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1.0 PURPOSE and SCOPE

There are many factors to be considered in the design of an outdoor substation/switching station. The physical arrangement of air insulated substation/switching station buses affects the maintainability, availability, and reliability of the electricity delivery system. When a configuration requires the entire substation to be de-energized to work on a specific component, it impacts the availability of the substation. When the failure of one component of the circuit causes an outage of the entire substation it impacts the reliability. Maintenance is impacted when it cannot be accomplished because the circuit or equipment cannot be de-energized due to system needs. The majority of the station facilities throughout the industry were designed and constructed many years ago when operations were simpler. Customer’s expectations of power quality were not an issue either. Because of these changes, the station configurations have evolved to improve overall system performance. Maintainability, availability, operational flexibility, and reliability are as important as the initial physical ratings required for serving the system.

Bus Configuration

This document defines the PG&E design criteria for physical/electrical arrangement for the bus configurations found in outdoor substations, unit substations, and switching stations. Underground transmission line transition stations are not included in this document. The application of this Design Criteria applies to all electric transmission and distribution outdoor and indoor substations and switching stations. (Application to indoor situations may require some deviations and must be evaluated on a case by case basis.) The primary focus is on transmission buses and high side buses in distribution substations. Some information on low voltage (4 kV through 35kV) buses is included, but is not intended to be comprehensive.

This Design Criteria is not intended for use retroactively and shall be used only for new, upgraded or expanded substation installations.

This Design Criteria does not include seismic forces to which the substation could be subjected.

2.0 ACRONYMS and TERMS

2.1 General

There are many technical terms used to describe the substation/switching station bus configurations. The reader is referred to IEEE Guide for Design of Substation Rigid-Bus Structures IEEE Std 605-1998 and to the IEEE Standard Dictionary of Electronic and Electronic Terms IEEE Std. 100-latest revision. Major acronyms and terms used in this document are defined and listed below.

2.2 Acronyms

ANSI: American National Standards Institute

BAAH: Breaker and a Half station configuration

CAISO: California Independent System Operator

DBDB: Double Bus Double Breaker

DBSB: Double Bus Single Breaker

EASOP: Economic Analysis Software Program

IEEE: Institute of Electrical and Electronics Engineers

MPAC: Modular Protection and Control. A PG&E system of modern integrated control and protection scheme panels installed and tested in a engineered housing and delivered to the site.

N-1 and N-2: Utility industry shorthand for first and second contingencies - Where N represents the elements in the system, N-1 (N minus one) represents one element out of service, and N-2 represents the next worse-case event

NERC: North American Electric Reliability Corporation

OSHA: Occupational Safety and Health Organization

RB: Ring Bus

SBNM: Single Bus, Normal/Maintenance switchgear is used for an ultimate two bank station with each bank being less or equal to 16 MVA. One common enclosure is used the two banks and four feeders. Each bank should be able to carry all load.

SBSB: Single Bus Single Breaker

SMP: Sustainable Modular Protection is a relay design where any relay can be easily replaced with one from a different manufacturer or a different model. PG&E's older IPAC design is not sustainable because relay replacement is not possible with relays with a different brand. The complete panel and sometimes adjacent relays must be replaced if one of the IPAC relays becomes unavailable.

Bus Configuration

Unit Sub: Unit sub has two feeders only, with no maintenance breaker position, and is intended for small one bank stations.

2.3 Terms

Brownfield Substation: an existing substation to be expanded or subjected to a bus configuration upgrade

Bus Structure: an assembly of bus conductors, with associated connection joints and insulating supports

Critical Bus: asset management, operations, and planning will determine bus critically of each station's bus on a case-by-case- basis

Distribution Substation: a transforming station where the transmission is linked to the distribution system* (At PG&E, any substation with a bus operating at less than 60kV.)

Element: Any power system device connected to a bus, including line, transformer, or reactive compensation device. Bus sectionalizing breakers, bus tie breakers and substitute breakers are not counted as elements.

Greenfield Substation: newly proposed substation to be built on a new site

Rigid-bus Structure: a bus structure comprised of rigid conductors (tubing) supported by rigid insulators

Strain-bus Structure: a bus structure comprised of flexible conductors supported by insulators (rigid or strain)

Substation: an area or group of equipment containing switches, circuit breakers, buses, and transformers for switching power circuits and to transform power from one voltage to another or from one system to another*

Switching Station: a station where transmission lines are connected without power transformers*

Switchyard: a switching station located at a power plant

Transmission Bus: In the context of this document, a transmission bus is any bus, 60kV and above, with three or more transmission line terminals, that can be used as a switching bus. It does not include traditional distribution substations even though the high-side bus is considered transmission bus according to CAISO.

Transmission Substation: an assemblage of equipment for purposes other than generation or utilization, through which electric energy in bulk is passed for the purpose of switching or modifying its characteristics* (At PG&E, any substation with buses only operating at 60kV or above.)

* From the IEEE Standard Dictionary of Electrical and Electronics Terms

3.0 GENERAL INFORMATION

3.1 Substation Purpose

The substation is a basic part of the electrical system. Its configuration should enhance the system. When it is decided to build a new substation or expand an existing substation, a detailed study of system parameters is performed to determine location, size, voltage, sources, loads, and role the substation performs on the system. The substation or addition should reflect an economical and efficient design.

The station buses provide the electrical system with the following:

1. A means electrically to connect transmission lines, transformers, and voltage control equipment
2. Reliability to the overall transmission system by allowing interruption of one or more elements
3. A means for removing individual equipment for maintenance while allowing the transmission lines and other elements to remain in service
4. Multiple sources for loads
5. A means to serve customers

Bus Configuration

Exceptions to guidance in this document must be approved per [TD-3310P-01](#) – *Request for Waiver from Substation and Transmission Line Standards*.

3.2 Legacy Configurations and Future Direction

Distribution

For distribution substation HV buses, PG&E utilized the single breaker single bus (SBSB) configuration for many years. In general, it was connected to the transmission system by looping, single tapping, or double tapping (flip-flopping) transmission lines into the substation. The simple and straight forward design of the SBSB configuration was easy to expand and simple to operate for ultimate layouts of three (3) transformers and two (2) lines (see EDS 457211 and 470433 for 115 kV single line diagrams, and EDS 457212 and 470434 for 230 kV single line diagrams).

Initially the transformers were not directly protected by a circuit device. As reliability and power quality concerns grew however, fuses, circuit switchers and circuit breakers were added to minimize fault impacts to adjacent equipment on the single bus. Later, there were cases where a fourth (4th) transformer, a third (3rd) line or local generators were added as a sixth (6th) element to the single bus, expanding the station beyond its ultimate design. This resulted in a more-expensive bus design with up to six (6) breakers, yet with limited switching/clearance capability from the single bus design. Therefore, the decision was made in 2001 to optimize the ultimate layout for distribution substations as a six (6) breaker ring bus (RB) instead of a loop.

Transmission

Traditionally transmission substations have utilized the double bus single breaker (DBSB) configuration, which was adequate for reliability, maintenance, and switching issues in meeting most N-1 planning criteria. Nevertheless, the protection schemes were complicated, expensive, and became more so with the addition of more elements on the bus, bus sectionalizing breakers and substation (bus tie) breakers. Switching equipment for any reason became very time consuming and required reconfiguration of the circuits leaving the substation. This can impact reliability and make switching an extremely complex task. These substation designs were limited to ten (10) bay positions by PG&E's asset management personnel. Experience had shown anything beyond this number was unmanageable. The DBSB configuration requires a great deal of land for expansion, and is only moderately more reliable than the SBSB design.

The ring bus arrangement is very reliable and lower-cost, yet is not very flexible for expansion. Typically no more than six (6) breakers are found in a PG&E ring.

The breaker and a half (BAAH) design is the optimal balance of increased reliability, cost, and efficient land usage. Similar to the ring bus, the BAAH configuration allows double sources to each load circuit. Maintenance and relay changes can be accomplished without loss of service through simple switching operations. Therefore for transmission substations, the BAAH is the standard design. The newly adopted SMP protection designs allow straightforward expansion of a ring to BAAH. Therefore, a ring laid out to be expandable to BAAH is economically preferred for up to four elements. Short terms plans forecasting a major expansion may warrant initial construction to BAAH.

NERC (North American Electric Reliability Corporation) Reliability Standards address system performance under various contingency (emergency) operating conditions in its Standards TPL-001-4. This NERC standard identifies various contingencies. The standard states how the bulk electric system is to perform under each type. N-1 contingencies are referred to as Category B and N-2 contingencies are referred to as Category C and D. The requirements of these standards, particularly for Category C, further restrict the ability to clear elements and busses for maintenance. For example, a clearance is N-1 and the next contingency (N-2) is looked at for risk and consequence before the clearance is granted.

NERC Reliability Standard FAC-011 is also relevant in that the System Operating Limits must provide certain bulk electric system performance under various conditions. Also, the Regional Difference for the Western Interconnection, also included in FAC-011, lists additional contingencies which must be taken into consideration when planning and operating the bulk electric system.

Both the ring bus and the BAAH configurations help address today's operating environment of critical buses, where the N-2 criteria and other system performance compliance requirements must be met and clearances for maintenance cannot disrupt the system.

Bus Configuration

For facility rating purposes of Ring Bus or BAAH, our standard methodology for ampere rating assumes that 100% of the line or transformer load could be supplied from either breaker, although the power can split between adjacent breakers. Any past assumption for 500kV at a 50% value should be changed to 100%.

4.0 REFERENCES

All substations are built to both industry and PG&E standards. As standards are developed or modified, they shall be listed as a reference to asset management personnel.

4.1 Related PG&E Design Criteria

The following design criteria contain information that may be related:

Document	Document Title
073100	Introduction
073101	Site Preparation
073102	Structural and Foundation
073104	Design of Rigid Bus Systems
073113	Ambient and Electrical Service Conditions
073118	Signage
073134	Metal Clad Switchgear
073137	Bus and Cable
073138	Insulators

4.2 PG&E Drawings

Document	Document Title
EDS 428408	Standard Half Bay Arrangement BAAH for 500kV Substations
EDS 428409	Standard Main Bus Arrangement for 500kV Substations
EDS 457211	Single Line, 115/12kV Distribution Substation, Double Bus
EDS 457212	Single Line, 230/21kV Distribution Substation, Double Bus
EDS 470433	Single Line, 115/12kV Distribution Substation, Main/Aux
EDS 470434	Single Line, 230/21kV Distribution Substation, Main/Aux
EDS 4028711	Arrangement, 60kV Breaker and a Half Substation Switch and Bus Structure
EDS 4086272	Arrangement, 115kV BAAH, Compact Design
EDS 4042040	Arrangement, 115kV BAAH Substation
EDS 4042042	230kV BAAH Bus Arrangement—High Seismic Loading
EDS 4042043	230kV BAAH Bus Arrangement—Moderate Seismic Loading
EDS 4044014	Single Line, 230kV Ring Bus Configuration, with IPAC
EDS 4051051	Single Line, Double Bus Double Breaker Switchgear, with IPAC
EDS 4051173	Arrangement, 115 kV Ring Bus
EDS 4052756	Single Line, 2-Bank Normal/Maintenance Switchgear, with IPAC

Bus Configuration

- [EDS 4064166](#)Arrangement, 60kV Dist. Sub., Ring Bus
- [EDS 4064474](#).....Single Line, Ring Bus Configuration for 115/12kV Dist. Sub., Main/Aux
- [EDS 4064475](#).....Single Line, Ring Bus Configuration for 230/21kV Dist. Sub., Main/Aux
- [EDS 4064476](#).....Single Line, Ring Bus Configuration for 115/12kV Dist. Sub., Double Bus
- [EDS 4064477](#).....Single Line, Ring Bus Configuration for 230/21kV Dist. Sub., Double Bus

4.3 Regulatory Documents

- NERC Reliability Standard FAC-011System Operating Limits Methodology for the Operations Horizon
- NERC Reliability Standard TPL-001-4Transmission System Planning Performance Requirements,
- PG&E Transmission Interconnection Handbooks (control click for link)

4.4 Industry Standards

Document	Document Title
IEEE Std. 605-2008	Guide for Design of Substation Rigid-Bus Structures
IEEE Std. 1119-1988	Guide for Fence Safety Clearances in Electric-Supply Stations
IEEE Std. C2-2012	National Electrical Safety Code
IEEE Std. C37.20.2-2001	Metal-Clad Switchgear

5.0 DESIGN CRITERIA

5.1 New (Greenfield) Distribution Substations

Bus configurations for new distribution substations are summarized in Table 5.1 below.

Table 5.1 Bus Configurations for New Distribution Substations

Bus	Voltages	Configuration	Design Standard
High voltage bus	230, 115, 70 and 60 kV	Ring; 3 to 6 element, (BAAH: >6 elements)	4064166 , 4064476 , 4064477
Low voltage bus,	21, 12 and 4 ¹ kV	Open air (Bus 1/Bus 2) unless space constrained then use DBDB switchgear for all cases excluding unit substations, which are single bus.	4064476 , 4064477 4051051 4052756 ²

1. Generally 4 kV would not be used for new construction since it is a non-standard voltage, but may be used for rebuilding existing buses. See TD-3350P-06, "Substation 4 kV, Unit Substations and Transferring Substation Assets to Distribution" for alternate solutions at 4 kV.
2. EDS 4052756 shows two banks coming into a single switchgear line-up. Waivers were granted at Menlo and Redwood City to modify this drawing to DBDB and exclude the sectionalizing breaker. As of this writing, this drawing has not been revised. Vallejo B is another example of this allowable exception.

The ultimate distribution substation shall be a six (6) breaker ring bus design, as shown in Figure 5-1. The arrangement can also include 2 banks and 4 lines, or 4 banks and 2 lines, etc. Initially this can be a flip-flop, double-tap, expandable from three (3) up to six (6) positions on the ring. If the line is either critical or loops

Bus Configuration

through the station, it shall follow the three (3) breaker design illustrated in Figure 5-2. All switches are not shown in figures 5.1 and 5.2.

