Bonneville
POWER ADMINISTRATION

Substation Equipment Arrangement Application
STD-N-000003 REVISION 02 CN 01

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1. INTENT

The mission to provide reliable, cost effective transmission of bulk electricity to customers through BPA substations and over BPA transmission lines is supported by the following policy for arrangement of switching devices. This policy considers maintenance of switchyard equipment, personnel safety, flexibility of operation, consideration of the difficulty to obtain outages, and the desire to apply standard solutions and equipment to satisfy these objectives.

Continued process improvement to accommodate new connections to the power system requires the ability to predict what types of switchyard arrangement options might be applied. This allows pre-engineering and development of equipment standards that facilitate predictable reliability and comply with appropriate regulations. This standard enables greater efficiency in planning, designing, constructing, operating, maintaining, and supplying equipment for substations.

2. CURRENT REVISION

Revision 02, Change Notice 01, 8/10/2023: Updated the reference to STD-DS-000036 to indicate its latest title change. Updated references syntax and re-formatted the document to latest standards template.

For historical information on what has changed in all previous revisions or updates to this standard, please refer to the background document.

3. DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

3.1 Definitions

Arrangement: Relative position of switchyard equipment in reference to other adjacent equipment.

Auxiliary-bus: A bus that, when combined with a bus-tie breaker, provides an alternative path for sources or loads to attach to a main bus while their own circuit breaker is out of service. Can also be referred to as a Transfer Bus.

Bulk Electric System (BES): Power system elements at or above 100kV as defined by NERC. This equipment is subject to NERC regulations for transmission system reliability.

Bypass: Making a parallel connection around a breaker and its current transformers so that the breaker can be opened and maintained without loss of power transfer.

Element: Any electrical device with terminals that may be connected to other electrical devices such as a generator, transformer, circuit breaker, bus section, or transmission line. An Element may be comprised of one or more components. (NERC definition)

Layout: The location of equipment within the switchyard with consideration of dimension, arrangement, spare positions, and future development.

Line Tap: A connection to an existing Transmission Line anywhere between line terminals which of itself is not a source of fault current. The connection may be connected to a switch or breaker, a short or long segment of transmission line, a transformer, a load, or any combination of the preceding, as long as there is no other transmission network connection (i.e. the Line Tap is radial). Switches are typically added in the original “tapped” transmission line on either side of the Line Tap to facilitate sectionalizing of the original line for maintenance purposes.

Line terminal: The breaker and protective relay system that serves as an end of a transmission line where that end is a source of fault current.

Main-Grid: The Main Grid consists of Bulk Electric System facilities greater than 300 kV including all 500 kV and 345 kV transmission lines, and 500/230 kV and 345/230 kV transformers.

Transmission Line: A system of structures, wires, insulators and associated hardware that carry electric energy from one point to another in an electric power system. Lines are operated at relatively high voltages varying from 69 kV up to 765 kV, and are capable of transmitting large quantities of electricity over long distances. (NERC definition)

3.2 Acronyms and Abbreviations

CST: Customer Service Transformer.

4. BACKGROUND

4.1 Operations and Maintenance Flexibility Team Findings

During the late 1990s, a group of BPA substation operators met to develop a plan to address operations and maintenance flexibility issues for BPA facilities. This team was concerned that no alternative existed for breaker maintenance at single breaker arranged stations, and that outages could not be obtained to perform necessary maintenance. They produced a prioritized list to add bus tie PCBs to substations where they were needed. The team findings reinforced the need to arrange breakers in substations to allow for proper maintenance and operational flexibility and provide sufficient bus-tie PCBs in main and auxiliary-bus arrangements.

4.2 Standards and Criteria

When developing a plan-of-service for projects at existing substations or for future substations, Transmission Planning develops the breaker arrangement and substation layout needed to meet existing and future system performance required by the following Standards and Criteria:

- NERC TPL-001 Transmission System planning Performance Requirements
- NERC FAC-013 Transfer Capability Limits in the Planning Horizon
- WECC TPL-001-WECC-CRT Transmission Planning Performance Criteria
- STD-N-000010 BPA Reliability Criteria for System Planning
- STD-N-000001 BPA Technical Requirements for Interconnection to the BPA Transmission Grid

In addition, Transmission Planning coordinates with other groups across BPA Transmission Services to ensure plans-of-service meet operations and maintenance flexibility needs where practical and cost effective.

4.3 Findings from Benchmarking

Results of informal benchmarking by BPA personnel are included in background documentation of this policy. Several breaker policies are provided, one of which is for the New England Independent System Operator of the Northeastern US. Most large North American utilities have determined that the breaker-and-one-half arrangement is the most cost effective breaker arrangement for transmission level stations to meet required reliability performance and allow for maintenance. Each of these utilities has recommended that future expandability be provided and that a ring bus is acceptable in some cases as long as it can be expanded and converted in the future into a full breaker-and-one-half arrangement. More than one utility has converted main and auxiliary-bus stations into breaker-and-one-half arrangements in order to improve reliability.

5. STANDARD EXCEPTIONS

Any deviation from this standard must be requested and submitted in accordance with STD-P-000002, “Standard Compliance and Exception Policy.”

6. POLICY AND APPLICATION

To maintain consistency with evolving NERC standards, the following policy applies to all BPA transmission level equipment on the Bulk Electric System as defined by NERC and applied by WECC, generally 100kV or above.

These standard configurations consider factors to incorporate a basic design that is readily expandable and simplifies substation switching to safely isolate facilities and equipment with minimum adverse impact on power flows. The design must provide operating flexibility, allow for efficient and effective maintenance of substation equipment, provide for a safe working environment, and be cost effective.

