

Benefits of Limiting MV Short-Circuit Current in Large Data Centers

White Paper 253

Revision 0

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Executive summary

Once IT load levels exceed just a few megawatts (MW) of power, moving more of the electrical distribution infrastructure to the medium voltage (MV) level makes sense. The short-circuit rating of the MV transformers can have a large impact on the cost of the data center and footprint of the switchgear lineups. This paper shows the benefits of limiting this short-circuit current to 25 kA or less and how that allows the use of newer switchgear technologies that offer advantages in size, safety, cost, and reliability.

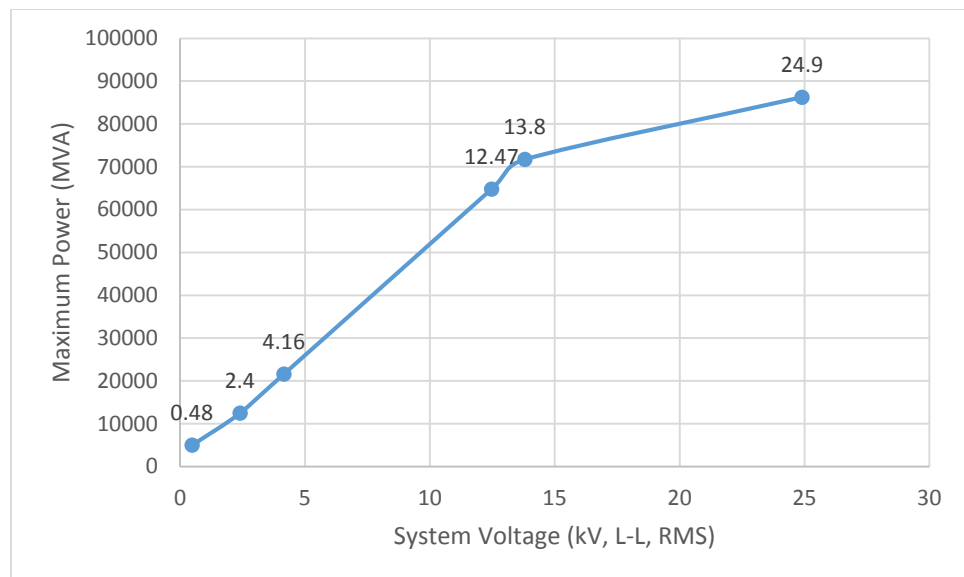
Introduction

The design of data centers, much like the applications and services that they help to provide, is ever evolving. Recent trends in data center design include a focus on scalability & modularity, as well as adoption of open source standards – even for hardware. There also has been a market shift towards larger and larger service provider type data centers with power capacities exceeding 10 MW. The largest data centers now being built exceed 100 MW.

The electrical power distribution system in a data center this large – regardless of the type of IT hardware that is used or on what schedule it is deployed – requires some special considerations, as the need to distribute large blocks of power in a reliable manner impacts the ultimate layout of the system and of the facility. Once total load levels exceed a few MW, low-voltage-centered power distribution systems (e.g., 380-480V) become less attractive, and as load levels continue to increase, less feasible. The obvious response is to move more of the power distribution network infrastructure – including connection points of standby generation, functionality such as auto-transfer systems, etc. – to the medium-voltage level. Since even 5 kV networks can place constraints on the design of an extra-large data center. Of course, while IT gear and other loads operates at LV, then LV distribution will not be eliminated. But the use of more extensive and more complex power distribution networks operating at 15 kV (or even higher) inside the data centers has become increasingly common as a result.

Since power is directly proportional to the product of voltage and current, higher voltage ratings very directly lead to higher possible power ratings for systems. **Figure 1** shows the relationship between maximum apparent power (i.e., MVA) capacity of air-insulated switchgear based on common nominal voltage ratings and common maximum switchgear ratings.

Figure 1
Relationship between max MVA capacity of air-insulated switchgear to common nominal voltage ratings and common max switchgear ratings.



