



**Transmission Reliability Margin
Implementation Document
(TRMID)**

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1. Purpose

The purpose of BC Hydro’s Transmission Reliability Margin Implementation Document (TRMID) is to address the requirements of the North American Electric Reliability Corporation (NERC) Mandatory Reliability Standard MOD-008 Transmission Reliability Margin Calculation Methodology adopted for British Columbia. This TRMID identifies the components of uncertainty used by BC Hydro for calculating Transmission Reliability Margin (TRM) set aside when it calculates Available Transfer Capability (ATC) for each ATC Path in the BC Hydro System for a time horizon up to 13 months including the current month.

2. Effective Date

Effective date: **23 May 2019**

3. Definitions

ATC_F is the firm Available Transfer Capability for the ATC Path for that period.

ATC_{NF} is the non-firm Available Transfer Capability for the ATC Path for that period.

CBM is the Capacity Benefit Margin for the ATC Path during that period.

CBM_s is the Capacity Benefit Margin for the ATC Path that has been scheduled during that period.

Counterflows_F are adjustments to firm Available Transfer Capability as determined by the Transmission Service Provider and specified in their ATCID.

Counterflow_{NF} are adjustments to non-firm Available Transfer Capability as determined by the Transmission Service Provider and specified in its ATCID.

ETC_F is the sum of existing firm commitments for the ATC Path during that period.

ETC_{NF} is the sum of existing non-firm commitments for the ATC Path during that period.

GF_{NF} is the non-firm capacity set aside for grandfathered Transmission Service and contracts for energy and/or Transmission Service, where executed prior to the effective date of a Transmission Service Provider’s Open Access Transmission Tariff or “safe harbor tariff.”

NITS_F is the firm capacity reserved for Network Integration Transmission Service serving Load, to include losses, and Load growth, not otherwise included in Transmission Reliability Margin or Capacity Benefit Margin.

NITS_{NF} is the non-firm capacity set aside for Network Integration Transmission Service serving Load (i.e., secondary service), to include losses, and load growth not otherwise included in Transmission Reliability Margin or Capacity Benefit Margin.

NL_F is the firm capacity set aside to serve peak Native Load forecast commitments for the time period being calculated, to include losses, and Native Load growth, not otherwise included in Transmission Reliability Margin or Capacity Benefit Margin.

OS_F is the firm capacity reserved for any other service(s), contract(s), or agreement(s) not specified above using Firm Transmission Service as specified in the ATCID.

OS_{NF} is the non-firm capacity reserved for any other service(s), contract(s), or agreement(s) not specified above using non-firm transmission service as specified in the ATCID.

Postbacks_F are changes to firm Available Transfer Capability due to a change in the use of Transmission Service for that period, as defined in Business Practices.

Postbacks_{NF} are changes to non-firm Available Transfer Capability due to a change in the use of Transmission Service for that period, as defined in Business Practices.

PTP_F is the firm capacity reserved for confirmed Point-to-Point Transmission Service.

PTP_{NF} is non-firm capacity reserved for confirmed Point-to-Point Transmission Service.

ROR_F is the firm capacity reserved for Roll-over rights for contracts granting Transmission Customers the right of first refusal to take or continue to take Transmission Service when the Transmission Customer's Transmission Service contract expires or is eligible for renewal.

System Operating Limit (SOL) is the value (such as MW, MVar, Amperes, Frequency or Volts) that satisfies the most limiting of the prescribed operating criteria for a specified system configuration to ensure operation within acceptable reliability criteria.

TRM is the Transmission Reliability Margin for the ATC Path during that period.

TRM_U is the Transmission Reliability Margin for the ATC Path that has not been released for sale (unreleased) as non-firm capacity by the Transmission Service Provider during that period.

TTC is the Total Transfer Capability of the ATC Path for that period.

4. Components of Uncertainty

The following is a list of the components of uncertainty that may be used to establish TRM:

- Aggregate Load forecast
- Load distribution uncertainty
- Forecast uncertainty in Transmission System topology (including, but not limited to, forced or unplanned outages and maintenance outages)
- Allowances for parallel path (loop flow) impacts
- Allowances for simultaneous path interactions
- Variations in generation dispatch (including, but not limited to, forced or unplanned outages and maintenance outages)
- Short-term System Operator response (Operating Reserve actions)
- Reserve Sharing Requirements
- Inertial Response and frequency bias

5. TRM Calculations

Table 1 below shows the components of uncertainty BC Hydro uses to calculate TRM for each applicable ATC Path for the following time periods:

- Same day and real-time;
- Day-ahead and pre-schedule; and
- Beyond day-ahead and pre-schedule, up to thirteen months ahead.

Table 1

ATC Path Name	Components for TRM	Components for TRM_U
BCHA – BPAT	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias. • Forecast uncertainty in Transmission System topology. 	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias.
BPAT – BCHA	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias. 	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias.
BCHA – AESO	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias. 	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias.
AESO – BCHA	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias. • Forecast uncertainty in Transmission System topology. 	<ul style="list-style-type: none"> • Aggregate Load forecast. • Variations in generation dispatch. • Inertial Response and frequency bias.

BC Hydro sets aside the following capacity amounts, to account for the components of uncertainty of Aggregate Load forecast, Variations in generation dispatch and Inertial Response and frequency bias, for each ATC Path:

Table 2

ATC Path Name	TRM _U (MW)
BCHA – BPAT	50
BPAT – BCHA	50
BCHA – AESO	65
AESO – BCHA	65

The capacity amounts shown in Table 2 have been established based on operating experience; they have proven sufficient and effective. Moreover, in February 2011 BC Hydro completed a study using probabilistic methods and techniques for estimating the standard deviation of SOL/TTC that is caused by these components of uncertainty (i.e., system load, generation patterns and operational responses) in the BC Hydro system. The results of this study generally confirm the capacity amounts needed to be set aside. See Appendix A (TRM Calculator Project Report) for details.

