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Performance Analysis of Wheeling Charges Determination Using Bialek's Tracing Method Employing With IPFC Controller in Deregulated Environment

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Abstract: *Transmission of electricity across the systems creates an essential link between the producers and consumers of the deregulated power sector. Transmission charges signify a minor proportion of overall operational expenses in utilities in the open market and transmission pricing need to be a reasonable and cost effective pointer used by the energy market for decision making, system enlargement and reinforcement of the system. The wheeling cost can be decreased by reducing power loss via incorporating proper FACTS devices in the system. In this scenario, tracing the flow of electricity has been gaining much more importance and its solution helps in evaluating a fair and transparent tariff. In this article, an attempt has been made to introduce a new flow based Bialek's tracing method to calculate the wheeling charge involving with optimal placement of recent FACTS devices of IPFC controller. The proposed approach has been tested on standard IEEE 30 bus system to prove the effectiveness of the proposed methodology. The simulation results are also compared with that of conventional method and with/without IPFC devices.*

Keywords: *Deregulation, Transmission pricing, Wheeling charges, Bialek's Tracing method, FACTS, IPFC controller*

I. Introduction

During the nineties, many electric utilities around the world are dealing with deregulation, restructuring, privatization and create introduction of competition in the electric power industry. These worldwide power industry reforms are forced to increase of electrical energy production, transportation and distribution to offer a lower price with higher quality and more secure production to customers.

In the restructured power system, the transmission network system is a key mechanism for generators to compete in supplying large users and distribution companies. In a competitive deregulated environment, defining a pricing scheme is needed for transmission services which could meet revenue expectations, support efficient operation of electricity markets, encourage investment in optimal location of generation and transmission lines and adequately reimburse owners of transmission assets and also to reduce the effects of transmission monopoly [1].

The wheeling of transmission services (electrical energy) is the one of the most important prevalent of such unbundled services [2]. Therefore, in the deregulated environment, pricing of transmission services occupies a vital role in determining whether providing transmission services are economically viable to both the wheeling consumers and wheeling utility.

In a monopoly power industry, there are many methods have been proposed to evaluate the cost of transmission services. They are categorized into three types of cost: embedded cost, marginal cost and incremental cost. The cost which is based on the actual network usage of a transaction and are addressed as embedded cost (e.g., postage stamp, contract path, MW-mile method, MVA-mile method, Distribution factors method and Tracing methods) , while others (marginal/ incremental) method , which is based on the additional transaction cost that is caused by a specific electricity transaction. Examples of these methods are: Short –run marginal cost (SRMC), Long-run marginal cost (LRMC) and Short–run Incremental cost (SRIC) and long–run incremental cost (LRIC). From this aforementioned method, embedded cost method is the basic method of transmission pricing [3]. The main aim of this method is to calculate the transmission service cost in a proper way to allocate it among the transmission users. In the Postage stamp method, the transmission charges are based on stamp rate on an average cost and the magnitude of the allocated power. This method is simple and easy to measure. Contract path method is another traditional method used by the power industry and the power flow is confined to flow along the artificial specified path [4].

Based on the calculation of the extent use of the transmission network MW –mile method, which is proposed to calculate the cost depends upon the magnitude, the path and the distance travelled by the transacted power [5]. Various modified MW-mile methodologies have been proposed by many researchers [6, 7].

MVA-mile method is an enhanced charging methodology over MW-miles, it has been recognized that the use of transmission resources is the best one for the measurement of real and reactive power and [8]. In this method, the power flow at each method caused by the generation / load pattern of each agent is based on the combination of real and reactive power flows.

Distribution factors is an sensitivity analysis method and it shows the relation between changes takes place in power injection in a particular bus and the power flow changes takes place in a particular line. There are three different ways to calculate the distribution factors methods: Generalized Shift Distribution Factors (GSDF), Generalized Generation Distribution Factors, Generalized Load Distribution Factors (GLDF) [9].

Topological Generation Distribution factors based Power flow tracing method was introduced by Bialek in the year 1996, in this method the assumptions is made for the nodal inflows are shared proportionally among the nodal outflows [10]. Another tracing method was proposed by kirschen in the year 1997, which is based on definitions for domains, commons and links [11]. Using this method, it is also possible to calculate equivalent transactions by minimizing the total MW-Km distance covered in the entire system.

The complete space of tracing can be modeled by considering equality and inequality constraints. The power flow tracing methods are tracing the power flow from a source and sink and vice-versa. It can be further sub classified as a proportionate tracing method and optimal tracing method [12].

A.J.Conejio et al.,[13] proposed a method to find the share of participants to transmission cost allocation by forming Z_{bus} that makes generator-load use the lines electrically close to it. The Z_{bus} formulation is based on mathematical behavior model which is based on circuit theory and relates the nodal currents to line power flows. In ref [14], the authors rationalized proportional sharing principle of cooperative game theory and information theory. They concluded that the shapely value validates the proportional sharing principle. Also the other way to trace the electricity from power flow tracing algorithms can be found in Extended Incidence Matrix (EIM) considering loop flows. In this methods the charges had been allocated to generators and loads in 50:50 ratios [15]. In 2010, Rao et al., [16] explained the Min-Max fair allocation criteria for transmission system usage allocation.

