Chapter 3

Transfer Capability in Power System

An important outcome of the electricity industry deregulation is it increases the competition to the power industry. Generation system is the first business unit that subject to this change while distribution system is usually scheduled to deregulate in the latter stage or remain monopoly as seen in many countries. It is foreseeable that a major outcome of deregulation process is the increasing of transactions since customers have more options for making transactions as long as they are interconnected by transmission system. Unfortunately, most of transmission networks were designed and constructed long before the deregulation processes are implemented. Therefore, the increasing of transactions under deregulated market is considered as unexpected situations in transmission network. This scenario may cause transmission network to be the vulnerable point of power system as seen from the incidents of recently major outages and blackout in power system are initiated by transmission network [23-25]. For this reason, in order to maintain security of power system, transmission network should be carefully monitored as well as appropriate frameworks for making transactions under deregulated market should be established. In order to achieve the above security criteria, this chapter will explain the definitions and functions of frequently used terms in power system planning and operation. Then, it will cover appropriate techniques to judge the utilization of transmission network under deregulated environment.

3.1 Definitions of Transfer Capability

According to the definition of North American Electric Reliability Council (NERC), "Transmission Transfer Capability - A Reference Document for Calculating and Reporting the Electric Power Transfer Capability of Interconnected Electric Systems - May 1995" [10]. Transfer Capability is the ability of the power system to reliably move or transfer electric power from one area to another area by way of all transmission lines between those areas under specified system conditions. Total Transfer Capability (TTC), Transmission Reliability Margin (TRM), Capacity Benefit Margin (CBM) [26] and Available Transfer Capability (ATC) [1] are members of Transmission Transfer Capacity. Generally, the term "reliably move" in transmission transfer capability definition is justified by the following conditions [27-28].

a) Under normal operation conditions (Pre-contingency), all facility loadings are within normal ratings as well as all voltage levels are in normal limits (voltage at regulated buses are maintained at their desired voltage and voltage at load buses are lying within ±5% from nominal voltage)

b) During the transient period, the electric power system is operated under stable conditions.

c) After the transient period and operation of automatic operating systems, all transmission facility loadings are within emergency limits (amount of power flow in transmission lines do not exceed their emergency ratings and voltage level at both regulated and non-regulated buses are lying within ±5% from nominal voltage).

Since transmission capability measurement is required to consider the contingency situations, it can be expressed in one of the following terms compared to operating conditions of the system as the following [1].

a) First Contingency Total Transfer Capability (FCTTC): FCTTC is the effects of all electric power transfers, both normal base and incremental, and represents the total amount of electric power that can be transferred between two entities while continuing to maintain system reliability.

b) First Contingency Incremental Transfer Capability (FCITC): FCITC is the amount of electric power; incremental above normal base power transfer, that can be transferred over the interconnected transmission system in a reliable manner.

Transmission Transfer Capability determination processes must ensure acceptable voltage levels and power flow in all facilities in the system prior and post contingency as well as guarantee stability of the system during transient period. The Transmission Transfer Capability between a source and a sink in power system directly depend on rating of facilities, connection of network, operating conditions and ambient temperature. Transmission Transfer Capability between the same locations may be varied if only one of the factors mentioned above is changed. All terms in ATC calculation formula, TTC, TRM, CBM, ETC and ATC, are subsets of transmission transfer capability which will be explained later.

3.2 Purposes of Transmission System

Under deregulated power system framework, transmission network is one of the most important parts that significantly influence both security level of the system and commercial opportunity of participants [1]. Many major outages in US have indicated that transmission system is the vulnerable part in the system causing these problems such the observation of many voltage stability incidents were reported in the last two decades [25]. In addition, transmission system limits may prevent an area from fair competition [12]. This phenomenon can create geographically zoned that a small group of units have potential to control the price in their area at least until new transmission lines are constructed or an appropriate method is employed to resolve the congestion problem. It is important to understand functions, applications and security level. Power system planner must consider both system security and the aspect of maintaining fairly competition in the deregulated market.

In the past, transmission system is recognized as the path to transmit electrical energy from sources to destinations. In fact, transmission system can be applied to provide more benefits to power system under deregulated environment. Applications of transmission system are summarized as following [1].

3.2.1 Deliver Electric Power to Areas of Customer Demand

This is the basic function of transmission lines. Transmission lines continuously bring electric power from generation sources to loads under a wide variety of operating conditions.

3.2.2 Provide Flexibility for Changing System Conditions

Since power system is dynamics, conditions in the system e.g. loading conditions, generation dispatch scheme, outages etc. are changing all the time. Therefore, power system is barely operated at any assumed base load conditions. Fortunately, in most cases, power system can be operated at the desired conditions since transmission system provides flexibility for these situations and maintains system security. This is a remarkable function of transmission system to power system security.

3.2.3 Reduce Installed Generating Capacity

When two or more power systems are interconnected, generation capacity of these systems can be shared through diversity of each system e.g. customer demands, type of generation units and generator availability due to time lagging. In most cases, construction of a new power plant can be delayed or may not be necessary. These benefits of transmission system directly reduce investment cost of utilities.

