Information Document
Transmission Protection Relay Loadability
ID #2012-004RS

Information Documents are not authoritative. Information Documents are for information purposes only and are intended to provide guidance. In the event of any discrepancy between an Information Document and any Authoritative Document(s)[1] in effect, the Authoritative Document(s) governs.

1 Purpose

This Information Document relates to the following Authoritative Document:

- Alberta Reliability Standard PRC-023-AB-2, Transmission Relay Loadability ("PRC-023-AB-2").

The purpose of this Information Document is to provide a link to the list of circuits that the Alberta Electric System Operator ("AESO") must maintain pursuant to requirement R6 of PRC-023-AB-2 and to provide additional information to assist market participants who are the legal owner of a transmission facility, a generating unit or an aggregated generating facility ("the legal owner") with load-responsive phase protection systems, to meet the requirements of PRC-023-AB-2.

2 List of Circuits

The list of circuits that the AESO must maintain pursuant to requirement R6 of PRC-023-AB-2 is available on the AESO website. All submissions to the AESO can be made to ARSsubmittals@aeso.ca.

3 Background and Scope

The Measures section of PRC-023-AB-2, describes in general terms the type of information to be provided by legal owners to demonstrate that requirements R1.1 through R1.14 have been met. This Information Document is to provide additional description and illustrative examples of the information to be provided.

This Information Document is intended to be complimentary to the North America Electric Reliability Corporation document entitled *Determination of Practical Transmission Relaying Loadability Settings, NERC, December, 2017, (the "PRC-023 NERC ID")* which provides clarification regarding the application of NERC reliability standard PRC-023, *Transmission Relay Loadability*. The AESO generally agrees with the information contained within the *PRC-023 NERC ID* and the AESO recognizes that both the *PRC-023 NERC ID* and this Information Document may be useful references for market participants as they implement PRC-023-AB. In addition, the AESO may use the information contained within these documents as reference material in assessing compliance with PRC-023-AB where it determines that the guidance information is applicable.

The NERC document entitled *"Considerations for Power Plant and Transmission System Protection Coordination – Technical Reference Document* – Revision 2", July 2015 provides background information applicable to this Information Document.

As described in requirement R1, the legal owner must use one of the criteria set out in requirements R1.1 through R1.14 inclusive, to meet the requirements of PRC-023-AB-2 for a particular facility. This Information Document only describes additional guidance information for requirement R1.1 regarding transmission line relays. This Information Document does not include guidance for the other requirements of R1.

4 Clarification of Evidence

Requirement R1 sets out criteria for each specific circuit terminal to prevent its phase protective relay settings from limiting transmission system loadability while maintaining reliable protection of the bulk

[1] "Authoritative Documents" is the general name given by the AESO to categories of documents made by the AESO under the authority of the *Electric Utilities Act* and associated regulations, and that contain binding legal requirements for either market participants or the AESO, or both. AESO Authoritative Documents include: the ISO rules, the Alberta reliability standards, and the ISO tariff.

electric system for all fault conditions.

To effectively comply with the requirements of PRC-023-AB, it is only necessary to provide evidence that the protection relays settings do not limit transmission loadability. PRC-023-AB does not require evidence that the protection relays reliably detect all fault conditions and protect the electrical network from these faults.

5 Clarification of Requirements

Requirement R1 states the requirement to evaluate the phase protection relays' loadability at 0.85 per unit voltage. When the voltage on a bus is reduced to 0.85 per unit voltage and 0.85 per unit voltage is measured by an associated impedance protection function, for a given protection relay impedance setting and a fixed line current rating, the impedance function is more likely to falsely trip than when the voltage is 1.00 per unit voltage. The application of this voltage effect is shown within *PRC-023 NERC ID*, requirement R1.1, page 6. This effect is further explained in this Information Document in Section 7 - Background Concepts. Given the requirement to "evaluate the phase protective relay's loadability at zero point eight five (0.85) per unit voltage", the added sensitivity of impedance functions to the 0.85 per unit voltage must be evaluated and included in the evidence submitted to the ISO.

Requirement R1.1 refers to "the highest seasonal facility rating of a circuit". Usually, in Alberta, the highest seasonal rating is the winter rating. Emergency ratings are applicable to R1.2.

Regarding requirements R1.3, R1.4, R1.5, R1.7, R1.8, and R1.9, refer to the *PRC-023 NERC ID* for a description of the calculation method and typical single line diagrams illustrating the applicability of each requirement.

Requirement R1.13 only applies to line protection relays that do not include a load encroachment function.

If a line protection relay includes a load encroachment function, it may be used to meet the line loadability requirement in a manner described by the protection relay manufacturer, while determining the protection relay's loadability at 0.85 per unit voltage and a load angle of 30°, as described in requirement R1. If the use of the load encroachment feature is not the limiting factor that determines the line loadability, then the evidence for this usage is only needed upon initial energization, when the line electrical properties are changed, or when the protection relay settings are changed.

Regarding requirement R6, it is the responsibility of the legal owners to ensure the loadability information provided to the AESO is updated when the lines or transformers listed as part of R6 have an updated facility rating.

Regarding Appendix 1, subsections 1(b) (out-of-step tripping), and 2(c) (protection systems intended for protection during stable power swings), dynamic short circuit data is required to perform the analysis needed to provide evidence that these requirements have been met. The basic idea of this requirement is that phase protection functions detect faults and trip circuit breakers to clear faults, but do not falsely trip during power swings between generators that occur for approximately 10 seconds after a fault has been cleared. This situation is described more fully in section 7 of the *PRC-023 NERC ID*. This type of analysis is typically performed for 500 kV and critical 240 kV transmission facilities, but can be applied at any location or voltage level. Additional information regarding the setting of protection systems during stable power swings is provided in this Information Document in section 9.

Example Application of Requirement R1.1 Using the PRC-023-AB Step 1-2-3 Process

The following information illustrates the use of a three step process, referred to as the PRC-023-AB Step 1-2-3 process within this Information Document, which can be used to help meet requirement R1.1. These steps can also similarly be used to meet requirements R1.2 through R1.11. The use of the PRC-023-AB Step 1-2-3 process is not necessary and is included in this Information Document for illustrative purposes only.

Step 1 – Clarify Facility Rating

The facility rating excludes any restriction caused by protective relays or current transformers. The transmission facility load rating can be described in the following three equivalent ways:

1. The ampacity or current rating:

For example, an ampacity or current rating of 1,250 amps at 240 kV.