Marginal pricing of electricity has been employed in several electricity markets. The marginal network revenue for a transmission entity results from the spatial discrimination of spot prices also called LMPs due to transmission constraints and losses. The revenue of this method is also used for financing future transmission investments. However typical marginal revenues account for a little percentage of the total fixed cost which leads to be additional charges and these charges are calculate using an embedded pricing method [17].

In 1986, N.G.Hingorani invented the FACTS technology based on Thyristor operation techniques and gained a greatest interest during the last few years; due to the recent techniques in power electronics are added. FACTS devices are found to be effective controller to solving various power system steady state control problem such as voltage regulation, transfer capability enhancement and control of power flow and enhance the flexible operation of the system [18].

FACTS controllers are broadly categorized as series type controllers, shunt type controllers and combination of series - series and shunt-series type controllers. Examples of shunt controllers: Static Var compensator (SVC).Static synchronous compensator (STATCOM). Thyristor controlled series capacitor (TCSC) and Static Synchronous series compensator (SSSC) is comes under the series type group controllers. Interline power flow controller (IPFC) is the example of series-series type controller and Thyristor controlled phase shifting transformer (TCPST) and Unified power flow controller (UPFC) are belongs to shunt-series type controller [19].

In the available FACTS devices, Interline power flow controller (IPFC) is the latest generation FACTS devices used in the power system for management of power flow in multi-line transmission system. The IPFC has the capability to carry out an overall real and reactive power compensation of the total transmission system [20]. In ref [21], the authors employed the Line-by-Line method with TCSC controller to determine the wheeling cost and losses of real and reactive power in the restructured power system. Here IEEE 30bus test systems are considered, illustrating the performance of the proposed system.

In this article, a new flow based Bialek's tracing methodology has been introduced in allocation of wheeling cost for various transactions. The FACTS devices are introduced in order to harvest the technological benefits. The problem formulation is done in two parts. The first part includes the mathematical approach without considering FACTS devices and the second part includes the FACTS devices in the system. The proposed approach has been tested on standard IEEE 30 bus test system to illustrate the superior performance of the proposed system.

1.1 Various categories of Transmission Transaction

Generally, a transmission transaction means it refers to the transmission component of the service used by a power utility. For example it deals with a power purchase, power sale or a wheeling transaction. There are several types of transmission transaction involved in power industry [22]. They are listed as follows:

1.1.1 Firm Transmission Transactions:

A firm transmission transaction is defined as the result based on contractual arrangements between the utility and wheeling customers. A firm power wheeling is also called as reserved transactions because it makes reservation of capacity on transmission facilities to meet the needed transactions. These transactions are not involved to discretionary interruptions.

1.1.2 Non-firm Transmission Transactions:

These transactions are considered as; it may be curtail able or as-available basis. Curtailed transactions are referred as ongoing transactions. It may be curtailed at the utility's discretion. As-available transactions are referred as short term, mainly economy and these transactions that take place when transmission capacity becomes available at specific areas of the system at specific times.

1.1.3 Long –term Transmission Transactions:

Long term transmission transactions means it takes place over a long period spanning several years. The duration period of a long-term transmission transaction is generally long enough to allow building new transmission facilities. This long-term wheeling transaction is the result of contractual agreements distinguishes between the utility and wheeling customers. Example of this transaction is transmission service provided as part of long term firm power sales.

1.1.4 Short -Term Transmission Transactions:

These short-term transmission transactions may be considered as short as a few hours to as long as one or two years only. It does not associated with transmission reinforcements and it comes under the pooling arrangement or bilateral contract.

1.2 Cost Component of Transmission System

Transmission cost has gained important economics scale in power industry and they are reflected in the investment cost of transmission line, transformer and substation.

The various cost component involved in transmission system are listed as follows [23,24]:

1.2.1 Operating Cost

This is the cost which includes variable cost primarily to generation rescheduling and re dispatches to reduce the system losses, maintaining system voltage profile, reactive power support and line flow limits.

1.2.3 Opportunity Cost

It is defined as the cost which a transmission company has to foregoes to meet the transaction such as it could not use cheaper generation and could not realize revenue from firm contract due to line flow reactive limits.

1.2.4 Reliability cost

It is defined as each transmission transaction may change the service reliability level and expected outage cost and hence results in reliability cost. It is very difficult to assess as they attributed to the many factors such as in the timing, the duration, the customer location and the extent of service outage e.t.c.

1.2.5 Reinforcement Cost

This cost is charged to only for firm transactions and include capital cost of new transmission facilities needed to accommodate the transaction and also include the installation of additional reactive power resources to support the transaction.

1.2.6 Existing Cost

This existing cost includes the capital cost of the existing facilities used by the transmission transaction.

Therefore the establishment of transmission pricing should be computed such that the total transmission charge include the cost of all the fore mentioned component and thus make a small require amount of profit to the owner.

II. Proposed Methodology

Tracing method was proposed by J.Bialek in 1996 and it is based on ac power flow methods aiming to evaluate the contribution of transmission users to transmission usage. Bialek's method concept is defined as tracing the flows of electricity through power network and could be used for transmission pricing and recovering fixed transmission cost [25].

