Transmission Bus Configuration Design Philosophy

The intent of this document is to provide bus configuration guidelines for new substations interconnected to PECO's bulk electric system (BES)..These guidelines should also be taken into consideration when major substation modifications take place. The guidelines presented in this document are consistent with PJM's Transmission Owner Technical Guidelines & Recommendations for Substation Bus Configuration Requirements, PJM's Protection Standards, and other applicable Industry Standards. They are intended to preserve PECO's transmission network reliability when PECO itself, an Independent Power Producer, or a transmission customer/merchant interconnect to the transmission system. The guidelines are developed in such a way that a good balance between operational flexibility and economic feasibility is reached at each voltage level and configuration.

Types of Bus Configurations

This section contains a summary of main bus configurations discussed in this document. Additional configuration details and requirements for each voltage class application are provided in the respective sections.

Breaker-and-a-Half

The breaker-and-a-half configuration is composed of two main buses connected by element strings (bays). Each element string is composed of circuit breakers, transformers or line elements as shown in Figure 1. When multiple strings are installed, it is recommended that bus-sectionalizing breakers are installed such that no more than two strings are grouped on the same bus section. Note that all elements in a breaker-and-a-half scheme terminate between breakers with no elements connected directly to the main buses. In addition, each element is connected to the bus via a disconnect switch or circuit switcher. This would ensure that the bus stays intact while one or more of the elements connected to the bus stay out of service for an extended period of time for scheduled maintenance or repairs.