2. The apparent power capacity rating:

A current rating of 1,250 amps at a voltage of 240 kV line-to-line is equivalent to an apparent power capacity rating of 520 MVA, calculated by the following equation:

$$S = I \times VLL \times \sqrt{3} \qquad \text{Equation (1)}$$

Where:

S is the apparent power capacity rating

I is the phase current

VLL is the line to line voltage

$$S = 1{,}250\ amps \times 240{,}000\ volts \times \sqrt{3}$$

$$S = 520{,}000{,}000\ volt\ amps$$

$$S = 520\ MVA$$

3. The apparent impedance capacity rating:

A current rating of 1,250 amps at a voltage of 240 kV line-to-line is equivalent to an apparent impedance capacity rating of 111 ohms, calculated by the following equation:

$$Z = \frac{VLL^2}{S} \qquad \text{Equation (2)}$$

Where:

Z is the apparent impedance capacity rating, or apparent impedance of the power flow

$$Z = \frac{240{,}000^2\ volts}{520{,}000{,}000\ \text{volt amps}}$$

$$Z = 111\ \text{ohms}$$

Alternately, Z can be calculated by the following equation:

$$Z = \frac{S}{3 \times I^2} \qquad \text{Equation (3)}$$

$$Z = \frac{520{,}000{,}000\ \text{volt amps}}{3 \times (1{,}250)^{\ 2}\ \text{amps}}$$

$$Z = 111\ \text{ohms}$$

Alternately, Z can be calculated by the following equation:

$$Z = \frac{VLL/\sqrt{3}}{I} \qquad \text{Equation (4)}$$

$$Z = \frac{240{,}000 \text{ volts}/\sqrt{3}}{1{,}250 \text{ amps}}$$

$$Z = 111\ ohms$$

The calculations above demonstrate the following ways to describe the same power flow, or power flow capacity rating, which are all equivalent to one another:

- A line current flow of 1,250 amps at 240 kV;
- An apparent power flow of 520 MVA at 240 kV; and
- An apparent impedance of the power flow of 111 ohms at 240 kV

Step 2 – Check Relays For Loadability

The purpose of Step 2 is to ensure that protective relays do not restrict the capacity of a transmission facility.

A list can be created of all, or the most loadability limiting of the following: 1) phase current detection functions; and 2) phase impedance detection functions within the protection relay system that can cause circuit breaker tripping in response to a fault. For each of these detection functions the protection relay loadability is determined, as described within this Information Document. The protection relay loadability is the current, apparent power or apparent impedance that results in the operation of the detection function. The protection relay loadability is compared to the transmission facility load rating, using the margins and factors described within PRC-023-AB. If the protection relay loadability, with the associated margins and factors, is greater than the transmission facility loadability, then the protection relay does not create a restriction of the transmission facility loadability, and no further action is required. If the protection relay loadability is equal to or less than the transmission facility loadability, then the protection relay creates a restriction of the transmission facility loadability and Step 3, shown below, is required.

Step 3 – Use of Protection Relay Settings That Restrict Loadability – Only if Required

In some cases, the transmission facility loadability cannot be met due to protection relay settings that are needed to ensure the protection relays can detect all fault conditions, and for the case of transformers, to ensure that no transformer damage occurs due to current and time values that exceed parameters (sometimes referred to as ‘damage curves’) provided by the transformer manufacturer.

If Step 3 is required, then requirements R1.12, R1.13 or R1.14 are used to determine the protection relay settings.

Figure 2 provides a graphical interpretation of the use of the PRC-023-AB Step 1-2-3 process for requirements R1.1 through R1.14. The first column indicates the facility type. The second column shows the relationship between a facility type, Steps 1 and 2 and the various requirements within requirement R1.

The relay loadability requirements of PRC-023-AB for impedance detection functions can often be met through the use of a load encroachment function. However if this function is not available or does not meet the requirement of PRC-023-AB, then Step 3 is required.

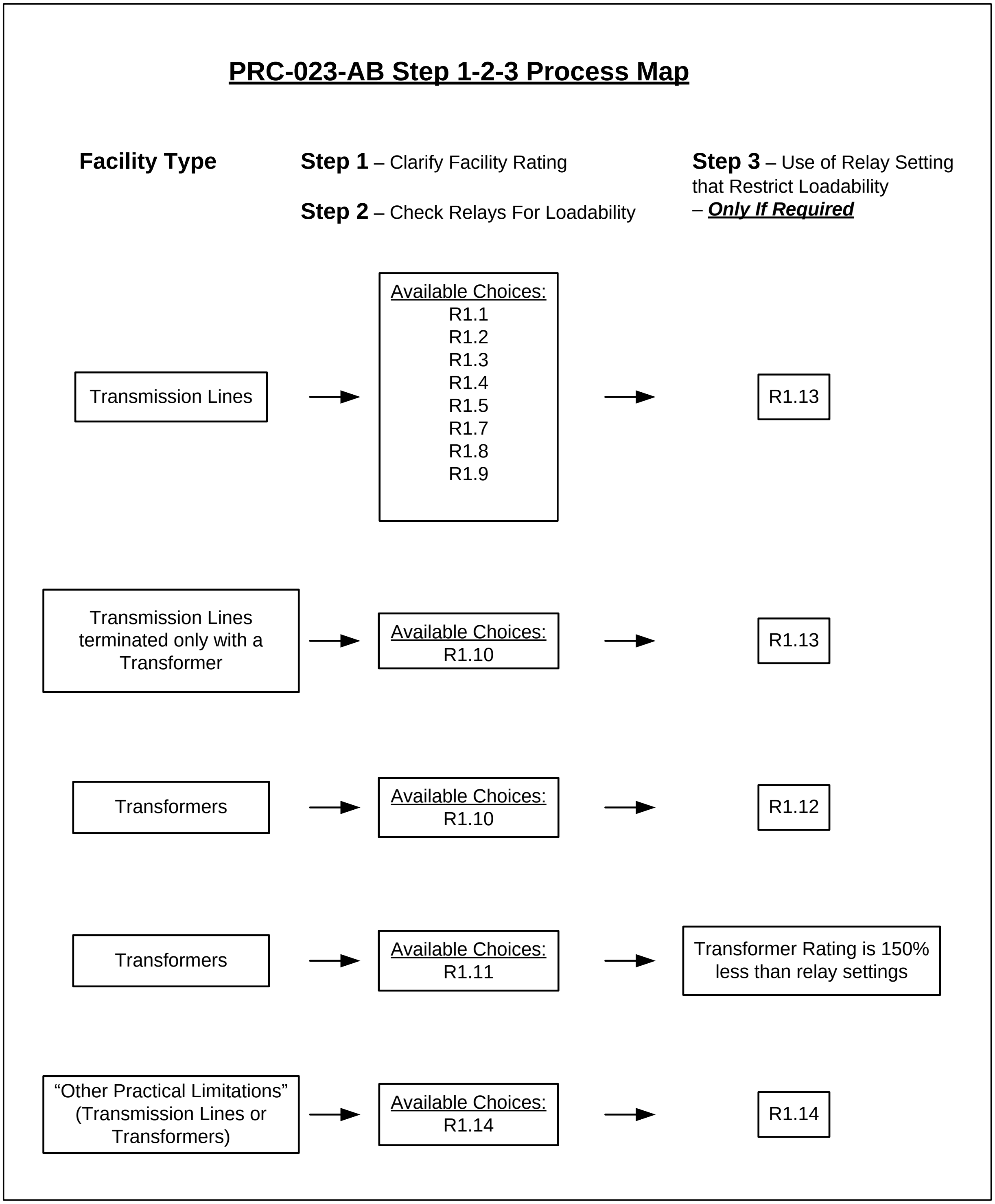

Figure 2 – PRC-023-AB Step 1-2-3 Process Map

6 General Clarification of PRC-023-AB

Protection relays can contain one or more of the following phase detection functions:

(a) phase overcurrent detection functions:

  (i) instantaneous phase overcurrent (non-directional or directional);

  (ii) inverse time or time phase overcurrent (non-directional or directional); and

  (iii) switch-on-to-fault phase overcurrent; and

(b) phase impedance detection functions (forward or reverse looking).

Older protection relays typically include only one detection function within one physical protection relay, in which case a number of separate protection relays would be used when a number of detection functions were required. Newer protection relays can have one or many detection functions within one physical protection relay.

