17. Switchgear and Substations

Switchgear and substations are not always matters of concern for transmitter designers, because they are often part of the facilities of a typical installation. However, this does not mean that a transmitter designer—or specifier, for that matter—can be ignorant of the characteristics of either. The substation, or what constitutes it, is often where the switchgear physically resides.

17.1 Switchgear

In general, switchgear comprise the devices that are necessary to make and break connections between the sources of primary power and the various loads that make up a transmitter system. These devices include power contactors, circuit breakers, and manual disconnects.

Usually electro-mechanical power contactors are normally open. Their contacts close in response to control power being applied to a magnetic solenoid. They open because of the force of gravity, a compressed spring, or both when control power is removed and the magnetic field of the solenoid collapses. Contactors of this type are usually slow to open (especially if they are air-insulated), often taking 5-10 cycles at a 60-Hz rate to completely clear the load circuit. As has been frequently mentioned in earlier sections, periodic fault conditions stemming from high-voltage breakdown will effectively short-circuit the feed lines to the high-voltage power supply of the transmitter. No matter how rapidly a circuit is mechanically disconnected, however, current will not cease flowing until it has been commutated off. Alternating current periodically passes through zero, which is a natural commutation point. Until it passes through zero, the conduction path will be maintained through a mechanically opened circuit by means of an arc between the contacts. Even if contacts could be made to open instantaneously, current could continue to flow. It would flow for another half-cycle for a single-phase or delta-connected three-phase rectifier feed, or for one-third cycle for a wye-connected three-phase rectifier feed.

The practical mechanical goal for a contactor's opening speed is to make it less than one-half cycle, which is about 8 ms for 60-Hz primary power. The switch mechanisms capable of doing this use vacuum-insulated contacts and are usually referred to as vacuum contactors. The vacuum insulation, with its greater dielectric strength, permits more closely spaced contacts for a given voltage-hold-off rating, thus lowering the opening time. A typical vacuum-insulated switch assembly is shown in Fig. 17-1. The fastest such mechanisms are either normally closed and therefore powered open, or they are normally open, in which case they have a high-speed mechanically coupled booster solenoid to assist the normal spring-driven opening. The opening coils in the highest-speed contactors are nominally low-voltage solenoids that are momentarily overvoltaged, usually by the discharge of an energy-storage capacitor bank through an electronic switch like an SCR. The triggering gate-signal for the electronic switch is generated by electronic monitoring circuits, which sense a microwave-tube fault-current overload and simultaneously fire the electronic crowbar, if one is used.

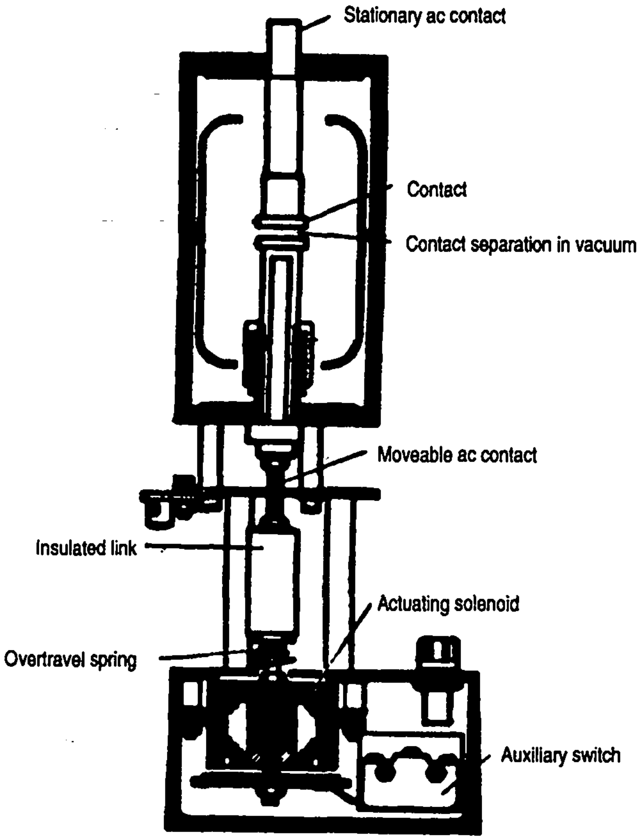

Figure 17-1. Section view of typical vacuum-insulated switch.