6.1 Arrangement of Breakers for New Substations

All new substations to be owned, operated, or maintained by BPA, used to terminate lines and provide interconnection to new facilities or existing lines or facilities, will be planned and designed as follows:

- Substations less than 300kV:
    - Standard design will be breaker-and-one-half layout with provision for three breakers in each bay and a main bus at both ends of each bay.
    - Ring bus layout can be considered on a case-by-case basis for sole-use substations where the long range plan indicates low likelihood of future development.
    - Ring bus arrangement with up to 6 breakers per ring is allowed for either layout.
    - All line and transformer positions must be in a bay position.
    - Line disconnects are considered on a case-by-case basis. Transmission Planning typically recommends line disconnects on radial-tie lines to generation facilities, to permit making up the ring or bay during extended line outages.
    - Shunt-reactive devices can be installed in a bay position or attached to a bus.
    - Shunt-reactive devices can require that an additional breaker be installed for reactive device switching or fault clearing.

  - For existing main-and-auxiliary-bus arrangements: When adding a terminal(s) to an existing site such that the total number of bays will be four or more, it is recommended that a bus-tie breaker be added to the scope of the project. A standard exception to this will be evaluated on a case-by-case basis as outlined in the Standard Compliance and Exception Policy STD-P-000002.
  - For existing main-and-auxiliary-bus arrangements, a bus-sectionalizing breaker addition is considered for reliability purposes on a case-by-case basis.
  - Disconnect switches used on incomplete bays of breaker-and-one-half layouts shall be located and installed immediately adjacent to a main bus.
  - A disconnect switch shall not be used in lieu of a bus-tie breaker to energize the auxiliary bus. (See Special Considerations section.)
- Substations at 300kV or above:
  - Standard design will be breaker-and-one-half layout with provision for three breakers in each bay and a main bus at both ends of each bay.
  - Ring bus configuration with up to 4 breakers per ring is allowed for standard layout. The ring bus must be expandable to breaker-and-one-half.
  - All lines and transformers are to be connected to a bay position.
  - Transformers shall be installed in foreseeable end bays so as not to obstruct future substation expansion unless an exception is made. Exceptions are on a case by case basis and require documentation.
  - A double-breaker / double-bus configuration is considered for critical substations on a case-by-case basis. This configuration is created using a breaker-and-one-half layout with one element connection and two breakers per bay.
  - A line-isolating disconnect addition is considered on a case-by-case basis. Transmission Planning typically recommends line-isolating disconnects on radial-tie lines to generation facilities, to permit making up the ring or bay during extended line outages.
  - Shunt-reactive devices can be installed in bay or bus positions.
  - Each shunt-reactive device will have its own breaker.
  - Disconnect switches used on incomplete bays of breaker-and-one-half layouts shall be located and installed immediately adjacent to a main bus.

6.1.1 *Disconnect Switches*

A disconnect switch will be provided on each side of each power circuit breaker to isolate the breaker from the adjacent circuit elements. An additional disconnect placed in series with a circuit element allows a ring bus to be restored during the removal from service of that circuit element. The disconnect switch in series with the circuit element may include the ability to ground the adjacent circuit element.

6.1.2 *Instrument Transformer Locations*

For dead-tank breakers: a minimum of three Bushing Current Transformers (BCTs) shall be provided on each side of each breaker so that the protection zones for adjacent equipment can overlap the breaker.

For live-tank breakers: only one set of free-standing CTs is typically available and a second set of CTs is unnecessary.

A single Voltage Transformer with dual secondary windings shall be supplied for each bus and for each circuit element as required for circuit element protection.

6.2 Expandability, Site Selection

New substations owned by BPA shall be planned and designed to include flexibility for future expansion. For 500kV substation development, expansion capability shall also consider the future need for 500/230kV transformation and a 230kV substation, shunt-reactive devices located outboard to main busses, and any future need for series-reactive compensation.

Sufficient land shall be purchased to satisfy future additions according to the future planning considerations typically shown on the Project Requirements Diagram (PRD). As a minimum, the site shall be chosen to allow for future expansion of at least two more bays. The ability to add bays in either direction is preferred.

Sufficient expansion room shall be provided in the control house for control and protection equipment for two additional bays. The control house shall be designed and located within the substation to allow further expansion for large-scale substation additions.

6.3 Ideal Progression and Layout of the Breaker Arrangement

The substation might begin as a ring bus when six or less network elements are to be served and reliability requirements can be met. The ring bus is laid out in a manner that will enable future conversion of the ring into a breaker-and-one-half arrangement. The layout shall facilitate an ability to progress from a ring into a breaker-and-one-half arrangement in a way that eliminates the need to re-terminate high voltage equipment, minimizes the need to re-configure protection circuits, and that minimizes the number of outages necessary to achieve the new arrangement. Refer to Figure 1-Figure 9.

Each circuit element, such as a transmission line, will terminate at the future permanent bay location (dead-end tower) so that future re-termination is unnecessary.

Disconnects contained within an incompletely developed bay and used to isolate a circuit element shall be located adjacent to each bus. This will prevent multiple bus outages during installation of future circuit elements within that bay (e.g. Figure 1).

Connect reactive groups to either main bus using a single breaker (Figure 9).

Direct connection of a power transformer into what will become the future main bus is allowed only if the substation will be operating initially as a ring configuration, such as is shown in Figure 3, Figure 4 or Figure 5. The power transformer must be connected into the same bay position that it will occupy once the third bay is added and a breaker-and-one-half configuration is realized. Otherwise, power transformers must be connected into the full bay positions with dual breakers, in the same manner as transmission lines (Figure 8).

If transmission planning personnel determine that higher reliability is required for particular elements, then these single elements shall reside in a single bay without any other element so that a double-breaker / double-bus arrangement is achieved for that element in that bay (e.g. Figure 5, left-hand bay).

Figure 1-Figure 8 depict an ideal progression of flexible arrangements where additional circuit elements can be added over time with minimized construction effort. These figures do not include all possible combinations of layouts; they do, however, describe basic principles, which when followed, will lower cost over time by minimizing the need for future re-configuration.

