Basics of Medium-Voltage for PV Power Plant AC Collection Systems

By Dan Simpson, PE
The ac collection system in a utility-interactive PV system includes all of the wiring and components from the inverter output circuit(s) to the interconnection point with the utility. Commercial-scale PV plants are generally interconnected to the utility via building wiring systems at common building utilization voltages, such as 208 Vac or 480 Vac. However, as the rated capacity of these interactive systems increases, so does the physical footprint of the PV power plant and the distances between wiring points. Based on the site layout, the desired PV generating capacity and other project-specific variables, system designers working on commercial-scale projects may find a practical need to use medium-voltage (MV) wiring for ac collection systems.

In this article, I provide an introduction to some common components used in MV circuits in PV systems and discuss basic design considerations for their application. I cover MV components for use in ac collection systems, including distribution transformers, overhead and underground feeders, pad-mounted switchgear, and metal-enclosed and metal-clad switchgear. I also provide example single-line diagrams (see p. 71) showing three representative uses of MV wiring methods and components in commercial- and utility-scale PV systems.

**SYSTEM VOLTAGE CLASSES AND WORKER SAFETY**

I use the term MV here to describe electrical system components rated between 5 kV and 38 kV. This definition corresponds to common US utility-distribution voltages.

In practice, voltage class definitions are somewhat tricky to pin down. They vary from industry to industry and from one set of codes or product standards to another. On one hand, *The Authoritative Dictionary of IEEE Standards Terms (IEEE 100)* defines medium voltage as “a class of nominal system voltages greater than 1,000 V but less than 100,000 V.” On the other, Article 490 of the *National Electrical Code* defines high voltage as “more than 600 volts, nominal.” While the NEC does not include a stand-alone definition of medium voltage, Article 328 details the Code requirements related to medium-voltage or Type MV cable. As described in NEC Sections 328.2 and 328.10, MV cable is rated at “2001 volts or higher” and is “permitted for use on power systems rated up to and including 35,000 volts, nominal.”

While the exact definition of MV may vary by context, the implications for worker safety are indisputable. The voltage and potential fault energy levels of MV wiring systems pose significant safety hazards. In addition to electric shock and arc-flash burn hazards, blunt force and projectile injuries are also possible due to arc-blast hazard. While it is beyond the scope of this article to go into the details of MV electrical safety, personnel must always be trained to recognize the particular hazards associated with the specific class of
system voltage they will be working with and understand how to mitigate those hazards through safe work practices. Workers must have the proper tools and PPE, and be trained in their use.

In addition to applicable city, state and county requirements, work in PV power plants may fall under one or both of the following OSHA standards:

- CFR 1910 Subpart S—Electrical General Design Considerations

The design goals for a MV ac collection system are essentially the same as those for other power distribution systems—or any electrical system, for that matter. According to Eaton Corporation’s Consulting Application Guide (see Resources), “The best distribution system is one that will, cost-effectively and safely, supply adequate electric service to both present and future probable loads.” The only distinction is that the MV wiring in a utility-interactive PV application does not supply loads, but rather is designed to supply adequate service to interconnected electric power production sources.

The Consulting Application Guide goes on to list seven electrical distribution design goals, the most important of which is a safe installation that does not present any electrical hazards to people or equipment. The other six design goals can be summarized as follows:

- Minimize initial investment
- Maximize service continuity
- Maximize flexibility and expandability
- Maximize electrical efficiency and minimize operating costs
- Minimize maintenance costs
- Maximize power quality

These objectives are not only laudable, but also familiar to anyone who spends time optimizing PV power plant designs according to levelized cost of energy, initial cost or some other metric. Based on these general goals, an engineer can create a list of tangible project requirements, and then proceed to develop a MV ac collection system design that meets those requirements. One additional design consideration that I find often applies to PV systems is the need to identify a design that can be constructed within the allotted project time frame.

In the interest of safety, most PV projects are required by law to comply with the requirements found in the locally adopted version of the National Electrical Code. The following is a partial list of NEC content pertinent to the design and construction of MV ac collection systems.

- Article 110: Requirements for Electrical Installations, Part III Over 600 Volts, Nominal
- Article 240: Overcurrent Protection, Part IX Overcurrent Protection Over 600 Volts, Nominal

Collection system components This SketchUp diagram shows the major MV components and wiring methods used in a PV power plant’s ac collection system.
Designers can identify other NEC sections that may apply specifically to MV wiring by referring to the entries under the term Over 600 volts in the index for the NEC.

