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Pricing Of System Security through Opf and Scopf Methods with N-1 Contingency Criteria in Deregulated Electrcity Market

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ABSTRACT

This work involves with a system pricing for power system security in deregulated electricity market that includes security constraints in a multi objective OPF problem. The most common target function in the classical formulation of the OPF is minimization of generation costs. The OPF increases social benefit, as well as the distance from the voltage collapse point. The effect of N-1Contingency on pricing is analyzed. The Day-ahead energy market is a financial market that enables market participants to purchase and sell energy at binding Day-ahead prices. The market participants bid according to their marginal price and market clearing price is decided by matching the generation and demand side bidding. ATC is computed by Linear Analysis method, considering N-1 contingency. The ATC shows amount of congestion. TTC is calculated offline.

Application of the proposed method on IEEE 30-bus standard network confirms its validity and effectiveness.

Index Terms – Security constraints, TTC, ATC, Contingency Analysis, OPF and SCOPF.

I. INTRODUCTION

In recent years, the electricity industry has undergone drastic changes due to a worldwide deregulation/privatization process that has significantly affected power system management and energy markets. In a deregulated system, operators goals are balancing consumer power demand using the available generation and ensuring that economical and technical constraints are respected [2],[3]. The prime economical aspect is the social benefit, i.e. power suppliers should obtain maximum prices for their produced energy, while consumers should pay the lowest prices for the purchased electric power [1]. In Deregulated Industry Structure, Power systems are operated under high loading conditions as market demands efficient operation and none of the services are allowed to be cross-subsidized by others as happens in monopolistic market [14]. So, in this environment the customers must pay for the additional services. As Independent System Operator (ISO) is bound to ensure certain level of stability, security and reliability of the system, system security is its major apprehension. So, there is a need to include suitable security constraints within the pricing mechanism; there by the correct market signals can be sent to all market participants while operating the system within reasonable security margins. Security Constraints have been included in many OPF based methods [4],[5].

This paper proposes a Linear Programming method is involved to solve the OPF problem [13]. This method is fast and efficient in determining binding constraints, but difficulty with marginal losses. The multi-objective OPF uses ATC as one of the constraints; ATC is calculated using linear analysis method, considering N-1 contingency. TTC is calculated offline.

II. TTC ASSESSMENT

TTC is a key factor for calculating Available Transfer Capability (ATC). TTC calculations are based on running different load flow cases from the base case until hitting thermal, voltage, or transit stability limits. TTC is calculated from area to area with any Generation/Load dispatch. In this work, TTC is calculated Off-line.

The North American Reliability Council (NERC) established a standard reference document [6] for the Total Transfer Capability (TTC). The engineering committee approved this document in November 1994. The value of TTC comes from its importance for calculating ATC [7] in the market transactions.

TTC "The amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post- contingency system conditions."

For TTC calculations, the modified IEEE 30-bus test system is divided into three areas. Here one area is considered as "source" area and another one is "sink" area. TTC is a directional quantity from the source to the sink i.e. TTC from area 1 to area 2 is not equal to the TTC from area2 toarea1. The term "area" used in this context can be used to refer to a generating station, power pool, control area, or a substation.

In this paper, “Generation/ Generation method (GG)” is used for calculation of TTC and it is calculated off-line. In this method, Generations are dropped in the sink area and the source area will increase its generation to balance these generation drops.

The Total Transfer Capability (TTC) computation flow chart is shown in Fig. 1.

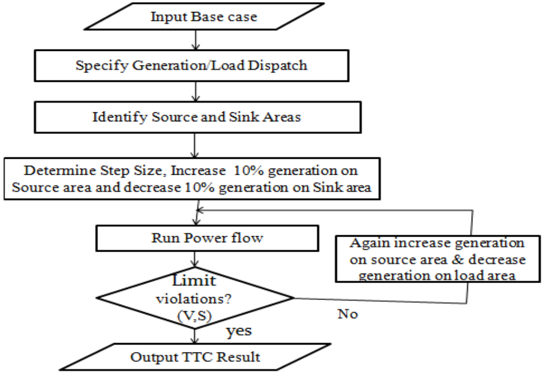

Fig.1 Algorithm for TTC calculation

It shows that TTC is calculated for first class contingency. Here number of iterations is present until to get a limit violation. The total transfer capability is the sum of transfers through the interconnecting lines. The main goal of transfer capability calculation from a security point of view is calculating the amount of generation in one area that can be exported to other areas.