Preferably the source and loads should be alternated around the ring as the bus is expanded.

The low side bus should be configured such that it is "in-line" (that is, bus sections should line up in a single row).

When an air-insulated design is used, the number of low voltage feeder bays constructed is typically four, but shall be at least two, and maximum six. Exceptions such as in within San Francisco or Oakland, for heavy PV areas or for the use of 75 MVA transformers at 12 kV, must be approved by the manager of distribution planning. The ultimate will be site specific and include the factors like space constraints, load growth, feeder loading, feeder re-termination for balancing, get away access, ultimate plan for the station, etc. Obtain input from Distribution Planning regarding their needs prior to deciding the number of feeder bays. Drawings should show ultimate planned future bays.

See section 5.4 for adding a new bank and new low voltage bus section to an existing substation.

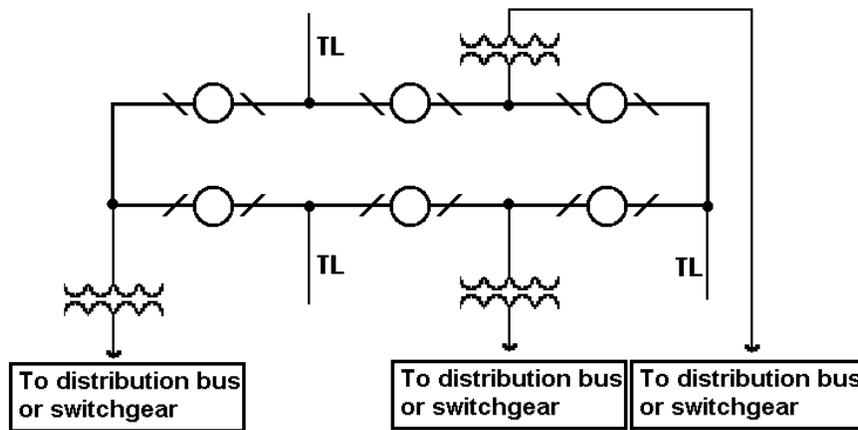


Figure 5-1 Standard Ring Bus Configuration (6-breaker)

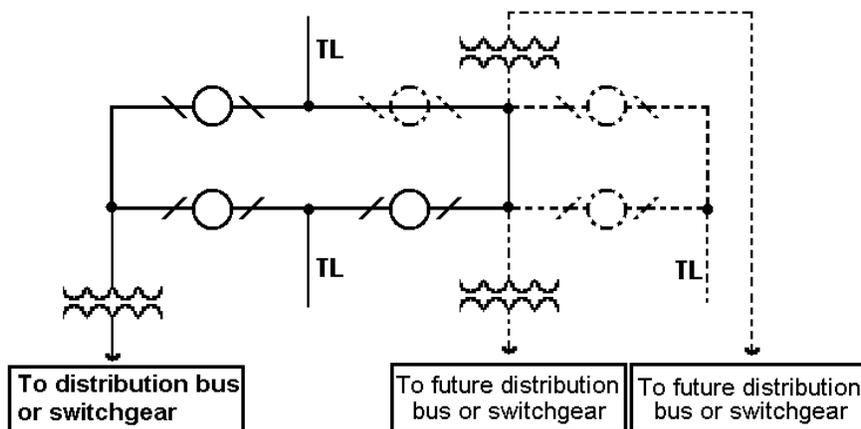


Figure 5-2 Expanding the Standard Ring Bus

Bus Configuration

5.2 New (Greenfield) Transmission Substations

Bus configurations for new transmission substations and switching stations are summarized in Table 5.2 below.

Table 5.2 Bus Configurations for New Transmission Substations and Switching Stations

Bus	Voltage	Configuration ¹	Design Standard
All buses	500 kV	BAAH	428408 , 428409
All buses	230 kV	BAAH	4042042 , 4042043
All buses	115 kV	BAAH	4086272 , 4042040
All buses	70 and 60 kV	BAAH	4028711

1. For new busses up to four initially planned elements “Ring expandable to BAAH” is allowed.

As shown in Table 5.2, all buses are to be designed as BAAH. For four or less elements, the initial design can be “Ring, expandable to BAAH”. For more than four elements then the initial design must be BAAH. Application of the BAAH design requires one and a half breakers per element. Ring expandable to BAAH is made possible with the new SMP (Sustainable Modular Design). SMP facilitates bus conversion more economically than the older MPAC design.

When Ring, expandable to BAAH, is used then, the bus and breakers must be arranged in a way that meets the Ultimate Site Plan (see TD-3350P-11).

Land must be acquired for at least three bays or one additional bay beyond the immediate need, whichever is greater. (Two additional bays if the initial number of elements is 10 or more.)

Bus sectionalizing is not required for eight (8) bays or less, based upon expected fault duty levels. For ultimate layouts larger than this, space should be reserved and planned for possible bus sectionalizing or series reactors.

Sufficient property space: Low-profile – follow EDS drawings

Constrained space: A compact 115 kV BAAH arrangement is available. Another possible option is GIS.

5.2.1 Seismic Considerations and Arrangement

For 230 kV, there are two bus design standards for the BAAH scheme: moderate seismic loading (EDS 4042043), and high seismic loading (EDS 4042042). The **moderate** seismic design utilizes a 2-bay H-frame structure for line tensions of 3500 pounds or less, and therefore is more compact than the high seismic design. The **high** seismic design utilizes a single-bay A-frame structure for line tensions up to 9600 pounds. The moderate design also utilizes one central dead-end structure in the bay, as compared to the two required for the high seismic design.

The moderate seismic design should be adequate for the majority of 230 kV installations, and is a more-efficient design due to less structures and foundations required. Whereas, the high seismic design should be utilized if any of the following applies: high seismic area, line tension more than 3500 pounds, transformer overhead entry to BAAH bus bay at 90-degree angle, or line entry into a bay requires crossover to other bus.

For both designs, if the property allocation is limited for standard bay length, some bay compaction can be considered between the breaker disconnect switches. For example, the standard spacing of 15 feet between the post support structure and both switch centerlines can be reduced to 9'-4" minimum by eliminating the post support. Minimal spacing is still required though between the breaker disconnect switches, to provide adequate man-lift working space for making bus connections. Also, some space can be compacted in the area of the wave trap if no traps are planned, or if vertically-oriented traps are used.

Bus Configuration

5.2.2 Element Pairings

When laying out a BAAH scheme, sources and loads should be mixed in each bay to maximize reliability and improve performance under N-2 conditions. For example, if two sources were in the same bay, breaker failure of the center breaker could result in the loss of both sources. Critical loads should not be located in the same bay for the same reason. For 500 kV buses, sources and loads must be mixed (e.g. two source lines from the north cannot be in same bay.) System Operations must be consulted in determining element pairing. Optimum element pairing is not always possible due to exorbitant costs to relocate towers and lines or the need to minimize transmission line cross overs for reliability.

5.3 Conversions and Upgrades of Existing (Brownfield) Substations

PG&E's existing transmission and distribution substations were built to a wide range of bus configuration designs. The preferred bus arrangements to support present and future system needs are shown in Tables 5.3.1 and 5.3.2 below. Significant operational improvements can often be made by certain 'upgrades' to the bus instead of a full conversion to BAAH. When a substation is considered for conversion, or an upgrade is required per 5.3.1 or 5.3.2 below, perform a detailed engineering study to determine the most cost efficient approach that meets minimum operating conditions for that substation and makes reasonable allowances for other projects planned in at least the five year horizon.

This study shall take into consideration many factors, including:

- The number of customers at risk for a sustained outage (including consideration for very large single customers, such as municipalities), primarily under N-1 contingencies.
- Severity of operating and maintenance constraints which impact granting of clearances, switching and the ability to continue with maintenance compliance.
- System impacts due to loss of bus under normal conditions (N-1) that are directly attributable to bus design (not otherwise able to mitigate)
- Past bus outage performance and the causes
- Plans for wholesale protection replacement, with accompanying SMP/MPAC (avoid installing new MPAC on poor bus configurations)
- Whether a high percentage of equipment is scheduled to be replaced or is near the top quartile of the ranked replacement list As an example, at least 30% of breakers, switches, insulators, etc. due either to age (condition) or overstressed.
- Existing ampacity of buses, drops, and associated equipment will not meet project requirements.
- Whether structures have serious degradation or have been determined by civil engineering as seismically inadequate, and thus need to have a high level of retrofit made or need to be replaced.
- Existing substation has significant space constraints or surrounding development and congestion. The inability or cost to acquire or mitigate additional land may lead to favoring one alternative over another.
- Whether bus or equipment has reached voltage or fault duty limits.
- Locale should be considered. For example, in areas with high generator and load interconnection growth, then the anticipated need for future bays should be accounted for.

The extent to which the items above are applicable directly impacts the benefit of a full conversion, as opposed to an upgrade.

Several logistical factors must also be considered in deciding the ultimate approach, including:

- Schedule constraints
- Risk of permitting (if required) on schedule and overall project cost
- Construction sequencing, including ability to maintain service during construction, switching complexity, the need to install temporary facilities, etc.

Bus Configuration

- Pairing of lines and bays on BAAH, and balance of generation and load or separation of loads on DBSB schemes with sectionalizing (extent of tower work, changes to line approaches, and avoiding line crossings)
- Location of any new buildings (SMP/MPAC, battery, etc.) regarding their proximity to the bus and not blocking future expansion opportunities.

During the preliminary scoping phase of major projects involving critical substation buses, asset management personnel will determine whether the bus and/or associated equipment must be replaced and rebuilt, usually as BAAH. If asset management personnel determine that the bus needs to be rebuilt as BAAH, then the economic analysis software program's (EASOP) analysis for the alternative not to convert to BAAH now must factor in at least the following additional costs:

- Include capital costs to replace the bus now or later, but within the EASOP study period, including associated deteriorated equipment. The alternatives must have equal capacity at the end of the study period (e.g. 20 years).
- M&O (Maintenance and Operations) cost differential to continue operating aged equipment in the DBSB arrangement. Asset management personnel will provide these costs with assistance from Operations and Maintenance groups
- The economic consequences of a one-time worse-case bus fault may be assumed

5.3.1 Distribution Substations

Table 5.3.1 below indicates the preferred final state after a distribution substation bus has been upgraded or converted for reliability or operational flexibility improvement.

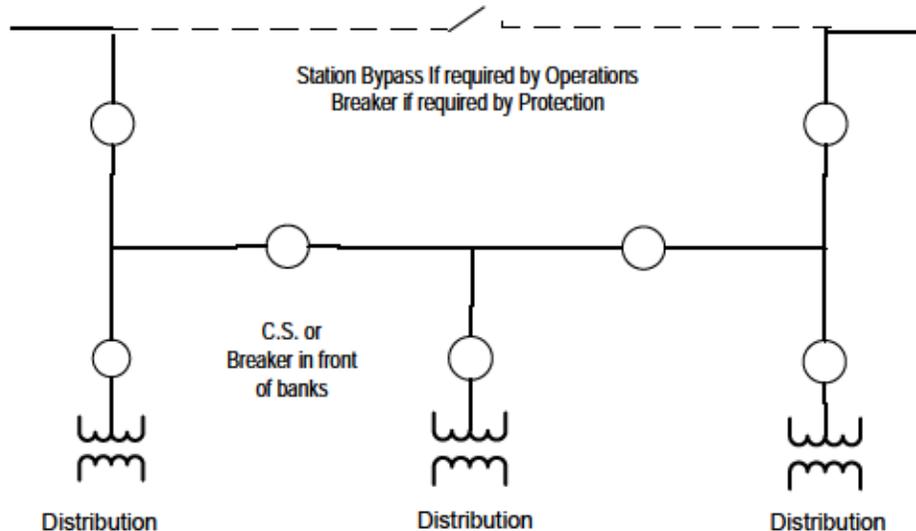
Table 5.3.1 Preferred Distribution Substation Upgrade Configurations

Bus	Voltage	Configuration	Design Standard
High Voltage Bus	230, 115, 70 and 60 kV	Ring; 3 to 6 element, max 3 transmission lines	4064166 , 4064474 , 4064475 , 4064476 , 4064477
		BAAH; > 6 element or if 4 or more transmission lines	4042042 , 4042043
		Loop (SBSB) ¹ ; max 5 elements	457211 , 457212 , 470433 , 470434
		SBSB; for tap substations max 3 banks (4 elements). For flip-flop substations, max 3 banks (5 elements), provided no plans in 10 years to close the loop. Each element to have protection.	N/A
		DBSB ² (Bus 1/Bus 2 or Main/Aux)	N/A
Low voltage bus	35 ³ , 21, 12 and 4 ⁴ kV	Continue with existing design either open air (Bus 1/Bus 2 or Main/Aux) ⁵ or switchgear. If space constrained then in lieu of open air use DBDB switchgear Consider unit subs for 4kV banks less than 5 MVA.	457211 , 457212 , 470433 , 470434 4051051 4052756 ⁶

Bus Configuration

Notes

1. When a station has an existing loop, it may be retained provided it follows the "enhanced loop" design. Zone tripping (bus sectionalizing) must be improved and meet current standard. The preferred approach is shown in the figure below. This "enhanced Loop" sets up the station for future conversion to a ring. However, protection or operational issues (e.g. important path) may warrant alternate configurations such as adding dedicated bank protection, or creating a non-standard ring (lines and banks not alternated) by using a breaker in lieu of a station bypass switch. The need for substantial line protection work at remote ends may also make a standard ring economically competitive. The enhanced loop provides the nearly the same level of system reliability as a ring.