For calculating ATC_F, BC Hydro may set aside additional capacity amount to account for Transmission System topology uncertainty due to unplanned and forced outages and maintenance outages. The impact of an outage varies depending on the actual element out of service. Studies show that the maximum SOL/TTC after a most severe single contingency is 600 MW, 850 MW, 2400 MW, and 2000 MW for AESO-BCHA Path, BCHA-AESO Path, BCHA-BPAT Path, and BPAT-BCHA Path respectively.

For SOL/TTC details for these paths, please see SOO-7T-17 and SOO-7T-18 available at:

<https://www.bchydro.com/energy-in-bc/operations/transmission/transmission-system/system-operating-orders.html>.

The published ATCID and TRMID can be found at:

<https://www.bchydro.com/energy-in-bc/operations/transmission/transmission-system/atc-methodology.html>.

TRM Amount Required for Transmission System Topology and Uncertainty

The specific capacity amount needs to be set aside to account for Transmission System topology uncertainty will depend on what the calculated SOL/TTC is for the relevant

time period. Therefore, the capacity amount for this component of uncertainty will be determined as shown in Table 3 below for the TRM and TRM_U for each ATC Path.

Table 3

ATC Path Name	TRM (MW)	Minimum TRM_U Value (MW)
BCHA – BPAT	Higher of (TTC – 2350, 50)	50
BPAT – BCHA	Higher of (TTC – 1950, 50)	50
BCHA – AESO	Higher of (TTC – 480, 65)	65
AESO – BCHA	Higher of (TTC – 535, 65)	65
FBC – BCHA	0	0
BCHA – FBC	0	0

BC Hydro will revise TRM values within seven days if any of the components of uncertainty changes, and will re-evaluate and re-establish, if required, this TRMID once every 13 months.

6. Information Sharing

BC Hydro will provide a copy of this TRMID and underlying documentation (if any) used to determine TRM to any of the following who make a written request no more than 30 calendar days after receiving the request:

- Transmission Service Providers
- Reliability Coordinators
- Transmission Planners
- Transmission Operators

Document Change History

Issue	Reviewer	Reason for Issue	Date
0		Initial Implementation.	21 November 2011
1		Correct typos	30 November 2011
2		Change in TRM amount required for transmission system topology uncertainty	25 June 2012
3		Revised link to system operating order (Page 7), revised table 3 and supporting information.	31 January 2016
4		Section 5 – revised hyperlink to posted System Operating Orders. Added hyperlink to the ATCID. Revised functions for calculating TRM to clarify/simplify, and to address BCUC decision on firm limits on BCHA to AESO. Revised TRM _u to indicate these are the minimum values.	23 May 2019

Appendix A

Transmission Reliability Margin

(Report BCH-ARPM-R1, dated 25 February 2011)



TRM Calculator Project Report

BC Hydro

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February 2011

TRM Calculator Project Report

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Wenyuan Li

Executive Summary

The objective of this project is to study and implement probabilistic methods and techniques for estimating the standard deviation of TTC that is caused by uncertainties of system parameters (system load, generation patterns and operational responses) in the BC Hydro system. The uncertainties of the parameters are estimated using historical data, whereas the uncertainty of TTC is calculated using the $2m+1$ point estimation method (PEM). The estimated standard deviations of TTC can be used as a reference in determining the time-varying TRM values for hourly, daily or weekly TTC.

In this project, the $2m+1$ point estimate method is investigated and improved. Several special issues in application to the uncertainty of TTC in power systems are resolved. The models and techniques for processing historical data are proposed. A program called the TRM calculator with a friendly user interface is designed and developed. A representative study is conducted using the developed TRM calculator and BC Hydro system data in the 2010 winter period. The standard deviations of typical hourly, daily and weekly TTCs for the export on the BCH-USA inter-tie are calculated and shown in the following Table 1:

Table 1: Standard deviations of TTC at BCH-USA inter-tie (unit: MW)

Case	mean value	1.0 σ (84.2%)	1.5 σ (93.3%)	2.0 σ (97.8%)	2.5 σ (99.4%)	3.0 σ (99.9%)
hourly TTC in high load	2089	46.39	69.58	92.78	115.97	139.17
hourly TTC in median load	2669	34.57	51.86	69.15	86.44	103.72
daily TTC in high load	2031	54.65	81.97	109.30	136.62	163.95
weekly TTC in high load	1812	59.78	89.67	119.56	149.45	179.34

In Table 1, the column “mean” corresponds to the TTC values at the base points. The column “1.0 σ ” corresponds to the standard deviations estimated. The columns “1.5 σ ”, “2.0 σ ”, “2.5 σ ” and “3.0 σ ” show the values of the standard deviation multiplying factor 1.5, 2.0, 2.5 and 3.0, respectively. The percentage in the bracket indicates the probability

that the TTC is not smaller than the value of the mean TTC minus the product of the standard deviation of that TTC and the corresponding factor if a normal distribution of the TTC is assumed. For example, the probability that the hourly TTC in high load is not smaller than $2089 - 46.39 \times 2042.61$ MW is 84.2%. For another example, the probability that the hourly TTC in high load is not smaller than $2089 - 139.17 \times 1949.83$ MW is 99.9%. The percentages below other column titles have similar meanings. Note that the probability that the TTC is not smaller than the mean TTC value is 50%.