As shown, the capacity increases linearly through approximately 15 kV, and rises somewhat more slowly to 25 kV. While the additional capacity is desirable, there are some drawbacks associated with the move to higher distribution voltages, such as larger and more expensive equipment, at least when considered in absolute terms. If switchgear cost and footprint are considered on a per-kW basis, “economies of scale” at MV may become evident. The need for higher system capacity

may require the use of MV networks, largely rendering the question of “LV vs. MV?” a moot point. But even so, it is still useful to consider how design parameters, such as available short-circuit rating, may affect the switchgear design, and how choices can be made to optimize in terms of both cost and footprint.

Medium voltage (MV) switchgear characteristics

The ANSI medium-voltage circuit breaker switchgear market has long been dominated by air insulated metal-clad (MC) switchgear built to IEEE Std. C37.20.2¹. The withdrawable vacuum circuit breakers these systems use have proven to be reliable and effective, and are available at many different voltage levels and over a wide variety of ratings. MC switchgear is suitable for use in demanding, high-power applications (see **Figure 2**), ranging from utility power generating stations to large petrochemical facilities, pulp and paper mills, and even data centers. Perhaps the most popular alternative to this traditional MV circuit breaker switchgear has been medium-voltage fusible switchgear – or metal enclosed interrupter switchgear per IEEE Std. C37.20.3² – which is less expensive, but also much less flexible in terms of available ratings and protection options. An example is shown in **Figure 3**.

Figure 2

Typical metal-clad switchgear with withdrawable breakers



Figure 3

Typical MV metal-enclosed switchgear



¹ IEEE C37.20.2-2015, *IEEE Standard for Metal-Clad Switchgear*, Institute of Electrical and Electronics Engineers, www.ieee.org

² IEEE C37.20.3-2013, *IEEE Standard for Metal-Enclosed Interrupter Switchgear (1kV-38kV)*, Institute of Electrical and Electronics Engineers, www.ieee.org

While MC switchgear allows for the most flexibility in terms of both application and ratings, there are certain aspects in which it is less than ideal. First, it is – relatively speaking – large and expensive (see the more detailed discussion below). The flexibility of application also means that the switchgear may require significant custom engineering, potentially increasing lead time from order to delivery. Since the design must allow for the breaker to be withdrawn from the gear, cable compartments are typically in the rear of the switchgear, requiring a larger equipment footprint and increased working space requirement around the gear.

Today, however, there are additional options available in the MV circuit breaker switchgear segment, including fixed circuit breaker designs that are smaller, less expensive, and that allow for increased worker safety without compromising functionality or reliability. Consider a comparison between traditional 15 kV-class MC switchgear and shielded solid insulated switchgear (SSIS). In SSIS, the live parts are surrounded first by an insulating layer (e.g., epoxy resin), and then by a conductive layer that is connected to ground³. Other differences between SSIS and MC switchgear will be discussed below. For our comparison, we will consider equipment rated 1200A with a short-circuit rating of 25 kA. Pictures of representative SSIS equipment is shown in **Figure 4**.

Figure 4
SSIS breaker section
(left) and insulated bus
structure (right)