Of course, the normally closed form of contactor is not inherently safe, because it requires coil power to stay in the open state. Therefore, it must be preceded by a "nominally fail-safe" normally open contactor. This contactor should not be vacuum-insulated but air-insulated, because even a normally open, vacuum-insulated switch is not safe if its vacuum bottle has taken on air. (The term "nominally" is used to modify "fail-safe" in this case because at least one power contactor so designated became locked in the closed position when its contacts welded together. The contactor was finally opened by the less-than-instantaneous application of a crowbar—and not the electronic type.) The normally open type that has a high-speed auxiliary opening coil provides extended-life operation of the vacuum-contact bottles because, under normal shutdown conditions, the opening of the contacts is relatively slow thanks to the compressed-spring actuation. The capacitor-discharge, high-speed opening occurs only in response to transmitter high-voltage faults (which, we would hope, are not responsible for the majority of shutdowns).

A contactor of this type has two distinct current ratings or VA ratings. One is the amount of current that can be continuously conducted. This rating is related to long-term temperature rise of the contacts due to ohmic heating. The other rating is the amount of short-term fault current that can be terminated following the mechanical opening of the contacts. If fault current exceeds this rating, the contactor cannot be expected to clear the circuit, because the arc between the open contacts may not be quenched when current passes through the zero point.

When primary-power input voltages are less than 600 V, solid-state relays are practical. If they are operated within their short-term (sub-cycle) peak current and heating-impulse ratings, they will clear the load circuit at the first current-zero following interruption of gate drive, which can be accomplished with electronic speed. Of course, if the power supply already has an SCR primary-voltage controller, the solid-state interrupter feature is included at no extra cost. Even if the power supply has a less-sophisticated means of voltage variation and the input voltage less than 600 V, a solid-state relay (SSR) should at least be considered. The SSR, however, should be treated with the same degree of caution as the vacuum relay, and it should always be backed up by a positive-action, air-insulated disconnect switch. (SCRs have been known to fail in this service, and when they do, their electrical properties bear a strong resemblance to the bus bars that connect them.)

Contactors, including SSRs, are closed by the application of control power. They will stay that way until the control power is removed. On the other hand, circuit breakers, which are usually located on the line side of contactors, may either be manually closed or closed by the action of a motor drive. Often in the process of closing, the motor drive charges powerful springs that store the energy required to open the breaker. Also unlike contactors, breakers will automatically open in response to a current overload, either because of thermal or magnetic effects. In addition, they can be used in a quasi-contactor mode when they are equipped with "shunt-trip" coils, which trip the breaker in response to the application of an external control signal. An even more useful feature is the "undervoltage trip." A breaker equipped with this feature will trip free when a control voltage, either ac or low-voltage dc, that is applied to the undervoltage-trip circuit falls below a specified minimum value. Such a feature can be incorporated in a "fail-safe" electrical interlock system, especially for personnel safety.

Circuit breakers have characteristic timing curves that relate the degree of current overload to circuit-clearing time. When these curves are properly coordinated with the circuit-clearing time of the high-speed contactor, the circuit breaker(s) will not open under normal fault-reaction conditions before the contactor does, but they will still protect major components and wiring even if the contactor completely malfunctions.

The other type of switchgear encountered is the manual load-break disconnect switch. Typically, this is a spring-loaded switch that resembles a knife-switch. It is operated by a polelike handle that is vertical and flush with the equipment front panel when the switch is closed. When it is pulled down in a 90° arc to the horizontal position, it is open, and it can be locked in that position. Most of the handle travel is used to charge the opening and closing springs, which then open and close the contacts quite abruptly near the endpoints of the operating-rod travel. The manual disconnect can be expected to have large fuses in series with it. These fuses, when properly coordinated with the switchgear, are the circuit-clearing devices of last resort. The combination is referred to as a manual-fused disconnect.

In systems without manual disconnects, draw-out circuit breakers can serve the same function. Such breakers are "racked-out" of their equipment cabinets on slides or rails, physically disconnecting their terminals from the line and load connections within the equipment enclosure. Although more cumbersome and slower than the manual disconnect, they can provide the same, or better, ultimate load disconnect.

17.2 The unit substation

It is often the case that a transmitter system of moderate average-primary-power demand (typically less than 500 kVA) must be integrated with a facility where the primary-power source is rated at a level many times greater, in the multiple-MVA category, for instance. If, in addition, the source voltage is considerably greater than the optimum for the transmitter system, a unit substation should be considered as part of the overall transmitter design.