When reviewing NEC requirements, remember that the Code outlines minimum requirements for an electrical system that is free of hazards. According to Section 90.1(B), NEC compliance is no guarantee of adequacy. As explained in Section 90.1(B), a hazard-free installation may not be “efficient, convenient, or adequate for good service.”

Don Wagner, vice president of engineering at Delta Diversified Enterprises, a full-service electrical contractor serving the Western US, provides a relevant example. He points out that simply meeting Code-minimum working clearance requirements for MV equipment does not necessarily ensure constructability. Wagner advises: “To provide sufficient space for installation and maintenance, it is often necessary to provide more working space than is required in the NEC.”

DISTRIBUTION TRANSFORMERS

A step-up transformer is required in a MV ac collection system to match the source voltage (the inverter output voltage) to the 3-phase distribution voltage. Ideally, the ac output voltage is in its native form, meaning direct from the semiconductor switching devices prior to any isolation transformer. Note that many inverters in the “2013 Central Inverter Specifications: 600 Vdc Models” (pp. 84–90) are matched to common 3-phase utilization voltages—such as 208 Vac, 240 Vac, 480 Vac or 600 Vac—generally by means of an internal or external isolation transformer sold with the inverter. Meanwhile, the ac output voltages for products in the “2013 Central Inverter Specifications: 1,000 Vdc Models” (pp. 46–52) are in the same general voltage range (300 Vac to 700 Vac), but do not necessarily match common utilization voltages. That is because the latter are native inverter ac output voltages, continued on page 64.
Pad-mounted, 3-phase distribution transformers—hereafter referred to simply as PM transformers—are typically used in the MV ac collection system of a PV power plant. This type of transformer is commonplace. It is used wherever 3-phase building loads are served by an underground MV distribution system.

Transformer location often varies based on system capacity. In commercial-scale PV systems that are interconnected using a single inverter—typically in the 100 kW to 500 kW range—a transformer is usually installed at each inverter location. On larger commercial- and utility-scale systems, integrators normally install one to four inverters on a common skid or within an enclosure along with a MV transformer. These integrated inverter blocks often carry nameplate ratings in the 500 kW to 2 MW range.

When these packaged systems are specified, the inverter manufacturer usually provides a step-up transformer for each block of inverters that matches the rated power output of the inverter skid. One benefit of these packaged solutions is that the low-voltage wiring between the inverter outputs and the low-voltage bushings on the transformer is factory installed, which reduces construction labor costs. Another benefit is that the specified step-up transformer should work optimally with the inverters as a system. Since ensuring proper performance is critical, I recommend having the inverter manufacturer provide the MV step-up transformer as part of its inverter package whenever possible. Continued on page 66
While it is beyond the scope of this article to detail all of the considerations applicable to the selection and specification of a MV distribution transformer for a MV ac collection system, some of the main criteria include:

- **Power rating**
- **Primary and secondary voltage ratings**
- **Winding configuration**
- **Dielectric fluid class**
- **High-voltage connection type**
- **Number of high-voltage bushings per phase**
- **Optional accessories**

**Power rating.** The unit of measurement used to identify the power rating of a transformer is the kilovolt-ampere (kVA). The PM transformers used in a PV plant’s MV ac collection system are commonly rated at 500 kVA, 750 kVA, 1,000 kVA, 1,500 kVA, 2,000 kVA or 2,500 kVA.

According to Kleber Facchini, solar inverter product manager at Eaton, “Transformers are usually sized at the same power rating as the inverters.” However, there are other considerations. He continues: “Be sure to let the transformer supplier know that the end use is an inverter application, as it is important to understand the inverter harmonics. Site temperature is another important consideration, since the supplier needs to size the transformer so that the transformer winding hot spot does not exceed ANSI limits. While transformers are usually designed to operate 24 hours per day and 7 days per week.”

**Voltage ratings.** By definition, the primary winding of a transformer is the winding that power is applied to, and the secondary winding is the winding that voltage is induced on. In the case of a MV ac collection system, the inverter applies power to the low-voltage side of the transformer, and MV is induced on the high-voltage side of the transformer. However, in practice, it is conventional to refer to the high-voltage windings as the primary and the low-voltage windings as the secondary. Both on the equipment itself and in electrical schematics, low-voltage connections to the transformer are often labeled $X_1, X_2, X_3$ and so on, whereas high-voltage connections are labeled $H_1, H_2, H_3$ and so on.

