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Pricing of Transmission Services in a Deregulated Power System

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Abstract—*Power system deregulation require a wheeling charge that is economically efficient to meet the financial requirements of the transmission system and maintain security and reliability of the system. This paper investigates the deregulated Nigerian power system with the existing wheeling charges methods to determine their suitability and ability to recover both fixed cost and the operating cost.*

Keywords— *Deregulation; MVA-km; MW-km; Wheeling Charges; Wheeling Transaction.*

I. Introduction

Transmission pricing is a difficult subject because the cost of transferring power between any points on the transmission system is not fixed, but dependent upon the overall pattern of load and generation on the system[1]. Energy wheeling is another term for a situation that occurs when there are several nearby utilities and one's system's transmission network is only being utilized to transfer electricity from one neighbor to another [2]. Electric power utilities need to know the actual costs of providing separate services in order to make correct economic decisions on the various types of services they should promote or curtail while at the same time fulfilling their service obligations. Utilities also need to know such costs in order to make correct economic and engineering decisions on upgrading and expanding their generation, transmission and distribution facilities[3].

Therefore, it is necessary to develop methods which allow the share use of the transmission services, by different users. Besides ensuring the technical quality of the transmission services, these methods should provide enough revenue to compensate for the existing transmission investment and incentives for the economic expansion[3].. To evaluate the costs of transmission transactions, various salient methods have been suggested and use these include the simple postage stamp method, the trajectory path contract, the family of load flow methodologies(based on the MW-Mile method), and the sophisticated formulations based on the marginal cost theory. In any methodology the main objective is the allocation of the use-of-network embedded charges, for each wheeling transaction, in such a way that a real benefit is comprised for both the wheeling agents and the owner network. The pricing of transmission services should be carried out to recover capital and op.erating cost, encourage efficiency of use and investment, provide equal opportunity to all users and understandable structure[4].

This paper is organised as follows. In section II, the concept of deregulation in electricity industry is presented. Section III discussed electric energy wheeling and the pricing of transmission services. In section IV described the test system. Section V discussed the case studies. In section VI the results and discussion are presented. In section VII the conclusion of the paper is presented.

II. Deregulation in Electricity Industry

There are many reasons for the restructuring of the power sectors and it varies in each different countries. However, some of the benefits of a deregulated power industry are to be able to provide consumers with cheaper yet reliable electical energy supply and generate financial supports in the operation of power systems [2]. For many decades, the electric power industry was operating under a regulated monopoly. It has been the tradition for the government to be in control of the generation and supply of the electrical energy as it is one of the basic necessities for the people, this creates a natural monopoly[1]. Thesame firm or power entity owned and operates the generation, transmission and distribution assets.These entities are often referred to as vertically integrated utilities and they are often the only source provider of the electrical energy in the region.

It has been argued and agreed that under a zero competition and well protected enviroment, power utilities have the higher tendency to be operating inefficiently and as a consequence, higher tariffs from consumers are usually neccesary in order to cover the extra expenses incurred [5]. With so many new power utilities entering the deregulated power market and without the incentives and protection enjoyed in the past under monopolized system. Restructuring of the management of power system is a must so as to ensure continued growth generating utilities (GENCO) enters the market.

This means that the amount of and profits for the power entity. The number of generation plant increases as more reserved electrical energy will be increasing also and hence there will be lower risk of having inadequates energy supply to meet system demand peak periods. Furthermore, in a competitive enviroment, the rights, obligations and responsibility of each party will be define clearly. Undoubtedly, this will encourage the parties involved to make better investments to their infrastrucure and improve the overall power system. Utimately, this will ensure higher quality and reliability in the supply of energy, service and reaching the objectives of energy conservation [6].

Restructuring of the power industry begin with separation of the transmission services from the generation activities.