A typical such substation is shown in Fig. 17-2. Such assemblies are intended to be used indoors. The key component of such a substation is the step-down line transformer. (Rarely does the voltage ever need to be stepped up.) It should be sized in VA rating as closely as possible to the maximum demand of the load system. The internal series impedance of this transformer, made up mostly of its leakage reactance, is the circuit element that will limit ultimate short-circuit cur-

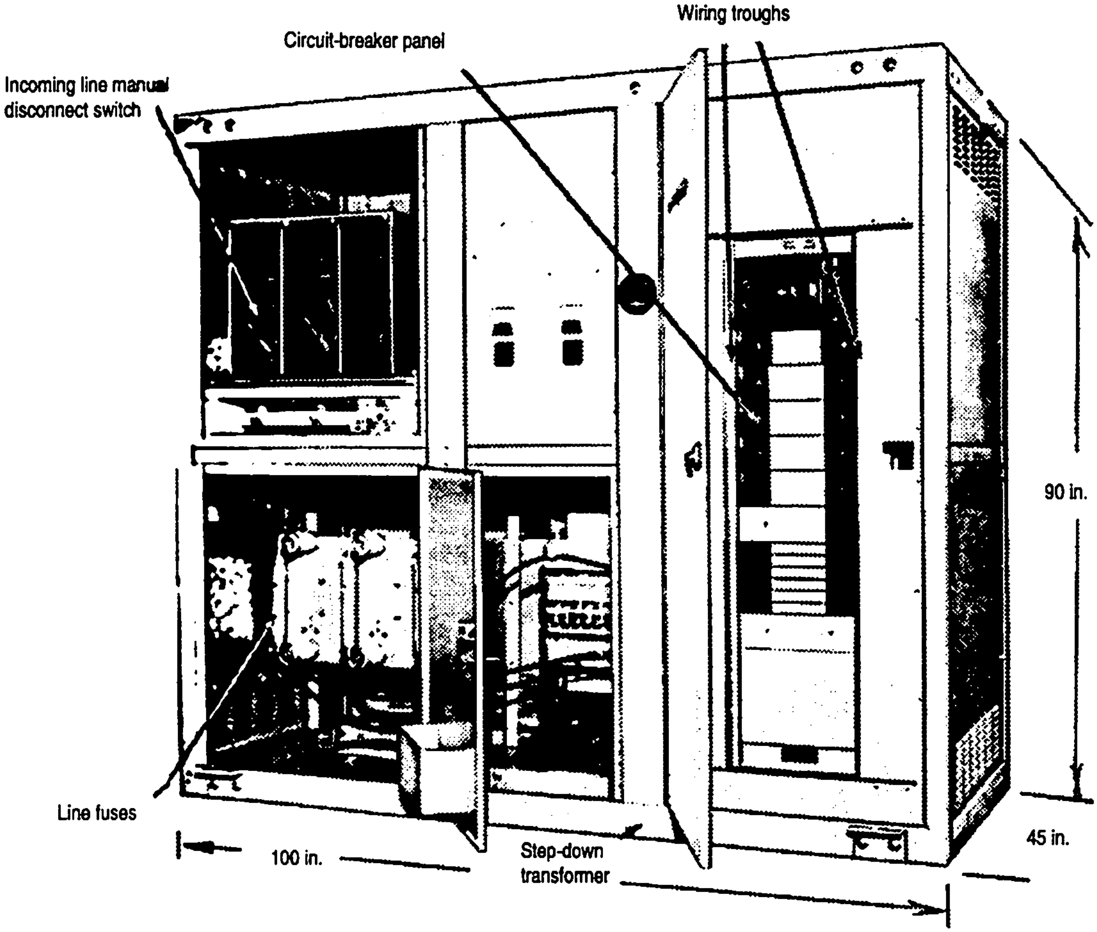

Figure 17-2. A typical unit substation for loads up to 500 kVA.

rent. A typical value of internal impedance normalized to a load impedance into which full-rated VA would be delivered is 6% to 7%. This would limit ultimate symmetrical short-circuit current to approximately 16 times normal full-load current. The designer should consider that there may be other current-limiting impedances in series with the transformer. For instance, if the fault occurs close enough to the load end of the supply chain, the leakage reactance of the high-voltage rectifier transformer would impede conduction, which would further reduce the magnitude of the fault current. However, in any case the ultimate fault current will always occur in response to a short-circuit located immediately on the load side of the substation. Such a fault can never be considered impossible.

In situations where there is a mismatch between source and load VA ratings but there is no necessity for voltage transformation, the role of the step-down transformer can often be more economically performed by line inductors or reactors that are sized to have the same inductive reactance as the leakage inductance of the transformer. Often such reactors do not even require magnetic cores and, therefore, will never saturate. The windings must be sized and braced, however, for the steady-state and overload currents and the magnetic forces that they can produce.

The substation is also the natural location for the fused-manual disconnect, the circuit breakers, and the metering point for line voltage and current. In the case of an ungrounded delta output, it is also the ideal location for indicators for three-phase line-to-ground voltage balance. In addition to accommodating the main circuit breaker, the substation can usually house the branch circuit breakers that feed and protect the multiple subassemblies of a complete transmitter installation.