Q. **System Design**

Provide simple diagrams on a Word document demonstrating load bus, ring bus, breaker and one-half bus, and breaker and one-third bus; and provide a brief discussion of the advantages and disadvantages of each bus design.

A. Figure 1 provides a diagram of a load bus arrangement[1].

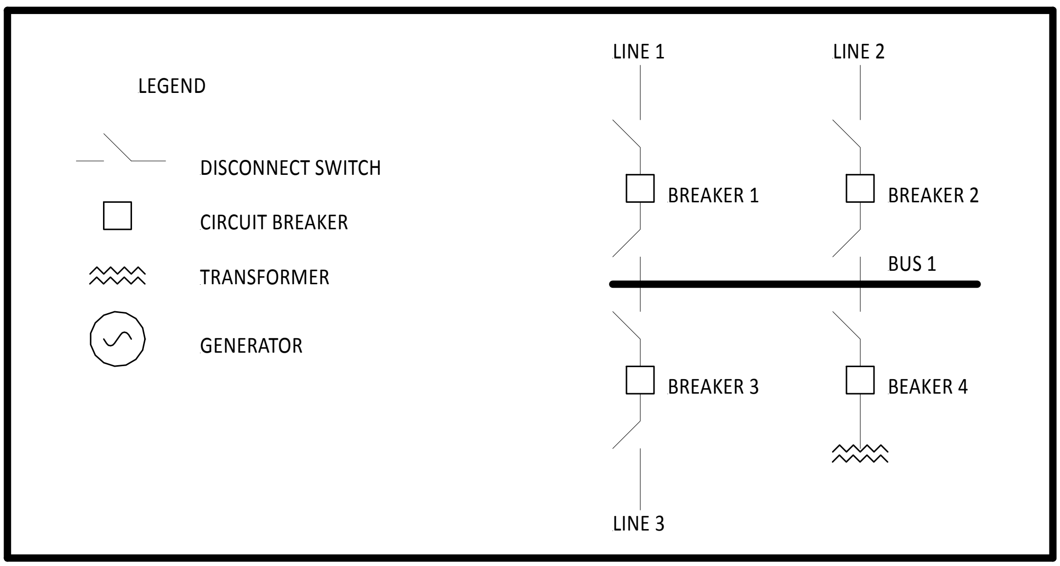



**Figure 1 – Load Bus Arrangement**

In the load bus arrangement, all circuits (i.e., lines, transformers and/or generators) are connected to a common station bus (i.e., Bus 1 in Figure 1). It is the simplest station bus configuration, and as such is the lowest cost alternative. Further, protective relaying in the load bus arrangement is straightforward. A fault on any single circuit requires that its dedicated circuit breaker trip to clear the faulted

[1] The load bus arrangement may also be called the single bus arrangement.

circuit. For example, a fault on Line 1 requires that circuit breaker 1 trip to isolate Line 1 from the station bus. However, there a number of reliability disadvantages associated with the load bus arrangement. First, a fault on Bus 1 requires that all circuit breakers connected to Bus 1 (breakers 1, 2 3 and 4) open to clear the fault. As a result, a fault on Bus 1 results in loss of the entire station. Second, for a breaker failure condition, all circuit breakers connected to the bus must be disconnected. For example, assume a fault on Line 2. Under normal operation, circuit breaker 2 must open to isolate Line 2 from the station bus. However, if circuit breaker 2 fails to open, then all remaining circuit breakers (1, 3 and 4) must open to isolate the faulted line 2. Consequently, under the breaker fail condition, all circuit breakers in the load bus arrangement must open, thereby isolating the station. Third, maintenance of the disconnect switches connected to Bus 1, or Bus 1 itself, requires a complete station outage.

To reduce the impact of bus and disconnect switch maintenance on service continuity, bus tie circuit beakers are often employed. Figure 2 provides an example of a load bus arrangement with a bus tie circuit breaker.