3.2.4 Allow Economic Exchange of Electric Power Among systems

This is an economic perspective of transmission capability when two systems are interconnected. Surplus of electric power in an area that is the non-profit part of utilities in the past can be transferred to another area. It is foreseeable that most of stakeholders in the market e.g. seller, buyer and retailed customers are the beneficiaries of this category of transaction since seller can sell surplus power, buyer can purchase cheaper electricity which may reduce retail electricity price.

3.3 Calculation of Transfer Capability

Computer simulation is a well-known method to calculate transfer capability of a specific case in power system. Basically, computer simulation method can be employed off-line or online to calculate transfer capability. The values of Real-time

Available Transfer Capability depends on both off-line and real-time factors e.g. system's configuration, generation dispatch and load conditions. For that reason, the implementation of real-time approach is more complicate than off-line approach.

For off-line study of transfer capability, the study must cover a number of possible cases which include majority of power system conditions in order to cope with dynamics of the system. Beside the statistical approach to select the cases for off-line study, selecting the study cases by considering background and experiences of the system are since most system conditions recur at the similar manner. Following are four transmission capabilities terms that are used to calculate Available Transfer Capability in this dissertation.

3.3.1 Total Transfer Capability (TTC)

Total Transfer Capability of a transaction is between a seller and buyer determined by the first transmission limit of that path that has been encountered. When system conditions change over time, the limiting facility and its limiting constraint may shift from one location to another similarly to type of limiting conditions may vary. For example, under a new dispatching schedule compare to based conditions, limiting facility may shift from transmission line connected between seller A and buyer B to transmission line connected between seller C buyer D. Additionally, limiting condition may shift from thermal limit to voltage limit or stability limits. Example of Total Transfer Capability calculation is shown as follows.

Example of Total Transfer Capability

Test System: 4 buses test system
Factors to be considered: Voltage and thermal limits
System Parameters are shown in table 3-1, 3-2 and 3-3.
System configuration is shown in figure 3-1.
Simulation method: Iterative incremental load

Table 3-1. Line parameters of the 4 buses test system

Line	Circuit #	R	X	Limit
1-2	1	0.20	0.60	40 MVA
1-2	2	0.20	0.60	40 MVA
1-3	1	0.10	0.20	80 MVA
2-3	1	0.07	0.20	60 MVA
2-4	1	0.05	0.25	100 MVA
3-4	1	0.04	0.20	50 MVA
3-4	2	0.04	0.20	50 MVA

Table 3-2. Loads level of the 4 buses test system

Bus	P (MW)	Q (MVAR)
1	40	15
2	25	10
3	60	30
4	70	25

Table 3-3. Generation level of the 4 buses test system

Gen #	Pmax (MW)	Pmin (MW)	Qmax (MVAR)	Qmin (MVAR)
G1	200	50	150	-150
G2	200	50	150	-150

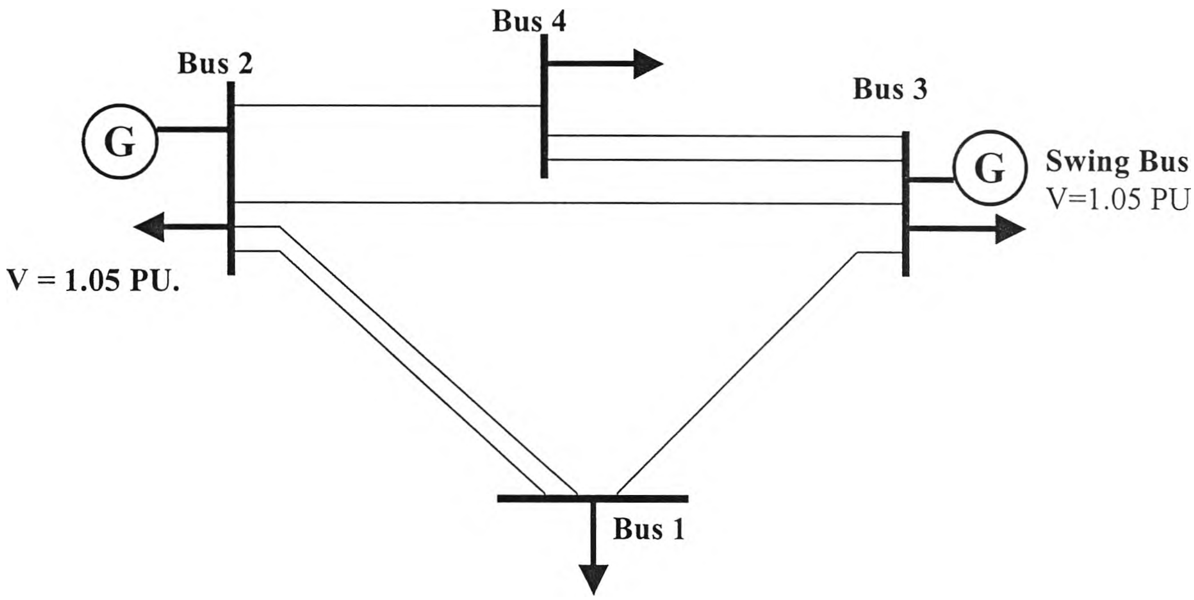

Figure 3-1. Schematic diagram of 4 buses test system

There are two simulation cases in this example. The first case is the transaction between bus 2 and bus 1. The second case is the transaction between bus 2 and bus 4. Base case conditions of the test system representing and base case power flow are shown in table 3-4 and table 3-5 respectively. Total transfer capability, maximum power transfers, corresponding to the two simulated cases under normal and contingency situations are shown in table 3-6 and table 3-7, respectively.