The three-element, three-breaker ring in Figure 1 might be expanded into either one of the four-element, four-breaker ring arrangements shown in Figure 2 and Figure 3. Either of these may then be expanded into the five-element, five-breaker ring of Figure 4, or the five-element, eight-breaker, breaker-and-one-half arrangement shown in Figure 5. These can then be expanded into the six-element arrangements shown in Figure 6 and Figure 7, which can eventually become the seven-element, eleven-breaker, breaker-and-one-half arrangement shown in Figure 8. Notice that space is reserved for future addition of bays in two/both directions. Figure 9 depicts addition of a reactive group served through a single breaker. High-voltage circuit elements are terminated at the switchyard location (dead-end tower) where they will reside permanently.

Re-configuration of control and protection circuits, both current measurement location and also breaker tripping, is necessary when progressing from one arrangement to another.

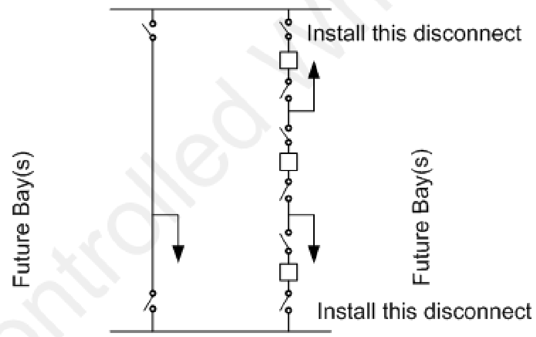

Figure 1.--- Three Element, Three Breaker Ring

Note: Disconnects within the incomplete bay must be included and located immediately adjacent to what will become each main bus once a full breaker-and-one-half arrangement is realized. Disconnects within the complete bay must also be included to minimize future and long term installation costs.

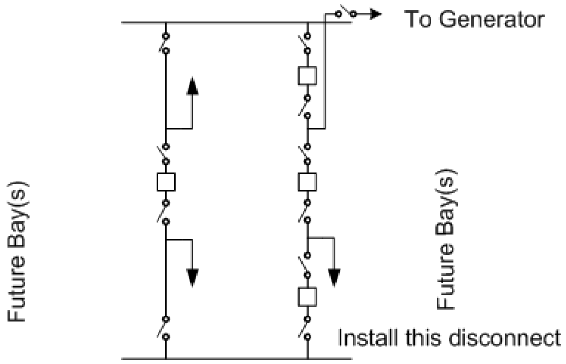

Figure 2.--- Four Element, Four Breaker Ring

Note: To keep the ring intact when an element is removed from service, each ring bus with four or more elements might include a series-connected disconnect (line disconnect) with one or more elements.

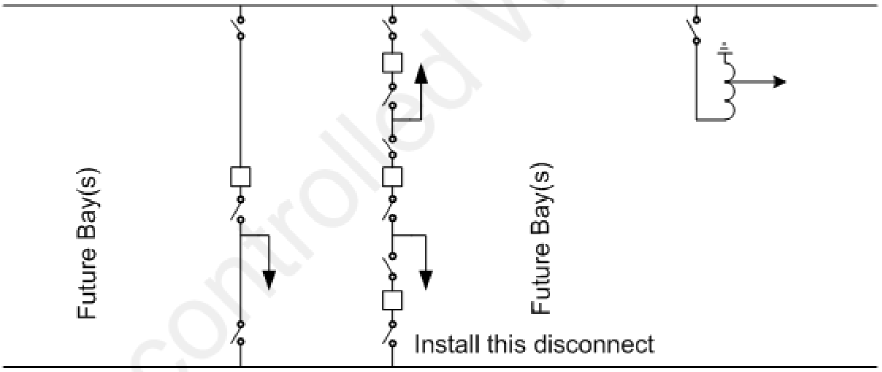

Figure 3.--- Four Element, Four Breaker Ring

Note: To make allowance for future bay additions, the power transformer shall be located in a remote bay where it will permanently reside once a full breaker-and-one-half arrangement is realized in that bay.

