Distribution and Substa

The relative simplicity of transformers belies their importance. Transformers are ubiquitous in ac electrical systems, used in appliances, inverters, measuring devices, construction tools and all manner of electronic devices. Transformers are also a key component for electrical power transmission and distribution. One of the power industry's guiding principles is that transmitting power at higher voltages is more efficient. Therefore, engineers use transformers at power generation facilities—including PV power plants—to step up to high-voltage levels for long-distance transmission. Closer to towns and cities, substation and distribution transformers step voltage levels down at multiple stages and locations to deliver electricity to commercial, industrial and residential loads.

In this article, we cover the fundamentals of transformer construction and operation. We discuss the general use of distribution and substation transformers in commercial and utility solar applications. We consider important transformer ratings and features. Finally, we summarize factory and field tests. If you do not take these considerations into account, the humble transformer can trip up your whole project. Our goal is to provide a definitive and practical guide that will help you select and specify pad-mounted distribution transformers for commercial and utility solar facilities.

Transformer Fundamentals

A transformer is a static electrical device used to transfer electric power by electromagnetic induction from one ac circuit to another—at the same frequency, but with different voltage and current values—without a direct electrical connection between the two circuits. Figure 1 (p. 20) shows the symbol

Courtesy SMA America

The transformer for your commercial or utility solar project may seem like a relatively mundane piece of equipment. However, this is true only if you choose the correct transformer and order it with sufficient lead time.

tion Transformers

By Alexey Kondrashov and Tobin Booth, PE

commonly used to represent a transformer in an electrical diagram, as well as the basic components of a simple two-winding transformer: an iron core plus primary and secondary windings (coils of insulated wire continuously wrapped around the core).

When you apply voltage from an ac source to the primary (input) winding, the constantly reversing current produces a magnetic field. This magnetic field has a certain magnetic flux associated with it that flows through the surface area of the transformer core until it reaches the secondary (output) winding, where it induces an electromagnetic force and produces a secondary voltage. The ratio of turns in the primary winding to turns in the secondary winding determines whether the transformer steps voltage up or down.

The transformer symbol in Figure 1 is a simplified picture of the device itself. The multiple-arched lines signify the primary and secondary windings on each side of the transformer. The gap between the lines representing the windings signifies the galvanic isolation between the two circuits. Because the windings are not physically connected in any way, the circuits are electrically isolated from one another.

Though manufacturers make a wide variety of transformers for different applications, they all operate according to the same basic principles. The *turns ratio* is perhaps most important: The ratio of the number of primary winding turns to the number of secondary winding turns is proportional to the ratio of the primary voltage to the secondary voltage. The unit of measurement used to identify the power rating of a transformer is the *kilovolt-ampere* (kVA).

Common distinguishing features include number of phases (single-phase, 3-phase or multiphase), number of windings (single, dual or multiple), cooling method (dry type or liquid type) and application (generation, substation, distribution, grounding or autotransformer).

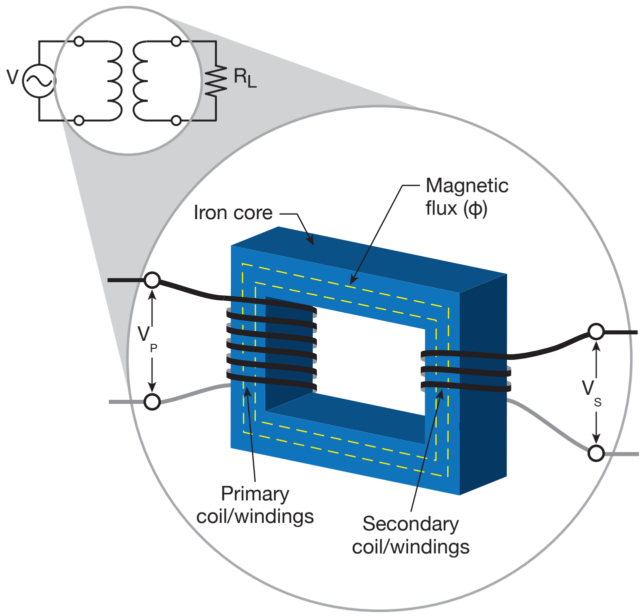

Figure 1 This figure shows the symbol commonly used to represent a transformer in electrical diagrams (top left), as well as the components in a basic two-winding transformer (foreground). Since the voltage ratio is proportional to the winding turns ratio, the secondary voltage (V_s) in this example equals one-half of the primary voltage (V_p).

