Design Considerations to Enhance Safety and Reliability for Service Entrance Switchboards

Robert P. Hansen, P.E., PhD
GE Specification Engineer

Introduction

Switchboards are a widely used type of equipment in low-voltage electrical distribution systems. They are typically used as the service entrance equipment for a variety of facility types. While consideration of safety and reliability must be given to all parts of an electrical distribution system design, the impact of choosing the correct design options to enhance safety and reliability is magnified at a service entrance. This white paper discusses simple switchboard configuration and equipment options that, when incorporated in the design phase of a project, can cost-effectively help reduce arc flash incident energy or reduce worker exposure to arc flash energy without reducing reliability.

The scope of NPFA 70E (reference 1) does not include design of distribution systems, but it does contain references to design practices and equipment options aimed at reducing arc flash energy or worker exposure.

> ***Article 130 – Work Involving Electrical Hazards***
> 130.5 Arc Flash Risk Assessment, informational note #3: "… Equipment and design practices are available to minimize the energy levels and the number of procedures that could expose an employee to high levels of incident energy. …"
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> ***Informative Annex O – Safety Related Design Requirements***
> O.1.2 "… The facility owner or manager, or the employer, should choose design options that eliminate hazards or reduce risk and enhance the effectiveness of safety related work practices."
>
> O.2.3 "Incident Energy Reduction Methods. The following methods have proved to be effective in reducing incident energy:
> (1) Zone-selective interlocking.
> (2) Differential relaying.
> (3) Energy-reducing maintenance switching with a local status indicator.
> An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to operate faster while the worker is working within an arc flash boundary, as defined in NFPA 70E, and then to set the circuit breaker back to a normal setting after the potentially hazardous work is complete."

Below, we will describe some of the design practices and options that can be applied to commonly used non-compartmented, service entrance switchboards. The application of zone-selective interlocking (ZSI), including instantaneous ZSI, and maintenance switching will be among the specific strategies discussed.

Background

In the one-line below (figure 1), a utility, or end-user-owned transformer is connected to a service entrance switchboard. The switchboard has a main breaker and any number of group or individually mounted feeder breakers. The over-current protective device (OCPD) that is upstream of the transformer would typically be a fused switch or a medium-voltage breaker. The protection settings (in the case of the medium-voltage breaker), or fixed time-current characteristics (in the case of the medium-voltage fuse) determine how quickly an arcing fault will be cleared on the transformer secondary side down to the low-voltage main device terminals. For a given system, that upstream device clearing time will determine the arc flash energy on the line-side of the low-voltage main breaker. The low-voltage main breaker protection settings are typically chosen to protect the bus on its load side and backup the protection afforded by the feeder breakers to parts of the system below the switchboard. The low-voltage main breaker settings will determine how quickly a load-side arcing fault will be cleared, which in turn influences the amount of arc flash energy on the load-side bus. In many cases, the low-voltage main device line-side and load-side arc flash energies are of different values, in some cases by a large amount, with the line-side energy being the higher of the two.

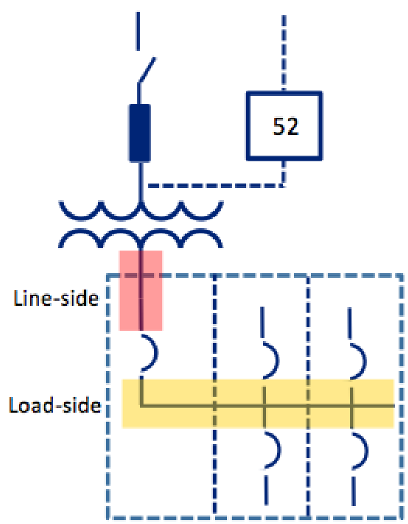

Figure 1.
Typical Service Entrance

As an example, on a 480-volt service entrance fed by a 2,000-kilovolt-ampere (kVA) transformer with standard impedance, the low-voltage main breaker can limit incident energy to below 4 cal/cm^2 when the low-voltage main breaker is allowed to clear arcing faults using its instantaneous response[1]. The incident energy on the low-voltage main breaker line-side would be over 130 cal/cm^2 and have a corresponding arc flash boundary of 36 feet when the transformer primary is protected by a fuse[1]. For non-compartmented switchboards, the highest incident energy calculated anywhere within the switchboard could be reflected on the arc flash labels for all sections in that continuous lineup. This can render the entire switchboard unapproachable while it is energized.

