**Introduction**

The selection of system arrangement has a profound impact upon the reliability and maintainability of the system. Several commonly-used system topologies are presented here, along with the pros and cons of each. The figures for each of these assume that the distribution and utilization voltage are the same, and that the service voltage differs from the distribution/utilization voltage. The symbology (low voltage circuit breaker, low voltage drawout circuit breaker, medium voltage switch, medium voltage breaker) reflects the most commonly-used equipment for each arrangement. The symbology used throughout this section is shown in figure 5-1:

![Figure 5-1: Symbology](image)

**Radial system**

The radial system is the simplest system topology, and is shown in figure 5-2. It is the least expensive in terms of equipment first-cost. However, it is also the least reliable since it incorporates only one utility source and the loss of the utility source, transformer, or the service or distribution equipment will result in a loss of service. Further, the loads must be shut down in order to perform maintenance on the system. This arrangement is most commonly used where the need for low first-cost, simplicity, and space economy outweigh the need for enhanced reliability.

Typical equipment for this system arrangement is a single unit substation consisting of a fused primary switch, a transformer of sufficient size to supply the loads, and a low voltage switchboard.
Radial system with primary selectivity

This arrangement is shown in figure 5-3. If two utility sources are available, it provides almost the same economic advantages of the radial system in figure 2 but also gives greater reliability since the failure of one utility source will not result in a loss of service (note that an outage will occur between the loss of the primary utility source and switching to the alternate source unless the utility allows paralleling of the two sources). The loss of the transformer or of the service or distribution equipment would still result in a loss of service. Maintenance on the system requires all loads to be shut down.

An automatic transfer scheme may optionally be provided between the two primary switches to automatically switch from a failed utility source to an available source. Most often metal-clad circuit breakers are used, rather than metal-enclosed switches, if this is the case. More about typical equipment application guidelines follows in a subsequent section of this guide.
Expanded radial system

The radial systems shown in figures 5-2 and 5-3 can be expanded by the inclusion of additional transformers. Further, these transformers can be located close to the center of each group of loads to minimize voltage drop. Reliability increases with a larger number of substations since the loss of one transformer will not result in a loss of service for all of the loads.

Figure 5-4 shows an expanded radial system utilizing multiple substations, but still with only one utility source and only one primary feeder:

![Figure 5-4: Expanded Radial System with one utility source and a single primary feeder](image)

A more reliable and maintainable arrangement utilizing multiple primary feeders is shown in figure 5-5. In the system of figure 5-5, each unit substation is supplied by a dedicated feeder from the service entrance switchgear. Each substation is also equipped with a primary disconnect switch to allow isolation of each feeder on both ends for maintenance purposes.

Typical service entrance equipment consists of a metal-clad switchgear main circuit breaker and metal-enclosed fused feeder switches. Metal-Clad circuit breakers may be used instead of metal-enclosed feeder switches if required.

![Figure 5-5: Expanded Radial System with one utility source and multiple primary feeders](image)
Figure 5-6 shows an expanded radial system utilizing multiple substations and two utility sources, again with metal-clad primary switchgear but with a duplex metal-enclosed switchgear for utility source selection:

![Figure 5-6: Expanded Radial System with two utility sources and multiple primary feeders](image)

Of the arrangements discussed this far, the arrangement of figure 5-6 is the most reliable – it does not depend upon a single utility source for system availability, nor does the failure of one transformer or feeder cause a loss of service to the entire facility. However, the loss of a transformer or feeder will result in the loss of service to a part of the facility. More reliable system arrangements are required if this is to be avoided.

**Loop system**

The loop system arrangement is one of several arrangements that can allow one system component, such as a transformer or feeder cable, to fail without causing a loss of service to a part of the facility.

Figure 5-7 shows a primary loop arrangement. The advantages of this arrangement over previously-mentioned arrangements are that a failure of one feeder cable will not cause one part of the facility to experience a loss of service and that one feeder cable can be maintained without causing a loss of service (note that an outage to part of the system will be experienced after the failure of a feeder cable until the loop is switched to accommodate the loss of the cable).

In figure 5-7 metal-clad circuit breakers are used as the feeder protective devices. Fused metal-enclosed-feeder switches could be utilized for this, but caution must be used if this is considered since the feeder fuses would have to be able to serve both transformers and the feeder and transformer fuses would have to coordinate for maximum selectivity.

It must be noted that the system arrangement of figure 5-7 is designed to be operated with the loop open, i.e., one of the four loop switches shown would be normally-open. If closed-loop operation were required, metal-clad circuit breakers should be used instead to provide maximum selectivity (this arrangement is discussed further below). Momentary paralleling to allow maintenance of one section of the loop without causing an outage to one part of the facility can be accomplished with metal-enclosed loop switches, however, if caution is used in the system design and maintenance.
Another method of allowing the system to remain in service after the failure of one component is the secondary-selective system. Figure 5-8 shows such an arrangement.