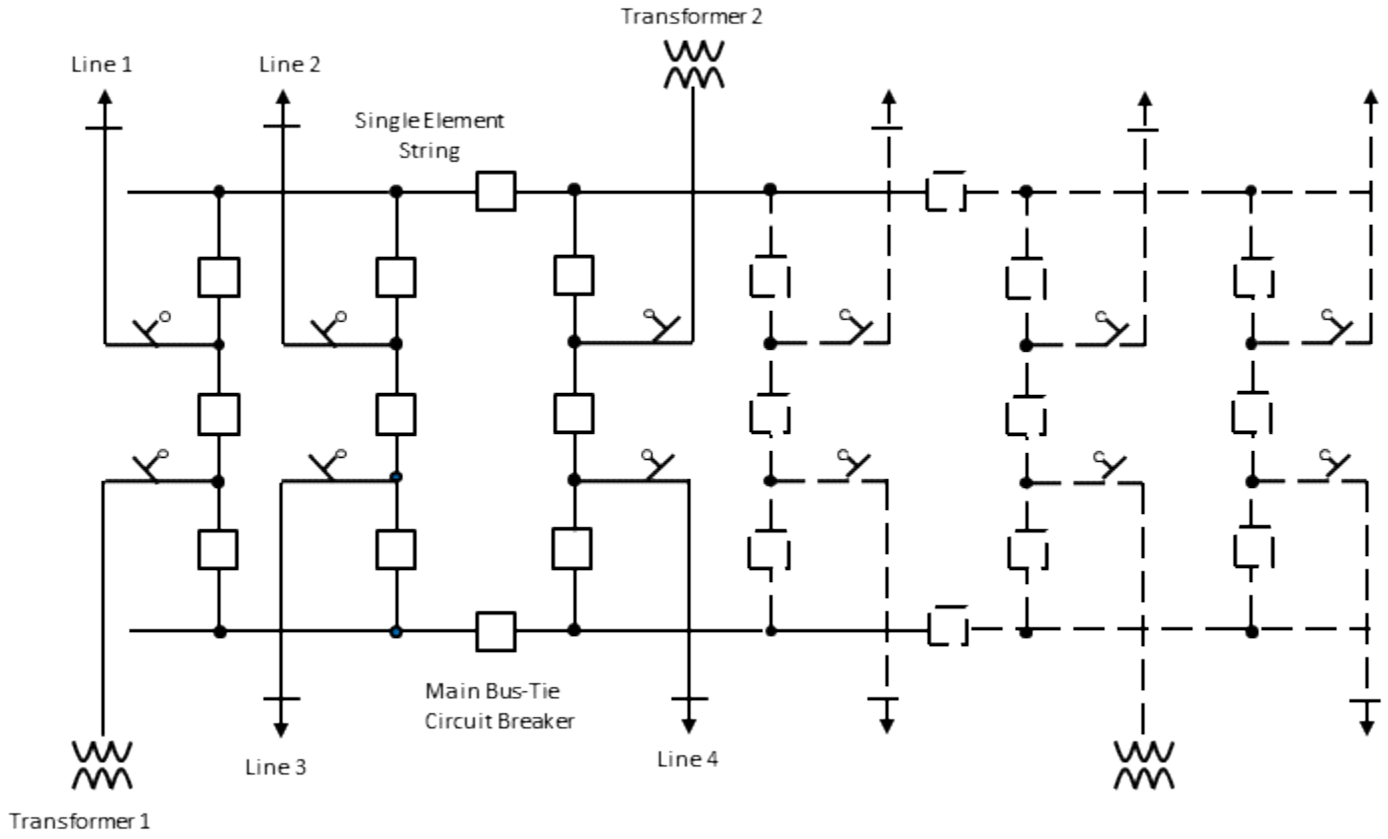

Figure 1: Breaker-and-a-half design

Ring Bus

The ring bus configuration is composed of several bus sections connected through bus-tie circuit breakers as shown in Figure 2. One transmission element is connected to a dedicated bus section; therefore, the isolation of one transmission element requires the operation of two bus-tie circuit breakers. In addition, each element is connected to the bus via a disconnect switch, circuit switcher or circuit breaker. This would ensure that the bus stays intact while one or more of the elements connected to the bus stay out of service for an extended period of time for scheduled maintenance or repairs.

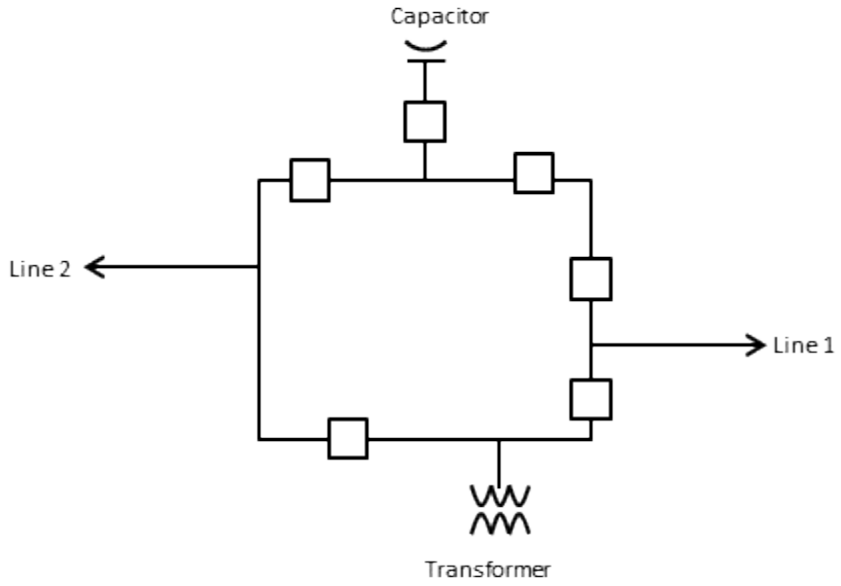

Figure 2 Ring Bus design

Straight Bus

The straight bus configuration is composed of a limited number of bus sections in which transmission elements terminate at a bus section through a circuit breaker. Figure 3 illustrates a transmission straight bus configuration

