Relay with eight (8) radial lens sensors was also tested. The radial lens sensors were placed in the breaker compartment in the vicinity of the arc chutes and in front of the circuit breaker. The following three phase current interruption tests were performed at 13.8kV.

Test Number	Average Symmetrical Current	Average Total Current
18	8.44kA	12.5kA
19	16.0kA	16.2kA
20	16.9kA	25.4kA
21	17.0kA	25.7kA
22	20.6kA	31.5 kA
23	20.2kA	26.6 kA
24	20.4kA	26.1 kA
25	20.6kA	24.8kA

The Arc Protection System was tested with the Trip Condition key switch in the Light Only Position. Trip activity was inspected after each test and adjustments were made between tests where necessary. Proper light detection tests were routinely conducted between current interruptions tests to ensure that the Arc Protection Relays would operate for an actual arc flash occurrence. A flash camera attachment was used to simulate an arc flash.

The optic fiber loops did not sense sufficient enough light to operate the Arc Protection Relays in either the breaker or main bus compartments when the Background Light Reference Level Adjustment was set from minimum to maximum for the current interruption levels in Tests 18 through 22, 24 and 25. The radial lens sensors did not detect enough light to operate the Arc Protection Relay in either the breaker or main bus compartments for current interruption levels in Tests 18 through 22, 24 and 25. During Test #23, a cable connected to a main bus bar pulled out of the connector causing a flashover. All Arc Protection Relays detected the arc flash including one of the relays that had its optic fiber loop broken as a result of the cable fault.

Figure 2 shows the MagnaBlast circuit breaker racked into the breaker compartment with the back metal sheet removed. The openings on the top of the arc chutes allow gas and pressure from the arc interruption to escape. A radial lens senor was mounted over the top of the left arc chute. Figure 3 shows the MagnaBlast circuit breaker in the disconnect position. In order to allow removal of the circuit breaker without breaking the optic fiber, the optic fiber loop is fastened tightly to both side walls and a back wall flange above the breaker. Figure 4 shows the optic fiber in the background behind the chain.

 

