1997 ELECTRIC UTILITY CONFERENCE

SUBJECT VII-I

APPLICATION OF ARC-RESISTANT METAL-CLAD SWITCHGEAR IN POWER DISTRIBUTION CENTERS

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INTRODUCTION

As many utilities switch from free-standing outdoor substation breakers to metal-clad switchgear, the Power Distribution Center (PDC) is increasingly evaluated as the preferred method of acquisition and installation. The PDC is viewed as a simple method of reducing installation costs and avoiding an organizational burden, thereby adding value to utility customers, particularly those with diminished in-house engineering and installation resources. Reduced real estate requirements and improved aesthetics are also valued for installations in residential areas. Coupled with this trend is a movement toward arc-resistant switchgear, which presents special problems for PDC applications. This paper discusses both trends, and describes the ABB solution for integrating arc-resistant switchgear into Power Distribution Centers.

THE MOVEMENT TOWARD POWER DISTRIBUTION CENTERS

A PDC is a prefabricated, modular, skid-mounted enclosure for switchgear and auxiliary equipment. As a self-contained unit, it is completely assembled at the factory. Primary switchgear and control applications include low and/or medium voltage switchgear and motor control center enclosures; relay panel enclosures; and RTU and SCADA enclosures. With integral transformers, close-coupled to switchgear or with bus duct connections, a PDC can serve as a complete, enclosed unit substation. Typically, a PDC is provided with station electric service that includes a panelboard, interior and exterior lighting, power outlets, and appropriate HVAC systems. A PDC also can include a battery and charging system, emergency equipment (eyewash fountains, fire suppression systems), and convenience facilities (work areas, toilets). The PDC is an alternative to on-site building construction (usually concrete block) with separate acquisition and installation of electrical subsystems. A PDC is also an alternative to purchasing, installing and connecting outdoor types of loose electrical subsystems for new substations or distribution system expansions. Figure 1 shows the exterior appearance of a typical PDC.

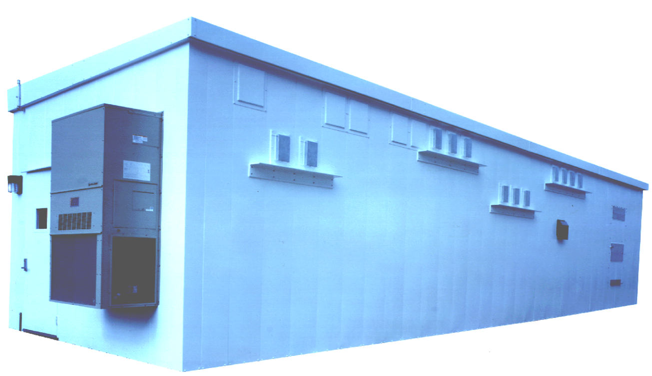

Figure 1. Typical PDC exterior view

PDC Construction

A PDC must comply with rigorous industry standards and local building codes, in addition to applicable standards for switchgear and other enclosed systems. As a portable building, it can be constructed from a variety of materials, including steel panels, aluminum or fiberglass. Self-framing interlocking wall and roof panels are attached to a structural steel base. Material selection and finish depend on application requirements, which can include very rugged, corrosive or hazardous environments, and stainless steel is occasionally specified. Modular construction minimizes costs while maintaining good dimensional and application flexibility. Roof structures are often designed to accommodate roof-mounted primary entrance bushings and overhead bus supports. The resulting enclosure can be designed for extreme ambient temperature and humidity environments, while allowing the use of lower cost indoor switchgear and electronic equipment within the PDC. The entire structure, with all contents installed, is supplied on skids for easy shipping and efficient field installation.

Figure 2 illustrates typical PDC construction.