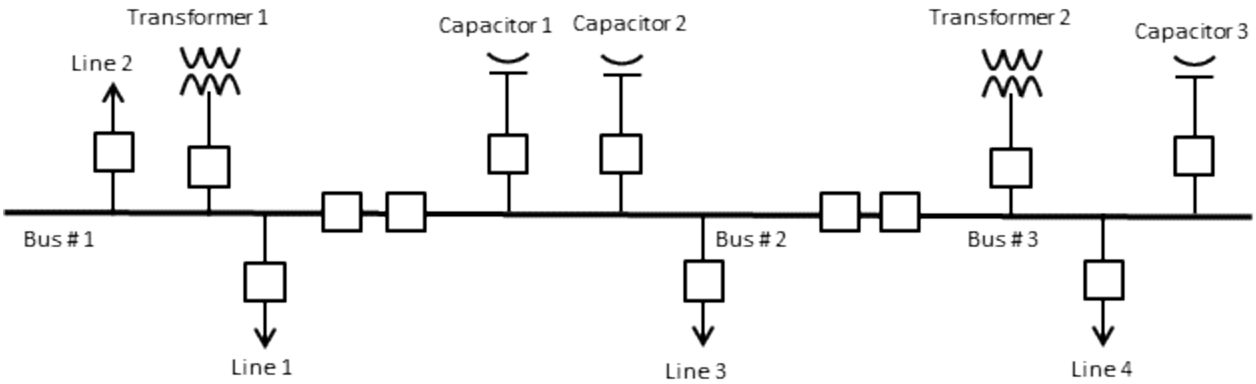

Figure 3 Straight bus designs

Extra High Voltage (EHV) Bus Configuration Guidelines

PECO's 500kV EHV system is designed to solely transport bulk power across broad areas and interconnect large generators. No load is allowed to be connected on the EHV system.

The substation design and configuration philosophy for the Extra High Voltage (EHV) system is intended to provide the EHV system with the highest level of reliability of all voltage classes. Given the level of reliability it provides, a breaker and a half configuration as is shown in Figure 1 is generally required, though a ring configuration may be considered if four or fewer elements emanate from the substation. (Figure 4)

The ring bus configuration would be mostly preferred in areas where:

1. No future expansion is anticipated
2. Land availability is limited
3. Physical location and the layout of the buses and the lines entering or leaving the substation may introduce reliability concern if the breaker and a half scheme is utilized.

If a ring bus configuration is used, the guidelines listed below should be considered

1. The bus should be designed in such a way that conversion to a breaker-and-a-half design is possible if needed
2. One element per terminal position is connected
3. Source and sink elements are alternated
4. Elements of a common type are not adjacent to one another. (This requirement would be applicable on four breaker ring bus configuration where more than one type of transmission elements are connected)

Note: At the design stage when ring bus configuration is being considered, additional studies should be conducted by Transmission Planning and Operation to ensure that maintenance or other extended outages of any of the elements connected to the ring bus does not cause reliability concerns.