"Enhanced Loop"
Note this is the same as EDS 470433, 4

Enhanced Loop Design

2. DBSB configuration is not common, but can be retained if existing. Add bus parallel (Bus 1/Bus 2) or substitute breaker (Main/Aux) if not existing. Maximum 8 elements without sectionalizing.
3. 35 kV is unique to Embarcadero Substation (San Francisco Z) and is configured as BAAH.
4. 4 kV systems should not be expanded, and should be converted to a higher voltage whenever feasible.
5. See Section 5.4 – Expansion of existing busses under MV distribution.
6. EDS 4052756 shows two banks coming into a single switchgear line-up. Waivers were granted at Menlo and Redwood City to modify this drawing to DBDB and exclude the sectionalizing breaker. As of this writing, this drawing has not been revised. Vallejo B is another example of this allowable exception.

Drivers for Upgrades (for high side buses of distribution substations)

The criteria in the bus reliability program will identify certain substations for upgrade. However, other upgrades will be triggered as a result of project work, such as new line or bank capacity projects, system reliability projects or interconnection projects. An upgrade is required under any of the following conditions on the transmission side:

1. Adding an element results in more than 5 elements for an existing loop or double tap substation. Convert to ring (or BAAH if needed).

Bus Configuration

2. Adding a line to a tap (SBSB) substation to create a loop through it. Convert to ring (or BAAH if needed). (Typically tap buses are very minimalist and it is not desirable to entrench the design by adding additional elements to the single bus.) †
3. Adding a second tap to a single tap substation, thereby creating a closed loop between the two lines. Convert to ring (or BAAH if needed). †
4. Closing a normally open loop on a flip-flop (dual source) substation (usually as a result of line upgrades or line reconfigurations). Convert to ring (or BAAH if needed) if the loop now constitutes an important transmission path. †
5. Adding a 3rd or 4th bank to a loop type station. Convert to ring bus if space is available and economic evaluation shows additional NPV of approximately 20% or less.

† These projects are usually done for reliability enhancement, so improving the bus to a ring configuration supports that intent. However, if space is not available to create the ring (adjacent property already developed, adjacent road, steep terrain, or other very difficult barriers), **and** minimal growth is projected for the long term (15 - 20 yrs), then an “enhanced loop” as referred to in Table 5.3.1 can be employed.

The typical substation design has been a SBSB arrangement (loop) of two lines and three banks in the substation. An exception has allowed two (2) lines and four (4) banks within the substation, or occasionally three (3) lines and three (3) banks. However, as noted in section 3.2 the desire is to consciously move toward rings as the primary preferred design for distribution high side buses.

The following additional items must be taken into consideration for distribution substation bus upgrades or conversions when scoping and planning the work.

- Plan for future expansion. Development of an ultimate arrangement at the time of upgrade is highly recommended to indicate how an ultimate build-out is envisioned.
- Access for mobile equipment (transformers and breakers)
- Connection points for mobile equipment

5.3.2 Transmission Substations

Table 5.3.2 below indicates the preferred final state after a transmission substation bus has been upgraded or converted for reliability or operational flexibility improvement.

Table 5.3.2 Preferred Transmission Substation Upgrade Configurations

Bus	Voltage	Configuration	Design Standard
High or Low side	230 kV	BAAH or ring expandable to BAAH	4042042 , 4042043 , 4044014
High or Low side	115 kV	BAAH or DBSB (Bus 1/Bus 2 or Main/Aux) or ring expandable to BAAH	4086272 , 4042040
Low side	60/70 kV	DBSB (Bus 1/Bus 2 or Main/Aux), or BAAH or ring expandable to BAAH	4028711

Drivers for Upgrades

Bus Configuration

The criteria in the bus reliability program will identify certain substations for upgrade; however, other upgrades will be triggered as a result of project work, such as new line or bank capacity projects, system reliability projects or interconnection projects. An upgrade is required under any of the following conditions:

1. If additional element(s) are to be added to a DBSB configuration which results more than 8 elements without sectionalizing, then add sectionalizing breakers and additional bus tie breaker, or convert to BAAH based on an evaluation of the factors listed in section 5.3 above.
2. If additional element(s) are to be added to a BAAH configuration which would result in more than 8 bays (16 elements). Add bus sectionalizing breakers.
3. If additional element(s) are to be added to a SBSB configuration, convert to BAAH.
4. If bus differential protection on a DBSB configuration is upgraded to B90 scheme and bus has more than 10 elements without sectionalizing, then sectionalize bus or convert to BAAH based on an evaluation of the factors listed in section 5.3 above.
5. This is an exception to the 8 element rule above. If the bus is the primary area source with limited options for transfer (high radial load) as determined by Transmission Planning and element(s) are to be added to a 60 kV or 70 kV DBSB configuration which results in more than 6 elements, then sectionalize the bus or convert to BAAH based on an evaluation of the factors listed in section 5.3 above.
6. Critical 115 kV busses, whether identified under the Bus Reliability Program or as identified by Transmission Planning as part of an area improvement study/project to correct performance deficiencies, shall be converted by rebuilding the bus to ultimate BAAH scheme.

Development of an ultimate arrangement at the time of upgrade is highly recommended to indicate how future expansion is envisioned.

For 115 kV BAAH, when sufficient property space exists, use the Low-profile 115kV designs listed in Table 5.3.2 above. If space is constrained, consider the compact design, or a GIS option.

5.4 Expansion of Existing Buses

To expand **transmission** (HV) busses by one or more terminals in an existing DBSB configuration, many factors must be considered. Conversion to ring bus expandable to BAAH for up to four terminals or BAAH must be considered, as explained in 5.3 above. For substantial bus expansions (e.g. multiple projects connecting to a bus at the same time) where it is not justifiable to do a complete conversion, the new bus section shall transition to BAAH if space is available. Bus sectionalizing breakers can be used at the transition point to improve reliability.

The exceptions to the expansion of the existing bus are:

1. Where space is limited or the bus defined as critical, some existing DBSB bus sections may be converted to BAAH rather than adding BAAH bays.
2. A project that only inserts a bus-tie breaker or bus-sectionalizing breaker into an existing bus may not require conversion.

For existing **distribution** (MV) busses, a bus expansion (adding bays to an **existing bus section**) should follow the existing design, whether main-aux or double-bus (Bus 1/Bus 2). In addition, the following enhancements should be incorporated with the expansion:

1. For B1/B2, add a bus-tie disconnect switch between the existing transformer and the new transformer on Bus 1. Do not retrofit existing busses with a bus-tie disconnect.
2. For Main/Aux, install bus tie disconnects between banks on the aux bus. See drawings 4064474 and 4064475. Do not retrofit existing busses with bus tie disconnects.
3. For Main/Aux, install a second tie breaker when installing the third transformer in a three bank station. Do not retrofit existing station with additional tie breakers.

Bus Configuration

Note that exceptions can be made by following [TD-3310P-01](#) - *Request for Waiver from Substation and Transmission Line Standards*. See appendix E.

When expansion is by way of **adding a bank and a new bus section**, the new bus section is to be double bus, to enhanced reliability, except main/aux is acceptable for banks ≤ 16 MVA with only two feeders and where field switching will allow one feeder to pick up the full bank load so the other feeder can be cleared for maintenance.

When the existing buses are of the Main/Aux design, the following applies:

1. If the existing bank(s) are 30 or 45 MVA and the structure is from the mid 1970s onward (i.e. low profile design, not the older pipe type structures),¹ then include in the scope of work to upgrade the existing busses to B1/B2 (verify during walkdown). To convert, replace #1 disconnect switch with a #7/9 disconnect switch and install the cross bus to the #9. (See standards 457211 & 470433). This conversion is especially helpful if there is no substitute breaker and field load transfers are required for maintenance.
2. If the above conditions do not apply (i.e. smaller bank or pipe-type structure), then the existing bus is to be left as M/A but the new bus should still be designed as B1/B2. The addition of a double bus adjacent to an existing main-aux bus should not cause any operational difficulties, but does create a situation that Operations must be aware of. Obtain the concurrence of Maintenance and Operations before creating a hybrid bus arrangement.

See section 5.1 for information on the number of feeder bays to incorporate for the ultimate plan.

6.0 REVISION NOTES

Rev 00 – 9/18/08. Issued as new document

Rev 01—3/16/09. Added Moderate Seismic Loading EDS standard for 230 kV BAAH bus, along with direction where to apply this version versus the High Seismic Loading version. Also referenced the pending 115 kV Ring Bus design standard, and added discussion on expanding existing main/aux distribution buses.

Rev 02 – 07/20/11. Added 'Element' to terms, minor clarifications and correlation to NERC standards in Section 3 General Information, updated references in Section 4, Section 5.1 added Table 5.1 and minor edits, Section 5.2 added Table 5.2 and removed option for initial operation of BAAH as a ring, Section 5.3 elaborated on study conditions and implementation (logistical) considerations, added Table 5.3.1 and conditions requiring upgrades, added Table 5.3.2 and conditions requiring upgrades, revised existing text, Section 5.4 defined preference for additional distribution bus sections as double bus and minor edits for clarification.

Appendix A removed text in 1.0 redundant with main criteria, clarification to 2.1 SBSB limitations and deleted text on when to install sectionalizing breaker, 2.6 moved statement on bay pairings and balancing to main body (5.2), 2.7 added additional description and application for inverted design, 3.2 added description for DBSB, added 3.4 on DBDB for switchgear, other minor edits.

Appendix B clarified applicable to switching stations, deleted Implementation section, added paragraph regarding tapping, added reference to 3.1 for new BAAH station and minimum land requirement, and clarified application for adjacent properties, retitled 3.2 for new distribution substation and revised to ring instead of loop, deleted 3.3 for new DBDB, added reference to main criteria in 4.1 and 4.2, revised 4.3 for maximum number of elements, revised 4.4 for maximum number of elements and reference to main criteria, expanded 4.5, added 4.6 for Tap substations. Removed limit of 500 MW from figures (will be determined by system impact studies); other minor edits.

¹ Most outdoor substations built prior to early 1970's were built for main-aux operation. With the introduction of larger distribution transformers (i.e. 30, 45, 75MVA), the need for greater operating flexibility and reliability arose. Since the mid 1970s, even if the station is initially operated as main-aux, the bus structure is designed for easy conversion to double bus.

Bus Configuration

Rev 03 – 8/1/2012. Modified Table 5.1 and 5.3.1 for the low voltage bus to allow new stations to be open air. When the station is space constrained then use DBDB switchgear. Deleted all references to single-bus, normal maintenance switchgear, except for small two bank stations. Modified Table 5.3.2 and document list to show that EDS 4028711 (60 kV BAAH) has been published. Section 5.4 – added exception to use Main/Aux for low voltages busses for banks 16 MVA or under.

Rev 04 – 7/1/13. Added Appendixes C and D which all contain information related to two bank distribution substations. Appendixes C provide instructions and information for bus conversions for two bank stations. Appendix D provides a drawing of the preferred method to connect a two bank station to a radial line.

Rev 05 – 1/15/2014. A sentence was added in section 3.1 that tells how to obtain exceptions to this design criteria. New paragraph in section 5.4 provides rules for specific reliability enhancements. New Appendix E provides background and support for the reliability enhancements.

Rev. #06: 4/15/2014 Added clarification of ampacity splitting rating for Ring Bus and BAAH schemes in section 3.2, and noted the issuing of 4086272 for Compact Design of 115 kV BAAH.

Rev. #07: 7/4/17 Updated to allow: 1) For transmission busses, allow, “ring expandable to BAAH” up to four terminals. 2) All switchgear now DBDB, 3) Definition of SMP 4) Reflect that TPL-001-4 was changed from 4 separate docs to one 5) Miscellaneous clarifications.

Bus Configuration

APPENDIX A

Overview of PG&E Bus Configurations Past & Present

(Informative)

1.0 BUS CONFIGURATIONS

There have been many bus configurations used on the PG&E electrical system for both transmission and distribution substations (high voltage and low voltage) over the years. All bus configurations have their strong points and weaknesses. The engineer had to balance cost with reliability in the process of designing a substation. Section 2 illustrates the seven station configurations most frequently used at PG&E. In order to increase reliability and reduce costs, it has been decided to standardize on the two types of station configurations. Therefore all new transmission and distribution substations HV buses will be designed as BAAH or ring respectively.

The physical arrangements commonly found in PG&E substations are:

1. Single Bus Single Breaker (SBSB)
2. Double Bus Single Breaker (DBSB)
3. Main and Auxiliary Bus
4. Double Bus Double Breaker (DBDB)
5. Ring Bus (RB)
6. Breaker and a Half Bus (BAAH)
7. Inverted (folded) Breaker and a Half Bus

The low profile of transmission and distribution substation has become very important in this age of rigorous permitting. Aesthetics (e.g. eye appeal) is a prime consideration in most permitting processes today. Even in industrial areas governing bodies are acutely aware of visual impact. Structures and equipment have become an increasingly important aspect to consider in substation layout. In the past, large lattice and box-type structures supporting overhead strain buses were commonly used. Today, however, substation bus designs use low-profile structures with rigid bus work.

2.0 HIGH VOLTAGE BUS PHYSICAL ARRANGEMENT

2.1 Single Bus Single Breaker Configuration

This is also known as a radial bus, loop bus, or flip bus configuration. It is generally found in distribution substations on the high voltage side. It consists of one main bus to which the transmission circuits are connected to the bus through circuit breakers. The isolation device for the transformer connections may be a circuit breaker or a circuit switcher or just a disconnect switch.

Bus Configuration

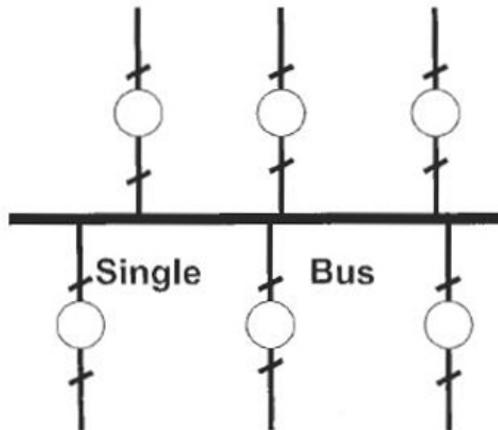


Figure A-1. Single Bus Single Breaker Design

When the SBSB substation is expanded, reliability can be affected due to the number of circuit elements added to the bus. The bus can be divided (split), as it expands, with sectionalizing disconnect switches and/or sectionalizing circuit breakers. This allows breaker failures or bus faults to affect only the section of bus on which the problem occurs. The other bus section is protected by the sectionalizing. Although some substations have up to ten (10) circuit elements with this design, distribution substations are now limited to 5 elements and transmission substations should be converted when triggered by project work.