Transmision of power is considered a natural monopoly to ensure fairness in the competition among the power generating utilities. Generation, transmission are independent activities. This is known as vertical unbundling [7]. Transmission Open Access, TRANSCO should provide non discriminatory transmission services to the power market participants who used the transmission network of the TRANSCO for tansfer of electric energy and have to pay for such usage and services. This is followed by introduction of more competition into the generation activities, either through spot markets bidding, direct bilateral power transactions creating power pool. In most restructured power industries, several generation utilities are created to introduced more competition. This is known as horizontal unbundling.

A. *Deregulation in the Electricity Sector: Nigerian Experience*

Electric power supply in Nigeria was the responsibility of the federal government owned National Electric Power Authority (NEPA), which has been restructured into a holding company named Power Holding Company of Nigeria (PHCN) in preparation for deregulation. The Niger Dams Authority (NDA) and the old Electricity Corporation of Nigeria (ECN) merged to form NEPA in April 1972. NEPA supplies electric power to an estimated four million customers in Nigeria and the Niger Republic from a combination of hydro, coal and gas-powered operating sources [8].

The Federal Government of Nigeria has put in place policy measures aimed at resuscitating the ailing power sector as a whole. Thus, the deregulation of the sector currently going on will facilitate and encourage the participation of both foreign and Nigeria companies in the generation, distribution, and sale of electric power. The ultimate objective of the electric power policy is to ensure that Nigeria has an Electricity Supply Industry (ESI) that can meet the needs of its citizens in the 21st century. To achieve a technically and commercially efficient ESI, which is essential for Nigeria's growth and development, a thorough reform of the sector is required at all levels. With this development, Nigeria’s electricity sector will meet current and future electricity demands in an efficient and economically viable manner [9]. In Nigeria, the multi-year tariff order (MYTO) pricing scheme is currently in used. A tariff model for incentive-based regulation, the multi-year tariff order (MYTO) aims to reward performance beyond predetermined benchmarks, lower technical and non-technical/commercial losses, and improve performance standards from all industry participants in the Nigerian electricity supply sector. It is used to establish industry-wide wholesale and retail power pricing by using a standardized method to calculate the overall industry revenue requirement, which is connected to quantifiable performance requirements and improvements.

The MYTO's goal is to establish cost-reflective tariffs that will enable the electricity industry to operate and be adequately funded. It offers a 15-year tariff path for the NESI, with major reviews occurring every five years after all inputs have been reviewed with stakeholders, and limited minor reviews occurring annually in response to changes in a small number of parameters (such as inflation, interest rates, exchange rates, and generation capacity). However, this pricing scheme is not without its shortcomings, thus the need to reconsider other pricing methods.

III. Electric Energy Wheeling

Electric energy wheeling is the transmission of electrical power and reactive power from seller to a buyer through a transmission network owned by a third party [4]. The third party charges for the use of its network. These charge are known as wheeling rates. The establishment of a wheeling rates is presently the subject of extensive debate [9]. Energy cannot be delivered from a remote source without movement over a physical transmission system. Even when a utility is delivering its own generation to its own consumers,changes in its own line flows will affect line flows in other utilities to which it is synchronously interconnected. Consumers costs are affected by the matching or mismatching of wheeling costs and revenues if their utility is providing transmission service to others. There are different types of wheeling in the electric utility industry. This depends on the relationship between the wheeling utility and other two parties [10]. The four broad categories are as follows:

1) Bulk Power Wheeling – This is also known as utility to utility wheeling as power transaction takes place between the regulated utility to another regulated utility via the trasmission network of an intervening utility.
2) Consumer Wheeling – This happen when a private user or customer who require power purchases it from a regulated utility which does not provide services to that particlar area. In such cases, an intervening transmission network of another utility has to be used to wheel the purchased power across.
3) Private generator to Utility wheeling – Regulated utility whose transmission network is not connected to the private generator purchases power from latter through the network to a third parties.
4) Private Generator to customer – Private generator sells its output power to the private user or customer who requires power using a transmission network that belongs to a transmission utility.