The system arrangement of figure 5-8 has the advantage of allowing one transformer to fail without causing a loss of service to one part of the plant. This is a characteristic none of the previously-mentioned system arrangements exhibit. The system can be run with the secondary bus tie breaker normally-open or normally-closed. If the bus tie breaker is normally-closed the failure of one transformer, if directional overcurrent relays are supplied on the transformer secondary main circuit breakers, will not cause an outage, however care must be taken in the system design as the available fault current at the secondary switchgear can be doubled in this case.

Typical equipment for this arrangement is low voltage power circuit-breaker switchgear with drawout circuit breakers, both for reasons of coordination and maintenance. However, a low voltage switchboard may be utilized also if care is taken in the system design and the system coordination is achievable. For a normally-closed bus tie breaker, low voltage power switchgear is essential since the breakers lend themselves more readily external protective relaying.

Note that if one transformer fails the other transformer and its associated secondary main circuit must carry the entire load. This must be taken into account in sizing the transformer and secondary switchgear for this type of system to be effective.

A larger-scale version of the secondary selective system is the transformer sparing scheme, as shown in figure 9. This type of system allows good flexibility in switching. The system is usually operated with all of the secondary tie breakers except one (the sparing transformer secondary main/tie breaker) normally-open. The sparing transformer
secondary main/tie breaker) normally-open. The sparing transformer supplies one load bus if a transformer fails or is taken off-line for maintenance. A transformer is switched out of the circuit by opening its secondary main breaker and closing the tie breaker to allow the sparing transformer to feed its loads. The sparing transformer may be allowed to feed multiple load busses if it is sized properly. Care must be used when allowing multiple transformers to be paralleled as the fault current is increased with each transformer that is paralleled, and directional relaying is required on the secondary main circuit breakers to selectively isolate a faulted transformer. An electrical or key interlock scheme is required to enforce the proper operating modes of this type of system, especially in light of the fact that the switching is carried out over several pieces of equipment that can be in different locations from one another. A properly-designed interlocking system will allow for the addition of future substations without modification of the existing interlocking.

With both types of secondary-selective system, an automatic transfer scheme may be utilized to switch between a failed transformer and an available transformer.

![Figure 5-9: Transformer Sparing Scheme](image)

**Primary-Selective system**

A selective system arrangement may also utilize the primary system equipment. Such an arrangement is shown in figure 5-10.

As with the secondary selective system, an automatic transfer scheme may be used to automatically perform the required transfer operations, should a utility source become unavailable. The bus tie circuit breaker may be normally-closed or normally-open, depending upon utility allowances. If the bus tie circuit breaker is normally-closed care must be taken in the protective relaying to insure that a fault on one utility line does not cause the entire system to be taken off-line. The available fault current with the tie breaker normally closed increases with each utility service added to the system.

Metal-Clad switchgear is most commonly used with this type of arrangement, due to the limitations of metal-enclosed load interrupter switches.

![Figure 5-10: Primary-Selective System](image)
Secondary Spot-Network system

In large municipal areas where large loads, such as high-rise buildings, must be served and a high degree of reliability is required, secondary network systems are often used. In a secondary network system several utility services are paralleled at the low voltage level, creating a highly reliable system.

Network protectors are used at the transformer secondaries to isolate transformer faults which are backfed through the low voltage system. These devices are designed to automatically isolate a faulted transformer which is backfed from the rest of the system. The transformers typically have higher-than-standard impedances to reduce the available fault current on the low voltage network. The common secondary bus is often referred to as the “collector bus.” An example of a secondary spot-network system is shown in figure 5-11.

Ring Bus system

Essentially a loop system in which the loop is normally closed, the ring bus is a highly reliable system arrangement. A typical ring-bus system is depicted in figure 5-12.

A fault at any bus causes only the loads served by that bus to lose service. Bus differential relaying is recommended for optimum reliability with this scheme. The bus differential relaying will open both breakers feeding a bus for a fault on that bus. Metal-clad switchgear is usually used for the primary ring bus.

Although figure 5-12 shows two utility sources, this system arrangement can be easily expanded to incorporate additional utility sources. As with the primary-selective system with a normally-closed bus tie breaker, the available fault current is increased with each utility source added to the system.
Composite systems

The above system arrangements are the basic building blocks of power distribution system topologies, but are rarely used alone for a given system. To increase system reliability it is usually necessary to combine two or more of these arrangements. For example, one commonly-used arrangement is shown in figure 5-13.

As can be seen, a fault on a primary loop cable or the failure of one transformer can be accommodated without loss of service to either load bus (but with an outage to part of the system until the system is switched to accommodate the failure). In addition, a single section of the primary loop or one transformer can be taken out of service while maintaining service to the loads.

The system of figure 5-13 can be expanded by the addition of an additional utility source and a primary bus tie breaker to form an even more reliable system, as shown in figure 5-14. With this arrangement, the failure of a single utility source, a single primary circuit breaker, a single loop feeder cable, or a single transformer can be accommodated without loss of service. And, any one primary circuit breaker, any one section of the primary distribution loop, or any one transformer can be taken out of service without loss of service to the loads. However, the cost of a second utility service and two additional metal-clad breakers must be taken into account.