Transformers in Solar Applications

Commercial, industrial and utility solar applications use distribution and even substation transformers to step up the inverter output voltage for interconnection to the utility grid. This practice, in contrast with typical net-metered applications, results from the interconnection of large-scale PV projects to the utility grid at significantly higher voltage levels. Whereas residential systems typically interconnect at 240 Vac single-phase, and many small commercial systems interconnect at 480 Vac 3-phase, most solar farms interconnect to 3-phase utility distribution or transmission systems at voltages in the 12–115 kV range.

While the main use for transformers in large-scale solar applications is to step up inverter output voltages for the delivery of renewable energy to the utility grid, transformers offer additional benefits. Because of the air gap between the input and output windings, transformers provide galvanic isolation between the solar facility and the utility grid, improving safety and protecting equipment by preventing ground-fault loops.

Distribution transformers. Pad-mounted distribution transformers are the most common type of transformer encountered in solar array fields. While pole-type distribution transformers are frequently the norm in conventional electric distribution systems to supply power to residences and some businesses, solar applications tend to use pad-mounted transformers because the associated ac circuits typically run underground rather than overhead. Standard capacity ratings for distribution transformers vary by vendor, but 50–2,500 kVA is typical. The maximum voltage rating for pad-mounted transformers is typically 35 kV or 36 kV, allowing for interconnection to 34.5 kV distribution lines; however, some vendors offer higher voltage ratings on request.

While both dry- and liquid-type distribution transformers are available, solar applications rarely use dry-type transformers because liquid-filled transformers dissipate heat more efficiently. Dry-type transformers require thicker conductor insulation than equivalent liquid-filled transformers, resulting in a larger core and larger coils. As a result, dry-type transformers cost more than liquid-filled transformers for the same power rating. Typically, solar applications use dry-type transformers only for indoor installations, where a site-specific spill prevention plan rules out the use of a liquid-filled transformer.

Substation transformers. If a utility-scale solar power plant needs to interconnect to the utility at transmission voltage levels above 35 kV, a substation CONTINUED ON PAGE 22

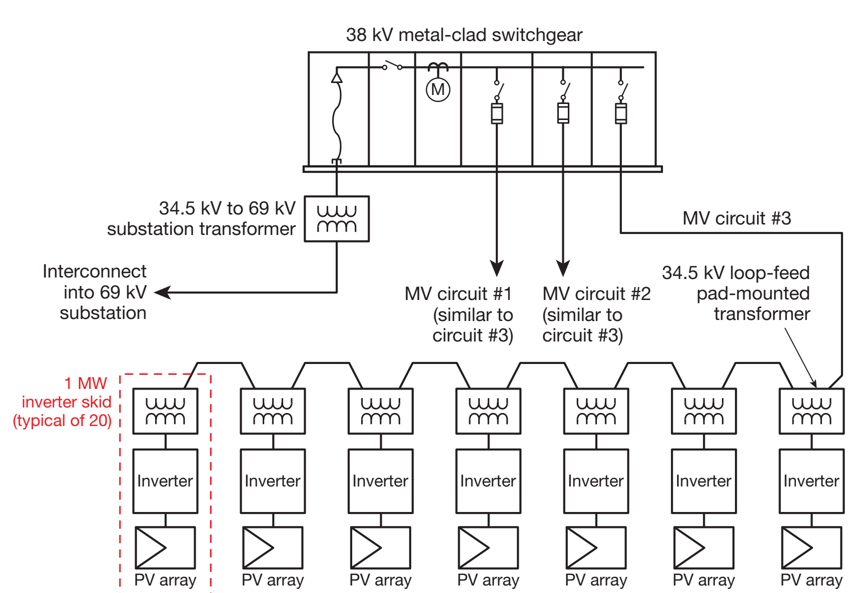

Figure 2 This figure shows a schematic example of a 20 MW PV plant with multiple ac voltage levels and transformer types. Distribution transformers step up the inverter output voltage to 34.5 kV. A substation transformer further steps up the voltage in the collection system for interconnection at 69 kV.

transformer must step up the voltage in the plant's medium-voltage collection system to the appropriate interconnection voltage. Substation transformers normally use the same cooling fluids as distribution transformers, and they have multiple kVA ratings based on the cooling class. Standard nameplate power ratings for substation transformers range from 2,500 kVA to more than 100 megavolt-amperes (MVA).