Radial bus designs are one of the simplest to expand, operate, and provide with protective relaying. Unfortunately, they provide the least reliable, since they are subject to a complete station outage in the event of a bus fault or breaker failure. Maintenance of elements necessitates the de-energization of the line connected to the element and extensive switching outside the station to pick up the load on other feeders. Maintenance of the bus requires the de-energization of the entire station.

Bypass switches have been applied to many breakers in the SBSB and DBSB configurations found on the PG&E system. They were utilized to increase the flexibility of maintenance and operation on these buses. In some cases, a substitute breaker arrangement is required in the station and that requires the breaker bypass configuration be installed.

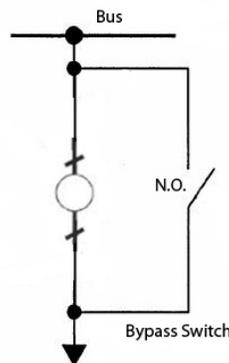


Figure A-2. Breaker Bypass Design

2.2 Double Bus Single Breaker configuration

The DBSB configuration consists of two (2) main buses connected together through one (1) circuit breaker. Each DBSB circuit element has one (1) bus paralleling (tie) circuit breaker. It can be connected to either bus through

Bus Configuration

disconnect switches. This configuration was used extensively at PG&E until approximately 2002 for 115kV and 230kV transmission substations. Maintenance is improved over the SBSB design, but it still is not recommended for locations where system reliability and availability are critical. Under normal conditions, the number of elements should be divided between the two (2) buses. This is a complicated and expensive design to protect due to the two (2) buses and the bus sectionalizing breaker. If all the circuits are on the same bus, all of the circuits (and possibly customers) will be lost in the event of an outage. Bus faults and breaker failures can cause an outage on that bus. Another drawback for the DBSB design is the necessity to take an outage to perform any type of maintenance on its associated circuit breaker. The DBSB configuration allows all circuits to be connected to one bus in case of an outage on the other bus or for bus maintenance. Like the radial bus arrangement, it is easy to add circuits, but takes up a lot of linear space.

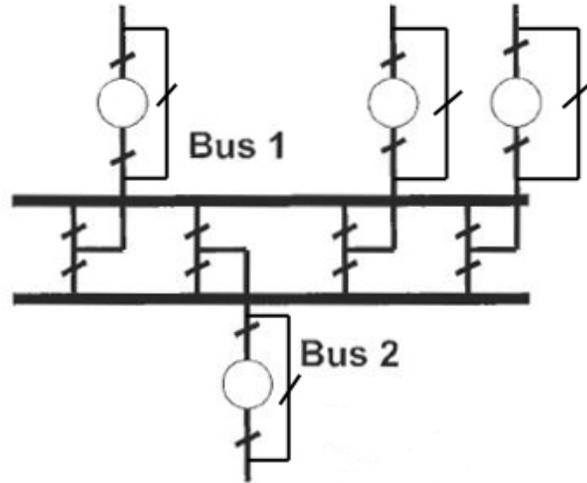
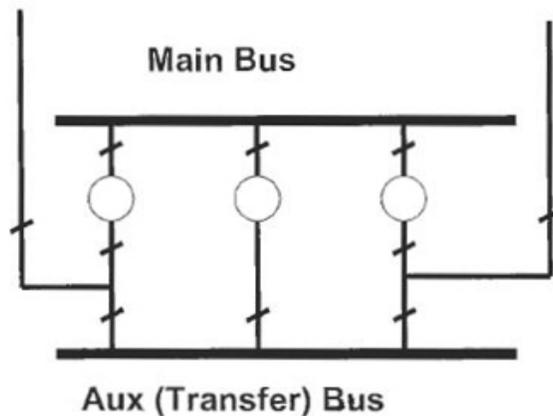


Figure A-3. Double Bus Single Breaker Design

2.3 Main and Auxiliary Bus Configuration

This is also known as main and transfer bus configuration. It consists of two (2) buses and one (1) substitute circuit breaker between the buses. It is a modification to the SBSB and DBSB configuration. This configuration is most commonly seen in 60/70kV and some 115kV transmission substations. All circuit elements are connected to the main bus via circuit breakers. Disconnect switches allow switching to the auxiliary bus. This arrangement allows a breaker to be removed from service by transferring the line termination from the main bus to the auxiliary bus utilizing the substitute beaker for protection. The protective relaying can become complex. A bus fault or breaker failure will cause the complete loss of the station.



Bus Configuration

Figure A-4. Main and Auxiliary Bus Design

2.4 Double breaker double bus configuration

The DBDB consists of two (2) main buses. The DBDB circuit is connected between two (2) circuit breakers, which makes it highly reliable. In this design configuration, each circuit has two (2) dedicated circuit breakers, which makes it one of the most expensive schemes. This is one reason why it isn't used extensively. Since there are two (2) circuit breakers and two (2) buses, it requires a great deal of land for a station of any size. One advantage is that maintenance of the bus or a circuit breaker can be done without interrupting any circuits. Similarly, all circuits will remain in service under a bus fault. In this configuration only one circuit is removed from service in the event of a fault, which is the faulted circuit.

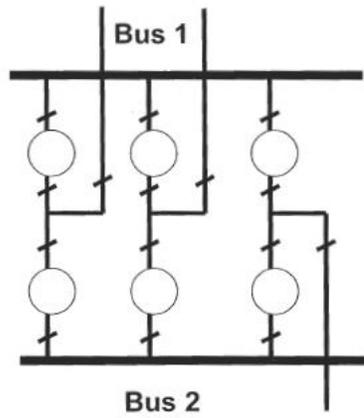


Figure A-5. Double Bus Double Breaker Design

2.5 Ring bus configuration

The ring bus configuration consists of a sectionalized bus with its ends connected through a power circuit breaker. This configuration is simple. It is also more reliable than the SBSB, DBSB or Main & Aux arrangements. A ring bus design will have up to six (6) elements (bus sections), each section sourcing one circuit. This configuration allows only the position needing to be removed to be taken from service. In the event of a line or bus fault the power circuit breakers on each end of the bus section are opened. The failure of a power circuit breaker to operate for a line or bus fault will cause two (2) circuits and two (2) bus sections to be removed from service. It also allows for any circuit breaker to be removed from service for maintenance without an outage on any circuit. Placement of the elements around the ring is important to minimize impact under N-2 scenarios if the ring already has one element out (ring is broken).

Bus Configuration

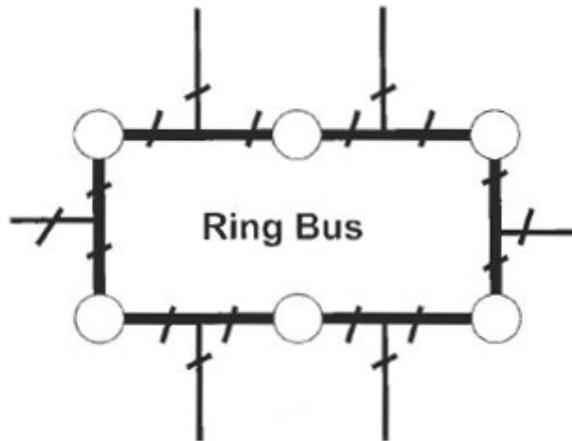


Figure A-6. Ring Bus Design

2.6 Breaker and a half bus configuration

The BAAH configuration consists of two (2) main buses with three (3) power circuit breakers between each bus. Each BAAH circuit is connected between two (2) breakers. This configuration allows each circuit to have a dedicated breaker and share a breaker with the adjacent circuit. There are one and a half ($1\frac{1}{2}$) breakers per circuit. This arrangement is therefore more economical than the DBDB design but with nearly the same level of reliability. Breaker maintenance and relay changes can be accomplished with no loss of service with the simple operation of the breaker disconnect switches. It requires only one circuit to be removed from service for a fault condition and that is the one faulted. If a bus fault occurs, no circuits are removed from service. The bus is isolated by the operation of the circuit breakers adjacent to the bus. The failure of a power circuit breaker between a main bus and a circuit requires the circuit adjacent to the circuit breaker to trip and the bus to be isolated. The failure of a circuit breaker between two (2) circuits to operate (for a fault) trips the two adjacent circuits.

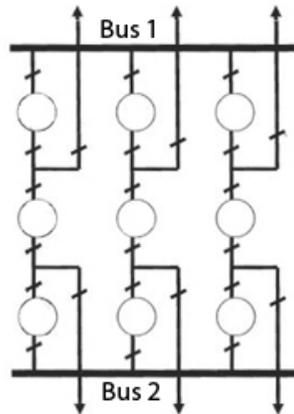


Figure A-7. Breaker and a Half Bus Design

2.7 Inverted (folded) breaker and a half bus configuration

The inverted breaker and a half configuration consists of two (2) main buses running parallel and adjacent to each other. Similar to the more conventional BAAH configuration, each circuit is connected between two (2) power circuit breakers. Thus, the inverted design electrically operates the same as the conventional BAAH. However, the buses are physically on the interior and the breakers are on the exterior. This configuration lends itself well to the modification of the DBSB into a more reliable configuration. This approach may be practical if the structures,

Bus Configuration

breakers and switches are in good condition and there is space to install the middle breaker, but can take longer to implement due to the phased conversion process. Folded bus design can be lower in cost to implement as it uses existing infrastructure and usually lines or towers do not have to be relocated.

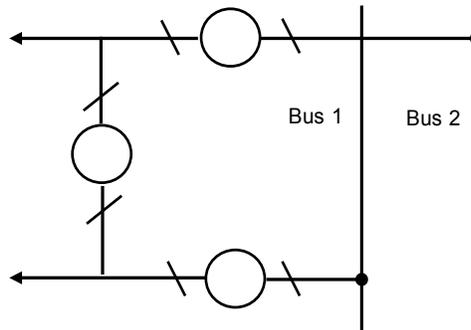


Figure A-8. Inverted Breaker and a Half Bus Design

3.0 LOW VOLTAGE BUS PHYSICAL ARRANGEMENT

The distribution feeders leave the substation from various bus arrangements much like the high voltage arrangements.

3.1 Main and Auxiliary Bus (Open Air)

The main and auxiliary configuration has been used at PG&E for many years. It offers more flexibility for switching and maintenance than the SBSB configuration, but its reliability is no better.

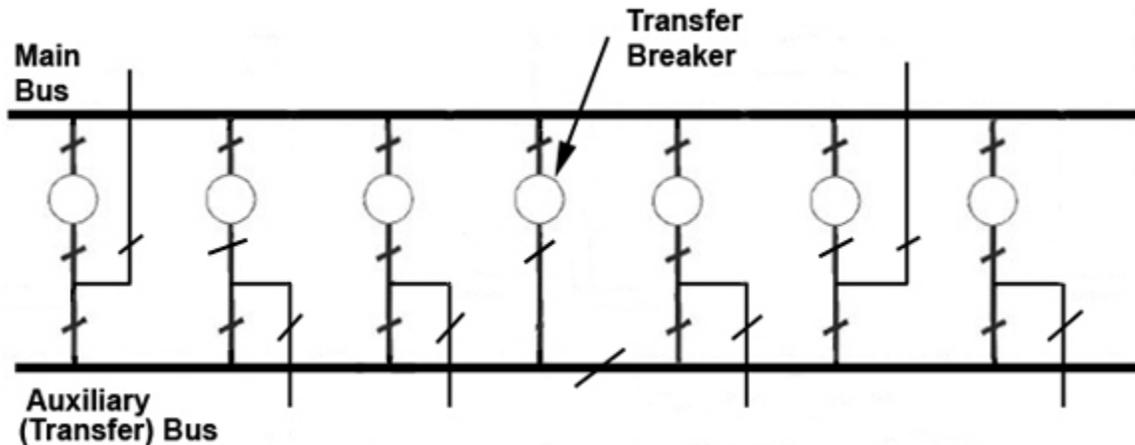


Figure A-9. Main and Aux Low Voltage Distribution Arrangement

3.2 Double Bus Single Breaker (Open Air)

The DBSB arrangement (also known as Bus 1/Bus 2) is also commonly used. Similar to the DBSB arrangement used on transmission buses, each circuit has one circuit breaker that is connected to either bus through bus selector switches. However, the breaker bypass switch is arranged differently. Also, the breakers are physically between the two buses. Refer to EDS 457211 (for 115 kV/12 kV) and EDS 457212 (for 230 kV/21 kV) to see the Double Bus arrangements

3.3 Normal and Maintenance (Metal-Clad Switchgear)

With low profile substations and substations located in residential areas, PG&E has standardized on outdoor metal clad switchgear for its expansions and newer substations. Metal-clad switchgear is a weatherproof housing consisting of a sheltered aisle with individual steel compartments and drawout switching devices. The

Bus Configuration

compartments are comprised of an upper cubicle and a lower cubical. The lower compartment houses the feeder circuit breaker. The upper compartment houses the maintenance breaker position. The switchgear is designed with the main bus located behind the lower compartment. A maintenance position is included for bypassing the feeder circuit breaker for maintenance. The typical equipment found in the switchgear are circuit breakers, protective relays, meters, bus conductors, potential transformers, current transformers, batteries, and other components.