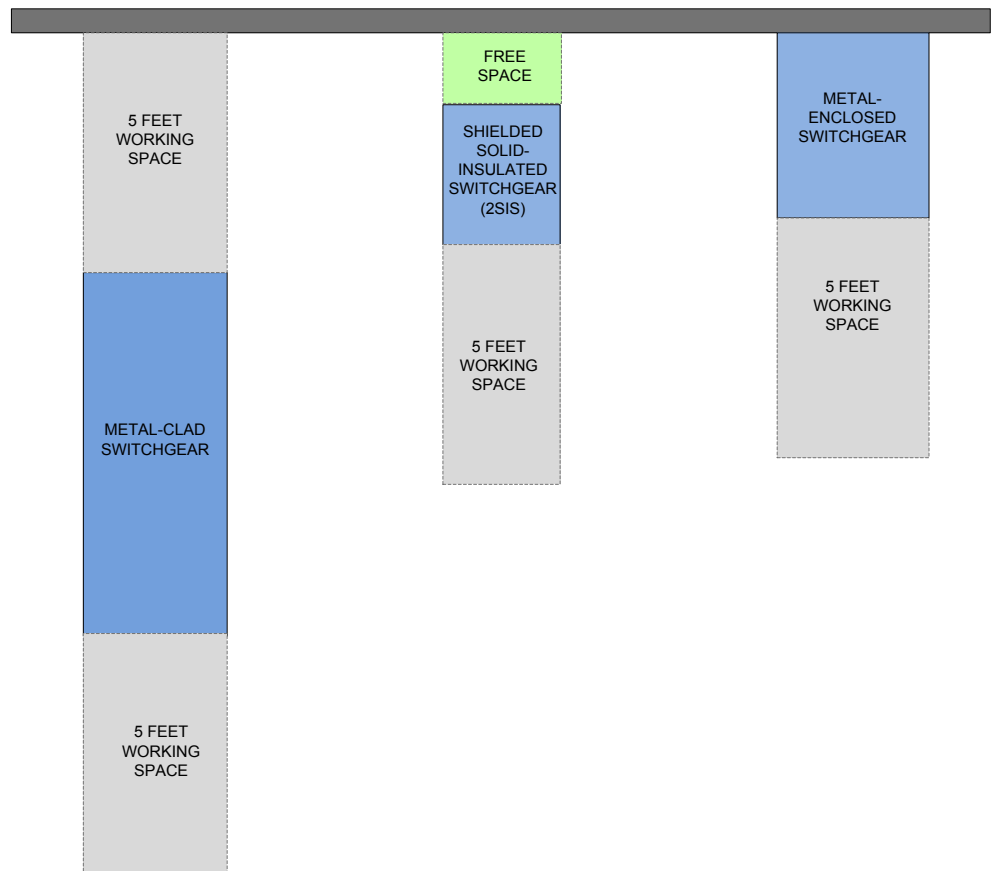
First, consider equipment footprint, where perhaps the most dramatic differences can be seen: the typical MC switchgear section is 36 inches wide and 91 inches deep, taking up a total footprint of 3276 in². The 1200 A SSIS section is 29.5 inches wide and 36 inches deep, for a total footprint of 1062 in². But this does not take into account the “clear working space” around the equipment required by NEC Table 110.34(A)⁴, which is supposed to be kept clear at all times. The working space requirements can vary based on the details of the installation, but the typical minimum “clear working space” required both in front of and behind the 15 kV class equipment would be 5 feet (60 inches). This pushes the total footprint for one section of gear to 36 inches x 221 inches, or 7596 in². Fixed-breaker SSIS requires only front access, so only one 5’ working space is required, though a working space of 18 inches behind the gear is recommended to facilitate replacement of a breaker section should one be required (10cm minimum clearance is required). The total footprint (including work space) of this gear would be 3363 in², only slightly larger than the actual equipment footprint of the traditional MC switchgear. See the illustration in **Figure 5** below.

³ Biasse, J. M., V. Ferraro, G. Wang; Schneider Electric Technical Paper # FP0314, “2SIS Technology in MV Switchgear fits harsh environments and drastically reduces internal arc probability.” Schneider Electric, www.schneider-electric.com

⁴ NFPA 70-2014, National Electrical Code. National Fire Protection Association, www.nfpa.org

Figure 5

Illustration of working space requirements for 1200A Metal Clad and Solid Insulated Switchgear



Note that this is a fairly basic comparison. In some cases, MC switchgear can be built in a “two high” configuration – i.e., one section can contain both an upper and lower breaker – while fixed-breaker switchgear like the SSIS typically allows for only one circuit breaker per section. However, 600A SSIS sections are only 14.75 inches wide, so smaller circuits (e.g., transformer feeders) would require less overall space even with this limitation. (For reference, a 600A feeder is capable of delivering more than 4 MVA at 4160V and over 12 MVA at 12.47 kV.)