When a fault occurs on a transmission line or within a transformer, one or more phase detection functions are activated. It is generally assumed in industry that the following minimum fault detection capability must exist:

(a) for redundant, independent protection systems (e.g. using both an “A” and “B” independent, physical protection relay) all types of fault conditions must be detected by at least one detection function within each of the independent protection systems; and

(b) for non-redundant protection systems all types of fault conditions must be detected by at least one detection function, in accordance with the intended design.

Prior to considering protection relay loadability, it is necessary that the selected protection relay type and associated settings will provide adequate fault detection for all types of fault conditions. The selection of the protection relay and associated settings is the responsibility of the legal owner, as required by Section 502.3 of the ISO rules, *Interconnected Electric System Protection Requirements*. As previously described in section 4 of this Information Documet, PRC-023-AB does not require evidence that the protection relays reliably detect all fault conditions and protect the electrical network from these faults.

7 Background Concepts

Figure 3 shows a complex impedance plot of reactance versus resistance (an “R-X Plot”) used for a typical transmission line. The tripping characteristic of a typical mho impedance detection function for balanced 3-phase faults or balanced 3-phase loads is shown as a circle with a diameter of Zrelay. The magnitude of Zrelay is a user selectable setting within a protection relay. The diameter of the circle is tilted at an angle called the Maximum Torque Angle (MTA).

PRC-023-AB requires loadability calculations to be performed with a 30° angle for the load, so a 30° load apparent impedance loci is shown, with two specific values of load indicated by dots, which are:

1. 222 ohms at 240 kV, which is equivalent to 260 MVA at 240 kV, which is also equivalent to 625 amps at 240 kV; and
2. 111 ohms at 240 kV, which is equivalent to 520 MVA at 240 kV, which is also equivalent to 1,250 amps at 240 kV.

The method to calculate these equivalent values is shown in section 5 of this Information Document.

In other words, if a protective relay measures a voltage of 240,000 volts line-to-line and a current of 1,250 amps at 30°, the relay will determine a measured apparent impedance of the power flow to be 111 ohms.

Referring to Figure 3, if the load apparent impedance 30° loci passes within the mho characteristic with a magnitude of Zrelay30 or less, then the protection relay will operate and trip one or more circuit breakers to de-energize the transmission line.

The parameters Zrelay and Zrelay30 are defined within the *PRC-023 NERC ID* and are shown in Figure 3. These two parameters are useful when describing and calculating line loadability and relay loadability. Zrelay is the relay setting which is the diameter of the mho operating characteristic, which is associated with a second relay setting of the MTA. Zrelay30 is the impedance reach of the operating characteristic when the power flow has a 30° angle between the voltage and current.

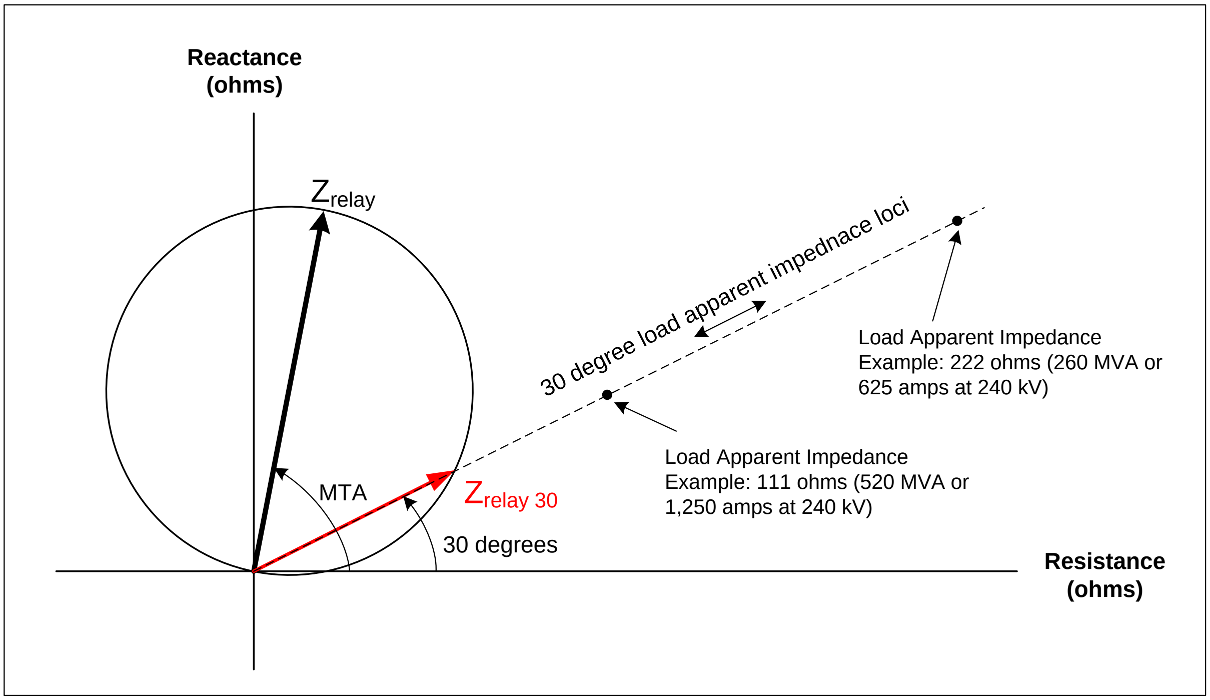

Figure 3 – Impedance Detection Function

Figure 4 shows the same mho operating characteristic as Figure 3 and illustrates specific values for Zrelay and Zrelay 30. The following equation describes the relationship between these two parameters, as described in the *PRC-023 NERC ID*.

$$\mathrm{Zrelay30} = \mathrm{Zrelay} \times \cos(\mathrm{MTA} - 30\ \mathrm{deg}) \qquad \text{Equation (5)}$$

Or, alternately Zrelay can be calculated using the following equation.

$$\mathrm{Zrelay} = \frac{\mathrm{Zrelay30}}{\cos(\mathrm{MTA} - 30\ \mathrm{deg})} \qquad \text{Equation (6)}$$

Using example data, if Zrelay30 = 63 ohms and the MTA = 85°

$$Zrelay = \frac{63\ ohms}{\cos(85 - 30)}$$

Zrelay = 110 ohms

Figure 4 illustrates the case when the MTA is 85°, Zrelay30 is 63 ohms and Zrelay is 110 ohms.