In this method, it is assumed that the nodal inflows are shared proportionally among nodal outflows. It uses the proportional sharing principle which states that for in any bus there are lines that inject power and other evacuate power. It allows quantifying how much of active or reactive power flow from a particular source to a specific load and also used to calculate the contribution of the generators and loads to the transmission line flows.

In this method, the proportional sharing principle is used to trace the power flow of electricity. There are two basic algorithms used in this method are: Upstream algorithm and downstream algorithm and the algorithm assumes a lossless system in transmission network branch.

Downstream algorithm: In this algorithm, the power flow tracing are takes place from the generator to the load. Here the transmission usage and supplement charge is allocated to individuals loads and losses are allocated to generators. Upstream algorithm: In this algorithm, the power flow tracing takes place from a load to generator. Here the transmission usage and supplement charge is allocated to individual generators and losses are allocated to the load. This method can deal with both dc-power flow and ac power flows; that is, it can be used to find contributions of both active and reactive power flows.

Basically the algorithm is developed using a matrix formulation and it enables the use of linear algebra to analyze the numerical properties of the algorithm. It can also give solution to the questions as how much of the power delivered from a particular load or otherwise how much of the requirement of a particular load comes from a particular generator. The topological distribution factors are always considered as positive, because of this it eliminates the many problems associated with counter flows. Some minor drawbacks may be incurred in this method, only when the lines are heavily loaded due to the assumptions avail in problem formulation [26,27].

The power injections in each bus of the system are given by:

$$P_i = \sum_{j\in\alpha_i^{(u)}} \left|P_{i-j}\right| + P_{Gi} \qquad \forall i = 1,2,...,n \tag{1}$$

where P_i is the total flow through bus $i, \alpha_i^{(u)}$ is the set of buses that directly supply bus i (the flow must go from other buses to bus i),

P_{Gi} is the generation in bus i and

P_{i-j} is the flow in line j-i, where

$$\left|P_{i-j}\right| = \left|P_{j-1}\right|$$

Using the proportionality principle, the flow in a line can be written as

$$\left|\mathbf{P_{i-j}}\right| = \mathbf{c_{ji}};\mathbf{P_j}, \text{where} \left|\mathbf{Cg_{ji}} = \mathbf{P_{i-j}}\right| / \mathbf{P_j} \tag{2}$$

Substituting the equation (2) in equation (1) and arrange it. The equation becomes

$$P_i = \sum_{j\in\alpha_i^{(u)}} C_{ji}.P_j + P_{Gi} \qquad \forall i = 1,2,...,n \tag{3}$$

$$P_i - \sum_{j\in\alpha_i^{(u)}} C_{ji}.P_j = P_{Gi} \quad o \quad A_u P = P_G \tag{4}$$

where A_u is an (n×n) distribution matrix per injected powers, P is the vector of bus flows and P_G is the vector of bus generations.

The elements of matrix A_u are defined as follow:

$$[A_u]_{ij} = \begin{cases} 1 & \text{for } i = j \\ -C_{ij} = \dfrac{-\left|P_{j-i}\right|}{P_j} & \text{for } j \in \alpha_i^{(u)} \\ 0 & e.o.c \end{cases} \tag{5}$$

where j must be a bus that supplies power to i.

If A_u^{-1} exists, then vector $P = A_u^{-1}.P_G$ and its elements are given by:

$$P_i = \sum_{k=1}^{n} \left[A_u^{-1}\right]_{jk}.P_{Gk} \qquad \text{for } i = 1,2...,n \tag{6}$$

The equation (6) represents the contribution from generator k to bus i is equal to $\left[A_u^{-1}\right]_{jk}.P_{Gk}$.

A withdrawal of power in line i-l from bus i can be calculated as:

$$\left|P_{i-l}\right| = \frac{\left|P_{i-l}\right|}{P_i}.P_i = \frac{\left|P_{i-l}\right|}{P_i} \sum_{k=1}^{n} \left[A_u^{-1}\right]_{jk}.P_{Gk}. \tag{7}$$

$$= \sum_{k=1}^{n} D^{G} i - l, k . P_{GK} \qquad \textit{for } l \in \alpha_i^{(d)}$$

where $\alpha_i^{(u)}$ is the set of buses directly supplied by bus *i* and $D^{G} i - l, k = \frac{|P_{i-l}|.\left[A_u^{-1}\right]_{jk}}{P_i}$ is a topological generation distribution factor, indicating the proportion of power that generator Contributes to line *i-l*.

These *D* factors are the ones that permit to allocate the actual use of the transmission lines.

III. Structure And Operation of IPFC

In general, the simplest Inter line power flow controller consists of two back- to-backs DC to AC (VSC1 and VSC2) converters, which can be used to address the series compensation of the line or in other form; the IPFC has a number of SSSC devices. It is connected in series with coupling transformer of two transmission lines and the dc terminals of another converter are connected through a common dc link. The function of series converter associated with the support system controls the DC voltage across the capacitor and the reactive power voltage magnitude. The shunt converter has the capability to controls both the real power and reactive power voltage magnitude in within the limits position. The series reactive compensation is done by; the converters are connected to the common DC link to exchange active power [28,29]. The schematic diagram of IPFC is shown in Fig.1.