![Figure 5-13: Composite System – Primary Loop/Secondary-Selective](image)

A logical expansion of this system, resulting in a further increase in system reliability, can be had by replacing the primary distribution loop with dedicated feeder circuit breakers from each primary bus, as shown in figure 5-15. In this system arrangement multiple primary feeder cable failures can be accommodated without jeopardizing service to the loads (an outage will be taken until the system is switched to accommodate the failures, however).

An example of an extremely reliable system arrangement is given in figure 16. Note that figure 5-16 is a re-arrangement of the primary ring-bus configuration shown in figure 5-12, along with the primary source-selective configuration shown in figure 5-3 and a variant of the transformer sparing scheme given in figure 5-9. This system arrangement gives good flexibility in switching for maintenance purposes, and also allows any one utility, primary switchgear bus, or transformer fail without loss of service to any of the loads (again, an outage may be taken until the system is switched to accommodate the failure, depending upon the failure under consideration). It also allows any three primary feeders to be faulted without loss of service to any of the loads. Other composite arrangements are possible.
Summary

Various system arrangements have been presented in this section, starting with the least complex and progressing to a very complex, robust system arrangement. In general, as reliability increases so does complexity and cost. It must be remembered that economic considerations will usually dictate how complex a system arrangement can be used, and thus will have a great deal of impact on how reliable the system is. Tables 5-6 and 5-7 show the features of each system arrangement given in this section.
Please note that the formulas given in these tables are for the systems as shown in the figures above. They will hold true for expanded versions of these system arrangements where the expansion is made symmetrically with respect to the configuration shown. They will not hold true when modifications are made to the system arrangements with respect to symmetry, with altered numbers of switching/protective devices, or for concurrent failures of different types of system components. When in doubt regarding a system which is derived from, but not identical, to the systems shown in the figures above, double-check these numbers.

From a maintenance perspective, the number of system elements that can be taken down for maintenance is the same as the number that can fail while maintaining service to the loads.

These tables do not attempt to address concurrent failures of different types of system components, nor are they a guarantee of loss of service to a particular load after a component failure while the system is being switched to an alternate configuration. However, they are a guide to the relative strengths and weaknesses of each of the system arrangements presented.

**Table 5-6: Power system arrangement summary for the basic arrangements as shown in this section**

<table>
<thead>
<tr>
<th></th>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Radial w/ Primary Selectivity</td>
<td>U-1 o</td>
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<td>$+</td>
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<td>$$</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>$$</td>
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<td>T  ▲</td>
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<tr>
<td>Primary Selective</td>
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<td>PB-F-U o,■,✓</td>
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<td>0</td>
<td>0</td>
<td>$$$$</td>
</tr>
<tr>
<td>Secondary Spot Network</td>
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<td>PB-1 o,■,✓,†</td>
<td>F-1 o,■,✓,†</td>
<td>T-1 o,■,✓,†</td>
<td>SB-1 o,■,✓,†</td>
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<tr>
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<td>U o,■,✓,▼</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$$$$$</td>
</tr>
</tbody>
</table>

- ♦ Assumes that each utility source has sufficient capacity to supply the entire system.
- ▲ Assumes that all secondary circuit breakers, including feeder breakers, are interchangeable.
- • Assumes that each primary main and bus tie (if applicable) circuit breakers has sufficient capacity to supply the entire system.
- ○ Assumes that all primary circuit breakers, including breaker breakers, are interchangeable.
- ☆ Assumes that each primary feeder has sufficient capacity to supply the entire system.
- † Assumes that each transformer, secondary main and bus tie (if applicable) circuit breaker have sufficient capacity to supply the entire system.
- ▼ Assumes that the ring bus has sufficient capacity to supply the entire system.
Table 7: Power system arrangement summary for the composite arrangements as shown in this section

<table>
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<tbody>
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<td>Primary Double-Selective / Secondary-Selective</td>
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<td>PB-F/2-U</td>
<td>F/2</td>
<td>T-1 †</td>
<td>T-1 †,▲</td>
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</tr>
<tr>
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<td>PB-F/2-U+1</td>
<td>F/2</td>
<td>T-1 †</td>
<td>T †,▲</td>
<td>$$$$$$+</td>
</tr>
</tbody>
</table>

♦ Assumes that each utility source has sufficient capacity to supply the entire system.
▲ Assumes that all secondary circuit breakers, including feeder breakers, are interchangeable.
◆ Assumes that each primary main and bus tie (if applicable) circuit breakers has sufficient capacity to supply the entire system.
▼ Assumes that all primary circuit breakers, including feeder breakers, are interchangeable.
☆ Assumes that each primary feeder has sufficient capacity to supply the entire system.
† Assumes that each transformer, secondary main and bus tie (if applicable) circuit breaker have sufficient capacity to supply the entire system.
▼ Assumes that the ring bus has sufficient capacity to supply the entire system.