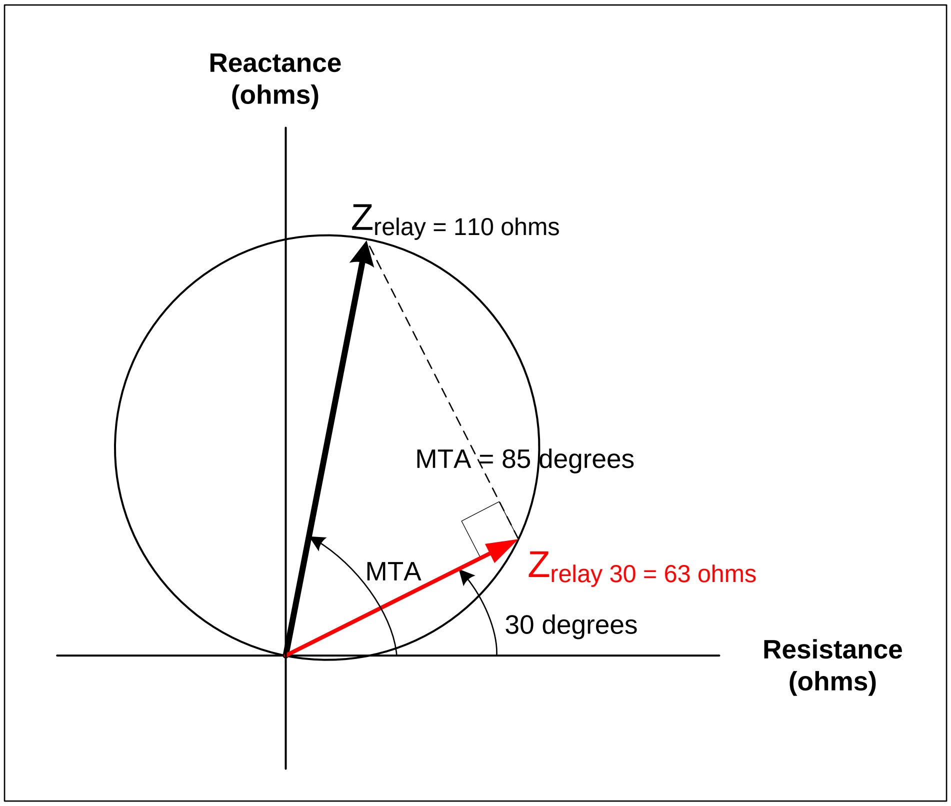

Figure 4 – Zrelay and Zrelay30

Using adifferent example data, if Zrelay30 = 63 ohms and the MTA = 87°

$$Zrelay = \frac{63\ ohms}{\cos(87-30)}$$

Zrelay = 116 ohms

Consideration of the 0.85 Per Unit Voltage Effect On an Impedance Detection Function

When the voltage on a bus is reduced to 0.85 per unit, for a given fixed relay setting and given fixed line current rating, the relay is more likely to falsely trip than when the voltage is 1.00 per unit. This is illustrated by means of example data, as follows.

In requirement R1.1, page 6 of the *PRC-023 NERC ID* the following equation is shown.

$$Zrelay30 = \frac{0.85 \times VLL}{\sqrt{3} \times 1.5 \times Irating} \qquad \text{Equation (7)}$$

As described in the *PRC-023 NERC ID* the 0.85 factor in the equation is included in reference to the 0.85 per unit voltage requirement within PRC-023 requirement R1. The 1.5 factor is included in reference to the 150% factor used within PRC-023 requirement R1.1. Irating is the fixed line current rating.

This equation may be generalized for any of the requirements in requirement R1 of PRC-023 by removing the 1.5 factor, and by removing the 0.85 factor, in the following equation.

$$Zrelay30 = \frac{VLL}{\sqrt{3} \times Irating} \qquad \text{Equation (8)}$$

Equation (8) can be used to illustrate two situations as follows:

Situation 1: At 100% voltage and a line current rating of 1,250 amps

$$Zrelay30 = \frac{240{,}000\ volts}{\sqrt{3} \times 1{,}250\ amps}$$

$$Zrelay30 = 111\ ohms$$

This means that at 100% voltage a relay setting of 111 ohms will cause a load current of 1,250 amps or greater to trip the relay.

Situation 2: At 85% voltage and a line current rating of 1,250 amps

$$Zrelay30 = \frac{0.85 \times 240{,}000\ volts}{\sqrt{3} \times 1{,}250\ amps}$$

$$Zrelay30 = 94\ ohms$$

This means that at 85% voltage a relay setting of 94 ohms will cause a load current of 1,250 amps or greater to trip the relay. To ensure the relay will only trip for a load current of 1,250 amps or greater, for either 100% or 85% voltage, the relay setting needs to be 94 ohms (or less).

Figure 5 illustrates the line capacity rating of 111 ohms being changed to 94 ohms to account for the 0.85 per unit voltage effect.

Equation (7), which is from requirement R1.1 of the *PRC-023 NERC ID*, using the same data, is calculated as follows.

$$Zrelay30 = \frac{0.85 \times 240{,}000\ volts}{\sqrt{3} \times 1.5 \times 1{,}250\ amps}$$

$$Zrelay30 = 63\ ohms$$

Figure 5 illustrates Zrelay30 being equal to 63 ohms and Zrelay being equal to 110 ohms, as previously calculated.

The blue arrows in Figure 5 illustrate how, for requirement R1.1, for a relay MTA = 85°, a line with an apparent impedance rating of 111 ohms results in a value of Zrelay30 = 63 ohms and Zrelay = 110 ohms. The green arrows in Figure 5 illustrate how, for requirement R1.1, for a relay MTA = 85°, a relay setting of Zrelay = 110 ohms results in a value of Zrelay30 = 63 ohms and a line apparent impedance rating = 111 ohms.

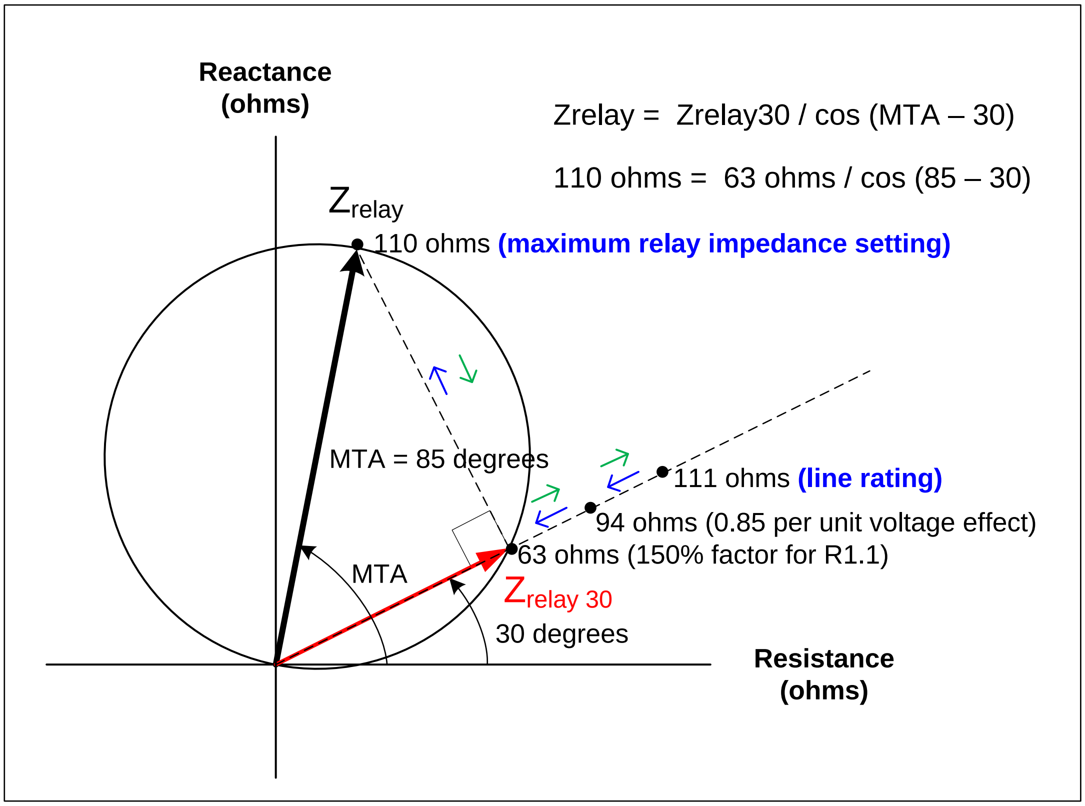

Figure 5 – Example Data

Figure 6 shows an R-X plot that illustrates the advantage of using a load enchroachment function within a line protection relay. The load encroachment function is designed to ensure the relay will not trip when the the impedance loci stays to the right hand side of the function. This diagram includes a mho operating characteristic set to 110 ohms with an MTA set to 85°, the 30° load line, and a typical load encroachment function set to 32 ohms at an angle slightly greater than +/- 30°. If a load encroachment function was not available, then the maximum loadability would be equal to ZRelay30, which is equal to 63 ohms. When a load encroachment function is used and is set to 32 ohms, this results in a loadability improvement of 31 ohms and also results in an arc accommodation of 23 ohms, all of which is shown in Figure 6.