Note that the standard deviations of hourly/daily/weekly TTC at the low load level are all zero and are not presented in the table. This is because when the system load level is very low, the uncertainties of system parameters do not have any impact on the TTC that is calculated from the TTC calculator, which is always fixed at the physical thermal limit of 3150 MW.

The standard deviation of the TTC values can be used as a reference to TRM in the following two ways:

- 1) The same TRM is used for firm TTC and non-firm TTC and it can be selected to be a value corresponding to 1.0 σ , 1.5 σ , 2.0 σ , 2.5 σ , or 3.0 σ depending on the willingness of accepting a different risk level.
- 2) The different TRM values are used for firm and non-firm TTC considering they are associated with different risk levels. For example, the mean TTC value which is calculated at the base point (under the system condition in the base case) can be used as a non-firm TTC with a higher risk (50% probability to be violated), whereas the TTC at a selected level of 1.0 σ to 3.0 σ can be used as a firm TTC with a lower risk.

The input information for calculating the standard deviations of the TTC values is presented in the following Table 2.

Table 2: Input information for the 7 Cases

Case Name	Sample Range	TTC Type	TTC Hour	Objective
hourly-high	22-Nov-2010 ~ 06-Dec-2010	hourly	07-Dec-2010 06:00 PM	Study the hourly TTC at a relatively high system load level
hourly-median			07-Dec-2010 09:00 AM	Study the hourly TTC at a relatively median system load level
hourly-low			07-Dec-2010 02:00 AM	Study the hourly TTC at a relatively low system load level
daily-high	29-Nov-2009 ~ 19-Dec-2009	daily	07-Dec-2010 05:00 PM	Study the daily TTC at the highest load for the day 07-Dec-2010
daily-low			07-Dec-2010 02:00 AM	Study the daily TTC at lowest load for the day 07-Dec-2010
weekly-high	29-Nov-2009 ~ 21-Feb-2010	weekly	06-Dec-2010 05:00 PM	Study the weekly TTC at the highest load for the week 05~11 of December 2010
weekly-low			09-Dec-2010 03:00 AM	Study the weekly TTC at the lowest load for the week 05~11 of December 2010

In addition to the developed program, the seven reports are completed including this report as the first one. The titles of the seven reports are listed in the following table:

Table 3: Reports

Report No	Report Title	Description
SPPA-R016A	Probabilistic Method for Estimating TTC Variation Ranges Caused by Uncertainties of Load, Generation and Operational Response	Scope of the project and proposed methods for probabilistic TTC and TRM
BCH-ARPM-R1	Project Report	The summary and report of the project
BCH-ARPM-R2	$2m+1$ Point Estimate Method and Its Application in TRM Calculations	The $2m+1$ PEM, several special issues and their solutions
BCH-ARPM-R3	Uncertainty Modeling and Processing of Parameter Data	The models and techniques for processing historical data and extracting uncertainty patterns
BCH-ARPM-R4	Process Manual	The design of the TRM calculator
BCH-ARPM-R5	User Manual	A detailed guide for users to run the calculator
BCH-ARPM-R6	Programmer Manual	The specification of the software

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TRM Calculator Project Report

Zhenhua Lin
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1 INTRODUCTION

The TRM project is a part of the undergoing TTC (total transmission capability) project. The uncertainties of system conditions (system load, outputs of generating units and tie-line flows) in a power system result in uncertainty of TTC. To ensure system security under uncertainties and comply with NERC's requirements, a TRM (transmission reliability margin) should be calculated and posted with the TTC. Uncertainty factors related to TTC can be classified into four categories: the uncertainties in load forecast, generation pattern, operational response and random outages of system components. The last uncertainty factor can be deterministically considered by applying the N-1 and N-1-1 (one component failure while another one out-of-service) principles in calculating TTC. However, the other three factors cannot be treated in a similar way. The purpose of this project is to investigate probabilistic methods for estimating the standard deviation of TTC caused by the first three factors, develop a program to implement the methods, and perform a representative study for calculating the standard deviation of TTC for BC Hydro system [1]. The standard deviations of TTCs obtained in the representative study can be used as a reference in determining TRM.

The probabilistic method employed in the project is the $2m+1$ point estimate method (PEM) [2]. This method was selected because of its satisfactory accuracy, high computational efficiency and no requirement for any change in calculating TTC. There are some challenging issues when the $2m+1$ PEM is applied to estimate the standard deviation of TTC, including bounded domain of parameters, correlation between parameters, and data processing. These issues have been successfully resolved in the project [3, 4].

Based on the $2m+1$ PEM and techniques proposed to process historical data, a process for calculating the standard deviation of TTC is designed [5] and a standalone program called the TRM calculator is developed [7]. The TRM calculator provides users a convenient interface to configure input settings and conduct calculations for the standard deviation of various types of TTC (hourly, daily and weekly TTCs). A detailed user guide is provided with the program [6]. By using the TRM calculator, a representative study was performed to confirm the effectiveness of the proposed methods and techniques, and provide the typical standard deviations of TTCs for the BC Hydro system.

This report summarizes the methods and techniques in Section 3, the TRM calculator program in Section 4, data processing in Section 5, and particularly the typical results in Section 6.

2 SCOPE OF THE PROJECT

The project includes the following tasks:

- 1) Investigating probabilistic methods for estimating the standard deviation of TTC;
- 2) Developing models and techniques to process historical data for extracting uncertainty patterns of all system parameters (system load, outputs of generating units and tie-line flows) ;
- 3) Developing a computer program (called the TRM calculator) using the proposed methods and techniques;
- 4) Performing a study to calculate the typical standard deviations of hourly, daily and weekly TTCs for the BC Hydro system.

