DETERMINATION OF AVAILABLE TRANSFER CAPABILITY FOR A DEREGULATED POWER SYSTEM USING FUZZY LOGIC

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LIST OF PAPERS BASED ON THE PRESENT RESEARCH

1. "Slack-Load Bus Pair Technique Using Full AC Load Flow Algorithm for On-line Determination of ATC", *Proc. of Second World Engineering Congress*, 22nd-25th July 2002, Sarawak, Malaysia, pp. 25-28.

2. "Fuzzy Logic Assisted Evaluation of the ATC in a Deregulated Power System", submitted to IEEE Power Engineering Society Letters, USA, 2002.

3. "Static ATC in a Deregulated Power System through Fuzzy Logic", submitted to Electric Power Systems Research, UK, 2002.

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5. "Real-time evaluation of the impacts of MVAR supports on ATC in spot electricity market", submitted to IEE Proc. GTD, UK, 2003.

Dedicated to arwah ayah, mek and my family, Salemah, Nur Syamimi, Nur Syaheera and Ahmad Azran.

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ABSTRACT

The emerging trend of deregulating power industries requires the operator to keep the transmission network congestion free when the generation companies compete to sell electricity to the distributors or wholesale purchasers. This requires real-time predetermination of an index termed Available Transfer Capability (*ATC*), between every possible pair of source (selling or injection point) and sink (purchase or extraction point) buses. *ATC* between a given pair of source and sink buses is quantified by the allowable highest magnitude of active power (*MW*) that can be transferred from the source to the sink over and above the already committed uses (base case) of the whole network without exceeding any line thermal loading and bus voltage limits. The works reported to date on *ATC* determination have the drawbacks of either oversimplification of the problems or too high computational burden to be implemented in on-line environment. Moreover, the methods that consider both line thermal loading (*MVA*) and bus voltage constraints lack effective exploitation of the correlation between reactive power (*MVAR*) support and *ATC*. The present research has developed a real time compatible novel method based on fuzzy logic for concurrent determination of *ATC* with and without *MVAR* supports. This method provides outputs through trivial computations in one shot from a given base case involving only three input variables in any power system. The architecture of the fuzzy logic model appropriate for *ATC* determination has been developed in the research. The developed method has been extensively tested and compared against a conventional full scale *AC* load flow based *ATC* determination method in terms of accuracy and *CPU* time using the same array of transactions, base cases, and generation/line outage scenarios in the standard *IEEE* 24 bus Reliability Test System and *IEEE* 118 bus test system. The method has yielded satisfactory results with much favourable computational time compared to the load flow method.

ABSTRAK

Keadaan terkini deregulasi bagi industri kuasa memerlukan pengendalinya memastikan rangkaian talian tidak sesak semasa syarikat penjanaan bersaing untuk menjual elektrik kepada pengagih atau pembeli pukal. Penentuan masa sebenar satu indeks iaitu Keupayaan Pemindahan Tersedia (*ATC*) adalah perlu bagi setiap kemungkinan transaksi antara pasangan bas sumber (titik jualan atau suntikan) dan destinasi (titik belian atau pengambilan). *ATC* adalah ditafsirkan sebagai magnitud kuasa (*MW*) tertinggi yang boleh dipindahkan daripada sumber ke destinasinya melebihi penggunaan sedia ada (kes asas) sesuatu rangkaian tanpa melebihi samada had pembebanan talian atau voltan bas. Kerja terdahulu berkaitan penentuan *ATC* mempunyai kelemahan samada kerana terlalu mempermudahkan kaedah penyelesaian masalah atau memerlukan kadar pemprosesan yang tinggi. Kaedah lain yang cuba mengambilkira kedua-dua had juga tidak dapat menentukan secara efektif hubungan antara sokongan kuasa reaktif (*MVAR*) dengan *ATC*. Penyelidikan ini telah membangunkan kaedah serasi masa sebenar berasaskan kepada logik kabur untuk menentukan secara serentak *ATC* dengan atau tanpa sokongan *MVAR*. Ia menyediakan penyelesaian dengan pengiraan mudah bagi sesuatu kes asas dengan hanya melibatkan tiga pembolehubah masukan bagi suatu sistem kuasa. Struktur logik kabur yang sesuai bagi penentuan *ATC* juga telah dibangunkan. Kaedah tersebut diuji secara menyeluruh dan dibandingkan dengan pengiraan *ATC* konvensional berasaskan aliran beban arus ulangalik dari segi ketepatan dan masa pengiraan dengan susunan senario yang sama bagi kes asas dan penjanaan/talian terputus pada Sistem Ujian Keboleharapan 24 bas dan sistem ujian 118 bas *IEEE*. Kaedah ini telah menghasilkan ketepatan yang memuaskan dengan masa pengiraan yang lebih baik berbanding kaedah aliran beban.