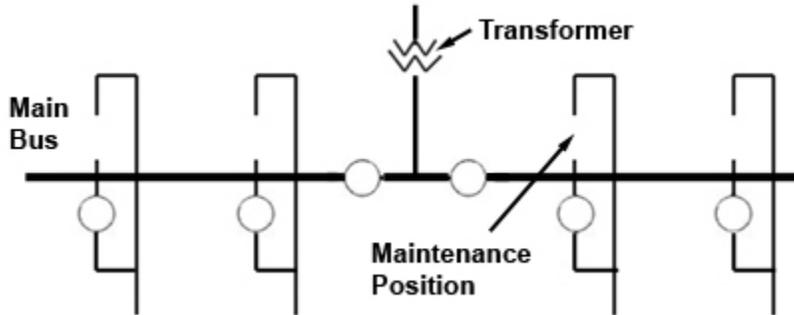


Figure A-10. Metal-Clad Switchgear Arrangement

3.4 Double Bus Double Breaker (Metal-Clad Switchgear)

The DBDB arrangement for distribution is used in switchgear located in major urban substations as this arrangement provides the highest level of reliability. The arrangement is identical to the transmission DBDB configuration, except the breakers are draw-out type housed in metal clad switchgear. Refer to EDS 4051051 for a depiction of the arrangement.

Bus Configuration

APPENDIX B

Bus Configurations For Generator Interconnections

1.0 PURPOSE

This appendix provides additional guidance for interconnection of generators to the PG&E system. It shall be used in conjunction with the PG&E Transmission Interconnection Handbook. This appendix only covers interconnections at the transmission level.

2.0 GENERAL

The various substation bus configurations permitted herein are consistent with meeting “Liability, Reliability, and Operating Flexibility” (LRO) guidelines defined as follows:

Liability – There shall not be shared facilities between PG&E and the generator. This includes breakers, control buildings, yard, etc. PG&E’s equipment is not intended to protect third party’s equipment. In addition, PG&E does not desire to maintain the third party’s equipment.

Reliability – There shall be a clear line of demarcation, physically and electrically, between the generator and PG&E. This is to ensure maximum reliability and minimize impact from a third party’s failure on PG&E facilities and vice-versa. To facilitate a clear line of demarcation, a fence is required to separate physical ownership when properties are adjacent. To facilitate demarcation of electrical ownership there shall be a PG&E approved lockable disconnect switch. The preferred location of the disconnect switch will be on PG&E property but can be installed on the third party’s property with access provided to PG&E.

Operating Flexibility – There shall be no third party facilities that will prevent the utility from operating its portion of the transmission bus and/or that require generator equipment clearances prior to operating the PG&E transmission bus.

The alternatives for the PG&E bus configuration are based upon the following:

- System Impact to PG&E
- Ability to clear breakers for scheduled or unscheduled maintenance without impacting system integrity
- Reliability requirements of PG&E transmission - bus and lines
- Generator capacity
- Adherence to PG&E standard configurations

Tapping a transmission line for new interconnections is not permitted on the Bulk Electric System (BES) which is defined as 100 kV and above. The preferred method of interconnecting new load/generation is via a new or existing substation.

For the non-bulk system (below 100 kV) interconnections are preferred via new or existing substations but there are exceptions listed in Section 5.3 of Design Criteria 076257, “Tapping Transmission Lines”.

Above 100 kV or Bulk System	Below 100 kV or Non-Bulk
Tapping not permitted. All new connections to the bulk system must be to a new or existing substation.	Interconnections are preferred to new or existing substations. Exceptions are allowed on a restricted basis as described in section 5.3
Existing taps are “grandfathered” in	Existing taps are “grandfathered” in

Bus Configuration

Generator interconnections to a PG&E substation or switching station are shown in figures B1 through B10. Determination of which configuration applies is contingent upon system impact studies. PG&E Transmission Planning will make a recommendation based upon impact to the system. Substation asset management personnel shall review the recommendation and provide concurrence or alternate requirements to ensure it is consistent with future expansion plans and does not pose any operating and/or maintenance issues.

Multiple generating units may share a common generator breaker. System feasibility and impact studies will determine limitations or recommendations in terms of the maximum cumulative generation.

The configurations in this appendix are provided in a single line diagram format and are not intended to be representative of the physical arrangement. **Configurations are provided in simplified format and not all switches, breakers, metering units and other devices are shown.** Note that the generator configuration shown is for example only and that, although not shown in every figure, the generator should always have its own circuit breaker protection at the generation facility.

3.0 INTERCONNECTIONS INTO A NEW PG&E SUBSTATION OR SWITCHING STATION

3.1 Interconnection to a New Transmission Substation or Switching Station

The PG&E bus configuration is to be BAAH configuration, following the requirements of section 5.2 of the main criteria. An example is shown in Figure B-1. Sufficient land is to be acquired for a minimum of one additional bay beyond the immediate need, but for not less than 3 bays. For example, see figure B-1 where space is provided for a third future bay.

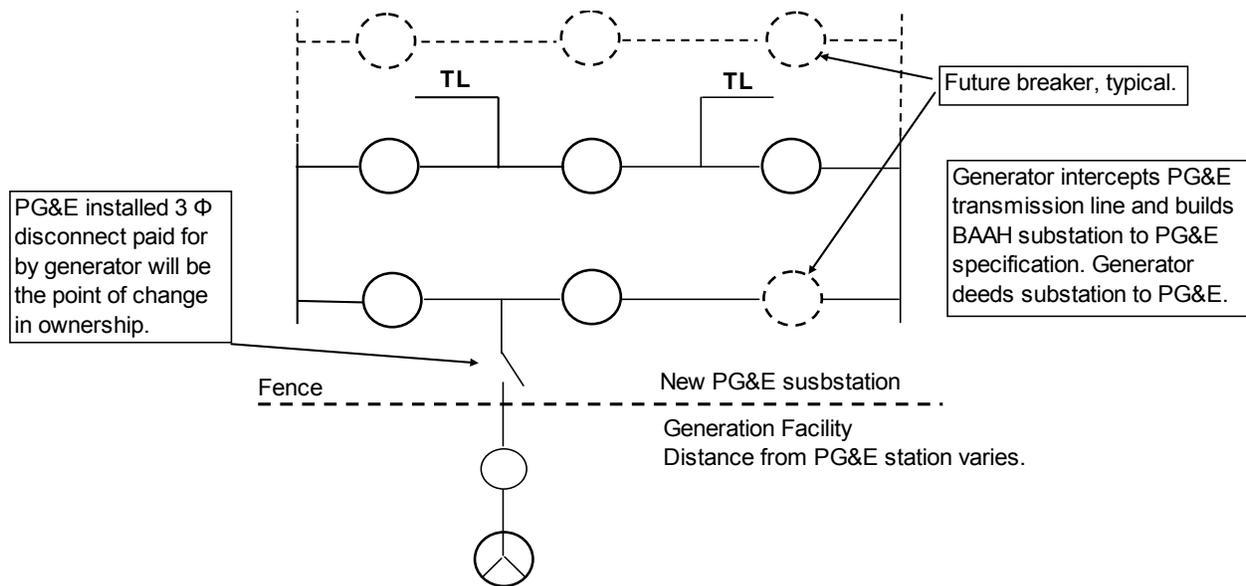


Figure B-1. Interconnection into a New PG&E Transmission Substation

In the special case where the PG&E substation and the generator properties are adjacent, the BAAH buses are expanded to the generation side, with disconnecting devices, as shown in Figure B-2.

Note: This option should no longer be used, particularly when there are only two bays. The reason is that when the center breaker is open (planned or unplanned) then all the loop flow goes through 3rd party facilities. Legal issues could surface, if the 3rd party wants reimbursement for facilities serving rate payers.

Bus Configuration

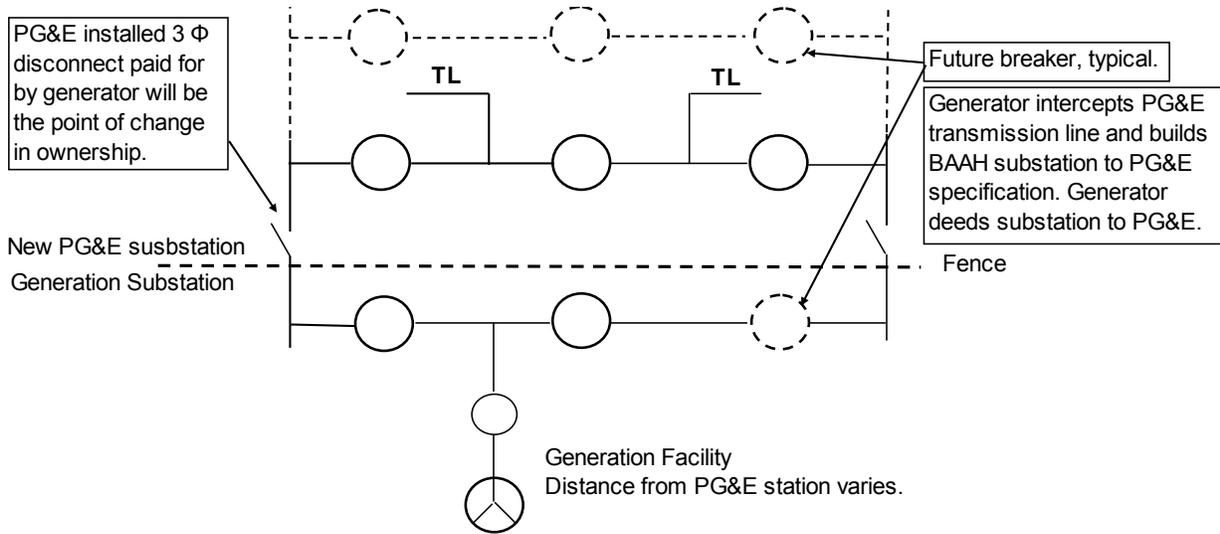


Figure B-2. Interconnection into a New Transmission Substation with Properties Adjacent

3.2 Interconnection to a New Distribution Substation

The PG&E bus configuration is to be a ring design, per section 5.1 of the main criteria. An example is shown in Figure B-3 below. Sufficient land to be acquired for the full 6 breaker ring unless Transmission Planning and Distribution Planning agree no additional lines or banks required in the 20 year planning horizon. In this case a four or five breaker layout is acceptable.

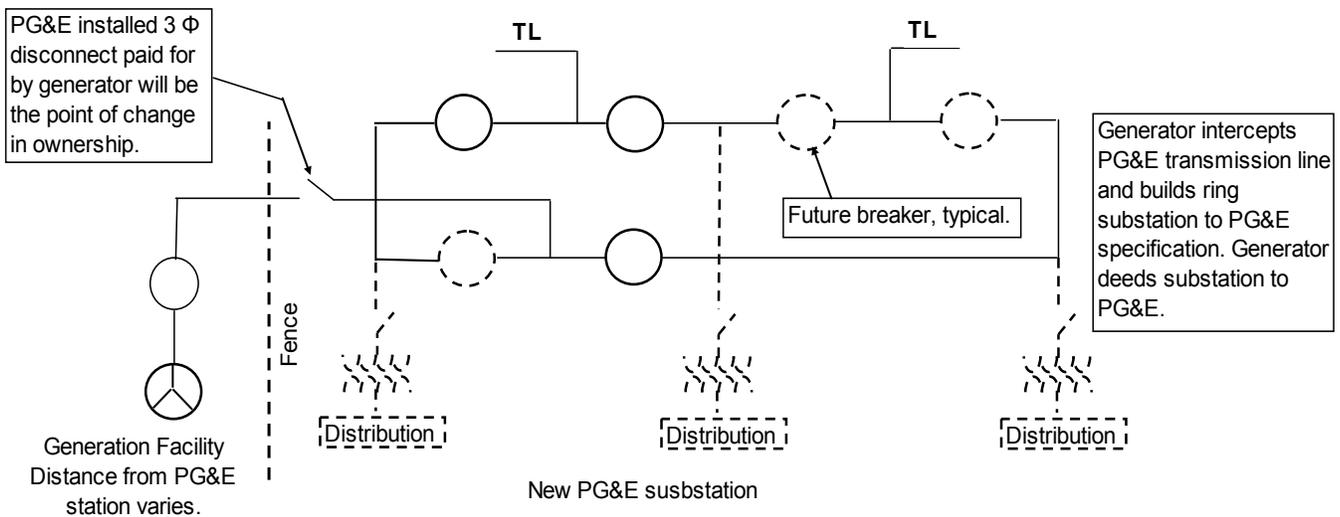


Figure B-3. Interconnection into a New PG&E Distribution Substation

4.0 INTERCONNECTIONS INTO AN EXISTING PG&E SUBSTATION OR SWITCHING STATION

When interconnecting new generators to existing PG&E substations, future expansion of the substation needs be taken into consideration.

Bus Configuration

4.1 Interconnection to an Existing Breaker and a Half Bus

Where the existing PG&E bus configuration is a BAAH configuration, the generator will interconnect as shown in Figure B-4. The constraints of section 5.3.2 of the main criteria also apply.

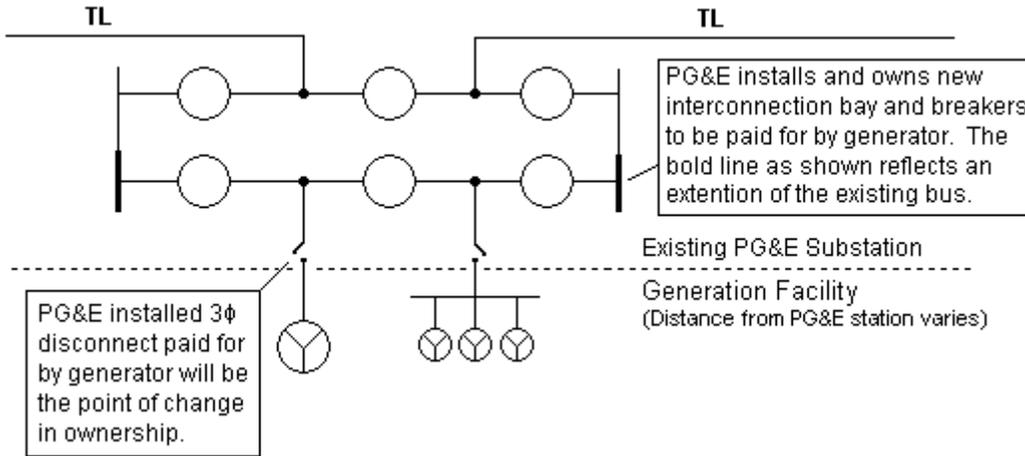


Figure B-4. Interconnection into an Existing PG&E Breaker and a Half Substation

4.2 Interconnection to an Existing Double Bus Single Breaker Bus

Where the existing PG&E bus configuration is a DBSB configuration and there is room for expansion of the existing bus section, the generator interconnection should be as shown in Figure B-5. The constraints of Section 5.3.2 of the main criteria also apply.