Table 3-4. Base case conditions for the 4 buses test system

Bus Number	**Voltage (PU)**	**Pgen (MW)**	**Qgen (MW)**	**Pload (MW)**	**Qload (MW)**
1	1.01	-	-	40	15
2	1.05	88.60	19.22	25	10
3	1.05	108.24	67.43	60	30
4	1.02	-	-	70	25

Table 3-5. Power flow under base case conditions of the 4 buses test system

From Bus	**To Bus**	**Line #**	**P (MW)**	**Q (MW)**
1	2	1	-10.51	-2.68
1	2	2	-10.51	-2.68
1	3	1	-18.98	-9.65
2	4	1	28.46	7.06
2	3	1	13.66	-4.57
3	4	1	21.17	10.98
3	4	2	21.17	10.98

Table 3-6. Maximum Power Transfer between buses 2 - 1

Conditions	**Power Transfer**		**Limiting Conditions**	**Limiting Facility**
	P (MW)	**Q (MVAR)**		
Base Case	51.4	13.0	Under Voltage	Bus 1
Line 1-3 out	45.2	16.8	Under Voltage	Bus 1
Line 2-4 out	53.4	6.2	Overload	Line 2-3
Line 2-3 out	63.2	6.6	Under Voltage	Bus 1

Table 3-7. Maximum Power Transfer between buses 2 - 4

Conditions	**Power Transfer**		**Limiting Conditions**	**Limiting Facility**
	P (MW)	**Q (MVAR)**		
Base Case	67.8	7.2	Overload	Line 3-4
Line 2-3 out	93.6	2.3	Overload	Line 2-4
Line 3-4 out	46.7	12.3	Overload	Line 3-4
Line 1-2 out	74.2	5.9	Overload	Line 3-4

As seen from table 3-4 to 3-7, there are many possible cases to be considered in the transfer capability calculation and the best strategy is trying to cover as much as possible cases. Currently, there are many applications have been employed in practical power system to compute the total transfer capability such as implementing a real-time control center or simulating a set of most feasible cases. However, due to the size of power system and the ability of software to handle this calculation in a limited of time, most of the practical monitoring system consider only thermal limit that may be insufficient for modern power industry.

According to the definitions of transfer capability, calculation of total transfer capability must ensure the following security criteria [10]

a) Thermal Limits: Under normal and post-contingency situations, amount of power flow (MVA flow) in the transmission lines must not exceed normal facility rating and emergency facility rating respectively. AC Power flow is a fast and reliable tool to investigate any violation in the system.

b) Voltage Limits: Similar to thermal limit, acceptable voltage level of buses in power system is a constraint to determine total transfer capability. Basically, acceptable voltage in high voltage buses is between $\pm$5% from nominal voltage (10% range). However, since voltage stability is one of the most common problems under deregulated environment, by maintaining voltage level at $\pm$5% from nominal voltage does not guarantee the risk from voltage instability. This is because voltage stability problem may occur while voltage magnitude at the collapsing point is relatively high [16] and develops to a severe situation. So, it is recommended that voltage stability study should be included in transfer capability study.

c) Transient Stability Limits: Transient stability is an important topic to transfer capability study because n-1 contingency simulations are required by NERC's framework. Objective of transient stability study is to ensure that power system is stable after disturbances. Long-term stability might be combined in long-term Available Transfer Capability study but it is beyond the main topic of this dissertation due to the development of fast-respond control equipment in power system has extended the results of transient stability study to overlap with long-term dynamics. For more information of transient stability, concepts, calculation procedures and study results of this issue will be discussed again in chapter 4.

Since amount and direction of electric power flows in the transmission system are determined by electrical distances and voltage gradients between sink and source, these two quantities cannot be directed without the installation of special equipments such as phase-shifting transformer or Thyristor-Controlled Series Capacitors (TCSC)*, Static Vars Compensators (SVC)*, Static Synchronous Compensator (STATCOM)* [FACT] etc. Transaction between a seller and buyer in a geographical area may result in parallel path flow in another area that may further limit the transfer capability of the whole system under the competitive environment. In some cases, transmission provider may not aware of this phenomenon and parallel path flow may cause security problem to the system. This problems leads to the concept of Transmission Reliability Margin (TRM) that leads to certain percentage of the entire system are reserved in order to maintain system security. Information of Transmission Reliability Margin will be discussed later.

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* Examples of from 13 FACTs devices currently applied for steady-state operation

Several methods such as AC power flow, DC power flow or Optimal power flow can be used to estimate amount of electricity power flow in transmission lines and voltage magnitude in power system buses. However, AC power flow is selected to be the main tool in this dissertation because it is the most reliable, flexible and quick enough to pickup the changes. Calculation using AC power flow covers all requirements of ATC calculation method defined by NERC that was mentioned in the introduction. DC power flow is a good method and is accepted to be the fastest method but it does not give any information about reactive power that directly affect the voltage magnitude. Optimal power flow is an interesting tool that combines constraints and objective function together but reliability of this method is still debatable.