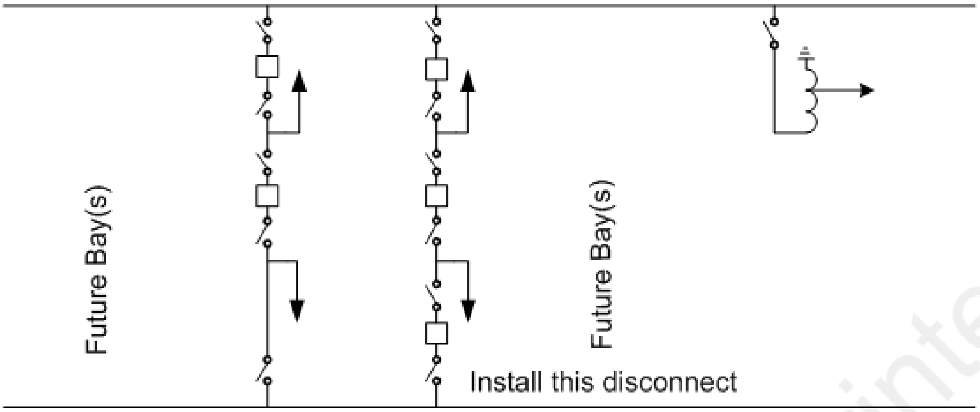

Figure 4.--- Five Element, Five Breaker Ring

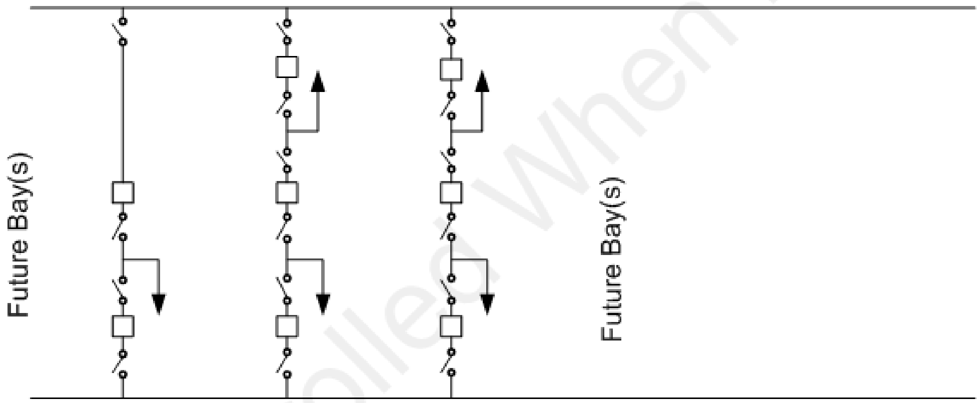

Figure 5.--- Five Element, Eight Breaker, Breaker-And-One-Half Arrangement

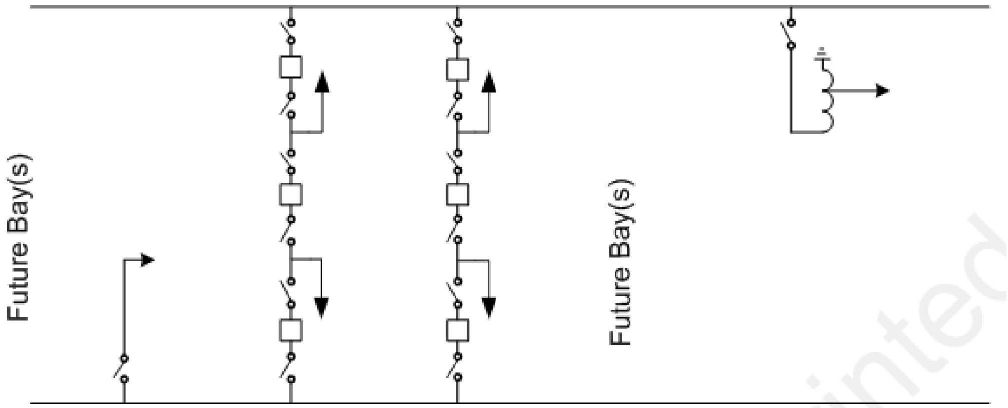

Figure 6.--- Six Element, Six Breaker Ring

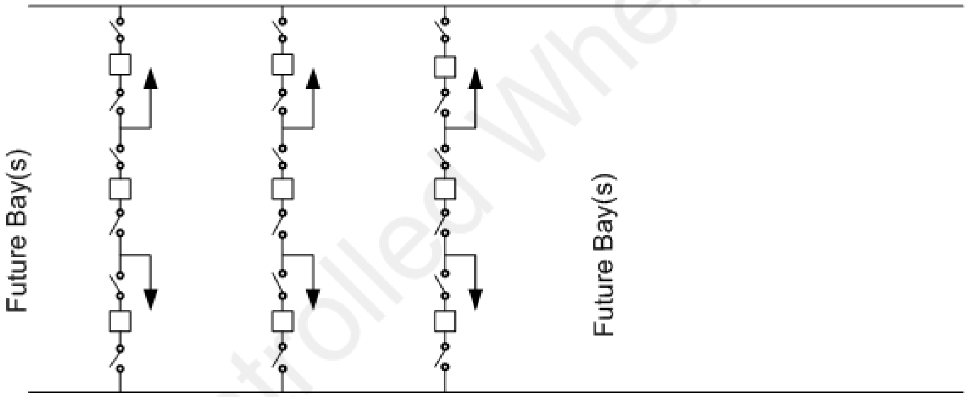

Figure 7.--- Six Element, Nine Breaker, Breaker-And-One-Half Arrangement

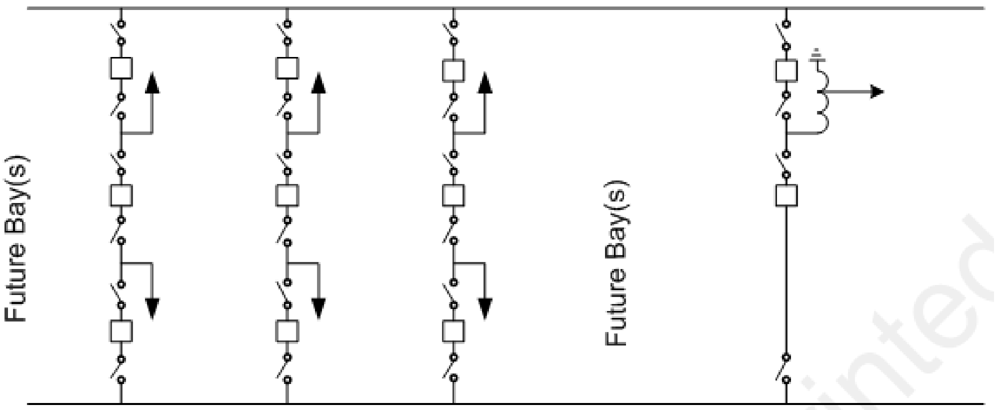

Figure 8.--- Seven Element, Eleven Breaker, Breaker-And-One-Half Arrangement

Note: In the breaker-and-one-half arrangement, lines and or power transformers shall be terminated with two breakers for maintenance flexibility.

