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Improving of Transmission Cost Allocation Method to Accelerate the Investment Recovery for Transmission lines in Deregulated Power System

***Abstract**. In the electricity supply industry are more important transparency and accountability on all participants in the grid with considered transmission usage on the load. In the restructuring and deregulation of the power system, many problems are faced by the power industry players especially with investment in transmission costs. To accelerate investment recovery in transmission lines, it is important to have a way of increasing the income for investment recovery based on an analysis of construction costs in the long run and an analysis of the high level of risk involved in the investment. This paper will propose a new algorithm for allocating the transmission pricing that considers the power factor correction coefficient (CLF) as an incentive factor to determine transmission cost. To justify this proposal, the MW-Mile method improved will be compared with an existing method to determine each line of users for two case studies; the sixth test bus and the 30 IEEE bus system. The result of the proposal shows that the transmission operator will get an additional charge when the load do not use the transmission effectively. The transmission owner can make a further profit by increasing more energy transfer and also from the generator to load. It also indicates the positive signal with an incentive investment in transmission lines operation in deregulated power system.*

***Streszczenie.** W branży elektroenergetycznej ważniejsza jest przejrzystość i odpowiedzialność wszystkich uczestników sieci przy uwzględnieniu wykorzystania przesyłu na obciążeniu. W procesie restrukturyzacji i deregulacji systemu elektroenergetycznego wiele problemów napotykają gracze energetyczni, zwłaszcza w zakresie inwestycji w koszty przesyłu. Aby przyspieszyć odbudowę inwestycji w linie przesyłowe, ważne jest posiadanie sposobu na zwiększenie wpływów z odbudowy inwestycji w oparciu o analizę kosztów budowy w długim okresie oraz analizę wysokiego poziomu ryzyka związanego z inwestycją. W niniejszym artykule zostanie zaproponowany nowy algorytm alokacji cen transmisji, który uwzględnia współczynnik korekcji współczynnika mocy (CLF) jako czynnik motywujący do określenia kosztów transmisji. Aby uzasadnić tę propozycję, ulepszona metoda MW-Mile zostanie porównana z istniejącą metodą określenia każdej linii użytkowników dla dwóch studiów przypadku; szósta magistrala testowa i system magistrali 30 IEEE. Z wyniku wniosku wynika, że operator przesyłu otrzyma dodatkową opłatę, gdy obciążenie nie wykorzysta efektywnie przesyłu. Właściciel przekładni może osiągnąć dodatkowy zysk, zwiększając transfer energii, a także z generatora do obciążenia. Wskazuje to również na pozytywny sygnał zachęty inwestycyjnej w pracę linii przesyłowych w rozregulowanym systemie elektroenergetycznym. (**Doskonalenie metody alokacji kosztów przesyłu w celu przyspieszenia zwrotu inwestycji w linie przesyłowe w zderegulowanym systemie elektroenergetycznym**)*

Keywords: Transmission Cost, Investment recovery, deregulated power system.
Słowa kluczowe: Koszt przesyłu, zwrot inwestycji, zderegulowany system elektroenergetyczny.

Introduction

In the restructuring and deregulation of the power system, many problems are encountered by the power industry players especially in regards with the investment in transmission costs. Although in the deregulated systems, the transmission planning has remained control of the operator, therefore the incentives must be offered to encourage the private sector to invest in transmission projects [1]. So, in power system deregulated, it needs accountability and fairness to determine of transmission charge for all participants in grid. Generally, the determination of transmission cost method have been classified into two approaches; namely, based on embedded cost and capacity used cost. Although almost all method using approach based amount of transmission capacity used and unit cost on each line. One of the main problems in the power quality, especially the power factor rate is to determine transmission charge to consider in investment of transmission line. The power factor can be caused power delivery in transmission will decrease, so impact to voltage stability [2]

Several countries (regulator) have established about power quality standard ect.the power factor (standard) through a charged penalty. For instance; National Electricity Company in Indonesia has standardized on the power factor of the user is less than 0.95 lagging [3]. It have been if any user has poor power factor (less than reference power factor, 0.95), company will charge an additional fee in accordance with the amount of reactive power.