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α_h	-	h-th premise parameter
μ_i	-	Membership grade for the i-th input
θ_k	-	Voltage phase angle at bus k
ϕ_{kn}	-	Angle of bus admittance matrix element between bus k and n
μ_o	-	Membership grade for the output from o-th fired rule
σ	-	Standard deviation
$[\Delta P]$	-	Real power mismatch vector
$[\Delta Q]$	-	Reactive power mismatch vector
$[B]$	-	Target output vector
$[X]$	-	Consequent parameter vector
a_{ij}	-	Crisp value of i-th input at the leftmost vertex of its j-th fuzzy attribute triangle
A_{max}	-	Thermal loadability of the line having the highest limit in a given power system
ANN	-	Artificial Neural Network
ANFIS	-	Adaptive Network-based Fuzzy Inference Systems
ATC	-	Available Transfer Capability
ATC'	-	Overall crisp value of *ATC*
ATC_o'	-	Crisp *ATC* from o-th fired rule in Takagi-Sugeno model
ATC_o^f	-	Fuzzy attribute for the *ATC* from o-th fired rule in Mamdani model
ATM	-	Available Transfer Margin
b_{ij}	-	Crisp value of i-th input at the rightmost vertex of its j-th fuzzy attribute triangle

C	-	Category index
c_{ij}	-	Crisp value of i-th input at the central vertex of its j-th fuzzy attribute triangle
DISTCO	-	Distribution Company
E	-	Sum of squares of the difference between available and computed crisp values of the output for each pattern
GENCO	-	Generation company
I^2X	-	Mega Volt Ampere Reactive loss in transmission line
I_i	-	Crisp value of i-th input
I_i^f	-	Fuzzy value of i-th input
IPP	-	Independent Power Producer
ISO	-	Independent System Operator
L	-	Loading index
MW	-	Mega Watt
MVAR	-	Mega Volt Ampere Reactive
m_i	-	Total number of fuzzy attributes for i-th input
p.u.	-	Per unit
P_{di}	-	Real power demand at bus i
P_k	-	Real power injected at bus k
P_n	-	Real power injection at neighbouring bus
P-Q	-	A bus with specified real and reactive power injection i.e. 'load bus' in load flow analysis
P_s	-	Real power injection at sink bus
P-V	-	A bus with specified real power injection and voltage magnitude i.e.'voltage controlled bus' in load flow analysis
PX	-	Power Exchange
Q_k	-	Reactive power injected at bus k
r_{io}	-	Consequent parameter (coefficient) to be multiplied with crisp value of i-th input in the polynomial expression for output from the o-th rule of Takagi-Sugeno model
SVC	-	Static Volt Ampere Reactive Compensator
$\bar{u}_o$	-	Normalized firing strength of a particular o-th rule in Takagi-Sugeno model
V_k	-	Voltage magnitude at bus k

Y_{kn}	-	Magnitude of bus admittance matrix element between bus k and n

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CHAPTER I

INTRODUCTION

This Chapter presents a coherent definition of the problem addressed by this thesis, and highlights the aims, scope, and major contributions of the present research.

1.1 General Considerations

Electrical energy is the most convenient form among all types of energy, and considered the driving force to keep the modern civilisation dynamic. Traditionally, electricity is supplied over a given territory by a utility under a monopolistic framework i.e. the generation, transmission and distribution sectors are vertically integrated under a single ownership. However, with increase in demand due to rapid industrialization and urbanization recent years have witnessed, in some countries, participation of private companies termed Independent Power Producers (*IPPs*) in the generation sector. The *IPPs* sell electricity to the utilities.

Since mid-1990s, in view of the key role played by electricity, and customer-benefits achievable from competition under a free market configuration, the electric utilities all over the world have been subjected by the governments to the process of a gradual transition from a regulated and monopolistic configuration towards a full-scale deregulation [1]. In the new environment, the generation, transmission and distribution sectors are unbundled as independent entities to promote competition in supplying affordable but reliable electricity to the consumers.