III. ATC ASSESSMENT

The ATC calculation is directly related to physical capabilities of the interconnected network. The ATC can be defined [7] as “A measure of transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses”.

This definition can be formulated as equation

ATC = TTC – TRM – CBM

Where TTC – Total Transfer Capability
TRM – Transmission Reliability Margin
CBM – Capacity Benefit Margin

TRM “The amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.”

CBM “The amount of transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.”

TTC “The amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post- contingency system conditions.”

In this paper, Linear Analysis Method is used for determining ATC and considering N-1 Contingency. Single linear step technique is used and ignoring reactive power. Linear ATC typically assumes a lossless system. Linear techniques only require a single power flow solution (must start with a solved power flow case) and provide accurate results in a fraction of the time even for a large number of monitored elements and contingencies. Here, the proposed network is divided into two areas. ATC is calculated between two areas. It is a MW transfer capability. The results are obtained by using ATC Tool of power world simulator.

ATC for all lines present in these areas are calculated. ATC, i.e., the amount of power carrying capacity left for any line is related to congestion. If ATC is higher, congestion will be less and vice-versa. ATC is used as a constraint of OPF; it takes care of system congestion and its effect on pricing. ATC values are for N-1 contingency, so it ensures that the system will be free from congestion for both normal and N-1 contingency operations.

IV. SCOPF BASED ELECTRICITY MARKET

A. Problem Formulation

The OPF-based approach is typically formulated as a non-linear constrained optimization problem, consisting of a scalar objective function and a set of equality and inequality constraints. The classical OPF formulation does not take into account “security constraints.” The OPF can be extended to include security constraints; this formulation is also referred to as “Security Constrained Optimal Power Flow”.

In this paper, A “standard" OPF-based market model can be represented using the following.

$$Max\ (C_D^T P_D - C_S^T P_S) \rightarrow \quad Social\ Benefit \qquad (1)$$
$$S.t.\ \mathrm{f}\,(\delta, \mathrm{V}, \mathrm{Q_G}, \mathrm{P_S}, \mathrm{P_D})=0 \rightarrow \text{Power flow eq} \qquad (2)$$
$$0 \le P_S \le P_{Smax} \quad \rightarrow Supply\ Bid\ Blocks \quad (3)$$
$$0 \le P_D \le P_{Dmax} \quad \rightarrow Demand\ Bid\ Blocks \quad (4)$$
$$|P_{ij}\,(\delta, V)| \le P_{ij\ max} \quad \rightarrow \qquad (5a)$$
$$|P_{ji}\,(\delta, V)| \le P_{jimax} \quad \rightarrow \qquad (5b)$$
$$I_{ij}\,(\delta, V) \le I_{ij\ max} \quad \rightarrow \qquad (6a)$$
$$I_{ji}\,(\delta, V) \le I_{ji\ max} \quad \rightarrow \qquad (6b)$$
$$Q_{G\ min} \le Q_G \le Q_{G\ max} \quad \rightarrow \qquad (7)$$
$$V_{min} \le V \le V_{max} \quad \rightarrow \qquad (8)$$

Where C_S and C_D are vectors of supply and demand bids in \$/MWh, respectively; Eq. (5a),(5b) represent power flow limits. Eq. (6a),(6b) represent thermal limits. Eq. (7) represents Generator ‘Q’ limits, Eq. (8) represents voltage “security” limit. Q_G stands for Generator reactive powers; V and ∂ represent the bus phasor voltages; P_{ij} and P_{ji} represent the power flowing through the lines in both directions, and are used to model system security by limiting the transmission line power flows, together with line current I_{ij} and I_{ji} thermal limits and bus voltage limits; P_S and P_D represent bounded supply and demand power bids in MW. In this model, which is typically referred to as a security constrained OPF market model, P_{ij} and P_{ji} limits are obtained by means of off-line stability studies, based on N-1 contingency criterion. Thus, taking out one line that realistically creates stability problems at a time, the maximum power transfer limits on the remaining lines are determined through angle and/or voltage stability analysis; the minimum of these various maximum limits for each line is then used as the limit of corresponding OPF constraint. Here the main objective function (1) maximizes the social benefit, i.e. ensuring that generators get the maximum price for their power production and consumers pay the cheapest prices for their power purchase.