Currently, transmission development growth is increasing rapidly in line with the construction of new power plants. In the restructuring and deregulation of the power system, many problems faced by the power industry players especially related to investment in transmission costs [4]. In order to accelerate investment recovery in transmission lines it is necessary to have a way of increasing the income for investment recovery based on an analysis of construction costs in the long run and an analysis of the high level of risk involved in investing. However, in practice that investors' income, in investment is not only limited to the use of transmission, but there are additional benefits that investors get from energy production, namely how to reduce risk. The MW-mile method is considered as practical and appropriate method and is commonly used to determine transmission costs in order to accelerate recvering investment costs.

Several methodologies has report utilization network facilities cost due real and active power flows [1-4]. This method introduces a uniform measurement for transmission service usages by active and reactive powers, however this method cannot be able to see the correlation efect power factor varies on load. This paper proposes a new scheme which includes the power factor parameter in the cost of transmission usage. The MW-mile mechanism is used for the investment recovery of transmission projects. The results indicate that by making an investment in certain transmission lines, the transmission owner can make further profit by increasing more energy transfer and also from generator to load.

The paper is organized into five sections. In the first part contains an introduction of the method to be propose. Then in the second part, containing about methods of transmission costs that already exist. In the third part is a proposal which outlines the contribution method of power factor in the formulation of an existing method. While in the fourth section is an example use case with the discussion of results. Then in the last part is the conclusion of the propose method.

Research Method

The concepts of transmission pricing paradigms and methodologies to better illustrate how transmission costs are transformed into transmission pricing [5]. Application of the MW-MILE methodology to allocate the transmission supplementary charge to real and reactive power loads have been describe in ref [7,8]. To avoid counter flow problem, a negative flow-sharing approach to allocate transmission transaction charges among users of transmission service [25]. Active and reactive power flows are converted into monetary flows by using nodal prices. The MW-mile methodology is a technique to allocate the use of the electric power transmission system among the various beneficiaries [5-24]. It may be regarded as the first pricing strategy proposed for the recovery of fixed transmission costs based on the actual use of transmission network.

Many methods have been proposed to accelerate the recovery of investment in transmission line development, among them the method that presents a structural model that consists of joint planning for the short term operation and to verify the profitability of the investment in the transmission construction project. Providing the planned transmission is completed earlier than the scheduled time, congestion is reduced, which improves the accessibility of the Generator to consumers. The objective function consists of the additional expected return from energy production, the investment recovery from the MW-Mile method, and the transmission investment costs [26-28]. In order to accelerate investment recovery in transmission lines it is necessary to have a way of increasing the income for investment recovery based on an analysis of construction costs in the long run and an analysis of the high level of risk involved in investing. However, in practice that investors' income, in investment is not only limited to the use of transmission, but there are additional benefits that investors get from energy production, namely how to reduce risk. The MW-mile method is considered a practical and appropriate method and is generally used to determine transmission costs in order to accelerate recovering investment costs. This method also allows investors willing to invest in transmission lines [27-29]. Many economists prefer this concept because it encourages the efficient use of the transmission facility and, further, the expansion of the system.).

Electric power that transmit can be expressed as:

(1) $$P_{Loss} = I_L^2 . R_L$$

Electric energy transmitted through the line is expressed as follows:

(2) $$P_{trans} = P_L + I_L^2 . R_L$$

The smaller the line current, I_L the smaller the line loss is also reduce. Thus, the transmission line carrying capacity can be optimized.

For a circuit k, relationship between power factor and active power each load. Defines: Power factor (PF) or $\cos\phi$ is the ratio of working power to apparent power [2], that follows:

(3) $$\cos\phi = \frac{Active\ power}{Apparent\ power}$$

Therefore, the equation [2] can be obtaned ;

(4) $$MW = MVA \ . \cos\ \phi$$

(5) $$MVA = \frac{MW}{\cos\phi_l}$$

Propose Method

According to [1], Let, expressed $\cos\ \phi_l$ as power factor line, where this factor is a parameter used to determine the variation of load power factor of the power factor reference. function $\cos\ \phi_l\,(\phi_{ref}\ ,\phi_{real}\ )$; ϕ_{ref} is power factor reference (according to regulation), and ϕ_{real} as power factor real on load.