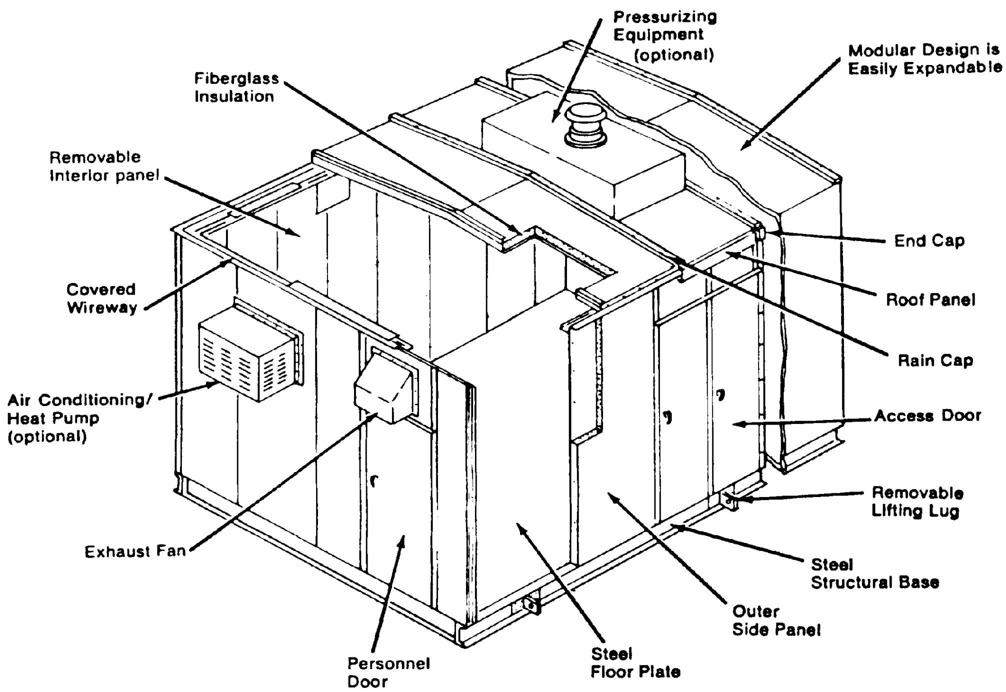

Figure 2. Typical PDC construction

Comparison to Conventional Outdoor Switchgear Enclosures

Enclosure evaluation centers around the issues of effectiveness for the application, initial installation costs, and total life cycle costs. Most major switchgear suppliers offer a line of sheltered aisle switchgear in single-row or double-row arrangements that comply with NEMA 3R requirements for outdoor installation. The overall design provides weather protection and good economy of space, but is limited in application flexibility and room for auxiliary equipment. A separate enclosure must be sourced for each type of electrical equipment. The outdoor enclosure usually requires job-site interconnection of major equipment, control wiring, main bus and external connections. Even the internal bus requires assembly at shipping splits, and outdoor aisles must usually be assembled in the field.

In comparison to conventional concrete buildings, there is no difference in the electrical equipment that can be installed in a PDC. The manufacturer is simply responsible for all equipment inside the PDC, instead of the separate solicitation, evaluation and sourcing of the building, switchgear, battery systems, bus duct, etc. The complete PDC package is designed and engineered by the manufacturer, whereas the purchaser must perform or subcontract this work. The PDC has minimal foundation requirements, usually curb or pier types. Conventional buildings require full slab foundations and job site leveling by the purchaser of individual pieces of equipment. A PDC can be provided with hinged rear doors for access to power terminations. Conventional buildings must be 25-40% larger to permit access to the switchgear bus and terminations. Other solutions require job-site interconnection of major equipment, control wiring, the main bus and bus duct, and grounding system, usually with first time connections at the job site.

A PDC is easily adaptable to overhead or underground conduit systems, whereas conventional slab construction means that exact conduit locations must be planned well in advance, greatly limiting the flexibility to make changes. A PDC often arrives in a single shipment (depending on size), is usually unloaded in one hour, and can be stored indefinitely as an integral unit with "built in" protection against the environment. Other solutions require the purchaser to provide for receiving and storing multiple units made at different times by different suppliers. This often involves redundant handling for storage, trucking to intermediate locations, and protection during storage from pilferage or other loss, or from lost time due to weather delays. In contrast to PDCs, installation of conventional buildings and equipment usually requires many union crafts, all with foremen and helpers. Modular PDC construction results in convenient expandability as the distribution system grows. If an investment in expansion room is not made in concrete buildings during initial installation, future growth is even more expensive.

In the case of either conventional concrete buildings or standard outdoor switchgear, the purchaser or contractor must coordinate and provide for field labor to install and interconnect and test all equipment. The PDC is completely wired and tested at the factory, from a single set of drawings, and the customer can complete many pre-energization tests before installation. After functional testing and inspection, changes can be made in a controlled factory environment. In either case, experience has shown that up to four times the man-hours must be allotted for site equipment installation because of the additional work done in the field, while a PDC arrives complete, pre-tested and ready for installation.

