Teck

Requirements for Interconnection Facilities Teck Metals Ltd. Transmission Assets:

1. **Facility Connection Requirements**
2. **Technical Performance Requirements**

References:

(Most recent version in each instance)

- BC Hydro 69 kV to 360 kV Technical Interconnection Requirements for Load Customers
- BC Hydro 60 kV to 500 kV Technical Interconnection Requirements for Power Generators
- FortisBC Facility Connection Requirements
- FortisBC Standard Facility Interconnection Procedures (SFIP)
- Teck Standard Operating Procedure: Facilities Connection Requirements
- FortisBC Operating Order OO 2P-17 – Communications
- FortisBC System Control Centre Emergency Plan

Preface

This document is not intended as a design specification or as an instruction manual for a third party to connect to the Teck Metals Ltd. (Teck) Transmission System and this document shall not be used by any third party for those purposes. Teck has no obligation to provide any interconnection to any third party other than FortisBC.

This document is intended to provide the guidelines by which the performance characteristics of the existing transmission interconnection facilities are evaluated in accordance with the requirements of the British Columbia Utilities Commission (BCUC) Mandatory Reliability Standard (MRS) FAC-001.

Persons using the information included in this guide shall do so at no risk to Teck, and they rely solely upon themselves to ensure that their use of all or any part of this guide is appropriate in the particular circumstances.

The information contained in this document is subject to change and may be revised at any time. Teck should be consulted in case of doubt on the current application of any item.

This document is intended to closely follow the BC Hydro and FortisBC documents referenced above. The above referenced documents have been used in the creation of this document with consideration of the characteristics unique to Teck and the Teck Transmission System.

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1.0 Intent and Limitations

1.1 Intent

- To establish a technical benchmark for designing, constructing, operating and evaluating electrical equipment interconnected to and within the Teck Transmission assets, operated at nominal voltages from 60 to 230 kV, that will meet Teck's service requirements and be technically compatible with and safe at all times for the Transmission system, for Teck's servants or agents, and for the general public.

- To meet the requirements of regulatory agencies and authorities having jurisdiction such as the British Columbia Utilities Commission (BCUC), the North American Electric Reliability Corporation (NERC), and the Western Electricity Coordinating Council (WECC).

- To facilitate Teck's prompt and efficient handling of information requested by regulatory authorities relevant to design, construction and operation of the Transmission System in accordance with BCUC Mandatory Reliability Standard FAC-001.

- To maintain compliance with BCUC Reliability Standards and applicable Regional Reliability Organization, subregional, Power Pool, and individual Transmission Owner planning criteria and facility connection requirements.

- These requirements are intended to address connection requirements for generation facilities, transmission facilities and end-user facilities.

1.2 Limitations

- This guide is not intended or provided by Teck as a design specification or as an instruction manual for any third party. Persons using information included in the guide do so at no risk to Teck, and they rely solely upon themselves to insure that their use of all or part of this guide is appropriate in the particular circumstances.

- The adoption by Teck of these requirements for new plant design or equipment meets certain limited requirements of Teck, but does not mean, expressly or by implication, that all or any of the requirements are met by Teck's legacy equipment in its plant.

1.3 Contact Information

Interested parties shall communicate any Technical Performance Requirements issues with Teck's Superintendent, Energy and Business Relations.

Contact details for Teck's Superintendent, Energy and Business Relations are:

Attn: Adam Brooks
Teck Metals Ltd.

Trail Operations
P.O. Box 1000, 25 Aldridge Avenue
Trail, BC Canada V1R 4L8

Phone: 250 364 4222
Direct: 250 364 4711
Email: adam.brooks@teck.com

This document is available online at:
http://www.teck.com/operations/canada/operations/trail-operations/

2.0 General Requirements

This section identifies the information regarding:

- Updates and notification procedures
- Planning horizon and Coordinated Studies
- The system configuration wherein the particular equipment is utilized
- System operation.

2.1 Notification Requirements

a. Changes to the Teck Transmission System

Teck shall promptly notify FortisBC Inc. (FortisBC) of any changes to the Teck Transmission System that is not within the FortisBC operating boundaries. FortisBC regularly submits system model data to BC Hydro and the Regional Entity. Teck shall promptly respond to any concerns identified by FortisBC regarding actual or proposed changes to the Teck Transmission System

Teck relies on FortisBC to advise if any changes to the FortisBC Transmission System will cause impacts to any assets in the Teck Transmission System.

b. Changes to the Requirements for Interconnection Facilities

Teck shall provide these Requirements for Interconnection Facilities to FortisBC for comments commencing on 1 May 2011, and thereafter within one month after each revision.

2.2 Planning Horizon and Coordinated Studies

Teck has adopted a 5 year planning horizon.

At this time, both Teck Trail Operations load and the generating capability of the Waneta Generating Station are static, and there are no changes planned to the Teck Transmission System. System studies have been performed that demonstrate the adequacy of the current Teck Transmission System for all Trail Operations loads between 0 MW and 250 MW, and for all Waneta Generating Station generation levels between 0 MW and 500 MW.

Teck will conduct system studies once the Teck Trail Operations load is expected to exceed 250 MW, or the Waneta Generating Station generation level exceeds 500 MW.

2.3 System Configuration

The information identified in this section shall be available for each piece of equipment in the System.

a. Electrical One-Line Diagram
An electrical one-line diagram should show the connections of all substation and generating station electrical equipment. It should contain, or be accompanied by another drawing which shows the proposed primary metering equipment locations used for coordinating relay settings.

b. Protective Device Coordination Graph
A standard size 4 1/2 x 5 cycle log-log graph should be used for coordination studies. Each entrance protective device or setting must coordinate with upstream protective equipment. See also Section 3 for protective requirements.

c. Site Plan
The site plan must show details of the primary electrical installation. The plan shall show the location and orientation of the generating station or substation and the transmission tap point.

d. Substation Layout
The substation layout (plan and elevation) must show the general arrangement of equipment including connections to the transmission line terminal structure and, if applicable, to the metering transformer and duct route to the metering cubicle. See also Section 4 for metering requirements.

2.4 System Operation

Teck's transmission system assets are managed, operated and maintained under contract by FortisBC.

Parties that interconnect to the Teck transmission system will be expected to implement procedures to interface directly with the FortisBC System Control Center for all issues related to operations and communications.

Interconnecting parties are referred to the following documents for all matters related to communications and procedures during normal and emergency operating conditions:

a. FortisBC Operating Order OO2P-17 – Communications
b. FortisBC System Control Centre Emergency Plan

3.0 Equipment Technical Requirements

3.1 Equipment Requirements

Interconnection Requests submitted to Teck must specify maximum and minimum MW/MVAR capacity or demand, as well as the approximate location of the proposed Point Of Interconnection (POI). The requesting interconnecting party (Customer) identifies alternative POIs, configurations and voltage levels at scoping meeting, which Teck will submit to FortisBC for evaluation. Based on the FortisBC feasibility study results, Teck reserves the right to select the most advantageous POI and voltage level based on Teck's business requirements.

The point of interconnection is to be clearly described. Usually the change of facility ownership and the point of interconnection are the same point. The voltage level, MW and MVAR capacity or demand at point of interconnection shall be compatible to, and coordinated with Teck and FortisBC, and shall be in conformance with Teck, FortisBC and WECC Operating Procedures.

Station insulation must be coordinated with the incoming transmission line insulation. At 230 kV it is Teck's practice to install overhead ground wires on transmission structures from the station out 500 m. The critical flashover levels for standard Teck line construction are as follows:

Nominal Voltage	Critical Flashover Voltage
	(1.2 x 50μs waver +ve)
230 kV	860 kV

Note that in some cases lines may be insulated for higher levels than the level at which they are energized.

In order to coordinate with the indicated levels, Teck has its stations designed as follows:

- 63 kV Nominal
  - Normal Maximum 60 cycle voltage 69 kV
  - BIL All equipment 350 kV

- 230 kV Nominal
  - Normal Maximum 60 cycle voltage 253 kV
  - BIL Transformers 850 kV
  - Other Equipment 950 kV

The entire transmission system is effectively grounded, but the 63 kV system may become ungrounded at some locations, in which case surge arresters rated for temporary ungrounded operation must be applied. Teck's 230 kV system is always referenced to ground.

a. **Surge Arresters**

Surge arresters are recommended for protection of transformers. Where they are applied, Teck metering equipment shall be located close enough to the surge arrester to be effectively protected. The preferred location for surge arresters shall be as depicted in Fig. 1. If this is not possible the surge arresters must at least be located on the load side of the manual group operated load break disconnect.

b. **Isolation Equipment**

At Points of Interconnection to the Transmission System, isolating disconnect switches shall be provided that physically and visibly isolate the Transmission Systems from each other. Safety and operating procedures for the isolating device shall be in compliance with the WorkSafeBC safety guidelines. Terms and conditions covering the control and operation of the disconnect device are normally covered by the interconnection agreements between entities. These operating agreements are normally in the form of "Local Operating Orders" (LOOs).

The disconnect device must be:

- Rated for the voltage and current requirements of the particular development.
- Gang operated.
- Operable under all weather conditions in the area.
- Lockable in both the open and closed positions, if manually operated.
- Interlocked with the applicable adjacent breaker. (Disconnecting interlocks shall be in accordance with the latest Canadian Electrical Code requirements.)

Since the disconnect device is primarily provided for safety and cannot normally interrupt load current, consideration shall be given as to the capacity, procedures to open, and the location of the device.

Fuses, circuit breakers or circuit switchers used for fault clearing shall be capable of interrupting the ultimate fault duty stated by Teck at the specific location as determined by Teck.

All circuit breakers at 63 kV or above in the Bulk Electric System should have the following characteristics:

- An interrupting rating equal to or higher than the fault duty at the specific location as determined by Teck
- An ability to meet Teck's "ultimate" fault duty for the location. If the CB supplied has a lower interrupting rating, the owner of the equipment assumes the responsibility for upgrading when necessary to accommodate changes to the system.

- A stated interrupting capability that does not rely on fault reduction schemes such as intentional time delays in clearing;
- An ability to perform all required switching duties, including but not limited to capacitive current switching (line/cable dropping in particular), load current switching, and out-of-phase opening; and
- An ability to perform all required duties without creating transient over-voltages that could damage equipment of Teck or third-parties.

In the absence of a high voltage circuit breaker or circuit switcher, disconnects associated with fuses shall be capable of switching transformer magnetizing current. Installations with in-house parallel generation shall have circuit breakers rated to trip the capacitive load of the incoming supply line.

c. **Transformers**

Teck refrains from using transformer winding arrangements which result in zero sequence current contributions to faults on the Transmission System, as these are generally not acceptable for protection reasons. Other than for generator applications, a delta connected HV winding is recommended unless fuses are being used, in which case ferroresonance considerations may force use of an alternate configuration.

d. **Transmission Lines**

The design of the line should be in accordance with sound engineering practices to ensure satisfactory operation and to avoid adverse impacts on the safety and security of the Transmission system.

Teck will only allow point-to-point transmission line interconnections. Three source terminal interconnection configurations of transmission lines, such as line taps, will not be allowed, due to problems associated with protective relay coverage from infeed, sequential fault clearing, outfeed or weak source conditions, reduced load flow, and automatic reclosing complications.

Taps into existing transmission lines shall require at least two breakers to sectionalize the line and in some cases as indicated by system studies and examination of customer load/generation characteristics, three breakers will be necessary to isolate customer effects. Some new connections to the Teck transmission system may require one or more Teck transmission circuits to be looped through the new facility.

The design and ratings of the new facilities and the transmission loop into them shall not restrict the capability of the transmission circuits or impair Teck transmission service requirements. Long taps to feed connected load directly tied to a transmission line are to be avoided.

Any new interconnection configuration should be designed in such a way so as to minimize the likelihood that Teck's system operator, FortisBC, would be prohibited from taking a Teck transmission facility out of service for just cause. FortisBC shall not be forced to open a transmission facility for an adjacent interconnected generator or transmission line to obtain an outage, other than during approved scheduled outage periods as such are coordinated with, and approved by Teck and FortisBC, or in the case of an emergency. Manual switching or clearing electrical faults within the customer's facility shall not curtail the ability of Teck to transmit power.

Reliable station and breaker arrangements will be used when there are new or substantial modifications to existing Teck substation(s). In general, transmission substations must be configured such that transmission line, transformer, bus and circuit breaker maintenance can be performed without degrading transmission connectivity. This generally implies a breaker and a half double breaker, double bus configuration. A ring bus may be used when a limited number of transmission lines are involved.

Design studies must be conducted to determine the actual climatic loadings at high elevations (rime icing), long water crossings (high wind exposure) and coastal areas (possible heavy glaze icing). Transmission lines shall be designed in conformance with all applicable CSA

Unless the expected life of the installation is shorter, the design regarding wind and ice storms should be based on a 40 year return period for lines 138 kV and below and a 100 year return period for lines 230 kV and above. Also, outages due to conductor galloping should be negligible.

e. **Substation Grounding**

The equipment and station shall be grounded in accordance with the latest Canadian Electrical Code. It is recommended that the ground grid be designed based on the ultimate fault duty for the site.