(6) $$MVA = f\lfloor MW, \phi_{ref}, \phi_{real} \rfloor$$

(7) $$MW_{act} = C_{LF}\, MW_{ref}$$

Where :

(8) $$C_{LF} = f\lfloor \phi_{ref}\ , \phi_{real} \rfloor$$

By define C_{LF} as power factor correction coefficient, that follows;

If C_{LF} is less than one then the user transmission pay more for an additional cost beyond the power factor reference with considere power factor in these equation , therefore:

(9) $$C_k = C_{LF} \cdot \left[\sum_{i=1}^{N} \frac{L_i . F_i . P_i^k}{\overline{P}} \right]$$

Based on [9], trasmission owner will get additional charge (C_{add}) if the power factor as follows:

(10) $$C_{add} = C_{LF} . C_k$$

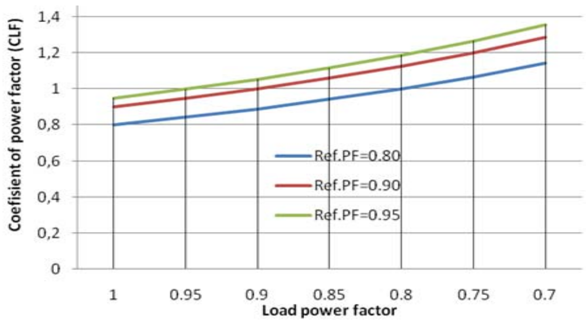


Fig.1 Coefficient power factor base on reference

Case Study for Graver's Test system

In order to verify this method as illustration, we have been tested above on Graver's test system.

From the table [1-2], that showing users (load) which has the power facto 0.95 (lagging) will obtain a reduction of 13.1% of transmission costs, and if the user the power factor is 0.7 (lagging) it will pay increase of 11.1%. Similarly, if the users (industrial) uses a capacitor bank compensation so that the lagging power factor will have a reduction in transmission costs.

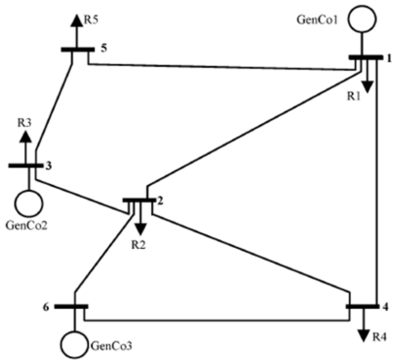


Fig. 2. Bus test Graver's

Table 1. Line data for the graver's bus system

From	To	Xl(ohm),pu	L(km)
1	2	0,4	40
1	4	0,6	60
1	5	0,2	20
2	3	0,2	20
2	4	0,4	40
3	5	0,1	20
2	6	0,15	30

Table 2. Coefficient power factor base on load characteristic

Load Factor Reference, $\phi_{ref} = 0{,}80$				**Load Factor Reference,** $\phi_{ref} = 0{,}90$			
Load factor lagging		**Load factor leading**		**Load factor lagging**		**Load factor leading**	
ϕ_{real}	C_{LF}	ϕ_{real}	C_{LF}	ϕ_{real}	C_{LF}	ϕ_{real}	C_{LF}
1	0,833	1	1,25	1	0,909	1	1,111
0,95	0,869	0,95	1,1764	0,95	0,952	0,95	1,052
0,9	0,909	0,9	1,1111	0,9	1	0,9	1
0,85	0,952	0,85	1,0526	0,85	1,052	0,85	0,952
0,8	1	0,8	1	0,8	1,111	0,8	0,909
0,75	1,052	0,75	0,9523	0,75	1,176	0,75	0,869
0,7	1,111	0,7	0,9090	0,7	1,25	0,7	0,833
0,65	1,176	0,65	0,8695	0,65	1,333	0,65	0,8
0,6	1,25	0,6	0,8333	0,6	1,428	0,6	0,769
0,55	1,333	0,55	0,8	0,55	1,538	0,55	0,740
0,5	1,428	0,5	0,7692	0,5	1,666	0,5	0,714

Table 3. Coefficient power factor base on reference

Numb er	Cos phi=0,95 (reference)	cos phi=0,7(lagging)		cos phi=0,8(lagging)	
Load	Reference (k$)	k$(real)	% addition al cost	cos phi=0, 7	% addition al cost
L1	3,825	4,402	13,1	4,891	11,1
L2	8,312	9,565	13,1	10,627	11,1
L3	1,497	1,723	13,1	1,9145	11,1
L4	8,495	9,775	13,1	10,861	11,1
L5	12,628	14,532	13,1	16,145	11,1