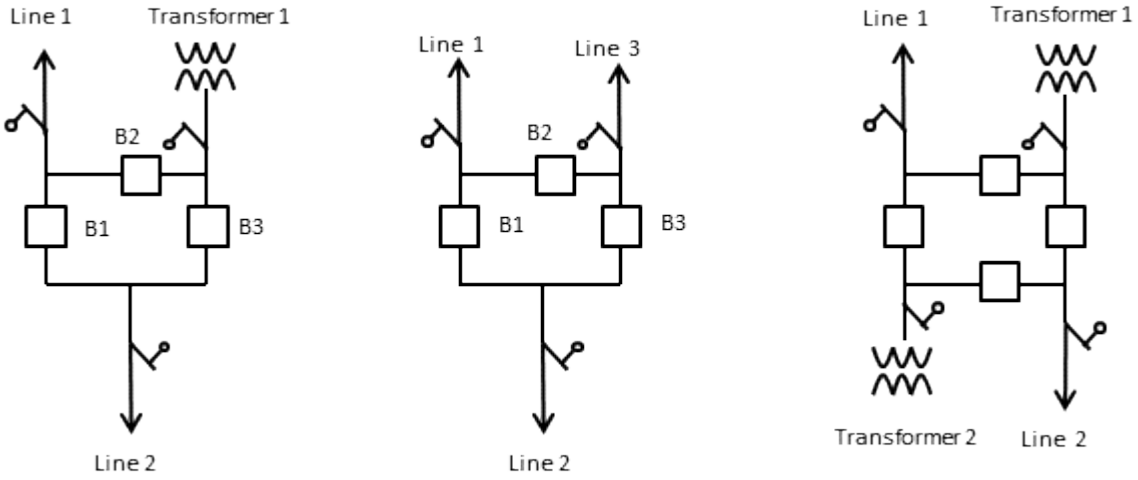

Figure 4 Typical three and four element ring bus designs

Generation Interconnection at an Extra High Voltage substation

As mentioned above, a breaker and a half and ring bus arrangement (for four or fewer elements) is preferred at these substations. In both arrangements the interconnection of a new generator on the bus requires the installation of new circuit breaker to create a new line position for the generator lead.
In areas where multiple generators are in close proximity to each other, the "Generator Hub" concept should be utilized. The "Generation Hub" avoids the excessive segmentation of the transmission lines which may degrade system integrity and network reliability. In addition, a line with excessive segmentation presents various challenges including difficulty in outage planning and increased maintenance costs
A generation hub is essentially an EHV interconnection substation that is shared by multiple transmission lines and generators. A generation hub employs "breaker-and-a-half" configuration in order to facilitate expansion and provide greater operational flexibility. A generation hub is designed to interconnect up to four generators and two transmission

lines. The ultimate configuration shall meet PECO, and PJM planning criteria including loss of largest resource. The figure below shows the ultimate configuration of a Generation Hub with four generators and two transmission Lines

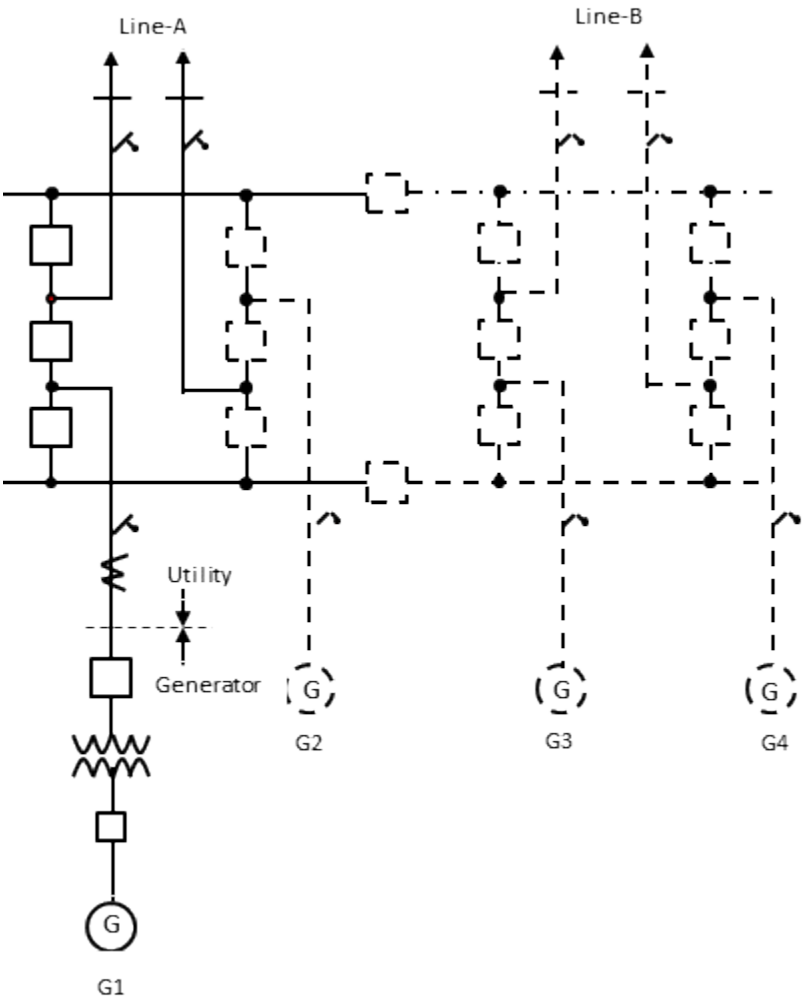

Figure 5 Generation Hub Configuration

Note: The dashed line shows future elements to be added to the bus. Depending on the complexity of the protection scheme and the scope of changes that would be necessary to accommodate the interconnection of the second generator, PECOmay decide to design and install initially additional breakers as shown on figure 6