The ratio of the number of primary winding turns to secondary winding turns is known as the turns ratio, which is proportional to the ratio of the primary voltage to the secondary voltage. A transformer used in a MV ac collection system is referred to as a step-up transformer, indicating that in this application there are more turns in the high-voltage winding than in the low-voltage winding, resulting in, for example, a 1:10 or 1:30 turns ratio. Note that in a conventional power distribution application—in which a MV utility-distribution network supplies 3-phase power to a commercial facility—the same device could be used as a step-down transformer.

Standard PM transformers are manufactured with turns ratios matched to common distribution and utilization voltage combinations, such as 13.8 kV to 480 V. While these standard winding configurations may work in some PV power plant applications, native inverter output voltages do not necessarily match common utilization voltages. Therefore, custom turns ratios are often specified for PM transformers used in utility-scale MV collection systems.

**Winding configuration.** While the system engineer may have a design preference with regard to transformer winding configuration, in practice the choice of inverter on the one hand, and the utility interconnection requirements on the other, significantly impact this decision. Therefore, it is important to coordinate carefully with both the inverter manufacturer and the AHJ when specifying transformers for a MV collection system.

Chris Thompson is the solar business unit manager for Eaton. He notes that three types of MV transformers are used in solar applications, depending upon the inverter manufacturer’s requirements. Thompson elaborates: “Some inverter manufacturers use the transformer like an inductor to provide filtering and therefore require a special PWM-capable transformer, one that is designed to operate with a pulsed inverter. Then there are multi-winding transformers, which have multiple isolated low-voltage windings and are used for inverters that cannot be connected in parallel. As an example, a 3 MW multi-winding transformer might have two separate 1.5 MW low-voltage windings, each of which would be dedicated to a separate 1.5 MW inverter. The third type of transformer used in solar applications is the simplest solution, with one low-voltage winding and one medium-voltage winding.”

Transformer manufacturers can provide both low- and high-voltage windings in either a delta or a wye configuration. In PV applications, it is common to use a wye configuration for low-voltage windings—either grounded or ungrounded, as directed by the inverter manufacturer—and a delta configuration for high-voltage windings.

**Dielectric fluid.** Liquid-type PM transformers are often used in PV power plant applications. These are also referred to as liquid-filled or liquid-immersion transformers because the steel enclosure is filled with a dielectric fluid, a fluid that is not conductive under normal circumstances. The primary and secondary windings are installed around a common core and immersed within this fluid. In addition to electrically insulating the internal components, the dielectric fluid helps keep them cool. As waste heat is generated in the core and windings, the dielectric fluid circulates via natural convection within the transformer tank, facilitating heat transfer to the environment.

Engineers specifying liquid-type PM transformers for MV collection systems typically have two basic dielectric fluid options: mineral oil or vegetable oil. **Continued on Page 68**
Mineral oil has been used as a dielectric fluid for many decades and is a proven and cost-effective option. Vegetable-based dielectric fluids are less flammable than mineral oil and more environmentally friendly. Vegetable oil not only is biodegradable, simplifying disposal, but also is made from a renewable resource. Examples of vegetable-based dielectric fluids include Envirotemp FR3, which Cargill recently acquired from Cooper Power Systems, and BIOTEMP, which ABB developed. Both of these vegetable-based dielectric fluids are available from major transformer manufacturers.

Adam Peterson is an applications engineer at Cooper Power Systems who specializes in solar energy applications. According to Peterson, seed oil–based Envirotemp FR3 dielectric fluid is broadly specified in renewable energy generation projects for several reasons: “It has been specifically formulated to be biodegradable and nontoxic; it has an extremely high flash point; and because of its thermal characteristics, the transformer can be design-optimized to the solar load profile in terms of cost, footprint and insulation life.”

**High-voltage connection type.** Engineers effectively determine the type of high-voltage connection based on the transformer construction type they specify. A live-front transformer uses electrically exposed high-voltage connections, such as porcelain bushings with eyebolts or spade terminals. Alternatively, a dead-front transformer provides electrically insulated and shielded high-voltage connection points. Applications engineers typically recommend dead-front transformers and connectors for PV power plants. Dead-front construction provides an additional level of safety in comparison to live-front construction, and the vast majority of PM transformers employ it.

The epoxy bushings in the high-voltage transformer compartment in Figure 1 are typical dead-front transformer termination points. This is where installers make connections to the MV ac collections system wiring. In the opposite compartment, inverter output conductors can be connected to the low-voltage bushings of a PM transformer using standard compression-type spade connectors with NEMA hole patterns.