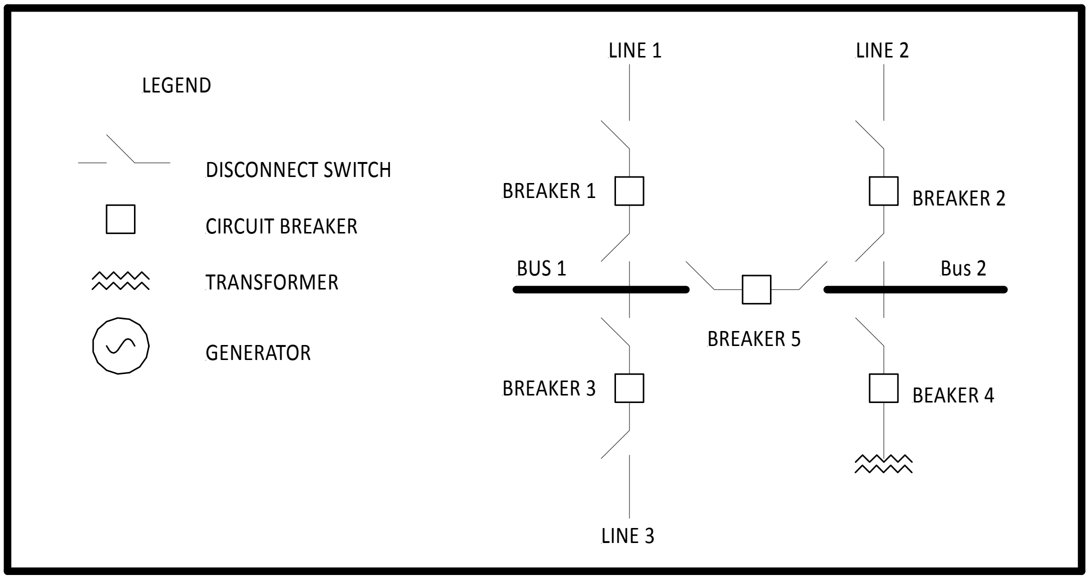



**Figure 2 – Load Bus Arrangement with Bus Tie Circuit Breaker**

The bus tie circuit breaker in the load bus arrangement does provide a slightly improved level of reliability and maintainability over the simple load bus arrangement with no bus tie circuit breaker. Given that the load bus is now split into two buses (Bus 1 and Bus 2), only part of the station is lost for a bus fault. From Figure 2 one will note that a fault on Bus 1 requires breakers 1, 3 and 5 to open to isolate the faulted bus. Bus 2, Line 2 and the transformer remain connected. Similarly, for Line 1 fault with the circuit breaker 1 failing to open, the bus tie breaker will open to isolate only Bus 1 connected elements. The same is true for Bus 2 connected elements with a failed circuit breaker on a Bus 2 element. Unfortunately, if the bus tie circuit breaker 5 fails to open for a Bus 1 or Bus 2 fault then the entire station must be isolated by opening all circuit breakers. The bus tie circuit breaker adds capital cost and some complexity to the protection and control to account for the bus tie circuit breaker.

Figure 3 provides a diagram of a four circuit ring bus arrangement[2]. In general the ring bus arrangement requires one circuit breaker per circuit connected to the ring. As such, the ring bus arrangement has a relatively low initial capital cost. The circuit breakers are arranged in a ring and the circuits connected between circuit breakers. This arrangement eliminates a common single bus. In the ring bus arrangement, there are no dedicated circuit breakers for each circuit. As shown in Figure 3, circuit beaker A is used to protect both generator G1 and Line 1. In other words, G1 and Line 1 share a common circuit breaker (breaker A). However, unlike the load bus that requires one circuit breaker to open to isolate a faulted circuit, the ring bus configuration requires two circuit breakers to open to isolate a faulted circuit. For example, a fault on G1 requires that not only circuit breaker A open, but also requires circuit breaker D to open. Similarly, a fault on Line 1 requires both circuit breaker A and circuit breaker B to open in order to isolate Line 1. The same is true for a bus fault. Given the ring arrangement, the bus sections are limited to the connections between the circuit breakers. As a result, the protective relaying for the ring bus arrangement is more complex than the load bus arrangement as the protection must consider the impact of faults on two circuits instead of one, and must trip only the correct two circuit breakers to isolate the faulted circuit. Automatic reclosing in the ring bus configuration becomes more complex than the load bus arrangement.