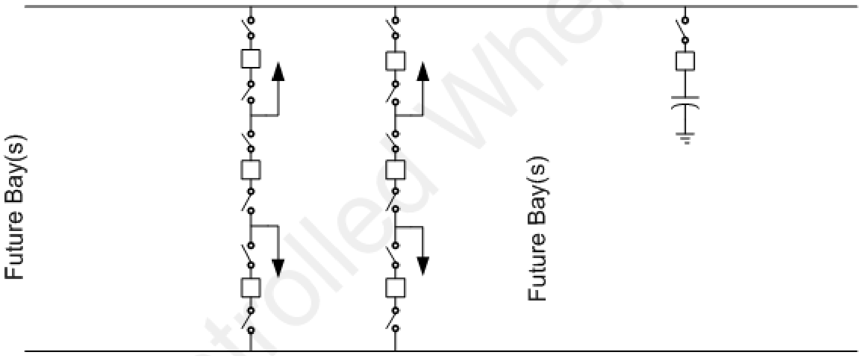

Figure 9.--- Four Element, Six Breaker, Breaker-And-One-Half Arrangement PLUS Single Breaker Reactive Group

Note: Reactive groups are permitted to be served by only one breaker if these elements can be removed from service during breaker maintenance. Once the reactive group is connected to the bus, then the bus can no longer be operated as a ring and now full bus protection including trip and close interlocks for each breaker are required, effectively becoming a breaker-and-one-half arrangement.

7. SPECIAL CONSIDERATIONS

7.1 Additions to Main and Auxiliary Bus Substations

Total life cycle cost, including cost of operation, maintenance, obtaining outages, etc. will be used to determine if conversion of a substation from a main-and-auxiliary-bus arrangement to a ring bus or breaker-and-one-half arrangement is prudent. The costs and complications that arise from reconfiguring the bus as well as all of the associated control and protection systems will be considered and compared to maintaining the original configuration. These will be considered on a case-by-case basis.

Auxiliary-bus arrangements will not be used for design of any new BPA facility/substations. Most existing auxiliary-bus substations will generally be expanded as system needs grow, because the cost to reconfigure these substations is high. Addition of a bus-tie breaker will be considered whenever a new element is added to an auxiliary-bus arrangement. A bus-tie is required whenever the new-element addition results in four or more elements on the bus section, unless an exception is made as outlined in the Standard Compliance and Exception Policy STD-P-000002.

7.1.1 *Sectionalizing PCB requirements*

Transmission Planning determines which main and auxiliary buses are sectionalized and how many sections the bus will contain, based on system reliability requirements. The number of PCBs on a bus does not determine whether the bus will be sectionalized or how many sections will be created. Meeting NERC standards may require two sectionalizing breakers in series to provide adequate performance for a sectionalizing-breaker failure.

7.1.2 *Bus Tie PCB requirements*

Evaluation is required whenever expanding an existing main-and-auxilliary-bus location lacking a bus-tie PCB. A dedicated bus-tie PCB shall be installed during an expansion, particularly when the expansion results in four or more elements. A disconnect switch shall not be used in lieu of a bus tie breaker to energize the auxiliary bus. Some existing stations include a direct connection of the main bus to the auxiliary bus using a disconnect switch. However, this arrangement and the expectation to make and break parallel using this disconnect to bypass a breaker is no longer an accepted practice.

7.1.3 *Bus Tie PCB configurations*

There are three versions of bus-tie PCB configurations used on a main and auxiliary bus layout when more than one bus section exists. These are shown in Figure 10, Figure 11, and Figure 12.

1. Figure 10– A single bus-tie PCB is connected to each bus section. This is the recommended configuration for main and auxiliary bus arrangements. The advantage of this configuration is that more than one PCB outage could be accommodated at the same time. The disadvantage of this configuration is the cost of the additional bus-tie PCB.
2. Figure 11– A single bus-tie PCB is connected to one of the bus sections. The advantage of this configuration is a lower cost, since only one bus-tie PCB is installed. The disadvantage of this configuration is that an outage of the bus section with the single bus tie will make that bus tie unavailable for any of the other many PCB outages. Where only one bus tie breaker serves more than one bus section, the protection must be set up to enable that bus tie breaker to bypass any breaker on any section.
3. Figure 12– A single bus-tie PCB is located adjacent to the main-bus sectionalizing PCB and is shared between two bus sections. The addition of disconnects allows the bus tie to be connected to either bus section. The advantages of this configuration are that the bus tie would be connected to the same bus section as the PCB that is out of service, and the lower cost of not having a second bus-tie PCB. Also, if a bus section is removed from service, one of the lines from that section may be served from the bus tie breaker that is connected to the other intact section. The disadvantage of this configuration is the complexity of both the protective relaying and the required switching by Substation Operators.