As noted in the discussion above, one of the differences between MC switchgear and the newer alternatives such as SSIS is that MC designs allow for the use of withdrawable breakers, while the more compact designs typically use fixed breakers instead. Withdrawable breakers were originally developed because early medium-voltage air and oil-circuit breakers (ACBs and OCBs) required frequent maintenance. ACBs might require maintenance after only a few switching operations, while typical manufacturers’ recommendations called for users to inspect and test the oil in an OCB tank as often as every three months. Modern vacuum circuit breakers can be rated for up to thousands of switching operations and may only require maintenance on a relatively infrequent basis, but the habit of using withdrawable circuit breakers has largely continued in the ANSI market. (Somewhat ironically, some of the maintenance requirements for modern switchgear are driven by the need to maintain, clean, and lubricate parts that allow for the breakers to be withdrawn from the gear.) The increased reliability of modern circuit breakers has made fixed-type switchgear a viable alternative to the traditional arrangement; see this footnote⁵ for a further discussion on this topic.

⁵ Chandrapati, J., V. E. Wagner, and J. K. Stacy; “Moving from Withdrawable to Fixed Circuit Breaker Switchgear in ANSI Medium-Voltage Applications.” To be published in the proceedings of the 2016 IEEE PCIC Conference, Philadelphia, PA.

There has been an increased awareness of electrical safety in industry in general in recent years, particularly involving arc flash hazards. While taking actions such as performing system studies and equipping workers with both proper training and proper Personal Protective Equipment can do a lot to help address the issue, an even better response is to use “safety by design” principles to reduce or eliminate hazard and risk levels before issues arise. Fixed circuit breaker switchgear can reduce risk by eliminating the need to “rack” withdrawable breakers, a task recognized as an arc flash hazard in both IEEE⁶ and NFPA⁷ standards. The presence of integral isolating and grounding switches in fixed breaker switchgear may also reduce risk compared to traditional designs. Gas-insulated switchgear (GIS) or the SSIS also provide some advantages related to the busbar insulation. For both GIS and SSIS, the individual phase busbars may be partially or totally segregated from one another and from grounded parts by a physical barrier that makes it much more difficult to instigate a fault in the system, whether related to contamination, component failure, or accidental contact. “Arc Resistant” air insulated switchgear⁸, which has been tested to show that it can help to contain the effects of internal arcing faults, can help to minimize the effects of such incidents on workers, but internal damage to the equipment resulting from an arcing fault can still be significant. GIS or SSIS can also achieve an “Arc Resistant” rating, but with the added benefit that the probability of damaging arcs (either phase-ground or phase-phase) occurring at all is significantly reduced. This not only provides protection for workers, but also for the equipment itself – possibly helping increase overall system reliability. The shielding around the solid insulation in SSIS gear also provides some degree of protection against shock – it can be rated for Protection Category “PA” according to IEC Standard 62271-201⁹, which means that it is considered to be safe enough to allow for “accidental touching” during maintenance activities. (A part classified to guard against “intentional touching” would have to meet some additional requirements, but the end result would be similar – i.e., the employee is not electrocuted.)

The benefits outlined above do come along with some tradeoffs, primarily involving available ratings of equipment. The SSIS equipment described above, for example, is limited to 1200A continuous current and 15 kV maximum voltage with a 25 kA short-circuit rating. For higher voltages or higher currents, use of traditional MC switchgear or other options (e.g., GIS) is still required, and may still be necessary for the Primary MV switchgear in a large data center. But the size, cost, and safety advantages of the alternatives certainly warrant consideration where they might be appropriate. **Table 1** summarizes some of the key differences between Metal Clad and SSIS Switchgear.

⁶ IEEE 1584-2002, IEEE Guide for Performing Arc Flash Hazard Calculations, Institute of Electrical and Electronics Engineers, www.ieee.org

⁷ NFPA 70E-2015, Standard for Electrical Safety in the Workplace. National Fire Protection Agency, www.nfpa.org

⁸ C37.20.7-2007, IEEE Guide for Testing Metal-Enclosed Switchgear Rated up to 38kV for Internal Arcing Faults, Institute of Electrical and Electronics Engineers, www.ieee.org

⁹ IEC 62271-201:2014, High-voltage switchgear and controlgear – Part 201: AC solid insulation enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV, International Electrotechnical Commission, www.iec.ch.

