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EVALUATION OF TRANSMISSION PRICING STRATEGY IN RESTRUCTURED POWER SYSTEM BY IMPLEMENTATION OF STATCOM DEVICES

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ABSTRACT-----Deregulation of electric power industry improves the quality of generation, transmission and distribution. In this, Transmission companies play a vital role in providing a network interconnection for effective transmission of power between the electric utilities. Transmission pricing has become an core issue of research in the process of restructuring. More over the pricing schemes determines whether the transmission services is economically benefit to both the utility and consumers. Therefore a systematic development of novel pricing scheme becomes a major concern of transmission companies. The pricing methodology must be non-discriminatory, transparent, economically efficient and have to recover all the costs involved in the transaction. 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 MW-Mile 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 STATCOM. The proposed methodology has been tested on a standard IEEE 14 bus system to illustrate the concepts of this framework.

KEYWORDS: Restructuring , Transmission Pricing, Power Transaction, Wheeling Charges, MW-Mile method, Cost, FACTS, STATCOM.

Nomenclature

WC_t - Transmission or wheeling charge for transaction ($/hr)
TC-Total Transmission charge ($/hr)
P_t -magnitude of transacted power (MW)
P_{peak}-System peak demand (MW)
TC_k -Transmission charge of contract path ($/hr)
Pxt -Cost of the Transaction ($/hr)
Dt -Airline Distance
PM -Magnitude of real power
L_K -Length of line k in mile
C_k -Cost per MW per unit length of line k
MW-Mile - Mega watt mile
$MW_{t,k}$ -Flow in line k due to transaction t
T -Set of transactions
K -Set of lines
FACTS-Flexible Alternating Current Transmission System
STATCOM- Static Synchronous Compensator

1. INTRODUCTION

Transmission pricing happened to be an core issue in the field of power system restructuring and deregulation. The ever increasing cost of electrical energy has invited researchers to make efforts in reforming the transmission pricing strategies. A transmission pricing scheme is one which could provide the useful economic information to market participants.

A proper transmission pricing scheme could meet revenue expectations, ensures an efficient operation of electricity markets, attract investments, optimal location of generation and transmission lines. The schemes that could be implemented should be fair and practical. Several methods have been used and proposed to evaluate the pricing method analysis of different markets [1].

Transmission companies are responsible in determining charges for wheeling transaction. Power wheeling is one of the important prevailing unbundled services, and it is economically viable to wheelers and customers [2]. Wheeling means transfer of power between two or more utilities using a transmission network of third one [3].

Many Methods have been suggested to obtain the cost of transmission transaction. These methods touch upon two basic components. These methods are classified as embedded cost and incremental cost or marginal cost. Among these methods embedded cost methods are commonly used by the power industry [4].

Transmission pricing methods are the overall process of translating transmission cost into overall transmission charges. These transmission pricing philosophies can be classified into three categories. They are embedded cost incremental cost, and composite. Normally the choice of selecting a particular category of pricing is depends on the degree of deregulation or liberalization in the power sector of the country [5,6].

There are four type of embedded cost methods extensively used to share the transmission transaction cost namely Postage stamp method, Contract path method, Distance based MW-Mile Method and Power Flow Based MW – Mile Method [7].

Kirschen et al., [8] introduced a graphic technique which identified a contribution of each generator to supply load and line flows. The details of domain, common, link and state graph are needed to implement this technique.

Bialek et al., introducing a concept of matrix based approach to solve the same problem. In this method, topological generation and load distribution factors has to be calculated using the upstream looking and downstream looking algorithm [9].

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 MW-Mile method with UPFC controller to determine 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.

2. EXISTING PRICING METHODOLOGIES:

The embedded cost method is one which is widely followed by the power industry. These methods have the advantage that they are practical and fair to all participants easy, to measure and provide adequate revenue in the transmission system [14].

2.1 Postage stamp method

Postage stamp method is regularly used by power companies to distribute the fixed transmission cost among the users of transmission service. Here the cost is proportional to the power alone. Same price per MW is changed irrespective of distance and location of transmission in the same control area.