Summary of Advantages

Key advantages are (1) single source responsibility and coordination of multiple subsystems, (2) economics, and (3) environmental compatibility. *Sourcing* is improved because one purchase order can be issued to a single PDC supplier for a turnkey system, including mechanical and electrical design, enclosure fabrication, acquisition and integration of electrical subsystems, and equipment interconnection and testing. All of this activity is performed in a controlled factory environment. *Economics* are usually advantageous for several reasons. Site preparation, on-site equipment storage, field assembly, erection, interconnection and testing services are greatly reduced in comparison to alternative power distribution installations. Less advance engineering, specification, acquisition and coordination effort and resources are required, since much of this work is delegated to the PDC supplier who maintains expertise in these areas. Additionally, costs are lowered because installation space is usually lower, and because the PDC is a portable building that is not regulated or taxed as a permanent improvement. *Environmental considerations* favor the PDC to the extent that a smaller package can be supplied, and appearance can be more aesthetically pleasing.

INCREASING DEMAND FOR ARC FAULT PROTECTION

Only slightly behind the trend toward Power Distribution Centers in the growing interest in arc-resistant switchgear. Awareness of the dangers of an internal arc fault is underlined by OSHA standard 1910.269 for protective clothing for electrical workers, and by the increasing presence of related advertising in trade press. In an increasingly global utility environment, there is heightened awareness of international standards which already provide for arc-resistant switchgear construction and testing. The US market is also characterized by growing emphasis on life cycle cost evaluations which include safety, maintainability and repair costs. A proposed ANSI standard C37.20.7 is now under consideration by an IEEE Working Group (PAR 1405), as the US industry formally addresses this trend.

Causes and Effects of Internal Arc Faults

A number of causes of internal arc faults have been documented and are recognized by the proposed standard. These include improper maintenance, mechanical and interlock failures, failures to follow operating procedures, gradual component or insulation breakdown, operation outside the rating envelope of the switchgear, and introduction of foreign objects or rodents, among other causes.

The most destructive effects of an internal arc fault are caused by the rapid pressure increase in an enclosed compartment. An arc burning with a temperature of 10-20,000^{o}K quickly heats and expands the air in the enclosed space. This pressure increase is a function of arc voltage, current, the number and duration of the arcs, and the volume of the enclosure. The rapid onset of the maximum pressure value (in only 10-15ms) results in explosive forces. Thermal effects include the burning and vaporization of copper, steel and other materials in the enclosure, and the emission of fire and hot, possibly toxic gases. In conventional metal-clad switchgear, the result is catastrophic to nearby personnel and equipment. The extensive damage also means high repair costs and down time.

Draft 5 of Proposed ANSI Standard C37.20.7-19xx

The proposed ANSI standard will be applicable to metal-clad switchgear (C37.20.2-1993) and metal-enclosed switchgear (C37.20.3-1987). The standard is founded on the international standards, but adapted to US practices, and is currently planned to be optional. The current draft is scheduled to be reviewed again by the Working Group in May, 1997. The proposed ANSI standard establishes rated types of arc-resistance which are levels of protection based on accessibility to personnel: Type T-1 (access at the front only), Type T-2 (access to the entire perimeter), and Type T-3 (access around the perimeter, plus protection between adjacent internal compartments). The standard also prescribes test arrangements and procedures, and sets criteria for successful tests.

The proposed ANSI standard defines the *Rating Basis* as the rated short time current of the equipment. The Rated Arc Duration is defined by two test circumstances. Test 1 is a 10 cycle (160ms) arc fault test to verify the ability to contain explosive forces until the expanding gas can be relieved in a controlled manner. Test 2 is a burn-through test with a 1 second duration, to verify adequate resistance to arc erosion that would otherwise perforate switchgear walls and panels.

The tests are based on fully-rated voltage and current. The arc is initiated by a thin metal wire. Cotton fabric indicators verify protection from flames that could cause severe burns or ignite clothing. In successful tests, doors and panels do not open (bowing and distortion is allowed); parts which could be hazardous do not fly off; no doors, panels or other structural surfaces are perforated by an arc; fabric indicators do not ignite; and ground connections remain effective.

Issues Under Consideration by the IEEE Working Group

Several technical issues must still be addressed by members or the IEEE working Group before a standard can be recommended. One hurdle is the inability of domestic test facilities to maintain full rated symmetric current for a 1-second burn-through test, without overcompensation at the beginning of the test. A related issue is the inability to consistently supply the required peak current when testing at lower voltages. It is also difficult to sustain an arc in compact 5kV switchgear due to phase spacing, which may lead to broader test voltage ratings, perhaps based on actual phase spacing in the equipment being tested.