**Number of high-voltage bushings per phase.** Depending upon the application, PM transformers can be specified with either one or two high-voltage bushings per phase. A radial feed transformer has one bushing per phase; a loop-feed transformer has two high-voltage bushings per phase. The transformer in Figure 1 is a loop-feed transformer. **CONTINUED ON PAGE 70**
According to Peterson at Cooper Power Systems, loop-feed transformer configurations are popular in PV power plant applications because they allow several transformers to be paralleled together on a common MV collection circuit. However, increasing the capacity connected to the collection circuit means that the engineer must account for higher design currents. Peterson cautions, “Whenever multiple transformers are paralleled on a single collection circuit, the engineer must consider the effect this has on the required ratings for the transformer bushings and cable terminations—for example, 600 A bushings may be required in lieu of 200 A bushings based on the total connected kVA.”

Optional accessories. I recommend that engineers specifying PM transformers for collection circuits include the following items, which are typically available from the manufacturer as optional accessories: tap changer, overcurrent protection, load-break–rated switch and surge protection.

Tap changer: As explained in the Cooper Power Systems document S210-12-1, “Three-Phase Pad-Mounted Compartmental Type Installation and Maintenance Instructions” (see Resources), “Transformers equipped with a tap changer can be changed from one operating voltage to another.” To safely use the tap changer, a worker first needs to de-energize and ground the transformer. An electrician can then operate the tap-changer handle with a hot stick, an insulated pole that electric utility workers use as a standard service tool.

A hot-stick–operable five-position tap-changer switch is shown inside the high-voltage transformer compartment in Figure 1 (p. 68). The available operating voltages are indicated to the right of the switch. Based on the location of the lock screw, the tap changer in this photo is set to position C, which in this case corresponds to 24,320 volts. If this transformer were used in a PV application, the four additional tap settings—ranging from 25,570 to 23,070 volts—would provide the plant operator with some flexibility for dealing with inverter-input–voltage tolerance issues that might arise.

Overcurrent protection: If multiple transformers are connected in parallel on a common circuit, then overcurrent protection is likely required. Since a variety of schemes can provide the necessary protection, I recommend consulting an applications engineer to get advice for your specific project.

In a PM transformer, Bay-O-Net fuse assemblies are used. Three Bay-O-Net fuse housings are visible above the drip shield in Figure 1. A hot stick can be used according to the transformer manufacturer’s instructions to safely install or remove these fuse assemblies.
Three Examples of MV Wiring in PV Power Systems

EXAMPLE 1: MV Wiring Used for Long-Distance Interconnection
This is a single-line diagram of a 300 kW PV system installed at an agricultural site. The array and inverter are located approximately 2,000 feet from the 3-phase 240 Vac premises wiring. Because of the long distance and the low interconnection voltage, MV wiring is used in the inverter output circuit. The inverter produces a 480 Vac output, which is stepped up to 12.47 kV via a pad-mounted distribution transformer. A 12.47 kV feeder is run underground via MV cable to the interconnect point, where it is stepped down via a second pad-mounted distribution transformer to the interconnect voltage of 240 Vac.

EXAMPLE 2: Simple MV AC Collection System
This is a single-line diagram for a 2 MW PV system at a university campus. A pad-mounted transformer is installed adjacent to each of the six inverters to step the inverter output voltage up to 12.47 kV. Two MV collection circuits are used, each with three loop-feed transformers. The feeder circuits are collected at a lineup of 12.47 kV metal-enclosed switchgear that provides fused disconnecting means for the collection circuits and energy metering for the PV power plant. A single PV plant output feeder is routed from the switchgear to the point of common coupling, which in this case is the campus’s primary metered 12.47 kV distribution system.

EXAMPLE 3: Utility-Scale MV AC Collection System
This is a theoretical example of a MV collection system for a 20 MW utility-scale PV power plant. Twenty 1 MW inverter skids are distributed throughout the array field, each with a MV distribution transformer that steps the inverter output voltage up to 34.5 kV. Three ac collection circuits are routed back to the MV metal-clad switchgear. A single output feeder is routed to a substation transformer that steps the interconnection voltage up to 69 kV.
**Load-break-rated switch:** If a load-break-rated switch is included in a PM transformer, then it is possible to use a hot stick to manually open or close the connection between the loop-feed conductors and the primary transformer windings. This option is useful whenever service needs to be performed on the low-voltage side of the device. The PM transformer in Figure 1 includes a two-position load-break-rated switch.

**Surge protection:** The purpose of surge arresters in a PM transformer application is to protect against overvoltage surges due to lightning or other transients. Consult a product applications engineer for help selecting the proper surge arrester for your application.

