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DETERMITION OF TRANSMISSION COST IN DEREGULATED POWER SYSTEM BY IMPLEMENTION OF FACTS CONTROLLERS

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Abstract— Deregulation of electric power industry improves the quality of generation, transmission and distribution. In deregulated electricity markets, cost allocation of transmission services is critical for transmission open access. It is necessary to develop an appropriate pricing scheme that can provide the useful economic information to market participants, such as generation, transmission companies and customers. Though many methods have already been proposed, but accurately estimating and allocating the transmission cost in the transmission pricing scheme is still a challenging task.The cost of the transmission network can be interpreted as the cost of operation, maintenance and construction of the transmission system. Recently Facts devices invited the attention of researchers because of their superior qualities. These devices are installed in the system in order to reduce the operational costs. When these devices are introduced, a more flexible operation and control of transmission networks are possible. In this paper, an attempt has been made to calculate the Transmission cost allocation by Distribution factor method by installing FACTS devices in the proposed system. Also a comparison has been done on a standard IEEE 14 bus system for with and without FACTS controllers. The proposed methodology has been tested by using programming in MATLAB and Load flow solution is observed by using Power world simulator software.

Index Terms— Deregulated electricity market, AC power flow, Distribution factor method, FACTS controllers

I. INTRODUCTION

Fair pricing of the transmission service is one of the challenging issues that have to be faced after the deregulation of power systems. Objective measures are needed that will allow the transparent remuneration of transmission-network usage and that will give appropriate economic signals to the network users. To solve this problem, several approaches have been proposed.

The postage-stamp method is a straightforward method because a tariff provides the transmission-network usage remuneration independently of the distance or location of the contractual power source and the drain throughout the entire power system. However, the time of a particular transaction and the increased transmission losses due to the transaction are not taken into account. The postage-stamp method allocates the transmission costs among the various users of the transmission service only according to the amount of power involved in each transaction. It is commonly used for recovery of transmission investment under a regulated regime. Since this method ignores the actual system operation, it does not send the correct economic signal to the network users. The contract-path method artificially selects a specific path between a producer and a consumer according to the wheeling transaction, without performing a power-flow calculation. As a result, some transmission facilities that are involved in the actual energy transaction are ignored, thus their usage is not being paid.

Given a transaction with the actual points of generation and load, the distance relating the transmission pricing method known as the MW-mile method [6] calculates the maximum transaction related power flow on every transmission line using dc power-flow and linear programming algorithms. The line length and a factor reflecting the cost per unit capacity of aline further multiply this value. The price is proportional to the transmission usage for the transaction. It does not, however, reflect the actual power flows and may, in certain cases, discourage competition. Another approach for power wheeling pricing, called MVA-Km method applying AC power flow, has also been developed. This approach is more reasonable and valid than the commonly used MW-mile method [6] which is based on DC power flow. Since the already developed transmission service pricing methods have certain difficulties in assessing the actual transmission network usage, this paper GGDF method was introduced, using this method contingency analysis, safe operation are determined. GGDF is the best way of transmission pricing among three Pricing methods. Flexible AC transmission system are growing trends of technology for salient operation of the system for bulk power transfers and optimally exploiting the transmission corridors more flexibly. Functions are simplified by their having advanced power electronics components which make them respond promptly to control inputs.