Current ANSI switchgear design standards specify a rated permissible tripping delay of 2 seconds, which conflicts with the proposed pressure withstand and burn-through test durations of 160 milliseconds and 1 second, respectively. This issue must be reconciled with laboratory arc testing capabilities, and with common relay protection settings. Since the explosive threat of an arc fault is manifested in only a few milliseconds, and since the vast majority of relay and back-up breaker applications clear a fault in less than 250 milliseconds, it may be most practical and beneficial to the industry to recommend a standard for arc-resistant testing which does not relate to the rated tripping delay of the switchgear.

Other issues for discussion include recommendations for the exact placement of the cotton fabric indicators, and application guidelines based on testing in minimum room space and development of an overall solution for the switchgear room to address reflected heat, over-pressure, collateral building damage and the elimination of hot, possibly toxic gases.

ABB Development Approach

The ABB decision to develop arc-resistant metal-clad switchgear was based on the availability of extensive practical experience within the ABB family, the desire to add value for US customers by helping them address the growing emphasis on safety and life cycle cost evaluations, and the need for a single, competitive product line to meet the requirements of all of North America, including the Canadian market which already required arc-resistant protection to a considerable extent.

The result of the ABB development program was SafeGear™ arc-resistant metal-clad switchgear, a product in full compliance with current metal-clad switchgear standards, but also arc-resistant as defined by current EEMAC and proposed ANSI standards. Key features of the design include reinforced doors to withstand the internal pressure surge, a pressure vent system to safely relieve the overpressure and hot gases through roof-mounted flaps, an internal collection chamber (patents pending), dedicated and isolated low voltage instrument compartments, double side wall construction for superior burn-through resistance, and closed-door operation of circuit breakers and auxiliary devices (PTs, CPTs, Fuse units).

Development objectives specifically included the availability of both 1-high and 2-high configurations common to utility and industrial customers to minimize overall floor space and therefore control the profile and building costs of PDC enclosures. In addition to meeting this goal, a reduction in switchgear depth of 10 inches was achieved without compromising other dimensions, and a method of stacking 1200 amp breakers and auxiliary equipment over 3000 amp breakers was developed to further economize floor space requirements for PDC applications.

ABB Experience and Application Guidelines

In any indoor application of arc-resistant switchgear, design considerations can include protection from potential injury due to heat and gases reflected from low ceilings; the possibility of over-pressure in the electrical room; clearance for top-mounted vent flaps to operate; and adequate volume to avoid excessive back-pressure, which in turn could rupture the switchgear at internal chambers or worse, at the perimeter where the safety would be compromised. Other considerations include protection against accumulation of possibly toxic gases, and protection for overhead equipment such as trays for primary and control wiring.

Installation considerations for arc-resistant switchgear can include a number of topics: switchgear configuration (1-high vs. 2-high); determination of building volume and design; product ratings; installation practices (cable feed, accessibility by personnel, etc.); and maintenance and operation practices, among others. The arc-resistant construction of SafeGear requires that one or more vertical sections in a lineup be open to the top to exhaust expanding hot gases from the internal collection chamber, through the roof. Ceiling height is therefore a consideration due to the potential dangers of reflected heat, exhaust gases and particles. Initial analysis of infra-red imaging (10 cycle tests) indicates peak exhaust gas temperatures in the range of 2300-2500 ^{O}F, extending 3-6 feet from the exhaust ports, but quickly diminishing in less than 10 milliseconds. Based on this data and analysis of high-speed video recording of actual tests, ABB has recommended the following clearances be maintained from the top of the switchgear to the ceiling of the room: 4 feet for 23kA fault levels (15kV, 500 MVA); 6 feet for 36kA (15kV, 750 MVA); and 8 feet for 49kA (15kV, 1000 MVA).

Switchgear room ventilation provisions are typically part of building design, and need not be different for arc-resistant or conventional switchgear. A provision can be made for forced venting of the switchgear room after a fault event, to exhaust hot, possibly toxic gases. This is primarily to allow for quick access to equipment by maintenance personnel. Since type T-3 switchgear keeps the fault from propagating throughout the switchgear, thereby limiting the burning material and production of hot gases, more capable venting provisions are not necessary.

ARC-RESISTANT SWITCHGEAR IN POWER DISTRIBUTION CENTERS

In PDC applications, all normal indoor criteria apply, but some parameters become particularly important, and a few new considerations are added. Personnel safety at the front (for type T-1 construction) and rear (type T-2) remains the paramount consideration. The required ceiling clearances place an unacceptable size constraint on PDCs due to shipping height restrictions (typically 16 feet), possible installation in aesthetically sensitive areas, and the cost of a taller enclosure. Vent flaps must not compromise weatherproofing, and a minimum overall footprint (which is aided by the close coordination and integration of subsystems) greatly reduces building costs. The compact nature of the resulting enclosure is a low volume that could either create back pressure in the switchgear, or which could rupture from overpressure during an arc fault. While this is not a factor of the arc-resistance of the switchgear (in similar conditions, it would also happen with conventional switchgear), it is desirable to have a fully integrated arc-resistant system.