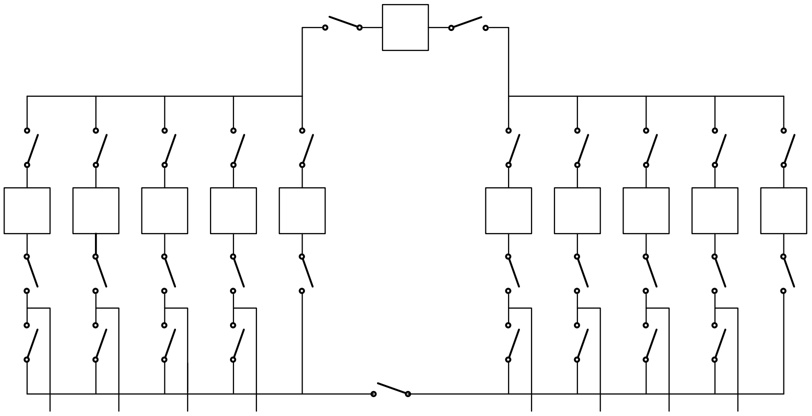

Figure 10.--- Bus tie PCB on each bus section

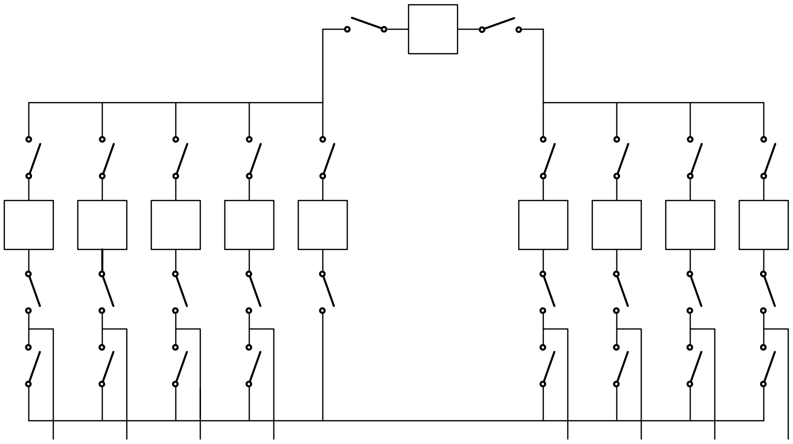

Figure 11.--- Bus tie PCB on one bus section

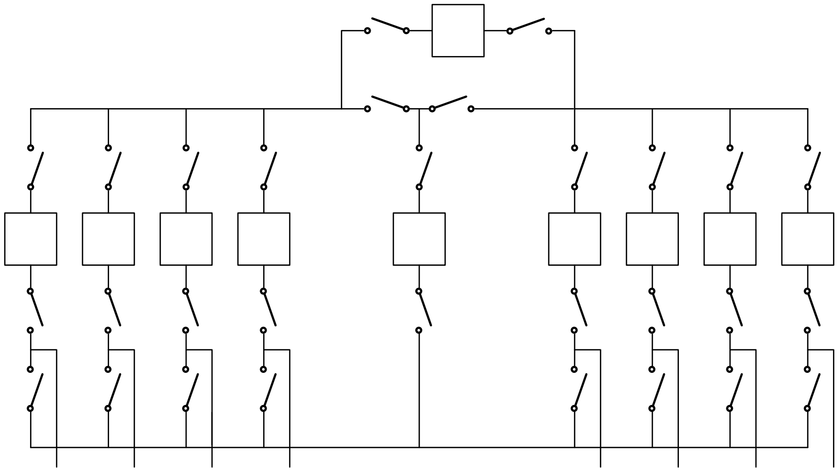

Figure 12.--- Shared bus tie PCB

7.2 Line Taps

Breakers that serve taps off Main-Grid lines may not be bypassed using bypass disconnect switches if a fault on the tap circuit would diminish line reliability or system performance.

7.3 Customer Service Transformers

Customer Service Transformers (CSTs) deliver power to a customer by stepping the transmission voltage down to the customer’s distribution voltage. CSTs are typically 60MVA or smaller. BPA prefers that these be owned by the customer and located within the customer’s substation. If a new CST is to be supplied from a BPA substation, located either within or immediately adjacent to it, then the requirements of this standard apply to the high-side breaker(s). In many existing legacy applications, high-side fuses protect the CST. BPA no longer provides fuse protection for new CSTs. Low-side, BPA-owned circuit breakers are not required. Instead, high-side circuit breaker(s) and protective relays are provided. For information about protection and winding configuration, refer to standard policies STD-DC-000022, “Control and Protection for Power Transformers” and STD-DS-000036, “Power Transformer Substation Design Policy”.

8. REFERENCES

Bonneville Power Administration (BPA), U.S. Department of Energy (DOE). STD-DC-000022, Control and Protection for Power Transformers, Portland, Oregon.

Bonneville Power Administration (BPA), U.S. Department of Energy (DOE). STD-DS-000036, Power Transformer Substation Design Policy, Portland, Oregon.

Bonneville Power Administration (BPA), U.S. Department of Energy (DOE). STD-N-000001, Technical Requirements for Interconnection to the BPA Transmission Grid, Portland, Oregon.

Bonneville Power Administration (BPA), U.S. Department of Energy (DOE). STD-N-000010, Reliability Criteria for System Planning, Portland, Oregon.

Bonneville Power Administration (BPA), U.S. Department of Energy (DOE). STD-P-000002, “Standard Compliance and Exception Policy.” Portland, Oregon.

North American Electric Reliability Corporation (NERC), Western Electricity Coordinating Council, WECC, TPL-001-WECC-CRT, Transmission Planning Performance Criteria, Washington, D.C.

North American Electric Reliability Corporation (NERC), NERC, TPL-001, Transmission System planning Performance Requirements, Washington, D.C.

North American Electric Reliability Corporation (NERC), NERC, FAC-013, Transfer Capability Limits in the Planning Horizon, Washington, D.C.