Each substation shall have a ground grid that is solidly connected to all metallic structures and other non-energized metallic equipment. This grid shall limit the ground potential gradients to such voltage and current levels that will not endanger the safety of people, or damage equipment, which are in or immediately adjacent to the station under normal and fault conditions. The ground grid size and type are in part based on local soil conditions and available electrical fault current magnitudes. In areas where ground grid voltage rises beyond acceptable, safe limits (for example due to high soil resistivity or limited substation space), grounding rods and grounding wells might be used to reduce the ground grid resistance to acceptable levels.

If a new ground grid is close to another substation, the two ground grids may be isolated or connected. If the ground grids are to be isolated, there shall be no metallic ground connections between the two substation ground grids. Cable shields, cable sheaths, station service ground sheaths and overhead transmission shield wires can all inadvertently connect ground grids. Fibre-optic cables are highly preferable for providing telecommunications and control between two substations while maintaining isolated ground grids. If the ground grids are to be interconnected, the interconnecting cables shall have sufficient capacity to handle fault currents and control ground grid voltage rises. Any connection to a Teck substation ground grid must be approved by Teck.

f. **Telecommunications Systems**

As all Teck transmission assets are operated by FortisBC, Teck relies on FortisBC to specify the particular telecommunications required for operating purposes.

Telecommunications assisted protection facilities may be required for power system protection between locations. Teck will specify the type of equipment required, the interface points and other characteristics required. The required facilities may include:

- Specialized high-speed teleprotection signals for transmission line protection,
- Specialized high speed transfer-trip teleprotection signals for functions such as transformer protection, reactor protection, over-voltage protection, circuit overload protection, breaker failure protection, and the initiation of generator shedding or other remedial actions scheme actions,
- Telecommunications media for the protection facilities, and for remote access to electronic relays, event recorders and fault recorders (used for the analysis of power system disturbances), and
- The battery and charger system for which parameters and size will be determined on a case by case basis. Some systems may be specified as 24V floating or 48V positive ground. The battery reserve will typically be 8 hours for sites with easy access, or 24 hours for sites without easy access.

  In order to ensure compatibility of design and operation, Teck will provide technical requirements for the telecommunications equipment needed to transmit and receive teleprotection signals between locations. Teck will not provide High Voltage Telecommunication Entrance Protection equipment.

3.2 Protective Requirements

a. **General Requirements**

The protection equipment must satisfy the following two fundamental requirements:

i. The equipment shall provide protection with adequate sensitivity for all electrical faults, present to ultimate levels, which will coordinate with upstream protection systems. In terms of this document, coordination is defined as either:

- fully selective clearing – the protection will clear all faults in the local installation before upstream relaying initiates tripping for such faults; or
- simultaneous clearing - the local protection will clear all faults in the local installation coincidentally with upstream clearing of such faults.

Unless conditions on the Transmission system dictate otherwise, Item (i) will apply for all installations.

ii. The local equipment shall be rated to carry and interrupt the fault levels that are, or will be, available at its location, including the ultimate fault currents specified by Teck. Local equipment includes those items listed in Section 3.1 "Equipment Requirements" and all protection equipment forming the entrance protection: current transformers, potential transformers, secondary cabling, dc system/battery charger, switchboard wiring and protective relays.

The following are additional general requirements:

iii. The entrance transformer(s) high voltage winding(s) must be connected delta or ungrounded wye (unless special system conditions preclude these types of connections; see Section 3.1 "Equipment Requirements").

iv. Where protective relays are used as the entrance protection, the HV interrupting device (i.e., circuit breaker) shall be included in the entrance protection zone. That is, protective relays shall connect to source side CT's on the HV interrupting device as shown in Fig. 1.

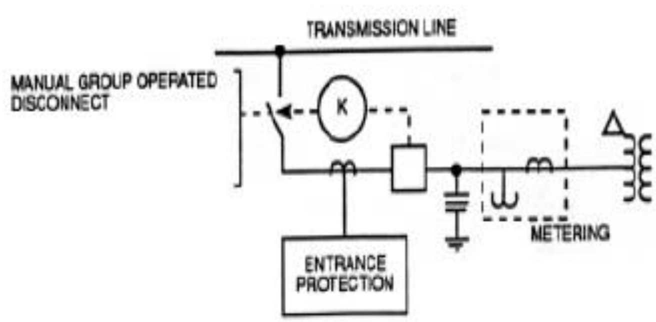


Fig. 1 - One-Line Diagram Subsection 3.2.1

Note: Where a circuit switcher is applied as the HV interrupting device, the CT's may be located on the load side of the circuit switcher, provided that the metering equipment is included in the entrance protection zone. Transformer bushing CT's are therefore not acceptable for this application.

v. When a circuit breaker or circuit switcher is used as an HV interrupting device, the maximum allowable device interrupting time for fault clearing is 8 cycles.

vi. Teck's metering equipment shall be included in the entrance protection zone.

vii. Local equipment may be subjected to negative sequence current unbalances because of:
- negative sequence unbalance on the Transmission System itself;
- primary fused installations where only one fuse operates for a Local fault. These negative sequence unbalances will be of particular concern where rotating three-phase machines are present. It is prudent to consider the provision of negative sequence (unbalance) protection (device 46) to protect local equipment.

viii. During emergencies or other abnormal operating situations on the Transmission System, the local application may experience undervoltage conditions. It is prudent to consider the provision of timed undervoltage tripping (device 27) to protect equipment.

ix. In certain cases spare CT and PT secondary metering windings may be utilized to fulfill the potential requirements for protective relays.

b. **Local Generation**
Equipment must be provide to prevent generating plant from energizing a de-energized transmission supply line (back feed) and to promptly remove contributions to faults on the Transmission System. The type of equipment required will depend upon which of three general categories the installation falls under. In addition to the protection requirements described herein, requirements listed in Sections 3.2.1, 3.2.3 and 3.2.4 are also applicable.

i. <u>Local Generation With No Parallel Connection to the Transmission System Required or Intended (Standby Generation)</u>.

Special considerations for this type of installation are a suitable mechanical and/or electrical interlock to prevent the standby generation from operating in parallel with the Transmission System and from energizing the de-energized transmission system.

Permanent standby power supply generators must be equipped with approved transfer switches or approved key interlock switches designed to ensure that the generators cannot feed into the Transmission System. Teck considers such connections to be non-hazardous infeeds for electrical worker safety.

Scheduling is required for planned power system source outages. Teck will advise FortisBC if temporary portable generation or an alternative power supply will be used during the outage. If Teck's electrical configuration will be changed during the outage, Teck will be considered to be a "hazardous" infeed and the "Guarantee of Isolation" procedure will be used. (Teck and FortisBC will jointly sign a Local Operating Order which describes operating procedures).

Two sample installations are shown in Figs. 2 and 3.

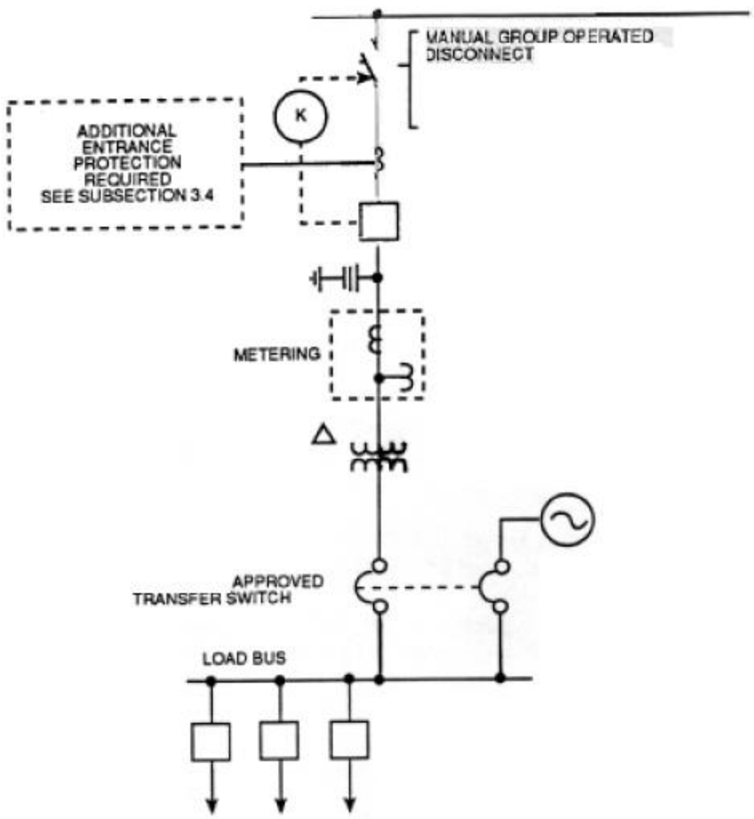


Fig. 2 - One-Line Diagram Subsection 3.2.2(a) - Standby Generation

For the arrangement shown in Fig. 2 the transfer switch must be an approved device. For approval process and list of approved transfer switches, contact Teck for specific review.

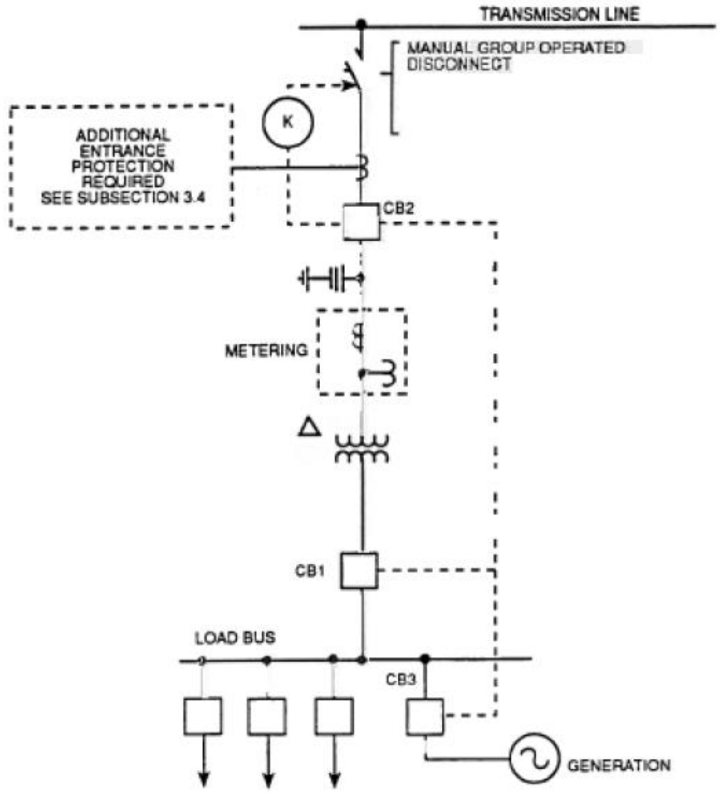


Fig. 3 - One-Line Diagram Subsection 3.2.2(a) - Standby Generation

For the arrangement shown in Fig. 3 Circuit Breaker 1 (CB1) or Circuit Breaker 2 (CB2) must be electrically interlocked with CB3 in such a way that CB3 cannot be closed unless one of CB1 or CB2 is open. Specific details of the proposed interlocking scheme are to be submitted to Teck for acceptance.

ii. <u>Local Generation in Parallel with Teck with No Power Flow to Teck</u>

Since the local generation is a fault contributor to the Transmission System, the local generation should have redundant equipment to clear from all phase and ground faults on the transmission supply line. In some cases Teck will require equal grade primary and standby protection to meet this requirement. For more simple installations redundant protection in a single scheme may be acceptable to Teck. As well as providing redundant protection, breaker failure protection must be provided for the entrance CB.

The installation shall also have equipment to prevent energization of an unfaulted circuit which is open upstream. Depending upon the specific circumstances, redundant equipment may have to be provided.

- *Detection of Ground Faults*
  For the detection of ground faults on the Transmission System, zero sequence voltage detection (Vo) should be considered. The usual method of detecting zero sequence voltage involves the connection of a suitable overvoltage relay (device 59N) to the broken delta secondary connection of primary voltage instrument transformers. A second alternative for the detection of ground faults is a single phase primary voltage instrument transformer connected phase-to-ground, combined with both an undervoltage and an overvoltage relay. For these applications the spare secondary windings of the metering transformer may be used, subject to the constraints of Teck's metering requirements.