[2] The ring bus arrangement may contain more than four power system element connections. Four element arrangement is presented here for discussion purposes.

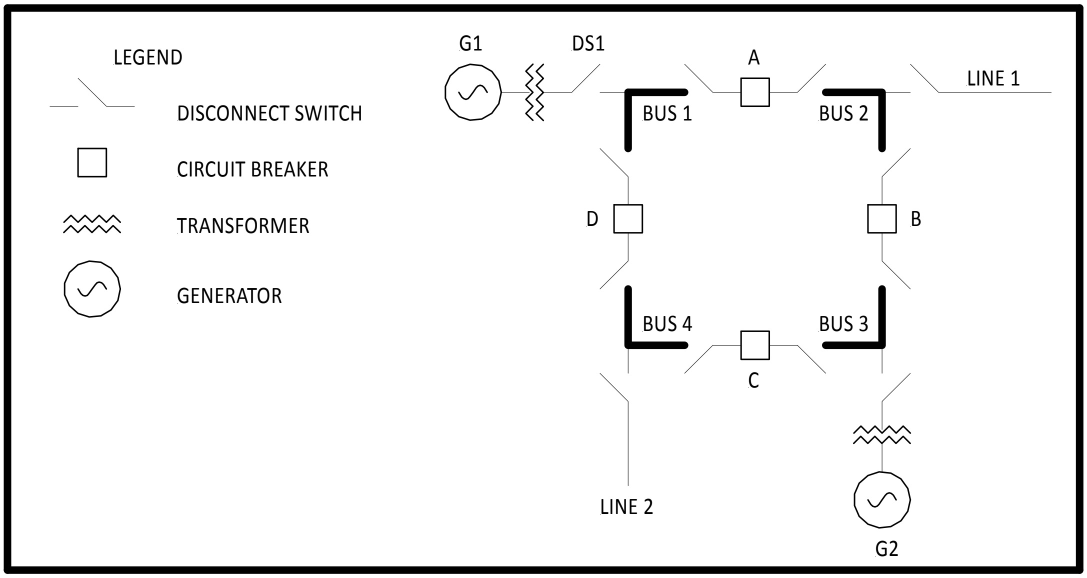



**Figure 3 – Four Element Ring Bus Arrangement**

The connection points for circuits around the ring bus arrangement are generally such that adjacent elements in the ring do not connect to the same point elsewhere in the system. As shown in Figure 3, starting at generator G1 and moving around the ring clockwise one finds G1, Line 1, G2 and Line 2. The arrangement exhibits what is referred to as a “line-load-line-load” or “source-load-source-load” configuration. This configuration provides an improved level of reliability over the load bus arrangement for the circuit breaker fail scenario. A fault in Bus 1 or generator G1 requires that circuit breakers A and D open. Should circuit breaker A fail to open, circuit breaker B will open. This leaves circuit breaker C closed such that generator G2 and Line 2 are connected permitting power to flow from source (G2) to load (Line 2). Similarly, a fault on G1 or Bus 1 with circuit breaker A opening and circuit breaker D failing to open requires circuit breaker C to open. This leaves circuit breaker B closed and generator G2 connected to Line 1. Once again there is a path from source (G2) to load (Line 1). For the breaker fail scenario only two circuits are isolated in the ring bus arrangement as opposed to all circuits in the load bus arrangement.