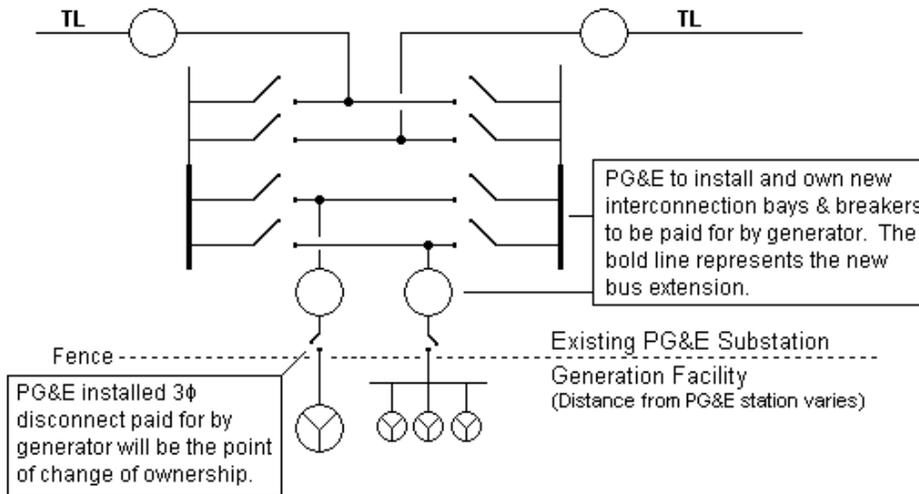


Figure B-5. Interconnection into an Existing PG&E Double Bus Single Breaker Substation

4.3 Interconnection to a Double Bus with a Breaker and a Half Transition

Where the existing PG&E bus configuration is a DBSB configuration and there is limited space for expansion of the existing bus section or expansion of the existing bus section requires bus sectionalizing breakers (addition of new interconnection results in >8 elements on a the bus section), the new bus section should be a BAAH design (space permitting) and the generator will interconnect as shown in Figure B-6.

Bus Configuration

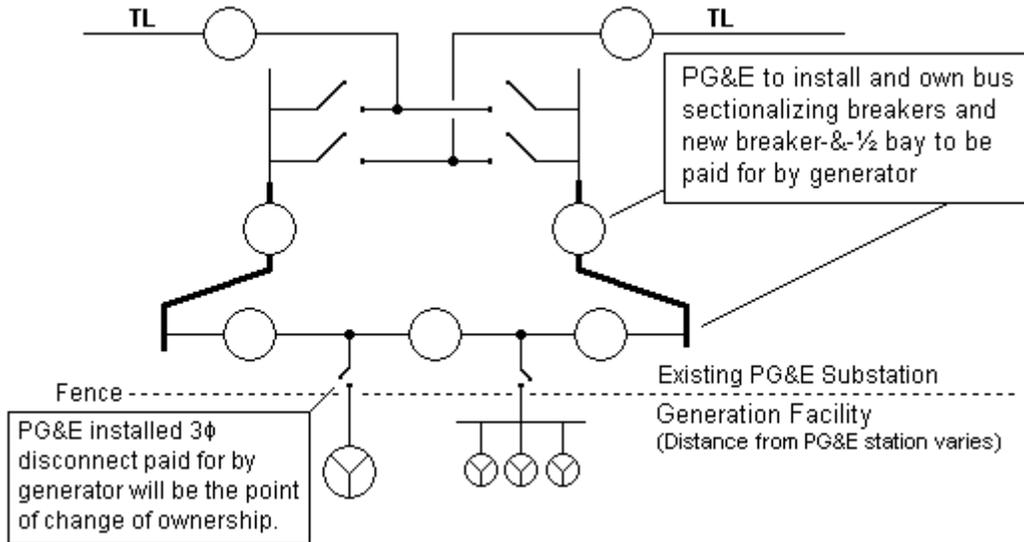


Figure B-6. Interconnection into a Double Bus with Breaker & a Half Transition

4.4 Interconnection to a Looped or Flip-Flop Substation Spare Bay

Where interconnection into an existing looped distribution substation is desired and a spare bay exists, it may be possible to interconnect a generator as shown below. This configuration is acceptable when there is no foreseeable (10 year horizon) distribution need for the bay and **system impact is low**. No more than 5 elements can be connected at a loop or flip-flop substation. The constraints of section 5.3.1 of the main criteria also apply. If five elements already exist, a ring (or BAAH) must be created. See 4.5 below.

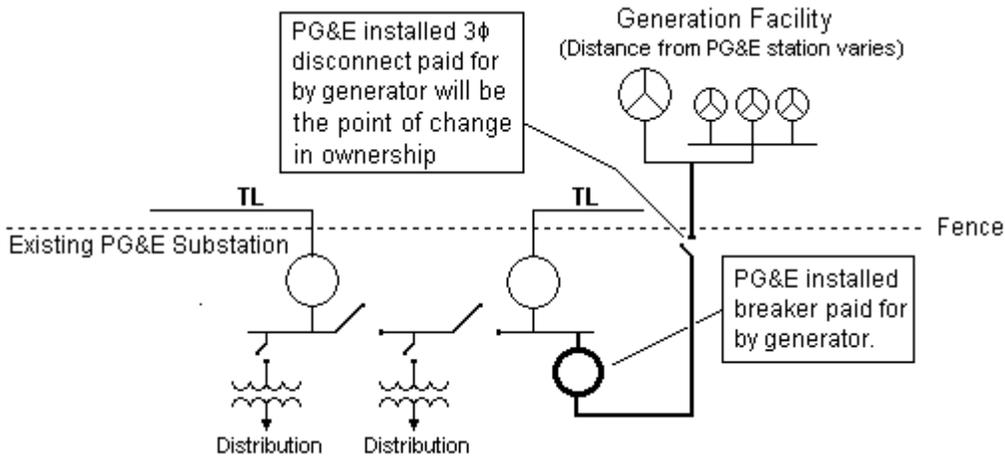


Figure B-7. Interconnection to a PG&E Looped or Flip-Flop Substation Spare Bay

4.5 Interconnection Via Converting Looped or Flip-Flop Substation to a Ring Bus

Where interconnection into an existing looped distribution substation is desired and no spare bay exists (5 elements already), the bus needs to be converted from a looped bus into a ring bus as shown in Figure B-8 below. This configuration is only acceptable where **system impact is low**. If the system impact is moderate to high, the bus needs to be converted to the standard ring as shown in 3.2 above. If the generator requires more than one interconnection point, then a) the bus needs to be converted to BAAH, b) an alternate location identified,

Bus Configuration

or c) a new substation/switching station created. The last two options are also applicable if the substation has no room and no possibility of expansion (land locked).

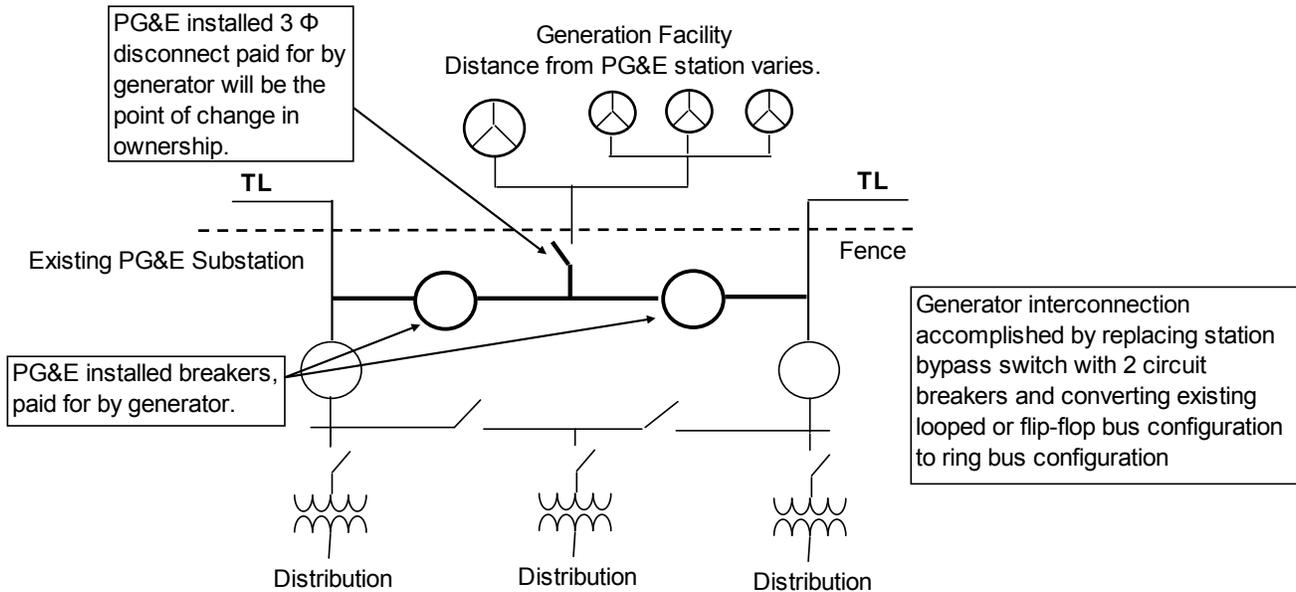


Figure B-8. Interconnection via Converting Looped or Flip-Flop Substation to a Ring Bus

4.6 Interconnection to a Tap (Radial) Type Substation

Interconnection to a tap substation is discouraged as these are generally small substations with weak ties and carry the highest reliability risk. Conversion to a ring is recommended to enhance bus reliability, but the line reliability is often a more dominant concern. If the tap arrangement is retained, generation connected should be small (<20 MW). No more than 4 elements, including the generation interconnect, are allowed for a tap substation. The interconnection would be as shown in Figure B-9 below. If there are already 4 elements, an alternate location must be determined or the bus converted to a ring as shown in 3.2 above, with a second line brought to the substation if practical.

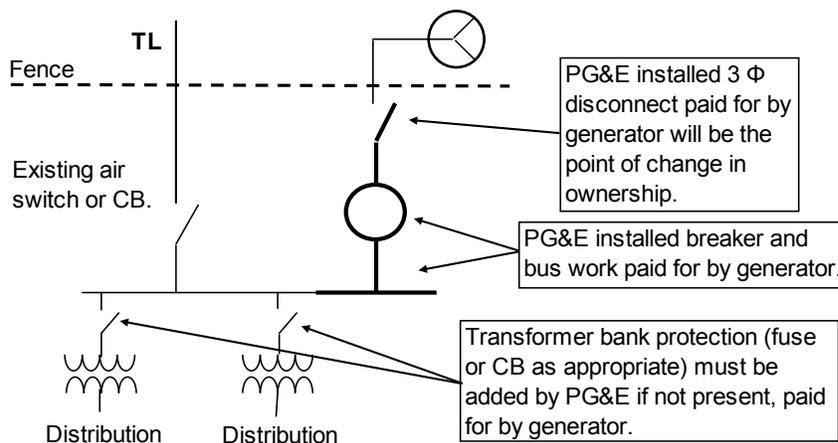


Figure B-9. Interconnection to a PG&E Tap Substation

Bus Configuration

5.0 INTERCONNECTIONS INTO A PG&E SUBSTATION VIA A COLLECTOR STATION

Where multiple generators propose to interconnect with an existing PG&E substation, a collector station may be required. It is recommended that the collector station utilize a BAAH bus configuration and the generators would typically interconnect as shown in Figure B-10:

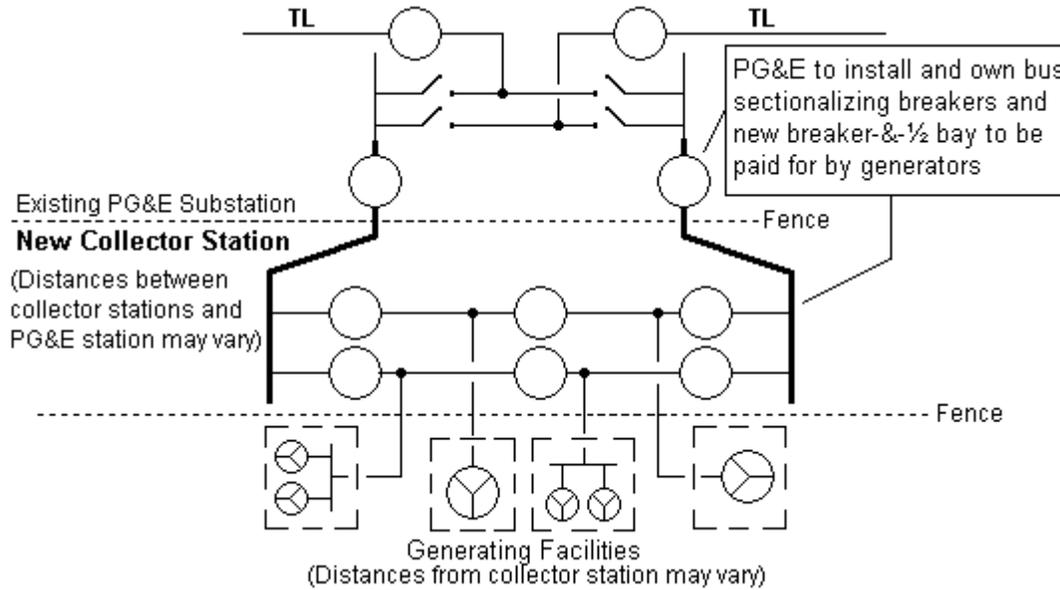


Figure B-10. Interconnection into an Existing PG&E Substation via a Collector Station

6.0 GENERATOR BUS CONFIGURATIONS

There are a number of generator bus configurations (owned and operated by the generator) that are consistent with the principles of LRO, as noted above in the various bus configuration arrangements. The generator bus portion of the figures in Sections 4 & 5 show configurations recommended by PG&E. However, these are merely recommendations. If the generator opts for a different configuration, it will be evaluated for system impact. The need for any mitigation work resulting from system impact will be noted by PG&E.