  A further alternative for the detection of supply system ground faults is the application of a power relay (32) which would operate after the source opened. Should such a device be considered, it is preferred that it be connected to look into the entrance transformer from the low voltage side and pick up on the magnetizing watt loss component of the transformer. In some special circumstances the magnetizing watt loss component will be so low as to preclude power relay operation. In this case, although it is not the preferred approach, the power relay will have to be applied to sense loss of real power flow into the plant. Manufacturer's transformer/relay test data shall be provided to confirm whether or not the preferred connection will work. To check the effectiveness of the power relay with this connection, Teck will require testing of the device by actual back energization of the transformer and, where feasible, the supply line.

- *Detection of phase faults*
  Dedicated phase fault protection must be provided to clear isolated multi-phase faults on the Transmission System. Appropriate to the installation, this protection will consist of undervoltage relaying (27) and/or directional inverse time overcurrent relaying (67), impedance relaying (21), inverse time overcurrent relaying (51), power relaying (32).

- *Breaker Failure Protection*
  Breaker failure protection in the form of a CB auxiliary switch scheme could be considered. One other alternative is to provide remote back-up coverage via other relaying within the plant.

- *Prevention of Infeed*
  A power relay is an acceptable device to remove any infeed to the transmission system when the source has opened.

Summarized in Fig. 4 is a sample installation which meets the minimum requirements for generation operating in parallel with the Transmission System with no power flow to Teck.

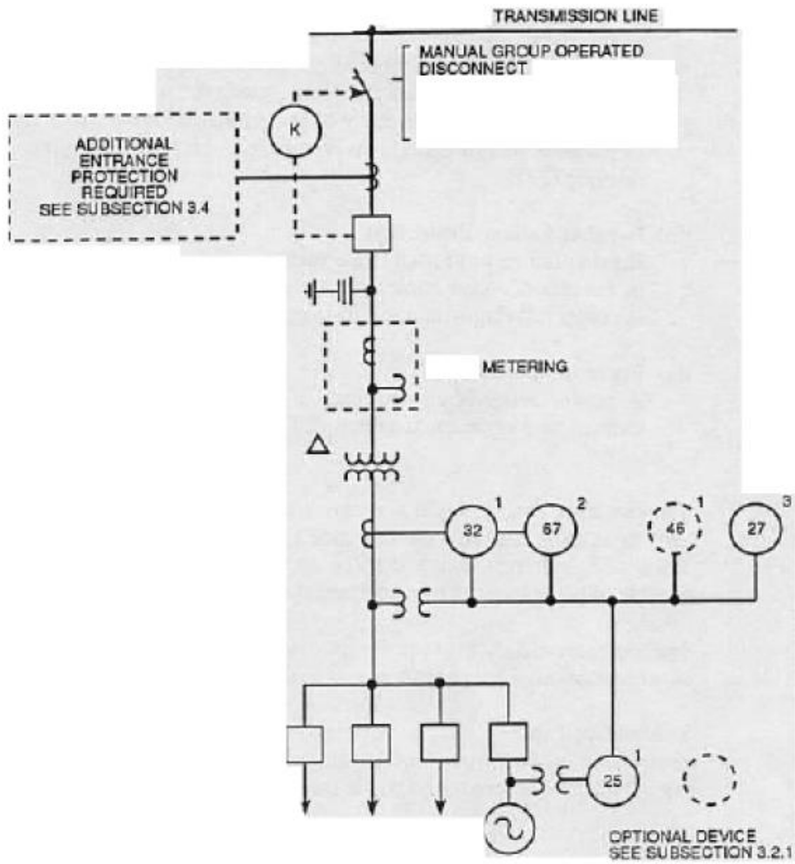


Fig. 4 - One-Line Diagram Subsection 3.2.2(b)

iii. Local Generation in Parallel with Teck Transmission - Power Flow to Teck

Similar to Subsection 3.2.2(b), the local generation is a fault contributor to the Transmission System and shall clear from all phase and ground faults on the transmission supply line by providing redundant protection. As well, breaker failure protection for the entrance CB must be provided.

- *Detection of Ground Faults*

  The options for the detection of system ground faults are some form of zero sequence voltage detection or overvoltage/undervoltage detection as described in Subsection 3.2.2(b). A power relay looking into the entrance transformer is not applicable, as it could operate on the intended MW power flow to the Transmission System.

- *Detection of Phase Faults*

  As described in Subsection 3.2.2(b), undervoltage relaying, directional inverse time overcurrent relaying, impedance relaying and non-directional inverse time overcurrent relaying are examples of relaying types which could be applicable for the detection of system phase faults.

- *Breaker Failure Protection*
  Breaker failure protection in the form of a CB auxiliary switch scheme could be considered. One other alternative is to provide remote back-up coverage via other relaying within the plant.

- *Prevention of Infeed*
  Prevention of infeed to the transmission system when the source has opened is desirable. However, it is not a requirement in this instance, since solutions to prevent it are not practical or universally acceptable.

Local generation shall have its own synchronizing facilities to allow synchronization of the generator units with the Transmission System.

Fig. 5 is a sample installation which meets the minimum requirements for local generation providing power to the Transmission System.

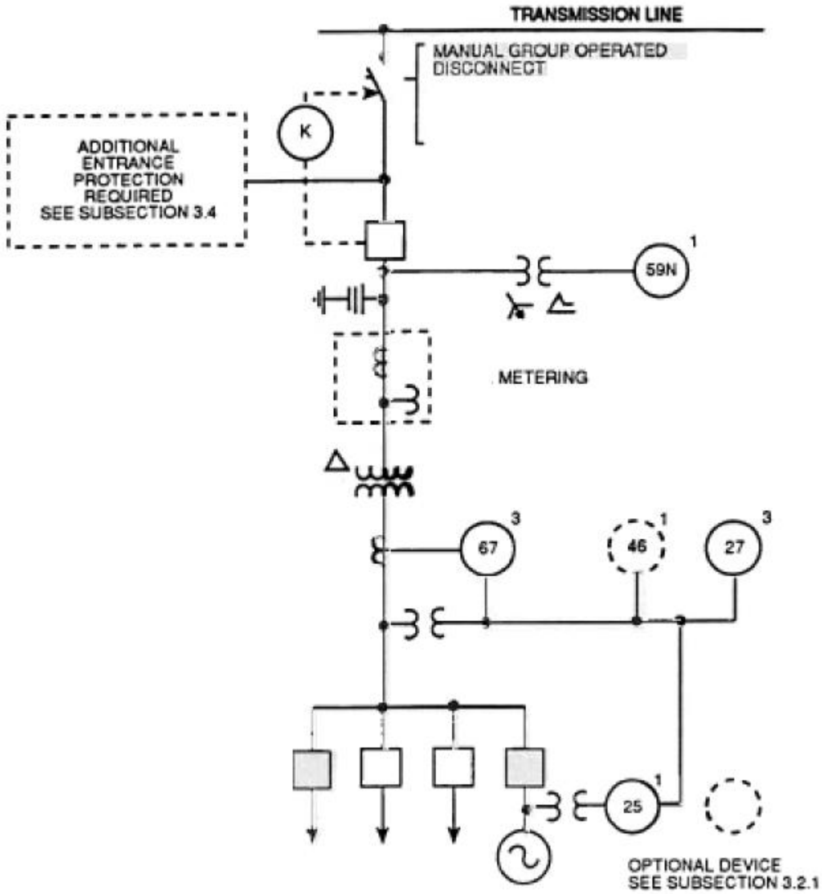


Fig. 5 - One-Line Diagram Subsection 3.2.2(c)

c. **Underfrequency Load Shedding**

Underfrequency load shedding is required if specifically directed by the Regional Reliability Organization. Otherwise, Teck has no specific policy that requires the installation of underfrequency load shedding.

If installed, the underfrequency relay shall be of the solid state type with an instantaneous operating element. The relay shall be approved by Teck. The underfrequency relay shall be equipped with a short internal time delay to override transients and be capable of being set between 58 and 59.5 cycles. Its setting will be specified by Teck.

The total tripping time of the load shedding scheme (underfrequency relay operate time + auxiliary relay operate time + circuit breaker operate time) shall be less than or equal to 14 cycles.

The underfrequency relay usually trips the incoming circuit breaker; however, on receipt of detailed proposals, Teck may permit emergency load retention of approximately 10 percent of normal load, or 2 MW, whichever is the lesser.

A staged load shedding scheme may be acceptable to Teck. Such installations should indicate the MW load in each block to be shed and an order of preference with respect to shedding. In any case, the frequency set point for the shedding of each block will be established by Teck.

d. **Batteries/Battery Chargers**

Where applicable, it must be ensured that the continuous DC supply voltage rating of any solid state relay or its associated power supply is not exceeded due to sustained overvoltages on the DC supply bus. Common examples of conditions resulting in high sustained overvoltages are:

i. Battery chargers at the equalize setting;
ii. Battery chargers connected to the DC supply bus without the station batteries (not a recommended practice); and
iii. Battery chargers set in the constant current charging mode.

If there is any chance that the DC rating of a solid state relay will be exceeded, then passive voltage regulator of suitable rating shall be applied to each solid state relay to limit the DC voltage to within the solid state relay's DC rating.

3.3 Voltage, Reactive Power, Power Factor, Power Quality and System Considerations

a. **Electricity Supply**

The electricity supply to transmission users shall conform to the existing Transmission System and is alternating current, three-phase, at a frequency of 60 Hz ± 0.1 Hz.

Transmission line connections to the Teck transmission system shall meet the power factor requirements set forth in the FortisBC procedure "FortisBC Facility Connection Requirements" to ensure that transmission voltages and reactive power flows are within limits permitted by the applicable reliability standards.

Existing Transmission System installations and connections are reviewed on an exception basis for endangerment and interference with the Transmission System or Teck's employees, their agents and the general public that may arise from the interconnected equipment and its operation. Teck may require corrective action, including the provision of corrective equipment. If, in the judgment of Teck, the endangerment or interference is critical Teck may, without notice, suspend the supply of electricity, and refuse supply until corrective action is taken.

Endangerment and interference includes:

- the introduction of harmonics into the Transmission system;
- the creation of undue and abnormal voltage fluctuations on the Transmission system;
- the depression or elevation of the voltage level on the Transmission system below or above the voltage range provided by Teck for electricity supplied under normal operating conditions; and
- the creation of an undue voltage unbalance between phases.

All synchronous generators connected to the Teck transmission system are to be equipped with automatic voltage regulators (AVR). Generators must operate with their excitation system in the automatic voltage control mode unless otherwise approved by Teck’s systerm operator, FortisBC. Generating equipment owners shall maintain a log which records the date, time, duration and reason for not being in the automatic voltage control mode when operating interconnected to the system. Generating equipment owners shall make this log available to Teck and FortisBC on request.

b. **Harmonics**

Operation of the plant and equipment shall not introduce adverse harmonics onto the Transmission System. There are both voltage and current harmonics each requiring separate analysis and control. Harmonic effects are dependent on the magnitude and frequency of the harmonic, and the electrical characteristics of the total electrical system.

Upon request, Teck shall be provided with the characteristics of any harmonic-producing devices connected to the Teck Transmission System, the magnitude and frequency of harmonics produced, and harmonic filtering, if any.

On request, Teck will supply the ambient harmonic levels at the supply bus and the harmonic impedance spectrum at any point of connection.

Teck follows the IEEE Standard 519-1992 titled "Recommended Practices and Requirements for Harmonic Control in Electric Power Systems". A detailed outline of the requirements for harmonic control is included as Appendix A.

Installations that meet the requirements of a Category 1 installation as outlined in Figure 2.1 of Appendix A will be accepted automatically by Teck. Upon request, Category 2 installations must have harmonic studies performed and submitted for Teck's review and approval. These harmonic studies must demonstrate that the harmonic design limits specified in Appendix A will be met.

c. **Permissible Voltage Dip/Flicker**
Teck's standards for voltage dip at the point of delivery are:

Voltage Dip	Number of Times Permitted
	(Not to Exceed)
3% of normal voltage	Once per hour
6% of normal voltage	Once per shift of 8 hours

Voltage dips exceeding 6 percent but not exceeding 9 percent may, at times, be permitted by Teck. Permissible voltage dips more frequent than once per hour or rapid load fluctuations causing voltage flicker are limited to the percent voltages indicated by the Border Line of Visibility curve shown in Appendix A. Some relaxation of these limits may be permitted by Teck provided that the user demonstrates that the effects of its operation will not be as severe as sudden load changes on the average threshold of perceptibility of flicker, such as a slower rate of change in the voltage.

Of particular concern are the following types of equipment which may cause excessive voltage disturbances or unbalances to the Transmission System: large motors, arc furnaces, induction furnaces, resistance welders, static converters, capacitors, electric shovels, rolling mills and other similar voltage fluctuating equipment.