A complete approach for safe design will attempt to minimize both the line-side and load-side arc flash energies. In cases where the owner of the service entrance switchboard owns the transformer and decides what primary protection to apply, protection strategies using the speed of a medium-voltage circuit breaker and relaying can be applied to reduce the line-side arc flash energy. In all other cases where the service entrance switchboard owner may not have the authority to select the substation transformer primary protection device/settings, the strategy of emplacing the low-voltage main section remote from the feeder sections, as discussed in the next section of this white paper, can be used to reduce worker exposure to the higher line-side arc flash energy. Independent of the substation transformer primary protection ownership, the equipment options (ZSI and maintenance switching) discussed in the following section can be used to help enhance safety for workers.

[1] IEEE 1584 calculation using the following inputs: 4160V primary voltage, 50kA utility fault current available, 350A 9F62 series EJO-1 primary fuse (clearing time limited to 2 seconds per IEEE-1584), 2000kVA transformer with 5.75% impedance, 2500A Entelliguard G LV main beaker (50ms clearing time), 32mm switchboard bus gap, 18” working distance.

In the case of a service entrance switchboard with no main device (a "six handle rule" service entrance per NEC Article 230.71), the distinction between line-side and load-side arc flash energy as described above is lost. The low-voltage arcing fault clearing time of the protective device upstream of the transformer will determine the amount of arc flash energy of the entire service entrance bus. For service entrance switchboards without main devices, the protection techniques needed to minimize arc flash energy at the low-voltage service entrance bus are beyond the scope of this white paper. Reference 2 describes one option that could be used.

In a conventional switchboard service entrance design, the main breaker and the feeder breakers are connected by hard bus such that the main section is in a continuous lineup with the feeder section(s). While this is convenient from the perspective of installation, it does have disadvantages when the arc flash energy at the line-side of the main breaker is greater than the load-side arc flash energy. High line-side arc flash energy can increase risks to workers interacting with other parts of the switchboard that are not part of the incoming section. The arc flash boundary for sufficiently high line-side arc flash energy can easily extend past the feeder sections. Main circuit breaker trip unit settings or temporary settings, such as those used by a maintenance switch, only influence the load-side. The elevated line-side energy potentially increases the frequency and duration of exposure for personnel who interact only with feeder sections. In the conventional configuration, there is greater impetus to employ line-side energy reduction methods. The following section will discuss some options for improving upon the conventional switchboard design.

Options for Improving the Conventional Design

Remote Main Breaker Section

Many users now recognize the simplicity and effectiveness of employing a switchboard with a remote main circuit breaker section. In this design strategy, the section that receives the incoming feed from the utility transformer contains only the main circuit breaker, and this single breaker section is cabled to a separate lineup containing the feeder breakers. The concept is to provide distance between the higher arc flash energy normally found on the line-side of the low-voltage main device and the sections on the load-side. With sufficient distance between the main section and the feeder sections, the feeder breaker sections can be outside of the main section's line-side arc flash boundary. This reduces the risk to personnel who interact with the feeder sections, when the main breaker is appropriately set to clear arcing fault currents, and allows workers within the arc flash boundary of the feeder sections to wear personal protective equipment (PPE) appropriate for the incident energy at that location. When interacting with the remote main breaker section, the appropriate PPE for the higher line-side incident energy is still required.

A remote main breaker section can also be used in a retrofit situation. For an existing switchboard using a conventional layout with a main device, a new main breaker section can be inserted between the transformer secondary and the existing main. The protection settings of the new main breaker will determine the amount of arc flash energy at switchboard sections of the original conventional lineup. A service entrance with a main-lug-only switchboard ("six handle rule") can be converted to a single disconnect service entrance by adding a remote main section.