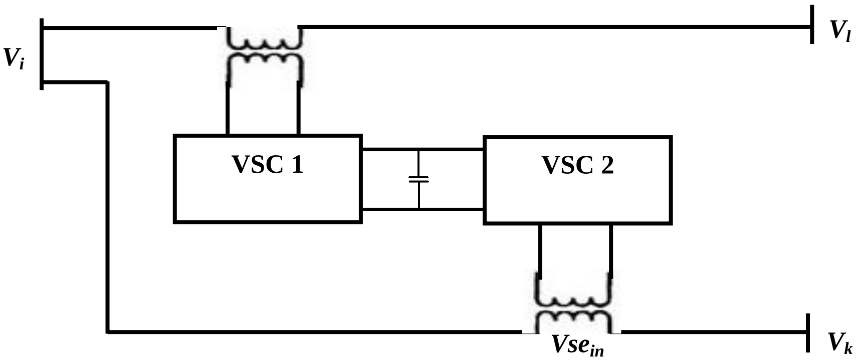

Fig 1. Schematic diagram of IPFC

The attractive features of IPFC offers the numerous advantages: Increasing the effectiveness of the overall compensating system for dynamic disturbance, independently controllable series compensation, direct transfer of real and reactive power between the compensated lines, reduce the resistive line voltage drops, transfer power demands from over loaded to under loaded lines, balancing both the real and reactive power flow in a multi-line system reducing the line power losses and improving the voltage profile [30,31]. The IPFC has the capability where the injected voltage in the line is controlled by exchange the real power to the series converter.

In this paper, the proposed Bialek's tracing method is combined with Interline power flow controller (IPFC) to obtain the minimized losses with the reduction of wheeling charges of various transactions. The algorithm of the proposed method is given below:

Algorithm for Bialek's method

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

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

Step 3: Evaluate the base power flows of each lines, from the base case studies

Step 4: Read the line lengths in miles of the system.

Step 5: Evaluate the tracing of line flow for each line with Bialek's method and find the new power flow by installing with and without IPFC.

Step 6: Calculate the real power and reactive power losses.

Step7: Determine the total cost of all transactions (TC).

$$\mathbf{TC} = \frac{\textit{total transmission cost of each generator}}{\textit{total transmission cost of all generator}}$$

Step 8: Compute the wheeling charge of each transactions.

$$\mathbf{TCt} = \mathbf{TC} \times \frac{\textit{each transaction cost}}{\textit{power generation of generators}}$$

IV. Results And Discussions

The proposed Bialek's tracing method has been fused with IPFC controller and tested on a standard IEEE 30 bus test system using computer with Pentium-4, Intel Dual core 2.25 GHz, 2GB-RAM and simulated in MATLAB 10.0 platform. In order to show the supreme performance of the proposed method, an attempt has been made to test the system on Standard IEEE 30 bus system. The system comprises 6 generating units with total demand of 1200MW. The transmission network includes 30 buses linked by 41 transmission lines with 4 tap changing transformers. The system configuration data can be found from ref [32] and the one line diagram is shown in figure 2.

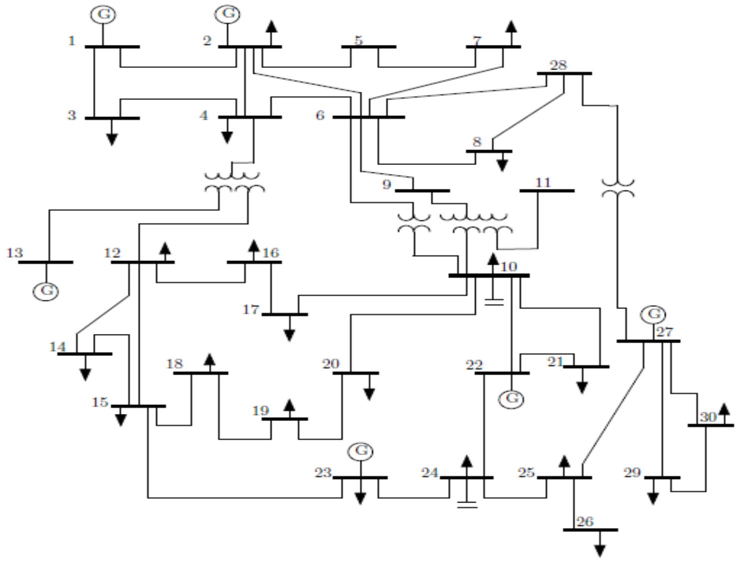

Figure 2: One line diagram of IEEE 30 bus system

V. Simulation Results

Case 1: Simulation Results of IEEE 30 Bus Test Systems without FACTS Devices

Table 1 depicts the base case power flow of the network with two different approaches, i.e with/without FACTS (IPFC). In the first case, the IPFC devices are not considered for the purpose, because the equality and inequality constraints are not considered. It can be seen that the base case power flow increase in most of the cases. In order to calculate the line flows and flows caused by each transaction, AC load flow analysis has been carried out. By satisfying the transmission constraints and implementing the IPFC in the system, the power flows follow a linear change. It is proved that the wheeling charges have been minimized after installing the FACTS devices in the considered test system.