References on this subject are:

- Walker, M.K. "Electric Utility Flicker Limitations," IEEE Transactions on Industry Applications, Vol. 1A-15, No. 6, November/December 1979
- "Supply to Arc Furnaces", Electricity Council (U.K.) Engineering Recommendation, P 7/2 (1970).

d. **Phase Voltage Unbalance**
Unbalanced load in plants will cause phase voltage unbalance on Teck's high voltage system with possible harmful effects to other installations connected to the system. Of particular concern is the negative sequence voltage created and the resulting effect, particularly on rotating generators and motors connected to the system. Under normal operating conditions the negative sequence voltage at the Point of Delivery shall not exceed 1 1/2 percent, or such limit as agreed to by Teck.

e. **Reactive Power and Power Factor**
The minimum power factor (PF) to be maintained by the installation, when the kVA demand is greater than 75% of the maximum demand, measured over an

interval of 5 minutes is 90% lagging unless circumstances of electricity supply require otherwise. In general, the power factor requirement will be monitored through the use of information derived from Teck's metering equipment. Factors derived from the several forms of metering equipment would permit the following power factor calculation:

$$PF = \frac{kW.h}{\sqrt{(kW.h)^2 + (kVAR.h)^2}}$$

Where kQ.h is measured instead of kVAR.h, the kVAR.h is calculated as follows:

$$kVAR.h = \frac{2kQ.h - kW.h}{\sqrt{3}}$$

All generators shall have the ability to operate continuously in a range from an over-excited power factor of 90% to an under-excited power factor of 95% over the generating unit’s complete range of output power.

All synchronous generators shall have the ability to follow a specified voltage or VAR schedule issued on an hourly, daily, or seasonal basis depending upon the location of the generator. As Teck’s system operator, FortisBC specifies the desired generator voltage setting or desired MVAR output level for each generator connected to the Teck transmission system. The generator may be required to change its MVAR output or voltage reference set point from time to time depending on system conditions and the location of the generator. If the FortisBC system operator does not have direct control over the generator's voltage regulator via supervisory control, the generator’s operator shall be able to implement the new MVAR output or voltage reference set point within an agreed time.

f. **Impact of System Disturbances on Connected Users**

On a long term basis, power system disturbances at or near the intertie between a plant and the Transmission network are inevitable.

It is important, therefore, for users to recognize that disturbances in the Teck transmission network will adversely affect the operation of their plants. It is prudent for them to understand the nature of such disturbances and to take whatever action is possible to minimize the impact on their plants' electrical systems.

Depending on the user's location in the Transmission System, the causes and the frequency of disturbances will vary. The following is a list of the most usual types of power system disturbances:

i. sustained overvoltage,
ii. sustained undervoltage,

iii. sustained underfrequency,
iv. impulse, spike, lighting or switching surges,
v. excessive voltage flicker caused by starting of large motors,
vi. supply circuit forced outage,
vii. voltage sag caused by remote faults.

Items (i), (ii) and (iii) are usually emergency upset conditions from which the Transmission system in the area of the plant is not expected to recover immediately. For such disturbances, Teck may dictate that either loads be shed in the plant or the plant be isolated from its system in order to assist in the recovery to normal voltage and frequency. In some cases, the user may have the option of either disconnecting the service from Teck or riding through the disturbance. In either case, without in-plant generation to supply the plant load, a plant electrical system outage and consequent loss of production could be expected.

Dealing with Item (iv) requires surge protection and insulation coordination both in the user's plant and in the Transmission System, and must be addressed by both the user and Teck. Further discussion is beyond the scope of this document.

For Item (v), the starting inrush current of large motors, if not controlled, can cause excessive voltage flicker in the Transmission System and in the user's plant.

For Item (vi), the supply circuit will be interrupted, usually for a short duration. The effect of such an interruption is generally understood by users.

For Item (vii), the supply circuit will remain intact, but the plant supply voltage will dip to a certain magnitude for a short duration until the remote fault is cleared. The location and type of fault have an important impact on the severity of voltage dip on the user's plant. The majority of faults on the Transmission System are single-line-to-ground faults which can result in a wide range of voltage dips. Three-phase faults result in much more severe voltage dips than single-line-to-ground faults, but are relatively infrequent.

Modern industrial plants have a variety of equipment which are sensitive to these voltage sags. Some examples of voltage sensitive equipment include:

- motor starter contactors
- process controllers
- control relays
- programmable logic controllers
- AC and DC adjustable speed drives
- arc furnaces

Any or all of these devices could trip out due to a voltage dip and cause a shutdown in a specific process area of a user's plant. For example, motor starter contactors may drop out at a voltage of about 70% of rated voltage within 1 or 2 cycles. Modem process electronic power converters for AC Drives and programmable logic controllers could trip off-line at about 85% of rate voltage for dips as short as 1/2 cycle.

It is important, therefore, for a user to recognize that, in addition to supply service outages (Item (vi)), voltage sags can also cause plant shutdowns.

Some suggestions for minimizing the impact of system disturbances on plant operation are as follows:

- Meet with Teck to gain an understanding of the operation of their system in the area of the plant and to receive data from them regarding the estimated frequency and severity of the listed disturbances.
- For Items (i) to (iii) and Item (vi) of Section 3.3(f), evaluate the practicality of operating isolated from Teck, or increasing supply system redundancy versus accepting the inevitability of plant outages from time to time.
- For Item (vii), consider system and/or equipment design techniques which can help minimize the effect of system disturbances. Examples of design techniques to consider are:
  - *System Design*
    An important plant design consideration to reduce the magnitude of voltage disturbances is to include in the design an impedance "buffer" between the point of disturbance and the plant loads. This includes the appropriate selection of the plant system configuration, and equipment ratings and impedances, to provide the optimal "stiffness" required for the system. The use of in-plant generation to provide isolate operation for critical processes also merits special consideration.

  - *Ride-through Capabilities of Plant Equipment*
    The voltage-dip sensitivity of industrial plant control and drive equipment can vary greatly. Consideration should be given to equipment with the appropriate voltage dip, ride-through ability.

  - For loads which are essential to the plant processes, and where additional expenditure is justified, the following techniques could be considered:

    – For adjustable speed drives, adding voltage-dip ride-through options;

    – Using uninterruptible power supplies for low-power loads such as programmable logic controllers;

    – Install power conditioning equipment such as ferroresonant or constant voltage transformers for process controllers;

- Install time-delayed drop-out control circuits to permit motor starter contactors to ride through the required voltage dip duration;
- Install automatic transfer schemes to back up normal power sources.

The main contact for users in regards to system operating conditions will be the FortisBC System Control Centre (SCC) responsible for operating the portion of the system to which the user's plant is interconnected. The appropriate communication procedures and contact personnel will be provided in the Local Operating Order (LOO).

3.4 Sample Installations

a. **General**

Sections 3.4(b) through 3.4(d) illustrate the protection requirements for some specific sample installations. These sample installations are not meant to be an all-encompassing set which covers all installations. The examples do not include any generating facilities. If these were to be included, additional protection over and above that detailed in the examples would be required – see Section 3.2(b) "Local Generation" for more details. The connection to the Teck Transmission System generally takes one of three forms, as shown in Figs. 6, 7 and 8.

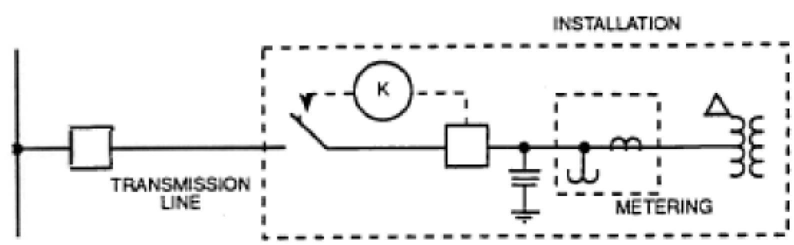


Fig. 6 - Radial Source Subsection 3.4.1

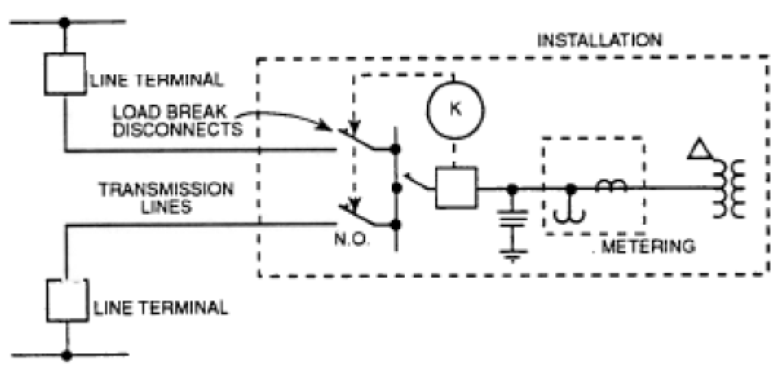


Fig. 7 - Dual Radial Source Subsection 3.4.1

For a supply connection via a dual radial system as depicted in Fig. 7, several considerations apply:

- The user's incoming protection shall coordinate with either supply source.
- Each of the two group-operated load break disconnects (L.B.D.) must be capable of being locked open, to prevent a tie between the two sources.

In special cases, permission may be granted to have these switches equipped with control equipment for automatic transfer from one source to the other. Such control equipment would remain under the jurisdiction of Teck and be subject to periodic testing.

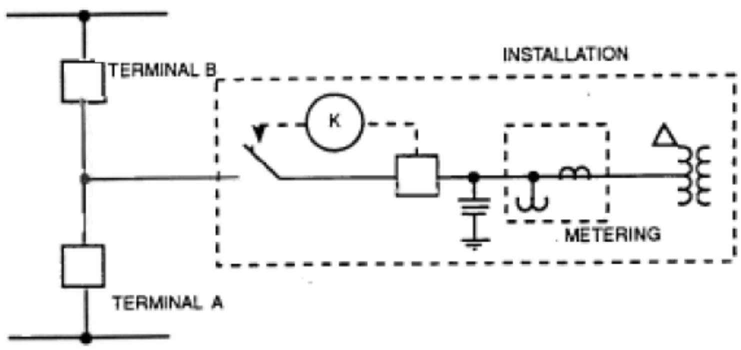


Fig. 8 - Tap Into Transmission Line Subsection 3.4.1

In the case of an installation tapped into a transmission line as shown in Fig. 8, the protection shall coordinate on a radial basis with either line terminal. This is interpreted to mean that the protection shall coordinate with terminal A relaying when the terminal B breaker is open, and coordinate with terminal B relaying when the terminal A breaker is open.

There may be particular protection requirements for each of the three connections shown, but invariably the type and form of protection at the source station(s) will have a more major impact on the installation's protection than the supply connection. In addition to the protection specified in the examples which follow, extra relays may be optionally installed for improved sensitivity. Optional relays include: overload (49), phase unbalance (46), gas detector (63).

b. **Primary Fused Installations**

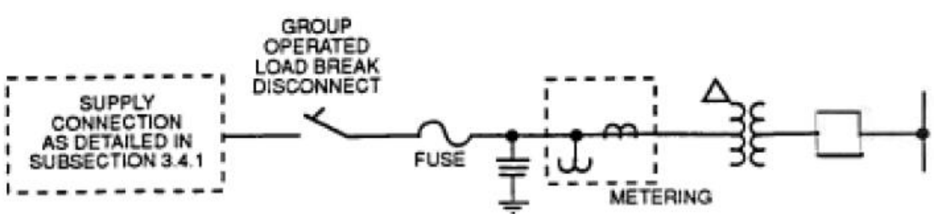


Fig. 9 - Primary Fused Installation Subsection 3.4.2

As noted in Section 3.1 "Equipment Requirements", fuses must have adequate interrupting capacity for the initial and ultimate fault levels specified by Teck. Maximum permissible current ratings of the fuses will be specified by Teck for proper coordination with protective equipment installed at the sources.

Typically, fuses for this application must coordinate with the source phase and ground overcurrent relays over the full range of fault levels specified by Teck. The coordination curves in Fig. 10 depict this.