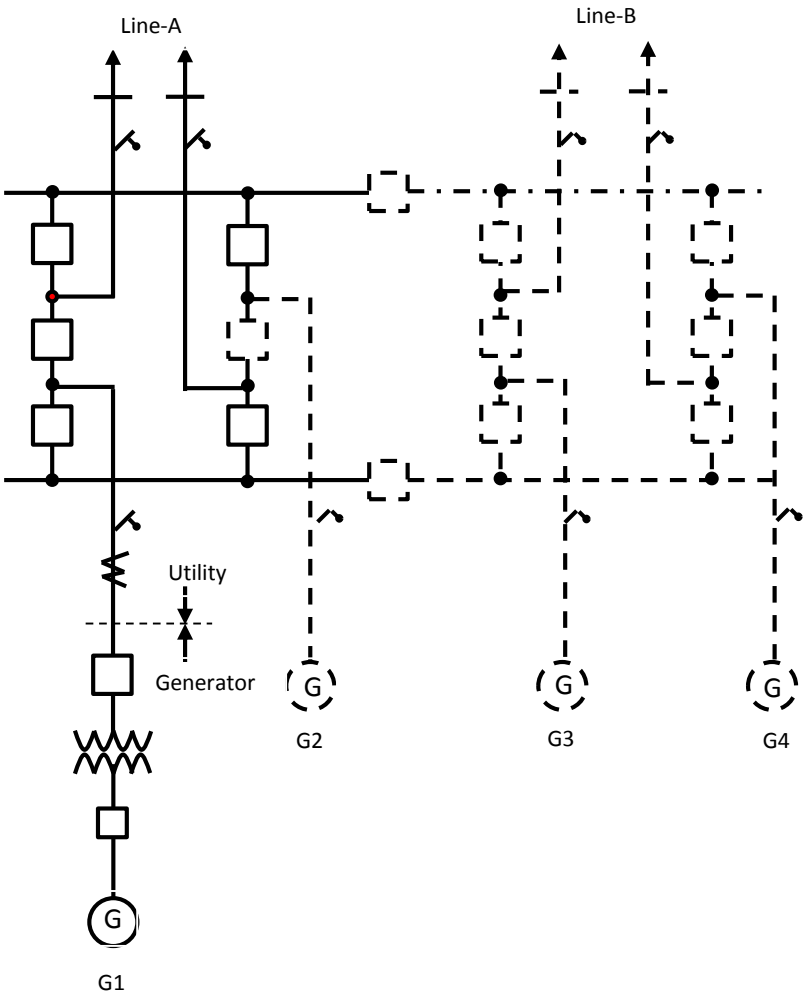

Figure 6 Generation Hub Configuration (initial installation)

High Voltage Bus Configuration Guidelines

PECO's High Voltage System includes all facilities at 230 and 138kV voltage levels. PECO uses its high voltage system i to transport bulk power, to deliver power to local load and to interconnect Independent Power Producers. The bus design configuration of this voltage class requires consideration of the various uses intended.

Given the level of reliability and service it provides, a breaker and a half configuration as shown in Figure 1 would be initially considered for the 230 and 138kV systems; however, other bus configurations should be considered following acceptable performance results of a reliability analysis.

If it is determined that a ring bus configuration is acceptable, the following guidelines should be considered based on the voltage class:

230kV System

1. Elements of a common type are not adjacent to one another. (This requirement is applicable in substations where more than one type of transmission elements are connected)
2. Source and Sink are alternated
3. One element per terminal position is connected
4. Four or fewer transmission elements (6 or fewer elements per color for ComEd) are connected on the ring bus

5. The bus should be designed in such a way that conversion to a breaker-and-a-half design is possible if needed
6. Additional planning and/operational studies should be conducted to ensure that the maintenance or other extended outages of any of the elements connected to the ring bus does not cause reliability concerns.

