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Model Formulation for Fixing of Two-Part Tariff for Bulk Sale Of Energy In The Electric Energy Sector Using Declining Tariff Method

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ABSTRACT

The electric power sector may be aimed at making life meaningful and comfortable for man, but this cannot be done without making profit. However, the supplier must keep his tariff at competitive prices to keep his costumers while he makes profit especially in a competitive market. It is important for the bulk seller of electric energy to know the best tariff that can guarantee these from the very start of the business. This paper has developed a mathematical model the bulk electricity seller can use in fixing a two-part tariff that will be both profitable to the investor and affordable to his customers. The tariff is such that it is highest at the initially life time of the plant and will be declining as the plant ages. This model reveal how a power plant of 470MW and $480 million installation cost with a life span of 42 years and a targeted $24 million profit can be archived by using a two-port tariff of $4.2439/kWh and $0.0006/kWh as variable and fixed tariff respectively for the first to three years of plant life time; and $1.6506/kWh and $0.00294/kWh also as variable and fixed tariff respectively. With this, the investor can know how to set and vary energy tariff that can generate his expected profit for the investment.

Keywords:Model fixing two-port tariff, Formulation, Energy, Electric and Methods

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NOMENCLATURE

IC	Installation cost of the Plant ($).
S	Salvage value of plant after m years ($).
m	Lifetime of the plant (years)
CD_g^h	Cash deposit to be made for between year 'g' and 'h' ($).
r	Rate of depreciation per annum.
n	1, 2, 3 ……. year.
g	1, 2, 3 …. …year
h	1, 2, 3, …… year
TI	Cash paid for tax and insurance per annum($).
x	Interest rate (% of IC).
I	Interest paid on capital per annum ($).
MC	Expected/estimated maintenance cost per annum ($).
MPD	Maximum power delivered (MW)
K	Fix tariff ($/kWh).
t_g^h	Variable tariff for 'g' to 'h' year ($/kWh).
SW	Expected salaries/wages per annum ($).
M	Expected Miscellaneous expensive per annum ($).
PT	Expected total profit to be made in the investment ($).
P	Expected profit to be made per annum ($).
a	% of installation cost to be made as profit by investor
FC	Annual Cost of fuel burnt ($)
Y	Period under analysis
Lf	Load factor

1. INTRODUCTION

The rate at which electric energy is sold to consumers is known as tariff. Fixing tariff for bulk sale of electricity especially in a competitive market shall be examined in this paper; a two-part tariff plan shall be considered in this paper. This two-part tariff consists of the fix and variable tariffs. The bulk sellers of electricity are the generation companies and they selling to transmission companies. For a market with many sellers and buyers of this commodity, the tariff of the electricity sold by these generation companies should be done considering among others the following [1].

(i) Ability of the consumer to pay
(ii) annual cost of generating and transmitting of the electric energy (which comprise of the fixing and running cost);
(iii) Service rendered.

Out of the above three factors, the second factor is the only factor that is quantifiable [1].

At the end of the useful life time of the power plant, it should be replaced so as to keep the supplier in business; hence, cash allocation for the replacement of the plant should be in considered while fixing tariff. Inflation and interest rates should also be strongly considered when fixing tariff. This is because these monies set aside for the replacement of the power plant will have appreciated by the time the replacement is due. Also, inflation may catch up with the monies reserved for the plant replacement.

In this paper, d declining tariff method is used. In this method, higher tariffs are set at the initial plant life time when its efficiency is high and reliability and customer attraction are in turn high. At the later plant life when efficiency and reliability has drop, the investor stand the chance of losing his customers (in a competitive market). Hence, fixing low tariff at this stage will keep customers to the investor.

1.1 Advantages Of Declining Tariff Method

1. Most part of the capital for the investment (and may be profit) will be realized during the plant's best working period (of high efficiency and reliability).
2. It is better to set high tariff and make more money at this stage as more expenditure shall be incurred form advertorials and marketing of the 'new brand' to customers.