The question that how to find the maximum capability of transmission system within a limited time frame where most network constrains are considered is the technical challenge of ATC and TTC calculation. A practical method to calculate TTC and ATC is proposed in this dissertation as the following processes.

a) Prepare base case of the system: A base case for ATC calculation must represent the practical conditions in power system such as transmission capability, load conditions (committed load), generation capability including power purchase agreements (PPAs) both in firm or non-firm contracts. A practical base case should not contain constraint violation. However, if constraint violation exists, redispatching technique may be applied to the base case to mitigate the problem. In addition to constraint violation, zones and areas territories [21] should be clearly specified since transactions in power system are not restricted only between buses but also between areas. In case of off-line study, a number of base cases are require for ATC calculation to ensure accuracy of results. In contrary, real-time ATC study need much less base cases than off-line study since this procedure relies on real-time information.

b) Define regulatory must take units in the system. These units will be distracted from competitive market's scheduling process since they satisfy some requirements from the government. These units are eligible to be guaranteed an amount of electricity sold to the market at the price referred to their contract.

c) Define reliability and regulatory must run units in the system. Similar to must take units with the eligibility to sell electricity to the market at the contract price but different in the purpose of classification, reliability must-run units are distracted from competitive market's scheduling process since they are necessary to system security or satisfy to some requirements defined by the government. These units are necessary to be available to deliver power to the system anytime upon request. Must run and must take units concepts and definitions will be explained in details in chapter 5

d) Specify sellers and buyers in the systems (define ATC interfaces): A transactions under deregulated environment can be divided into three combinations of transaction, transactions between buses (sink and source are buses), transaction between group of generation facilities (sub-portfolio) and bus and transaction between sub-portfoio. This issue will be explained again in chapter 5.

e) Generate Contingency cases: According to NERC's ATC framework, calculation of ATC must consider the situations when power system undergoes n-1 contingencies. Therefore, a suitable method for calculating unexpected situations must be performed in this stage to ensure security of power system during contingency situations. In this stage of contingency study, contingency cases are generated by simulating scenarios when a major facility in the system out of service.

f) Contingency Analysis: Since contingency concept in step 5 results in loss of a facility in the system, transient stability analysis must be applied to these cases in order to ensure continuity of service after a contingency. Contingency cases that fail to remain stable after transient period are passed to be reliability must run (RMR) calculation in order to be justify that the outage facility is must run unit or not. Stable cases are prepared for contingency ranking program. Then all stable cases are investigated by power flow program to compare post-contingency voltage level and amount of power flow in transmission lines to pre-contingency cases. Meanwhile, a scoring program which converts the deviation of power flow, voltage level in voltage-controlled buses and load buses into score is applied. Finally, these contingency cases are ranked according to their severity score. Details of allocation of reliability must run units are discussed in chapter 5 as well as contingency analysis calculations are explained in chapter 7.

g) Voltage stability study: As mentioned earlier, voltage level is one of major constraints in ATC calculation. Normally, acceptable voltage level is lying within 5% from nominal voltage. However, this does not guarantee that power system are secure to voltage instability problem since an voltage collapse incident may happens at high voltage level or power system may be operated too close to the insecure area. From this reason, this dissertation proposes the voltage stability analysis at each transaction. This step adds a new constraint to the transaction that operating point at a new transaction must not go beyond required voltage stability margin of the system.

h) Finding the maximum power transfer (TTC) by increasing amount of transaction between selected source and sink until TTC is determined. This repeated incremental analysis defines TTC at each transaction when the first constraint violation in the system is detected. In fact, several methods are recommended as options to estimate the TTC based on the concept of sensitivity analysis such as Power Transfer Distribution Factors (PTDF) [13], Rated System Path (RSP) or Network Respond Path (RSP) [1]. However, this dissertation will base on AC power flow calculation since it is more reliable, gives better accuracy and completed details of results. Because ATC values in real-time operation requires more accuracy than ATC values in planning perspective that contains more uncertainties. Errors in real-time ATC calculation should be eliminated as much as possible. In addition, sparse technique in this program has enhanced the ability of program to handle large power system. General formula for TTC calculation is shown below:

$$TTC = \min(thermal \lim voltage \lim) \quad (1)$$

i) Interpretation of results: TTC values given by this approach is interpreted as the maximum amount of real power that can be safely transferred from area A to area B by all physical paths. Comparing to TTC recommended in available transfer capability reference document provided by NERC [1,10], this result gives better result than the TTC value given by Network Response Method (NR). Unlike the NR method, this proposed method provides both real and reactive inforation at the same time. Flowchart of TTC calculation is shown in the figure 3-2.

In the next four sections, Available Transfer Capability (ATC), Existing Transmission Commitments (ETC) and Transmission margins, Transmission Reliability Margin (TRM) and Capacity Benefit Margin (CBM), will be discussed in details. ETC is recognized as the total load of transmission system at a period of time. It depends on amount and classification of customers in each system. TRM and CBM are introduced as a portion of ATC formula with the purpose to handle with inherently uncertainty in power system.