Table 4. Coefficient power factor base on ref power factor load#1

Contribution to Load L1		**Original (k$)**	**Proposed (k$)**		
From	**To**	**L1**	**cos phi=0,8 (ref)**	**cos phi=0,95 lagging**	**cos phi=0,7 lagging**
1	2	202,47367	202,4736704	175,9496196	224,9684952
1	4	137,36154	137,3615406	119,3671788	152,6224078
1	5	302,27005	302,2700521	262,6726753	335,8522549
2	3	48,457843	48,45784261	42,10986523	53,84150892
2	4	3,5687984	3,568798386	3,101285797	3,965291886
3	5	302,27005	302,2700521	262,6726753	335,8522549
2	6	150,44703	150,4470294	130,7384686	167,1616944
4	6	140,93034	140,930339	122,4684646	156,5876997

This proposal has demonstrated a treatment difference for users who use the power transmission based on the power factor reference [table 4]. Customers who use power with a power factor below the reference value is greater *CLF*. As for the users that have a power factor above the reference, or leading, the *CLF* will decrease, Fig [4-7]. Consequence of the *CLF* will affect the cost of transmission usage at each load. This proposal has also given clear information to any user of the transmission to operate under the required conditions. Customers who take advantage of the power with the same level of power factor with reference to the factors *CLF*=1, transmission price will decrease.

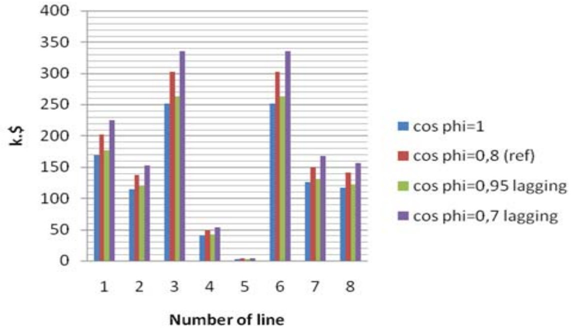


Fig. 3. The relationship between total costs ($C_k.F_k.L_k$) of the power factor on each line that contribute to the load # 1

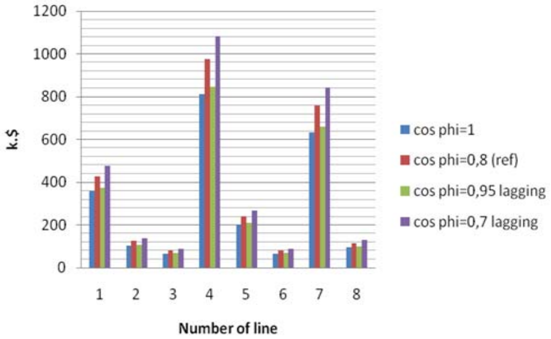


Fig. 4. The relationship between total costs ($C_k.F_k.L_k$) of the power factor in each line that contribute to the load # 2

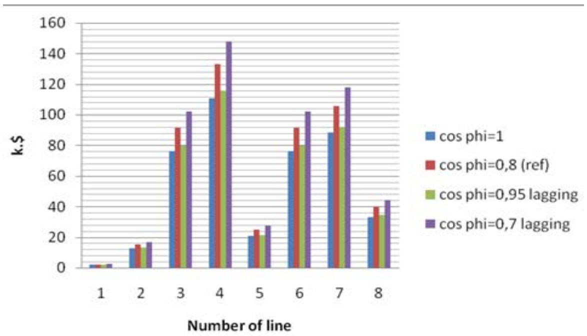


Fig. 5. The relationship between total costs ($C_k.F_k.L_k$) of the power factor in each line that contribute to the load #3

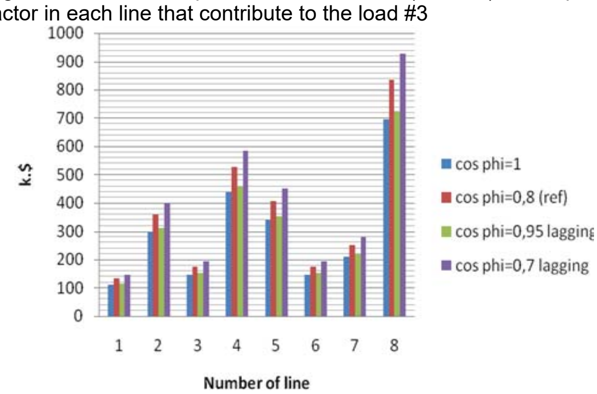


Fig. 6. The relationship between total costs ($C_k.F_k.L_k$) of the power factor in each line that contribute to the load #4