1.2 Disadvantages Of Declining Tariff Method

1. It is bad to give more financial obligations to a new business with little customers by setting high initial tariff.
2. The early stage encounter the challenge from the manufacturer's error which may cause reduced reliability; hence, setting high tariff at this stage may not be fair.
3. This method does not take appreciation/interest of deposit into considerations.

2. MODEL FORMULATION FACTORS

The formulation of the model to be used to determine electric energy bulk sale will depend on a number of parameters. These among others include

1. Cost of fuel source to be burnt during the period under analysis.
2. Taxation and Insurance.
3. Depreciation of the power plant over its expected useful life time.
4. Interest payable on invested capital.
5. Expected profit (a percentage of the invested capital).
6. Expected energy to be generated in the period under analysis.
7. Estimated maintenance cost during the period under analysis.
8. Estimated salaries and wages of staffs throughout the period under analysis.
9. Load factor.

2.1 Expected Annual Cost of Fuel Source

This is the cost of the primary source of fuel burnt annually for the generation of the expected power. The actual quantity of fuel will not be constant for the entire life time of the plant. As the plant is ageing, the expected fuel cost per annum of running the power will be increasing as long as the net output power of the plant will be unchanged. To compensate for this increase, 2% rise in fuel consumption will be adopted at the end of every ten years of the plant's life time.

For first three years of the plant (0-3 years), annual cost of fuel burnt is $FC.

The plant life of 04 -06 years, annual cost of fuel burnt is $1.02FC.

Between 07-09 years, annual cost of fuel burnt is $1.04FC and so on.

2.2 Cash reservation due to depreciation

They say nothing last forever; so, the plant that is commissioned for use today that is expected to run for a useful life time of 'n' years will surely be uneconomical in the power generation business after its useful life time. Hence, a good businessman will make reservation to replace the power generating plant be the end of its useful life. The cash reservation should be made during the useful life time of the plant.

Determination of the cash that should be reserved can be done in three ways- straight line depreciation, diminishing value and sinking fund methods [2].

The straight line depreciation method of calculating replacement allocation will not be use because of its low accuracy. The sinking fund and diminishing value methods can be for being more accurate. In this paper, the sinking fund method will be used as its result is suitable for this analysis.

$$CD_n = \frac{(IC-S)r}{(1+r)^n-1}\ldots \quad (1)$$

$$CD_{g=1}^{h=3} = \sum_{n=1}^{3}\left[\frac{(IC-S)r}{(1+r)^n-1}\right] \quad (2)$$

2.3 Servicing of interest due to collected loan

Most businessmen will never invest with their own capital; they will rather take loans from the banks. These loans will have to be serviced and the servicing must be included in the model formulation for fixing of the tariff.

2.4 Estimated maintenance cost

This includes all expected daily, weekly, monthly and annual maintenance expenditures that will be made during the period under analysis for the running of the plant. It include expected rotten plant inspection and maintenance cost. This will not be constant all through the life time of the plant, as the plant is aging, maintenance activities on the plant will be more frequent; hence, the maintenance cost of the plant per annum should increase by a percentage, say 10% in every 3 years.

2.5 Expected Profit

The profit the investor should want to make is a major determinate of the tariff of the power that will be generated. No doubt, the profit should be such as to encourage investment in the power sector; but the investor should place his profit margin in such a way that consumers will be willing to buy his power (especially in a competitive market). The profit should be a very small percentage of the investment cost and should be spread throughout the lifetime of the plant.

$$P_T = a\%\ of\ IC = \frac{a(IC)}{100} \quad (3)$$

As this will be spread throughout the lifetime of the plant, a profit of

$P = \frac{a \times IC}{100m}$ will be made each year.