The transmission distance and network topology is not important in the technique. Even though, this method is simple it is likely to show incorrect economic signal to the consumer because this method does not consider the entire system operation [15, 16].

The Transmission service charge using this scheme can be written as

$$WC_t = TC \times \frac{P_t}{P_{Peak}}$$

2.2 Contract Path Method

In contract path method, the transaction cost is charged on the basis of well-defined contract path. The contract path is created by the shortest route aligned by the series of transmission lines between contract nodes. Moreover the contract path need not be a physical power flow path and hence this methodology yields inaccurate economic signals [17].

The Transmission charge using the contract path is defined as

$$WC_t = \sum_k TC_k \times \frac{P_t}{P_{Peak}}$$

2.3 Distance based MW - Mile Method

Distance based MW - mile technique distributes the cost by considering the magnitude of transacted power and the distance travelled by the transacted power between delivery and receipt nodes of the system. This method mostly sends incorrect economic signals to customers because it ignores the operational condition of the network system [18].

The Transmission charge using the Distance based MW - mile method can be modelled as

$$WC_t = TC.\frac{Pxt}{\sum_1^T Pxt}$$

2.4 Power Flow Based MW-Mile Method

Power flow based MW-mile method is one which overcomes the above drawback. By considering the actual system operation, this method accounts the charges of every wheeling number based on the extent of use of transmission utilities. These allocated charges are then added up over all transmission utilities to evaluate the total price [19].

3. Methodology of Proposed Method

The Power flow based MW-Mile method may be regarded as the first pricing strategy proposed for the full recovery of fixed transmission costs based on the actual use of the system [20].This method is most widely used in transmission system because it is more reflective to usage of actual power transmitted in allocating the transmission cost.

The MW-Mile method is an embedded cost method that is also known as line-by-line method. In this method charges for each wheeling transaction are based on the measure of transmission capacity use. This is determined as the magnitude, the path and the distance travelled by the transacted power. These allocated charges are then added up to all transmission facilities to calculate the total price. Many economists prefer this concept because it encourages the efficient use of transmission facility and further expansion of the system. [20].

The proposed MW-mile method calculates the incremental power flow in all transmission lines when a new wheeling participant is introduced in the system. The contribution of each transaction to the total transmission capacity cost of the MW – mile method can be summarized as follows:

$$WC_t = TC * \frac{\sum_{k \in K} c_k L_k MW_{t,k}}{\sum_{k \in T} \sum_{k \in K} c_k L_k MW_{t,k}}$$

Where,

TC_t = Price charged for transaction t in \$/MW
TC= Total cost of all lines in \$
L_K= length of line k in mile
C_k= cost per MW per unit length of line k
$MW_{t,k}$ = flow in line k due to transaction t
T = set of transactions
K = set of lines

3.1 Algorithm for proposed method

Step 1: Read the line data, Bus data and Generator data of the proposed system.

Step 2: Run using DC power flow to analyze the base case studies.

Step 3: From the base case studies determine the base power flow for each line.

Step 4:Line cost is obtained by the product of price per unit length (C_K) and actual length of the line (L_K) in miles.

$$MW\ Mile_t = C_K L_K$$

Step 5: Find the new power flow by installing with and without STATCOM and evaluate transaction cost for a particular Transaction (T_1) and hence the above process is repeated for remaining transactions (*T2*,*T3*,*T4* and *T5*) at different locations.

$$MW\ Mile_t = \sum_{k \in K} c_k L_k MW_{t,k}$$

Step 6: Calculate the incremental power flow on each line caused by the particular transaction (*T1*) and the difference of base case power flow and new power flow. The above process is repeated for remaining transactions at different locations.

Step 7: Calculate the total cost of all transactions (*TC*).

Step 8: Compute the wheeling charge for each transaction.

$$WC_t = TC \times \frac{MWMILEt}{\sum_{1}^{T} MWMILEt}$$

4. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

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 [21].

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.

4.1 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].