Deregulation of electricity industry has now evolved to an almost mature reality. Various models postulated or implemented so far [2] for deregulation have an essence and spirit in common. This is that the electricity sellers (investor or utility owned generation companies) and the wholesale purchasers (brokers or distributors) in deregulated or free market environment can go for bilateral contracts on short or long term basis. Also they can participate in a real-time bidding process initiated hourly or several times a day by a facilitator often termed 'Power Exchange'. The consequent transactions, triggered by open-competition or negotiation, are effected through the transmission network that is operated by an agency termed Independent System Operator (*ISO*). This involves on the part of the *ISO* an operational planning in real-time. This process is concerned with handling the available resources of an existing system in order to meet the actual requirements at any time. It is well known that gap between design (planning at pre-implementation stage) and commissioning of a power system is several years. So studies carried out under an assumed set of operating conditions several years, or even days, in advance can not cater for all the loading situations, generating patterns and the wide range of outages likely to arise in practice. The need for an operational planning is more obvious for a deregulated system in which the *ISO* has no ownership of the generation and distribution sectors.

One of the significant impacts caused by deregulation is keeping the transmission network secure. It is the responsibility of the *ISO* to encourage prospective market participants (sellers/buyers) and honour the viable transactions. For this, *ISO* determines an index on the unutilised transmission capacity termed Available Transfer Capability (*ATC*). This index is periodically computed from real-time data, and disseminated via a web system called *OASIS* (Open Access Same-time Information System) [3].

1.2 Available Transfer Capability

In the deregulated power system the *ISO* has to update and disseminate, at periodic intervals of a day, the *ATC* between every possible pair of source and sink buses, so that the market participants can plan their strategies in securing access to the transmission network. Source bus is that at which a generation company sells (injects) power, and sink bus is that at which a distribution company or broker purchases (extracts) power.

Available Transfer Capability (*ATC*) between a given pair of source and sink buses in a transmission network is quantified by the allowable highest magnitude of power (*MW*) that can be transferred from the source to the sink over and above the already committed uses (base case) of the network as a whole. Such a transfer (transaction) must not violate any constraint related to the transmission network security. These constraints mainly refer to transmission elements' thermal limits for power flow, and bus voltage limits when the system remains in steady state [4] i.e. the system has not developed angular instability or loss of synchronism of the generators under operation following any outage of a generator or a line.

Thermal limit or ampacity is the maximum allowable flow (*MVA*) through a transmission line or transformer without exceeding the current carrying capability of the conductors. Voltage limit is the lowest or the highest steady state voltage allowable at a bus. It is generally set as a window of ±10% of the nominal value for load serving buses (substations).

The main challenge for *ISO* is to predetermine the *ATC* value in real-time. This is because *ISO* has to determine and disseminate *ATC* separately for each of the possible transactions considering the latest operating condition (base case that exists just before the instant of "call for bid") coupled with various outage scenarios anticipated in the given power system. After the bidding takes place and its on-line evaluation is over, *ISO* has the information of all the transactions (bilateral negotiation or bid based) intended by the confirmed participants. Then *ISO* arranges the transactions in descending order [5] of *ATM* (Available Transfer Margin). The difference between *ATC* and the corresponding transaction size (*MW*) is termed *ATM* that must be positive in order for the transaction to be allowed. The transaction having the highest *ATM* is deemed honoured, and the consequent scenario is considered as the new base case to recalculate the *ATC* corresponding to the next transaction in the 'descending order list'. This recalculation is applied to other transactions in the list by turn. It is obvious that *ATC* computation, a real-time process, is highly dimensional when the system size, outage scenarios, number of transactions, and recalculations due to changing base cases increase.

1.3 Review of Literature

The researches related to *ATC* date back to the near past i.e. the year 1996 when the concept of deregulation was first introduced. Since then until now, various methods for evaluating *ATC* have been proposed in the literature. These can broadly be categorised into three groups viz. (i) Load Flow based techniques [4-17], (ii) Stochastic methods [18-19], and (iii) Artificial Neural Network method [20]. While a detailed review of the methods under each group follows in Chapter 3, the essences are highlighted in this Section.