Though similar to distribution transformers, substation transformers are larger, and they have more complex controls and higher insulation levels to accommodate higher voltages. Cable terminations for substation transformers typically consist of busway conductor systems in free air. The unique nature of these terminations, connection methods and structural support systems can make substation transformers seem intimidating. In reality, the same fundamental transformer concepts apply.

Transformer Specifications

Manufacturers typically build transformers for solar applications to order. This is because vendors offer many options—in terms of materials, configurations and accessories—within the same product line. The product is highly customizable, so delivery lead times for transformers are generally longer than for PV modules or inverters. That makes forethought essential when ordering distribution or substation transformers. For example, a 12-week lead time is typical for distribution transformers in the 0.75–2.5 kVA range. However, that lead time can extend to 16 weeks at certain times of the year or in the event of a factory backlog. If you do not wish to incur expedite fees, you need to plan ahead.

When specifying distribution and substation transformers for solar applications, pay particular attention to device ratings and optional features.

IMPORTANT DEVICE RATINGS

Important transformer ratings to consider relate to voltage, winding connections, basic impulse level, impedance, efficiency, winding material, temperature rise, insulation class, cooling, seismic resistance and altitude deratings.

Voltage. It is critical to specify the correct nominal voltage levels for distribution and substation transformers. As illustrated in Figure 2 (p. 20), inverter selection and interconnection voltage, as well as the voltage used in the medium-voltage collection system if this differs from the interconnection voltage, determine voltage levels. (For more information on medium-voltage ac collection systems in PV power plants, see "Basics of Medium-Voltage Wiring," *SolarPro* magazine, December/January 2013.)

In the example shown in Figure 2, inverter selection determines the voltage level on the low-voltage side of the distribution transformers, which will likely be in the 300–700 Vac range. Meanwhile, the collection system voltage is 34.5 kV, the maximum standard voltage level for distribution transformers. This collection system voltage determines not only the voltage level on the high-voltage side of the distribution transformers, but also the nominal voltage level on the low-voltage side of the substation transformer. The utility-interconnection voltage determines the voltage level on the high-voltage side of the substation transformer.

Winding connections. In addition to specifying nominal voltage levels, you must also specify the primary and secondary winding connections in 3-phase applications. The standard winding connection options on both the primary and secondary sides of the transformer are delta, ungrounded wye and grounded wye.

On the one hand, inverter selection normally governs low-voltage windings. Therefore, it is important to ensure that specified low-voltage winding connections conform to the inverter manufacturer's requirements. This is especially true when you are connecting multiple inverters to a single transformer, as you cannot connect some inverters in parallel on the secondary side of a transformer without providing galvanic isolation between the inverters. On the other hand, utility interconnection standards typically govern the high-voltage winding connections on the primary side of the transformer, as well as the required protection scheme. Note that utility requirements apply to the primary circuit only if this circuit is interconnected with utility. In other words, if there is a substation, utility standards apply to the primary circuit of the substation transformer and not to the collector system transformers.

The most common 3-phase distribution configuration for transformers in solar applications is the delta-to-wye configuration, shown in Figure 3, with the wye CONTINUED ON PAGE 24

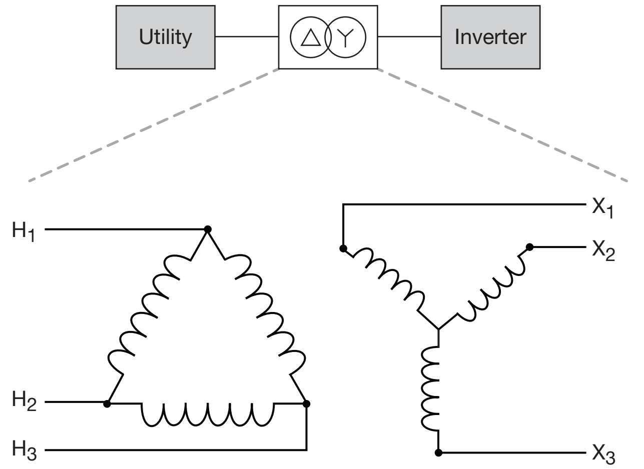

Figure 3 The most common distribution transformer winding configuration in solar applications is the delta-to-wye with wye grounded or ungrounded.

grounded or ungrounded. This configuration allows for an independently derived neutral on the wye-connected secondary winding, which not only is essential for safety purposes but can also provide multiple voltages at the inverter pad without requiring additional transformers. The delta-connected primary winding provides a reliable configuration for the utility, because it allows harmonic currents to circulate within the transformer. This prevents harmonics from flowing into the electrical distribution system.