Individual circuit breaker maintenance can be performed in the ring bus arrangement without interrupting load (i.e., all lines remain connected). Should a fault occur during circuit breaker maintenance, the ring will be separated into two sections. Figure 4 provides an example of the impact of a fault during circuit breaker maintenance. Assuming circuit breaker F is out of service for maintenance, a fault on T1 requires circuit breakers B and C to open to isolate the faulted transformer. This action splits the ring into two segments: T2, Line 4 East, G1, and Line 1 West connected in one segment; and Line 2 East, G2 and Line 3 West connected in a second segment.

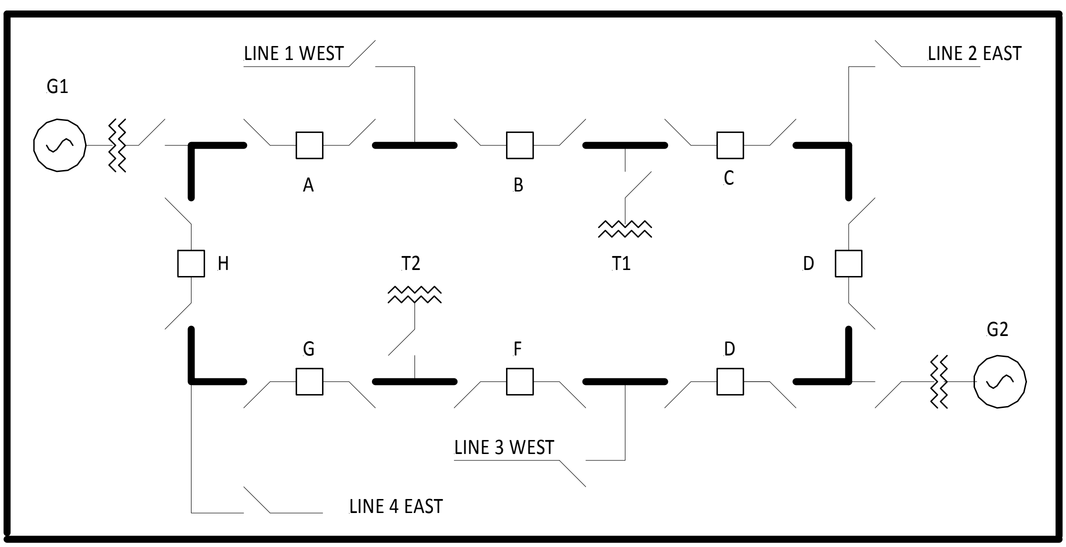



**Figure 4 – Eight Element Ring Bus**

Figure 5 provides a diagram of a breaker-and-one-half arrangement. The breaker-and-one-half arrangement has three circuit breakers in series between two main buses. The three breakers in series are referred to as a breaker-and-one-half diameter or leg. Two circuits are connected between the circuit breakers on each diameter. Consequently, three circuit breakers protecting two circuits or 1 1/2 breakers per circuit. The breaker-and-one-half arrangement provides for increased flexibility on operation and a high level of reliability. For example, a main bus fault (Bus 1) results in no loss of load under normal operation as only main bus side circuit breakers (breakers A and D) are required to open. This arrangement permits main bus maintenance without loss of load by opening all bus side circuit breakers. In fact, with source circuits connected opposite load circuits on the same diameter it is possible to remove both main buses and maintain supply of load through the station. Similar to the ring bus arrangement, circuit breaker maintenance does not require removal of a circuit from service.