A. *Pricing Transmission Services*

The pricing of transmission services should be carried out to recover capital and operating cost, provide equal opportunity to all users, encourage efficiency of use and investment and simplicity over time [2]. The components of the cost of transmission transactions are[2]:

1) Operating costs: Providing (fuels) cost due to generation redispatch and rescheduling resulting from the transmission transaction.
2) Opportunity cost: Benefits of all transactions that the utility forgo due to operating constraints that are caused by the transmission transaction
3) Reinforcement cost: Capital cost of new transmission facilities needed to accommodate the transmission transaction

4) Existing system cost: The allocated cost of existing transmission facilities used by the transmission transaction.

B. Method of Energy Wheeling Charges Calculation

Many different methodologies have been proposed for transmission charges (wheeling charge) – a payment for using a transmission system. They are as follows:

- Postage stamp method

A postage stamp rate is a flat per kW charge for network access within a particular zone, based on average system costs. Postage stamp transmission tariffs allocate total system costs to consumer on the basis of load share: a customer pays a transmission charge equal to the total system cost-weighted according to their consumption divided by total consumption[2].

- Contract path method

Contract path pricing calls for transmission from point A to point B based on the cost of single identified path. The price includes a capacity charge to cover the capital costs, and energy charges based on losses and other operating costs. This method requires the identification of the supply charges based on losses and other operating costs. This method requires the identification of the supply and reciept point for a bilateral traansaction and a “contract path” between two nodes[2]..

- MW-kilometer method

In this method rates explicitly reflect the fact that the cost of transmission depends on the distance the power is transmitted and how much power is transmited. Megawatt kilometer pricing involves load fow analysis to model the power flows on the transmission network to determine the transmission charge. The Megawatt-kilometer pricing is based on the economic principle that the buyer pays only for the transmission capacity they use and nothing else[2].

- MVA-kilometer method

The use of transmission resources is best measured by monitoring both real and reactive power given the line MVA loading limits and the allocation of reactive power support from generators and transmission facilities. Consequently, the basic concepts of Megawatt-kilometer methodology can be extended to include the charging for reactive power flows resulting in the so-called MVA-kilometer method [11] (Tong Wu et al., 2000) .

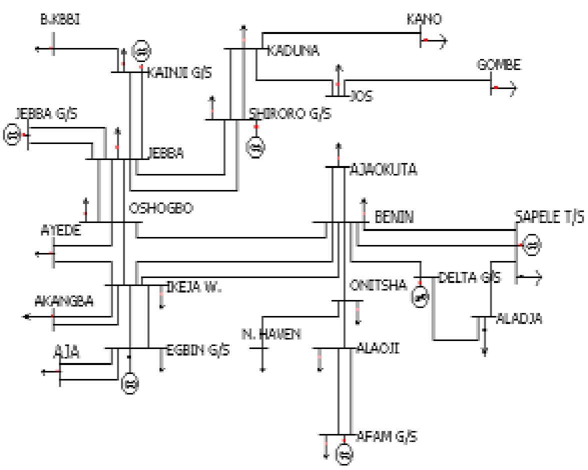

Fig. 1. A single line diagram of the Nigerian 330kV power system [12].

IV. TEST SYSTEM DESCRIPTIONS

The 24-bus model of Nigerian network is a relatively large system with 24 buses including 7 generators, 23 loads, and 39 lines as shown in Fig.1.

TABLE 1. Line data[13].

From Bus	To Bus	R (p.u)	X (p.u)
Osogbo	Ikeja	0.0099	0.0745
Osogbo	Benin	0.0098	0.0742
Egbin	Aja	0.0006	0.0044
Ikeja	Akangba	0.0007	0.0050
Osogbo	Ayede	0.0045	0.0340
Ikeja	Egbin	0.0023	0.0176
Ikeja	Benin	0.0110	0.0828
Ikeja	Ayede	0.0054	0.0405
Benin	Delta	0.0043	0.0317
Benin	Sapele	0.0020	0.0148
Kainji	Jebba	0.0032	0.0239
Shiroro	Kaduna	0.0038	0.0284
Afam(iv)	Alaoji	0.0010	0.0074
Ajaokuta	Benin	0.0077	0.0576
Jebba	Osogbo	0.0061	0.0461
Kaduna	Kano	0.0090	0.0680
Kaduna	Jos	0.0081	0.0609
Jos	Gombe	0.0118	0.0887
Sapele	Aladja	0.0025	0.0186
Benin	Onitsha	0.0054	0.0405
Onitsha	Newhaven	0.0036	0.0272
Delta(iv)	Aladja	0.0012	0.0089
Onitsha	Alaoji	0.0060	0.0455
Jebba GS	Jebba	0.0002	0.00020
JebbaTS	Shiroro	0.0096	0.0721
Kainji	Birnin	0.0122	0,0916