Table 1

Summary of key differences between MC and SSIS Switchgear

Category	MC Switchgear	SSIS Switchgear
Size (footprint)	Baseline	30-60% smaller
Price (capex)	Baseline	20% less
Breaker type	Withdrawable	Fixed
Maintenance frequency	3-5 years	10 years
Safety	Good	Better
Design & Operability	Isolation by breaker withdrawal; Larger design requiring rear access	Isolation via disconnect; compact design with front access
Reliability	Manual steps to withdraw breaker & isolate circuit; requires use of racking mechanisms and shutter assemblies	Intuitive interlocked operation; no complex racking mechanism or shutter assemblies required; integrated grounding switch

Data center design considerations

Reliability & Tier Classifications

Power distribution infrastructure and design is often centered on the data center's requirements for reliable, uninterrupted power to the IT loads in the facility. Whether the resilience of a power distribution network is measured in terms of "reliability" or "availability"¹⁰ or simply in terms of expected downtime, improvement in the statistical measures of system reliability require more complex power distribution networks. The Uptime Institute provides data center tier classifications that take into account reliability and availability in terms of the number of power distribution paths, redundancy, compartmentalization, maintainability and fault tolerance¹¹, and are summarized in **Table 2**. Each successive tier includes the requirements of the previous tiers. Data center Uptime Tier requirements drive the design infrastructure.

Table 2

Uptime Tiers I-IV characteristics

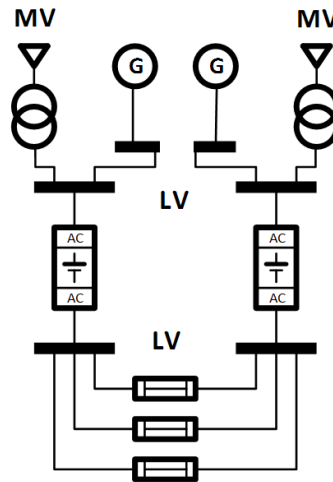
Characteristic	Tier I	Tier II	Tier III	Tier IV
Number of Delivery Paths	1 Active	1 Active	1 Active 1 Passive	2 Active
Redundancy	N	N+1	N+1	2(N+1)
Compartmentalization	No	No	No	Yes
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerance to Worst Event	None	None	None	Yes

¹⁰ IEEE Standard 493-2007, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, Institute of Electrical and Electronics Engineers, www.ieee.org.

¹¹ Turner, W.P., J.H. Seader, V. Renaud, K.G. Brill; "Tier Classifications Define Site Infrastructure Performance." 2008, Uptime Institute, NM.

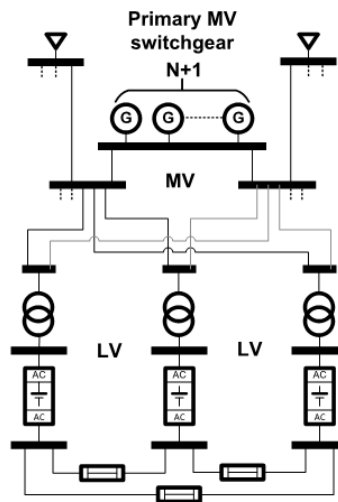
A typical Tier III/IV architecture for a large data center is shown in **Figure 6** below.

Figure 6
Basic Tier III/IV
electrical architecture for
a large data center



The system shown in **Figure 6** has 2N MV generation, 2N LV generation, but also 2N generators and 2N UPS systems. For system capacities above approximately 5 MW IT load, it may be desirable to move to a different architecture to reduce the number of standby generators required and also to manage the high required ratings of switchgear on the LV network. Both of these would tend to drive more of the electrical infrastructure to the MV level. **Figure 7** shows a Tier III/IV system with the generation connected at MV resulting in the need for N+1 (rather than 2N) generators, 2N MV distribution, and tri-redundant LV distribution. The net result is a simplified LV distribution system, but more complexity at the MV level.