**Other considerations.** While some basic requirements can be self-evident, like transformer capacity and voltage ratings, more-nuanced design decisions require careful consultation with applications engineers. For example, Peterson points out, "Transformer impedance needs to be matched with that of the associated inverters, as specified by the inverter manufacturer." He continues, "There are harmonic and shielding requirements to consider, as well as gauge package options to specify."

**MV Wiring**

MV wiring is necessary to carry PV plant power from the PM transformers to the point of common coupling, where the power production equipment connects to the utility distribution network. The MV wiring components utilized in PV plants are essentially the same as those found in power company distribution systems and in industrial power systems. The two basic categories of MV wiring are overhead and underground.

**Overhead wiring.** Uninsulated conductors attached to wood or steel poles via porcelain insulators are representative of overhead MV wiring methods. Installers place anchored guy wires in specific locations as required to offset lateral forces on the structures. Where overhead wiring transitions to underground wiring, a MV cable riser extends up the pole and terminates there. Fused cutouts at the MV cable termination point provide overcurrent protection. In addition, installers often place surge arrestors at the overhead-to-underground transition point. Figure 2 identifies the components used to transition between underground and overhead MV wiring systems.

In MV collection systems, overhead wiring methods are less common than underground methods. This is due in part to the fact that pole-mounted overhead wiring is problematic when crossing an array field, since shading can adversely impact PV performance. Nevertheless, in some instances overhead wiring methods provide an opportunity for cost savings. One example is when a PV plant’s main output feeder needs to run for some distance to a remote interconnection point. Overhead wiring will likely prove more cost effective than underground wiring in this situation.

**Underground wiring.** Type MV cable, in one of its many forms, is used in underground MV wiring applications. Type MV cable is available in both single-conductor (single-core) and three-conductor (three-core) variations.

As shown in Figure 3 (p. 74), six distinct layers, each performing a unique function, are used in the construction of a single-conductor Type MV cable. Moving from the inside to the outside, these layers are: conductor, strand shield, insulation, insulation shield, metallic shield and cable jacket.

**Conductor:** This layer can be made of copper or aluminum and carries current. Aluminum conductors are commonly used in utility-distribution applications, whereas copper conductors are commonly used in industrial applications. While either material is acceptable in PV plant installations, aluminum is generally more cost effective.

**Strand shield:** Made of a semiconducting material, this layer separates the conductor and the insulation. Its function is to shield the insulation from air pockets between the conductor and insulator. Without the strand shield, this air would ionize and cause partial discharges that could deteriorate the insulation and lead to cable failure.

**Insulation:** This layer contains the voltage within the cable. Common MV cable insulation materials **continued on page 74**
include water-tree retardant, cross-linked polyethylene (TR-XLPE) and ethylene propylene rubber (EPR). MV cables are typically available with two basic insulation thickness options: 100% level or the thicker 133% level. According to the **Engineering Handbook** published by electrical cable manufacturer the Okonite Company (see Resources), 100% level cables are generally intended for applications in which ground faults are cleared within 1 minute or less; 133% level cables should be applied when fault clearing times in the 1 minute to 1 hour range are expected, or when increased insulation strength is desired.

**Insulation shield:** Made of a semiconductor material, the function of this layer is similar to that of the strand shield. The insulation shield protects the insulation from air pockets between the metallic shield and insulator material.

**Metallic shield:** This layer serves several purposes. It confines the cable’s electric field, equalizes electrical stress within the cable, limits radio interference and reduces shock hazard. Various types are available, including tape shield, wire shield and concentric neutral shield.

**Cable jacket:** The jacket layer provides mechanical protection for the cable. PVC is commonly used as a jacket material, but some Type MV cable is available with PVC-jacketed aluminum armor for enhanced mechanical protection.

**MV cable terminations.** MV cables must be properly terminated for reliable service. In addition to facilitating the cable’s electrical connection, MV cable terminations perform several other important functions, such as relieving voltage stress that would otherwise build up at the insulation shield termination point; sealing the termination against moisture and environmental contaminate; and preventing electrical treeing or tracking at the termination point.

Various materials and methods are available for MV cable terminations, including separable insulated connectors, cold shrink, heat shrink, tape and porcelain. Separable insulated connectors, also known as elbows, are typically used where separable dead-front construction is desired. Common separable elbows include 200 A load-break and 600 A dead-break connectors. Load-break elbow connectors with a 200 A rating can be removed with a hot stick, whereas 600 A dead-break elbows are bolted connectors. Where non-elbow-type connectors are used, molded-rubber cold-shrink terminations are generally preferred because they require less technical skill to install than tape terminations and they do not require a torch. Porcelain bushings are commonly used where MV cables transition to overhead wiring.

