BC Hydro’s Transmission Reliability Margin Assessment in Total Transfer Capability Calculations

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Abstract—NERC requires considering the uncertainties in assessing the total transmission capability (TTC) by calculating a term called transmission reliability margin (TRM). As part of a new BC Hydro TTC calculator, an improved $2m + 1$ point estimation based method (PEM) was developed to estimate the standard deviation of TTC due to the uncertainties of system parameters including forecasted system load, generation patterns, inter-tie schedules and change in projected load and dispatch conditions as a result of system stress. The standard deviation of TTC is used to determine TRM. The developed method has now been accepted as part of new BC Hydro’s TTC calculator for determining TRM in real-time and pre-scheduling timeframes. Typical results on BC Hydro’s large scale system, which were obtained using the developed TRM method, are presented in this paper. The presented TRM method has already been filed as an attachment to a BC Hydro’s report to NERC for meeting the mandatory reliability compliance.

Index Terms—NERC reliability standards, point estimation method, total transfer capability, transmission reliability margin, uncertainty.

I. INTRODUCTION

Total transfer capability (TTC) is defined as the amount of electric power that can be transferred over a path or interconnected transmission network in a reliable manner. Similarly, available transmission capability (ATC) is the amount of capacity left on a specific path that can be made to provide transmission service.

North American Electric Reliability Corporation (NERC) has mandated [1] the utilities to publish ATC on their inter-ties to facilitate electricity transactions between different utilities. Utilities need to publish this information on the two time frames of “real-time” and “pre-scheduling”. The real-time schedule covers a few hours (e.g., 12 hours) starting the current hour, whereas pre-scheduling covers three different time frames of:

- Hourly ATC calculations for about a week (e.g., 168 hours)
- Daily ATC calculations (peak and off-peak) for about one month (e.g., 30 days)
- Weekly ATC calculations (peak and off-peak) for about one year (e.g., 52 weeks)

The ATC values calculated are posted on the Transmission Market Site called OASIS (Open Access Same Information System) for transmission reservations on a first-come, first-served basis.

As mentioned earlier, ATC is defined as the remaining transfer capacity in a transmission system for commercial activity and is calculated by [2]

$$ATC = TTC - TRM - CBM - ETC$$

where $TTC$ refers to total transfer capability, $TRM$ refers to transmission reliability margin, $CBM$ refers to capacity benefit margin, and $ETC$ refers to existing transmission commitment (base power flow).

Obviously, in addition to ETC which is known value for each operation state, TTC, TRM and CBM need to be estimated to obtain ATC. The NERC reliability standard MOD-008 [3] requires that various uncertainties of system conditions be considered in TTC and TRM calculations, whereas CBM can be generally specified based on utility’s market model. The uncertainty factors can be classified into four categories: uncertainties in load forecast, generation patterns, operational responses (inter-ties schedules) and random outages of system components. The requirements of NERC provide the guidelines for TTC and TRM calculations.

Many methods for calculating TTC have been developed [4]–[9]. Some of the methods considered the N-1 contingencies whereas others did not. Majority of the TTC calculation methods are based on steady state analysis using power flow or optimal power flow but do not include the limits due to voltage instability and transient instability. All the limits of thermal restriction, voltage stability and transient stability should be included in TTC calculations. Because the system conditions as input data are uncertain, TTC as an output holds uncertainty. TRM is a necessary margin to take care of this uncertainty. Several probabilistic approaches were used to evaluate TRM [10]–[12]. These approaches modeled the uncertainty of load forecast but did not address the uncertainties in other aspects such as generation patterns and operational responses. In these approaches, either a bootstrap technique [11] or Monte Carlo simulation [12] is used to create system operation states. These methods require considerable computing time and may not be applicable to real time or hourly TTC calculations.

This paper presents a $(2m + 1)$ point estimation method to evaluate the uncertainty of TTC, based on which TRM can be determined. The presented method has the following features:

- Thermal limits, voltage stability and transient stability are all incorporated in TTC calculations.
- All the uncertainties in load forecast, generation patterns, operational responses and system component random outages are considered.