2.6 Load factor

In the running of the power plant during the period under analysis, it is certain that the plant maximum power (plant capacity) will not be demanded throughout this period; at some times, an average load will be demanded from the plant. The load factor is the ratio of the expected average load demanded from the plant to the expected maximum load demanded during this period.

$$Lf = \frac{expected\ average\ power\ demanded}{expected\ maximu\ power\ demanded} \quad (5)$$

In actual fact, the Lf decreases as the plant is aging.

2.7 Period Under analysis

Cost of fuel throughout the life time of the plant cannot be the same; this can be due to inflation and increase of fuel cost, ageing of the plant among others. This period could vary from plant to plant depending on the source of fuel (most importantly). For example, a gas turbine plant uses natural gas whose price is control by the international market and could change easily, analysis of such plant should not exceed three to five years at a time. In this paper, a three-year analysis period shall be used.

2.8 Wages and salaries (SW)

An estimate of what should be spent annually on salaries and wages should be known from the start of the business.

2.9 Fixed Charge or Tariff (K)

The electric power supplied by any plant is not constant; hence, it will be beneficial for any generation company to charge his client by using a two part tariff – the fix and variable charges. The fix charge is the amount paid by the client when ever power is supplied to the client irrespective of the power supplied; i.e this tariff does not varies with the power supplied. In this paper, the fix tariff will be slightly increased by +0.3 after the period of analysis (say 3 years as will be used in this paper).

3. MODEL FORMULATION

As stated earlier, a 3-year analysis period shall be used in this paper. However, using a smaller time frame will result more number of equations but will give more accurate results. Now combining all the expensive incurred in running the plant for a 3-year interval plus 3 times the expected annual profit; should be equal to the total money realized from sale of energy for the 3 years.

Considering the first 3 years of the plant

$$\sum_{n=1}^{3}\left[\frac{(IC-S)r}{(1+r)^{n}-1}\right]+3TI+3MC+\frac{3xIC}{100}+3FC+3M+3SW+\frac{3aIC}{100m}=Lf\times MPD\times 3\times t_{1}^{3}\times 8.76\times 10^{3}+3\times 8.76\times 10^{3}K \quad (6)$$

The second 3 years,

$$\sum_{n=4}^{6}\left[\frac{(IC-S)r}{(1+r)^{n}-1}\right]+3TI+3.1MC+\frac{3xIC}{100}+3.02FC+3.1M+3SW+\frac{3aIC}{100m}=Lf\times MPD\times 3\times t_{4}^{6}\times 8.76\times 10^{3}+3\times 1.3\times 8.76\times 10^{3}\times K \quad (7)$$

$$\sum_{n=7}^{9}\left[\frac{(IC-S)r}{(1+r)^{n}-1}\right]+3TI+3.1MC+\frac{3xIC}{100}+3.02FC+3.1M+3SW+\frac{3aIC}{100m}=Lf\times MPD\times 3\times t_{7}^{9}\times 8.76\times 10^{3}+3\times 1.6\times 8.76\times 10^{3}\times K \quad (8)$$

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The last (k^{th}) ten years

$$\sum_{n=k-2}^{k}\left[\frac{(IC-S)r}{(1+r)^{n}-1}\right]+3TI+3MC+\frac{3xIC}{100}+3\ldots FC+3\ldots M+3SW+\frac{3aIC}{100m}=Lf\times MPD\times 3\times t_{k-2}^{k}\times 8.76\times 10^{3}+8.76\times 10^{3}\times 3\ldots\times K \quad (9)$$

The sum of the RHS of equations (6) to (k) is the sum of the present worth of the installation cost and the total profit to be made at the end of the investment by the investor.

$$Lf\times 3\times MPD\times 8.76\times 10^{3}\times\left[t_{1}^{3}+t_{4}^{6}+\cdots+t_{k-2}^{k}\right]+3\times 8.76\times 10^{3}\times\left[K+0.3K+\cdots+..\times K\right]=IC+P_{T} \quad (10)$$

4. ASSUMPTIONS MADE IN MODEL DEVELOPMENT

1. It was assumed that the maximum output power delivered by the plant will be constant throughout its useful lifetime.
2. The system is free from inflation.