The load flow methods based on *DC* [5-7] or *AC* [4, 8-10, 12] have mainly been used in determining *ATC* so far. For this the sink bus load is incremented and the complete load flow analysis is repeated for every increment until any line flow or bus voltage constraint is hit. Methods involving such repetitive full-scale load flow solutions are also termed Continuation Power Flow (*CPF*) methods. The *DC* methods, though a bit faster than *AC* methods, are less accurate as those consider only real power component (*MW*) of line flow limits while assuming the network to be lossless, and bus voltages fixed at nominal values i.e. 1.0 per unit (*p.u.*). As an alternative to *ATC* determination through full-scale load flow, applications of an array of power transfer or outage distribution factors derived from *DC* [14-16] or *AC* [11,13, 17] load flows have also been reported. But use of these stationary factors, derived on the basis of one scenario, to different situations is questionable. Moreover, these factors are defined to take into account the real power (*MW*) flow only but not the line *MVA* flow.

In view of the myriads of situations likely to arise in terms of base load and outages, probabilistic or stochastic methods using Monte Carlo simulation [18] or Gaussian/binomial distribution [19] have also been applied for *ATC* determination. While the methods can predict *ATC* faster than load flow based deterministic methods, their probabilistic nature is more suited to the planning stage of a power system instead of real-time operation.

Artificial Neural Network (*ANN*) has been used [20] to determine multi-area transfer capability in a special situation where a power system is considered as divided into areas, and only one area is receiving power from all the remaining areas. However, the technique requires many input variables that directly increase with the number of areas. Moreover, it has mainly been targeted for "Power Pool" scheme that fosters the pre-deregulation era theme of resource sharing at aggregate (Area) level. It is not suitable for a deregulated system nurturing a competitive environment in which bus-to-bus power transactions and load changes at individual buses need to be tracked down.

It appears that the reviewed *ATC* determination methods have drawbacks of either oversimplification of the problems or too high computational burden to be implemented in on-line environment even on the fastest processors available to date. Moreover, the methods that considered both line thermal loading and bus voltage limits did not evaluate the contributions of availability or unavailability of reactive power (*MVAR*) supports towards *ATC*. Such a break up is necessary to confirm if *ATC* can be enhanced through *MVAR* supports, and hence prompt sellers or buyers to opt for self managed or on-payment *MVAR* supports what is categorised as "Ancillary or Supportive Services" in the electricity market.

1.4 Statement of the Problem

The demand from market participants for access to the transmission facilities is ever escalating due to the competitive environment inherent in a deregulated power system. This requires that *ISO* determine *ATC* in real time for all the possible source-sink pairs as accurately as possible considering the latest base case operating scenario so that viable transactions can be allowed without compromising system security. *ATC* computation is not straightforward since a transaction (power transfer) between any two points (buses) of a power system affects the flows in almost all the lines, and is influenced also by the demands and generations at other buses for a given system topology and operating scenario. The effects and influences vary from line to line and bus to bus. Consideration of all the inputs will definitely enhance accuracy but seriously offset the compliance with the real time requirement for *ATC* computations.

The rigorous mathematics intensive *ATC* computation methods (e.g. full-scale *AC* load flow based methods) are considered the most accurate but require processing of *2N* number of inputs for *ATC* between any pair of source-sink buses. *N* is the total number of buses in a transmission system. So when *N* approaches a large value, the base case operating condition may change by the time these methods calculate all the *ATC*s needed even though the computers available to date are significantly fast. Moreover, each *ATC* computation would have to be done considering the base case together with a significantly large number of probable outage cases one after another. The contingencies are selected from a ranked contingency list usually predetermined by the control centre i.e. Energy Management System (*EMS*) belonging to the *ISO*. As mentioned in Section 1.2, apart from pre-bid computations, just before effecting transactions a post-bid recalculation of *ATC*s for all the transactions sorted in descending order of *ATM* needs to be also done in real-time.

However, the conventional methods may consider *ATC* computation in a sufficient lead-time using projected or forecasted base case. But the uncertainties related to forecasting, even though a complete set of inputs is used, may lead to either an optimistic value for *ATC* that may compromise system security or a pessimistic (conservative) value that may unnecessarily discourage access to the usable transmission capacity.

Therefore, the problem being addressed by the present research work may be stated as follows.

"A methodology is warranted for accurate but real-time determination of *ATC* in a deregulated power system. The method must be capable of handling dimensionality, and at the same time curb uncertainties. It should determine *ATC* with and without the *MVAR* supports. Also it must be applicable for a system of large size ".