The simulation results of Line-wise wheeling cost are displayed in Table 2. The wheeling charges have been calculated by considering the network capacity and sum of actual power flows. The simulation results of line cost, actual power flow for six different transactions are displayed in Table 3.

Case 2: Simulation Results of IEEE 30 Bus Test Systems with FACTS Devices

In this case, the performance of the proposed method has been improved by installing IPFC devices. The IPFC devices are placed in the buses which has the poor voltage profile. The IPFC has the capacity to control the power flow in multi transmission lines. The IPFC devices are introduced in the buses 5, 17, 21 and 25, so as to reduce the wheeling charges for the corresponding transaction with minimizing active and reactive power losses. After the placement of IPFC devices in the above mentioned buses, the overall line reactance values are correspondingly reduced. From the simulation, it is observed that the base case power flow shows a linear change and it is better when compared that of results obtained from system without IPFC. The simulation results of line cost, actual power flow for six different transactions are displayed in Table 4.

Table 5,depicts the active power and reactive power losses of with/ without IPFC devices. Table 6 represents the simulation results of active and reactive power losses due to various transactions are compared and graphically represented in figure 3.

The simulations results of wheeling charges for various transactions are compared and reported in Table 7.The graph shown in figure 4 illustrates the difference in transmission charges due to the placement of IPFC. From the above observations it is deserved that the proposed methodology provides significant reduction in transmission charges by the installation of FACTS devices.

Table 1: Base case power flow of with/without IPFC

Line No	Base case flow Without IPFC	Base case flow With IPFC
2-1	90.65	87.68
1-3	34.26	26.48
2-4	2.26	1.98
2-5	8.71	8.02
2-6	16.84	15.78
3-4	15.43	14.28
4-6	54.43	50.65
4-12	23.16	22.11
5-7	42.68	39.78
6-7	0.56	0.46
6-8	3.78	2.92
6-9	21.90	20.14
6-10	98.65	85.72
6-28	0.43	0.36
8-28	7.89	6.68
9-10	43.67	42.17
9-11	65.98	62.56
10-17	76.22	74.18
10-20	14.55	10.23
10-21	12.98	6.76
10-22	55.26	29.96
12-13	9.91	8.78
12-14	0.87	0.54
12-15	31.45	29.78
12-16	66.54	62.23
14-15	25.90	23.65
15-18	11.66	9.96
15-23	7.87	6.81
16-17	34.77	32.62
18-19	89.32	87.34
19-20	80.67	72.34
21-22	50.78	47.89
22-24	42.78	40.65
23-24	12.81	10.86
24-25	0.96	0.65
25-26	52.89	48.90
25-27	22.88	18.86
28-27	91.67	89.44
27-29	68.90	66.78
27-30	76.65	74.23
30-29	80.22	79.14

Table 2: Results of Line-wise wheeling cost of with /without IPFC

Line No	Wheeling cost without IPFC	Wheeling cost with IPFC
2-1	10002.12	9876.43
1-3	11445.43	11124.87
2-4	5678.09	2765.12
2-5	3342.22	2089.67
2-6	9876.08	9275.02
3-4	7223.12	6543.7
4-6	0	0
4-12	2113.45	2100.23
5-7	2587.90	2332.65
6-7	4200.19	3167.56
6-8	0	0
6-9	216.75	189.56
6-10	661.22	597.12
6-28	0	0
8-28	2654.13	2208.23
9-10	3110.32	3106.89
9-11	1663.64	1244.56
10-17	941.01	939.75
10-20	800.32	526.45
10-21	800.32	789.01
10-22	365.34	345.85
12-13	626.62	600.62
12-14	2109.87	2208.6

12-15	412.56	408.45
12-16	1342.14	1265.67
14-15	1234.67	1233.56
15-18	46.87	39.88
15-23	1598.43	1498.2
16-17	1988.21	1888.6
18-19	556.89	555.1
19-20	544.34	453.87
21-22	2900.30	1989.2
22-24	1245.50	1205.6
23-24	289.45	276.78
24-25	4678.5`4	4278.4
25-26	6786.0	6766.9
25-27	2223.4	2188.4
28-27	0	0
27-29	992.34	678.9
27-30	0	0
30-29	472.87	470.68
29-30	642.78	220.70