Solutions could include larger (especially taller) buildings, or perhaps blast deflection plates mounted at the top of the switchgear. The change in building height was determined to be impractical due as explained above. Blast deflection plates were eliminated from consideration for two reasons. They do not provide a comprehensive solution that addresses building height, overpressure and handling of exhaust gases. They also would mandate extensive testing of various types and sizes of PDC enclosures to assure that structural failure of the blast barriers or buildings would not occur.

The Plenum Solution

The ABB solution is to use a plenum, a sealed duct which extends across the top of the switchgear and covers all arc exhaust flaps. This duct allows for opening of the flaps due to the pressure generated by arc fault conditions, provides room for the gases to continue to expand, and channels the gases out of the switchgear building through a wall penetration and weatherproof vent. This solves the potential problems with weatherproofing; building volume; reflected heat; protection of cable trays and other equipment in the PDC; and the possible accumulation of hot, toxic gases. It also complements overall PDC design philosophy by providing a completely factory tested system, including the arc-resistance of the entire package.

The plenum is constructed from 11 gauge steel with bolted flanges at each vertical section to achieve the required strength, rather than a continuous section of unformed, unbraced steel. An arc-resistant seal is provided by gaskets at each flanged joint. Figures 3 and 4 show the location and construction details of a plenum mounted on arc-resistant switchgear in a utility PDC installation.

The size and shape of the plenum is driven by practical application constraints. The depth must cover front and rear vent flaps, but must not preclude access to primary and secondary cable entrances. The vent flaps must have clearances for unimpeded operation. The volume and shape must not create excessive turbulence or otherwise result in back pressure that would compromise the integrity of the switchgear doors or exterior panels for type T-2 construction, or internal barriers and the collection chamber for type T-3 construction. In actual ABB testing, the plenum solution has been proven in ratings to 36kA at 15kV (for types T-2 or T-3 construction).

Figure 3. Arc-resistant switchgear in PDC

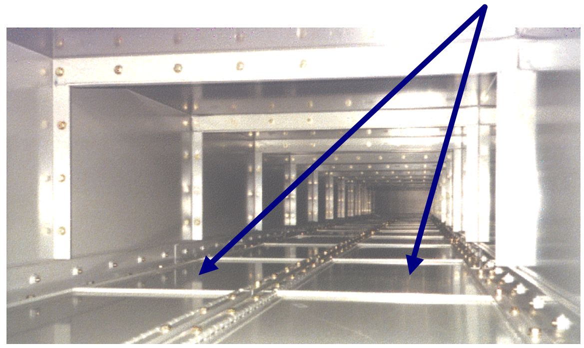

Figure 4. Plenum interior

One additional problem in PDC applications is the accessibility of rear compartments for power cable terminations. Standard PDC rear access doors are not designed to meet the requirements for type T-2 construction. In the most common PDC arrangements, SafeGear rear compartments are provided with arc-resistant rear barriers which can be removed through the rear PDC doors to gain access to power cables. Alternatively, the switchgear can be positioned within the PDC to provide an aisle behind the switchgear for access to rear compartments and power cables, if desired. These solutions complete the integration of arc-resistant switchgear technology into PDCs.

SUMMARY

A PDC provides a self contained, pre-engineered and pre-fabricated solution to housing switchgear and auxiliary equipment. Of particular significance are (1) the ability to provide rugged, reliable enclosures, (2) the ability to acquire the complete outdoor equipment package from a single supplier with design and engineering responsibility, and (3) the ability to provide complete pre-delivery interconnection and testing. An ANSI Standard is being prepared to offer users a method for specifying and assuring the benefits of arc-resistant switchgear. Arc-resistant construction provides the best personnel protection available, as well as the ability to reduce equipment damage, repair costs and down time. The use of a plenum solves PDC application problems associated with reflected heat, overpressure, building size and removal of exhaust gases. We believe ABB is the first to offer a fully-tested plenum solution to take full advantage of the benefits of arc-resistant switchgear in Power Distribution Centers, and we are pleased to have made this investment on behalf of our customers and the power distribution industry.

REFERENCES

IEEE Proposed Standard C37.20.7 (P1405) Draft 5 (August, 1996), Guide for Testing Metal-enclosed Switchgear for Internal Arcing Faults

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