For new construction or retrofit situations, using a circuit breaker in the remote main section helps the owner to take advantage of maintenance switching and ZSI (with circuit breaker feeders). Electrical operation of the main breaker with remote control is also an option to reduce exposure of personnel to arc flash energy.

Line-side arc flash energy reduction methods can be applied to the remote main section to further help enhance safety for anyone interacting with the incoming section. Even if no personnel interact with the remote main section while it is energized, line-side arc flash energy reduction can be desirable to help protect the equipment.

Maintenance Switching

A maintenance switch controls a temporary protection setting on a circuit breaker electronic trip unit and can provide benefits for any switchboard configuration. The temporary setting can be enabled to reduce the arc flash energy of an arcing fault on the low-voltage bus downstream of the breaker that has the maintenance switch function. A maintenance switch is typically enabled when an operator has to perform a task inside of the arc flash boundary. When the task is complete, the switch is set back to its default position which turns off the temporary protection setting. The temporary setting is a second instantaneous pickup setting that must be pre-selected by the user. An arc flash study would determine the appropriate pickup level for the maintenance setting. Because the maintenance setting should be set to a lower instantaneous pickup relative to the normal instantaneous setting, coordination is generally reduced while the maintenance setting is enabled. The local status indicator (or optional remote status indicator) provides visual confirmation (usually in the form of a light) of the maintenance setting state.

Maintenance switching can be used on the main breaker in the conventional or remote main switchboard layouts. Maintenance settings can also be used on feeder breakers to improve protection on other downstream switchboards, motor control centers or panelboards. The switch can be provided on the face of the switchboard section or wired to a location outside of the arc flash boundary. On trip units that communicate with monitoring and control software, the maintenance setting may also be enabled or disabled over the network. The amount of incident energy reduction that is achieved by using a maintenance mode is dependent on the particular system and on the breaker protection settings before the maintenance mode is enabled. A maintenance switch can be provided with new equipment or retrofit to existing equipment with a trip unit upgrade.

Zone-Selective Interlocking

General

ZSI is available as an optional feature on selected electronic trip units in specific breakers. For arc flash safety, the two forms of low-voltage ZSI of primary interest are short-time ZSI and instantaneous ZSI. Each form may be used individually or they can be used concurrently with each other. Both forms of ZSI are specialized protection schemes between two breakers in series, such as a main and a feeder. Multiple feeders may be in a ZSI scheme with one main. The ZSI scheme may also be extended to main-tie-main configurations. Similar to the maintenance switch, ZSI can be provided in new equipment or as a retrofit to existing equipment.

The safety benefit of a ZSI scheme is its potential to reduce arc flash energy on the system between the upstream and downstream breakers in the scheme. An arc flash study is needed to determine the appropriate protection settings to achieve the maximum benefit from the scheme. While maintenance switching is designed as a temporary arc flash energy reduction method (applied at specific times when operators interact with the equipment), ZSI is intended to be active continuously. The details of any ZSI implementation will be specific to the particular vendor and the particular generation of equipment. In the context of a switchboard, a ZSI scheme created between the main breaker and feeder breakers will allow lower pickups (and delays in the case of short-time ZSI) to be set on the main breaker without loss of selectivity. If the feeder breaker senses a fault within the pickup range of the ZSI scheme, a signal informs the main breaker and it will adjust its protection response, allowing the downstream breaker to clear the fault first and preserve selective coordination in the range of fault current where the ZSI is employed. The arc flash energy reduction potential of ZSI is derived from the lower settings (relative to traditional nesting techniques) that can be used on the main breaker. These lower settings allow for the main breaker to respond quicker to arcing faults on the switchboard bus.