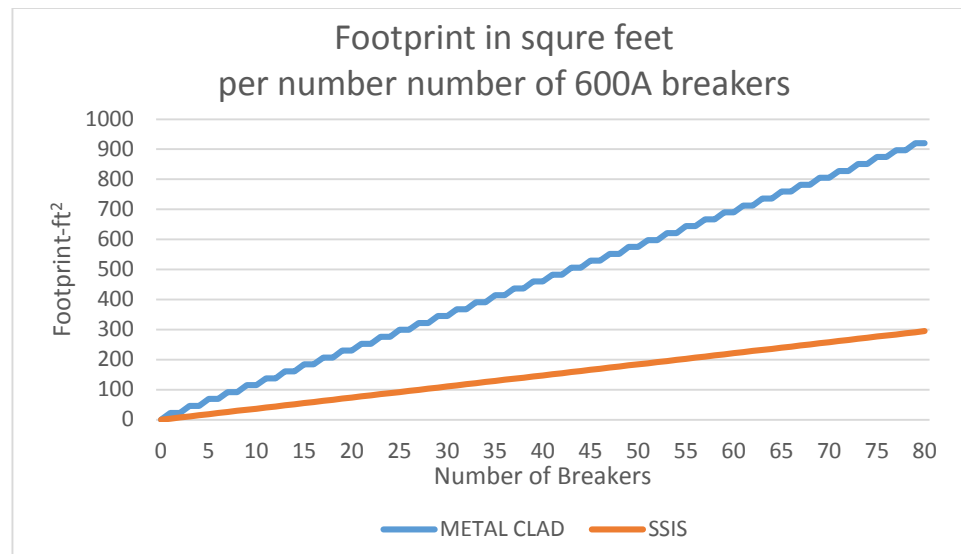
Figure 7
Sample Tier III/IV
electrical architecture for
extra-large data center



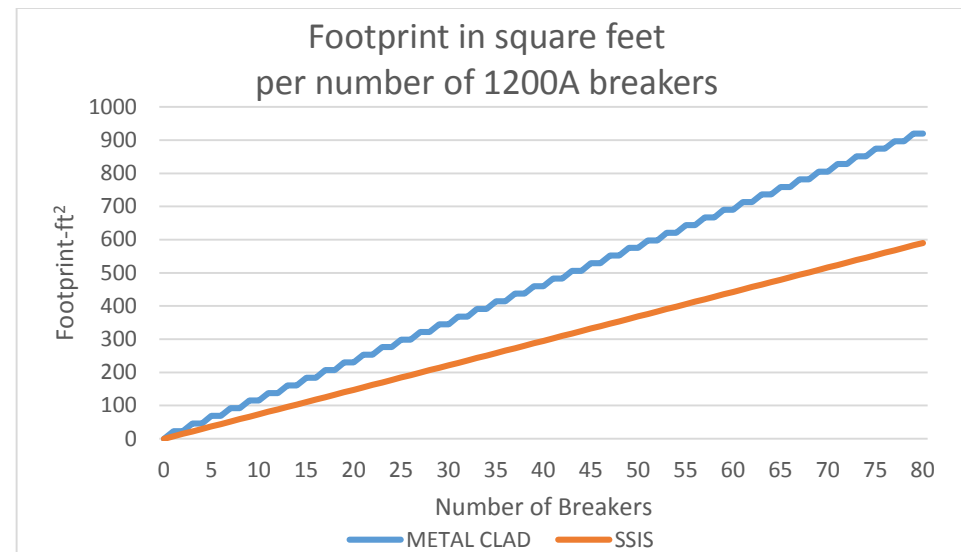
Of course, many other system architectures are also available, but these two show what are to some degree the extreme cases – a system with minimal MV distribution and complex LV network, and a system with a more complex MV distribution level and simplified LV network. The more complex and extensive the MV network, the more breakers and switchgear sections that are required, and therefore the more advantage to be gained by using gear having a smaller footprint. The graph in **Figure 8a and 8b** show total required footprint (not counting the code-required working space) for MC and SSIS switchgear, for both 600A and 1200A feeders. Note that the metal-clad sizing assumes the breakers are applied in a two-high configuration, while the SSIS has one breaker per section. Large data centers can require dozens of MV feeders, making the savings in required floor space quite significant.