Bus Configuration

APPENDIX C

Bus Conversions for Two Bank Distribution Stations

(Informative)

A two-bank distribution substation is an existing facility with two sources where the ultimate build out is not expected, or is physically-constrained, to grow beyond what two transformer banks can support. Typically, these substations are in rural areas with one or two small transformer banks. The load and customer count is relatively low, as is the growth rate.

A radial substation only has one source and is addressed in Appendix D. Double Tapping is shown in Figure 3.

Analysis

Reliability: The frequency/duration method of reliability analysis was performed for three different bus configurations to compare the overall system impacts and impacts to the substation alone. The methodology used covered every possible N-1 component failure (breakers, transformers, transmission lines, buses) and its impact to loads and generation. Outages due to or following a planned clearance (or N-2 failures) were not included in the analysis.

Segmented loop², as shown in Figure 4, may “appear” to the best for reliability but is ruled out because it violates a key design principle which is; a planned or unplanned outage of distribution equipment (i.e. bank) should not interrupt the transmission path. The reason segmented loop appears to be better is because there are fewer elements in the model which can fail (e.g. one less breaker compared to all other solutions with four breakers) and planned outages were not included.

Results of the reliability analysis are shown in Table 1 and indicate that excluding segmented loop, the alternating ring design provides the best “system” and “substation” reliability.

Table 1 – Reliability Comparison

	Total system impact		Sub in question only	
	λ	U	λ	U
Alternating ring	2.582	256.86	0.058	6.60
Segmented loop	2.55	253.08	0.050	5.88
Loop	2.584	257.04	0.104	9.84
Ring	2.602	258.66	0.078	7.50

λ = probability of failure (annual) - frequency

U = expected unavailable minutes per year - duration

² A looped bus is PG&E’s commonly used term for a single bus.

Bus Configuration

Guiding Principles

The guiding principles reflect PG&E goals of safety, reliability and operational excellence. Reliability is supported by operational efficiency and flexibility to improve restoration times and reduce transmission path interruption risks. Consideration is given to life time O&M costs. In short, the strength of system configuration³,⁴ is given weight such that the first year installation costs can't easily override all other considerations.

The following design principles guided the final recommendation⁵:

1. Provide worker safety -- the design shall promote switching sequence consistency and eliminate any possible confusion during switching operations. It must also promote ease of incorporating appropriate working clearances into the design.
2. Promote reliability -- the design shall be such that planned N-1 outages of equipment will not result in the interruption of a transmission path. Unplanned N-1 outages of distribution equipment must not interrupt the transmission path. Specifically distribution bank outages must not interrupt the transmission path. In addition, a bank outage should not interrupt the adjacent bank.
3. Provide operating flexibility -- allow for any substation element or piece of electrical equipment to be safely isolated with minimal interruption or risk to the flow of power on the transmission grid.
4. Allow future expandability – The stations covered in this appendix have no intention to expand beyond two banks.
5. Maintenance -- the design must promote the efficient and effective maintenance of substation electrical equipment. The design shall promote familiarity with a consistent physical design philosophy and equipment arrangement throughout PG&E.
6. Cost effective.

³ Refer to “Aging Power Delivery Infrastructures” by H. Lee Willis for an in depth discussion on how aging infrastructures and high utilization factors call for stronger system configurations to combat increasing failure rates and increased maintenance requirements. Willis advises to avoid compromising system configurations for capacity (Page 271).

⁴ Refer to PG&E’s 2010 Annual Report, page 2 – Interconnectedness is the term used to mean stronger system configurations. “This program aims to create more capacity and interconnectedness on the power grid, enabling us to better isolate power outages and redirect power flows onto neighboring circuits to restore service more quickly.”

⁵ Transmission Owners and ISO-NE Substation Bus Arrangement Guideline Working Group Report Presented to the NEPOOL Reliability Committee April 4, 2006

Bus Configuration

Table 2 – Pros and Cons of Loop Vs Ring Bus for 2-Bank Substations with Loop Flow

		RING - including alternate ring		LOOP	
		PROS	CONS	PROS	CONS
Six design Principles	1) Safety - Promote consistency in switching and eliminate possible confusion during switching operations	Fewest number of switching steps to clear station equipment, which also reduces risk of WPE.			Transformer protection difficult to clear. Use of station by-pass switch complicates switching as does extensive field switching to clear transformers.
	2) Reliability - planned or unplanned N-1 outages will not result in interruption of a transmission path	Alternating ring provides the best system and station reliability indices (see Table 1) All station equipment can be cleared without interrupting the transmission path. Protection is simpler and more straight forward. No bus protection required.	Can be restrictive physically to implement alternating ring.	Clear separation of D-owned protection facilities from T-owned protection facilities. Allows for fusing banks < 12.5 MVA.	Fall - Transmission path is interrupted for bus outages or breaker failures. Bus fault will take both banks out. Requirement for separate bus protection complicates protection scheme. By-pass switch may not work in all cases.
	3) Operating Flexibility	Maximizes flexibility. Any equipment can be individually isolated without interrupting the power flow.	All breaker clearances require CAISO notification, yet loop flow not impacted.	Two of the breakers and the transformers can be cleared without CAISO involvement.	Transmission path is interrupted and/or at higher risk during clearances. Clearances may be denied.
	4) Expandability	N/A--station not expanding	More costly to expand a ring beyond its intent, in general.	Less costly to expand, in general.	
	5) Promote efficient and effective maintenance of station equipment	Provides easier clearance planning for equipment maintenance. Minimizes switching steps for routine maintenance. Results in lowest life cycle costs to maintain equipment.			Clearances can be resource intensive. Protection and/or planning engineer typically needed for clearances involving station by-pass and field switching. There may be cases where clearances are severely restricted due to power flow impact.
	6) Cost Effective	All the breakers are transmission facilities, using FERC funding which is easier to obtain.	More expensive in general, though requires the same major equipment (4 breakers, 2 transformers). May require control room expansion using IPAC.	Less expensive, particularly if fuses are used rather than breakers for transformer protection. Fusing is becoming less desirable from a reliability and arc-flash standpoint.	Two of the four breakers are distribution facilities using GRC funding.

Recommendation

All existing 115 kV and 230 kV substations should be converted into a four breaker alternating ring configuration, per Figure 1 when triggered by expansion. (Expansion means when going from a one bank to a two bank station.) See Figures 7 & 8 for other methods to achieve the alternating ring design depending on available space. A straight ring design can be used in cases where physical limitations prevent from alternating the lines and banks.

The loop arrangement is discouraged, as the loop configuration violates the principle interrupting the transmission path for unplanned outages and because of increased costs associated with life cycle O&M.

Existing 60-70kV stations⁶ can retain the loop configuration with station by-pass arrangement. Exceptions:

1. When the stations are located on 60-70kV lines targeted for conversion to 115 kV. Just as decisions to purchase a cross-wound transformer (115-70kV) are made, so should building to the ultimate 115 kV ring standard.

⁶ NERC defines the bulk system as above 100 kV. This is why 60-70 kV does not need to meet the same level of performance as the bulk system.

Bus Configuration

2. In cases where the addition of a fourth breaker is more economic than a by-pass switch situation that requires protection upgrades on the remote terminals.

Figure 1 – Alternating Ring

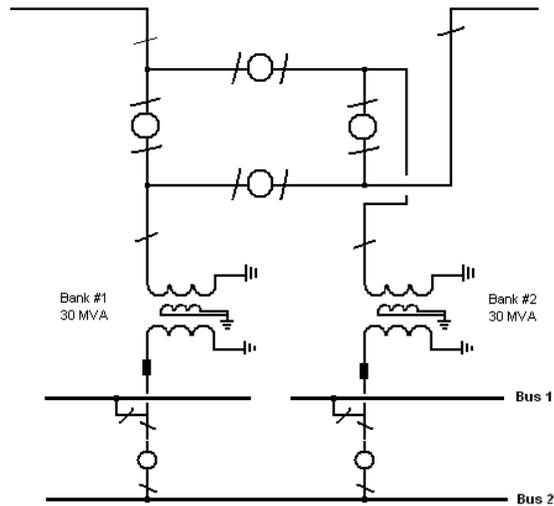
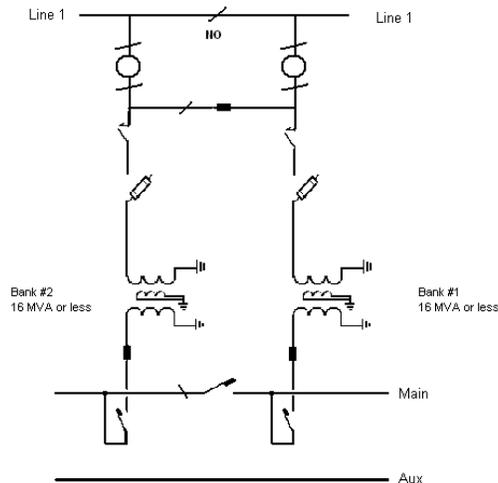
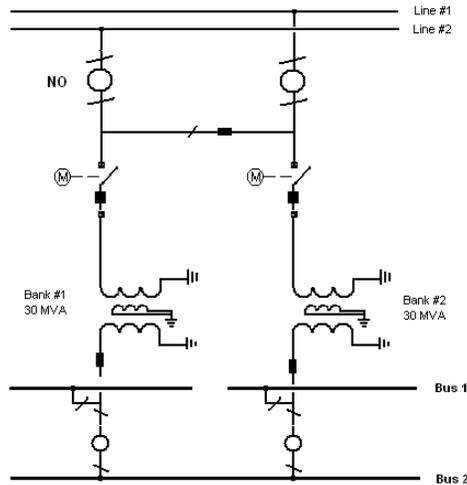


Figure 2 - Loop . Two fused banks are shown. If the banks are not fusible then a circuit switcher or breaker can be used to protect the banks. Circuit switcher is recommended when physical space is tight.



Bus Configuration

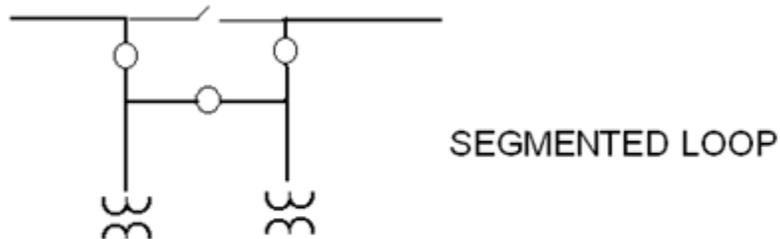
Figure 3 – Double Tap – Circuit Switchers are shown for bank protection, yet breakers can be used instead.



The loop or single-bus configuration for a two-line, two-bank layout is more specifically referred to as the “H” bus design. Further, the letter H is followed by a number which represents the number of breakers/circuit switchers/fuses used in the bus. For example Figure 3 is an H-4 bus.

The following Figures show H-3 through H-5 busses.

Figure 4 - H-3



Bus Configuration

Figure 5 – H-4

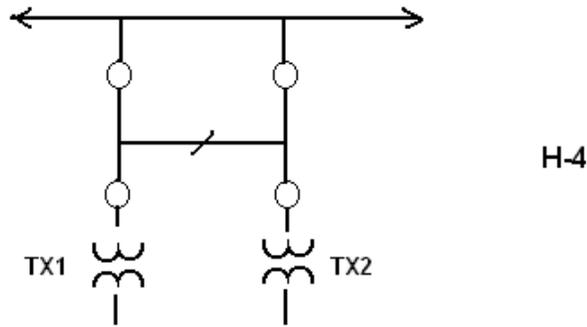
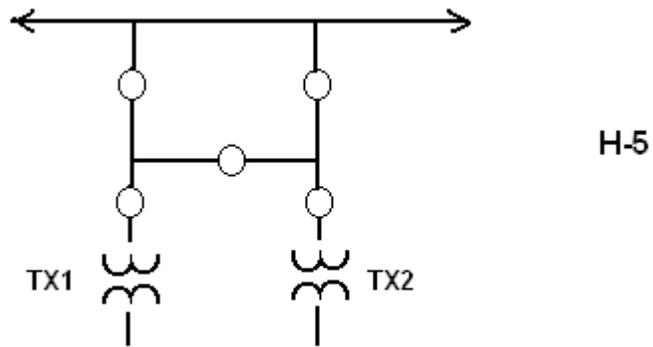


Figure 6 – H-5



Bus Configuration

Figures 7 & 8 are methods to achieve an alternating ring bus that minimizes the number of bus crossovers. Both Figures have one cross-over.