Its immediate response leads to a high ability for a power system stability enhancement in addition to the control factor [10,11]. Canizares et al., [12] describes the two categories of FACTS devices based on different modes of operation which is commonly used in transmission system. It could be installed in the system either in series or shunt mode as a controller, so as to enhance the voltage and reactive power controllability. Advances in power electronics technology along with the sophisticated control methods have made FACTS a promising pattern of power system. STATCOM is one of the important shunt connected Flexible AC transmission system controller to control the power flow and make better transient stability. These devices are operating as reactive power compensators. In reference [13], the authors employed the wheeling charges in the restructured power system. Here 6 bus test system are consider to illustrate the performance of proposed method. This paper proposes a novel approach based on wheeling charge reduction in transmission cost allocation. A standard mathematical approach of MW-Mile method is incorporated with FACTS technology to determine the wheeling charges for various power transactions. Hence FACTS devices are introduced in order to harvest the technological benefits. By installing these devices the economic benefits on companies and consumers sides are improved. A numerical example with IEEE-14 bus system is considered to emphasize the superior performance of the proposed method. This paper is organized as follows: The second section describes literature survey of transmission cost allocation methods. The third section describes the transmission pricing schemes. The fourth section describes the algorithm of proposed method. The fifth section describes the Flexible AC Transmission System (FACTS) controllers. The sixth section describes the results and discussion and seventh section describes the conclusion.

III. TRANSMISSION PRICING SCHEMES

The objective of any transmission pricing method is to allocate all or part of the existing and the new cost of transmission system to customers. However, tariffs for transmission services are more often set by government regulations, and are based on its policy directives. The pricing of transmission services should be carried out to achieve the following goals are It recovers the capital and operating costs, It encourages efficiency of use and investment, It provides equal opportunity to all users, It offers a simple and understandable price structure, It is easily implementable. In general, the following three pricing schemes are employed for transmission services:

- Rolled-in (embedded) transmission pricing
- Marginal transmission Pricing
- Composite transmission pricing

The transmission costs may include:

- Running costs, such as costs for operation, maintenance, and ancillary services.
- Past capital investment.
- Ongoing investments for Future expansion

In the following, we discuss major transmission cost allocation methods. Some of these methods are used widely by electric utilities, while others are still in developmental stages

1. Postage-Stamp Rate Method
2. Contract Path Method
3. MW-Mile Method
4. Unused Transmission Capacity Method
5. MVA-Mile Method
6. Counter-flow Method
7. Distribution Factors Method
8. AC Power Flow Methods
9. Tracing Methods

IV. ALGORITHM OF PROPOSED METHOD.

Step1: Run the load flow by using N-R method for base case data.

Step2: compute power flows of each line MW-Mile method with UPFC controller to determine the

Step3: Read the line lengths in miles

Step4: Fix the unit rate i.e.,$/MW/Mile

Step5: Find the new power flow by installing with and without FACTS devices

Step6: Calculate A factors by using equation (10).

Step7: Calculate D factors using A factors and using equation (12).

Step8: Evaluate the tracing of line flow of each line by using equation (11).

Step9: Evaluate total cost of each generator.

Step10: Evaluate the transaction cost for each generator.

$$\text{Transaction cost}(\$) = \frac{\text{total transmission cost of each generator}}{\text{total transmission cost of all generators}}$$

Step11: Calculate cost ($/MW) for each generator [3].

$$\textbf{per unit cost}\left(\$/_{\textbf{MW}}\right) = \frac{\textbf{each transaction cost}}{\textbf{power generation of generator}}$$

Generation Shift Distribution Factors (GSDFs or *A* factors):

GSDFs or A factors provide line flow changes due to a change in generation.

These factors can be used in determining maximum transaction flows for bounded generation and load injections. GSDFs or A factors are defined as[2]

$$\Delta P_{l,jk} = A_{jk,i} . \Delta P_{gi} \quad \text{--- (1)}$$

$$\Delta P_{ge} + \Delta P_{gi} = 0, jk \in R, i \in {}^{N}/_{e} \text{---- (2)}$$

Where

$\Delta P_{l,jk}$ - Change in active power through the element jk in network.

$A_{jk,i}$ - Generation shift factors through network element jk, corresponding to the change at bus i.

ΔP_{ge} - Change in generation at slack bus.

ΔP_{gi} - change in generation at bus i $(i \neq e)$.