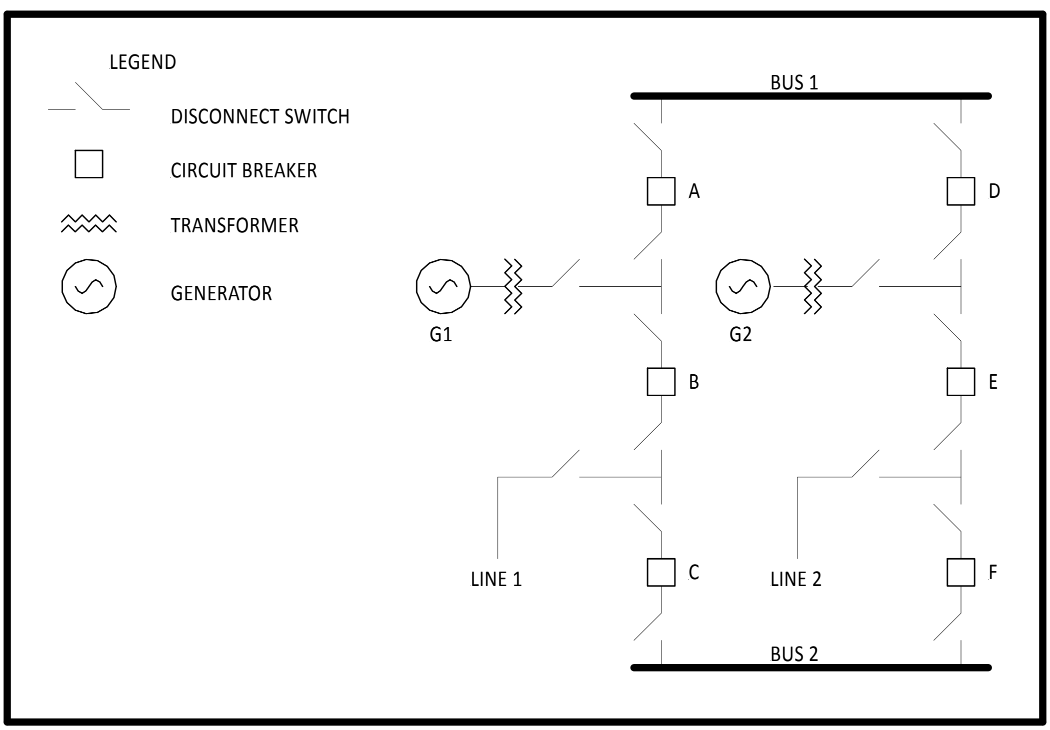


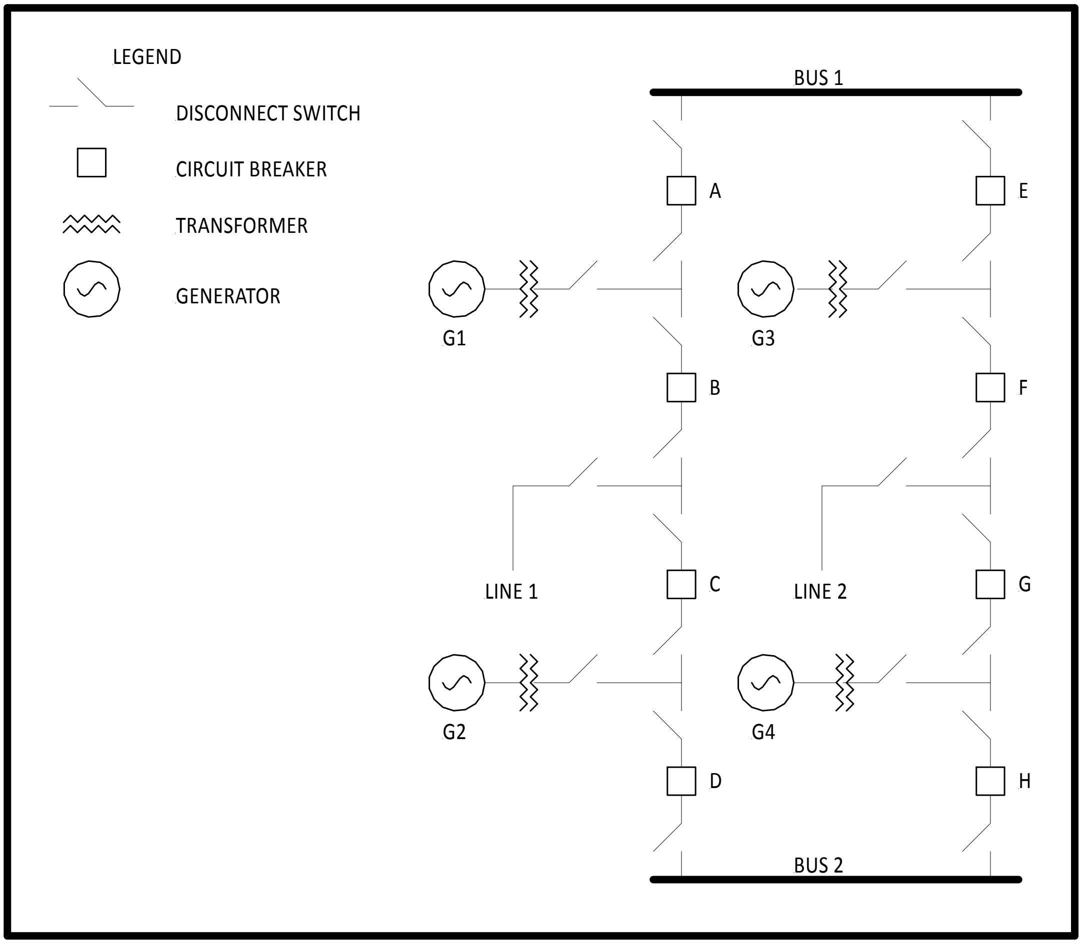

**Figure 5 – Breaker-and-One-Half Arrangement**

For circuit faults, two circuit breakers are required to open to isolate the faulted circuit. For example, for a fault on Line 2, circuit breakers E and F are required to open. If the middle breaker in the diameter fails to open (i.e., breaker E does not open but breaker F does open) for the Line 2 fault, circuit breaker D is required to open to isolate the fault. In this case a circuit breaker failure results in the loss of one additional circuit. However, if the bus side circuit breaker F fails to open for the Line 2 fault (with breaker E opening), then the remaining Bus 2 circuit breakers, circuit breaker C in this case, are required to open. For this breaker fail scenario there is no additional loss of circuits. This is an improvement over the ring bus configuration.

The breaker-and-one-half arrangement is more expensive than the load bus and ring bus arrangements. As well, the protection relaying and automatic reclosing schemes are more complex than the other arrangements.

Figure 6 provides a diagram of a breaker-and-one-third arrangement. The breaker-and-one-third arrangement is similar to the breaker-and-one-half arrangement. In essence there are four circuit breakers in series between two main buses with three circuits connected between the three breakers on the diameter. In essence four breakers protecting three circuits, or 1 1/3 breakers per circuit. The breaker-and-one-third arrangement provides the same benefits as the breaker-and-one-half arrangement. Bus and circuit breaker maintenance do not require an outage to a circuit. Further, circuit breaker failure results in loss of one additional circuit. The protection relaying and automatic reclosing schemes are complex and the arrangement is more expensive than the load bus or ring bus arrangement.

The breaker-and-one-third arrangement provides an operationally flexible and reliable station configuration when there are twice as many source circuits as load circuits and vice-versa. As demonstrated in Figure 6, with four source circuits and two load circuits connecting one load circuit to the midpoint of each diameter and two source circuits to the outside connection points on each diameter provides a very balanced and reliable arrangement. The arrangement requires a total of eight circuit breakers. By comparison, connecting the six circuits in a breaker-and-one-half arrangement would require three diameters totaling nine circuit breakers (one additional breaker) and the arrangement would have two diameters with a source and load circuit and one diameter with two source circuits. Breaker fail in the two source circuit diameter would result in loss of two sources as opposed to loss of only one source circuit for a breaker fail in the breaker-and-one-third arrangement.




1 **Figure 6 – Breaker-and-One-Third Arrangement**