These objectives are successfully achieved. The work is documented in the following 6 reports:

- 1) This report titled by Project Report summarizes the developed methods, program and typical results.
- 2) The report titled by “Probabilistic Method for Estimating TTC Variation Ranges Caused by Uncertainties of Load, Generation and Operational Response” [1] describes the scope of the project.
- 3) The report titled by “ $2m+1$ Point Estimate Method and Its Application in TRM Calculations” [3] discusses the $2m+1$ PEM [2] with the special issues (bounded parameters and correlation between parameters) which occur in actual applications to power systems.
- 4) The report titled by “TRM Calculator: Uncertainty Modeling and Processing of Parameter Data” [4] presents effective models and techniques for processing historical data to extract uncertainty patterns of parameters.
- 5) The report titled by “TRM Calculator: Process Manual” [5] documents the process to calculate the standard deviation of TTC using the developed computer program called TRM calculator.
- 6) The report titled by “TRM Calculator: Programmer Manual” describes the design details of the TRM calculator program, which includes both computing engines and a friendly user interface.
- 7) The report titled by “TRM Calculator: User Manual” provides a detailed guide for users of the TRM calculator.

3 METHODOLOGY

Mathematically, the $2m+1$ point estimation method (PEM) is a special method to calculate raw moments of a function of multiple random variables with each having its probabilistic distribution or statistical characteristics. In the case of TTC, the multiple variables are the parameters representing system conditions including system load, outputs of generating units and tie-line flows, whereas the function is an hourly, daily or weekly TTC. Once the first and second raw moments of TTC are estimated using the $2m+1$ PEM, the standard deviation of TTC can be easily obtained.

The $2m+1$ PEM includes two phases. In the first phase, it takes as inputs the TTC base case (forecasted data) and uncertainty patterns of the parameters to generate $2m+1$ evaluation points (called locations) and corresponding weighting factors. The TTC values at the evaluation points of the parameters are evaluated by a TTC calculator. In the second phase, the evaluated TTC values and weighting factors are combined to compute the standard deviation of TTC.

In the deterministic TTC evaluation, a set of forecasted values of parameters from the TTC base case is used to calculate hourly, daily or weekly TTC value. The TTC base case corresponds to one evaluation point, which is referred as the *base point* and is the mean value of TTC. The purpose of the TRM calculator is to calculate the uncertainty (standard deviation) around the base point. This base point plays an important role in generating other evaluation points.

For each parameter X_t , three values $x_{t,1}, x_{t,2}, x_{t,3}$ referred as locations are determined by

$$x_{t,k} = \mu_t + \sigma_t \xi_{t,k}, \quad k = 1, 2, 3$$

where μ_t and σ_t are the mean and standard deviation of parameter X_t , respectively. The variables $\xi_{t,k}$ which are called standard locations are computed by

$$\xi_{t,k} = \frac{\lambda_t}{2} + (-1)^{3-k} \sqrt{\kappa_{t,4} - \frac{3}{4} \lambda_t^2}, \quad k = 1, 2 \quad (1)$$

$$\xi_{t,3} = 0$$

where λ_t and κ_t are skewness and kurtosis of parameter X_t .

By replacing the value corresponding to parameter X_t in the base point with $x_{t,k}$ ($k=1,2,3$), three points $p_{t,1}$, $p_{t,2}$, and $p_{t,3}$ for X_t are generated. Their corresponding weighting factors are calculated by

$$\omega_{t,k} = (-1)^{3-k} \frac{1}{\xi_{t,k} (\xi_{t,1} - \xi_{t,2})}, \quad k = 1, 2$$

$$\omega_{i,3} = \frac{1}{m} - \frac{1}{\kappa_i - \lambda_i^2}$$

It can be seen that for each parameter, one of the three locations is nothing else than its mean value, which is the same as the base point. Therefore, the total number of different points to be evaluated is reduced to $2m+1$ from $3m$.

These $2m+1$ points are sent to a TTC calculator for estimating TTC values. When the TTC calculator returns the values, the following formulas are used to estimate the standard deviation of TTC.

$$r_k \approx \sum_{i=1}^{2m+1} TTC(p_i)^k \omega_i, \quad k = 1, 2.$$

$$\sigma_{TTC} = \sqrt{r_2 - r_1^2}.$$

where $TTC(p_i)$ is the evaluated value of TTC at point p_i , r_k is the k -th raw moment of TTC, and σ_{TTC} is the standard deviation of TTC.

When the $2m+1$ PEM is applied to estimate the standard deviation of TTC, several practical issues must be considered and resolved. First, the value under square root of equation (1) must be positive. The original reference [2] suggested some restrictions on the probabilistic distributions of variables in order to meet this condition. In fact, we proved mathematically that this condition is always met regardless of distributions of parameters. Second, each parameter has its own operational or physical limits (bounds) but locations computed may be beyond such limits. A power transformation method is used to convert original data samples into new samples whose locations can be guaranteed to be within the bounds. Finally, there may be a correlation between parameters (such as outputs of generating units). The original $2m+1$ PEM does not automatically deal with the correlation. A linear transformation method based on Cholesky decomposition of the covariance matrix of parameters is used to resolve this issue. The details of these issues and solutions are documented in a separate report [3].

The $2m+1$ PEM takes as input the uncertainty pattern of each parameter characterized as its mean, standard deviation, skewness and kurtosis. Unfortunately, complicated factors contributing to historical data make it difficult to extract uncertainty patterns from historical records. Based on considerable analyses of historical data, it has been found that sample data of parameters (system load, outputs of generating units and tie-line flows) contain both deterministic and random patterns. An appropriate technique is developed to separate these two patterns so that a set of samples only for random pattern of each parameter can be constructed. This data processing technique greatly improved accuracy in estimation. The models and techniques for data processing are also documented in another separate report [4].