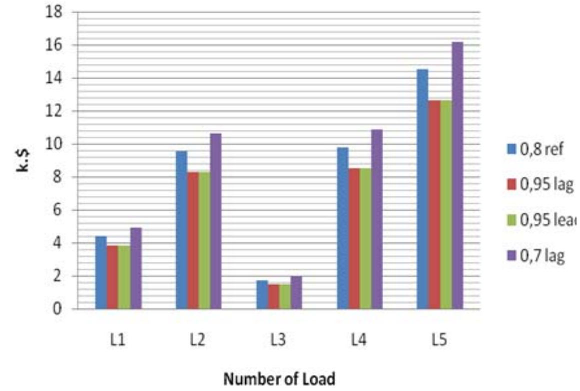


Fig. 7. The relationship between total costs ($C_k.F_k.L_k$) of the power factor in each line that contribute to the load #5

From case study using examples case 6-bus Graver's test systems in table [4] that shows the contribution generator in each line. Based on the result of the tracing generator to the loads and flows in the power system network has become a main issue since the deregulation of the electric power system. It is necessary for the operation of the system, congestion management, competition of transmission pricing, ancillary services and related issues. Based on the graphic that shows in the figure shows the power factor equal to the reference (cos phi = 0.8) then the use of the transmission (ie: Line 1 to 2) for k $ 202.47367 (reference). However, if the user the power factor (cos phi = 1) to the transmission cost is reduced to 168.721 k $. Conversely, if cos phi = 0.7 lagging, then the user pays is 224.968 k $. These costs indicate that the user will pay for the use of the transmission when working with poor power factors.

In this propose will be make an investment cost in transmission lines which are determine with distance and power factor quality all user in transmission line. The analysis must be conduct all user in transmission line are carried out by the transmission operator to identify the most profitable plans for investment. The MW-mile mechanism is used for the investment recovery of transmission projects. The results indicate that by making an investment in certain transmission lines, the transmission owner can make further profit from increase more energy transfer and also from generator to load. By the selected type contract with consider power factor will be get the accelerate investment recovery method.

Case study for the 30 IEEE Bus systems.

The proposed method has been further tested using the IEEE 30 bus system to further highlight its advantages in providing incentive charges to the users. The data for generators bus are as follows: G1 = 117.73 MW; G2 = 60.97MW; G14 = 37MW; G22 = 21.59MW; G23 = 19:20 MW and G27 = 29.91 MW. Total loads amounted is 283 MW (the system is considered without loss).

Figure 5, shows the user's transmission cost for a power factor of 0.8 and the reference power factor is set as 0.9 and 0.95 respectively. It can be seen that the transmission cost for users with the load power factor is less than the reference power factor receives an additional charge. For example, by using MW-Mile method the load # L2, obtained a transmission cost of k$ 16,4725 but if the power factor is set at 0.95 power factor reference, then the load #L2 pays k$ 19,561, which an increase of 18.75%. However, if the reference power factor is set as 0.9, load#L2 pays by k$ 18,531, which an increase of 12.5%.

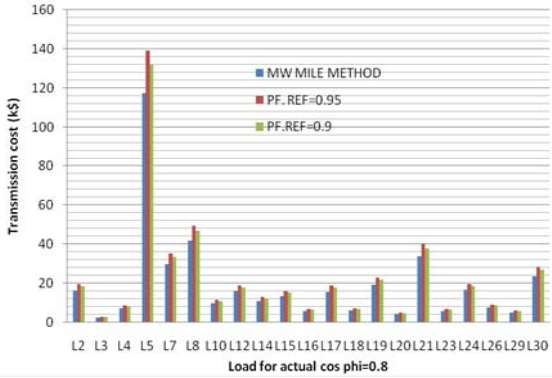
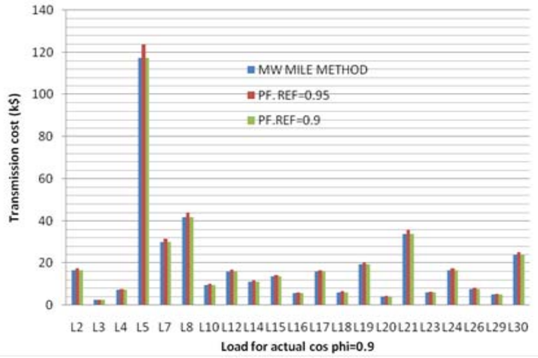


Fig. 8. Transmission cost of each load with actual power factor of 0.8



Fige 9. Transmission cost of each load with actual power factor of 0.9.