TABLE 2. Demand data[13].

Bus No	Bus Name	P_{load} (MW)	Q_{load} (MVAR)
1	Sapele	21	15
2	Delta	0	0
3	Aja	274	206
4	Akangba	345	259
5	Ikeja	633	475
6	Ajaokuta	14	10
7	Aladja	97	72
8	Benin	383	288
9	Ayede	276	207
10	Osogbo	201	151
11	Afam	53	39
12	Alaoji	427	320
13	N-Haven	178	133
14	Onitsha	185	138
15	Birnin	115	86
16	Gombe	131	98
17	JebbaTS	11	8
18	JebbaGS	0	0
19	Jos	70	53
20	Kaduna	193	145
21	Kainji	7	5
22	Kano	200	150
23	Shiroro	320	256
24	Egbin	69	52

TABLE 3. Generator data[13].

Bus Name	Pg (MW)	Qg (MW)	Qgmax (MVAR)	Qgmin (MVAR)
Sapele	690	400	952	0
Delta	770	1407	3350	0
Afam	431	2155	9050	0
Jebba GS	495	1040	2475	0

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Kainji	625	1312	3124	0
Shiroro	389	817	1945	0
Egbin	0	0	0	0

V. Case Study

The following wheeling transactions were present in the 24-bus network shown in Fig 1.

Transaction T1: 250 MW of power was injected at Kainji and removed from the network at Benin.

Transaction T2: 400 MW of power was injected at Delta and removed from the network at Osogbo.

Transaction T3: 70 MW of power was injected at Kainji and removed from the network at Ikeja.

Transaction T4: 100 MW of power was injected at Afam and removed from the network New Haven.

Megawatt- kilometer method

This is known as the base-case, where the power-flow analysis of the system was carried out without the transactions and the power-flow was once more resolved with the transactions. The power flow results for transaction T1, T2, T3 and T4 are shown in Table4 and Table5.

TABLE 4: Power flow results for Transaction T1 and T2 using MW km method.

From Bus	To Bus		T1	T2
		Base MW	MW-km	MW-km
Osogbo	Ikeja	35.64	3202.72	13920.88
Osogbo	Benin	200.09	45330.60	496.9
Egbin	Aja	100.08	1402.80	1401.12
Ikeja	Akangba	90.17	1591.38	1657.8
Osogbo	Ayede	145.49	19932.13	20550
Ikeja	Egbin	40.84	995.10	9737.1
Ikeja	Benin	54.92	4704.00	1666
Ikeja	Ayede	202.78	1260.40	13700
Benin	Delta	172.59	1658.08	16577
Benin	Sapele	66.26	3323	3223
Kainji	Jebba	150.7	12960	12960
Shiroro	Kaduna	8.31	1190.4	1190.4
Afam(iv)	Alaoji	11.30	330.25	330.25
Ajaokuta	Benin	45.15	9184.5	9184.5
Jebba	Osogbo	117.36	7928.5	7928.5
Kaduna	Kano	21.25	5706.3	5706.3
Kaduna	Jos	10.25	3016.07	3016.07
Jos	Gombe	13.32	7473	7473
Sapele	Aladja	50.66	3455.55	3455.55
Benin	Onitsha	41.31	1400.14	1400.14
Onitsha	Newhaven	30.15	2899.2	2899.2
Delta(iv)	Aladja	58.20	1587.3	1587.3
Onitsha	Alaoji	58.20	1739.52	1739.52
Jebba GS	Jebba	60.22	689.60	689.6
JebbaTS	Shiroro	6.37	1.74	4418.84
Kainji	Birnin	10.16	3317	3317

TABLE 5: Power flow results for Transaction T3 and T4 using MW km method.