Figure: 2 Figure: 3

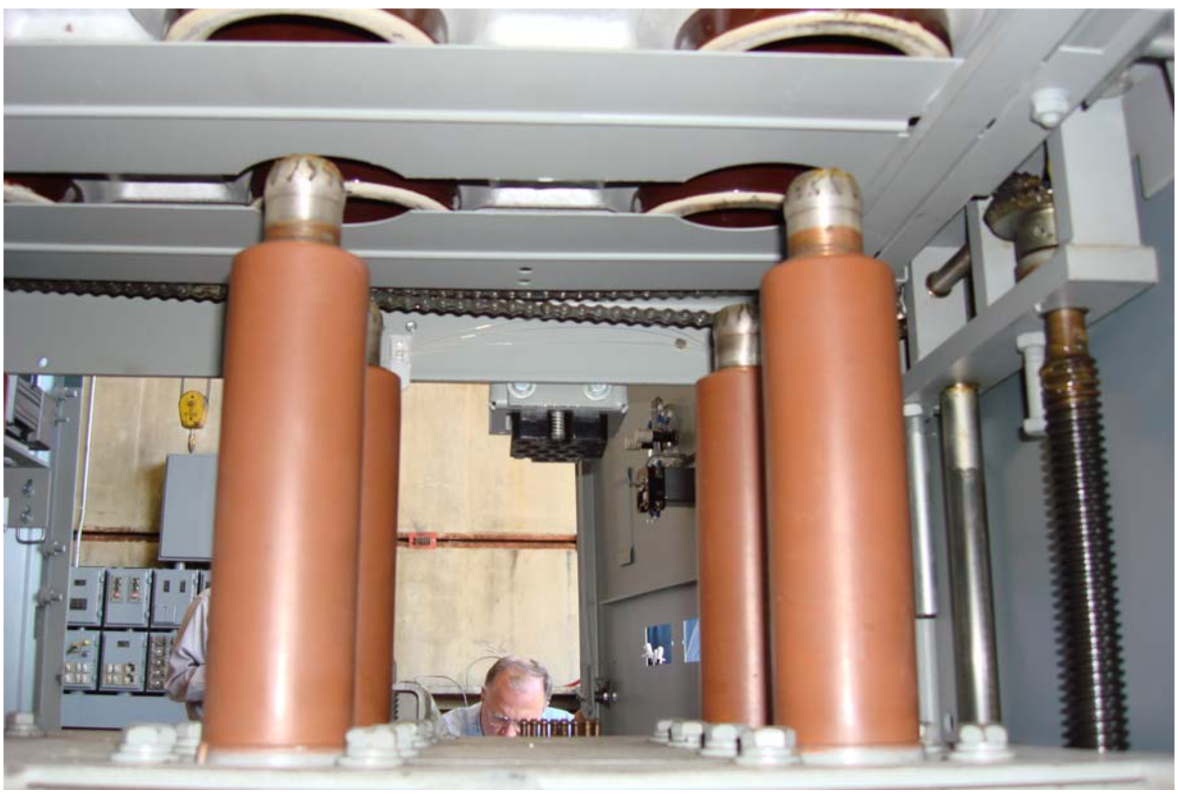

Figure 4

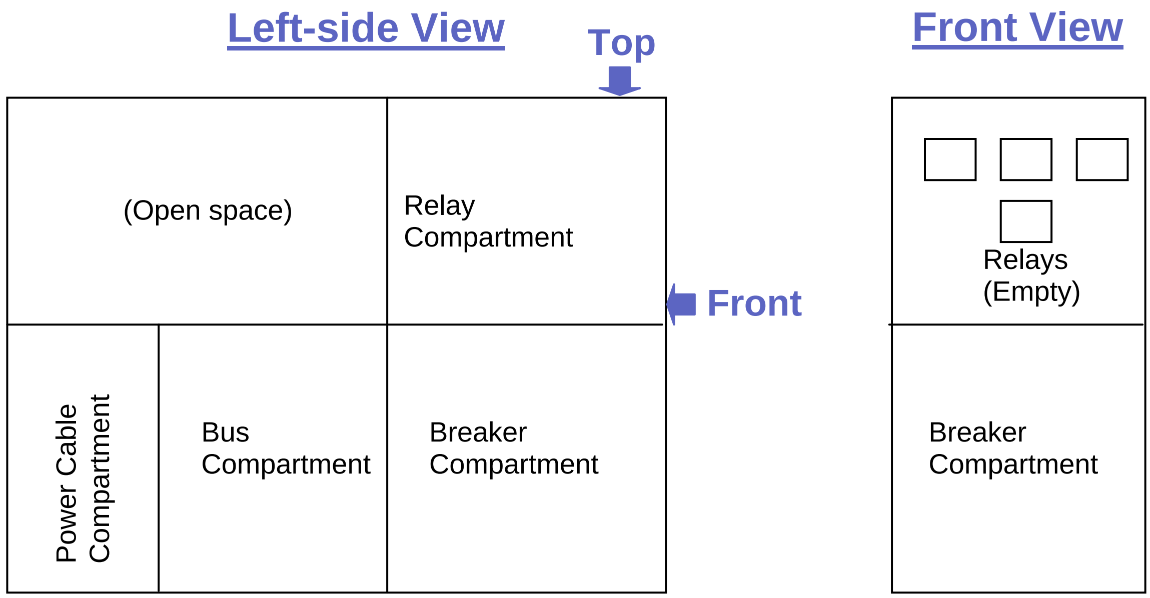

Figure 5: Westinghouse DHP Cubicle Structure

On the Westinghouse DHP circuit breaker, nine (9) Arc Protection Relays were tested simultaneously with the Relays setup into three groups of 3 to test different fiber optic routings and sensitivity settings at the same time. In each group of three, the sensitivity settings of the units were adjusted such that one unit each was tested at minimum, maximum and midway between minimum and maximum. Three sets of optic fiber were looped through the breaker, main bus and feeder cable compartments. The optic fiber sensor groups were laid out in three distinct patterns with some in a clear plastic ¼" OD hose for added protection.

4 Across the bottom of the structure away from the arc chutes
5 Along the side of the structure as it is installed in new switchgear allowing for easy removal of the breaker
6 Along the back of the structure also allowing for easy removal of the breaker

Another Arc Protection Relay with eight (8) radial lens sensors was also tested. Radial lens sensors were located in the main bus and breaker compartments. The radial lens sensors were placed in the vicinity of the arc chutes and in front of the circuit breaker. The following three phase current interruption tests were performed at 4.76kV:

Test Number	Average Symmetrical Current	Average Total Current
3	2.92kA	3.98kA
5	2.90 kA	3.99 kA
6	2.93 kA	4.02 kA
7	2.94 kA	4.04 kA
9	19.7 kA	29.1 kA
10	10.1 kA	14.3 kA

11	10.0 kA	14.2 kA
12	10.2 kA	14.3 kA
13	16.5 kA	23.4 kA
15	14.1 kA	18.8 kA

During Test #9, the Westinghouse DHP breaker failed to interrupt the 19.7 kA test current. The DHP breaker is rated 250MVA and at 4.76kA, it's interrupting ampere capacity is 30.3kA. The optic fiber loops and radial lens sensors detected sufficient light to operate all of the Arc Protection Relays when the DHP breaker attempted and failed to interrupt the 19.7kA current. During Tests 3 through 7, the optic fiber loops sensed sufficient light to operate the Arc Protection Relays when the Background Light Reference Level Adjustment was set at minimum setting for the 2.9kA current interruption. For Test #10 to #13 and #15, the optic fiber loops in the breaker compartment shown in Figure 7 did not sense sufficient light to operation the Arc Protection Relays when the Background Light Reference Level Adjustment was set between midway and maximum. The optic fiber loops placed in the vicinity of the arc chutes sensed sufficient light to operate the Arc Protection Relays for Tests #10 to #13 and #15. All radial lens sensors detected sufficient light to operate the Arc Protection Relay in the breaker and bus compartments at all levels of current interruption.

Figure: 6

After the current interruption testing was stopped, the Westinghouse DHP breaker was inspected. Figure 8 shows the external damage to the DHP breaker resulting from the failed 19.7kA interruption test. Further inspect revealed that the main B Phase contacts were not properly adjusted prior to the start of the current interruption testing.

Figure: 7

Figure: 8

VI. CONCLUSIONS

The breaker cell design must be studied carefully to determine the best location to route the fiber optic loop sensors and to place the radial lens sensors in order to minimize damage to the sensors. The location of the fiber optic loop sensors is best located along side the arc chutes as opposed to above them.

The setting of the Background Light Reference Level Adjustment relative to the location of the fiber optic loop sensors is critical to security. The radial lens sensors which utilizes the end of an optic fiber is more sensitive to background light than the optic fiber loop sensors which utilizes the side wall of the optic fiber.

The Arc Protection Relay can be effectively applied in Switchgear with 15kV/500MVA GE MagnaBlast Breakers with high to good security at all Background Light Reference Settings.

While the testing of the Arc Protection Relay in Switchgear with 5kV Westinghouse DHP Breakers was not conclusive above 16.5kA, it demonstrated the effectiveness of the Arc Protection Relay to detect excessive light resulting from an improperly adjusted breaker attempting to interrupt fault current.

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BIOGRAPHICAL SKETCH

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