4 TRM CALCULATOR

This section describes the architecture of the TRM calculator. The PI server, TTC calculator, input files and output files are outside the TRM calculator. The relationships between these four entities and the TRM calculator are shown in Figure 1. The functionalities of the TRM calculator are also presented in Figure 1.

Inside the TRM calculator, there are two modules, namely, the data processor and $2m+1$ PEM. The data processor is responsible for outputting a set of samples for each parameter. It retrieves raw data from the PI server and TTC base case (forecasted) data from an input file outside the TRM calculator. The $2m+1$ PEM module takes care of generating evaluation points and weighting factors in the first phase and computing the standard deviation of TTC in the second phase.

Users are requested to enter some setting information at the beginning. This is called configuration. Once the configuration is done, the calculator automatically starts a control flow from the data processor module. The data processor verifies availability of data in a local database and retrieves unavailable data from the PI server. The raw data from the PI server is transformed to the data in the needed format for constructing samples of parameters. Then a data cleansing routine is automatically called to clean up transformed data. This will ensure the quality of data. After data cleansing is completed, a data processing method is performed to generate a set of samples of parameters.

After the data processing is completed, the calculator brings the $2m+1$ PEM module into effect. In the first phase, several processes are performed including basic $2m+1$ point estimations, treatment of bounded domain of parameters, and transformation calculations for correlation between parameters. The outputs from the first stage calculations are $2m+1$ evaluation points for selected parameters and their corresponding weighting factors. When the first phase is completed, the TRM calculator is suspended while waiting for the multiple TTC values that will be calculated from a TTC calculator outside the TRM calculator.

The TTC calculator evaluates TTC values at the $2m+1$ points provided by the TRM calculator. After these TTC values are handed over back to the TRM calculator, the second phase of the $2m+1$ PEM module is conducted. In this phase, it calculates the standard deviation of TTC using the returned multiple TTC values from the TTC calculator and the weighting factors generated in the first phase. The standard deviation value of TTC will be stored in the final output file. At this point, the TRM calculator finishes one cycle of calculation.

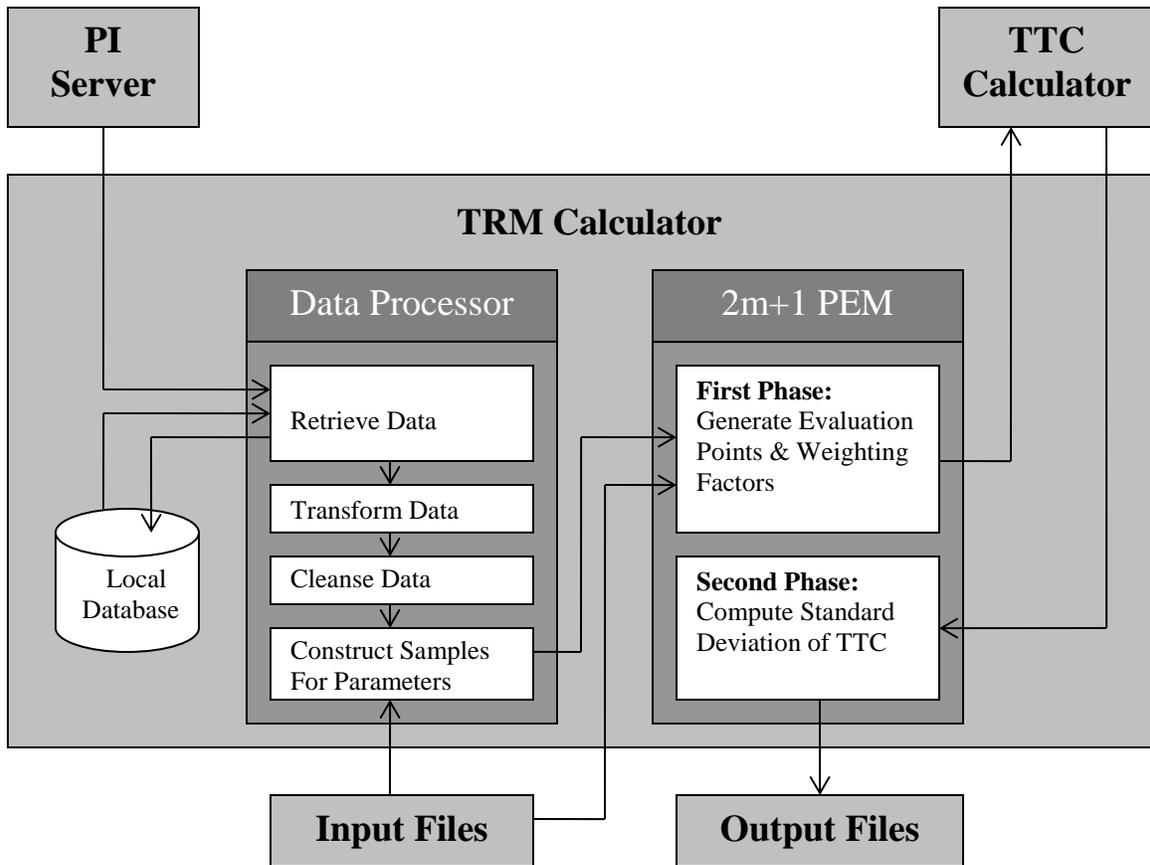


Figure 1: Architecture of TRM Calculator

5 DATA PROCESSING

In the new TTC calculator under development, hourly, daily, and weekly TTCs are considered. Hourly TTC at a given hour is defined as the TTC value corresponding to a set of system conditions at the hour. Daily/weekly TTC at the high/low load for a given day/week is defined as the hourly TTC at the hour with the highest/lowest system load level in the day/week. It can be seen that the TTC is always evaluated at a specific hour, which is referred as the *TTC hour*. Therefore, the technique of estimating statistics of each parameter for hourly TTC can also be applied to daily and weekly TTC.