Properly terminating MV cables requires specialized skills and tools. It is essential that installers receive product-specific training and follow the manufacturer’s instructions. Since MV cable termination methods and procedures vary by manufacturer, the best resource for installers is always the specific product manufacturer.

**MV SWITCHGEAR**

In a PV plant with a MV collection system, it is often necessary to use MV switchgear to collect the various MV feeder circuits. In addition, the MV switchgear often serves as the demarcation point between the PV power plant and the utility distribution system. The switchgear serves multiple purposes. It provides
Live-front MV termination  The MV bus (top left) inside this GE substation is insulated using porcelain bushings. The MV cables bolted to this bus are terminated with compression-type spade connectors and molded-rubber cold-shrink sealing assemblies.

both disconnecting means and overcurrent protection for the MV feeders that make up the collection system. It provides a location for the utility and the facility owner to measure the total energy output of the PV plant. In some cases, the switchgear also provides the utility with remote supervisory control capabilities.

The concepts that govern the use of MV switchgear are similar to those governing the use of equivalent 600 V–rated devices. MV switchgear is specified according to basic parameters such as voltage class, continuous current rating, momentary current rating, interrupting rating and enclosure type (indoor or outdoor). To properly use MV switchgear in an ac collection system, the engineer must consider specific PV power plant parameters and information about the interconnecting utility grid, such as the available fault current.

MV switchgear differs considerably from 600 V–rated devices in its construction. In PV applications, three different types of MV switchgear construction are common: metal clad, metal enclosed and pad mounted. In many cases, the design engineer tasked with specifying the MV switchgear can choose between MV circuit breakers or MV fused switches to provide the required disconnecting and overcurrent protection means.

Metal-clad and metal-enclosed switchgear. Historically, metal-clad and metal-enclosed switchgear are used primarily in large commercial, institutional and industrial applications. However, in PV plants with MV ac collection circuits, a single lineup of metal-clad or metal-enclosed equipment is often used as the plant’s primary switchgear.

Metal-clad switchgear is built to ANSI Standard C37.20.2 and uses draw-out circuit-breaker devices. Metal-enclosed switchgear is built to ANSI Standard C37.20.3 and can accommodate draw-out circuit breakers, fixed-mounted circuit breakers or load-break switches and fuses. By the nature of its construction, metal-clad switchgear offers superior fault isolation properties compared to the metal-enclosed type; however, it costs significantly more.

Scott Brady, a district applications engineer for Eaton, describes the differences in construction between metal-clad and metal-enclosed switchgear: “Metal-clad switchgear is constructed using draw-out overcurrent devices only and insulated primary bus connections; it is available with voltages up to 38 kV, high fault-current ratings and automatic shutters that close when draw-out devices are removed. In contrast, metal-enclosed switchgear can use fixed-mounted devices, such as vacuum breakers or fuses; live parts are not individually insulated; and bus connections can be uninsulated. Metal-enclosed switchgear is voltage range limited to 15 kV with vacuum breakers or to 38 kV with fused switches. Since the breakers or fuses are front accessible only, shutters are not required.”

While the type of MV switchgear used in PV applications varies according to system size, Brady notes that the interconnection voltage and utility requirements also drives this choice. "For the main interconnect switchgear,” says Brady, "if the distribution voltage is 15 kV and below, metal-enclosed switch and breaker switchgear typically provides the best value for the project. This type of switchgear incorporates a switch and fixed breaker in a single structure and can be provided with the type of metering compartments required by Western utilities. The switch portion of the switchgear provides a visible means of disconnect, which utilities sometimes require, while the vacuum circuit breaker incorporates adjustable 3-phase overcurrent protection, remote operation if required, and arc-flash reduction safety features not available with a fuse. If the distribution voltage is above 15 kV, then metal-clad switchgear is typically required to meet utility interconnection requirements. Metal-enclosed fused switches do not provide the relay protection required to coordinate with the utility protective devices, and remote operation is complex with switches versus stored-energy vacuum circuit breakers.”