Figure 8a

Comparison of required floor space for MC vs. SSIS Switchgear – 600A breakers

**Figure 8b**

Comparison of required floor space for MC vs. SSIS Switchgear – 1200A breakers



Design Practices vs. Short-Circuit Ratings

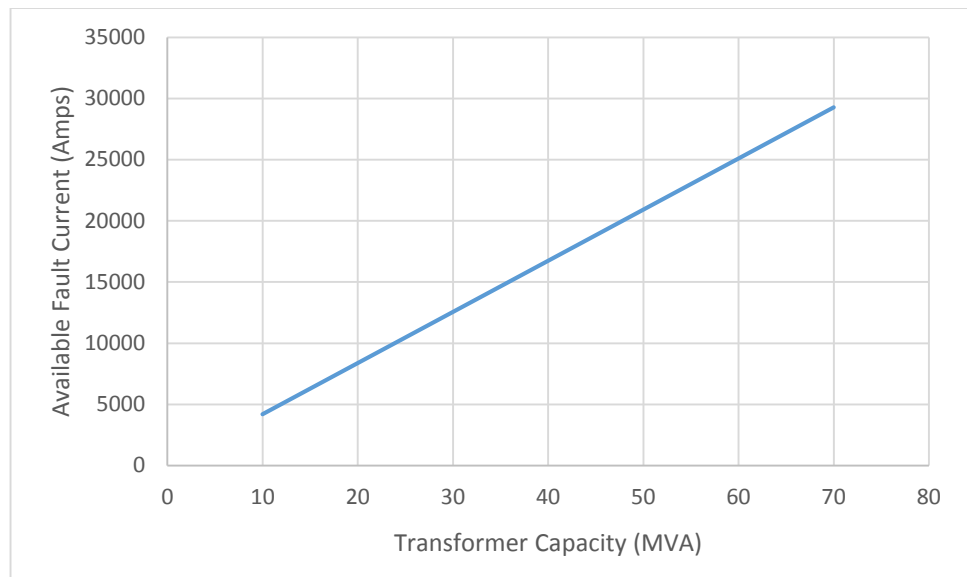
As seen in the previous section, designing for the combination of increased facility load plus desired redundancy can cause the total number of medium-voltage switchgear lineups required to increase significantly. The total size of the facility is not the only consideration, though – it is often desirable to split the facility load into smaller blocks in order to improve reliability (e.g., if all 100 MW of a facility load could flow through a single switchgear, does that become a “single point of failure?”) or for purposes of scalability, as total installed facility load is ramped up over time. The way that a facility’s load is divided also affects the required ratings of the switchgear to be used.

Two ratings are relevant – the continuous current rating and the short-circuit rating. Medium-voltage distribution switchgear typically has continuous bus ratings of 1200A-3000A. At 13.8 kV, this translates to roughly 30-70 MVA, so the continuous rating of the gear does not tend to be a limiting factor. Short-circuit ratings, however, may be a different story. The larger the capacity of a power distribution system, the larger the current that can flow if there is a “fault” or a short-circuit in the system. Circuit breakers must be rated to interrupt the level of fault current available – otherwise, a fault could persist for a long period of time and potentially cause a

great deal of damage. Since breakers can't always react to interrupt a fault immediately (e.g., if the protective relays are programmed with a delay to allow them to coordinate with devices farther downstream in the system), the switchgear must also be rated to withstand the fault current for some defined period of time in order to minimize the level of damage the equipment may sustain during a fault event.

Figure 9 shows the relationship between maximum available fault current and transformer capacity for a 13.8 kV distribution system, based on a typical transformer impedance of 10%¹². These levels will vary depending on the actual distribution voltage level used (12.47 kV, 13.2 kV, and 13.8 kV are common), as well as the impedance of the transformer. They can also vary depending on the operation of the system – operating two similar transformers in parallel would double the available fault current, while closed-transition operation between a utility source and standby generation would result in addition of the contribution of the two sources.