TRM is designed to foster system security benefit to entire of the systems while CBM is purposed to support commercial availability. Details of TRM and CBM are explained in section 3.3.4 and 3.3.5 of this chapter. When North American Reliability Council (NERC) first approved a framework from determining Available Transfer Capability in 1996 [20], NERC realized that a practical approach for ATC calculation is still required lot of improvements and development to be suitable to power industry.

3.3.2 Existing Transmission Commitments (ETC)

Existing Transmission Commitments (ETC) is the amount of existing loading level of transmission system (including retail customers). In some case ETC may include CBM since these two terms are closely related in planning point of view. However, this dissertation will explain these two terms separately in order to give a clear definition between these terms and time frame.

Determination of ETC is directly depended on load classification of power system that is varied in each system. Generally, transmission loads are classified as

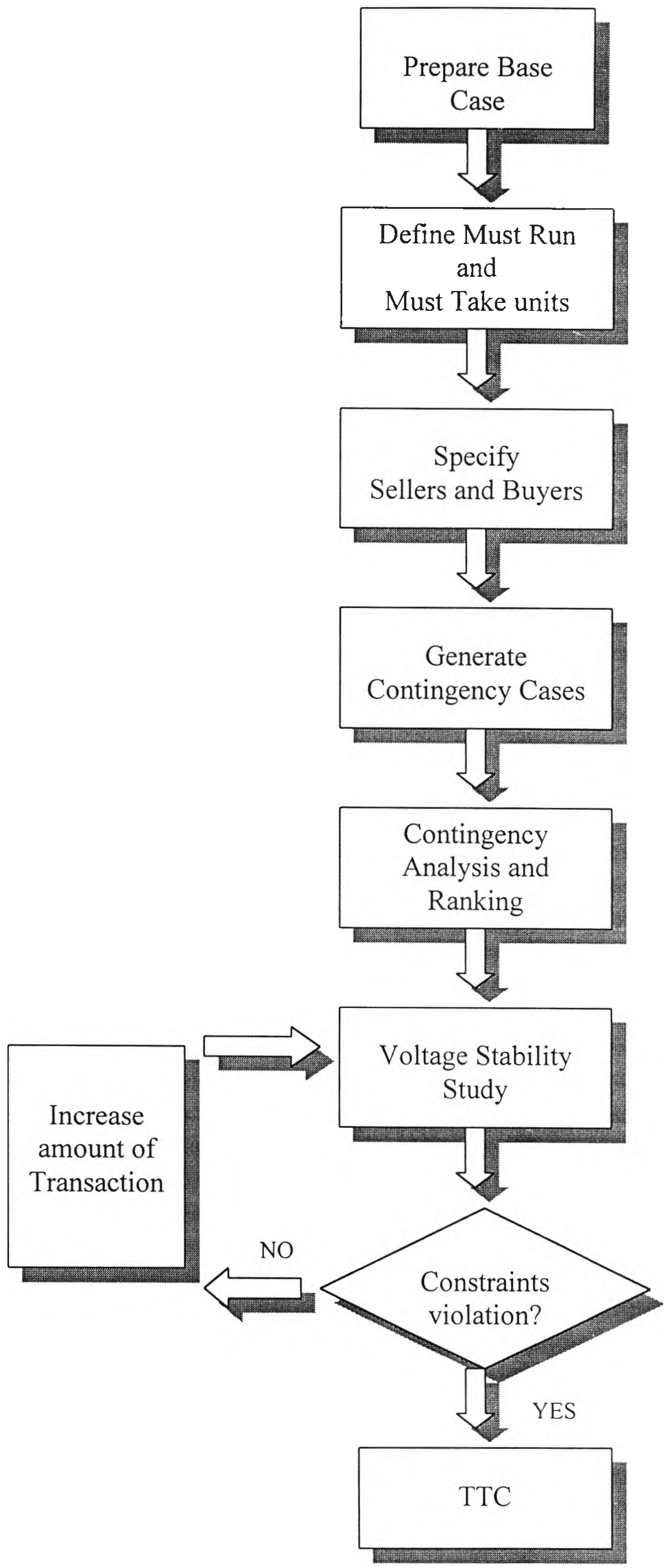

Figure 3-2 Processes of Total Transfer Capability calculation

firm and non-firm load that is easily to cause confusion. Consequently, terms curtailability and recallability are introduced since they give better understanding to users. Definitions of these terms are addressed below [29]

a) Curtailability is the right of a transmission provider to interrupt all or part of a transmission service due to constraints that reduce the capability of the transmission network to provide that transmission service. Curtailment is to be applied if only in cases where system reliability is threatened or emergency conditions exist. Curtailment does not apply to situations in which transmission service is discontinued for economic reasons.

b) Recallability is defined as the right of a transmission provider to interrupt all or part of a transmission service for any reason (including economic).

Curtailability and Recallability of load classification are suitable for long-term ATC calculation. In real-time ATC calculation, ETC is represented by total contracted load in the system which is always higher than scheduled load in the system. Therefore, Curtailability and Recallability will be excluded in the real time ATC calculation.