Substation transformers usually use the grounded wye–to–grounded wye configuration, shown in Figure 4. However, substation transformers are multiwinding transformers that also have a tertiary delta winding. This delta winding prevents harmonics from circulating in the electrical transmission system and stabilizes the neutral point when loads become unbalanced.

Basic impulse level (BIL). Product safety standards require that manufacturers subject medium-voltage transformers to a series of *impulse tests,* which characterize the level of momentary overvoltage that the transformer insulation can withstand without damage or failure. Manufacturers assign the transformer a BIL rating based on these test results. It is important to specify transformers with the appropriate BIL rating to ensure that the electrical system can withstand lightning strikes or other electromagnetic impulses. Table 1 (p. 26) provides examples of standard and enhanced BIL ratings for distribution transformers based on voltage class.

Impedance. Electrical impedance, symbolized by *Z,* characterizes opposition to alternating current that accounts for both resistance and reactance in the circuit. As it pertains to transformers, impedance represents the amount of potential energy you must apply to the transformer before you can put it to work. The higher the impedance of the transformer, the more potential energy is necessary. Calculations typically represent transformer impedance as %Z, a value that electrical engineers can easily factor into a variety of applications. However, you can also think of transformer impedance as the voltage drop across the transformer at full load.

Technicians determine transformer impedance by short-circuiting the secondary winding and applying an adjustable voltage to the primary winding. Starting at 0 V, they slowly increase the primary voltage until they measure full-load current in the secondary winding. They then calculate transformer impedance by comparing applied voltage to nominal primary voltage. For example, if a technician needs to apply

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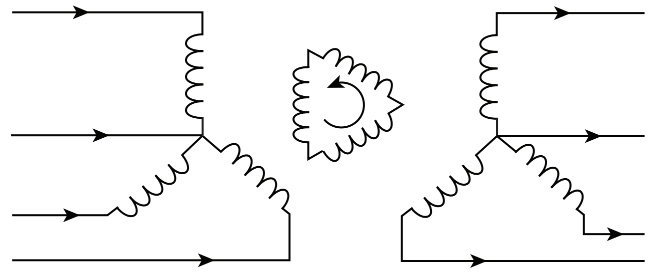


Figure 4 Substation transformers, like the one in the photo on the left, are typically grounded wye–to–grounded wye transformers with a tertiary delta winding, as shown in the diagram on the right.

600 V to a 12,000 V primary winding to create full-load current in the secondary winding, then the transformer impedance is 5% (600 ÷ 12,000).

Transformers under 50 kVA have impedances of less than 2% because they contain less copper and steel to energize. For 750 kVA–2,500 kVA transformers, the standard nominal impedance value is 5.75%. The IEEE standards permit a tolerance of ±7.5% for targeted impedance values in two-winding transformers and ±10% in multiwinding transformers. Manufacturers build high-efficiency transformers to higher design standards to reduce internal impedance and thus produce lower impedance values. While impedance values for conventional substation transformers are typically in the 7%–10% range, you can order these products with special impedance values or desired losses.

Efficiency. Transformer efficiency is a measure of output power relative to input power expressed as a percentage. It tends to increase with transformer capacity. For example, 3-phase distribution transformers in the 75 kVA–1,000 kVA range are 98%–99% efficient, as required by federal law and associated standards established by the National Electrical Manufacturers Association (NEMA). However, general purpose transformers in the 0.05 kVa–1.5 kVA range are typically 85–95% efficient. Because internal transformer eddy current and hysteresis losses are constant at all load levels, they can cause a significant percentage of loss at lower load levels, especially for small transformers. Designing and manufacturing high-efficiency transformers—as compared to general-purpose transformers—requires a larger core with more highly processed silicon steel and larger-diameter conductors for the windings, all of which increases costs. Unless you specify more-stringent requirements, distribution transformer vendors typically design and manufacture products to meet minimum efficiency standards established by the Department of Energy.

Winding material. Manufacturers offer distribution and substation transformers with copper or aluminum windings. Copper offers better electrical conductivity by volume than aluminum, while aluminum offers better electrical conductivity by mass than copper. Given the same capacity, a distribution transformer with copper windings is typically more compact than one with aluminum windings; however, the latter may weigh less than the former. The biggest difference is that transformers with copper windings cost more than those with aluminum windings.