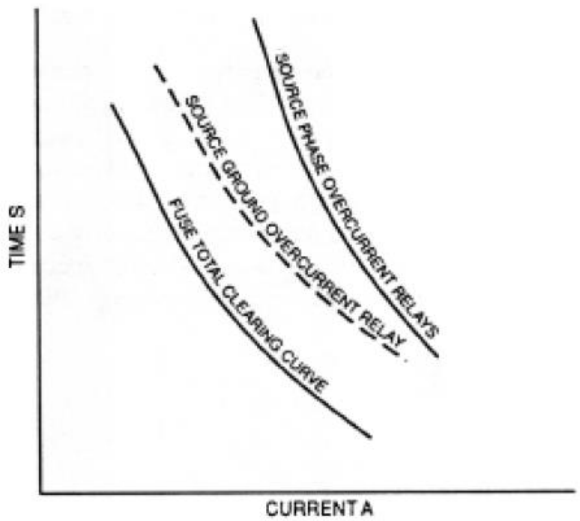


Fig. 10 - Coordination Curves Subsection 3.4.2

In some situations it may not be possible to apply primary fuses and assure coordination with Teck's relaying. This may be true for installations fed from radial/dual-radial sources, but is usually true when an installation is tapped into a transmission circuit, since these circuits are generally equipped with high speed protection. Where coordination is not possible, other alternatives must be considered- see Subsections 3.4© and 3.4(d) for examples.

c. **Primary Fused Installations with Circuit Switcher**

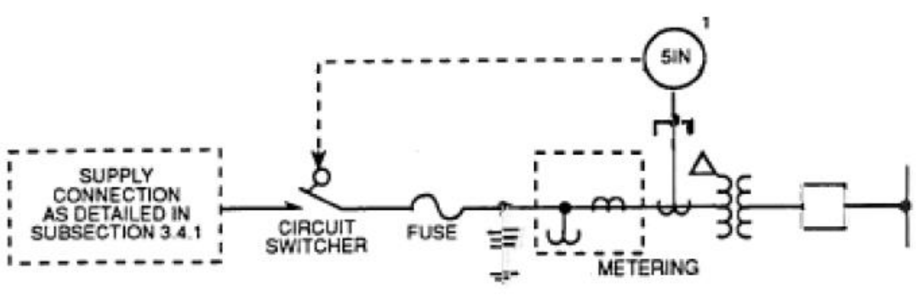


Fig. 11 - Primary Fused Installation With Circuit Switcher Subsection 3.4.3

As noted in Section 3.1 "Equipment Rating", fuses must have adequate interrupting capacity for the initial and ultimate fault levels specified by Teck. Maximum permissible current ratings of the fuses will be specified by Teck for proper coordination with the protective equipment installed at the sources.

Fuses for this application must coordinate with the source phase and ground overcurrent relays, with the exception of a range of low ground fault currents where tripping may be achieved by means of a circuit switcher and a ground overcurrent relay (51N). In this range the composite curve of the circuit switcher clearing and the fuse clearing must coordinate with the source ground overcurrent relay. In addition, the fuses must take over the interrupting duty for fault currents in excess of the circuit switcher's interrupting capability, achieved by proper coordination of the local ground relay and fuse time-current curves. These aspects are depicted in the coordination curves in Fig. 12.

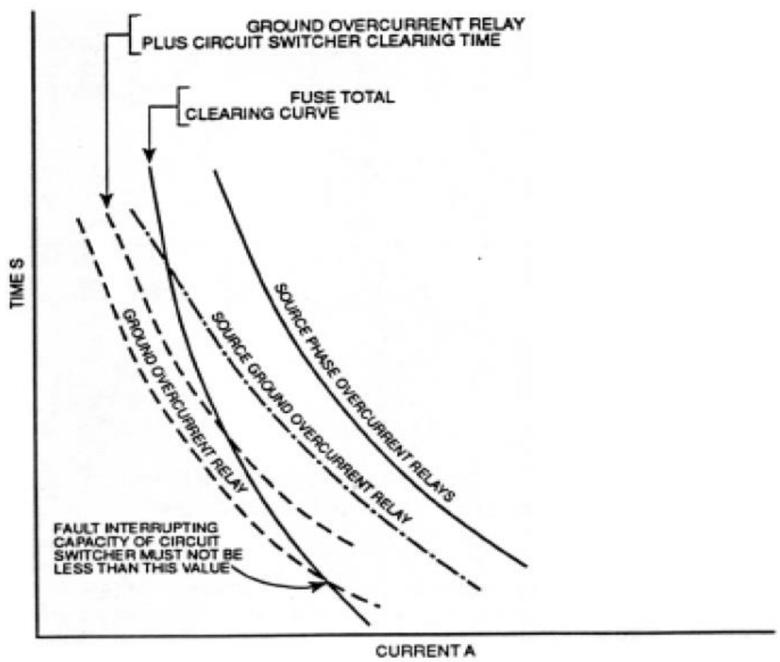


Fig. 12 - Coordination Curves Subsection 3.4.3

In some situations it may not be possible to apply a circuit switcher/fuse combination as the incoming protection and assure coordination. As indicated in Subsection 3.4.2 this may be particularly true when the installation is tapped into a transmission circuit equipped with high speed protection. In cases where coordination is not possible, it may be necessary to resort to an entrance circuit breaker with relay protection.

d. **Circuit Breaker With Protective Relaying**

A circuit switcher may be accepted as a substitute for a circuit breaker provided it is equipped with a shunt trip (maximum operate time 8 cycles) and provided the interrupting capability of the circuit switcher is adequate for the present and ultimate fault levels specified by Teck.

The relay types, ranges, and time characteristics will be subject to Teck approval in each individual case.

Minimum relay requirements for Example 1 are three phase overcurrent relays (51) and one ground overcurrent relay (51 N), all with inverse or very inverse characteristics. Their pickup and time settings shall be adjusted so that the composite relay and breaker time curves coordinate with the respective phase and ground relays at the source(s). The relays must be equipped with instantaneous trip elements to coordinate with Teck's existing and future requirements. Fig. 14 depicts the coordination curves for this sample installation.

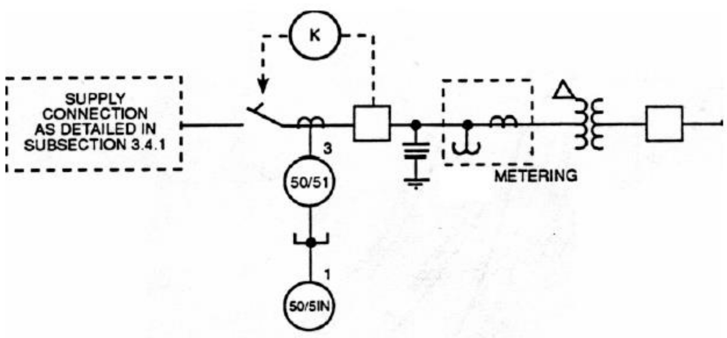


Fig. 13 - Protective Relaying With Circuit Breaker Subsection 3.4.4, Example 1

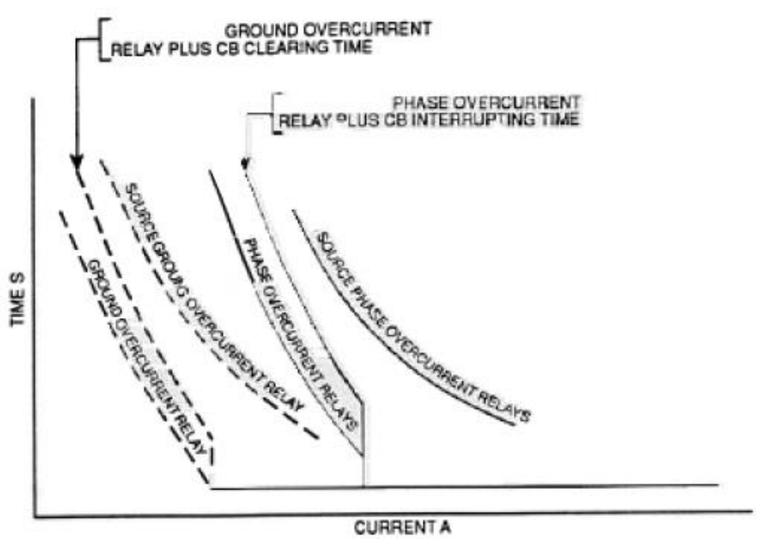


Fig. 14 - Coordination Curves Subsection 3.4.4, Example 1

Minimum relay requirements for Example 2 are three phase overcurrent (50/51) relays and one ground (50/51N) overcurrent relay of the inverse or very inverse type with instantaneous trip elements, selected and set so that they will coordinate with the respective phase and ground relays at the sources.

In fault current ranges where fully selective coordination is not possible, the local relays must trip their associated circuit breaker at the same time as the line terminal trips, in order to ensure that the installation has definitely been tripped off prior to automatic or supervisory reclosing of the line terminals. Fig. 16 depicts the coordination curves for this sample installation.

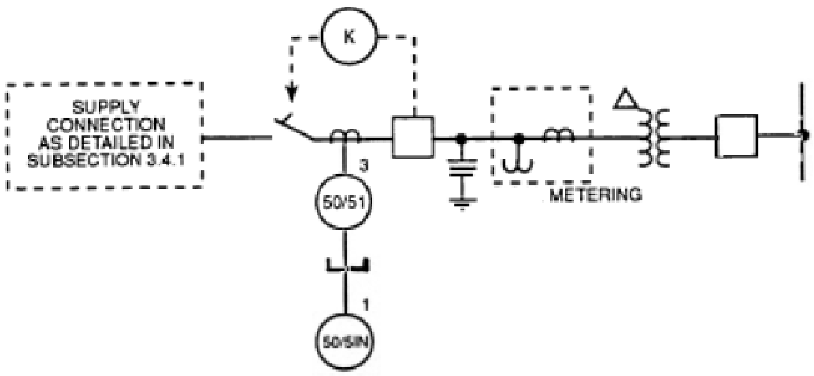


Fig. 15 - Protective Relaying With Circuit Breaker Subsection 3.4.4, Example 2

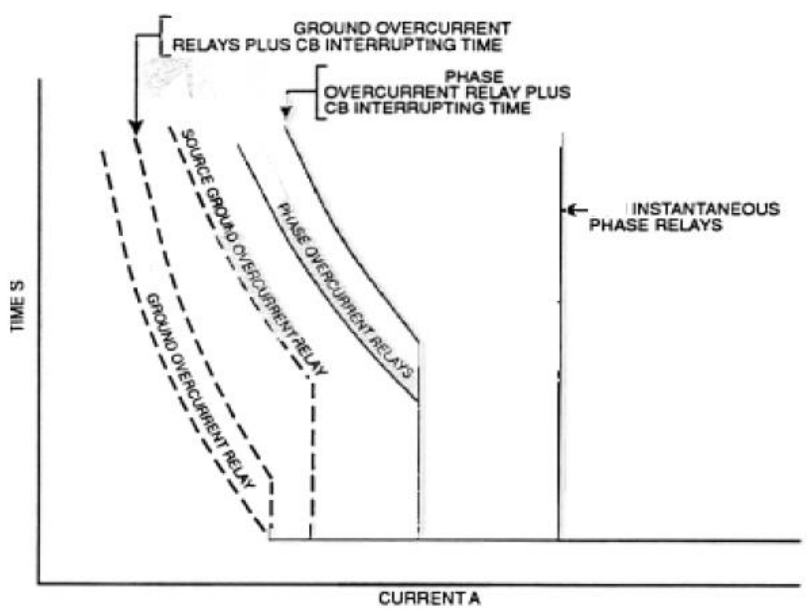


Fig. 16 - Coordination Curves Subsection 3.4.4, Example 2

In order to achieve coordination, settings of the local instantaneous phase elements may in certain cases have to be so low that some coordination within the installation may have to be sacrificed. If the degree of miscoordination is too great, another approach may be applicable. See Example 3 below.

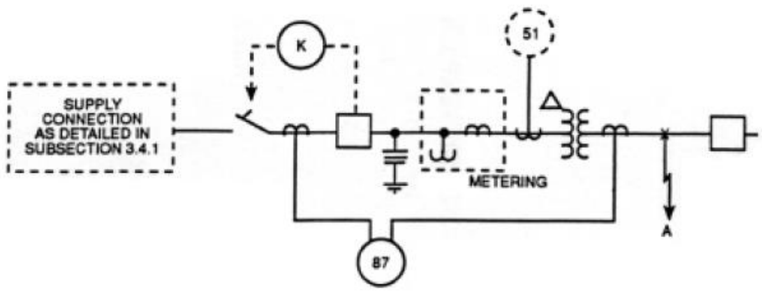


Fig. 17 - Protection Relaying with Circuit Breaker Subsection 3.4.4, Example 3

The minimum relay requirement for Example 3 consists of a transformer differential relay (87). In some instances Teck may require the optional phase overcurrent relays (51) if the upstream protection can detect faults on the secondary of the entrance transformer outside the differential zone; for example, a fault at location A (Fig. 17).

3.5 Testing and Maintenance

a. **General**

Prior to energization of any installation, Teck requires assurance that the main incoming protection is as per agreement between Teck and the user. This may involve Teck's verifying the calibration of the relays by electrical testing and testing of associated circuits and equipment, including tripping to the circuit breaker. Where feasible, it would also include on-load checks of the relays following energization of the installation. The settings applied to the relays will be as determined or approved by Teck.

For the installations involving generation infeeding to Teck's Transmission System, additional specific protection required to protect the Transmission System from unintended infeed will be subject to setting and testing as above.

Teck reserves the right to inspect and test the protection at any time and to request that the user perform any necessary maintenance. The user is responsible for maintenance of the protection and shall keep records thereof to be available to Teck on request. The user shall also keep current as-built drawings. It is recommended that this maintenance include calibration testing of the relay and trip testing to the circuit breaker at intervals of not more than 5 years.