GSD's (A factors) determined by DC power flow

$$P = B.\delta \text{ ---- (3)}$$

Where

P – Vector of injected power in system buses

δ –vector of nodal voltage angles

B- Nodal Susceptance matrix.

Voltage angle results

$$\delta = -B^{-1}.P \text{ ---- (4)}$$

Which means (nothing with $b^{-1}{}_{ji}\; j \in N, i \in N$ the elements of B^{-1})

$$\delta_j = -\sum_{i \in N} b_{ji}^{-1} P_i, j \in N \text{ ---- (5)}$$

Hence the relation (3) becomes

$$P_l = -B_l . \delta_l \text{ ----(6)}$$ Where

P_l -Vector of power through elements of the network

B_l -Diagonal matrix of longitudinal susceptances of network elements jk.

δ_l -vector of difference of voltage angles from ends of network elements jk

Writing in extended the relation (6) lead to:

$$P_{l,jk} = -B_{l,jk} . (\delta_j - \delta_k), jk \in R \text{ ----(7)}$$

Using the relation (5), relation (7) becomes

$$P_{l,jk} = -B_{l,jk}\left[\sum_{i\in N}(b_{ji}^{-1}P_i) - \sum_{i\in N}(b_{ki}^{-1}P_i)\right]$$
$$= -B_{l,jk}.\sum_{i\in N}\left[\left(b_{ji}^{-1} - b_{ki}^{-1}\right).P_i\right], jk \in R \text{ --(8)}$$

Equation (**8)** is linear and the modification of power through network element, $\Delta P_{l,jk}$ due to changing of power injected in bus i, ΔP_i can be expressed as

$$\Delta P_{l,jk} = -B_{l,jk}\left(b_{ji}^{-1} - b_{ki}^{-1}\right).\Delta P_i \text{ -----(9)}$$

By comparing the equations (9) and (1)**,** the expression of A factors for network element jk , corresponding changing of generated power in bus i

$$A_{jk,i} = -B_{l,jk}\left(b_{ji}^{-1} - b_{ki}^{-1}\right), jk \in R, i \in {}^{N}/_{e} \text{ ---(10)}$$

Generalized Generation Distribution Factors (GGDFs or *D* factors):

They determine the impact of each generator on active power flows thus they can be negative as well. Since GGDFs are based on the dc model, they can only be used for active power flows. GGDFs or *D* factors are defined as[2]

$$P_{l,jk} = \sum_{i\in N}(D_{jk,i}\,.P_{g\,i}), jk \in R \text{----(11)}$$

$P_{l,jk}$ -Active power flow

P_{gi} -power generated in bus i

$D_{jk,i}$–D factor of a network elements jk, corresponding to power generated in bus i

$$D_{jk,i} = D_{jk,e} + A_{jk,i} = \frac{P_{jk}^{0} - \sum_{i\in N/_e}(A_{jk,i}P_{g\,i})}{\sum_{i\in N}P_{gi}} + A_{jk,i} \text{ ----(12)}$$

Where

P_{jk}^{0} - Power flow on network elements jk from the previous iteration.

e- Slack bus.

It determines the impact of each generator on active power flow on network elements (they can have negative values). D factors reflect the utilization rate of electricity transmission capacity depends upon the generated power and they depend on network elements and operating regime and not on the choice of reference bus.

V. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) CONTROLLERS.

Flexible AC transmission systems have attracted a great interest due to recent advances in power electronics. The Facts technology opens up newer opportunities for controlling power, and enhancing the usable capacity of lines. They control the power flow in the transmission lines by handling the one or more of the parameter nodal voltage, angular difference and line serious Impedance [11]. Generally FACTS Controllers can be divided into two categories. The first category employs conventional Thyristor switched capacitors and reactors and quadrature tap changing transformers. The second category includes gate turn-off (GTO) Thyristor switched converters such as voltage source converters (VSC), Static var compensator (SVC).Thyristor - controlled series capacitor (TCSC) and Thyristor controlled phase shifter (TCPS) are belong to first category. The second category includes static synchronous compensator (STATCOM), the static synchronous series capacitor (SSSC), the Unified power flow controller (UPFC) and the Interline power flow controller (IPFC). There FACTS controllers exhibit different operating and performance characteristics. Among the available FACTS devices, the STATCOM is one of the important and well known shunt compensation devices which has been used to enhance the power transfer capability and to maintain the transient and dynamic stability of the system.