Temperature rise. During operation, efficiency losses result in waste heat, which causes the transformer to operate at temperatures higher than those in the environment. Transformer temperature rise provides a measure of the thermal impacts associated with efficiency losses. This rise is technically defined as the average temperature rise of the windings as compared to the ambient temperature, when the transformer is loaded at its nominal rating.

In practice, however, standard limits based on a maximum ambient temperature of 40°C characterize transformer temperature rise. The standard temperature-rise values for liquid-filled transformers are 55°C and 65°C; the standard values for dry-type transformers are 80°C, 115°C and 150°C. If a technician installs a liquid-filled transformer with a temperature rise of 65°C in a 40°C environment and loads it at its nameplate rating, the average temperature of its windings should not exceed 105°C. Transformers used at PV projects experience more thermal cycling than a typical utility distribution transformer. A solar project transformer starts cold in the morning and reaches its peak temperature midday during peak ambient and peak energy periods. Then it cools back down and starts the cycle over again. Special consideration needs to be given when selecting a solar project transformer to ensure that the cooling system can handle the temperature swings. A watchful O&M team is also important to carefully monitor and reset the pressure system in some geographic locations.

Generally speaking, highly efficient transformers have lower temperature-rise values than less efficient transformers, because efficient transformers generate less waste heat. However, temperature rise is also a function of how quickly the transformer removes heat at full load. At partial load levels, transformers with a low temperature rise are not always more efficient than those with a high temperature rise.

Insulation class. As illustrated in Table 2, a transformer's insulation class correlates to its temperature-rise value. Manufacturers generally accomplish electrical isolation in the transformer with enamel-coated wires and insulating material between the winding layers, and they vary materials and thicknesses to achieve different insulation-class ratings. Once they have insulated the transformer winding, they typically impregnate the coils with a varnish to minimize the possibility of moisture intrusion, reduce sound levels, increase mechanical strength and improve heat transfer, and they then mount the transformer winding in a protective enclosure.

Basic Impulse Level (BIL) Ratings

Voltage class (kV)	Standard BIL (kV)	Optional BIL (kV)
2.4	45	60
5	60	75
8.3	75	95
15	95	110
25	125	150
35	150	200

Table 1 Standard and optional BIL ratings vary by voltage class and vendor.

NEMA Insulation Classes for Transformers

NEMA class designation	Max. operating temperature allowed (°C)	Allowable temperature rise at full load (°C)	Insulating material
A	105	60	Organic materials such as cotton, silk, paper and some synthetic fibers
B	130	80	Inorganic materials such as mica and glass fibers
F	155	105	Same as Class B but with adhesive binders stable at the higher temperature
H	180	125	Same as Class B but with silicone elastomers and inorganic materials with high-temperature binders

Table 2 The insulation within a transformer is rated according to standard NEMA classifications, which determine the maximum operating temperature and the allowable temperature rise.

Cooling. Dry-type transformers are self-cooled and rely on passive methods—conduction, convection and radiation—to transfer heat from the transformer to the environment. For example, you might use small air-cooled dry-type transformers to provide station power at the inverter pad. Otherwise, liquid-type transformers are more common in solar applications.

Steel enclosures filled with a nonconductive dielectric fluid, which insulates the internal components and helps keep them cool, protect liquid-type transformers. The heat that the windings generate transfers to the dielectric fluid, which circulates via natural convection. The heat then dissipates into the environment via the transformer's oil cooler, which is an external heat exchanger or radiator. This is a rather elegant and energy-efficient cooling method.

As shown in Table 3 (p. 28), the industry classifies liquid-filled transformer cooling according to internal cooling medium, internal cooling mechanism, external cooling medium and external circulation method. For example, pad-mounted distribution transformers have a cooling classification of ONAN: *O* indicates that the cooling medium in contact with the windings is an oil with a flash point of 300°C or less; the first *N* indicates that the oil circulates via natural convection; *A* indicates that the external cooling medium is air; the second *N* indicates that the air circulates via natural convection.

Substation transformers of 10 MVA and larger typically have multiple capacity ratings, such as 12/16/20 MVA, which correspond to different cooling classes, such as ONAN/ONAF/OFAF. In this example, the lowest rating, 12 MVA, represents the self-cooled transformer capacity and has the ONAN cooling class rating. The next one, 16 MVA, is the capacity of the transformer when it uses fans to force air through the oil cooler radiators; this rating has the ONAF cooling class rating. The highest rating, 20 MVA, is the capacity of the transformer with both internal coolant circulating pumps and external fans, and it has the OFAF cooling class rating. Each cooling level typically adds approximately 25% more capacity.