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The uncertainties of input parameters are dynamically and statistically modeled using immediate historical records and no parametric probability distribution assumption is required.

Only three separate points on the distribution of each input parameter are needed, which leads to computational efficiency and is particularly appropriate to real-time TTC application.

To our best knowledge, the above features are addressed in calculating TRM for the first time. These are the main contributions of the paper. Section II describes a TTC calculation tool. Section III illustrates the modeling technique for the uncertainties of input parameters, and Section IV presents the point estimation method (PEM) for calculating the mean and standard deviation of TTC. Section V provides an application to BC Hydro system, followed by conclusions in Section VI.

II. TTC CALCULATIONS

TTC represents the maximum power flow on an inter-tie considering the system operating limits during normal conditions and N-1 contingencies. At BC Hydro, the system operating limit is calculated as the minimum of the thermal, transient stability and voltage stability limits. BC Hydro has developed a customized application on its Energy Management System to calculate TTC values. The following process is used to calculate TTC:

1) Develop the system conditions reflective of the scenarios to be studied. This would need:
   a) load forecast;
   b) generation forecast and generation dispatch;
   c) inter-tie schedules;
   d) transmission and generation outages.

2) Simulate system conditions with N-1 critical contingencies to determine:
   a) static security limits ensuring that the thermal limits and voltage profiles are respected;
   b) transient stability limits;
   c) voltage stability limits.

3) Calculate the TTC limits using the smallest of the three limits.

It should be noted that in step 2, the system base case needs to be stressed by increasing system load and developing a corresponding generation dispatch. This adds another element of uncertainty. The deterministic process for calculating TTC is shown in Fig. 1, whereas the probabilistic process is depicted in Fig. 2. The deterministic process has been implemented in a TTC calculator at BC Hydro’s control center for years.

III. MODELING UNCERTAINTIES OF INPUT PARAMETERS

A. Basic Concepts

As discussed in Section II, the effects of system component random outages, i.e., N-1 or N-1-1 contingencies, have been incorporated in the TTC calculation module. The remaining uncertainties are those in load forecast, generation patterns and operational response (inter-tie schedules). The load uncertainty refers to a random variation around its forecasted mean. The generation uncertainty may include two random factors: 1) Generation allocation among generators, which can be represented by a percentage of a generator’s output with regard to the total system generation; this factor, which represents the “stress direction” in a generation space, is associated with both random sources (such as water levels) and specified rules (such as operational criteria). 2) Random fluctuation of each generator’s output at a generation level. The operational response includes automatic frequency control, which may be represented by tie-line flows. When the TTC on a tie-line is calculated, flows on other tie lines, which have sort of uncertainty, are parts of input parameters.

We call an input variable (including load, each generator’s output, its percentage in the total system generation and tie-line flow) as an input parameter in TTC calculations in the following discussions. It can be assumed that the uncertainty characteristic of each parameter in a future time point follows the same probability distribution as that in the corresponding past time points. To calculate the standard deviation of TTC for a specific time in the future, the first step is to model and estimate the uncertainty...
pattern characterized as mean, standard deviation, skewness and kurtosis of each parameter using immediate historical data.

In the TTC module, hourly, daily and weekly TTCs can be calculated. Hourly TTC for a given hour is defined as the TTC value corresponding to a set of system conditions at that hour. Daily/weekly TTC at the high/low load level for a given day/week is defined as the TTC at the hour with the highest/lowest system load level in that day/week. Therefore, the TTC is always evaluated at a specific hour, which is referred to as the TTC hour. The technique of estimating statistics of each parameter for hourly TTC is also applied to daily and weekly TTC except that the input data sequences are different.