Table 3 : Power Flow Results of IEEE 30 Bus System Without FACTS

		Power Flow Due to Various Transactions					
Line No	**Line cost**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
2-1	11560	28.876	54.39	50.291	60.751	24.186	29.986
1-3	5780	104.07	98.346	76.01	99.526	12.425	58.462
2-4	9830	96.46	108.12	57.62	0	21.129	47.228
2-5	4860	185.69	188.52	33.243	88.087	27.295	28.019
2-6	2170	98.25	139.98	92.56	154.38	66.516	69.56
3-4	2890	0	219.91	294.31	117.48	58.128	229.78
4-6	4630	57.89	0	89.176	384.10	0	0
4-12	1230	53.46	82.624	42.263	72.666	18.978	79.451
5-7	21300	38.74	73.824	47.485	0	69.420	39.896
6-7	2020	70.85	46.691	45.015	68.757	93.45	40.286
6-8	3460	76.36	24.88	48.726	42.926	42.678	0
6-9	2430	95.418	66.046	79.150	0	64.153	70.120
6-10	1450	0	69.325	0	38.6	76.261	0
6-28	6780	89.140	0	0	66.621	87.780	65.067
8-28	2450	98.126	95.367	88.264	59.023	29.542	80.662
9-10	3740	69.391	92.279	17.510	0	34.022	18.258
9-11	4050	92.782	84.84	169.56	92.157	182.56	0
10-17	2860	68.360	0	0	0	14.67	152.6
10-20	2920	0	86.16	27.175	86.41	69.67	17.875
10-21	3120	77.261	19.26	59.872	0	86.96	47.867
10-22	6680	78.327	14.123	169.25	19.542	179.28	149.23
12-13	8710	56.282	0	0	37.077	0	28.186
12-14	9840	99.486	223.53	37.695	186.28	0	32.019
12-15	1980	99.45	69.27	89.817	21.109	77.82	0
12-16	4460	42.328	125.98	13.29	59.67	13.98	67.184
14-15	1200	68.853	79.624	61.95	45.726	17.67	0
15-18	5780	52.826	65.518	59.69	88.46	96.18	182.48
15-23	5690	96.724	64.326	23.243	93.657	51.823	19.826
16-17	2230	89.616	12.472	77.656	179.28	19.976	126.81
18-19	3400	62.420	41.697	293.30	0	82.624	38.13
19-20	5690	0	0	0	177.56	0	76.29
21-22	1340	29.76	23.45	88.27	229.13	22.196	33.546
22-24	9780	58.128	69.85	46.543	77.67	29.824	22.876
23-24	4860	36.098	43.39	36.584	68.758	46.126	59.210
24-25	7980	34.75	74.36	43.005	0	222.50	68.756
25-26	2500	340.74	93.12	47.716	37.926	47.81	97.128
25-27	3450	320.04	172.45	68.104	44.18	66.67	0
27-28	2430	54.38	288.67	77.624	0	29.30	0
27-29	1680	68.66	66.508	86.20	64.271	0	34.38
27-30	2940	88.81	38.295	0	86.016	27.546	28.67
30-29	5780	52.78	14.298	149.56	89.914	33.876	18.128
Wheeling charges ($)		**2954.20**	**2142.7**	**3213.77**	**2826.513**	**3568.626**	**1865.20**

Table 4: Power Flow Results of IEEE 30 Bus System With FACTS

		Power Flow Due to Various Transactions					
Line No	**Line cost**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
2-1	11560	18.876	44.39	30.291	40.751	14.186	9.986
1-3	5780	99.07	88.346	72.01	97.526	11.425	48.462
2-4	9830	92.46	98.12	54.62	0	20.129	41.228
2-5	4860	183.69	182.52	30.243	80.087	26.295	18.019
2-6	2170	94.25	138.98	91.56	152.38	65.516	66.56
3-4	2890	0	216.91	290.31	110.48	48.128	220.78
4-6	4630	52.89	0	88.176	364.10	0	0
4-12	1230	48.46	81.624	41.263	70.666	8.978	75.451
5-7	21300	36.74	72.824	42.485	0	59.420	36.896
6-7	2020	69.85	44.691	46.015	58.757	83.45	30.286
6-8	3460	73.36	28.88	44.726	22.926	40.678	0
6-9	2430	93.418	62.046	78.150	0	62.153	40.120
6-10	1450	0	67.325	0	28.6	72.261	0
6-28	6780	79.140	0	0	56.621	81.780	45.067
8-28	2450	88.126	90.367	80.264	58.023	19.542	70.662
9-10	3740	67.391	91.279	11.510	0	32.022	8.258
9-11	4050	82.782	83.84	160.56	82.157	180.56	0
10-17	2860	65.360	0	0	0	12.67	132.6
10-20	2920	0	83.16	20.175	76.41	68.67	12.875
10-21	3120	75.261	17.26	52.872	0	84.96	42.867
10-22	6680	68.327	10.123	162.25	9.542	178.28	140.23
12-13	8710	46.282	0	0	36.077	0	24.186
12-14	9840	97.486	220.53	32.695	184.28	0	20.019
12-15	1980	89.45	67.27	86.817	20.109	75.82	0
12-16	4460	40.328	124.98	12.29	58.67	12.98	64.184
14-15	1200	66.853	78.624	51.95	40.726	13.67	0
15-18	5780	50.826	63.518	54.69	84.46	86.18	162.48
15-23	5690	93.724	60.326	20.243	83.657	41.823	15.826
16-17	2230	88.616	10.472	72.656	170.28	17.976	116.81
18-19	3400	60.420	40.697	290.30	0	72.624	28.13
19-20	5690	0	0	0	171.56	0	74.29
21-22	1340	28.76	22.45	86.27	228.13	12.196	23.546
22-24	9780	48.128	67.85	41.543	75.67	25.824	12.876
23-24	4860	26.098	41.39	33.584	65.758	16.126	57.210
24-25	7980	33.75	72.36	42.005	0	220.50	58.756
25-26	2500	240.74	90.12	45.716	34.926	45.81	87.128
25-27	3450	220.04	170.45	64.104	34.18	64.67	0
27-28	2430	44.38	258.67	74.624	0	28.30	0
27-29	1680	62.66	65.508	85.20	54.271	0	14.38
27-30	2940	86.81	28.295	0	56.016	20.546	18.67
30-29	5780	50.78	12.298	146.56	87.914	13.876	12.128
Wheeling charges ($)		**2865.582**	**2998.493**	**2638.727**	**2795.71**	**1940.024**	**1830.966**