5.1 Static Synchronous Compensator (STATCOM)

A Static synchronous compensator or STATCOM (also called static condenser or STATCON)is a gate-turn off (GTO) Thyristor based voltage-sourced inverter was proposed by Gyugyi in 1976.STATCOM is the advanced version of SVC and can be operated as a shunt connected static var compensator. It is used as a regulating device in alternating Current electricity transmission networks. Usually, a STATCOM are installed in a electricity network to supply reactive power to the system which that they are have a poor power factor and often poor voltage regulation. The STATCOM provides better damping characteristics compared to svc and more over it is able to enhance transiently exchange active power with the system [22].

STATCOM offers lot of advantages: Small/Compact, fast response, better dynamics, lower investment and maintenance cost, no harmonic pollution, no rotating parts, inherently modular and re-locatable [12]. STATCOM is capable of having more superior performance as compare to conventional svc. In General, the STATCOM consists of three main parts: a voltage source converter (VSC), a coupling transformer and a controller. It is the static form of rotating synchronous condenser but it supplies or draws reactive power with a fast rate because there is no moving parts with it. The voltage source converter is driven by a dc storage capacitor. The voltage source converter that produces a set of three phase ac output voltage. During the steady state operating condition, the output voltage produced by the voltage source converter is in phase with the ac system Voltage, in this case only the reactive power is flowing. If the magnitude of voltage produced by the voltage source converter (VSC) is lesser than ac system voltage, the STATCOM absorbs reactive power and moreover, the voltage source converter (VSC) output voltage is greater than the ac system voltage, the STATCOM produces reactive power.

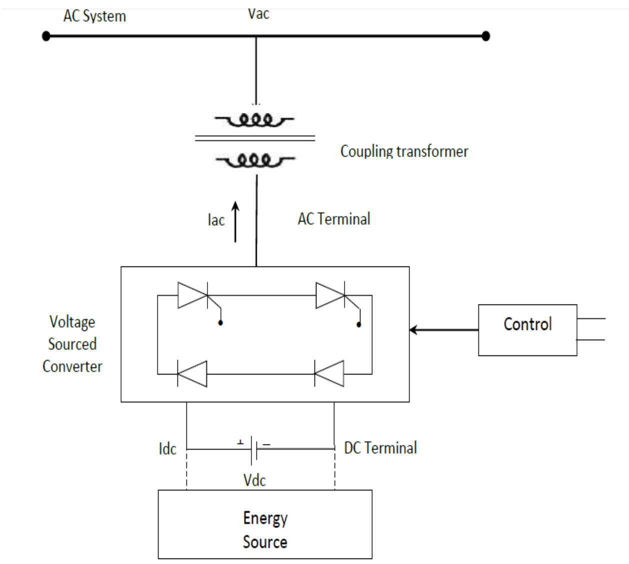

Figure 1 Functional Block diagram of STATCOM

If the voltage produced by the voltage source converter (VSC) is equal to the system Voltage, there is no exchange of reactive power takes place. This enables the STATCOM to supply or absorb the right amount of reactive power required in order to compensate the reactive power required by the ac power system [10,11].