B. Maximization of the distance to Voltage Collapse

The second objective function is to maximize the distance to voltage collapse instead of simply determining the collapse point. Where two sets of power flow equations are used, one for the current operating point and one for the "critical" solution associated with either voltage collapse condition (i.e. saddle-node bifurcation or SNB) or a security limit as follows:

$$\text{Min.} \quad \lambda_P - \lambda_C \quad \rightarrow \quad (9)$$

$$\text{s.t.} \quad f\left(\delta_P, V_P, Q_{GP}, P_S, P_D, \lambda_P\right) = 0 \quad \rightarrow \quad (10a)$$

$$f(\delta_C, V_C, Q_{GC}, P_S, P_D \lambda_C) = 0 \quad \rightarrow \quad (10b)$$

$$H_{Pmin} \leq H\,(\delta_P, V_P, Q_{GP}) \leq H_{Pmax} \quad \rightarrow \quad (11a)$$

$$H_{Cmin} \leq H\,(\delta_C, V_C, Q_{GC}) \leq H_{Cmax} \quad \rightarrow \quad (11b)$$

$$\boldsymbol{\lambda_{min}} \leq (\boldsymbol{\lambda_P} - \boldsymbol{\lambda_C}) \leq \boldsymbol{\lambda_{max}} \quad \rightarrow \quad (12)$$

Where H is constraint functions of the dependent variables; H_{min} and H_{max} is their lower and upper limits respectively. Suffixes p and c indicate the current and the critical operating points, respectively, which solve the two sets of power flow equations. In objective function (9) the distance to the maximum loading condition is certainly maximized because of the use of the two loading parameters λ_P and λ_C. In Eq. (12), lower value of λ_{min} means the system is near to unstable point and higher value of λ_{max} makes system highly stable. But with higher system margin asset utilization is less and system becomes less efficient. As none of these conditions are acceptable, system can be made to operate efficiently with sufficient but minimum margin by choosing proper limit of λ. The approach of doubling power flow equations and including the dependence on a loading parameter will be used in this thesis to formulate a Voltage Security Constrained OPF.

V. BIDDING STRATEGY AND MARKET CLEARING PRICE

The market dynamics in the electricity market would drive the spot price to a competitive level that is equal to the marginal cost of most efficient bidders. In this market, winning bidders are paid the spot price that is equal to the highest bid of the winners.

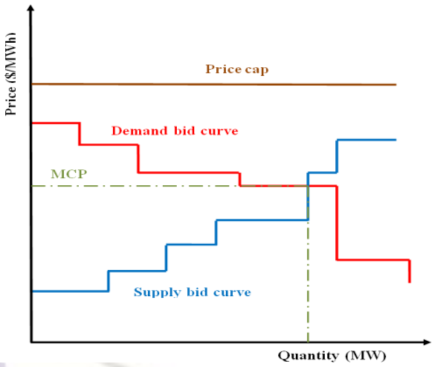

Fig.2. Market equilibrium point

Power exchange (PX) accepts supply and demand bids to determine a MCP for each of the 24 periods in the trading day [8]. Computers aggregate all valid supply bids and demand bids into an energy supply curve and energy demand curve. MCP is determined at the intersection of the two curves, and all trades are executed at the MCP, in other words MCP is the balance price at the market equilibrium for the aggregated supply and demand graphs. Generators are encouraged to bid according to their operating costs because bidding lower would lead to financial losses if MCP is lower than the operating cost and bidding higher could cause units to run less frequently or not run at all.