			T3	T4
From Bus	To Bus	Base MW	MW-km	MW-km
Osogbo	Ikeja	35.64	10555.36	10401.44
Osogbo	Benin	200.09	53334.99	50071.99
Egbin	Aja	100.08	1401	1401.12
Ikeja	Akangba	90.17	1623.06	1623.06
Osogbo	Ayede	145.49	19934.87	19891.03
Ikeja	Egbin	40.84	2668.84	2587.88
Ikeja	Benin	54.92	15386	15265.60
Ikeja	Ayede	202.78	25686.13	27821.96
Benin	Delta	172.59	18162.24	18162.24
Benin	Sapele	66.26	3313.00	3323.00
Kainji	Jebba	150.7	14069.7	14096.70
Shiroro	Kaduna	8.31	797.76	797.76
Afam(iv)	Alaoji	11.30	282.50	1282.50
Ajaokuta	Benin	45.15	8804.25	8804.25
Jebba	Osogbo	117.36	18526.00	18425.50
Kaduna	Kano	21.25	4887.50	4887.50
Kaduna	Jos	10.25	2019.25	2019.25
Jos	Gombe	13.32	3529.80	352.25
Sapele	Aladja	50.66	3191.58	3191.58
Benin	Onitsha	41.31	5659.47	5960.87
Onitsha	Newhaven	30.15	2894.40	3086.40
Delta(iv)	Aladja	58.20	1513.20	1513.20
Onitsha	Alaoji	58.20	5568.00	2880.00
Jebba GS	Jebba	60.22	481.76	481.76
JebbaTS	Shiroro	6.37	1554.28	1554.28
Kainji	Birnin	10.16	3149.60	3149.60

MVA-kilometer method

The power-flow analysis of the system was executed with and without the transaction, taking into consideration the impact of both active and reactive power flow in the network, and the results obtained are shown in Table 6 and Table 7.

TABLE 6: Power flow results for Transaction T1 and T2

			T1	T2
From Bus	To Bus	Base MVA	MVA-km	MVA-km
Osogbo	Ikeja	93.40	20128.00	3737.60
Osogbo	Benin	280.60	75350.20	75425.5
Egbin	Aja	100.10	1401.40	1401.4
Ikeja	Akangba	102.20	1850.40	1990.8
Osogbo	Ayede	234.80	18727.90	13700
Ikeja	Egbin	254.80	18612.40	16771
Ikeja	Benin	57.60	16128.00	16828
Ikeja	Ayede	200.00	45278.50	45278.5
Benin	Delta	203.90	13440.00	9600
Benin	Sapele	143.40	10055.00	7500
Kainji	Jebba	89.20	8626.50	8140.5
Shiroro	Kaduna	70.30	3889.92	7680
Afam(iv)	Alaoji	40.00	1002.00	1051.5
Ajaokuta	Benin	103.10	20143.51	20143.5
Jebba	Osogbo	150.00	35325.00	36125.7
Kaduna	Kano	80.10	13492.00	19642
Kaduna	Jos	60.10	11861.37	11861.37
Jos	Gombe	40.10	10647.70	7420
Sapele	Aladja	130.20	8851.50	9166.5
Benin	Onitsha	45.10	6932.20	6932.2
Onitsha	Newhaven	40.30	3916.30	4032
Delta(iv)	Aladja	100.10	2602.60	2602.6
Onitsha	Alaoji	40.01	4800.96	4800.96
JebbaGS	Jebba	60.21	497.68	497.68
JebbaTS	Shiroro	25.25	6161.00	7905.6
Kainji	Birnin	15.05	5586.20	5586.2