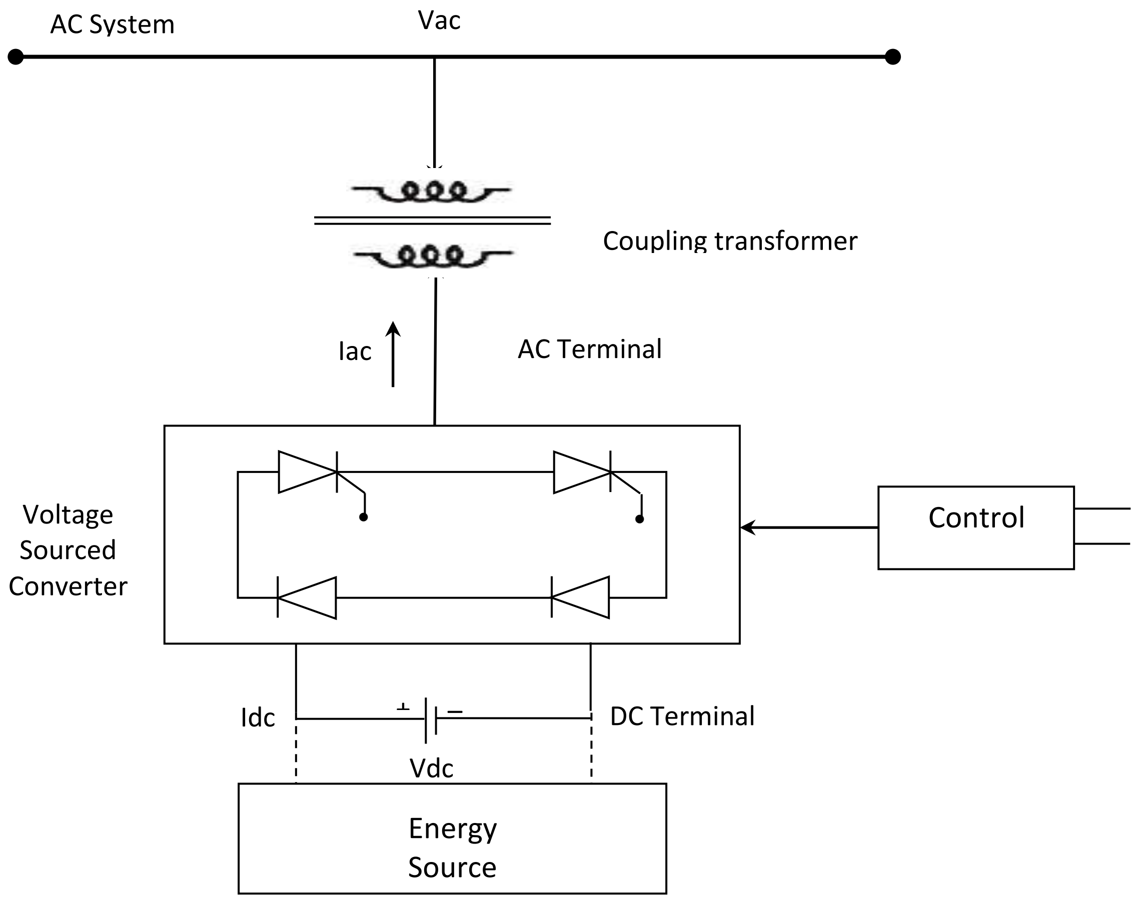

Figure 1 Functional Block diagram of STATCOM

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 [23]. 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. 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 [24,25].

5. CASE STUDIES AND DISCUSSION

The proposed MW-Mile 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 [26], 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.