VI. RESULTS AND DISCUSSION

The proposed Distribution factor method fused with STATCOM methodology is applied on IEEE-14 bus test system to represent the wheeling transaction and to show its performance and ability to provide appropriate revenue to the company. The test system in taken from the reference [16], consisting of five generating units, Fourteen buses and twenty transmission lines. Moreover eleven loads are placed at buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, and 14. There are two generators with the local load at buses 2 and 3. The system Line data, Bus data are adopted from the same reference. The single line diagram of IEEE-14 bus test system is displayed in fig. 2. The network shows that how the power injected by generator is distributed between the lines and loads of the system. provides minimized wheeling charges by the introduction of FACTS devices.

Here, all generators are scheduled to deliver the full capacity through their transmission line to meet the load. The Generator G1 delivers the output power of 1200MW to the transmission line 1-2 and 1-5. Similarly remaining Generators G2,G3, G4 and G5 delivering the output power of 1000MW, 1500 MW, 1200MW and 1400MW respectively. In this work, there are five wheeling transactions have been considered which involves five different Transactions locations. The detail of five different Transactions is represented as follows.

T1: Injection of power at bus 1 and received at bus 5.
T2: Injection of power at bus 2 and received at bus 5.
T3: Injection of power at bus 6 and received at bus 9.
T4: Injection of power at bus 8 and received at bus 13.
T5: Injection of power at bus 3 and received at bus 4.

The simulation results were carried out on standard IEEE-14 bus test system with two different cases.

Case 1: Results without FACTS devices

In the first case, Transmission System do not consider the FACTS Devices of STATCOM. In order to calculate line flows and flows caused by each transaction a Newton – Raphson based load flow analysis has been carried out. Table 1 depicts the base case power flow of without and with FACTS devices (STATCOM). The simulation results of line cost, base case power, actual power flow of various transactions and wheeling charges are displayed in Table 2.

Case 2: Results with FACTS devices

An experiment has been done by introducing the STATCOM in the proposed system to reduce wheeling charges. The STATCOM are placed at buses 2 and 3. After implementing the STATCOM in the bus 2 and 3, the base case power flows are linearly changed and given in Table 1. The simulation results of line cost, base case power flow, Actual power flow for five different transactions and wheeling charges with STATCOM are displayed in Table 3. Finally the simulation results of wheeling charges are compared and reported in Table 4. It is graphically represented in Fig:3. From the results, it is observed that the proposed method provides minimized wheeling charges by the introduction of FACTS devices.