The statistical moments (mean, deviation, skewness and kurtosis) of a parameter can be calculated using a standard statistical method and recorded values at the same hours as the TTC hour for all days in a short time range in history. For example, if the hourly TTC for 9 o’clock today is considered, the recorded values of a parameter at 9 o’clock in each of last 15–20 days are used as samples for estimating the moments of the parameter at 9 o’clock today. However, the parameters are not completely random in nature. There are deterministic factors contributing to their behaviors such as increase or decrease of system load due to periodic behaviors of human being’s activities or effects of dispatching strategy on generating unit outputs. For instance, the system load at noon is generally higher than that at midnight, in weekday higher than in weekend, and in winter higher than in summer (or vice versa depending on geographical location). The generation dispatching plan depends on not only water levels (random) but also on pre-specified rules (deterministic). The deterministic factors affecting forecasted mean values of load or generator’s output or generation stress direction are assumed not to impact the random uncertainty around the mean values of the parameters. In estimating the uncertainties of the parameters, the deterministic impacts should be filtered so that only the randomness is captured.

The actual value of a parameter at a given hour is composed of two parts. One is the deterministic part contributed by deterministic factors at that hour. The other is the random part due to random factors at the same hour. It is reasonable to assume that the random parts of the actual values at the same hour of different days follow the same distribution. The assumptions based on this insightful observation enable us to estimate the moments of a parameter at a TTC hour using its historical data. To deal with uncertain factors, it is a commonly accepted idea to use historical data that contains uncertain information. Historical data have been used to deal with uncertainties in load forecasting for many years.

B. Additive Model

The deterministic and random parts of a parameter are modeled as two additive factors contributing to the actual value in the additive model. Given any hour \( i \) (in the history or future), the following relationship holds:

\[
X(i) = D(i) + R(i) \tag{2}
\]

where \( X(i) \), \( D(i) \) and \( R(i) \) are the actual value, its deterministic part and random part at hour \( i \), respectively.

For each parameter, the following steps are performed:
1) Select \( s \) days in which historical data for the parameter is available. The same hour as \( i \) of each selected day is called sample hour. The number of days \( (s) \) and which days to be selected depend on the TTC type. For hourly TTC, the historical data from most recent 15–20 days can be used. For daily or weekly TTC, a time window having a seasonal condition similar to that containing the TTC hour should be used to minimize the impact caused by seasonal factors. For example, for daily TTC, a time window of 3 weeks in the same season as that containing the TTC hour in the present year could be considered. For weekly TTC, a time window with 3 months (12 weeks) in the same season as that containing the TTC hour in last year could be considered. According to the NERC requirement [3], 52 weekly TTCs in a year need to be calculated.

2) For each sample hour, its deterministic part is estimated. If hour \( i \) is an hour in daytime (6:00 AM–10:00 PM), the deterministic part is estimated by the average of the actual values at all hours in the daytime of that day; if hour \( i \) is an hour at night (12:00 AM–6:00 AM and 10:00 PM–12:00 AM), the deterministic part is estimated by the average of the actual values in all hours at night of that day. Such estimation is based on the fact that deterministic factors for daytime (night) hours of the same day should be similar.
3) For each sample hour, its random part is calculated by subtracting the deterministic part from the actual value at the hour.

Once a set of samples of the random part at hour \( i \) is obtained, the mean, standard deviation, skewness and kurtosis of the random part of a parameter at hour \( i \) can be calculated using the following equations [13]:

\[
\mu_R = E(R) = E(X) - D \tag{3}
\]

\[
\sigma_R^2 = E[(R - \mu_R)^2] = \sigma_X^2 \tag{4}
\]

\[
\lambda_R = \frac{E[(R - \mu_R)^3]}{\sigma_R^3} = \lambda_X \tag{5}
\]

\[
\kappa_R = \frac{E[(R - \mu_R)^4]}{\sigma_R^4} = \kappa_X \tag{6}
\]

where \( \mu_R, \sigma_R, \lambda_R \) and \( \kappa_R \) are the mean, standard deviation, skewness and kurtosis of the random part of a parameter, respectively; \( \sigma_X, \lambda_X \) and \( \kappa_X \) are the standard deviation, skewness and kurtosis of a parameter, respectively; \( X \) and \( R \) represent the random variables of a parameter and its random part, respectively; \( D \) is the deterministic part of a parameter; \( E(\cdot) \) denotes finding a mean value of (\( \cdot \)) using the regular sample mean concept.