Pad-mounted switchgear. Electric utilities commonly use pad-mounted switchgear in their distribution systems throughout cities and neighborhoods. It has the advantage of being much more compact than metal-clad or metal-enclosed switchgear, with the trade-off of providing fewer features. Unlike metal-clad or metal-enclosed switchgear, pad-mounted switchgear is typically limited to three distribution circuits. Fused switching means are generally for circuit protection and isolation; however, other design options are available. Pad-mounted switchgear is typically hot-stick operated and is available in live-front and dead-front construction.

The simplest form of a PV plant MV ac collection system involves one or more collection feeder circuits extending from loop-feed transformers directly back to the plant’s primary stand-by source. In some cases, the designer may specify the use of pad-mounted switchgear for the interconnection of the plant’s primary switchgear. Pad-mounted switchgear is typically limited to indoor applications, making it unsuitable for use in areas with moisture or chemical exposure. Pad-mounted switchgear is not available in voltages above 60 kV; however, capabilities range from 750 ampere continuously rated service to 25,000 ampere momentary rated service. Pad-mounted switchgear is often used in conjunction with medium-voltage loop-feed multilayer transformers, which are used to step-down a specific number of phase voltages and interface with the low-voltage network.
MV switchgear. However, in larger PV plants, pad-mounted switchgear is sometimes used in the array field to further sectionalize MV feeder collection circuits. In this scenario, MV ac collection circuits extend from the plant’s main switchgear to one or more pad-mounted switch locations, at which point they separate into several smaller collection feeder circuits. When used this way, pad-mounted switchgear can reduce the number of main ac collection feeder circuits and therefore cut down on the number of distribution cubicles required in the main MV switchgear.

The use of pad-mounted switchgear in strategic locations in the array field offers reliability and maintenance benefits by allowing the main ac collection circuits to be broken into smaller radial circuits that can be individually fused and switched. This practice also allows for the use of smaller feeder conductors downstream from the switch locations. Disadvantages associated with the use of pad-mounted switchgear include increased ac collection system complexity, higher cost for the pad-mounted switches and additional space requirements for the switches.

**MV circuit breakers.** MV circuit breaker systems consist of two parts: the circuit breaker and one or more relays. The circuit breaker component is essentially a set of contacts that open or close the circuit. The primary difference between the various MV circuit breaker technologies available is the medium used to extinguish the arc that develops when the breaker is operated under load. Depending on the design of the MV circuit breaker, the insulation medium could be air, oil, SF₆ gas or vacuum. Modern vacuum circuit breakers are the most common choice for new installations.

MV circuit breakers are available for either draw-out mounting or fixed mounting. A draw-out breaker consists of two parts: the base, which is bolted to the MV cubicle frame, and the actual breaker itself. This two-part construction allows the breaker to be racked in or racked out of the cubicle for maintenance or replacement. In addition to being easier to service than fixed breakers, draw-out breakers have the advantage of providing visual confirmation whenever a circuit is disconnected from the switchgear.

Since most circuit breakers do not contain any internal operational logic, a separate relay is required to operate the breaker. This relay senses the circuit-fault condition and sends a signal to the MV breaker that causes it to open. Historically, relays were electromechanical devices that each performed only one protective function. If a single circuit breaker required multiple circuit-protection features, that also necessitated several electromechanical relays. In modern circuit breakers, solid-state relays, which provide multiple circuit-protection functions in a single package, have replaced electromechanical relays.

Each of the circuit-protection functions available in a solid-state relay has a unique ANSI device number. For example, Schweitzer Engineering Laboratories’ SEL-351, which is commonly used as a feeder-protection relay in utility and industrial electrical systems, includes the following circuit-protection functions: overcurrent (ANSI device numbers 50 and 51), undervoltage (27), overvoltage (59) and frequency (81). The relays sense voltage and current using instrument transformers. If circuit breaker switching is required during a power outage, then battery-backup systems can provide control power to the relays.

In addition to facilitating many modes of circuit protection, solid-state relays also offer flexibility with regard to **selective coordination**, which refers to the ability to localize the effects of an outage. The 2008 cycle of revisions added this concept of **coordination** to the NEC; see the definition in Article 100. As described in the explanatory text in the NEC Handbook, “The main goal of selective coordination is to isolate the faulted portion of the electrical circuit quickly while at the same time maintaining power to the remainder of the electrical system.”

**MV switches and fuses.** The switches used in MV gear for load-break switching operations are classified as **load-interrupter switches**. These switches are gang operated and can be fused or nonfused. They are...
generally provided with viewing windows that allow operators to verify switch blade position without exposure to live parts.