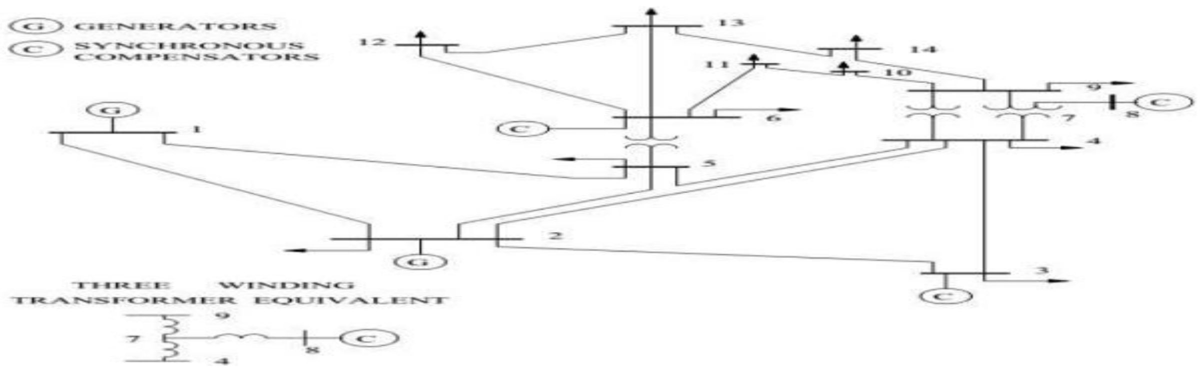

Figure 2: Single Line Diagram of IEEE 14 bus test system

Line. No	Base power flow without STATCOM (MW)	Base power flow with STATCOM (MW)	Line. No	Base power flow without STATCOM (MW)	Base power flow with STATCOM (MW)
1-2	48.04676	6.9325	6-11	10.33291	8.982
1-5	72.44505	35.628	6-12	11.14197	6.725
2-3	111.13418	45.334	6-13	25.20962	19.81
2-4	92.35483	45.178	7-8	0.0000	0.100
2-5	76.01001	56.234	7-9	39.41355	23.564
3-4	26.41689	15.625	9-10	7.44470	4.325
4-5	68.44920	45.603	9-14	13.14123	8.925
4-7	39.41355	15.423	10-11	5.17657	3.245
4-9	22.47239	12.41	12-13	2.42008	1.232
5-6	62.36450	32.218	13-14	8.15814	4.5691

Table 1: Base Case Power Flow of Without and with STATCOM

Line No	Line Cost	Base power flow (MW)	Power flow due to various Transactions				
			T1 (MW)	T2 (MW)	T3 (MW)	T4 (MW)	T5 (MW)
1-2	364000	48.04676	12.463	83.502	22.122	82.574	21.876
2-3	202500	111.13418	166.38	159.06	98.925	157.29	97.826
2-4	134400	92.35483	165.29	162.17	98.457	160.37	97.363
1-5	197880	72.44505	316.25	308.77	40.037	305.34	39.592
2-5	48600	76.01001	142.23	224.96	132.42	222.46	130.95
3-4	245000	26.41689	456.61	528.59	531.55	522.71	525.64
4-5	12000	68.44920	126.81	143.32	158.9	141.73	157.14
5-6	217000	32.218	95.653	121.51	74.778	120.16	73.947
4-7	280000	39.41355	40.193	49.852	63.873	49.298	63.163
7-8	70000	0.0000	49.852	59.199	81.009	58.541	80.109
4-9	871000	22.47239	105.94	115.28	84.125	114	83.19

7-9	21300	39.41355	84.125	112.17	126.19	110.92	124.79
9-10	24330	7.44470	168.87	169.81	143.32	167.92	141.73
6-11	289900	10.33291	143.32	158.9	17.137	157.14	16.946
6-12	312000	11.14197	128.37	148.93	269.2	147.28	266.21
6-13	42000	25.20962	143.32	18.85	32.715	18.641	32.352
9-14	319800	13.14123	99.704	74.155	89.733	73.331	88.736
10-11	212200	5.17657	112.17	377.16	286.65	372.97	283.46
12-13	198000	2.42008	139.27	42.218	49.852	41.749	49.298
13-14	292000	8.15814	50.008	118.55	152.67	117.24	150.97
Wheeling Charges ($)			**322777**	**671083**	**198567**	**243211**	**413543**

Table 2 Simulation Results of IEEE – 14 Bus Test System without STATCOM

Line No	**Line Cost**	**Base power flow (MW)**	**Power flow for various Transactions**				
			T1 (MW)	**T2 (MW)**	**T3 (MW)**	**T4 (MW)**	**T5 (MW)**
1-2	364000	15.752	6.9239	46.39	12.29	41.751	11.061
2-3	202500	58.16	92.434	88.366	54.958	79.529	49.462
2-4	134400	58.16	91.828	90.097	54.699	81.087	49.229
1-5	197880	142.72	175.69	171.54	22.243	154.38	20.019
2-5	48600	70.104	79.019	124.98	73.566	112.48	66.209
3-4	245000	212.04	253.67	293.66	295.3	264.29	265.77
4-5	12000	63.007	70.45	79.624	88.279	71.662	79.451
5-6	217000	36.35	53.141	67.508	41.543	60.757	37.389
4-7	280000	18.175	22.329	27.695	35.485	24.926	31.936
7-8	70000	28.128	27.695	32.888	45.005	29.6	40.505
4-9	871000	53.66	58.853	64.046	46.736	57.641	42.062