3.3.3 Transmission Reliability Margin (TRM)

According to "Transmission Capability Margins – ATCWG Position Paper" prepared by the North American Electric Reliability Council [29], Transmission Reliability Margin is defined as "The amount of transmission transfer capability necessary to provide a reasonable level of assurance that the interconnected transmission network will be secure and reliable. TRM accounts for the inherent uncertainty in system conditions and its associated effects on ATC calculations, and the need for operating flexibility to associated reliable system operation as system conditions change. All transmission system users benefit from the preservation of TRM by Transmission Providers."

Generally, uncertainties in power system are classified by time frame or components that always contain errors. Uncertainties that are associated to the time frame including short-term uncertainties, unexpected situations inside or directly influence power system such as weather conditions, forced or scheduled outages and long-term uncertainties that depend on health of economy, load growth and power developing plan. Therefore, TRM is concluded to be a time-dependent quantity. Appropriate amount of TRM defined by Transmission Provider Company must be revised according to the change of the operation conditions.

Besides, sets of component that frequently contains uncertainties [14] due to errors, which should be carefully concerned in TRM calculation, are listed below.

a) Aggregate Load Forecast Error: Since future load level is impossible to precisely forecast, an amount of transmission capability is required to be reserved for this uncertainties.

b) Load Distribution Error: Similar to aggregate load forecast error, load distribution error is an in system facilities. This category of error is the uncertainty of load distribution within the system

c) Variation in facility loadings due to the balancing of load and aggregation within a control area: This uncertainty results from dynamics of generation units that try to follow up dynamics of load. Since load is dynamics in nature, generation units must increase and decrease their generation level continuously. Fluctuation of power due to this behavior requires uncommitted transmission capability to maintain satisfactory system performance.

d) Variation of interface capability due to dynamic interdependency with others: As the concept of "Parallel Path Flow" was introduced, a transaction between a seller and buyer may affect many transmission interfaces. Since it is complicated and time-consuming to calculate all possible cases as a reference for future transactions, reserving an amount of transmission capability as TRM is a novel strategy to handle unexpected power flow.

e) Allowances for simultaneous path interactions: This component is introduced to handle with the situation when many transactions are scheduled in the system at the same time. TRM might be determined as the difference between the firm capability (Existing Loading) and maximum capability of each transmission path.

f) Allowances for parallel path flow: Similar to the previous topic, unexpected power flow (additional or subtraction) in one area may occur because of transactions in other area in the system that transmission provider may not aware of. TRM is required in this case although parallel path flow may increase or decrease power flow in an area.

NERC only provides guidelines to establish frameworks to determine TRM values of a specific path. This framework give two deterministic guideline for TRM calculations depend on characteristics of uncertainty:

3.3.3.1 TRM determined by rating reduction

By this method, facility ratings can be reduced consistent with distribution of uncertainty among facilities. In case that uncertainty is relatively uniform, a typical amount of facilities reduction of 2-5% can be applied uniformly for the entire system. On the other hand, different amount of facility reduction in each area can be applied if transmission provider knows the distribution of uncertainty of the system. Facility reductions can be a function of time and the transmission providers may vary these values in an extended time horizon.

Determination methodologies of TRM based on the method mentioned above can be done as follows:

a) Determine TTC and ATC by assuming TRM is zero. This step defines the case when uncertainties in the system are overlooked. The processes started by assigning full rating to facilities in the system (normal rating) and then calculate TTC and ATC respectively.

b) Determine TTC and ATC using facility reduction ratings. Assign different percentage of facility reduction in different areas to reflect desired margin. Flowchart of deterministic TRM calculation is shown in figure 3-3.

3.3.3.2 TRM determined by interface application

In the system where uncertainties can be associated to a specific area or facility, it is possible to apply TRM to that critical interface instead of distributing uncertainties among the systems. Detailed calculation of this approach is similar to the rating deduction method as shown in figure 3-3. However, this method requires actual experiences with the system and contains a level of error.

TRM calculation in this dissertation is based on the rating reduction method where reduced facility ratings in each area of the test systems are varied. Since this method is more flexible to modify and similar to real situation which happen in the system. Finally, TRM values calculated from this method is assigned as a deduction from Total Transfer Capability in ATC formula.

In summary, TRM has two unique characteristics as the following

a) TRM benefits to participants in large area in the system as an uncommitted transfer capability. Objective of TRM is to maintain system security and specific beneficiaries of TRM cannot be identified.

b) TRM is introduced by the motivation to handle with uncertainties in power system which are dynamics and unpredictable.

3.3.4 Capacity Benefit Margin (CBM)

Capacity Benefit Margin (CBM) is introduced in the same time as TRM as a transmission margin of deregulated power system. However, purposes of CBM are relatively different from TRM.