TABLE 7: Power flow results for Transaction T3 and T4

			T3	T4
From Bus	To Bus	Base MVA	MVA-km	MVA-km
Osogbo	Ikeja	93.40	30.192	23739.2
Osogbo	Benin	280.60	84180	67870.4
Egbin	Aja	100.10	1401.4	1401.4
Ikeja	Akangba	102.20	1839.6	1839.6
Osogbo	Ayede	234.80	34184.24	31578.5
Ikeja	Egbin	254.80	15884.4	15896.8
Ikeja	Benin	57.60	16520	22400
Ikeja	Ayede	200.00	24660	27400
Benin	Delta	203.90	20208	19574.4

Benin	Sapele	143.40	7170	7325
Kainji	Jebba	89.20	7225	7225.2
Shiroro	Kaduna	70.30	6748.8	6748.8
Afam(iv)	Alaoji	40.00	1000	2100
Ajaokuta	Benin	103.10	20085	20085
Jebba	Osogbo	150.00	26564.4	23550
Kaduna	Kano	80.10	18423	18423
Kaduna	Jos	60.10	11839.7	11839.7
Jos	Gombe	40.10	10626.5	1062.5
Sapele	Aladja	130.20	8202.6	8202.6
Benin	Onitsha	45.10	6178.7	6603.4
Onitsha	Newhaven	40.30	3868.8	7891.2
Delta(iv)	Aladja	100.10	2602.6	2602.6
Onitsha	Alaoji	40.01	3868.8	86.40
JebbaGS	Jebba	60.21	497.68	497.68
JebbaTS	Shiroro	25.25	6161	6161
Kainji	Birnin	15.05	4665.5	4665.5

TABLE 8: Wheeling cost results for 24-bus network

Transaction	**MW-km (₦/Yr)**	**MVA-km (₦/Yr)**
T1	19429680	20910120
T2	22513200	23214000
T3	5694000	4774200
T4	6482400	7183200

VI. Discussion of the Results

Two existing methods of computing wheeling charge namely, Megawatt-Kilometer (MW-km), and MVA-kilometer (MVA-km) were investigated on the Nigerian 24-bus network. Four wheeling transactions were simulated and the wheeling cost of each transaction calculated. In the MW-kilometer approach two power flow were executed with and without wheeling transactions T1, T2, T3 and T4. The wheeling charge obtained in this method is shown in Table 8. In this method, only the real power in the network was considered in the computation of the wheeling charge. The results obtained using this method reflect the effect of both the magnitude of the transacted power and the distance between the point of injection and delivery of electric power. The MVA-kilometer method gave a higher wheeling charge than Megawatt-Kilometer for transaction T1, T2, T3 and T4. This is because in this method the magnitude of the power (active and reactive) wheeled, the distance between the point of injection and delivery of the power wheeled were all used in the computation of the wheeling cost.

VII. Conclusion

Accurate wheeling cost is essential for proper investment planning by the utility and the customers so as to maximize overall social welfare. This paper investigated two existing wheeling cost methodologies, Megawatt-kilometer, and MVA-kilometer. These methods have been able to provide a viable and economic method of allocating energy wheeling cost to cover cost and provide incentive for investment in new infrastructure as and when necessary. Power flow and optimal power flow solutions were employed to know the amount of power flow in MW with and without a wheeling transaction. The results from the investigation carried out on the test systems showed that that these existing methods are simple, reliable and reflective of the actual usage of the transmission network.

It is believed that the right wheeling cost methodology will help to improve the transmission facilities and infrastructure as more funding will be made available. However, there are great difficulties in determining the competitive transmission prices. This is due to the non-linearity of power flow functions when it comes to transmission of electrical energy. Furthermore, the rapid increase in the number of wheeling transactions after deregulation has led to an even urgent urge in finding the economically sound and technically feasible wheeling cost methodologies. In as much as a reliable and secure power system does not depend only on the physical infrastructure, but also on correct economic policy in a deregulated environment, it is recommended that the wheeling cost methodology suggested in this paper should be utilized instead of the existing but complex MYTO pricing methods currently in used in the Nigeria deregulated power system. These methods as analyzed in the paper are transparent, fair, recovers costs, and will encourages investment in the transmission system.

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