The use of a load encroachment function is more fully explained in the document *Increase Line Loadability by Enabling Load Encroachment Functions of Digital Relays*, NERC, December 7, 2005.

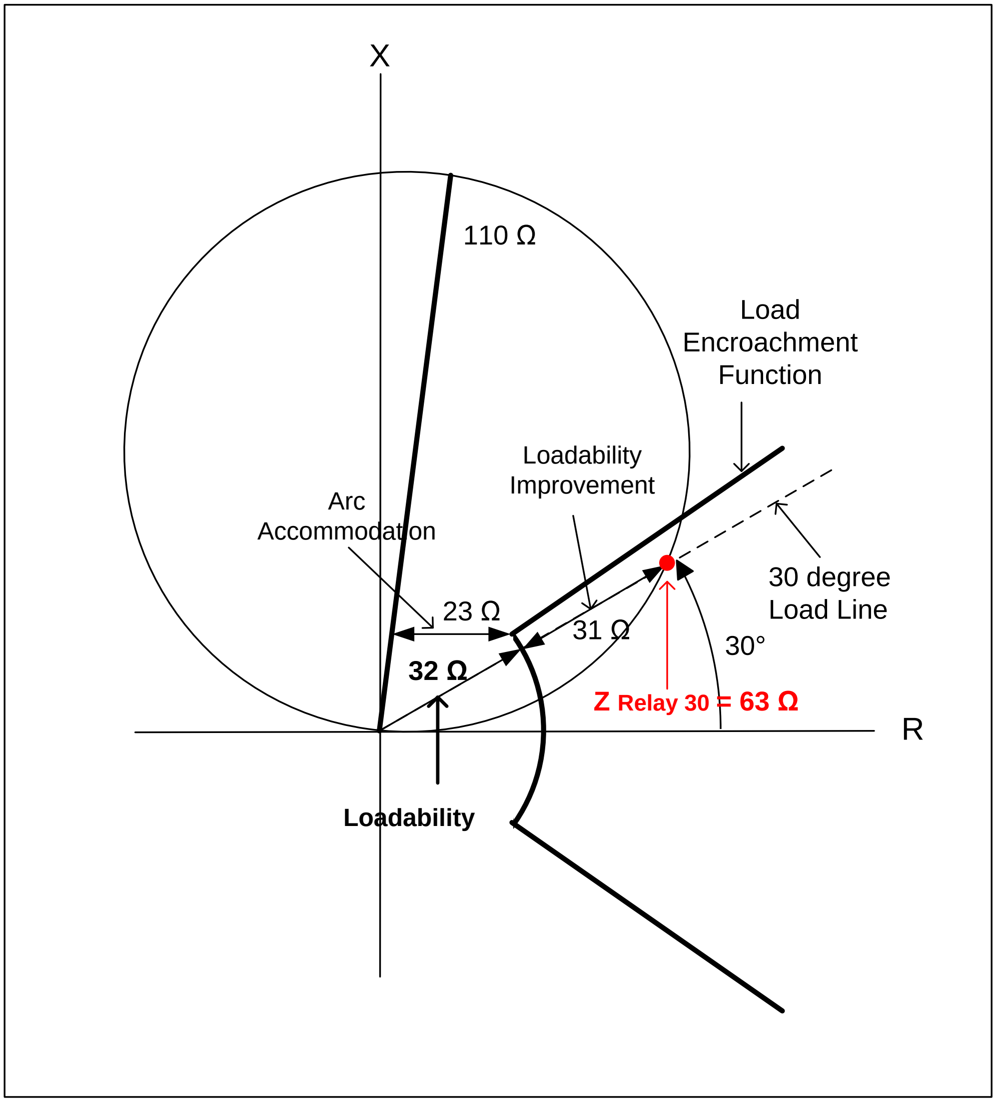

Figure 6 – Load Encroachment Function

8 Requirement R1.1 – Information Template

Figure 7 shows an example of a blank information template for Step 1 and Step 2 for requirement R1.1. This template illustrates the typical type of information to be provided as evidence of compliance with requirement R1.1. This template may be used at the discretion of the legal owner but its use is not required.

Figure 8 shows the same template that was shown in Figure 7 and also includes example data, for a hypothetical transmission line identified as “Line A”.

Some of the data shown in the R-X plots in Figure 5 and Figure 6 has been added into the information template shown in Figure 8.

As shown in Figure 8, the legal owner completes Step 1 by entering the indicated data regarding the transmission line capacity rating.

As also shown in Figure 8, the legal owner completes Step 2 by entering the indicated information for the current detection functions and impedance detection functions that can trip a circuit breaker and de-energize Line A. The legal owner also indicates for each individual detection function whether it “Meets

Limits?", meaning it meets the loadability requirement, by entering either "Yes" or "No'.

To determine whether a current function meets the loadability requirements, the current setting value must be greater than the current loadability limit, in this particular example, of 1,875 amps. To determine whether an impedance function meets the loadability requirement the impedance setting value, converted from Zrelay to Zrelay30, must be less than line loadability impedance limit, Zrelay30, in this particular example, of 63 ohms.

When all data is entered and if the "Meets Limits?" column for all individual functions is "Yes", then the loadability evaluation is completed for requirement R1.1.

As also shown in Figure 8, a brief report is intended to be included with the information template, or similar document, to provide relevant background information for the data provided within the information template, which includes at a minimum, the manufacturer and model number of the relays, the relay setting, the PT ratio, and the CT ratio.

PRC-023-AB Section R1.1

(Example Data)

Step 1 – Clarify Facility Rating

Transmission Line Id: ____________

Line Rating

Current:	______ (amps)
Apparent power at 1.0 p.u. voltage of _______ kV:	______ (MVA)
Current loadability limit using 150% of facility rating: (current values assume a 30 degree load angle)	______ (amps)
Impedance at 1.00 p.u. Voltage: (at _____ amps)	______ (ohms)
Impedance at 0.85 p.u. Voltage:	______ (ohms)
Impedance at 0.85 p.u. Voltage and 150% of facility rating which is also the line Impedance loadability limit Zrelay30 (at 30 deg):	______ (ohms)

Step 2 – Check Relays For Loadability

Line Terminal 1

Relay Id	Function ID	Setting	Zrelay30	Most Limiting ?	Meets Limits ?

Line Terminal 2

Relay Id	Function ID	Setting	Zrelay30	Most Limiting ?	Meets Limits ?