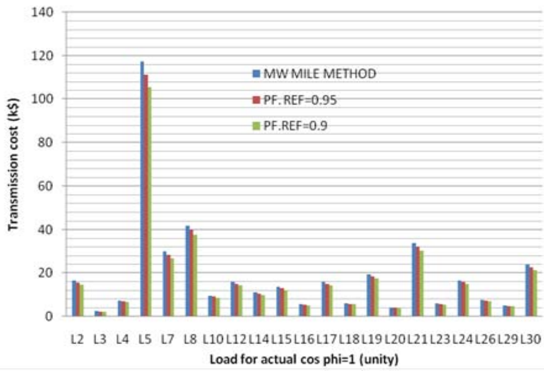


Fig. 10. Transmission cost of each load with actual power factor of unity

Figure 9 show the user's transmission cost for the load factor of 0.9 and the reference power factor is set similar as before. It can be seen that the transmission cost with the power factor consideration is higher than the one calculated using original MW-Mile method. For instance, load with actual power factor of 0.9 pay same charges with the one using MW-Mile method. However, the user has to pay an additional charges when the references power factor is set to 0.95.

Fig.10, shows the load power factor is set to cos Φ = 1 (unity). It can be seen that the proposed method can be reduced the transmission cost of the user which is not in case of the MW-Mile method. By setting a reference power factor to 0.95, then there is a reduction of 5% on every bus load. However if the regulator sets the reference power factor by 0.9 the cost reductions will be higher with 10% in average. Cost reduction of 5% based on the assumption that the calculation does not take into account the transmission distance and a cost per -mile.

Conclusion

The paper proposed a modified MW-Mile method based on power factor quality that has presented correlation transmission usage cost by considering the power factor quality effect on the load. The advantage of this method has been shown on several conditions of power factor. Users who use electricity at a lower power factor of the reference, then it will cost you use a higher transmission than the cost to be paid. Conversely, if the user is using electric power with a higher power factor than the reference (or to be leading), then it will obtain a reduction in the transmission usage costs compared with costs to be paid. This proposal can be applied for countries that apply a standard factor in determining the cost of power or transmission rate. The results indicate that by making an investment in certain transmission lines, the transmission owner can make a further profit from increase more energy transfer and also from the generator to load. The increase in cost as a penalty for the use which has a low power factor can be used as an incentive for transmission investment costs.