VI. SIMULATION AND RESULTS

The Simulation has been carried out for the modified IEEE 30-bus system by using "Power World Simulator" software.

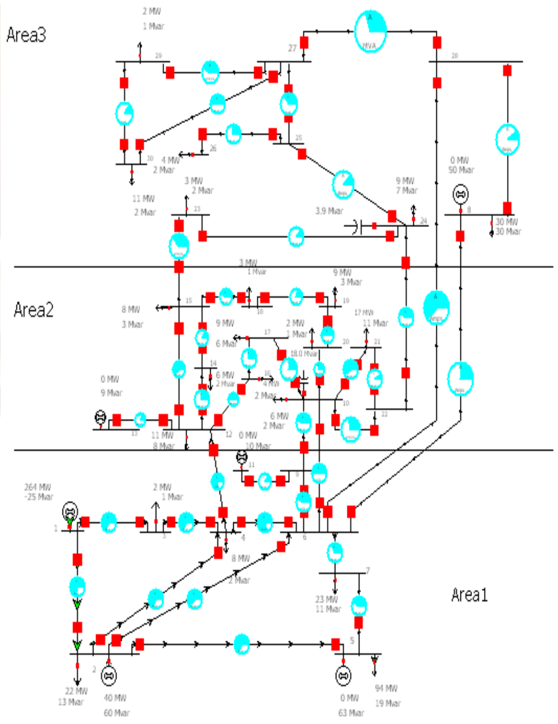

Fig 3: Modified IEEE 30–bus system

The proposed pricing strategy is established on modified IEEE 30-bus system. TTC values are shown in Table I

Table I
TTC for Pre- and Post Contingency Conditions

Area		**Pre-Contingency**	**Post-Contingency**
From	To	S(MVA)	S(MVA)
1	2	141.99	140.52
2	3	15.7	13.55
1	3	116.79	112.25

From the Table I, the TTC values are reduced at post-contingency condition compared to pre-contingency condition for all the areas. This result is shown in pictorial representation below:

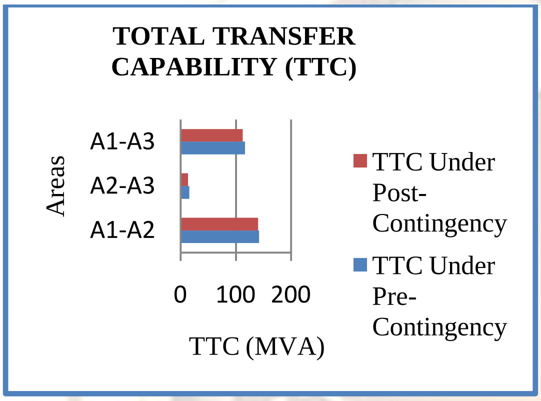

Figure 4

The ATC enhancement results for 30-bus system are shown below, here consider three cases. I.e., Case 1: Area1 to Area2 (A1-A2); Case 2: Area2 to Area3 (A2-A3); Case 3: Area1 to Area3 (A1-A3).

ATC under pre- and post contingency conditions for both the conditions are shown in plots below:

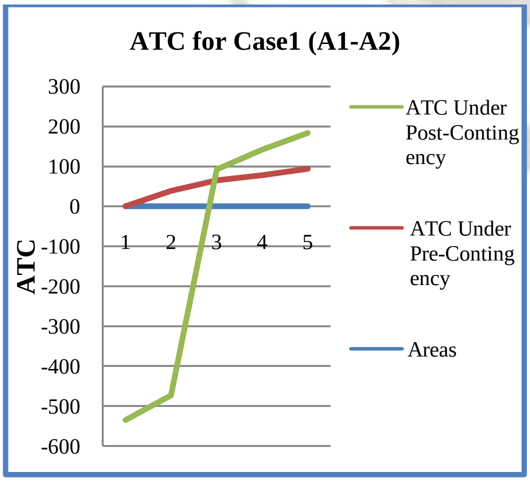

Figure 5

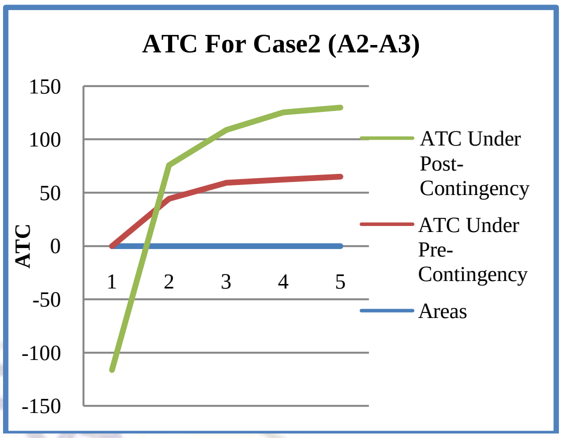

Figure 6

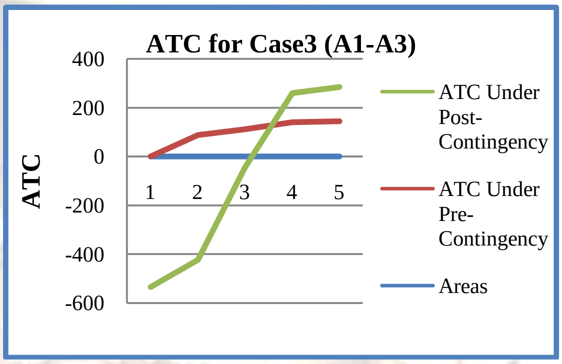

Figure 7

The above plots (Fig: 5, 6, 7) represent ATC value is reduced at post-contingency condition compared to pre-contingency condition. That means congestion is very higher at post-contingency condition.

Generator Supply Quantity and Bid Prices for pre- and post-contingency conditions are shown in Table II.

Table II
Generator Supply Quantity and Bid Price

Generator number	Quantity (MW)		Price ($/hr)	
	Pre-contingency	Post-contingency	Pre-contingency	Post-contingency
1	263.803	282.6	530.93	568.90
2	40	40	73.47	73.47
5	0	0	6.25	6.25
8	0	0	0.83	0.83
11	0	0	2.50	0.25
13	0	0	2.50	0.25

From the above Table, Generation of generator 1 has increased after contingency; even through its bidding Price is much higher than other generators and others have not reached their capacity limits.

Simple OPF and Security Constrained OPF results are shown in Table III.

Table III
Simple OPF and Security Constrained OPF Results

Simple OPF	Security Constrained OPF
Social Benefit = 12657.91 $/hr	Social Benefit = 48848.78 $/hr
Actual generation= 289.58 MW, 120.9 Mvar	Actual generation= 290.64 MW, 121.99 Mvar
Total Loss = 6.16 MW, 17.42 Mv ar	Total Loss = 7.24 MW, 18.26 Mvar
Shunt Injection = 22.73 Mvar	Shunt Injection = 22.48 Mvar
Total Tie flow = 192.2 MW, 70.1 Mvar	Total Tie Flow = 299.1 MW, 68.5 Mvar

Table III explains the Standard OPF and SCOPF results. The objective function value i.e. Cost is increased in SCOPF due to increased security level. Total Tie line flow for SCOPF has also been increased considerably. Actual Generation also amplified. Thus the anticipated method results into better utilization of transmission lines.

VII. CONCLUSIONS

In this paper, the anticipated method for including contingencies in a SCOPF based market is proposed and demonstrated on a simple modified IEEE 30-bus test system. Comparisons between the results obtained with the proposed technique i.e. SCOPF and the standard OPF based market model indicates that a proper representation of system security and a proper inclusion of contingencies, which results improved transactions, higher security margins and lower prices. This proposed technique improves the total tie line power flows, so it results the better utilization of transmission lines.

The distance from critical loading point can be monitored by changing upper and lower limits to loadability factor (λ) and the system can be made to operate with minimum margin and more efficiency. The anticipated pricing method can easily be used to find effect of security on pricing for any practical system, but with some approximations. ATC is calculated at contingency condition and it is much lesser than ATC at normal operating condition. TTC also reduced at post contingency condition compared to normal operating condition.

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