Figure 9
Available fault current
vs. transformer capacity,
13.8 kV distribution
system



For the largest systems and closed-transition operation, fault current levels can approach the maximum 63 kA interrupting rating of standard metal-clad switchgear. One of the trade-offs with the compact switchgear such as that discussed previously is lower available maximum ratings, such as 1200A continuous current and 25 kA short-circuit current at 15 kV. Based on **Figure 9**, for the 30 MVA rating that roughly corresponds to the 1200A limit, the fault current is roughly half of the 25 kA limit for a SSIS switchgear lineup. When SSIS is used in systems with larger capacity (e.g., as secondary MV distribution switchgear) more careful analysis is required to ensure that the equipment is applied within its ratings – the data in Figure 8 is based on an “infinite bus” assumption where calculations are simplified by assuming the utility system has an infinite capacity. Actual values would be expected to be somewhat less.

As shown in Figure 8, 25 kA is projected to be adequate for a fairly wide range of single-source systems. Where multiple sources are intended to be operated in parallel for an extended period of time, it is clear that short-circuit calculations must take this into account. But what about “closed transition” operation, where two sources may only be operated in parallel for a short period of time – e.g., when transitioning from a standby generator source back to the utility after a momentary outage. Some in the industry believe that such systems can be treated as if the

¹² IEEE Standard C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers, Institute of Electrical and Electronics Engineers, www.ieee.org

sources remain separate, particularly if the two sources are only in parallel for some defined short time period, e.g., 100 ms. However, the origin of the 100 ms “time limit” is unclear, and the issue of “closed transition” operation is not addressed specifically in IEEE C37.010¹³, the standard which defines how MV and HV circuit breakers are rated for short-circuit currents. The conservative approach would be to either employ open-transition systems with interlocking systems to ensure that sources are not paralleled, and rely on UPS systems to make sure the critical loads could ride through the transfer back to the normal source. Alternatively, of course, equipment can be rated based on the two or more sources operating in parallel, even if this occurs only for a short time. This could require other considerations to limit fault current in the system, such as use of higher-impedance transformers. While this could require other considerations, such as special transformer design to help limit transformer losses and use of on-load tap changers to help improve voltage regulation in the facility, any added expense related to these should be offset by savings related to use of the more compact MV switchgear.

Implications of transmission level service

The increasing size of large data centers is not only causing changes inside the facility, but is also affecting the way the facilities connect to the utility grid. Small to mid-size data centers have historically been connected to utility distribution circuits operated at medium-voltage (15-35 kV), but this arrangement becomes less practical as data center sizes exceed a few MW. Facilities of this size (whether data centers, industrial plants, etc.) would either require multiple utility distribution circuits to be brought in, or would require connection to the HV utility transmission grid. This in itself can present several benefits to the data center owner, as they may have a great deal of control of key design considerations that ultimately influence the infrastructure and operation of the facility. Even if the utility builds and operates the substation feeding the data center, the end-user typically has the opportunity to significantly impact the selection of equipment. This means that the owner has the opportunity to either request or select medium voltage distribution equipment and load blocks that leverage the advantages of SSIS gear in size, cost, and maintainability. The selection of transformer ratings (MVA, impedance) ensures the system will operate as desired. Receipt of service at transmission level may also provide the additional benefits of influence on construction schedule, rates, location of the data center and capacity to expand to accommodate future growth needs.

Conclusion

As data centers grow in size, the need for higher capacity has fueled the growth of large medium-voltage power distribution networks inside such facilities. However, up to this point, the typical data center power system has used medium-voltage switchgear similar to that used in heavy industrial facilities, as alternatives were either not available or did not provide an attractive set of features and specifications. Newer alternatives to traditional air-insulated switchgear offer the opportunity to use medium-voltage distribution equipment that can offer advantages in terms of size, cost, safety, and reliability. While this may require some considerations at the design stage to ensure that the required equipment ratings will be compatible with the switchgear ratings, a strategy to optimize the data center design around these parameters can drive significant benefits to the owners/operators of such facilities.

¹³ IEEE Standard C37.010-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, Institute of Electrical and Electronics Engineers, www.ieee.org



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Antony Parsons is a Sr. Staff Engineer with Schneider Electric's Power Systems Engineering team. He holds the BSEE from the University of Houston and MSEE and Ph.D. from the University of Texas at Austin, all in Electrical Engineering. He has nearly 20 years of experience in the industry, specializing in power system analysis, protective relaying, and electrical safety. He is a licensed engineer in the state of Texas.



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