8.1 Associated Standard Drawings and Design Templates

Construction One line Diagram Position numbering 184613

69KV Fuseless Shunt Bank 332948-1

69KV Fuseless Shunt Bank 332948-2

69KV Fuseless Shunt Bank 332948-3

69KV Air Core Reactor 332949-1

69KV Air Core Reactor 332949-2

69KV Air Core Reactor 332949-3

115KV Main & Transfer 272602-1

115KV Main & Transfer 272602-2

115KV Breaker and a Half 280937-1

115KV Breaker and a Half 280937-2

115KV Ring Bus Expandable 280937-3

115KV Ring Bus - Fixed 280938-1

115KV Ring Bus - Fixed 280938-2

115KV Ring Bus - Inside D.E. 280939-1

115KV Ring Bus - Inside D.E. 280939-2

115KV Ring Bus - Inside D.E. 280940-1

115KV Ring Bus - Inside D.E. 280940-2

115KV Fuseless Shunt Bank 262982-1

115KV Fuseless Shunt Bank 262982-2

230KV Bus Sectionalizing 201702-1

230KV Bus Sectionalizing 201702-2

230KV Bus Sectionalizing 201702-3

230KV Main & Transfer 272603-1

230KV Main & Transfer 272603-2

230KV Main & Transfer 272603-3

230KV Main & Transfer 272603-4

230KV Breaker and a Half 273774-1

230KV Breaker and a Half 273774-2

230KV Breaker and a Half 273774-3

230KV Ring Bus Expandable 273774-4

230KV Ring Bus - Fixed 274794-1

230KV Ring Bus - Fixed 274794-2

230KV Ring Bus - Fixed 274794-3

230KV Ring Bus - Inside D.E. 274795-1

230KV Ring Bus - Inside D.E. 274795-2

230KV Ring Bus - Inside D.E. 274796-1

230KV Ring Bus - Inside D.E. 274796-2

230KV Ring Bus - Inside D.E. 274797-1

230KV Ring Bus - Inside D.E. 274797-2

230KV Fuseless Shunt Bank 262983-1

230KV Fuseless Shunt Bank 262983-2

230KV Reactor 313283-1-0

230KV Reactor Details 313283-2-0

500KV Transformer 205168-1

500KV Transformer 205168-2

500KV Transformer 205168-3

500KV Transformer 205168-4

500KV Transformer 205168-5

500KV Breaker and a Half 272604-1

500KV Breaker and a Half 272604-2

500KV Breaker and a Half 272604-3

500KV Ring Bus Expandable 272604-4

500KV Fused Shunt Bank 262984-1

500KV Fused Shunt Bank 262984-2

500KV Reactor 302389-1

500KV Reactor Details 302389-2

XXXKV Strain Bus 323307-1

APPENDIX

A. General Equipment & Bus Configurations

Generators, loads, lines, transformer banks, and reactive devices are interconnected to form the high-voltage power network. When faults or other problems occur, these elements must be removed and isolated from the functioning power system without affecting its ability to supply the full load. Control and relay systems are used to sense these conditions and initiate separation automatically or manually. Interruption of fault or load current is accomplished by power circuit breakers. After a fault is removed from failed equipment, disconnect switches are opened, locked, and tagged to further isolate the equipment for repair crews.

Network segmentation is accomplished by the strategic placement within the switchyard of power circuit breakers, disconnect switches, and instrument transformers. This arrangement impacts the ability to supply electricity by providing flexibility for operation during credible outages including equipment removal for maintenance. Equipment monitoring may be used to alert system operators of pending equipment problems.

Because requirements for reliability include the continuation of power transfer through the transmission-level substation, the design must provide at least one alternative way to serve each element during equipment maintenance or failures.

Due to increasing demand, heavier loads make it more and more difficult for relays at remote ends of adjacent lines to reach far enough to detect local faults after primary protection components have failed. A second independently operating relay set is applied as a local backup to protect each circuit element in the case of failure of the main relay set to detect or initiate tripping. A local breaker-failure relay scheme is applied to provide a local backup in case the breaker fails to interrupt. This scheme avoids the reach problem and can be combined with the proper substation arrangement to minimize the number of circuit elements lost due to a single failure.

Types of Arrangements Used by the Industry

Besides a simple line tap, arrangements applied as industry best practice by North American utilities include: a single breaker connection; a single-bus-single-breaker connection, the main-and-auxiliary-bus arrangement; the ring bus, the breaker–and-one-half arrangement; and the double-breaker/double-bus arrangement.

I. Line Tap without a Breaker or Recloser at the Tap Point

Simple line taps without automatic switching devices require the least maintenance (at the tap point) and are generally not subject to failure. Taps without a breaker or recloser are only allowed when the additional customer equipment would not significantly decrease the reliability of the transmission line. Disconnect switches with interruption capability are often installed on each side of the tap to maintain uninterrupted service to the customer when switching for line maintenance. Auto-sectionalizing schemes may be applied to disconnect switches at the tap point to maintain service to the maximum number of customers.

II. Line Tap with a Breaker or Recloser at the Tap Point

A line tap with a breaker or recloser at the tap point has the same attributes as other line taps except it requires more maintenance. The breaker or recloser at the tap point also maintains the reliability of the transmission line by eliminating exposure to customer equipment outages.

III. Single Breaker Connections

Provision of a single breaker and relays allow customers to connect to the transmission line at intermediate locations away from an existing substation, while minimizing the exposure of the line to customer faults. Line continuity is affected only if the relay or breaker fails to clear a customer-side fault. Where single breakers are applied, disconnects are placed on each side to isolate the breaker for maintenance purposes. At many lower voltage locations, bypass disconnects exist in parallel with the breaker and, when closed for breaker maintenance, these bypass the breaker. This requires relays at the remote terminals of the transmission line to reach into the customer’s system. Without the ability to bypass, there is no local alternative during breaker maintenance and the customer must receive power from a different source.

IV. Single-Breaker / Single-Bus

Single breaker / single-bus arrangements have one or more circuit elements connected to a single bus through individual breakers - one dedicated for each circuit element. There is no provision for alternative service other than bypassing. These are not commonly used by BPA at the transmission level.

V. Main-and-Auxiliary-Bus

Many BPA main-and-auxiliary-bus substations exist. For this arrangement, an “auxiliary bus” and a “bus-tie PCB” are provided as an alternative to serve any circuit element whenever the dedicated breaker for that element is removed from service. For “N” circuit elements, “N+1” breakers are normally required. To mitigate a single relay failure, two sets of relays, each measuring separate CTs and VT secondaries, are typically applied to each breaker. A breaker failure scheme is provided for each breaker, and a primary and possibly a second primary protection scheme is provided for the main bus.

Once the auxiliary bus and bus-tie PCB are put into service to “bypass” a line position breaker, further alternatives for additional contingencies no longer exist. A bus fault or a failure of any dedicated element breaker will, by design, result in disconnection and temporary loss of service to all connected elements.

Where only two or three circuit elements exist, a historic BPA practice has been to supply an auxiliary bus without a bus-tie PCB. Instead, a disconnect switch or pair of disconnect switches have been installed at the future bus-tie PCB location. This creates the opportunity to bypass using only the disconnect switch. With this scheme, if a fault occurred during switching, there is no local protection for the line being bypassed. Because the disconnect switch is not designed to interrupt fault current, this could create an unsafe operating condition. Therefore, this is no longer an accepted BPA practice. If the lines must remain in service during bypass of one of the primary breakers, then a bus-tie PCB must be provided.