A set of test switches are required for incoming protection to isolate current transformers, potential transformers and trip buses for ac injection tests. Relays with built in test switches are acceptable.

Planned outages for maintenance on equipment shall be coordinated with FortisBC's System Control Centers (SCC). Planned outages should not impair the safe and reliable operation of the Transmission System where at all possible.

b. **Underfrequency Load Shedding**
Teck reserves the right to inspect and test any installed underfrequency load shedding at any time and may do so at periodic intervals. The user will be requested to perform any maintenance that the testing shows to be necessary.

c. **Inspection, Test, Calibration and Maintenance**
Transmission elements (e.g. lines, line rights of way, transformers, circuit breakers, control and protection equipment, metering, and telecommunications) that are part of the Bulk Electric System and could affect the reliability of the Teck Transmission System need to be inspected and maintained in conformance with regional standards and Good Utility Practice. Each owner has full responsibility for the inspection, testing, calibration, and maintenance of their equipment, up to the location of change of ownership or POI as applicable. Transmission Maintenance and Inspection Plan (TMIP) requirements are a portion of the WECC Reliability Management System for Transmission. Each transmission asset owner or utility may be required by WECC to annually certify that it has developed, documented, and implemented an adequate TMIP.

4.0 Applicable Standards

The following list of standards is provided for reference only. It is the responsibility of the all users to comply with all applicable standards.

4.1 CSA Standards

- CSA C22.1, C22.2 and C22.3 – Canadian Electric Code Parts I, II & III.
- CSA C57-98 (Reaffirmed 2002) Electric Power Connectors for use in Overhead Line Conductors
- CSA C83-96(Reaffirmed 2000) Communication and Powerline Hardware
- CAN/CSA-C411.1-M89 (reaffirmed 2004) AC Suspension Insulators
- CAN/CSA-C411.4-98 (Reaffirmed 2003) Composite Suspension Insulators for Transmission Applications
- CAN/CSA-G12-92 (Reaffirmed 2002) Zinc-coated Steel Wire Strand
- CAN3-C108.3.1-M84 Limits and Measurement Methods of Electromagnetic Noise from AC Power Systems, 0.15 – 30MHz

4.2 IEEE Standards

- IEEE Std C37.1 – Standard Definition, Specification and Analysis of Systems Used for Supervisory Control, Data Acquisition and Automatic Control
- IEEE Std C37.2 – Standard Electrical Power System Device Function Numbers
- IEEE Std C37.122 – Standard Gas Insulated Substations
- IEEE Std. C50.12 – Salient Pole Synchronous Generators
- IEEE Std. C50.13 – Cylindrical-Rotor Synchronous Generators
- IEEE Std C57.116 – Guide for Transformers Directly Connected to Generators
- IEEE Std C62.92.5 – Guide for the Application of Neutral Grounding in Electrical Utility Systems ☐ IEEE Std 80 – Guide for Safety in AC Substation Grounding
- IEEE Std 81 – Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System
- IEEE Standard C95.6 – 2002 IEEE Standard for Safety Levels with respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz
- IEEE Std 100 – The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI)
- IEEE Std 122 – Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units
- IEEE Std 125 – Recommended Practice for Preparation of Equipment Specifications for Speed Governing of Hydraulic Turbines Intended to Drive Electric Generators
- IEEE Std 421-1 – Standard Definitions for Excitation Systems for Synchronous Machines
- IEEE Std 421-2 – Guide for the Identification, Testing and Evaluation of the Dynamic Performance of Excitation Control Systems
- IEEE Std 421-4 – Guide for the Preparation of Excitation System Specifications
- IEEE Std 519 – Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE Std 525 – Guide for the Design and Installation of Cable Systems in Substations
- IEEE Std 605 – Guide for Design of Substation Rigid-Bus Structures
- IEEE Std 979 – Guide for Substation Fire Protection

- IEEE Std 1127 – Guide for the Design, Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility

Teck

Appendix A – Guide & Requirements for Harmonic Control

Table of Contents

A1 - Introduction

A1.1 Scope

This document provides guidance and requirements on the limits of harmonic distortion that may be introduced into the Transmission System by installations taking supply at voltages from 60kV to 230kV.

A1.2 Definitions

- Point of common coupling (PCC): The point of common coupling is defined as the Teck point electrically nearest to the installation. This point is normally the primary bus of the installation's supply transformer.

- Individual harmonic distortion (IHD): The individual harmonic distortion value of a waveform is defined as the RMS value of a harmonic component expressed as a percentage of the RMS value of the fundamental frequency component. In the case of harmonic voltage distortion, the nominal operating voltage shall be used as the RMS value of the fundamental frequency component. In the case of harmonic current distortion, the maximum fundamental frequency load current under normal operating conditions shall be used as the RMS value of the fundamental frequency component.

- Total harmonic distortion (THD): The total harmonic distortion value of a waveform is the root-sum-square of individual harmonic distortion values, as defined in Equations (1.1) and (1.2). Teck requires that up to fortieth (40) harmonics shall be included in the THD calculation:

$$THD(voltage) = \frac{\sqrt{V_2^2+V_3^2+\cdots+V_{40}^2}}{V_{1(nominal)}} \tag{1.1}$$

$$THD(current) = \frac{\sqrt{I_2^2+I_3^2+\cdots+I_{40}^2}}{I_{1(maximum)}} \tag{1.2}$$

- Total harmonic current: Total harmonic current of a current waveform is defined as the root-sum-square of the RMS magnitudes of individual harmonic currents:

$$Total\ harmonic\ current = \sqrt{I_2^2 + I_3^2 + \cdots + I_{40}^2} \tag{1.3}$$

- Residual 1*T product: The residual I*T is the root-sum-square value of the zero sequence RMS harmonic currents multiplied by the TIF weighting factors. The values of TIF weighting factor can be found in reference [1] or [6].

- Noise Metallic (Nm): Noise metallic, which is also referred to as telephone circuit noise, is defined as a metallic voltage impressed between tip and ring of a telephone set and measured as a power level across a 60052 load. Nm is expressed mathematically as 10xlog (unit: dBrn) of the square of the difference between the tip-to-ground and the ring-to-ground voltages divided by the metallic circuit impedance. The metallic voltage is normally weighted with certain factors at different frequencies. This guideline uses C-message weighted voltage (dBrnC) [6].

- Noise to Ground (Ng): Noise to ground, which is a measurement of the influence of power system currents on a telephone circuit, is the average of tip-to-ground and ring-to-ground voltages measured as a power level across a 60052 load. Ng is expressed mathematically as l0xlog (dBrn) of the square of the average voltage divided by the reference impedance of 6001 This guideline uses C-message weighted average voltage (dBrnC) [6].

- Cable (longitudinal) Balance: Cable balance, which is a measurement of the susceptibility of a telephone cable, is the difference between noise to ground and noise metallic expressed in dBrnC [6].

- Background Voltage Harmonics: Background voltage harmonics are the harmonic voltages that exist at PCC when an installation is not connected to the supply system or is connected but not drawing load current from the supply system.

- Total Plant Load: Total plant load is the contract total plant MVA demand, without subtracting co-generation capacity if any, for normal plant operation.

- Harmonic Loads: Harmonic loads in a plant are those primary industrial loads that can cause more than 5% of total harmonic distortion in the load currents when supplied with a sinusoidal 60Hz voltage. In most cases, harmonic loads are DC drives, variable frequency AC drives, rectifiers, and possibly uninterruptible power supplies.

A1.3 References

This guideline makes reference to the following documents:

- IEEE Std.-519: "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", 1992.

- CSA-C22.2 No.0.16-M92: "Measurement of Harmonic Currents", 1992.

- CSA-C22.2 No.3: "Inductive Coordination", 1954 and No.3.1: "Inductive Coordination Handbook", 1974. (This standard is currently under revision.)
- CIGRE JTF 36.05.01/14.03.01 Report: "Connection of Harmonic Producing Installations in High-Voltage Networks with Particular Reference to HVDC", 1991.
- UK Engineering Recommendation G.5/3: "Limits for Harmonics in the United Kingdom Electricity Supply System", 1976.
- CEA&TCEC Joint Report: "Electrical Coordination Guide", 1989.

A2 – General Procedure

This guideline deals with harmonic-producing installations in categories, according to the size of an installation and the capacity of its supply system.

Category I (small) installations can be accepted by Teck without performing detailed harmonic analysis. If any category 1 installation causes harmonic problems, Teck is entitled to apply harmonic design and measurement limits to the installation.

Category II (large) installations are required to perform and submit for Teck's inspection a harmonic study. The study shall demonstrate that Teck's harmonic design limits are met.

At Teck's sole discretion, certain installations are required to demonstrate, through field measurements, that their installations comply with Teck's harmonic measurement limits during the plant commissioning stage and/or normal operation.

A2.1 Criteria for Category I Installation

An installation is considered as Category I if:

a. The ratio of total harmonic load MVA in the plant with respect to the total plant load MVA, in percentage, is below the curves shown Figure B.1. The total harmonic load MVA shall be estimated according to the following formula:

$$\begin{aligned} &Total\ harmonic\ load\ MVA = \\ &\quad 0.85 * (total\ MVA\ of\ harmonic\ loads\ configured\ in\ more\ than\ 6\ pulses) + \\ &\quad 1.00 * (total\ MVA\ of\ other\ harmonic\ loads\ in\ the\ plant) \end{aligned} \tag{2.1}$$

b. The installation's capacitors should not cause harmonic resonances, namely the following condition is satisfied for every harmonic number h:

$$|h_{resonance} - h| > \begin{matrix} 0.35 & h - 5,7,11,13,17,\dots \\ 0.10 & h - 2,4,6,8,10,\dots \\ 0.15 & h - 3,9,15,21,27,\dots \end{matrix} \qquad (2.2)$$

In the above equation, h resonance is the (parallel) resonance frequency in multiples of 60Hz. This frequency is normally obtained by a frequency scan analysis of the plant. This equation needs to be check only for the two harmonics adjacent to h resonance. If there is only one capacitor location in the plant, the frequency may be estimated according to Equation (2.3):

$$h_{resonance} = \sqrt{\frac{MVA_{sys}}{MVA_{cap}}} \qquad (2.3)$$

where MVA_{sys}, is the system fault MVA seen at the capacitor bus. This MVA shall include the contribution of non-harmonic-producing loads such as motors in the plant. MVA_{cap}, is the installed capacitor MVA calculated at normal operating voltage. It shall be noted that both MVA_{sys}, and MVA_{cap} may vary with the operating conditions of the supply system and the plant. The limits of Equation (2.3) shall be satisfied for all conditions.

A2.2 Criteria for Category II Installation

Any installations not belonging to category I are considered as category II. These installations shall satisfy Teck that the harmonic design and/or measurement limits as specified in Sections 3 and 4 are complied with.

A2.3 Engineering Information Required

Installations in either category shall trigger a requirement to provide to Teck the following data:

a. Single-line diagram of the installation.
b. All non-harmonic-producing industrial loads (for most installations this means the load with demand greater than 500 kW).
c. All harmonic producing industrial loads (demand greater than 500 kW for most installations) and their harmonic spectrums.
d. Supply transformers and other transformers for primary industrial application purpose. Distribution cables and lines that cannot be neglected for harmonic analysis. Power factor correction capacitors and harmonic filters, if any.
e. A harmonic assessment report based on the above information. For category 1 installation, the report shall demonstrate that the installation can be considered as category 1. For category II installation, the report shall demonstrate that the Teck harmonic design and/or measurement limits are satisfied.

A2.4 Examples

Example 1

The total plant load is 100MVA
Utility supply is at 230kV
The system fault level at PCC is 5000MVA
=> Therefore, ratio of system fault MVA to demand MVA is 50 (=5000/100).
Harmonic-producing loads in the plant areas as follows:

6.0 MVA 12-pulse DC drives
5.0 MVA other harmonic load

Total harmonic load is then 10.1 MVA (=1.00*5.00+0.85*6.00), as per Eq. (2.1)
=> Therefore, percentage total harmonic load is 10.1% (=10.1/100)

Conclusion: As per Figure B.1, point (50, 10.1%) falls above the 230kV curve. The installation is a category II type.

Example 2

The total plant load is 30MVA
Utility supply is at 69kV
The system fault level at PCC is 1700MVA
=> Therefore ratio of system fault MVA to demand MVA is 57 (=1700/30).
Harmonic-producing loads in the plant are as follows:

2.0 MVA 12-pulse adjustable speed drives
3.2 MVA other harmonic loads, including a 2MVA 6-pulse DC drive

Total harmonic load is then 4.9MVA (=1.00*3.2+0.85*2.0), as per Eq. (2.1)
=>Therefore, percentage total harmonic load is 16.3% (=4.9/30)
As per Figure B.1, point (57, 16.3%) falls below the 69kV curve. The installation passes harmonic chart requirement. Harmonic resonance check is followed.