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REFERENCES

[1]] S. Nojeng, M.Y. Hassan, D. Mat Said, P. Abdullah, F. Hussin, Improving the MWMile method using the power factor-based approach for pricing the transmission services, IEEE Trans. Power Syst. 29 (5) (2014) 2042–2048
[2] Julian WOSIK,et.al, Improvement of voltage stability in the HV distribution line using an Active Power Filter, Przeglad Elektrotechniczny, no 1 (2020), 134-137.
[3] S. Nojeng , et.al., “Distribution Factor Method Modified for Determine of Load Contribute based on the Power Factor in Transmission Line”,Vol 11, No 3: September 2018.
[4] Maziar Karimi, Morteza Kheradmandi, Abolfazl Pirayesh. MW-mile recovery method in merchant transmission investment by generation companies Electric Power Systems Research.Vol. 175, October. [5] Muhamad Zulkifli Meah, Azah Mohamed, and Salleh Serwan, Comparative Analysis of Using MW-Mile Methods in Transmission Cost Allocation for the Malaysia Power System, National Power and Energy Conference (PECon) 2003. Proceedings,Bangi,Malaysia,379-3,http:www.ieeexplore.ieee.org.
[6] Warit Anthong and Kulyos Audomvongsereem, Transmission Cost Allocation for Mixed Pool and Bilateral Markets Warit Anthong and Kulyos Audomvongsereem, http:www.ieeexplore.ieee.org.
[7] K.S. Verma,H.O.Gupta, Impact on real and reactive power pricing in open power market using unifield power flow controller, Ieee Transactions on Power Systems,2006. 21(1): 365-371.
[8] A.Augugliaro, et.al, A model for reactive power tracing by addition on fictional nodal injections, Electric Power Systems Research 83 (2012) 196:202.
[9] F. Li, N.P. Padhy, J. Wang, B. Kuri, Development of a Novel MW+MVAr-Miles Charging Methodology, 2005 IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China,www.ieeexplore.ieee.org.
[10] M. Murali, Student Member, M.Sailaja Kumari, Member, IEEE and M.Sydulu. A Comparison of Embedded Cost Based Transmission Pricing Methods,2011, http:www.ieeexlore.ieee.org.
[11] Maxwell Muchayi, M.E. El-Hawary,A method for optimal pricing of electric supply including transmission system considerations,Electric Power Systems Research 50 (1999) 43–46.
[12] R.E. Rotoras , T. Lefevre, R.B. Pacudan, Marginal transmission pricing and supplemental cost allocation method: A case of Philippines, Electric Power Systems Research 63 (2002) 213:227.
[13] Oscar Moya, Marginal cost of transmission system adequacy for spot pricing, Electric Power Systems Research 61 (2002) 89–92
[14] Tanachai Limpasuwana, Weerakorn Ongsakulb, Bundit Limmeechokcha, A Transmission Pricing Method Based on Electricity Tracing in Thailand, ScienceAsia 28 (2002) : 77-85.
[15] T. Limpasuwana, J.W. Bialekb, W. Ongsakulc, B. Limmeechokchai, A proposal for transmission pricing methodology in Thailand based on electricity tracing and long-run average incremental cost, Energy Policy 32 (2004) 301–308.
[16] Duan Gang, Zhao Yang Dong, Wei Bai, Xin Feng Wang, Power flow based monetary flow method for electricity transmission and wheeling pricing, Electric Power Systems Research 74 (2005) 293–305.
[17] Rui Lia, Luonan Chen, Ryuichi Yokoyama, Pricing for load and wheeling charge considering transmission paths in deregulated power markets, Electrical Power and Energy Systems 27 (2005) 496–505.
[18] A. R. Abhyankar,et.al, A Transmission Pricing Mechanism Based on Power Tracing for Central Transmission Utility in India, International Journal of Emerging
Electric Power Systems, Volume 2, Issue 1 2005 Article 1033.
[19] T. Zhang, A. Elkasrawy, B. Venkatesh,A new computational method for reactive power market clearing, Electrical Power and Energy Systems 31 (2009) 285–293
[20] A.R. Abhyankar a, S.A. Khaparde, Electricity transmission pricing: Tracing based point-of-connection tariff, Electrical Power and Energy Systems 31 (2009) 59–66
[21] Vijay Parmeshwaran, Kumar Muthuraman, FTR-option formulation and pricing, Electric Power Systems Research 79 (2009) 1164–1170,
[22] Chunyang Zhao, K L Lo, A New Method for Charging Transmission Services In Cross-border Trading, Universities Power Engineering Conference (UPEC), 2009. http:www.ieee.explore.org.
[23] C.W. Yua, S.H. Zhang, X. Wang, T.S. Chung, Modeling and analysis of strategic forward contracting in transmission constrained power markets, Electric Power Systems Research 80 (2010) 354–361
[24] Qixin Chen, Qing Xia, Chongqing Kang, Novel transmission pricing scheme based on point-to-point tariff and transaction pair matching for pool market, Electric Power Systems Research 80 (2010) 481–488
[25] K.L. Lo, M.Y. Hassan and S. Jovanovic, Assessment of MW-mile method for pricing transmission services: a negative flow-sharing approach, IET Gener. Transm. Distrib., 2007, 1, (6), pp. 904–911.
[26] F.F. Wu, F.L. Zheng, F.S. Wen, Transmission investment and expansion planning in a restructured electricity market, Energy 31 (2006) 954–966.
[27] P. Maghouli, S.A. Mousavimirkolaei, A transmission expansion planning model for maximizing merchant investment, J. Electr. Power Energy Convers. Syst. 1 (1) (2013) 8–15.
[28] M. Karimi, A. Pirayesh, M. Kheradmandi, Participation of generating companies in transmission investment in electricity markets, IET Gener. Transm. Distrib. 12 (3) (2018) 632–634.
[29] M. Karimi, M. Kheradmandi, A. Pirayesh, Risk-constrained transmission investing of generation companies, IEEE Trans. Power Syst. 34 (2) (2019) 1043–1053.)