Because the use of an auxiliary bus and bus-tie PCB requires proper manual positioning of relay-transfer and relay-selector switches, restoration of these circuit elements can take significant time if the station is not occupied. Also with this arrangement, it is advisable that an operator be present to verify the full travel for each disconnect blade each time these are operated, and to verify pickup or drop out of phase currents during making and breaking parallel. At locations where disconnect switches have been used to bypass dedicated breakers, due to the absence of a bus-tie PCB, additional complexity of the protection scheme can result in switching procedures that are more susceptible to human error. Once any single breaker is removed from service, further flexibility is greatly reduced. Under this scenario, only “long-lining” through the auxiliary bus is practical at this point, thereby bypassing protection of the local station. Repair of a disconnect switch adjacent to a main bus normally requires an outage to the entire main bus.

To reduce power-system exposure to main-bus faults on main-and-auxiliary-bus arrangements, sectionalizing breakers are added. This splits the main bus into two sections that each require separate and independent protection and operation. If the consequence of a sectionalizing breaker failure cannot be tolerated, then dual series-connected sectionalizing breakers shall be applied.

Schemes have been deployed where a single bus-tie PCB can be used for either of two adjacent bus sections. This requires special bus protection schemes that can sense the existing breaker arrangement. Manual switches are provided to “mimic” the existing configuration. These switches must be in the correct position at all times to maintain proper selectivity.

VI. Dual Breaker Arrangements used by the Industry

The ring-bus, breaker-and-one-half, and double-breaker / double-bus arrangements provide a parallel or alternative path for power transfer through the station. For these arrangements, each circuit element (line terminal) is terminated by two and sometimes three breakers. There is no need for manual switching or re-configuration of the control and protection circuits because the second breaker serves as the alternative path when the first breaker is removed from service. Each of the redundant circuit element protection systems measure the sum of currents from each breaker and trip open both breakers if there is a fault. A breaker failure scheme is applied for each breaker.

VII. Ring Bus

The ring bus arrangement consists of a ring or circle of “N” breakers that serve “N” circuit elements. When a permanent fault occurs, the faulted element remains out of service and power transfer continues through the unfaulted elements. Line and transformer disconnect switches can be installed so the ring can be restored while the equipment is being repaired or maintained. Maintenance of any breaker or disconnect opens the ring and thereby removes the parallel path. In that case, a second contingency (fault) might result in loss of power transfer through the station. Two relay sets measuring separate CTs and separate secondaries from line side VTs are provided to mitigate relay failures. A breaker-failure scheme is applied for each breaker.

VIII. Breaker-and-One-Half

To improve reliability beyond the ring bus, the breaker-and-one-half arrangement is used. Each bay of the breaker-and-one-half arrangement has three breakers that serve two circuit elements for a total of 3/2N breakers to serve N elements. Each end of each bay is terminated by one of two main buses. Redundant protection is provided for each bus and also for each circuit element. Breaker-failure protection is provided for each breaker. During a breaker failure, loss of power transfer occurs only for those circuit elements that are adjacent to and served by the failed breaker itself. A fault on either bus or a protection misoperation on either bus by itself will result in no loss of power transfer. A bus fault during breaker maintenance would result in loss of elements in the breaker bay on the faulted-bus side of the maintained breaker. The same applies to a circuit-element fault in the same bay as the breaker being maintained. When a second equipment element is removed from service, only those bays that contain the equipment are affected. Once each main bus is restored, circuit elements within the remaining bays are unaffected by the outages. For simultaneous line faults on elements in different bays, power transfer through the station is maintained by the unfaulted bays and elements.

IX. Double-Breaker / Double-Bus

Where greatest power transfer reliability is desired for particular elements, a single element shall occupy the bay with two breakers. The switchyard layout shall be a breaker-and-one-half, but shall begin as a double-breaker / double-bus. Future expansion can be into a breaker-and-one-half arrangement as more circuit elements are added. If only one circuit element is connected into a breaker-and-one-half bay, then this circuit element retains the additional reliability of the double-breaker / double-bus arrangement. Breaker-and-one-half arrangements are often a combination of three breaker-two element bays and two breaker-one element (double-breaker / double-bus) bays.

Table 1.— Risk for Bus Arrangements

	Bus Fault	**Breaker Failure**	**Line Fault One BRK OOS**	**Bus FLT Or BKR Fail One BKR OOS**	**Bus FLT Or BKR Fail Two BKR OOS**	**Line Fault One Bus OOS**	**Human Error**
Single Breaker		Loss of Element	No Service	No Service	No Service		Low Risk
Single Bus Single Breaker	LOSS OF All Bus Sect Elements	Loss of All Bus Sect Elements	No Service	No Service	No Service	No Service	Moderate Risk
Main & Auxiliary	Loss of All Bus Sect Elements	Loss of All Bus Sect or All Bus Elements	Service with Reclose	No Power Transfer, No Alternatives	No Power Transfer, No Alternatives	No Service	High Risk
Ring (5 Element)		Loss of 2 Elements	Service with Reclose, Possible ADJ Forced Out	Power Transfer Possible, No Alternatives	Power Transfer Possible, No Alternatives		Low Risk
Breaker-And-One-Half (3 OR + Bays)	No Loss of Elements	Loss of 1 or 2 Elements	Service with Reclose, Possible ADJ Forced Out	Loss of 3 Elements Possible. Segmented OP	Segmented Operation	Service Thru Bus ADJ Element Forced Out	Low Risk
Double-Breaker / Double-Bus (3 OR + BAYS)	No Loss of Elements	Loss of 1 Element	Service with Reclose	Loss of 2 Elements Possible	Loss of 3 Elements Possible	Service Thru Opposite Bus	Lowest Risk

Notes:

BKR: Breaker

OOS: Out of Service

ADJ: Adjacent

OP: Operation

FLT: Fault