Capacity Benefit Margin is the amount of firm transmission transfer capability preserved for Load Serving Entities (LSEs) on the host transmission system where their load is located, to enable access to generation from interconnected systems to meet generation reliability requirement. Preservation of CBM for a LSE allows that entity to reduce its installed generating capacity below that which may otherwise have been necessary without interconnections to meet its generation reliability requirements. The transmission capacity preserved as CBM is intended to be used by the LSE only in times of emergency generation deficiencies [29]

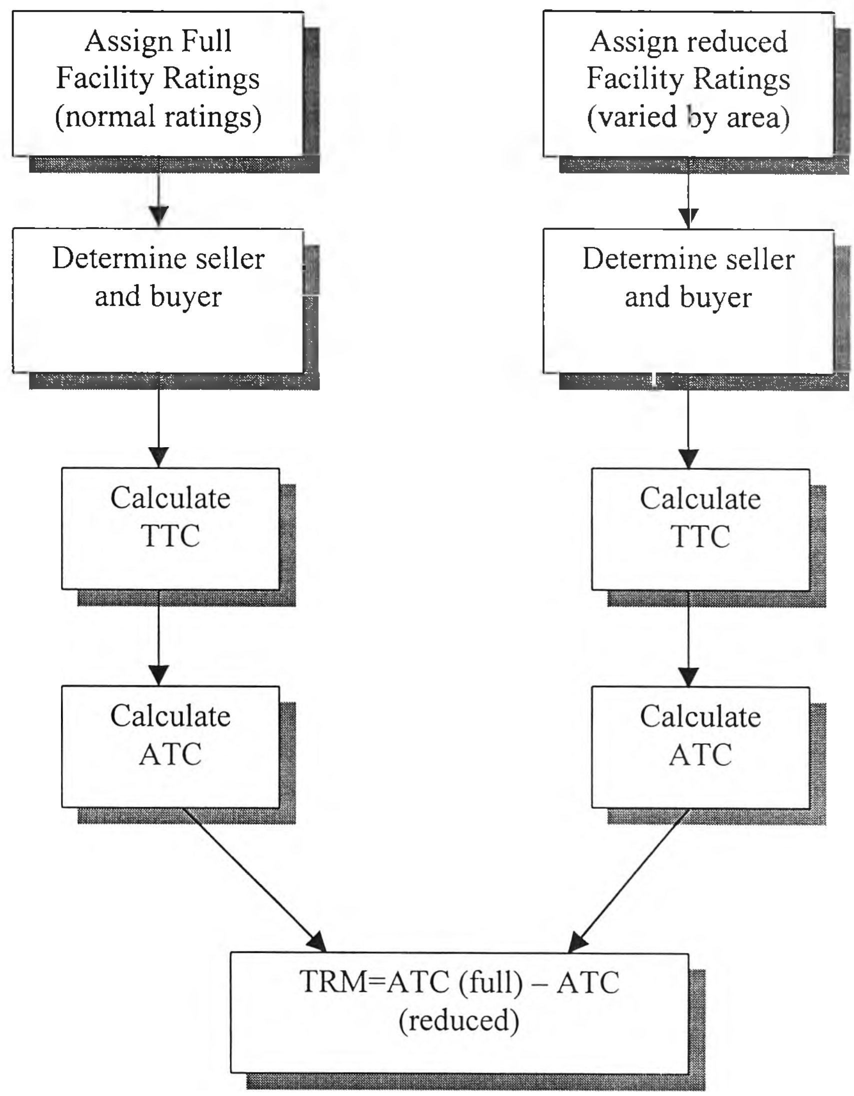

Figure 3-3 Flowchart of deterministic TRM calculation

As mentioned above, it is clearly seen that CBM is different from TRM since its beneficiaries is identifiable. CBM is key factor in Planning Reserve Sharing Program in deregulated power system that translate amount of generator capacity reserve margin into transmission transfer capability. In addition, CBM is a planning quantity that is excluded from planning purchase of utilities and transmission provider. In fact, planed purchase of electric power deducts amount of CBM in the system as mentioned in NERC's Interconnected Operations Services Implementation Task Force (IOSITF) [15].

Characteristics of CBM are summarized in details as follows:

a) CBM is a planning quantity which is available in long-term calculation. In general, CBM is primarily observed in next hour ATC calculation not the current ATC calculation. Planning Reserve Sharing Program in the current hour is considered as TRM since it is closely related to system security.

b) CBM is uni-directional since beneficiaries of CBM are specific LSEs in the area. Power system planners have to define beneficiaries and future transaction in order to determine CBM in deregulated power system.

c) CBM has lower priority than TRM when the systems undergo emergency situations. Therefore, interruptible customers should be classified as CBM in the system which maximum possible amount. It is important to notice that CBM is subjected to curtail by control area operator when unexpected situations have taken place.

The methodology used to calculate and allocate CBM of an LSE starts from determining the amount of Generation Reserve Requirement of a LSE. Generally, allocation of Generation Reserve Requirement for an LSE is accomplished by either deterministic or probabilistic method. However, an approach in which deterministic and probabilistic methods are combined according to time horizon of situations is recommended by NERC [14]. Deterministic method that assigns Generation Reserve Requirement as an amount of power which is sufficient to support the systems when the largest generation unit is outage. Probabilistic method which converts reliability index e.g. Loss of Load Probability (LOLP) to amount of generation reserve is appropriate for longer time period that containing high uncertainties.