138kV System

While the ring bus with only one element per terminal position is the preferred option, connection of two elements per section would be acceptable as long as no two common transmission element types are connected on the same section of the ring bus. When more than one facility is connected to the same bus, installation of additional circuit breakers/switchers at those facilities should be considered. By doing so the removal of additional facilities for a fault would be avoided. . See figure 7 below

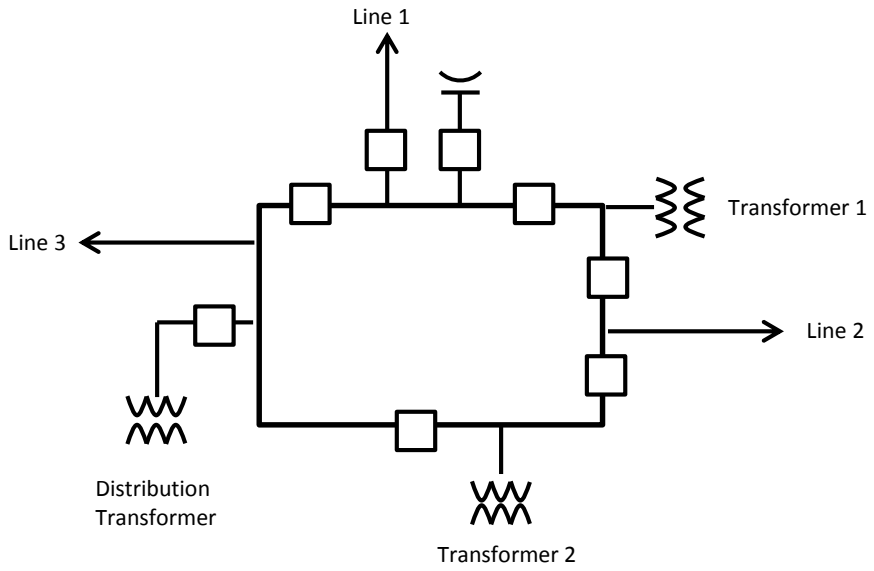

Figure 7 Acceptable ring bus configuration on 138 or 115kV system

Straight Bus configuration is another acceptable configuration for the 138kV system especially in heavily populated areas or other areas where land availability is limited. A straight bus configuration would be acceptable if bus sections are separated by double bus tie breakers and:

- No more than three bus sections (two bus sections per color on the ComEd transmission system)are in place
- No more than three elements are connected on each bus section
- In each bus section, source/sink points are evenly split.
- Each element is connected to the bus via a circuit breaker.

Generation Interconnection

All the above guidelines are applicable to any generation interconnection in the existing High Voltage substation. In some cases a generator may choose to interconnect to the high voltage network at a location of its choice. The bus configuration will be decided at the time of the interconnection taking into consideration the above guidelines as well as the current and future (planned) configuration of the system in the area of the interconnection. All IPP's will be required to provide an automatic full separation of its system from PECO's transmission system for any fault in their equipment

Load interconnection

a. Transmission Customers

All customers connected to the transmission facilities (network) operating at 69KV and above are considered as Transmission Customers. Per FERC Seven Factor rule customers fed of a radial facility (at any voltage level) are considered Distribution Customers

Capacity Expansion (Distribution Planning) organization in cooperation with Transmission Planning will make the determination if a customer could and should be connected to the Transmission System. In order to be considered to connect in the Transmission System, the customer should have a minimum of 20-30MVA of load. An exception to this rule would be in cases where customers with large motors may cause voltage problems if connected to the distribution system. If no other alternatives are available, these customers would be allowed to connect on the PECO Transmission system. When the customer is connected to an existing substation/ bus all considerations previously stated in the HV section of this document will be applied. A double feed - three breaker ring bus is the minimum configuration when a new substation is needed to connect the customer. An exception to this requirement may be made if the customer is implementing co-generation and the utility feed is used as back up service only or the customer is requesting single service. In these cases a straight bus tie with three circuit breakers as shown on figure 8 may be considered. The customer is required to provide an automatic full separation of their system from PECO's transmission system for any fault in customer's equipment. In addition, any customer equipment should meet EU equipment standards and requirements.