Table 5 : Active power losses and Reactive power losses of with/ without FACTS

Line No	**Active power loss**		**Reactive power loss**	
	Without IPFC	**With IPFC**	**Without IPFC**	**With IPFC**
2-1	0.2865	0.2865	0.2865	0.2865
1-3	0.1782	0.1452	0.1782	0.1552
2-4	0.1637	0.1637	0.1637	0.1537
2-5	0.2279	0.2379	0.2379	0.2379
2-6	***0.1983***	***0.1487***	***0.1983***	***0.0595***
3-4	0.1763	0.1763	0.1763	0.1763
4-6	0.0314	0.0314	0.0314	0.0214
4-12	0.1160	0.1160	0.1160	0.1160
5-7	0.0820	0.0820	0.0820	0.0820
6-7	0.0420	0.0420	0.0420	0.0420
6-8	0.2080	0.2080	0.2080	0.2080
6-9	0.5560	0.5560	0.5560	0.5560
6-10	0.2080	0.2080	0.2080	0.2080
6-28	0.1100	0.1100	0.1100	0.1100
8-28	0.2560	0.2560	0.2560	0.2560
9-10	0.1400	0.1400	0.1400	0.1400
9-11	**0.2680**	**0.1559**	**0.2559**	**0.5559**
10-17	0.1304	0.1304	0.1304	0.1304
10-20	0.1987	0.1987	0.1987	0.1987
10-21	0.1997	0.1997	0.1997	0.1997
10-22	**0.2632**	**0.1632**	**0.2432**	**0.1032**

12-13	0.2185	0.2185	0.2185	0.2185
12-14	0.1292	0.1292	0.1292	0.1292
12-15	0.0680	0.0680	0.0680	0.0680
12-16	**0.1890**	**0.1890**	**0.1640**	**0.1650**
14-15	0.0845	0.0845	0.0845	0.0845
15-18	0.0749	0.0749	0.0749	0.0749
15-23	0.1499	0.1499	0.1499	0.1499
16-17	0.0236	0.0236	0.0236	0.0236
18-19	0.2020	0.2020	0.2020	0.2020
19-20	0.1790	0.1790	0.1790	0.1790
21-22	0.2700	0.2700	0.2700	0.2700
22-24	0.3292	0.3292	0.3292	0.3292
23-24	0.3800	0.3800	0.3800	0.3800
24-25	0.2087	0.2087	0.2087	0.2087
25-26	0.3960	0.3960	0.3960	0.3960
25-27	0.4153	0.4153	0.4153	0.4153
28-27	0.6027	0.6027	0.6027	0.6027
27-29	0.5026	0.5026	0.5026	0.5026
27-30	0.3128	0.3128	0.3128	0.3128
30-29	0.2476	0.2476	0.2476	0.2476

Table 6: Comparison of Active power losses and reactive power losses of With/ Without IPFC

Transactions	Active power losses with IPFC	Reactive power losses with IPFC
T1	90.65	86.86
T2	26.48	23.48
T3	1.98	5.76
T4	8.02	8.43
T5	16.84	16.95
T6	15.43	16.78
Total Losses	**159.4**	**158.26**

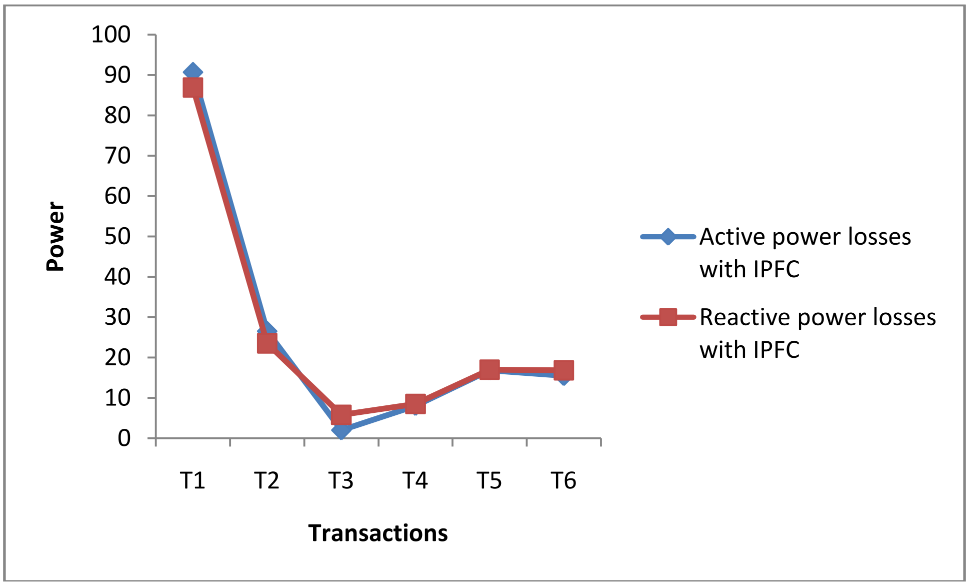

Fig. 3. Comparison of active power and reactive power losses with IPFC controller