Facility Owners's Report Name:_________________

Provided by: _________________
Contact info:_________________
Date: ___________

Figure 7 – R1.1 InformationTemplate – Blank

PRC-023-AB Section R1.1

(Example Data)

Step 1 – Clarify Facility Rating

Transmission Line Id: Line A

Line Rating

Current:	1,250	(amps)
Apparent power at 1.0 p.u. voltage of 240 kV:	520	(MVA)
Current loadability limit using 150% of facility rating: (current values assume a 30 degree load angle)	1,875	(amps)
Impedance at 1.00 p.u. Voltage: (at 1,250 amps)	111	(ohms)
Impedance at 0.85 p.u. Voltage:	94	(ohms)
Impedance at 0.85 p.u. Voltage and 150% of facility rating which is also the line Impedance loadability limit Zrelay30 (at 30 deg):	63	(ohms)

Step 2 – Check Relays For Loadability

Line Terminal 1

Relay Id	Function ID	Setting	Zrelay30	Most Limiting ?	Meets Limits ?
Relay A	50P-1	1,900 amps	-	Yes	Yes
	50P-2	2,400 amps	-	-	Yes
	51P-1	2,000 amps	-	-	Yes
	21P-Z1 (Z_{relay})	40 ohms (at MTA = 85 deg)	23 ohms	-	Yes
	21P-Z2 (Z_{relay})	56 ohms (at MTA = 85 deg)	32 ohms	-	Yes
	21P-Z3 (Z_{relay})	105 ohms (at MTA = 85 deg)	60 ohms	Yes	Yes
Relay B	51P-X	1,970 amps	-	-	Yes
	SOTF	2,000 amps	-	-	Yes
	21P-Z1 (Z_{relay})	40 ohms (at MTA = 87 deg)	22 ohms	-	Yes
	21P-Z2 (Z_{relay})	56 ohms (at MTA = 87 deg)	30 ohms	-	Yes
	21P-Z3 (Z_{relay})	95 ohms (at MTA = 87 deg)	52 ohms	-	Yes

Line Terminal 2

Relay Id	Function ID	Setting	Zrelay30	Most Limiting ?	Meets Limits ?
Relay C	50P-1	2.200 amps	-	Yes	Yes
	50P-2	2,400 amps	-	-	Yes
	51P-1	2,000 amps	-	-	Yes
	21P-Z1 (Z_{relay})	40 ohms (at MTA = 85 deg)	23 ohms	-	Yes
	21P-Z2 (Z_{relay})	56 ohms (at MTA = 85 deg)	32 ohms	-	Yes
	21P-Z3 (Z_{relay})	102 ohms (at MTA = 85 deg)	59 ohms	Yes	Yes
Relay D	Load Encroachment Feature				
	Loadability	32 ohms (at 30 deg)	n/a		Yes

Provided by: ______________
Contact info: ______________
Date: __________

Facility Owners's Report Name: Report abc

Figure 8 – R1.1 InformationTemplate – With Example Data

Figure 9 illustrates the same example data shown in Figure 8 entered into a spreadsheet. A copy of the spreadsheet template accompanies this Information Document. As described within the spreadsheet, if this spreadsheet is submitted to the AESO as evidence for line loadability, then the legal owner is responsible for the applicability and accuracy of all data and calculations. All cells except those with brown shading are locked to protect the calculations. A user can add new columns to add supplementary information and calculations.

The spreadsheet includes cells to provide background information as to the manufacturer and model number of the relay, the relay setting, the PT ratio, and CT ratio.

PRC-023-AB R1.1 Calculation

Refer to the ISO PRC-023-AB Information Document (ID), for a description of the methods and calculations included within this spreadsheet.
Intended For Discussion Purposes Only
If this spreadsheet is submitted to the AESO as evidence for line loadability, then the facility owner is responsible for the applicability and accuracy of all data and calculations.
All cells except those with brown shading are locked. A user is able to add new columns to add supplementary information and calculations.

User Data Entry Only In Brown Shaded Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
3	Line Rating Data												Relay Settings													
4													Overcurrent Function				Mho Impedance Function (if no load encroachment feautre is available)						Load Encroachment Function			
5	Line ID	Line Current Rating (amps)	Line Voltage (kV L-L)	Line Apparent Power Rating (MVA)	Line Current Rating x 150% (using R1.1)	Line Apparent Impedance Rating at 1 pu Voltage and the rated line current (ohms)	Line Apparent Impedance Rating at 0.85 pu voltage and the rated line current (ohms)	Line Loadability Maximum Allowable Zrelay30 for R1.1 using 150% Factor (ohms)	Line Terminal ID	Relay MFR & Model Number	PT Ratio	CT Ratio	Lowest Relay Current Setting (Secondary amps)	Lowest Relay Current Setting (Primary amps)	Current Setting Meets Loadability Requirement?	Overcurrent Function Line Loadability using 150% Factor (MVA)	Greatest Relay Setting of Zrelay (Secondary ohms)	Greatest Relay Setting of Zrelay (Primary ohms)	Relay Maximum Torque Angle (degrees)	Calculated Zrelay30 (Primary ohms)	Impedance Function Meets Loadability Requirement?	Line Loadability using 150% Factor and 85% Voltage Factor (MVA)	Relay Loadability (Secondary ohms)	Relay Loadability (Primary ohms)	Loadability Meets Requirements?	Load Encroachment Feature Line Loadability using 150% Factor and 85% Voltage Facytor (MVA)
6	The example data within the following two rows corresponds to the example data described and calculated within the AESO PRC-023 Information Document (ID)																									
7	L1	1,250	240	520	1,875	111	94	63	LT1	Relay A				1,900	Yes	527		105	85	60	Yes	542			-	0
8	L1	1,250	240	520	1,875	111	94	63	LT1	Relay B				1,970	Yes	546		95	87	52	Yes	631			-	0
9	L1	1,250	240	520	1,875	111	94	63	LT2	Relay C				2,200	Yes	610		102	85	59	Yes	550			-	0
10	L1	1,250	240	520	1,875	111	94	63	LT3	Relay D					-	0				0	-	0		33	Yes	1,030
11				0	0	0	0	0							-	0				0	-	0			-	0
12				0	0	0	0	0							-	0				0	-	0			-	0
13				0	0	0	0	0							-	0				0	-	0			-	0
14				0	0	0	0	0							-	0				0	-	0			-	0
15				0	0	0	0	0							-	0				0	-	0			-	0
16				0	0	0	0	0							-	0				0	-	0			-	0
17				0	0	0	0	0							-	0				0	-	0			-	0
18				0	0	0	0	0							-	0				0	-	0			-	0
19				0	0	0	0	0							-	0				0	-	0			-	0
20				0	0	0	0	0							-	0				0	-	0			-	0

Figure 9 – Loadability Data Within A Spreadsheet

9 Protection Relay Loadability During Power Swings

As referenced in PRC-023, Appendix 1, 1(b) (out-of-step tripping) and 2(c) (protection systems intended for protection during stable power swings), dynamic short circuit data is required to perform the analysis needed to provide evidence these requirements have been met, as shown below. This type of analysis is typically performed for 500 kV and critical 240 kV transmission facilities, but can be applied at any location or voltage level, as determined by the AESO.

When a fault occurs on the transmission system, the individual, nearby generators will have a response similar to what is shown in Figure 10, for a time period both: 1) prior to and during fault clearing; and 2) after fault clearing. The generator protection relays will measure this power swing. The parameter Pstep indicates the change in real power during the fault, and Pswing1 and Pswing2 illustrate real power oscillations (swings) occurring after fault clearing. The time duration of the power swings after fault clearing can last a number of seconds and be of significant magnitude. The general idea is that generator protection relays do not falsely trip in response to faults occurring on the transmission system.