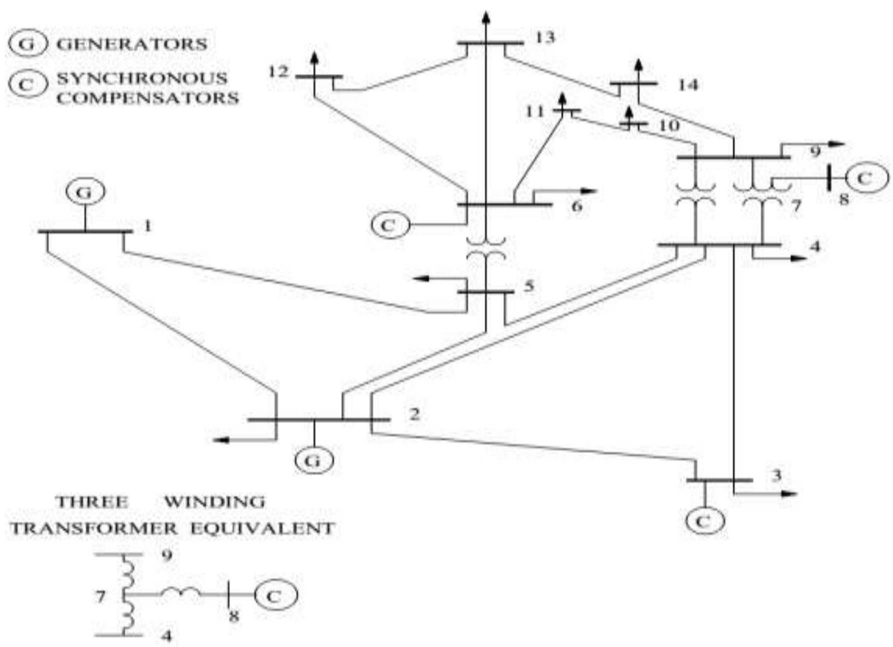

Figure 2: Single Line Diagram of IEEE 14 bus test system

The network shows that how the power injected by generator is distributed between the lines and loads of the system. 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 are 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.

Base Case Power Flow of Without and with STATCOM

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	28.038	6.9325	4-9	129.41	63.951
2-3	103.99	45.334	7-9	109.38	54.525
2-4	103.53	45.178	9-10	1251.1	623.3
1-5	254.04	121.36	6-11	20.181	7.7893
2-5	124.79	70.416	6-12	95.515	45.178
3-4	377.44	190.92	6-13	52.379	21.81
4-5	112.31	54.603	9-14	154.36	76.881
5-6	93.974	42.218	10-11	186.72	77.816
4-7	32.968	15.423	12-13	665.68	311.65
7-8	173.16	81.087	13-15	49.452	21.81

Table 2 Simulation Results of IEEE – 14 Bus Test System without 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	28.353	12.463	83.502	22.122	82.574	21.876
2-3	202500	104.69	166.38	159.06	98.925	157.29	97.826
2-4	134400	104.69	165.29	162.17	98.457	160.37	97.363
1-5	197880	256.89	316.25	308.77	40.037	305.34	39.592
2-5	48600	126.19	142.23	224.96	132.42	222.46	130.95
3-4	245000	381.68	456.61	528.59	531.55	522.71	525.64
4-5	12000	113.41	126.81	143.32	158.9	141.73	157.14
5-6	217000	65.431	95.653	121.51	74.778	120.16	73.947
4-7	280000	32.715	40.193	49.852	63.873	49.298	63.163
7-8	70000	50.631	49.852	59.199	81.009	58.541	80.109
4-9	871000	96.588	105.94	115.28	84.125	114	83.19
7-9	21300	66.677	84.125	112.17	126.19	110.92	124.79
9-10	24330	162.02	168.87	169.81	143.32	167.92	141.73
6-11	289900	136.94	143.32	158.9	17.137	157.14	16.946
6-12	312000	99.859	128.37	148.93	269.2	147.28	266.21
6-13	42000	112.32	143.32	18.85	32.715	18.641	32.352
9-14	319800	28.976	99.704	74.155	89.733	73.331	88.736
10-11	212200	18.85	112.17	377.16	286.65	372.97	283.46
12-13	198000	32.715	139.27	42.218	49.852	41.749	49.298
13-14	292000	26.184	50.008	118.55	152.67	117.24	150.97
Wheeling Charges ($)			**322777**	**671083**	**198567**	**243211**	**413543**

Table 3

Simulation Results of IEEE – 14 Bus Test System with 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 4

Comparison of Transmission pricing Results for with and without 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

Figure 3: Comparison of Wheeling Charges With /Without STATCOM

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 MW-Mile 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 MW-mile method with STATCOM technology is a promising approach for solution of various transmission pricing problems under deregulated environment.

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