The statistical standard deviation, skewness and kurtosis of a parameter, along with its mean which is the forecasted value for the base case (a normal system state) at the TTC hour \( i \) in the future, are the statistics of the parameter that are required by using the \((2m + 1)\) PEM, which will be discussed in Section IV.

C. Processing Historical Data

To estimate the statistics of a parameter (load, each generator’s output, its percentage in the total system generation, or a tie-line flow) in a TTC hour using the additive model, the most
important task is to construct a set of samples for the random part of the parameter at the TTC hour using historical data. Processing historical data of each parameter includes the following steps:

1) Identify the time window of historical data (sample range) for a TTC type (hourly, daily or weekly) and a given TTC hour.

2) Determine a list of parameters according to the TTC type and the forecasted value at the TTC hour for each parameter in the list. Note that some generators may not run or must run at a fixed output for the selected TTC hour due to maintenance/operational consideration, and therefore the corresponding parameters at that TTC hour are deterministic values without randomness.

3) Retrieve and cleanse the data within the sample range from the data source for each parameter. It is important to appreciate that invalid or damaged records may exist in historical data. It is necessary to filter these bad data. The data cleansing techniques have been presented [14], [15] and the computer software for this purposes has been developed at BC Hydro [16].

4) Construct samples of the random part of each parameter at the TTC hour using the additive model.

5) Calculate samples of the actual value of each parameter at the TTC hour by using its forecasted mean value $[\mu_t]$ in (7)] and estimated standard deviation, skewness and kurtosis of the parameter. These samples are the input data for the $(2m + 1)$ PEM which is discussed in the next section.

IV. TRM Determination

A. Estimating the Standard Deviation of TTC by $(2m + 1)$ PEM

Point estimation methods (PEM) are a family of techniques that are used to calculate raw moments of a function of multiple random variables with each having its probabilistic distribution or statistical characteristics [17], [18]. The $(2m + 1)$ PEM is a special point estimation method, in which the function is evaluated at only three values of each input variable and one of the three values is common for all input variables and therefore the function is calculated only $2m + 1$ times where $m$ is the number of input variables. It has been proved that the $(2m + 1)$ PEM is most accurate and efficient point estimation method in power system analysis [19], [20].

The $2m+1$ PEM for estimating the standard deviation of TTC includes two phases. In the first phase, it takes the TTC base case with forecasted data and raw moments of the parameters for a TTC hour as inputs to generate $2m + 1$ evaluation points (called locations) and corresponding weighting factors. The method of calculating these moments has been illustrated in Section III. The TTC values at the evaluation points of the parameters are computed by a TTC calculator which is described in Section II. In the second phase, the calculated 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 called as the base point and is the mean value of TTC. Our purpose is to calculate the uncertainty (standard deviation) of TTC around the base point so that TRM can be determined. This base point plays an important role in generating other evaluation points. For each parameter $X_t$, where the subscript $t$ indicates the $t$th one of $m$ parameters, three values $x_{t,1}$, $x_{t,2}$, $x_{t,3}$ referred as locations are determined by

$$x_{t,k} = \mu_t + \alpha_t \xi_{t,k}, \quad k = 1, 2, 3 \quad (7)$$

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

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

$$\xi_{t,3} = 0 \quad (8)$$

where $\lambda_t$ and $\kappa_t$ are skewness and kurtosis of parameter $X_t$.

The weighting factors corresponding to the three values $x_{t,1}$, $x_{t,2}$, $x_{t,3}$ are calculated by

$$\omega_{t,k} = \frac{(-1)^{3-k} \xi_{t,k} (\xi_{t,1} - \xi_{t,2})}{1 - \xi_{t,3}} \quad k = 1, 2 \quad (9)$$

$$\omega_{t,3} = \frac{1}{m} - \frac{1}{\kappa_t - \lambda_t^2} \quad (10)$$

where $m$ is the number of input parameters (system load, generator’s outputs, generation percentages of generators and tie-line flows). 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 actually reduced to $2m + 1$ from $3m$.