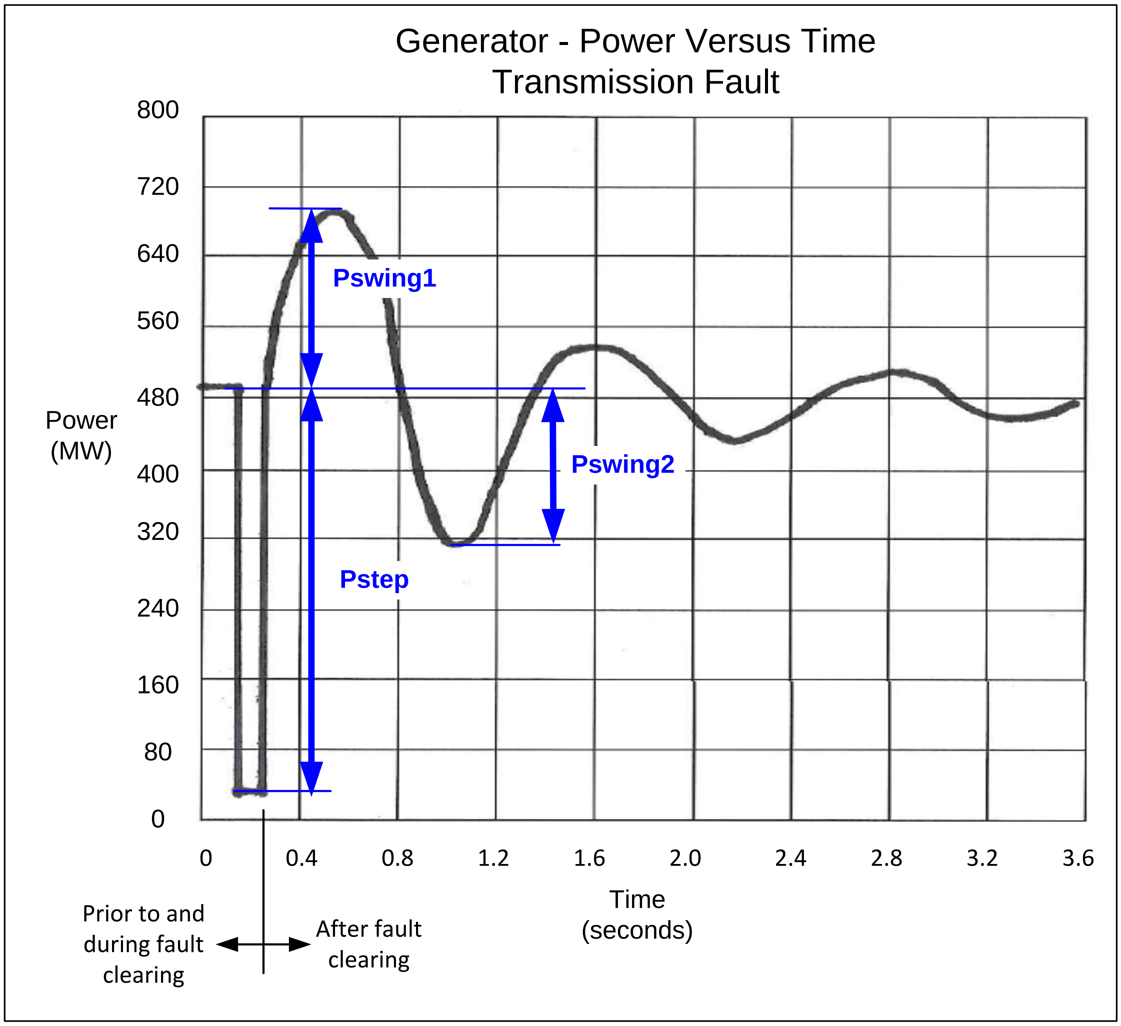

Figure 10 – Generator Power Swings

When a fault occurs on the transmission system, the line terminals will measure a power flow similar to what is shown in Figure 11, for a time period both: 1) prior to and during fault clearing; and 2) after fault clearing. The power oscillations are created both by the initial fault and line auto-reclose events following the fault clearing. The transmission line protection relays will measure these power swings. The shape of the power curve can be complex, as illustrated in Figure 11, due to the mechanical oscillation interaction of various generators, all of which can have different inertial time constants. The time duration of the power swings after fault clearing can last a number of seconds and be of significant magnitude. The general idea is that transmission line protection relays do not falsely trip in response to power swings on the transmission system.