In estimating the statistics of each parameter at the TTC hour using the additive model [4], the most important task is to construct a set of samples for the random part of each parameter at the TTC hour using historical data. A set of samples for each parameter itself is also needed.

To get a set of samples desired, the following steps are performed [4]:

- 1) Select a TTC type (hourly, daily or weekly TTC) and the TTC hour at which the TTC and TRM are to be determined, and identify the time window of historical data (sample range) according to the TTC type selected. For hourly TTC, the historical data from most recent 15 days can be used. For daily or weekly TTC, a time window in a season similar to the season of the TTC hour should be used to minimize the impact caused by seasonal factors.
- 2) Identify a list of parameters according to the TTC type, the historical data source and the forecasted values (in the base case) at the TTC hour for each parameter in the list. Different parameters (outputs of different generating units or generating unit groups) may be considered for different TTC types. For each parameter in the list, a data source should be specified in such a way that historical data for the parameter can be retrieved from the PI servers. A data source is a set of PI *raw points* with unique tags in the PI server
- 3) Retrieve, transform, and cleanse the data for each parameter within the sample range from the data source. Raw data in the PI server is recorded at different time intervals while the timeframe considered in the TTC calculator and TRM calculator is an hour. Therefore, the raw MW data is converted to hourly MW data. Also, a parameter may not directly correspond to a single tag in the PI server. If it represents a group of several units, its value per hour is the sum of values from the group members. Hence, the MW data for all such parameters in the specified time range are transformed into a consistent format of MW per hour. Raw data from the PI server is not clean and comes with outliers and corrupted portions. Bad data will cause severe troubles in subsequent statistical computations. A data cleansing routine is called to clean the transformed data. The routine fixes corrupted information and removes outliers.
- 4) Construct samples of the random part for each parameter at the TTC hour. First, a set of hours related to the TTC hour, which are referred as *sample hours*, is selected. Different TTC types have different selection criteria for sample hours. For a set of parameter values in sample hours of a parameter, the deterministic

part of each value is estimated and then this part is subtracted from the value to obtain the random part of the value. A set of samples for the random part of the parameter at the TTC hour is constructed.

- 5) Construct samples for actual value of each parameter at the TTC hour. According to the additive model, a set of samples for a parameter can be constructed from the forecasted value in the base case and samples of its random part at the TTC hour as follows: a) Compute the mean μ of samples of the random part; b) For each sample of random part, add the forecasted value to it and subtract μ from it.

The Figure 2 shows the process flow with the five steps. The first two steps are conducted by user's entries on the interface screen, whereas the last three steps are automatically completed by the TRM calculator.

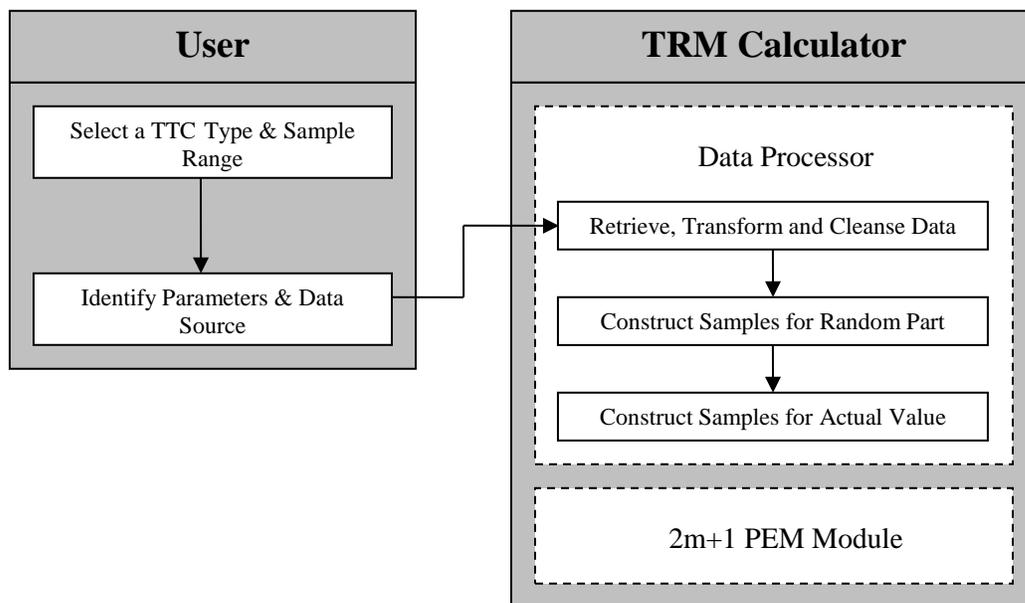


Figure 2: Data Process

6 TYPICAL STUDY USING BC HYDRO SYSTEM DATA

One of the most important tasks in the TRM project is to calculate the standard deviation of hourly, daily and weekly TTCs using the developed methods, process, TRM calculator program and BC Hydro system data. This section describes the data and results in calculating the standard deviation of typical hourly, daily and weekly TTCs on the inter-tie for export from BCH to USA. The existing TTC calculator does not calculate TTC values on other inter-ties and the TTC for import. The study includes 7 cases in which 3 cases are for hourly TTCs with high, median and low system load levels, 2 cases are for daily TTCs with high and low system load levels, and 2 cases for weekly TTCs with high and low load levels. In the hourly TTC case, the high, median and low load levels refer to the highest, median and lowest load in a typical period. In the daily and weekly TTC cases, the high load level refers to the maximum load in that day or week, whereas the low load level refers to the minimum load in that day or week. The standard deviation of TTCs can be used as references in determining TRM.