It appears that fuzzy logic holds potentials for addressing the stated problem.

1.5 Fuzzy Logic Applications in Power System

Fuzzy logic theory, introduced by Zadeh[21], was applied successfully by Mamdani *et al.* [22] to control the operation of a steam engine and boiler. Later on, the theory was further explored by other researchers [23-24] for various applications in engineering. The application of fuzzy logic in power system was first reported in 1984 [25] for expansion planning. In recent years, fuzzy logic has found numerous applications in various areas of power system [26-28]. The reported applications of fuzzy logic are as follows.

i. Planning - network planning and expansion, and maintenance scheduling[29-32].
ii. Operation – security analysis in vertically integrated power system, voltage control, load forecasting, unit commitment, and state estimation [33-39].
iii. Control – stabilisers, converters, and drives [40-42].

iv. Diagnosis – equipment malfunctions and system faults or disturbances [43-44].

Fuzzy logic has two main advantages. The way fuzzy logic tackles dimensionality is computationally more efficient than that by other *AI* techniques (such as *ANN*, Expert System etc.). Another advantage is that fuzzy logic can capture uncertainties inherent in the data. It is noteworthy that rigorous mathematics intensive conventional methods have none of these two advantages.

Dimensionality and uncertainty are two conflicting criteria. Dimensionality arises mainly due to the length of input vector (set of input variables), and the number of cases required to be solved. Uncertainty arises if the number of input variables is reduced leading to an incomplete set of data. But the uncertainty can easily be compensated by fuzzy methods. This is because fuzzy methods interpret a crisp (numerical) value of an available input variable in terms of more than one linguistic attributes with some degree of overlap. Also the fuzzy method has the capability to predict the output in one shot from an array of inputs through a rule-base that entails trivial on-line computations. This enables fast solution of a large number of cases by fuzzy methods. The steps of coding the input variables into a fuzzy set, inference making and determining a crisp output value are also computationally efficient.

Of course, the way fuzzy logic is to be applied and exploited to advantages depends upon the problem in particular. However, so far any work that uses fuzzy logic for determination of *ATC* appears to have not yet been reported.

1.6 Objectives

The main objectives of the present research are as follows.

i. To enhance the understanding of the deregulated system operation, the role of *ATC*, and the power system characteristics that influence *ATC*.

ii. To make a critical review of the existing methods for *ATC* determination.

iii. To investigate into the potentials of fuzzy logic and the way it can be applied for *ATC* determination.

iv. To identify the most suitable one from among the widely used fuzzy models for *ATC* determination.

v. To develop a novel method that would adopt fuzzy logic for determining *ATC* with and without reactive power supports involving minimum number of input variables in a large power system.

vi. To validate the developed method in terms of accuracy and *CPU* time through extensive simulation tests and comparison against a full-scale *AC* load flow method for the same array of transactions, base case and outage scenarios in a standard test system.

vii. To suggest the ways for further improvement of the developed method.

1.7 Scope

The present research is focused specifically on the following.

i. Development of a method using fuzzy logic for determination of bus-to-bus *ATC*s considering line thermal loadability and bus voltage constraints in a system operating under steady state.

ii. Confirmation if *MVAR* supports from the seller/ buyer or some other party can lead to an *ATC* higher than that obtainable without such support.

iii. Consideration of generation or line outages in the determination of *ATC*.

iv. Test and verification of the developed fuzzy method in terms of accuracy and *CPU* time against a full-scale *AC* load flow method for *ATC*s corresponding to a number of transactions (source-sink pair) in the standard *IEEE* 24 bus *RTS* (Reliability Test System) that has long been accepted in the literature as the typical representative of a practical power network.

v. Further verification of the method on the *IEEE* 118 bus system that is considered as a replica of a large power system.

vi. Determination of *ATC* by both the *AC* load flow and the developed fuzzy methods under given base case generation/loading scenarios and ranked contingency (outage) lists.