Dielectric fluids can be either mineral oil or less-flammable vegetable-based oils, such as Envirotemp FR3 and BIOTEMP. Transformer products designed for solar applications often use the latter because they are derived from a renewable resource and are biodegradable.

Seismic resistance. The 2009 and 2012 editions of the *International Building Code* contain specific seismic resistance requirements for transformers at certain facilities.

Transformer Cooling Classification

Internal				External			
Cooling medium		Circulation mechanism		Cooling medium		Circulation mechanism	
O	Liquid with flash point <300°C	N	Natural convection through cooling equipment and windings	A	air	N	Natural convection
K	Liquid with flash point >300°C	F	Forced circulation through cooling equipment, natural convention in windings	W	water	F	Forced circulation (fans or pumps)
L	Liquid with no measurable flash point	D	Forced circulation through cooling equipment, directed flow in main windings				

Table 3 Liquid-filled transformer cooling is classified according to a four-letter system. The first two letters identify the internal cooling medium and circulation mechanism; the last two letters identify the external cooling medium and circulation mechanism.

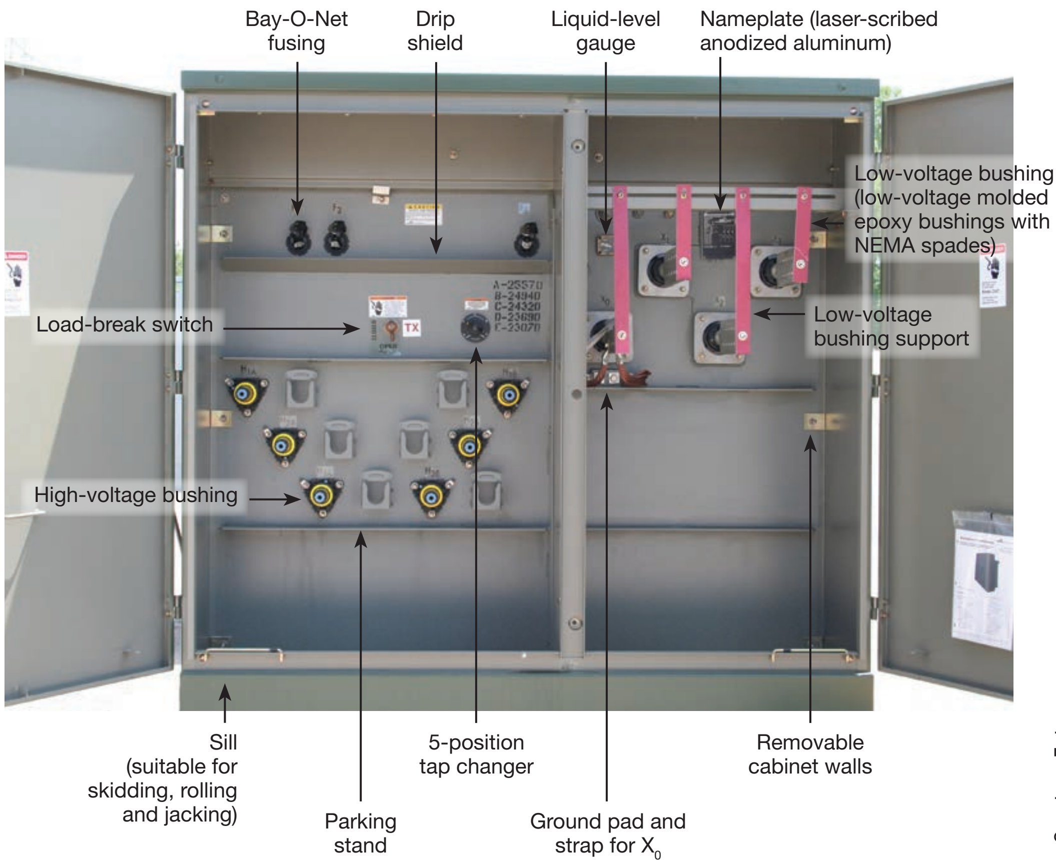
Installations at health care facilities, emergency response locations (such as fire and police stations) and critical government facilities frequently must have seismic certification. If you are installing a transformer at one of these types of facilities, check to see if seismic requirements apply.