The plant capacitor banks, installed in one location, are 1.2MVar
The fault level at the capacitor bus is 150MVA
=> Therefore, $h_{resonance}$ is 11.18 ($= \sqrt{150/1.2}$)

$$|h_{resonance} - h| = \begin{matrix} 0.18 < 0.35\ for\ h = 11 => not\ okay \\ 0.82 > 0.10\ for\ h = 12 => okay \end{matrix}$$

Conclusion: Although satisfying the harmonic chart requirement, the plant fails the harmonic resonance check. The installation is a category II type.

Example 3

The total plant load is 30MVA
Utility supply is at 69kV
The system fault level at PCC is 1700MVA
=> Therefore, ratio of system fault MVA to demand MVA is 57 (=1700/30).
Harmonic-producing loads in the plant are as follows:

2.0 MVA 12-pulse adjustable speed drives
3.2 MVA other harmonic loads, including a 2MVA 6-pulse DC drive

Total harmonic load is then 4.9MVA (=1.00*3.2+0.85*2.0), as per Eq. (2.1)
=> Therefore, percentage total harmonic load is 16.3% (=4.9/30)
=> As per Figure B.1, point (57, 16.3%) falls below the 69kV curve. The installation passes harmonic chart requirement. Harmonic resonance check is followed.

The plant capacitor banks, installed in one location, are 2.1 Mvar
The fault level at the capacitor bus is 190MVA
=> Therefore $h_{resonance}$ is 9.51 ($= \sqrt{190/2.1}$)

$$|h_{resonance} - h| = \begin{array}{l} 0.51 > 0.15 \; for\; h = 9 => okay \\ 0.49 > 0.10 \; for\; h = 10 => okay \end{array}$$

Conclusion: The installation meets the requirements of the harmonic chart as well as the harmonic resonance check. The installation is a category I type.

A3 – Harmonic Limits For Design Purposes

A3.1 General

At the plant design stage, the calculated current and voltage distortions at the point of common coupling shall not exceed the design limits. Worst case normal operating conditions shall be used in the calculation of harmonic distortions. For installations with transformer arrangements that result in zero sequence current injections into the Transmission System, the amount of zero sequence harmonic current injections must be calculated. For those installations whose loads are unbalanced among three phases and can result in a voltage unbalance (voltage unbalance is defined as the ratio of negative sequence voltage to the positive sequence voltage) greater than 1.5% at PCC, three-phase harmonic analysis is required.

A3.2 Harmonic Current Limits

Limits for harmonic current distortion are shown in Tables 3.1A, 3.1B and 3.1C. These limits apply to each phase current individually at the point of common coupling. Harmonic current distortion shall be calculated using two sets of system impedance data:

a. The supply system harmonic impedance as seen from the point of common coupling is zero at all harmonic frequencies. This assumption is needed since the system harmonic impedance can be zero at any frequency due to resonances in the Transmission System. Using zero harmonic impedance also ensures that the plants contain their own harmonic currents and the harmonic currents escaping into the Transmission System are minimized.

b. The supply system harmonic impedances are the same as those provided by Teck. The purpose is to determine if there is any excessive harmonic current injection into the Transmission System caused by the harmonic resonance between the system impedance and the local capacitor banks.

It must be noted that the limits shown in Tables 3.1 apply only to the harmonic currents introduced by specific installations. A zero background harmonic distortion shall be assumed in the calculation therefore. The results are the harmonic currents exclusively due to specific installations. Since problems may be caused by the amount of harmonic current injections into supply systems irrespective to the magnitude of fundamental frequency current at the PCC, this guide also imposes ampere limits on the total harmonic current injection. For most installations, satisfying the percentage harmonic current limits generally results in the satisfaction of the ampere limits.

Table 3.1A: Harmonic Current Distortion Limits (69 kV)

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	THD
≤20	4.0	2.0	1.5	0.6	0.3	5.0
(20 50]	7.0	3.5	2.5	1.0	0.5	8.0
(50 100]	10.0	4.5	4.0	1.5	0.7	12.0
(100 1000]	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Limits for total harmonic current: 20 A						
Note:	1. Even harmonics are limited to 25% of the IHD limits above. 2. Triple order harmonics are limited to 35% of the IHD limits above.					
Where	I_{SC} = Maximum system short circuit current at PCC I_L = Maximum fundamental frequency total load current at PCC h = Harmonic order					

Table 3.1B: Harmonic Current Distortion Limits (138 kV)

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	THD
≤20	2.0	1.0	0.75	0.3	0.15	2.5
(20 50]	3.5	1.75	1.25	0.5	0.25	4.0
(50 100]	5.0	2.25	2.0	0.75	0.35	6.0
(100 1000]	6.0	2.75	2.5	1.0	0.5	7.5

>1000	7.5	3.5	3.0	1.25	0.7	10.0
Limits for total harmonic current: 10 A						
Note:	3. Even harmonics are limited to 25% of the IHD limits above. 4. Triple order harmonics are limited to 35% of the IHD limits above.					
Where	I_{SC} = Maximum system short circuit current at PCC I_L = Maximum fundamental frequency total load current at PCC h = Harmonic order					

Table 3.1C: Harmonic Current Distortion Limits (above 138 kV)

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	THD
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75
Limits for total harmonic current: 6 A						
Note:	5. Even harmonics are limited to 25% of the IHD limits above. 6. Triple order harmonics are limited to 35% of the IHD limits above.					
Where	I_{SC} = Maximum system short circuit current at PCC I_L = Maximum fundamental frequency total load current at PCC h = Harmonic order					

A3.3 Harmonic Voltage Limits

Limits for harmonic voltage distortion at the point of common coupling are listed in Table 3.2. Reducing harmonic voltage distortion is a shared responsibility. A first-come-fast-served policy is adopted in this guide. While Teck is responsible to maintain the voltage distortion within the limits of Table 3.2, an installation is limited to add certain harmonic voltage distortion at the PCC such that the combined voltage harmonics of background and installation contribution is within the limits of Table 3.2:

$$IHD_{customer} + IHD_{background} \leq IHD\ Limits \tag{3.1}$$

$$\sqrt{\sum_{h=2}^{h=40} (IHD_{h-customer} + IHD_{h-backgroun})^2} \leq THD\ Limits$$

The harmonic voltage limits apply to each phase voltage individually at the point of common coupling. The supply system harmonic impedance data provided by Teck shall be used to determine the harmonic voltage distortions caused by the individual plants.

Table 3.2: Harmonic Voltage Distortion Limits

PCC Voltage	Voltage IHD (%)	Voltage THD (%)
69 kV	3.0	5.0
138 kV	1.5	2.5
230 kV and above	1.0	1.5

A3.4 Engineering Information Provided by Teck

Teck will provide, within its own reasonable expense, the necessary engineering information for harmonic analysis. If the information is considered to be critical to the equipment design, Teck can supply more accurate technical data, at the requestor’s expense, based on dedicated field measurements or harmonic studies on Transmission System. The engineering information provided by Teck includes:

a. System fault level for harmonic studies: It is the fault level calculated for the normal system operating conditions. The fault level may not be the same as those used to determine the breaker rating and protection setting of the plant. Teck will specify what fault levels shall be used for harmonic analysis.

b. Supply system harmonic impedance: This information may be determined from field measurements and/or computer simulations by Teck. It shall include various operating conditions, network configurations and future system expansions. Depending on the location and size of the plant, the harmonic impedance may take different forms:
   - Impedances calculated from several system fault levels.
   - A curve of system impedance as a function of frequency.
   - A family of impedance-frequency curves.
   - A range of harmonic impedances at each harmonic frequency.

c. Background harmonic voltage distortion: This information will be supplied in the form of harmonic voltage spectrums (magnitude). The data may be estimated according to Teck's power quality survey data bank, measured at the point of common coupling, or calculated from harmonic analysis.

d. Supply voltage unbalance: A voltage unbalance is defined as the ratio of negative sequence voltage with respect to the positive sequence voltage. Since the generation of harmonic currents is very sensitive to the supply voltage unbalance, the effects of voltage unbalance must be considered in harmonic studies. For those installations with balanced three-phase loads, this means that the harmonic current spectrums representing the harmonic-producing loads must be determined assuming that there exists a 2% unbalance at the supply voltage. Under such a condition, a twelve-pulse DC drive is expected to produce 5th and 7th harmonic currents. As long as the harmonic source spectrums are modified to take into account the unbalance effects, harmonic analysis with a single-phase network representation is acceptable. For those plants with unbalanced three-phase loads (see Section 3.1 for the criteria) three-phase harmonic analysis is required. A voltage unbalance of 1.5% at the PCC shall be used in the study.

A3.5 Other Considerations

a. *Telephone interference due to harmonics*

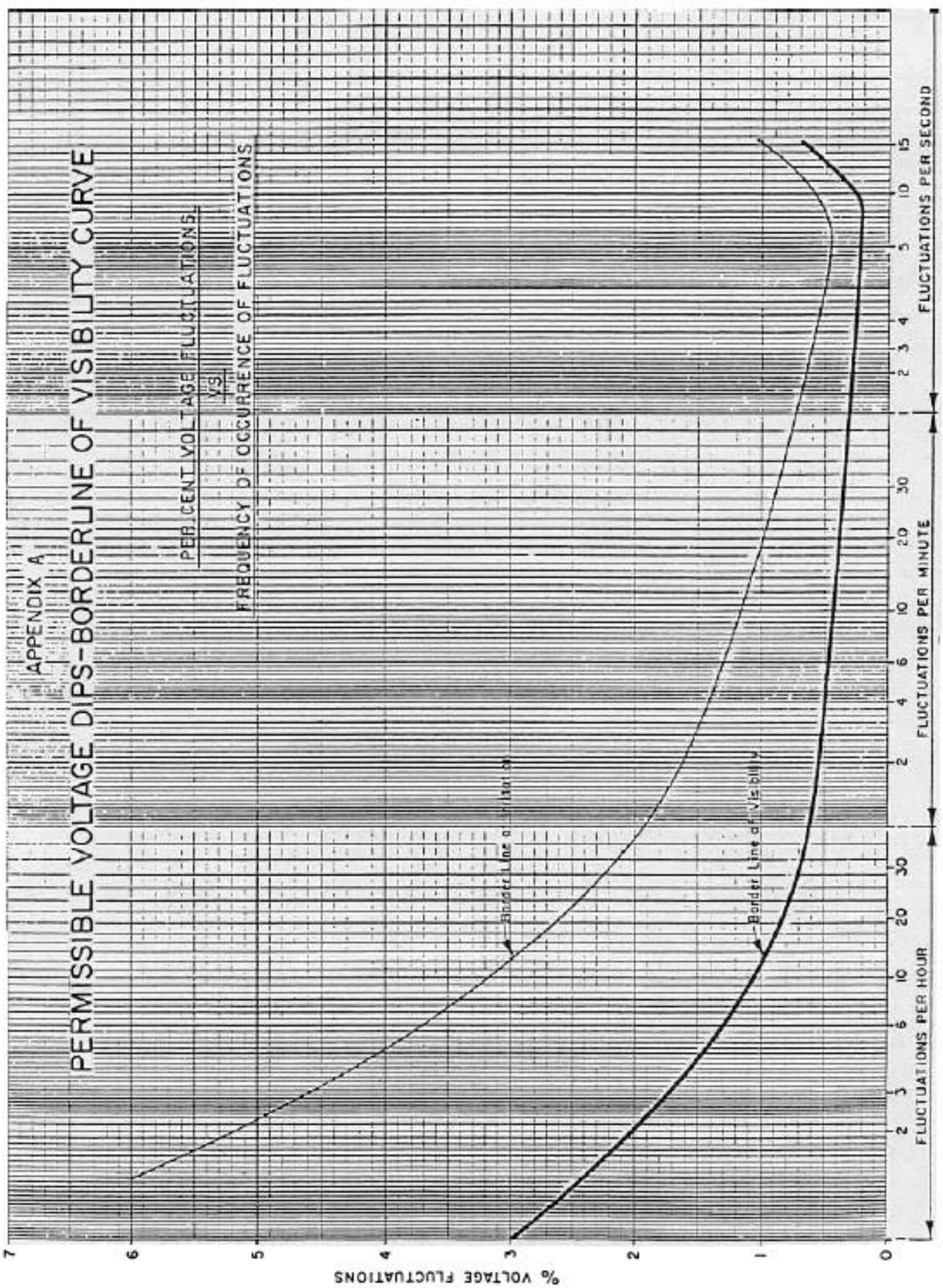
This guideline imposes no specific design limits on the calculated I*T values. This is because that the telephone interference is, in the majority of cases, caused by residual (zero sequence) harmonic currents. For those installations where the supply transformers are connected with primary in delta or ungrounded-star form, the calculated residual current flowing into the Transmission System is always zero, and therefore, no direct telephone interference is expected. It shall be noted, however, that indirect harmonic-telephone interference is still possible. These interferences may be caused by the interaction of non-residual harmonic currents with the equipment of the supply system. Since the indirect interference is impossible to predict in most cases, the philosophy adopted in this guideline is to limit the total harmonic current in ampere value and the triple order harmonic current distortion, in addition to the IEEE limitations on IHD and THD.