Table 7: Comparison of wheeling charges of with/ Without IPFC

Transactions	Without IPFC	With IPFC
T1	2954.20	2865.582
T2	2142.7	2998.493
T3	3213.77	2638.727
T4	2826.513	2795.71
T5	3568.626	1940.024
T6	1865.20	1830.966
Total Wheeling Charges ($)	**16571.009**	**15069.502**

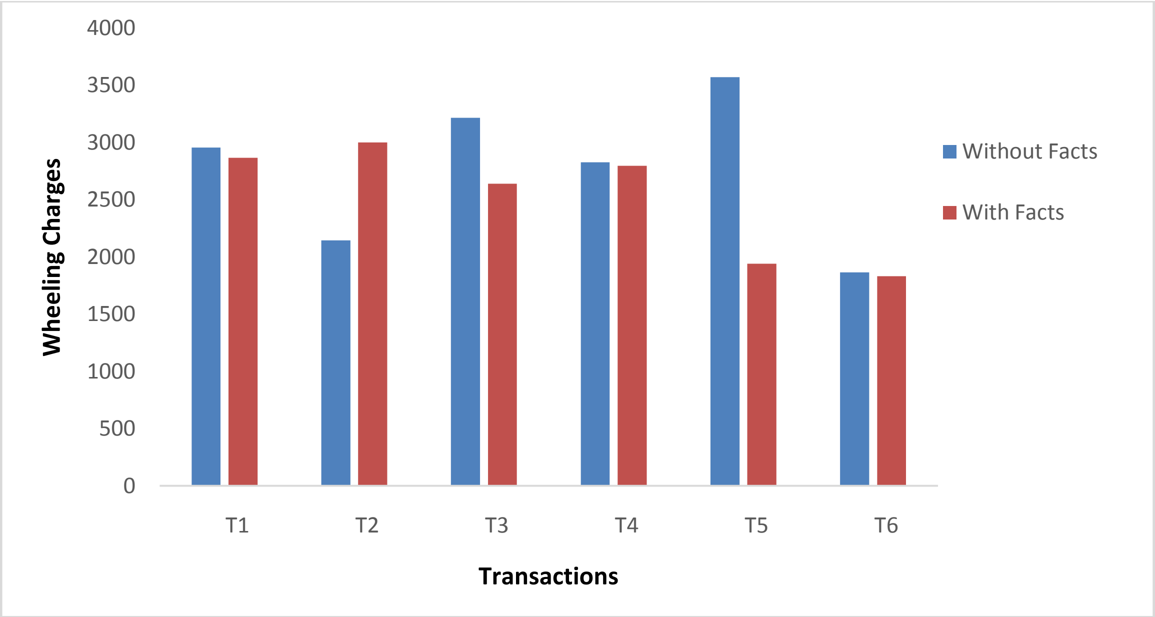

Fig. 4. Comparison of wheeling charges for various transactions for with/ without IPFC controller

VI. Conclusion

In the present open access restructured power systems , it is obligatory to develop a fair transmission pricing tariff to trace the power flow. This article proposes a simple and understandable price structure of flow based Bialek's tracing method employed with IPFC controller to allocate the transmission wheeling cost to the consumers. The performance and applicability of the proposed approach has been analyzed on IEEE 30 bus test system. The Bialek's tracing method used in this work creates only positive contributions to the line flows and it provides zero charges for some users. Among the all pricing methods, Bialek's method is intuitive and it is the best way of transmission pricing among pricing methods. The multi control capability of IPFC introduces in this paper paves the important role in the allocation of transmission wheeling charges. More over it is demonstrated that the proposed method is accurate and feasible and the use of IPFC device can increase the power flow**.**

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Nomenculture

P_i	-	Total Flow Through bus i
$\alpha_i^{(u)}$	-	Set of Buses that Directly Supply Bus
P_{Gi}	-	Generation in bus *i*
$P_{i\text{-}j}$	-	Flow in Line *j-i*
A_u	-	(n×n) Distribution Matrix Per Injected Powers
P	-	Vector of Bus Flows
P_G	-	Vector of Bus Generations
D^G	-	Topological Generation Distribution Factor
FACTS	-	Flexible Alternating Current Transmission System
IPFC	-	Inter Line Power Flow Controller
SVC	-	Static Var Compensator
STATCOM	-	Static Synchronous Compensator
TCSC	-	Thyristor Controlled Series Capacitor
SSSC	-	Static Synchronous Series Compensator
TCPST	-	Thyristor Controlled Phase Shifting Transformer
UPFC	-	Unified Power Flow Controller
MVA	-	Mega Volt Ampere
VSC	-	Voltage Source Converter

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