There are several basic considerations which must be included by the system design engineer to select and design the best power distribution system which will supply power to both present and future loads most economically. Among these are:

- Safety
- Reliability
- Maintenance
- Flexibility
- Voltage Regulation
- Initial Investment
- Simplicity of Operation

The characteristics of electrical service available at the building site, the types of loads, the quality of service required, and the size and configuration of building are also important factors that will influence system design and circuit arrangement.

Four basic circuit arrangements are used for the distribution of electric power. They are the radial, primary selective, secondary selective, and secondary network circuit arrangements. The following discussion of these circuit arrangements covers both the high-voltage and low-voltage circuits. The reader should recognize that the high-voltage circuits and substations may be owned by either the utility company or the building owner, depending upon the electric rates, the practice, and requirements of the particular electric utility serving the specific building site.

### Radial System

If power is brought into a building at utilization voltage, the simplest and the lowest cost means of distributing the power is to use a radial circuit arrangement. The radial system is the simplest that can be used, and has the lowest system investment. It is suitable for smaller installations where continuity of service is not critical.

The low voltage service entrance circuit comes into the building through service entrance equipment and terminates at a main switchgear assembly, switchboard or panelboard. Feeder circuits are provided to the loads or to other subswitchboards, distribution cabinets, or panelboards. Figure 1 shows the two forms of radial circuit arrangements most frequently used. Under normal operating conditions, the entire load is served through the single incoming supply circuit, and in the case of high voltage service, through the transformer. A fault in the supply circuit, the transformer, or the main bus will cause an interruption of service to all loads. A fault on one of the feeder or branch circuits should be isolated from the rest of the system by the circuit protective device on that circuit. Under this condition, continuity of service is maintained for all loads except those served from the faulted circuit.

The need for continuity of service often requires multiple paths of power supply as opposed to the single path of power supply in the radial system.

A fault in a primary feeder in the arrangement shown in Figure 2 will cause the main protective device to operate and interrupt service to all loads. If the fault were in a transformer, service could be restored to all loads except those served from that transformer. If the fault were in a primary feeder, service could not be restored to any loads until the source of trouble had been eliminated. Since it is to be expected that more faults will occur on the feeders than in the transformers, it becomes logical to consider providing individual circuit protection on the primary feeders as shown in Figure 3. This arrangement has the advantage of making it possible to limit outages due to a feeder or transformer fault to the loads associated with the faulted equipment. If circuit breakers are used for primary feeder protection, the cost of this system will be high. Even if fused switches are used, the cost of the arrangement of Figure 3 will exceed the cost of the arrangement of Figure 2.

### Primary Selective System

The circuit arrangement of Figure 4 provides means of reducing both the extent and duration of an outage caused by a primary feeder fault. This operating feature is provided through the use of duplicate primary feeder circuits and load interrupter switches that permit connection of each secondary substation transformer to either of the two primary feeder circuits. Each primary feeder circuit must have sufficient capacity to carry the total load in the building.
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Under normal operating conditions, the appropriate switches are closed in an attempt to divide the load equally between the two primary feeder circuits. Then, should a primary feeder fault occur, there is an interruption of service to only half of the load. Service can be restored to all loads by switching the deenergized transformers to the other primary feeder circuit. The primary selective switches are usually manually operated and outage time for half the load is determined by the time it takes to accomplish the necessary switching. An automatic throwover switching arrangement could be used to avoid the interruption of service to half the load. However, the additional cost of the automatic feature may not be justified in many applications. If a fault occurs in a secondary substation transformer, service can be restored to all loads except those served from the faulted transformer.

The higher degree of service continuity afforded by the primary selective arrangement is realized at a cost somewhat higher than a simple radial system due to the extra primary cables and switchgear.

Secondary Selective System

Under normal conditions, the secondary selective arrangement of Figure 5 is operated as two separate radial systems. The secondary tie circuit breaker in each secondary substation is normally open. The load served from a secondary selective substation should be divided equally between the two bus sections. If a fault occurs on a primary feeder or in a transformer, service is interrupted to all loads associated with the faulted feeder or transformer. Service may be restored to all secondary buses by first opening the main secondary switch or circuit breaker associated with the faulted transformer and primary feeder, and then closing the tie breaker. The two transformer secondary circuit breakers in each substation should be interlocked with the secondary tie breaker in such a manner that all three cannot be in the closed position simultaneously. This prevents parallel operation of the two transformers and thereby minimizes the interrupting duty imposed on the secondary switching devices. It also eliminates the possibility of interrupting service to all loads on the bus when a fault occurs in either a primary feeder or a transformer.

The cost of the secondary selective system will depend upon the spare capacity in the transformers and primary feeders. The minimum transformer and primary feeder capacity will be determined by essential loads that must be served under emergency operating conditions. If service is to be provided for all loads under emergency conditions, then each primary feeder should have sufficient capacity to carry the total load, and each transformer should be capable of carrying the total load in each substation.