For those installations supplied by transformers with grounded-star primary, three-phase harmonic and telephone interference studies are recommended. These studies can reduce the likelihood of the installation violating Teck's telephone interference measurement limits specified in Section 4. As an approximate guide, the limit on calculated residual I·T product can be determined according to Equation (3.2). More accurate methods to assess the interference are described in [6].

$$Maximum\ Residual\ I \cdot T\ (A) < \frac{1450\ (A{\cdot}km)}{Length\ of\ parallel\ exposure\ (km)} \tag{3.2}$$

b. *Effects of background harmonics on local capacitors*

While trying to meet Teck's harmonic limits at the point of common coupling, it should also be kept in mind that local capacitors may become a sink for the harmonic currents outside the local plant. This problem is normally caused by the parallel resonance between the capacitors and the system impedance (including the supply transformer impedance). Adherence to Equation (2.2) of Section 2.1 may reduce the likelihood of resonance and capacitor overload. But detailed harmonic and capacitor sizing studies are recommended.


APPENDIX A
PERMISSIBLE VOLTAGE DIPS-BORDERLINE OF VISIBILITY CURVE
PER CENT VOLTAGE FLUCTUATIONS
VS
FREQUENCY OF OCCURRENCE OF FLUCTUATIONS
Border Line of Irritation
Border Line of Visibility
FLUCTUATIONS PER HOUR
FLUCTUATIONS PER MINUTE
FLUCTUATIONS PER SECOND
% VOLTAGE FLUCTUATIONS

A4 - Harmonic Limits For Measurement Purposes

A4.1 General

Either Teck or another party can be responsible to perform harmonic measurement tests, depending on the purpose of the tests. Harmonic tests and limit checks shall be conducted during the normal plant operating cycles. Conditions that require harmonic measurements may include:

a. Harmonic problems are reported;
b. New plant is commissioned; and
c. Major system changes, either in the Transmission System or in connected plants, are implemented.

A4.2 Limits on Current and Voltage Distortions

The limits for measured harmonics are based on the design harmonic limits. However, factors such as time-varying nature of harmonics and plant startup conditions are taken into account. In other words, short time bursts of harmonic distortions higher than the design limits are generally acceptable. Two indices shall be used to measure the degree of harmonic bursts:

a. Maximum Duration of Harmonic Burst (Tmaximum): This is the maximum time interval in which the harmonic distortion exceeds a particular IHD or THD level during a 24 hour measurement period.
b. Total Duration of Harmonic Burst (Ttotal): This is the summation of all the time intervals in which the harmonic distortion exceeds a particular Q-ID or THD level during a 24 hour measurement period.

The 24 hour measurement period shall be established on a calendar day basis. Teck requires that, for 95% of the measurements (namely, 95 days out of 100 days), the measured IHD and THD levels must be limited according to the maximum and the total durations of harmonic burst $T_{maximum}$ and T_{total}, as shown in Table 4.1 and Figure 4.1.

A4.3 Limits on Telephone Interference

Telephone interference due to harmonics is a complex problem that involves three major factors: the existence of source of influence, the coupling between the source and telephone cable, and the susceptibility of telephone equipment. I*T product only addresses the problem of source of influence and therefore is incomplete. On the other hand, the complexity of the problem makes it impossible to accurately calculate the interference level with all three factors included. As a result, this guideline relies on measurements to check compliance.

The telephone interference measurement will be performed on any telephone set vulnerable to the plant harmonics. Two values, the noise to ground (Ng) and the noise metallic (Nm) will be measured. Teck requires that, subject to cable balance

(Ng-Nm) greater than 60.0 dBmC, the noise to ground level shall be lower than 80.0 dBrnC.

A4.4 Instrumentation Requirements

Instruments, which may include PT's and CT's, used for harmonic distortion and telephone interference measurements must be certified by Teck. If there is any dispute over the accuracy of an instrument, CSA standard C22.2 [2, 3] shall be used to resolve the dispute.

Table 4.1: Limits for Measured Harmonic Distortions

Maximum Duration of Harmonic Burst ($T_{maximum}$)	Acceptable Harmonic Distortion Level THD and IHD
1 sec. < $T_{maximum}$ ≤ 5 sec.	3.0*(design limits)
5 sec. < $T_{maximum}$ ≤ 10 min.	2.0*(design limits)
10 min. < $T_{maximum}$ ≤ 30 min.	1.5*(design limits)
30 min. < $T_{maximum}$	1.0*(design limits)
Total Duration of Harmonic Burst (T_{total})	**Acceptable Harmonic Distortion Level THD and IHD**
15 sec. < T_{total} ≤ 60 sec.	3.0*(design limits)
60 sec. < T_{total} ≤ 40 min.	2.0*(design limits)
40 min. < T_{total} ≤ 120 min.	1.5*(design limits)
120 min. < T_{total}	1.0*(design limits)

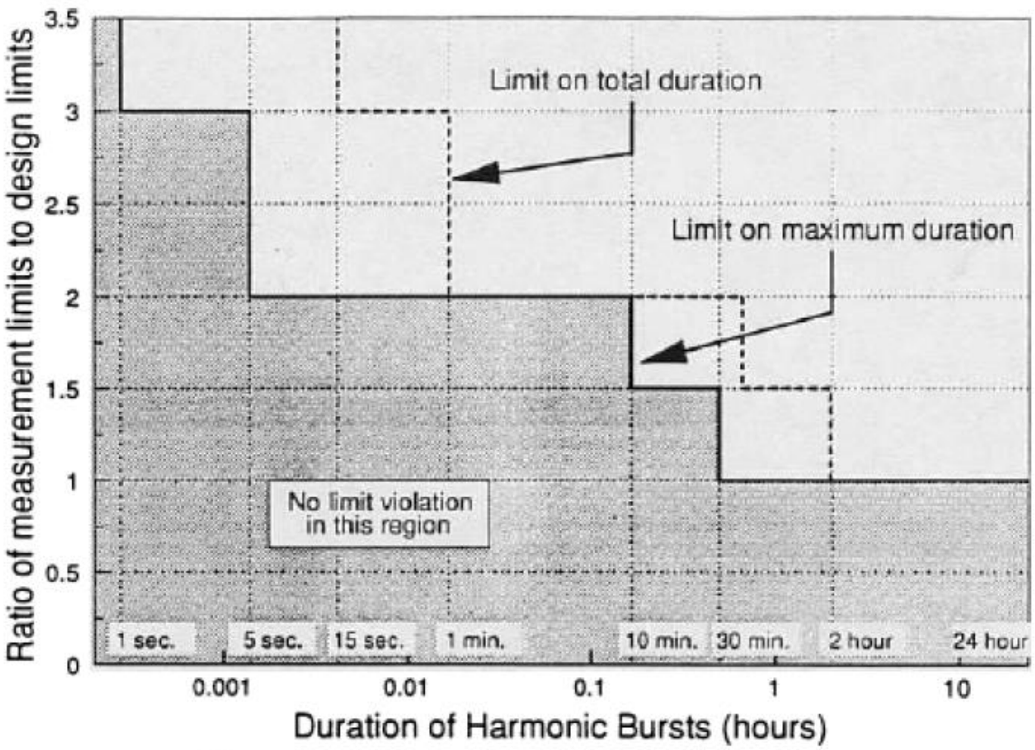


Figure 4.1: limits on measured harmonics.

A5 - Responsibilities For Mitigation Of Harmonic Problems

Adherence to the recommended limits of this guideline should reduce the risks of damage to, or malfunctioning of equipment. But there is no guarantee that this can completely prevent trouble from arising.

A5.1 Harmonic Limits Exceeded

Teck endeavours to provide that the background harmonic voltage distortion at the point of common coupling is within the voltage distortion limits jointly specified in Table 3.1 and Table 4.1.

Each installation is responsible to ensure that its portion of harmonic current distortion at the point of common coupling is always within Teck's harmonic current distortion limits.

Each installation is responsible to reduce the harmonic voltage distortion at the point of common coupling to Teck's voltage distortion limits.

Telephone interference limits shall be complied with only if there is a harmonic-caused telephone interference problem. Subject to (1) noise to ground level greater than 80.0 dBrnC and telephone cable balance greater than 60.0 dBrnC or (2) noise to ground level greater than 90.0 dBrnc, the installation is responsible to mitigate the telephone interference problem.

A5.2 Harmonic Limits not Exceeded

Problems caused by harmonics may arise even if harmonic limits are not violated. Under these circumstances, all involved parties may be responsible to mitigate the problems. Exact sharing of responsibilities shall be determined on case by case basis.

A5.3 Determination of Limit Violation

Teck is responsible to demonstrate the violation of harmonic voltage and current limits and identify the installation that causes harmonic problem. The telephone companies, with Teck's cooperation, are responsible to demonstrate the violation of telephone interference limits and identify the installation that causes the interference problem.

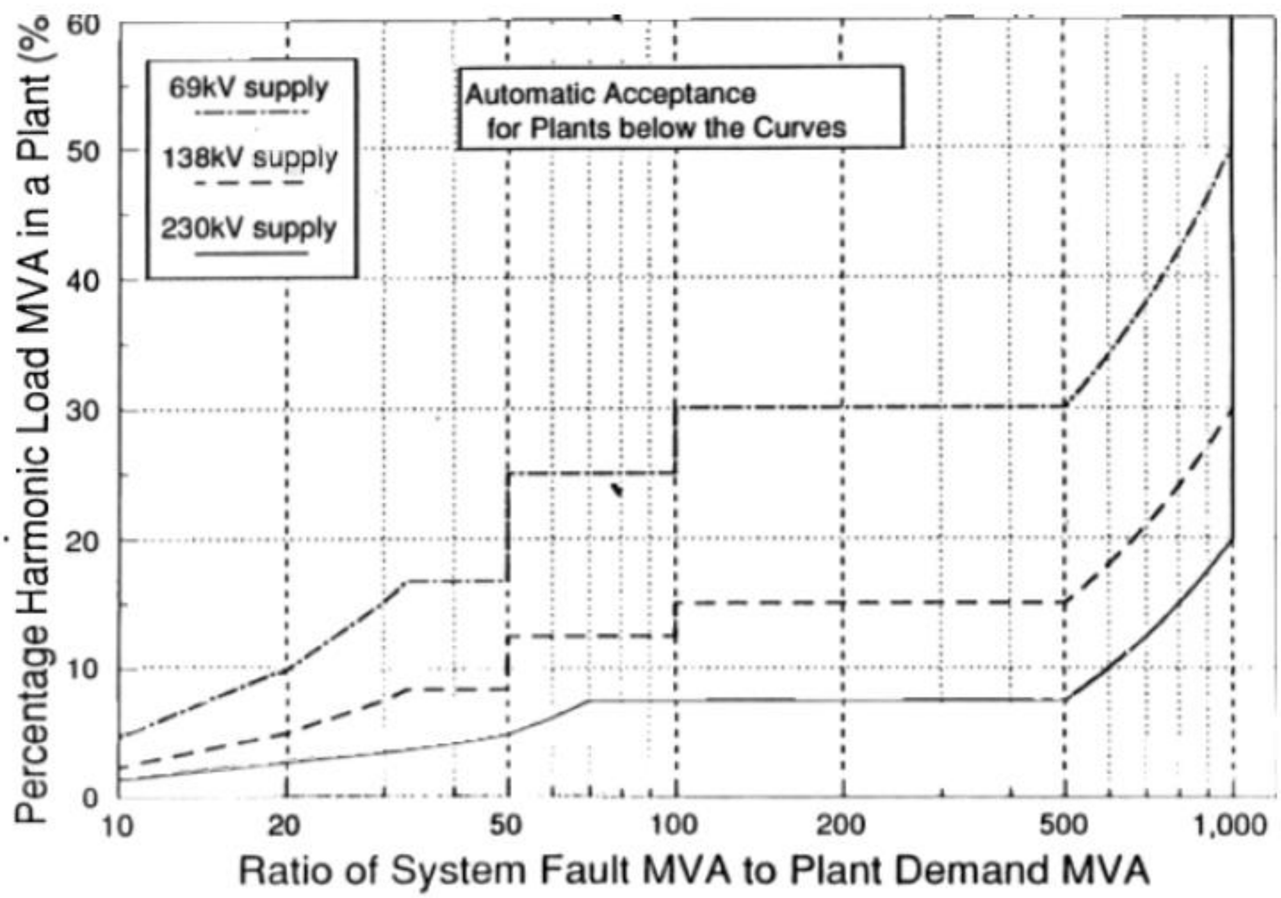


Figure B.1: Criteria for Category I Installation.