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

$$r_j = \sum_{t=1}^{m} \sum_{k=1}^{3} [TTC(x_{t,k})]^2 \omega_{t,k} \quad j = 1, 2 \quad (11)$$

$$\sigma_{TTC} = \sqrt{r_2 - r_1^2} \quad (12)$$

where $TTC(x_{t,k})$ is the evaluated value of TTC at point $x_{t,k}$, $r_j$ is the $j$th raw moment of TTC, and $\sigma_{TTC}$ is the standard deviation of TTC.

The procedure of the $2m + 1$ PEM for estimating the standard deviation of TTC can be summarized as follows. The system load, outputs of generating units, generation stress directions and tie-line flows are the four groups of random input parameter variables. An hourly, daily or weekly TTC is the function of these random variables, as shown in Fig. 2. The $2m + 1$ PEM method is used to calculate the first and second raw moments of TTC using (11). Once these raw moments are obtained, the standard deviation of TTC is calculated using (12). The three values $x_{t,1}$, $x_{t,2}$, $x_{t,3}$ of each parameter variable to calculate the TTC values and the three corresponding weighting factors $\omega_{t,k}$ ($k = 1, 2$ and $3$) are required in (11) and are calculated from (7), (9) and (10), respectively. $\xi_{t,k}$ required in (7) and (9) are obtained from (8). The other quantities ($\sigma_t$, $\lambda_t$ and $\kappa_t$) required by (7)–(10) are estimated from historical data of the parameter variables using (3)–(6). Note that $\mu_t$ in (7) is the forecasted value of the parameter at a TTC hour.
In applying the $2m + 1$ PEM to estimate the standard deviation of TTC, several practical issues must be considered and resolved. First, the value under the square root of (8) must be positive. [18] suggested some restrictions on the probability distributions of variables in order to meet this condition. In fact, it can be proved mathematically that this condition is always met regardless of distributions of parameters [21]. Thus, there is no restriction on the probability distribution of loads, generator’s outputs, generation percentages of generators and tie-line flows. Second, each parameter (such as generator’s outputs or tie-line flows) has its own physical limits (bounds) in power system operation but locations computed may fall outside such limits. A power transformation method has been developed to convert original data samples into new samples whose locations can be guaranteed to be within the bounds [21]. 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 [21]. The solutions to these issues are not detailed here due to limitation of space. An in-house computer program has been developed for processing input data of the parameters and calculating standard deviations of hourly, daily and weekly TTCs [22].

B. Determining TRM

Once the standard deviation of TTC is estimated, TRM can be directly determined by using a multiple of the standard deviation. Different multiples correspond to distinct risk levels. This will be explained in the example given in Section V. The whole procedure is shown in Fig. 3.

V. APPLICATION TO BC HYDRO SYSTEM

The presented method was applied to the calculations of the standard deviation of typical hourly, daily and weekly TTCs on the inter-tie for the export from BC Hydro system to USA in 2010/2011. The studied system includes the whole BC Hydro system and the equivalent WECC (the region along the west coast of USA) system. The study includes 7 cases in which 3 cases are for hourly TTCs with high, medium 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, medium and low load levels refer to the highest, medium 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.

A. Data

The parameters considered for all the cases include the system total load, two tie-line export flows from BC Hydro system to USA and from BC Hydro to Alberta (a neighbour province), and MW outputs of all 40 major generating plants in the BC Hydro system. The data source of each parameter can be found in [23, Appendix].

A typical hour in the winter period of 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, which is a real time database at the control center of BC Hydro. The input information for the 7 cases is presented in Table I.

B. Results

An hourly TTC at the high/medium/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 BC Hydro to USA in the 7 cases were calculated using the developed TRM calculator and the BC Hydro system data listed above. The results of the 4 cases at the high or medium load levels are shown in Table II. 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 voltage stability and transient stability limits nor cause any overloading on other cut-plane paths, and thus the TTC that is calculated from