This type of system will be more expensive than either the radial or primary selective system, but it makes restoration of service to all essential loads possible in the event of either a primary feeder or transformer fault. The higher cost results from the duplication of transformer capacity in each secondary substation. This cost may be reduced by shedding nonessential loads.

A modification of the secondary selective circuit arrangement is shown in Figure 6. In this arrangement there is only one transformer in each secondary substation, but adjacent substations are interconnected in pairs by a normally open low voltage tie circuit. When the primary feeder or transformer supplying one secondary substation bus is out of service, the essential loads on that substation bus can be supplied over the tie circuit. The operating aspects of this system are somewhat complicated if the two substations are separated by distance. The best arrangement is to use close-coupled, double-ended substations.

Secondary Network System

Many buildings with radial distribution systems are served at utilization voltage from utility secondary network systems. The network supply system assures a relatively high degree of service reliability. The utility network may take the form of a distributed network or a spot network. If the building demand is in the order of 750 kVA or higher, a spot network will often be established to serve the building. In buildings where a high degree of service reliability is required, and where spot network supply may not be available, the distributed secondary network system is often used. This is particularly true of institutional buildings such as hospitals. The network may take the form of several secondary substations interconnected by low voltage circuits. However, the most common practice is to use some form of the spot network circuit arrangement.

A simple spot network, such as shown in Figure 7, consists of two or more identical transformers supplied over separate primary feeder circuits. The transformers are connected to a common low voltage
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bus through network protectors and are operated in parallel. A network protector is an electrically operated power circuit breaker controlled by network relays in such a way that the circuit breaker automatically opens when power flows from the low voltage bus toward the transformer. When voltages in the system are such that power would flow toward the low voltage bus from the transformer, it will close automatically.

Network protectors are normally equipped with relays which operate for faults in the network transformer or high voltage feeder only. The network is often operated on the assumption that network failure will “burn” open.

Network protectors without supplementary protection do not meet the requirements of the NEC for overcurrent, ground fault, or short circuit protection. Protection of the network or collector bus may be added by providing sensing devices, including ground fault detection, with tripping of the network protectors. The most common use of the network protector, however, has been by utilities in vaults where failure of the network devices could cause damage limited to the vault. High integrity design involving wide phase separation and the use of “catastrophe” fusing minimize the danger and extent of a network failure. A conventional circuit breaker with time overcurrent and instantaneous trip devices plus network relays can meet the NEC requirements. However, the full reliability of the network may be compromised since selectivity between these devices is difficult to obtain.

Under normal operating conditions, the total load connected to the bus is shared equally by the transformers. Should a fault occur in a transformer or on a primary feeder, the network protector associated with the faulted transformer or feeder will open on reverse power flow to isolate the fault from the low voltage bus. The remaining transformer or transformers in the substation will continue to carry the load and there will be no interruption of service to the loads, except for a voltage drop during the time that it takes for the protective equipment to operate.

If only two transformers are used in a spot network substation, each transformer must be capable of carrying the total load served from the low voltage bus. The amount of spare transformer capacity in the substation can be reduced by using a primary selective switching arrangement with each transformer, or by using three or more transformers. If the primary selective switching arrangement is used, the total load can be about 160 percent of the nameplate rating of one of the transformers. This produces an overload on one transformer until such time as the remaining transformer can be switched to the other feeder in the case of a primary feeder fault.

The interrupting duty imposed on the low voltage protective devices in a spot network substation is higher than in radial, primary selective, or secondary selective substations having the same load capability because of the spare transformer capacity required in the spot network substation and because the transformers are operated in parallel.

The spare transformer capacity, the network protectors, and the higher interrupting duty will make the secondary network arrangement much more expensive than the other arrangements. At the same time, these elements make the reliability of the network system greater than for the other system configurations.

The secondary network may also take the form shown in Figure 8. In this arrangement there is only one transformer in each secondary substation, and the substations are interconnected by normally closed low voltage tie circuits. The tie circuits permit interchange of power between substations to accommodate unequal loading on the substations and to provide multiple paths of power flow to the various load buses. In normal operation, the substations are about equally loaded and the current flowing in the tie circuits is relatively small. However, if a network protector opens to isolate a transformer on a primary feeder fault, the load on the associated bus is then carried by the adjacent network units and is supplied over the tie circuits. This arrangement provides for continuous power supply to all low voltage load buses, even though a primary feeder circuit or a transformer is taken out of service.

In the network arrangement in Figure 9, if there were three incoming primary feeder circuits and three transformers, the combined capacity of two of the transformers should be sufficient to carry the entire load on the three substations on the basis that only one feeder is out of service at one time. Generally, these transformers would all have the same ratings. With this arrangement, as with the spot network arrangement, a reduction in spare transformer capacity can be achieved, if a primary selective switching arrangement is used at each substation transformer. However, if three or more primary feeder circuits are available, the reduction in transformer capacity achieved through the use of a primary selective arrangement may be small.

Cable ties or busway ties, as shown in Figures 8 and 9, will require careful consideration of load distribution during contingencies and of the safety aspects with regard to backfeeds. Key or other mechanical interlocking of switches or circuit breakers may be essential.