6.1 Data

The parameters considered for all the cases are the same, namely, the system total load tagged by BCH-Load, two tie-line export flows tagged by BC-US export and BC-AB export, and MW outputs of all 40 major generating plants in the BC Hydro system tagged by ALU, SFL, RUS, LB1, CMS, COM, LAJ, BR, SON, SCA, LDR, JHT, PUN, ASH, JOR, GMS, PCN, SEV, KCL, MCA, REV, WGS, SHU, WHN, RPG, BUT, MCM, NEW, SOR, WDN, AKO, MAM, BBH, DTR, BRL, SCG, ABN, ELK, SPN, ALH. The data source of each parameter can be found in Appendix of Reference [4]. The MW tags in the PI server are used.

A typical hour in the winter period 2010 in each case was selected as the TTC hour and the forecasted value at the TTC hour was picked up from the corresponding historical records in the PI server. The shifting value [4] is set to 2 for hourly TTC and 1 for daily/weekly TTC. The input information for the 7 cases is presented in Table 4.

Table 4: Input information for the 7 Cases

Case Name	Sample Range	TTC Type	TTC Hour	Objective
hourly-high	22-Nov-2010 ~ 06-Dec-2010	hourly	07-Dec-2010 06:00 PM	Study the hourly TTC at a relatively high system load level
hourly-median			07-Dec-2010 09:00 AM	Study the hourly TTC at a relatively median system load level
hourly-low			07-Dec-2010 02:00 AM	Study the hourly TTC at a relatively low system load level
daily-high	29-Nov-2009 ~ 19-Dec-2009	daily	07-Dec-2010 05:00 PM	Study the daily TTC at the highest load for the day 07-Dec-2010
daily-low			07-Dec-2010 02:00 AM	Study the daily TTC at lowest load for the day 07-Dec-2010
weekly-high	29-Nov-2009 ~ 21-Feb-2010	weekly	06-Dec-2010 05:00 PM	Study the weekly TTC at the highest load for the week 05~11 of December 2010

weekly-low			09-Dec-2010 03:00 AM	Study the weekly TTC at the lowest load for the week 05~11 of December 2010
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6.2 Result

An hourly TTC at the high/median/low load level is the TTC value computed under the system condition for the given TTC hour. The system condition is characterized by input values of the parameters (system load, outputs of generating plants and tie-line flows) at the selected TTC hour. A daily/weekly TTC at the high/low load level is the hourly TTC computed from the input values of the parameters at the hour with the highest/lowest system load level in that day/week.

The standard deviations of hourly, daily and weekly TTCs on the inter-tie export from BCH to USA in the 7 cases are calculated using the developed TRM calculator and the BC Hydro system data listed above. The results of the 4 cases at the high or median load levels are shown in Table 5. The standard deviations of hourly/daily/weekly TTCs at the low load level are all zero and are not presented in the table. This is because when the system load level is very low, the uncertainties of system parameters do not have any impact on the TTC that is calculated from the TTC calculator, which is always fixed at the physical thermal limit of 3150 MW.

In Table 5, the column “mean” corresponds to the TTC values at the base points. The column “1.0 σ ” corresponds to the standard deviations estimated. The columns “1.5 σ ”, “2.0 σ ”, “2.5 σ ” and “3.0 σ ” show the values of the standard deviation multiplying factor 1.5, 2.0, 2.5 and 3.0, respectively. The percentage in the bracket indicates the probability that the TTC is not smaller than the value of the mean TTC minus the product of the standard deviation of that TTC and the corresponding factor if a normal distribution of the TTC is assumed. For example, the probability that the hourly TTC in high load is not smaller than $2089 - 46.39 = 2042.61$ MW is 84.2%. For another example, the probability that the hourly TTC in high load is not smaller than $2089 - 139.17 = 1949.83$ MW is 99.9%. The percentages below other column titles have similar meanings. Note that the probability that the TTC is not smaller than the mean TTC value is 50%.

The standard deviation of the TTC values can be used as a reference to TRM in the following two ways:

- 1) The same TRM is used for firm TTC and non-firm TTC and it can be selected to be a value corresponding to 1.0 σ , 1.5 σ , 2.0 σ , 2.5 σ , or 3.0 σ depending on the willingness of accepting a different risk level.
- 2) The different TRM values are used for firm and non-firm TTC considering they are associated with different risk levels. For example, the mean TTC value which is calculated at the base point (under the system condition in the base case) can be used as a non-firm TTC with a higher risk (50% probability to be violated), whereas the TTC at a selected level of 1.0 σ to 3.0 σ can be used as a firm TTC with a lower risk.

Table 5: Standard deviations of TTC at BCH-USA inter-tie (unit: MW)

Case	mean value	1.0 σ (84.2%)	1.5 σ (93.3%)	2.0 σ (97.8%)	2.5 σ (99.4%)	3.0 σ (99.9%)
hourly TTC in high load	2089	46.39	69.58	92.78	115.97	139.17
hourly TTC in median load	2669	34.57	51.86	69.15	86.44	103.72
daily TTC in high load	2031	54.65	81.97	109.30	136.62	163.95
weekly TTC in high load	1812	59.78	89.67	119.56	149.45	179.34

7 CONCLUSIONS

In the TRM Calculator project, the $2m+1$ point estimation method (PEM) is studied, improved and applied to estimate the standard deviation of TTC due to uncertainties of system parameters (forecasted system load, generation patterns and operational response). The effective models and techniques are proposed to process historical data and extract uncertainty patterns of the parameters. A program with a friendly user interface is designed and developed.