MV fuses utilized in MV switchgear are broadly classified as either the expulsion type or the current-limiting type. Expulsion fuses are vented and use hot gases to facilitate the mechanical interruption of the circuit. Current-limiting fuses are sealed and do not expel heated gas during operation. As the name implies, current-limiting fuses limit the magnitude of the fault current, and do so within a quarter of a cycle provided that the impedance of the fault is low enough. Expulsion fuses are generally available with higher voltage ratings than current-limiting fuses, while current-limiting fuses are generally available with higher interrupting ratings than expulsion fuses.

**Circuit breakers vs. fused switches.** MV circuit breakers and MV fused switches each have their unique advantages. The advantages of MV fused switches include lower cost, simplicity and the possibility of providing current-limiting circuit protection. The advantages of MV circuit breakers include higher available continuous current ratings, the ability to relatively easily incorporate remote switching, and the benefits associated with the use of solid-state relays, which include multiple circuit-protection functions and selective coordination. CONTINUED ON PAGE 80
PLANNING FOR SUCCESS

Given the considerable expense and long lead times associated with PM transformers and MV switchgear, it is critical to ensure that the products specified meet everyone’s criteria. This includes the owner’s specifications, the technical needs of the project, the inverter manufacturer’s guidelines, the terms of the utility interconnection agreement and the AHJ’s requirements.

Bryan Grogan, senior project superintendent for Delta Diversified Enterprises, notes, “Effective coordination with the interconnecting utility company will reduce costly delays and equipment changes.” He explains: “This communication needs to happen at various stages of the project—including design, construction and acceptance phases. During the design phase, it is important to verify the utility company’s requirements for metering and distribution equipment, as each utility typically has its own specific requirements. You need to understand what is important to that utility and to make sure this is incorporated early in the design process. To smooth the final utility acceptance process, it is advisable to submit equipment shop drawings for approval before ordering any equipment and to request a courtesy inspection of the metering equipment when it arrives on-site.”

Until there is greater equipment standardization, the most effective way of dealing with long product lead times is to determine the application requirements as soon as possible and order the equipment as early as possible. Grogan warns: “The long lead times required for MV switchgear often prove challenging during construction.”

These logistical challenges are not limited to PM transformers and MV switchgear. Jeff Schilling, Phoenix district office sales manager for Okonite, observes, “Renewable projects go at lightning speed compared to industrial or utility construction projects, which makes component delivery a critical issue.” Strategic design decisions can ameliorate some of these issues. Schilling encourages designers to specify cable sizes that are commonly stocked (2 AWG, 1/0 AWG, 4/0 AWG, 350-kcmil, 500-kcmil, 750-kcmil and 1,000-kcmil), and notes that 15 kV cables are commonly available with 133% level insulation, whereas 35 kV cable is typically available with 100% level insulation.

When product lead times do not fit within the project construction schedule, the specifying engineer can consider making substitutions. According to Schilling: “While aluminum conductor cables with a tape shield are commonly requested for a solar project, they are not a commonly stocked item and may not be available in time to meet the project’s schedule. In these instances, higher-cost copper cables with tape shield or aluminum conductors with concentric neutral, which are commonly used by electric utilities, can be considered as a substitute to meet scheduling requirements.”

Schilling continues: “While direct-burial jacketed cable is commonly used in solar field applications, armored cable and jacketed cable installed in conduit are other options to consider. Cable installed in conduit has the benefit of being relatively easy to replace should a fault occur. However, there are cost and reliability trade-offs associated with each approach.”

For Grogan at Delta Diversified Enterprises, the higher up-front costs associated with cable in conduit are not necessarily a deal breaker. He explains: “We generally prefer cable installed in conduit as opposed to direct-bury installations. The use of conduit eliminates many of the concerns associated with direct-bury cable. This approach can even cost less than direct-bury cable, in some cases, if it can eliminate the need for sifting or importing trench bedding material to the site.”

CONTACT

Dan Simpson / Taylor RyMar / Tempe, AZ / dsimpson@tr-corp.com / tr-corp.com

Manufacturers

Cooper Power Systems / 877.277.4636 / cooperindustries.com
Eaton / 855.386.7657 / eaton.com
Myers Power Products / 866.696.9377 / myerspowerproducts.com
The Okonite Company / 201.825.0300 / okonite.com
Schneider Electric / 888.778.2733 / schneider-electric.com
Schweitzer Engineering Laboratories / 509.332.7990 / selinc.com

Resources

“Three-Phase Pad-Mounted Compartmental Type Installation and Maintenance Instructions,” Cooper Power Systems, Service Information S210-12-1, August 2012