1.8 Contributions of the Present Research

The major contributions made by this research are mentioned below in a chronological order.

i. A unified presentation of the basic modalities underlying various models postulated or implemented so far for deregulation, has been made.

ii. A review of the state-of-the-art methods in *ATC* determination has been made. This helps in perceiving the limitations and drawbacks of the existing methods *vis-à-vis* the requirements posed by the emerging deregulation trend.

iii. The correlation between reactive power supports and *ATC* has been focused coherently and consistently based on which *ATC* has been resolved into two separate components respectively for availability and unavailability of *MVAR* backups.

iv. Two widely used fuzzy models viz. Mamdani and Takagi-Sugeno, have been presented using mathematics in a unified, simpler and more systematic way ever to be found in available literature.

v. A novel method has been developed for determination of *ATC* by applying fuzzy logic.

vi. The identification of the right kind of fuzzy model for *ATC* determination has been associated with discovering the fundamental differences between a small (e.g. a 3-bus) and a large (more than 3 buses) power system. Moreover, the example of a 3-bus system has been used to illustrate the basics as well as problems of *ATC* determination.

vii. Though fuzzy logic can deal with incomplete set of input data, it requires judicious choice of inputs. This has been done for *ATC* determination by proposing the following novel ideas.

a) In a deregulated system each transaction is identified in terms of a source-sink bus pair. In this research a third bus has been proposed and labeled as "neighbouring bus" corresponding to each transaction. A concept of direct and indirect paths has also been proposed to identify the neighbouring bus in a large power system.

b) A unified index has been proposed and labeled as "loading index" to represent a given operating scenario of a large power system taking into account the information on generation/line outages, and demands at buses.

c) The above approaches (a and b) have enabled use of only 3 input variables, and hence involvement of a less number of rules and complexities in the implementation of fuzzy logic for *ATC* determination in a large system.

1.9 Organisation of the Thesis

The material studied in the present research has been organised as follows.

In Chapter 2, the operating principles adopted in a deregulated power system together with a specific focus on the main issues related to *ATC*, have been discussed.

Chapter 3 presents a detailed review of the methods that are available in literature for *ATC* determination, and that can mainly be classified under three groups *viz.* (i) Load Flow based Methods, (ii) Stochastic Methods, and (iii) Artificial Neural Network Method.

In Chapter 4, the theories of two widely used fuzzy models *viz.* Mamdani and Takagi-Sugeno models, are presented using a systematic approach and simplified mathematics.

Chapter 5 details the development process of the proposed method that applies fuzzy logic for *ATC* determination. This also highlights the common as well as distinguishing features between a small and a large power system leading to identification of the appropriate fuzzy model (i.e. Mamdani or Takagi-Sugeno) to be used.

Chapter 6 presents and discusses typical results obtained from extensive tests of the proposed Mamdani model based *ATC* method on a sample 3-bus test system, and the proposed Takagi-Sugeno model based *ATC* method on the standard *IEEE* 24 bus *RTS* and *IEEE* 118 bus test system, and compares their accuracy and *CPU* time with those from an *AC* load flow method under same scenarios.

Chapter 7 summarises the main findings of the present research together with some suggestions for further investigations.

The appendices include supporting materials to various Chapters.

iv. The constraints considered in this work are bus voltage and line thermal limits. These are adequate for a system that remains in steady state. However, effect of an outage may occasionally lead to transient instability. This can be considered by incorporating in the fuzzy method few judiciously chosen input variables that influence transient stability the most. This may be done through integrating in the fuzzy program a separate module so that the number of input variables requiring concurrent processing does not become high. The stability module will only be run to determine *ATC* for top ranking (most severe) contingencies (outages). In those cases *ATC* is the minimum of the two values respectively obtained from the steady state module (as the one developed in this research) and the transient stability module. If this fuzzy logic based stability module is implemented the conventional stability analysis that is real-time incompatible will not be required during on-line determination of *ATC*.

v. Even though the *ATC* determination by fuzzy method as proposed in this thesis is specifically developed for the deregulated power system, the method can also be applied in the vertically integrated system. An example is Malaysian power industry in which the sole utility Tenaga Nasional Berhad (*TNB*) also buys electricity from *IPP*s normally under a fixed power purchase agreement. The purchased power is fed to its (*TNB*) distribution entities through the *TNB* transmission network. If instead of fixed power purchase agreement the *IPP*s are subjected to competition with one another or with *TNB* generation entities, the need for *ATC* computation is obvious. In that case the proposed method can be adapted by the *TNB* transmission entity (as if an *ISO*) to compute the Available Transfer Capability for *IPP*s or *TNB* generation entities in supplying power to the load centres. Moreover, as suggested in (iii), the proposed method of *ATC* determination can also be incorporated in *TNB* National Load Despatch Centre for the purpose of enhancing system security.

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