The standard deviations of typical hourly, daily and weekly TTCs for the export on the BCH-USA inter-tie are calculated using the developed TRM calculator and BC Hydro system data in the 2010 winter period. These results provide the reference information in determining the TRM values or firm and non-firm TTC values on the BCH-USA inter-tie.

REFERENCES

- [1] Li, W. “Probabilistic method for estimating TTC variation ranges caused by uncertainties of load, generation and operational response.” *BCTC Report: SPPA-R016A*. January 12, 2010.
- [2] Hong, H. P. “An efficient point estimate method for probabilistic analysis.” *Res. Eng. and Sys. Safety*, 59(3), 261-167, 1998.
- [3] Lin, Z., and Li, W. “ $2m+1$ point estimate method and its application in TRM calculations.” *BC Hydro Report: BCH-ARPM-R2*, February 25, 2011.
- [4] Lin, Z., and Li, W. “TRM calculator: uncertainty modeling and processing of parameter data.” *BC Hydro Report: BCH-ARPM-R3*, February 25, 2011.
- [5] Lin, Z., and Li, W. “TRM calculator: process manual.” *BC Hydro Report: BCH-ARPM-R4*, February 25, 2011.
- [6] Lin, Z., and Li, W. “TRM calculator: user manual.” *BC Hydro Report: BCH-ARPM-R5*, February 25, 2011.
- [7] Lin, Z. “TRM calculator: programmer manual.” *BC Hydro Report: BCH-ARPM-R6*, February 25, 2011.

APPENDICES: FILES AND REPORTS

Appendix I: Files for Seven Cases

The data and result files used in the case studies are attached to this report. Below are file names and related information.

Table 6: Files for 7 Cases generated in the first phase of 2m+1 PEM

Case	Location File Name (Sent to TTC calculator for evaluation)	Weighting Factor File Name
hourly-high	LrbTtc_20101205-additive-hourly-15d-2s-High.txt	LrbTtc_20101205-additive-hourly-15d-2s-High-weight.txt
hourly-median	LrbTtc_20101205-additive-hourly-15d-2s-Median.txt	LrbTtc_20101205-additive-hourly-15d-2s-Median-weight.txt
hourly-low	LrbTtc_20101205-additive-hourly-15d-2s-Low.txt	LrbTtc_20101205-additive-hourly-15d-2s-Low-weight.txt
daily-high	LrbTtc_20101205-additive-daily-3w-High.txt	LrbTtc_20101205-additive-daily-3w-High-weight.txt
daily-low	LrbTtc_20101205-additive-daily-3w-Low.txt	LrbTtc_20101205-additive-daily-3w-Low-weight.txt
weekly-high	LrbTtc_20101205-additive-weekly-3m-High.txt	LrbTtc_20101205-additive-weekly-3m-High-weight.txt
weekly-low	LrbTtc_20101205-additive-weekly-3m-Low.txt	LrbTtc_20101205-additive-weekly-3m-Low-weight.txt

Table 7: Files of the TTC results from the TTC Calculator

Test Case	TTC Results Returned From TTC Calculator
hourly-high	bpa_20101205-additive-hourly-15d-2s-High-locations.xls
hourly-median	bpa_20101205-additive-hourly-15d-2s-Median-locations.xls
hourly-low	bpa_20101205-additive-hourly-15d-2s-Low-locations.xls
daily-high	bpa_20101205-additive-daily-3w-High-locations.xls
daily-low	bpa_20101205-additive-daily-3w-Low-locations.xls
weekly-high	bpa_20101205-additive-weekly-3m-High-locations.xls
weekly-low	bpa_20101205-additive-weekly-3m-Low-locations.xls

Table 8: Files of the standard deviations of TTC for the 7 cases

Test Case	Files of Standard Deviations of TTC
hourly-high	bpa_20101205-additive-hourly-15d-2s-High-trm.txt
hourly-median	bpa_20101205-additive-hourly-15d-2s-Median-trm.txt
hourly-low	bpa_20101205-additive-hourly-15d-2s-Low-trm.txt
daily-high	bpa_20101205-additive-daily-3w-High-trm.txt
daily-low	bpa_20101205-additive-daily-3w-Low-trm.txt
weekly-high	bpa_20101205-additive-weekly-3m-High-trm.txt
weekly-low	bpa_20101205-additive-weekly-3m-Low-trm.txt

Appendix II: Report Lists

Table 9: Reports

Report No	Report Title	Description
SPPA-R016A	Probabilistic Method for Estimating TTC Variation Ranges Caused by Uncertainties of Load, Generation and Operational Response	Scope of the project and proposed methods for probabilistic TTC and TRM
BCH-ARPM-R1	Project Report	The summary and report of the project
BCH-ARPM-R2	$2m+1$ Point Estimate Method and Its Application in TRM Calculations	The $2m+1$ PEM, several special issues and their solutions
BCH-ARPM-R3	Uncertainty Modeling and Processing of Parameter Data	The models and techniques for processing historical data and extracting uncertainty patterns
BCH-ARPM-R4	Process Manual	The design of the TRM calculator
BCH-ARPM-R5	User Manual	A detailed guide for users to run the calculator
BCH-ARPM-R6	Programmer Manual	The specification of the software