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**TABLE I**

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Sample Range</th>
<th>TTC Type</th>
<th>TTC Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>hourly-high</td>
<td>22-Nov-2010 – 07-Dec-2010</td>
<td>hourly</td>
<td>07-Dec-2010 06:00 PM</td>
</tr>
<tr>
<td>hourly-medium</td>
<td>06-Dec-2010</td>
<td>hourly</td>
<td>07-Dec-2010 09:00 AM</td>
</tr>
<tr>
<td>hourly-low</td>
<td>06-Dec-2010</td>
<td>hourly</td>
<td>07-Dec-2010 02:00 AM</td>
</tr>
<tr>
<td>daily-high</td>
<td>29-Nov-2009 – 07-Dec-2009</td>
<td>daily</td>
<td>07-Dec-2010 05:00 PM</td>
</tr>
<tr>
<td>daily-low</td>
<td>19-Dec-2009</td>
<td>daily</td>
<td>07-Dec-2010 02:00 AM</td>
</tr>
<tr>
<td>weekly-high</td>
<td>29-Nov-2009 – 06-Dec-2010</td>
<td>weekly</td>
<td>06-Dec-2010 05:00 PM</td>
</tr>
<tr>
<td>weekly-low</td>
<td>21-Feb-2010</td>
<td>weekly</td>
<td>09-Dec-2010 03:00 AM</td>
</tr>
</tbody>
</table>
the TTC calculator is always fixed at the physical thermal limit of 3150 MW of the tie-line.

In Table II, the column “mean value” corresponds to the TTC values at the base points. The column “1.0σ” corresponds to the standard deviations estimated. The columns “1.5σ”, “2.0σ”, “2.5σ”, and “3.0σ” 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 actual TTC as a random variable 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 the 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 the high load is not smaller than 2089 – 139.17 = 1949.83 MW is 99.9%.

There are the concepts of firm and non-firm TTC in power market operations. A firm TTC means that the TTC cannot be exceeded; otherwise, a penalty will apply according to a power trading agreement. A non-firm TTC means that the TTC may be exceeded in an emergency situation for system security. The standard deviation of the TTC values can be used as a reference to determine TRM for the two types of TTC in the following two ways:

1) If the same TRM is used for both firm TTC and non-firm TTC, it can be selected to be a value corresponding to 1.0σ, 1.5σ, 2.0σ, 2.5σ, or 3.0σ, depending on the willingness of accepting a different risk level. If a larger TRM value is used, it can cover a larger risk range and may not need to be updated for a relatively long period. However, this will lead to an economic loss because a larger TRM means a smaller ATC.

2) In many actual cases, different TRM values are used for firm and non-firm TTC since they are associated with different risk requirements. For example, the mean TTC value that 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, whereas the TTC at a selected level of 1.0σ to 3.0σ can be used as a firm TTC with a lower risk.

The TRM value on the BC Hydro-USA tie line that BC Hydro has used was based on statistical records of fluctuations of actual flows on the tie-line and was determined to be 50 MW. It can be seen that this value is basically consistent with the calculated hourly and daily TTC values with 1.0σ in Table II. This verified the effectiveness of the presented method and the results.

VI. CONCLUSIONS

NERC requires considering the uncertainties in assessing the TTC by calculating a term called TRM. As part of a new BC Hydro TTC Calculator, an improved 2m + 1 point estimation based method (PEM) was developed to estimate the standard deviation of TTC due to the uncertainties of system parameters including forecasted system load, generation patterns, inter-tie schedules and change in projected load and dispatch conditions as a result of system stress. The uncertainty of system network component outages has been included in the TTC calculator by taking system thermal, voltage stability and transient stability limits into consideration under contingencies. The effective models and techniques are proposed to dynamically and statistically process historical data and extract uncertainty patterns of the parameters. No parametric probability distribution assumption of the parameters is required.

The calculated standard deviation of TTC can be used to determine TRM. The developed method which has now been accepted as part of new BC Hydro’s TTC calculator is used to determine TRM in real-time and pre-scheduling timeframes. Typical results calculating TRM for hourly, daily and weekly TTCs for BC Hydro system have been presented in the paper. These results provide TRM values for both firm and non-firm TTCs on the BC Hydro-USA inter-tie. The presented method has been filed as an attachment to a BC Hydro’s report to NERC for meeting the mandatory reliability compliance.

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