Altitude deratings. Because the air is less dense at higher altitudes, the effectiveness of the cooling system and the dielectric strength of the transformer decrease at higher elevations. Therefore, you must either derate transformers installed above 3,300 feet or specifically design them for the location. The product safety standard that applies to liquid-filled distribution and substation transformers requires that you derate transformer capacity by 0.3% for every 330 feet increase in elevation above 3,300 feet.

FEATURES AND OPTIONS

Important transformer features and options to consider relate to dead- versus live-front construction, radial- versus loop-feed configuration, overcurrent protection, overvoltage protection, switches and gauges.

Figure 5 This figure shows the basic anatomy of a 3-phase pad-mounted distribution transformer. The high-voltage compartment features dead-front bushings in a loop-feed configuration.



Courtesy Eaton

Dead-front vs. live-front construction. As shown in Figure 5, a pad-mounted distribution transformer typically has two internal terminal compartments—a low-voltage and a high-voltage one—separated by a barrier. Inside the low-voltage compartment are low-voltage bushings and spades for each phase, as well as a bushing and spade for the neutral (if applicable based on winding configuration). The bare low-voltage bushings means that a person standing in front of the cabinet is exposed to live parts, which is characteristic of live-front construction.

While manufacturers always use live-front construction on the low-voltage side of a distribution transformer, you can specify either live- or dead-front construction for the high-voltage side. In live-front construction, medium-voltage cables terminate at porcelain bushings equipped with eyebolt terminals. To accommodate parallel conductors, specify two or four holes on each bushing. In dead-front construction, the transformer does not have any exposed current-carrying parts, and a separable interface connector system terminates the cables. The connector system components, known as *wells, inserts, elbow connectors* or *feed-through inserts,* are available in different voltage classes (15 kV, 25 kV and 35 kV) and current classes (200 A and 600 A).

Dead-front construction does not expose equipment operators to live, energized parts on the medium-voltage side of the transformer. This mitigates shock and arc-flash hazards, generally improving working conditions. Given the challenges and hazards associated with working around live-front equipment at medium-voltage levels, the safety that dead-front construction affords is often worth the additional expense.

Radial-feed vs. loop-feed configurations. With both live- and dead-front construction, you can specify high-voltage terminations in either a radial-feed or a loop-feed configuration. A radial-feed transformer has one bushing per phase; a loop-feed transformer has two high-voltage bushings per phase. The loop-feed configuration is common in large-scale solar applications, as it allows parallel connection of several transformers on a collection circuit.

Distribution transformers in a solar farm are located at inverter pads or power stations throughout the array field to step up voltage after the inverter. To eliminate the need to run individual homeruns between the interconnection point and each transformer, you can loop multiple transformers together on the same collection circuit, as shown in Figure 3 (p. 22). You must account for higher currents in the collection system when looping transformers in this manner.

Overcurrent protection. Pad-mounted transformers are available with or without internal overcurrent protection on the high-voltage side of the transformer. Multiple transformers connected in a loop likely require high-voltage side overcurrent protection. It is unusual to have overcurrent protection on the low-voltage side, as that is usually provided outside the transformer cabinet where required.

Fuses used for overcurrent protection provide two levels of protection. The main fuse is usually an expulsion-type fuse; the backup fuse is current limiting. In the event of a fault, the expulsion fuse limits its duration and the current-limiting fuse limits its magnitude. Therefore, the current-limiting fuse usually has a higher interrupting rating than the expulsion fuse. A two-fuse protection scheme connects the two fuses in series and coordinates them so that the current-limiting fuse operates upon internal equipment failure only.

Pad-mounted distribution transformers in solar applications typically have bayonet-style assemblies, designed to accept bayonet-style fuse links that can provide varying levels of circuit protection. For example, current-sensing or fault-sensing fuse links are sensitive to current only; dual-sensing fuse links are sensitive to both current and oil temperature, providing both primary circuit protection and overload protection. Some cases require a current-limiting fuse or an isolation link in series with the bayonet fuse. Isolation links improve safety by reducing the chance that an operator will close a fuse when the fault within the transformer still exists.

Selecting overcurrent protection for a distribution transformer can be challenging. You must consider transformer loading, fuse coordination, interrupting ratings, energization transients and inrush currents. A good engineering partner or product vendor can help you calculate the correct ratings and select the proper fuses. With substation transformers, you can use high-voltage breakers with special relays to accomplish overcurrent and overload protection. You typically determine the specific protection scheme during the substation design process.