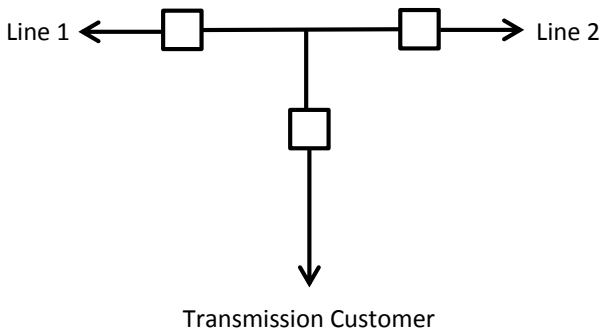

Figure 8: Three breaker straight bus configuration to feed transmission customers

b. Distribution substations connected on the 230, 138 or 115 kV System

For distribution substations, the high side ring bus with one element per bus section is the recommended configuration, however if the high voltage bus is installed for the sole purpose of feeding distribution load, a ring bus with two elements on the same section (transmission line and distribution transformer) or a straight bus configuration is acceptable depending on the available space, the amount of load connected to the substation and other determining factors. When straight bus configuration is utilized the following guidelines should be considered

1. Installation of a transformer high-side breaker or circuit switcher is recommended. Figure 9 below shows a typical configuration design of a distribution substation connected to 230 or138kV system
2. Studies should be completed to ensure that no reliability issues are identified for a stuck bus tie breaker contingency on the HV side.
3. If single bus tie breaker is installed on the HV side, the load dropped by single contingency should not exceed 300MVA.

If issues are identified when studying item 2 and 3, the installation of a second bus tie should be considered. In addition, cost to benefit ratio evaluation should be conducted to determine if the straight bus tie configuration is still the most optimal option

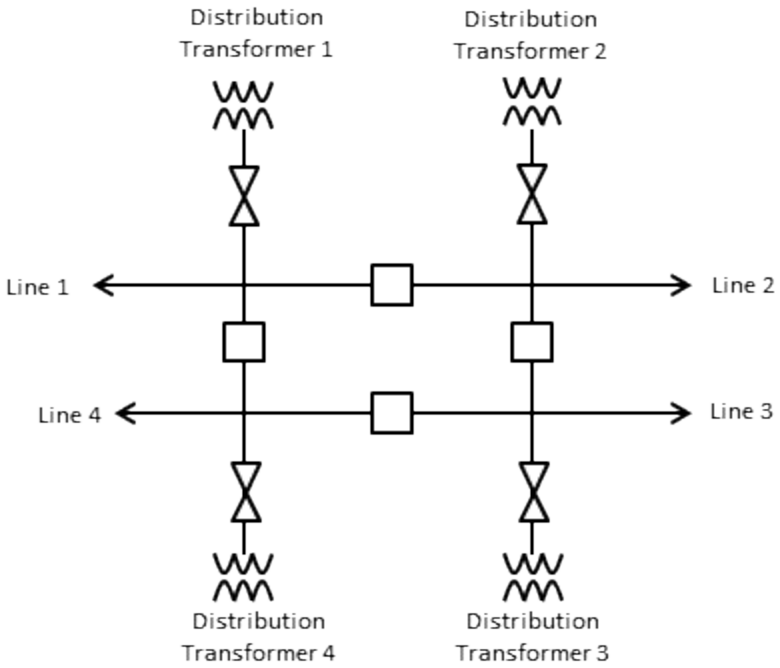

Figure 9 Ring bus configuration in a distribution substation

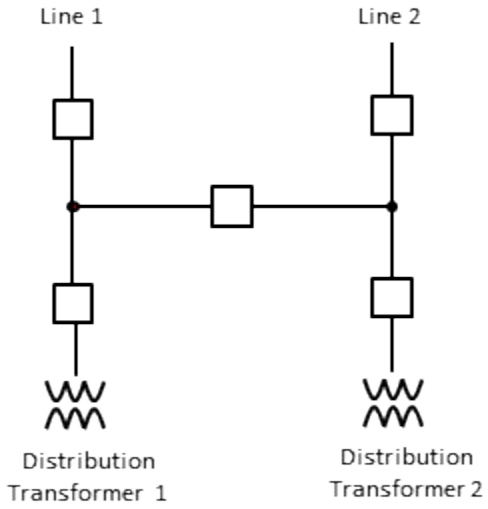

Figure 10 Typical Straight bus configuration in a distribution substation

Given the fact that this document is focused on transmission bus configuration and design, the distribution substation bus configuration will not be discussed. For new substations or major distribution substation additions, Distribution Capacity Planning organization should consult Transmission Planning on the proposed HV bus configuration and design. Transmission Planning organization should provide feedback based on the guidelines outlined in this document