Figure 7 – Alternating Ring

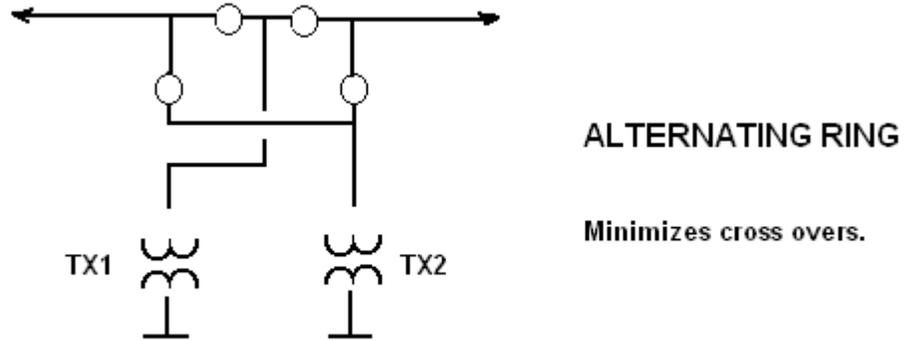
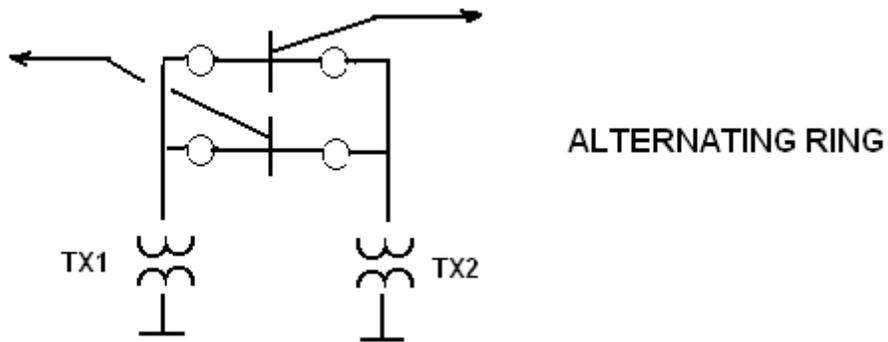


Figure 7 can also be shown to have the two breakers on the top moved to the bottom of the ring.

Figure 8 – Alternating Ring



Bus Configuration

Q&A

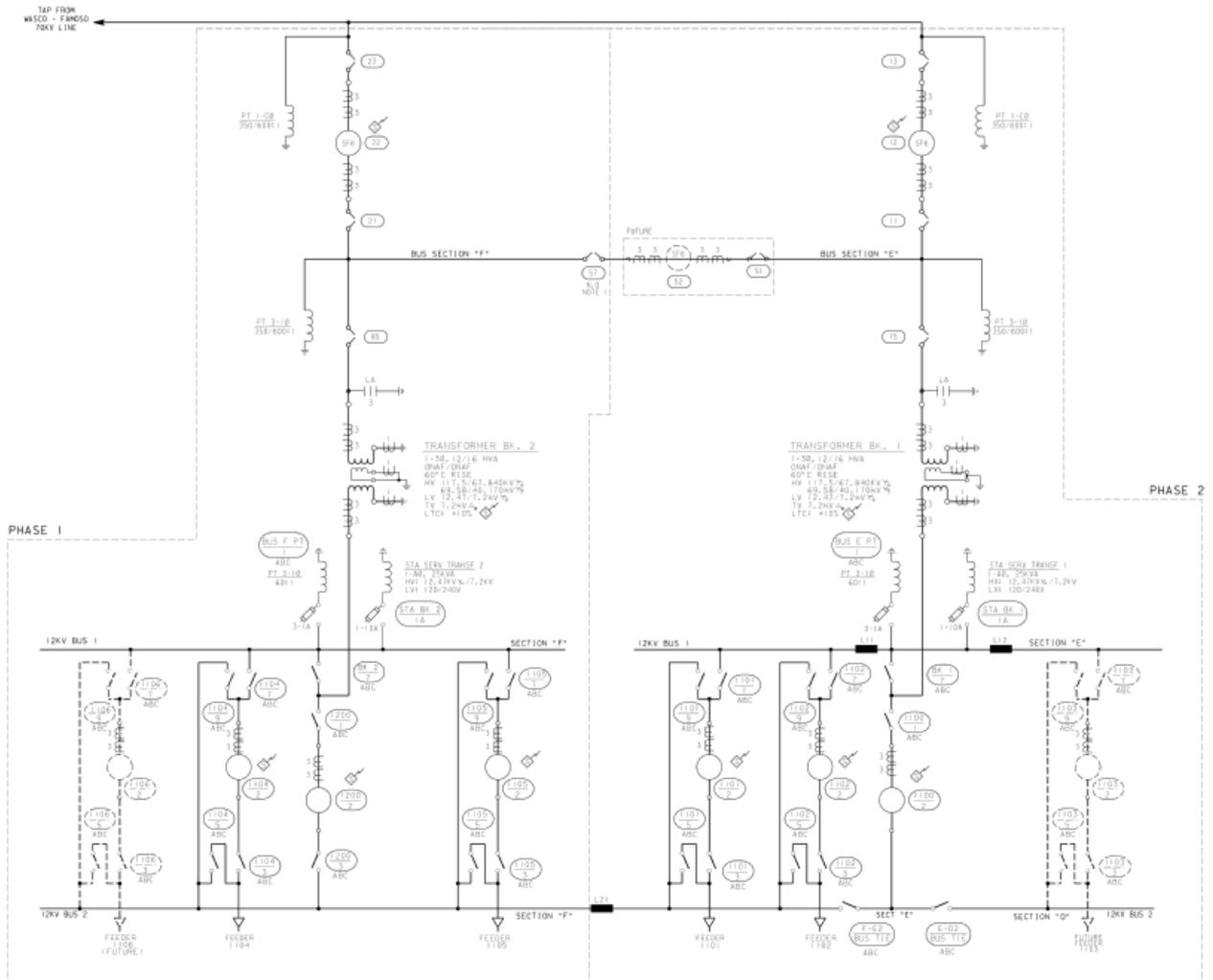
Q1: Does this mean PG&E will go back and programmatically replace loop busses with ring busses?

A1: No. Conversions to ring are recommended when triggered by expansion or reliability.

Bus Configuration

APPENDIX D

High Side Bus Configuration for Radially Fed, Two Bank Distribution Station (Informative)



Refer to Drawing 4084309 – McFarland Sub, Single Line Diagram.

Bus Configuration

APPENDIX E

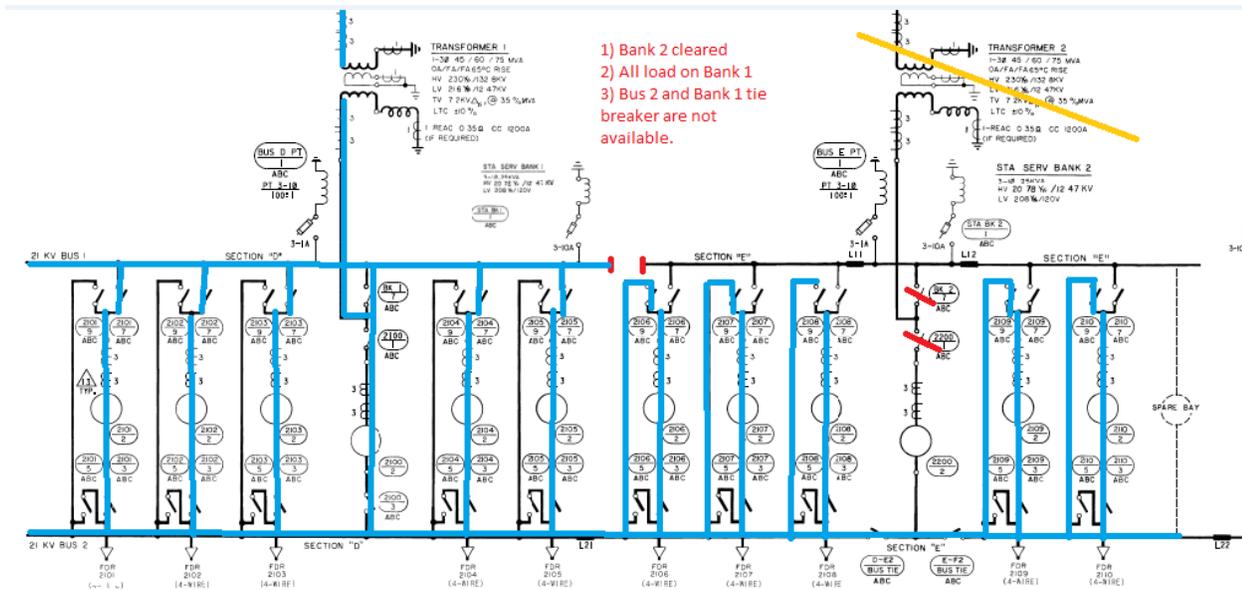
Distribution Bus Upgrades to Meet Today's Reliability Expectations (Informative)

SITUATION

For existing distribution 12 or 21 kV “double bus” (a.k.a. Bus 1/Bus 2) arrangements, there are no disconnects between transformer banks on Bus 1. See Figure 1. In order to clear bank #2, the bus-tie breaker for bank #1 is used to energize Bus 2. All the feeders served by Transformer #2 can then be picked up using Bus 2 as shown in Figure 1. The issue is that for the next contingency say, a failure of any breaker, there's no way to pick up the load served by the failed breaker using only station switching. Bus 2 and the Bank #1 tie breaker are tied up serving load.

Station switching is always preferred over field switching due to a minimum number of switching steps required and how quickly it can be accomplished. Field switching often involves multiple switching steps, multiple employees, distribution planning input on feeder loading capabilities, temporary protection changes and consideration of voltage regulation changes. Abnormal switching leaves load at risk.

Figure 1 – Switching arrangement for existing DB stations (green is serving load)



TASK

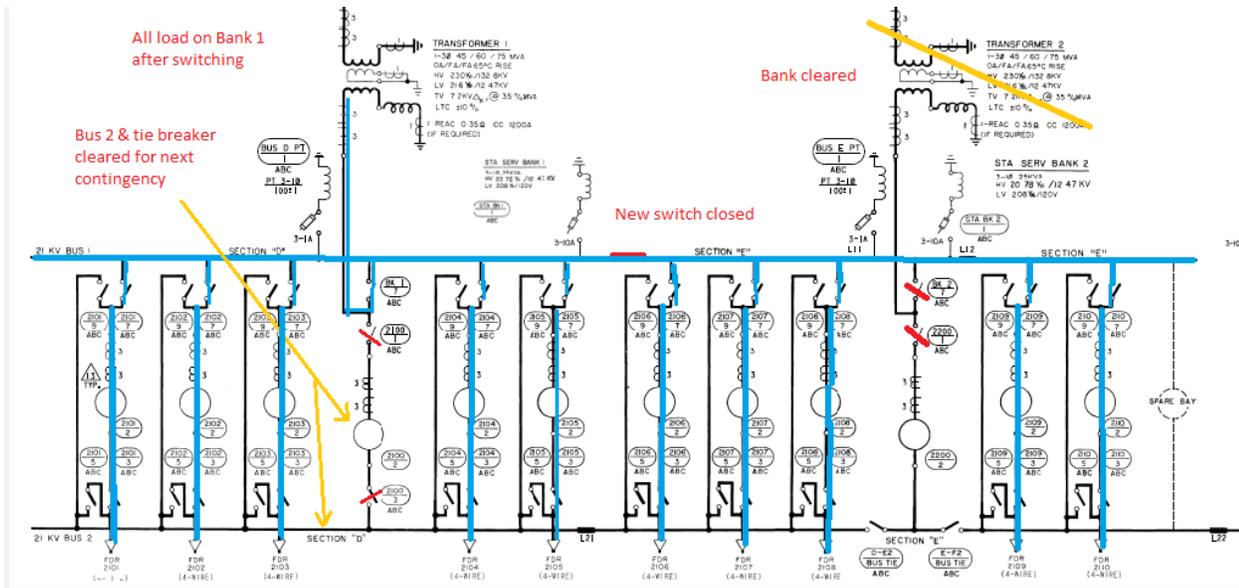
The task is to investigate what economic improvements can be made over the existing design to improve PG&E response time to outages and to reduce the “load at risk”.

Bus Configuration

ACTION

Install bus disconnect switches between transformer banks on Bus 1 for double bus arrangements. With this new switch in place, a clearance of Bank 2 can be accomplished while leaving Bus 2 and the Bank 1 bus-tie breaker available for the next contingency. With this switching arrangement, the loss of any breaker will allow quick restoration of customers utilizing station switching only.

Figure 2 – Switching arrangement utilizing the new bus-tie switches (green is serving load)



Economic Considerations of Installing New vs retrofitting with Bus-tie Switches

When building new or expanding an existing bus the cost of installing these bus-tie switches is negligible compared to the total project costs.

Retrofitting stations with these bus-tie switches is not economic. The reason is a fairly high unit cost, low probability of occurrence and a very large number of stations with this particular design.

High unit costs are driven by physical space constraints (if any space at all), clearance requirements and increased maintenance costs.

N-1-1 means the first outage is construction/maintenance clearance (N-1) and then the next outage (N-1-1) is looked at to make sure we can quickly restore load. This is different than N-2 which is two consecutive unplanned outages. The probability of an N-1-1 is very small. For example, if a bank is cleared once every 10 years for 5 days out of the year then that N-1 has an occurrence of $0.0014 = (5/(365 \times 10))$. The probability of failure of a breaker is 0.01 times the number of breakers say, 10 is 0.1. Together the probability is $(0.0014 \times .1)$ or 0.00014. These are very small odds even if you double it to account for WPEs and acts of God.

Bus Configuration

The following is recommended:

1. When building a new open air bus (DB) or when expanding an existing bus then install bus-tie switches on Bus 1 between banks.
2. DO NOT retrofit existing busses with bus-tie switches on Bus 1.

RESULTS

The recommendation above will:

- Result in nearly negligible costs to implement.
- Improve efficiency of operations.
- Improve reliability.

Other Upgrades (for distribution busses)

Two other upgrades have recently been proposed.

2) Install auxiliary bus tie disconnects for stations with a main-aux arrangement, per EDS 4064474/4064475.

3) EDS 4064474/4064475 shows one tie breaker for a three bank station. Install a second tie breaker for stations with a main-aux arrangement. The basic rule is the T-1 rule or install one less tie breaker than the station has transformers.

The analysis, recommendations and results detailed above apply to all three of these upgrades.