Overvoltage protection. Natural events such as lightning storms and solar flares can cause voltage surges on the utility grid. Common metal-oxide varistor (MOV) surge arresters are the best means of protecting transformers from transient overvoltage on power lines. When a surge occurs, the MOV quickly limits the overvoltage by conducting the surge current to ground. A quality MOV can reliably arrest many surges over a long period of time. Surge arresters are available for both substation and distribution transformers. Figure 6 (p. 30) shows elbow arresters for dead-front connections.

Switches. Vendors offer a variety of externally or internally mounted switch options for pad-mounted transformers. Two-position load-break–rated switches installed inside the high-voltage cabinet are most common in distribution transformers for medium-voltage collection systems. The factory mounts these switches in the transformer's enclosure, either welding them in place or ring-mounting them. The handle on the visible end of the switch is operable with a hot stick.

Operators can use load-break switches to isolate individual transformers from the primary circuit. For example, opening a two-position switch on a radial-feed transformer takes the transformer offline. Opening a two-position switch on a loop-feed transformer isolates the transformer windings from the primary circuit, but does not interrupt the collection loop. Loop-feed transformers can also have four-position sectionalizing switches, which provide operators with additional flexibility. With a four-position switch, the operator can interrupt the A or B side of the loop (see bushings in Figure 5, p. 28) and can also choose to isolate the transformer windings or leave them energized.


Courtesy Eaton

Figure 6 The high-voltage side of distribution transformers specified with dead-front construction uses elbow connectors. The surge elbows on the right integrate MOVs to provide overvoltage protection.

Gauges. Keeping a transformer clean and cool is critical to its health and longevity. One way to improve plant reliability is to specify liquid-level, thermometer and pressure gauges for pad-mounted distribution transformers so that operators and maintenance personnel can track these data over the project's service life. Additional gauges and devices—such as winding temperature indicators and fault-pressure relays—are available for substation transformers. You can specify any of this equipment with alarm contacts, so that operators can track alarm outputs via the power plant's supervisory control and data acquisition (SCADA) system. We highly recommend that you order transformers for solar facilities with external sampling and instrumentation lockers. Otherwise, the instruments are located in the medium-voltage side of the cabinet, and the technician needs to shut down the transformer during biannual testing.

Testing and Maintenance

IEEE standards determine the minimum factory test requirements for transformers. These production tests verify no-load losses at rated current, total losses at rated current, percent impedance at rated current and temperature rise. In addition, manufacturers must conduct excitation current tests, winding resistance measurement tests, tap ratio tests, polarity and phase relation tests, induced potential tests and impulse tests to check for defects and anomalies. If you have additional project-specific factory-test requirements, specify these before placing an order.

Once the factory has shipped a transformer and the crew has installed it, an InterNational Electrical Testing Association (NETA)–certified technician should perform the necessary field tests for transformers, which require specialized equipment and training. After conducting a visual and mechanical inspection of the transformer, the technician carries out a series of electrical tests. These tests typically include winding resistance measurements, a thermographic survey, turns-ratio tests at all tap settings, impedance voltage and load loss measurements, insulation resistance measurements, dielectric insulation tests, oil pressure tests, and liquid and gas measurements.

NETA-certified technicians are specially trained to conduct the required transformer acceptance tests without damaging the equipment or gathering inaccurate data. For example, the technician must disconnect surge arresters to conduct impulse or applied potential tests. Otherwise, the discharge voltage that the test equipment applies will cause the arrester to clamp, suppressing the power surge. Disconnecting the surge arrester ensures that testing does not damage the device. The technician can reconnect the surge arresters after completing these tests. The technician then compares the field-test measurements with the manufacturer's factory-test measurements. This process ensures that the installed transformer meets the minimum product specifications. It is also critical that the technician set the internal tank pressure based on expected high and low temperatures to ensure that operating pressures stay within the manufacturer's specs. Technicians may need to set the pressure biannually in hot climates or climates with large temperature swings across days or seasons.

Anything that adversely affects the insulating properties inside the transformer—such as poor-quality oil or insulating paper—will reduce its service life. Since high temperatures adversely affect transformer longevity, it is important not to overload the device. This is why manufacturers usually size transformers at the same power rating as the connected inverters. Periodic maintenance is also essential to avoid moisture in the transformer. If properly engineered, installed and maintained, most transformers will operate at the nameplate load for 20 or 30 years, or even longer.

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Resource

Peterson, Adam, et al., "Pressure Optimization of Medium-Voltage Liquid-Filled Transformers in Photovoltaic Solar Applications," Eaton Technical Data White Paper, May 2014, cooperpower.com