Then, this amount of generating capacity is converted to external generating reserve requirement (less TRM). Finally, specific transmission facilities or interfaces are allocated to responsible for power flow caused by external generating reserve requirement.

Flowchart of CBM calculation is shown in figure 3-4. Anyway, details of CBM calculation will not be covered in this dissertation since CBM is not included exist in Real-time ATC calculation. The appropriate methodology subject to NERC's CBM criteria will be the future work beyond this dissertation.

3.3.5 Available Transfer Capability (ATC)

As mentioned in chapter 1, Available Transfer Capability (ATC) is the "available capability of the interconnected transmission networks to support additional transmission service" [1]. It is interpreted as the solution between security and commercial viable point of view.

Therefore, ATC is calculated by algebraic calculation of TTC, TRM, CBM and ETC terms respectively. Since this dissertation concentrates on only real-time ATC calculation, CBM term does not exist in ATC formula because it is a planning quantity. Formula of ATC is shown in equation 1) where relationship between ATC and related terms are shown in figure 3-5.

$$ATC=TTC-ETC-TRM-CBM \tag{1}$$

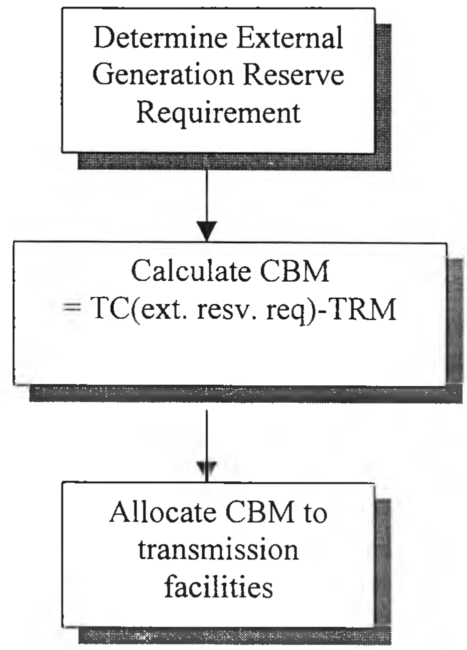

Figure 3-4. Flowchart of deterministic CBM calculation

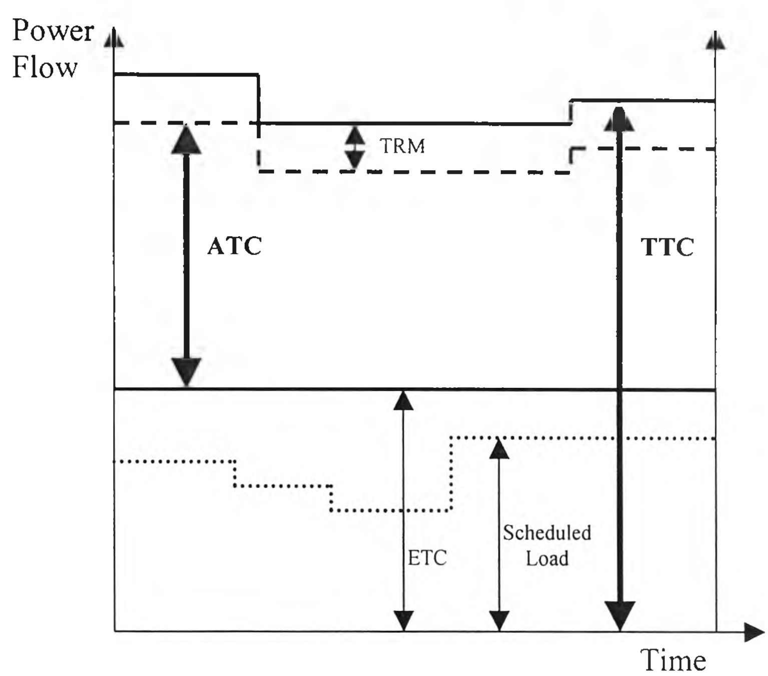

Figure 3-5. Relationship between ATC and other related terms

3.4 Summary and Conclusions

Available Transfer Capability (ATC) is an important quantity in power system planning and operation under the deregulated environment. North American Electric Reliability Council has issued a framework for ATC calculation that provides the basic concepts and calculation methodology as an umbrella program for the future implementation of ATC in each power system. Generally, ATC is calculated from four individual term TTC, TRM, CBM and ETC. TTC represents the maximum transfer capability of transmission system at a moment of time that will be used as the boundary between secure and insecure operation of the system. TRM and CBM are affiliated with reserved transmission capability margin for the purpose of security and commercial viable where ETC provides the information of current committed load in the system.

In this dissertation, a practical method to calculate real-time ATC in Thailand power system is proposed. Since CBM is clearly seen as a quantity in planning horizon, it will not be included in real-time ATC calculation that is an operation quantity. For ATC calculation procedure, this dissertation considers thermal limit, voltage magnitude limit, voltage stability limit and transient stability limit as the constraints monitored by TTC calculation. TRM is determined from deterministic approach (rating reduction method) where ETC is selected from the peak conditions in Thailand power system to represent the most severe starting condition of ATC calculation.