7-9	21300	37.043	46.736	62.315	70.104	56.083	63.094
9-10	24330	90.01	93.818	94.338	79.624	84.904	71.662
6-11	289900	76.076	79.624	88.279	9.5203	79.451	8.5683
6-12	312000	55.477	71.316	82.74	149.56	74.466	134.6
6-13	42000	62.401	79.624	10.472	18.175	9.4251	16.358
9-14	319800	16.098	55.391	41.197	49.852	37.077	44.867
10-11	212200	10.472	62.315	209.53	159.25	188.58	143.32
12-13	198000	18.175	77.374	23.455	27.695	21.109	24.926
13-14	292000	23.75	27.782	65.863	84.817	59.277	76.336
Wheeling Charges ($)			**210481**	**583918**	**126438**	**201432**	**342148**

Table 3 Simulation Results of IEEE – 14 Bus Test Systems with STATCOM

Transactions	**Wheeling Charges ($)**	
	Without STATCOM	**With STATCOM**
T1	322777	210481
T 2	671083	583918
T 3	198567	126438
T 4	243211	201432
T 5	413543	342148

Table 4 Comparison of Transmission pricing Results for with and without STATCOM

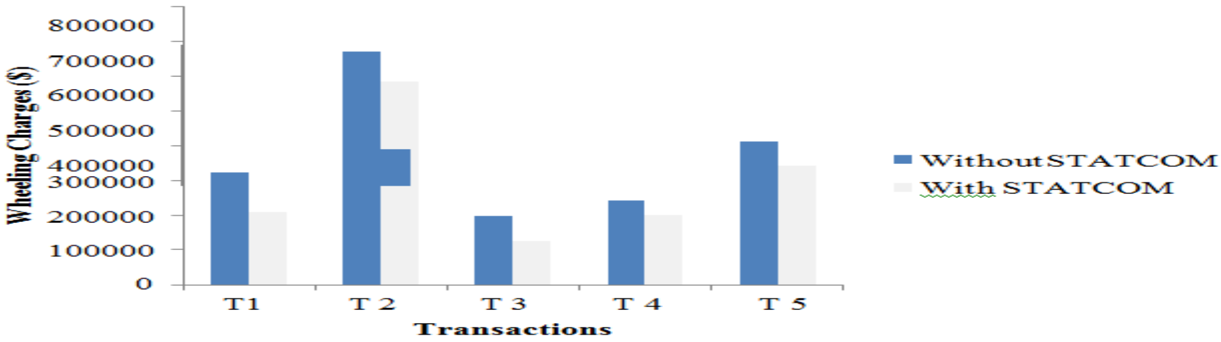

Figure 3: Comparison of Wheeling Charges With /Without STATCOM

VII CONCLUSION

In the present open access restructured power system market, it is necessary to develop an appropriate transmission pricing methodology scheme to the consumers and producer. The methodology that would allocate the transmission pricing charges among the users in a fair and flexible manner. This paper proposes a simple and reliable analytical approach of power flow based Distribution factor method fused with STATCOM technology to allocate the transmission wheeling charges in the market participants. The salient features of proposed method can be expressed as follows:

- It is possible to calculate the wheeling charges for various transactions without repeated load flow analysis.
- FACTS technology can be an alternate source to reduce the power flow in heavily loaded lines, resulting in an increased loadability of the network.
- It is well suitable for solution of various power system problems under deregulated environment such as Reactive power pricing, ATC Enhancement and Congestion management.

The effectiveness and applicability of the proposed methodology is tested on a IEEE- 14 bus test system and numerical results are tabulated. The numerical data includes base case power flow, actual power flow, incremental power flow and wheeling charges for multiple transactions. Also results are compared to with and without STATCOM devices connected to proposed test system. From the results, it can be concluded that the proposed Distribution factor method with STATCOM technology is a promising approach for solution of various transmission pricing problems under deregulated environment.

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