Short-Time ZSI

While the NFPA-70E reference to ZSI does not differentiate between short-time and instantaneous ZSI, there are important differences. A trip unit on the upstream breaker with short-time ZSI will use two short-time delay bands that are set by the user. One of these bands is the normal short-time delay band called the unrestrained position. The second short-time band, called the restrained position, is a longer delay band that does not overlap the unrestrained band. If the downstream breaker senses a fault within the range of the short-time pickup, it sends a signal that switches the short-time delay band of the upstream breaker to the restrained position. When applied to a main and a feeder, this allows the main breaker unrestrained short-time delay to be set at a low band without loss of coordination. This can facilitate a lower arc flash energy for arcing faults on the switchboard bus compared to using coordinated short-time settings without ZSI. The amount of arc flash energy reduction possible is, in part, limited by the intentional time delay in the unrestrained short-time delay band. While the short-time ZSI can enhance protection without affecting the short-time coordination, it has no effect on any lack of selective coordination in the instantaneous range where overlap between main and feeder responses invariably occurs. Disabling the instantaneous response of the main breaker is not an option for switchboards that do not have a 30-cycle withstand rating. Thus, using short-time ZSI by itself in a typical switchboard still leaves the designer with the issue of non-selectivity in the instantaneous region.

Instantaneous ZSI

Instantaneous ZSI coordinates the instantaneous response of the breakers in the ZSI scheme. The upstream breaker in an instantaneous ZSI scheme uses its normal (unrestrained) instantaneous protection setting (without intentional delay) when there are no faults on the system or a fault occurs in the zone between the breakers in the ZSI scheme. The upstream breaker response moves from instantaneous to a fixed short-time delay band (restrained position) only if the downstream breaker senses a fault in the instantaneous range of pickup. The restrained position of the upstream breaker gives the downstream breaker time to clear a fault before the upstream breaker commits to tripping. In this way, instantaneous ZSI provides for improved safety by helping the main breaker to clear a fault on the main bus at its instantaneous clearing speed, while also improving instantaneous coordination with feeder breakers by shifting the main breaker response if the fault is below the feeder.

As described above, a ZSI scheme manages the delays used by the upstream breaker. In the case of instantaneous ZSI, the instantaneous response of the upstream breaker moves from no delay to a delay when the downstream breaker also senses the fault. In the case of short-time ZSI, the upstream breaker response moves from one delay band to a longer delay band when the downstream breaker also senses the fault. In the traditional implementation of ZSI, the instantaneous and short-time pickups of the upstream breaker would normally be set above the corresponding pickups of the downstream breakers in the scheme to maintain selectivity (the pickups would be nested). This nesting of pickups forces the upstream breaker to be less sensitive to dangerous arcing currents. A recent new development in ZSI permits the nominal pickup settings of the upstream breaker to be set to the same value as the downstream breaker without loss of selectivity (reference 3). In the context of a service entrance switchboard, this means the pickups (short-time, instantaneous or both) of the main breaker can overlap the corresponding pickups of the downstream breaker where ZSI is enabled. In most systems, this will help the main breaker instantaneous pickup to be set low enough to clear load-side arcing faults predicted by an arc flash study in the shortest amount of time possible for that main breaker. For a given system, clearing an arcing fault on instantaneous results in lower arc flash energy compared to clearing using short-time ZSI. The most comprehensive application of ZSI would use short-time and instantaneous ZSI simultaneously. In GE's offering, the short-time ZSI (as well as the ground-fault ZSI) is included when instantaneous ZSI is ordered. Additional information about instantaneous ZSI, including application examples, may be found in references 3 and 4.

Summary

Each of the design options discussed can be considered as a discrete layer of improvement to the conventional switchboard design. The options can be applied individually or combined in various ways to best meet the needs of a particular situation. This white paper has elaborated on just a few of the design choices and equipment options that can be used to help enhance the safety and reliability of service entrance switchboards. Options such as draw-out mounting with remote racking, remote breaker operation and remote monitoring should also be considered. While service entrance switchboards have been the focus of the white paper, the strategies discussed here can also be applied to non-service entrance switchboards to help improve safety and reliability.

References

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