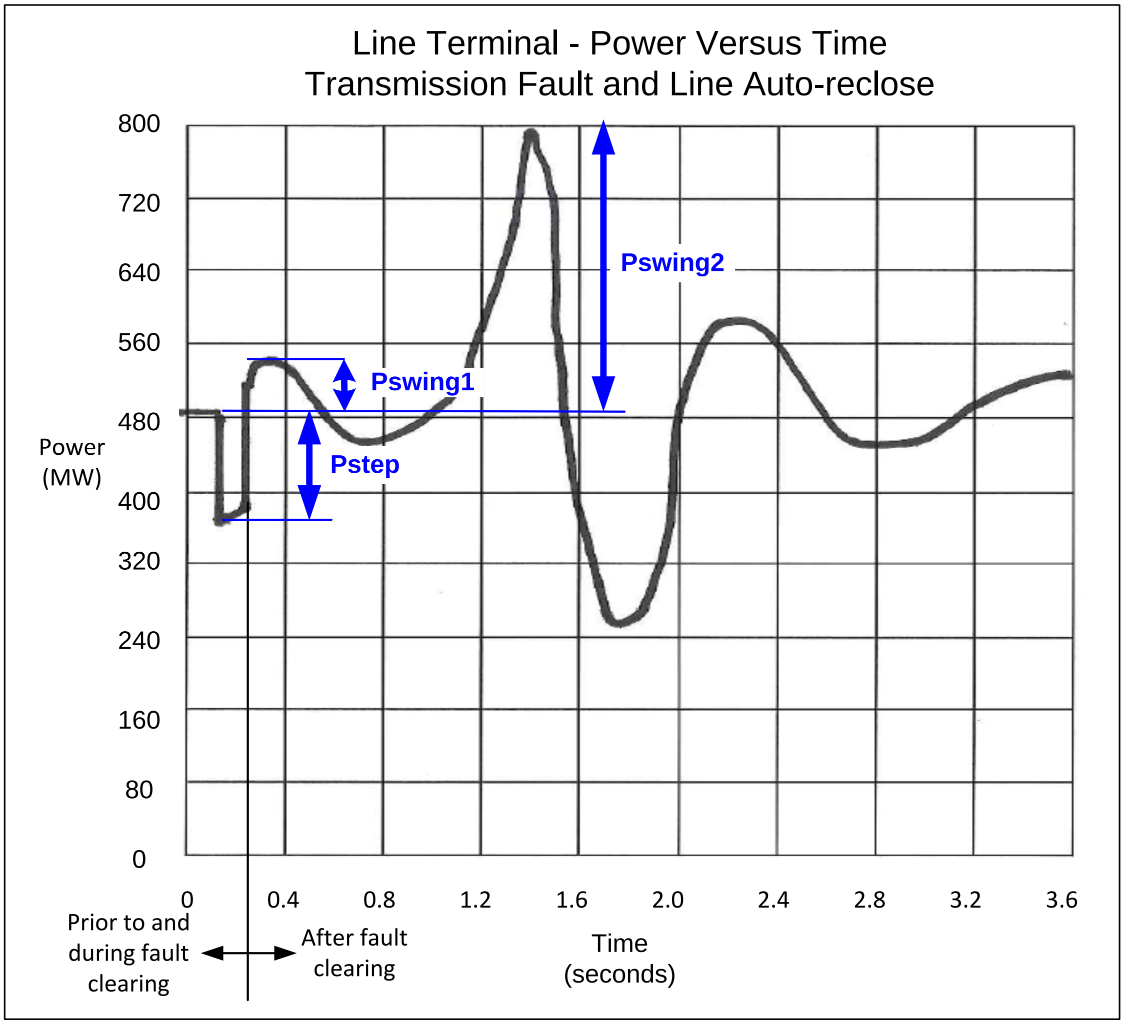

Figure 11 – Line Terminal Power Swing

Figure 12 provides a concept R-X plot for the apparent impedance loci measured by transmission line protection relays or generator protection relays. The dots represent the value of the apparent impedance of the power flow at regular time intervals, for example every 10 milli-seconds. The impedance loci has a 'Start' and 'End' for a particular time period. For example, a time period that includes time both prior to a fault and for a few second following a fault, for the time period similar to what is shown in Figures 10 and 11. This concept R-X plot shown in Figure 12 includes only a few dots for illustrative purposes, but illustrates the ideas that the dots are 'far apart' shortly after the Start, when the fault occurs, but then the dots become 'close together' after any circuit breakers have tripped to clear the fault. In other words, when the dots are far apart, the rate-of-change of the apparent impedance loci is fast, and when the dots are close together, the rate-of-change of the apparent impedance loci is slow. When the rate-of-change of the apparent impedance loci is fast, this indicates the presence of a fault, which results in the tripping ofcircuit breakers. When the rate-of-change of the apparent impedance loci is slow, this indicates the presence of a power swing, which requires the circuit breaker to not be tripped. Both the rate-of-change and magnitude of the apparent impedance loci are used to create the protection relay settings to avoid false tripping during power swings.

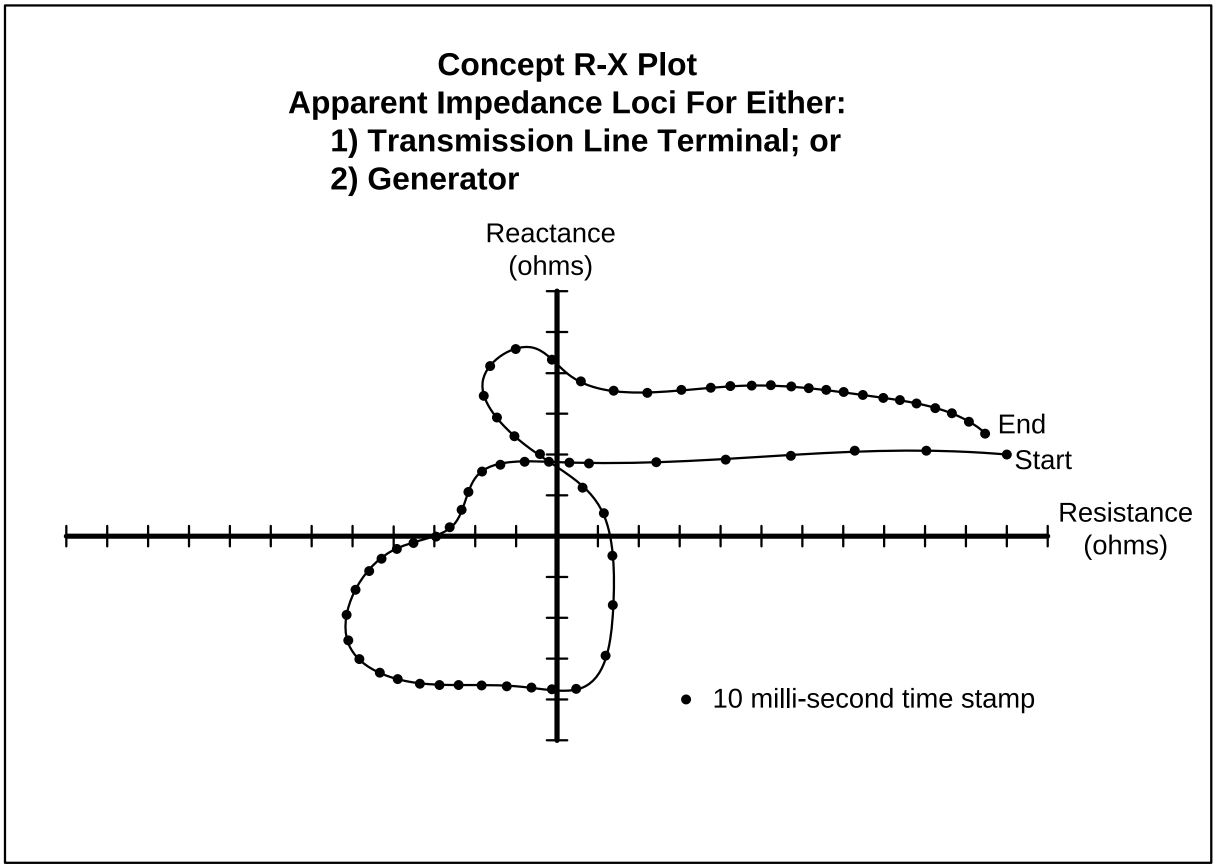

Figure 12 – Concept R-X Plot

Transmission line protection relays often include a function called 'power swing block' that is set to ensure the protection relay does not operate during power swings. The power swing block function is available in most new impedance protection relays. Transmission line protection relays can also include a function called 'power swing trip' that is used to detect power swings that can thermally damage the associated transmission line and cause circuit breakers to trip to remove the power swing. The use of a power swing tripping function is not common, but can be found on medium voltage transmission lines connected between major generating plants, for the situation of black start conditions when the high voltage transmission lines have not yet been returned to service, and large power swings could occurr between generating units through the medium voltage transmission lines.

Generator protection relays almost always include a function called 'out-of-step' tripping to detect a 'pole slipping' condition, to remove the generator from service if this occurs, yet is not supposed to trip for stable power oscillations (swings) occurring between generators, through the transmission system.

The required dynamic fault R-X loci data is usually stored as time series data, every 1.0 milli-second, as illustrated in Table 1 and Table 2, using a spreadsheet for convenient analysis and plotting.

Table 1 - Generator - Apparent Impedance Loci Data

Time (seconds)	Apparent Resistance (ohms)	Apparent Reactance (ohms)	IA (amps)	IB (amps)	IC (amps)	VAG (volts)	VBG (volts)	VCG (volts)
0.001								

0.002								
0.003								
etc.								

Table 2 -Line Terminal - Apparent Impedance Loci Data								
Time (seconds)	Apparent Resistance (ohms)	Apparent Reactance (ohms)	IA (amps)	IB (amps)	IC (amps)	VAG (volts)	VBG (volts)	VCG (volts)
0.001								
0.002								
0.003								
etc.								

The data shown in Table 1 and Table 2 is usually plotted as shown in Figure 12. A plot is created for each of many transmission line fault scenarios.

The main concepts in using the R-X loci data are:

1. A generator should not be tripped and removed from service for faults on transmission facilities (lines, transformers and buses) and not be tripped and removed from service for the subsequent power swings.
2. A transmission line with a fault should be tripped and removed from service to clear the fault, possibly followed by auto-reclose to restore the line to service following a temporary fault, for example, a lightning strike.
3. A transmission line that does not have a fault should not be tripped and removed from service due to power swings caused by a fault on a different transmission line or other nearby transmission or generation facilities.

Revision History

Posting Date	Description of Changes
2018-12-06	Inclusion of guidance information and template provided
2016-09-28	Inclusion of submission instructions
	Administrative amendments
2014-05-01	Moved the list of circuits to a separate document
2013-11-12	Administrative Updates
2013-04-30	Initial Release