5. SYSTEM ANALYSIS

This paper shall use the Nigeria's first ever Independent Power Plant (IPP), capable of generating 470MW of electricity, commissioned by Former Nigerian President Olusegun Obasanjo at Okpai in Delta State. This plant has a capital cost of $480million and uses 75 million standard cubic feet of gas per day (scfd) for its operation. The parameters of the power plant are given below

Table 1: Plant's Data (Source: [5])

ITEM	VALUE	ITEM	VALUE
IC	$480M	**S**	$30M
TI	$25,000	**MC**	$50,000
M	$100,000	**SW**	$200,000
Lf (0-70% of lifetime)	0.896	**Lf (71-100% of lifetime)**	0.850
FC	$1,200	**MPD**	460MW
r	5%	**m**	30 years
x	8%	**a**	5%
P_T	$24M		

Using these data, the plant tariff model for first to three years is

$$\sum_{n=1}^{3}\left[\frac{(480-30)\times10^{6}\times0.05}{(1+0.05)^{n}-1}\right]+3\times25{,}000+3\times50{,}000+\frac{3\times0.08\times480\times10^{6}}{100}+3\times1{,}200+3\times100{,}000+3\times200{,}000+\frac{3\times0.05\times480\times10^{6}}{100\times42}=0.896\times460\times10^{3}\times3\times t_{1}^{3}\times8.76\times10^{3}+3\times8.76\times10^{3}\times K \quad 11)$$

Tariff model for 4th to 7th years is

$$\sum_{n=4}^{6}\left[\frac{(480-30)\times10^{6}\times0.05}{(1+0.05)^{n}-1}\right]+3\times25{,}000+3\times1.2\times50{,}000+\frac{3\times0.08\times480\times10^{6}}{100}+3\times1{,}200+3\times1.2\times100{,}000+3\times1.05\times200{,}000+\frac{3\times0.05\times480\times10^{6}}{100\times42}=0.896\times460\times10^{3}\times3\times t_{4}^{6}\times8.76\times10^{3}+3\times8.76\times10^{3}\times1.3\times K \quad (12)$$

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Tariff for 28th to 30th year

$$\sum_{n=28}^{30}\left[\frac{(480-30)\times10^{6}\times0.05}{(1+0.05)^{n}-1}\right]+3\times25{,}000+3\times2.8\times50{,}000+\frac{3\times0.08\times480\times10^{6}}{100}+3\times1{,}200+3\times2.8\times100{,}000+3\times1.45\times200{,}000+\frac{3\times0.05\times480\times10^{6}}{100\times42}=0.896\times460\times10^{3}\times3\times t_{28}^{30}\times8.76\times10^{3}+3\times8.76\times10^{3}\times3.7\times K \quad (13)$$

Tariff for 31st to 33rd year is

$$\sum_{n=31}^{33}\left[\frac{(480-30)\times10^{6}\times0.05}{(1+0.05)^{n}-1}\right]+3\times25{,}000+3\times3.0\times50{,}000+\frac{3\times0.08\times480\times10^{6}}{100}+3\times1{,}200+3\times3.0\times100{,}000+3\times1.5\times200{,}000+\frac{3\times0.05\times480\times10^{6}}{100\times42}=0.850\times460\times10^{3}\times3\times t_{31}^{33}\times8.76\times10^{3}+3\times8.76\times10^{3}\times4.0\times K \quad (14)$$

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Tariff between the 40th to 42nd year is

$$\sum_{n=40}^{42}\left[\frac{(480-30)\times10^{6}\times0.05}{(1+0.05)^{n}-1}\right]+3\times25{,}000+3\times3.6\times50{,}000+\frac{3\times0.08\times480\times10^{6}}{100}+3\times1{,}200+3\times3.6\times100{,}000+3\times1.65\times200{,}000+\frac{3\times0.05\times480\times10^{6}}{100\times42}=0.850\times460\times10^{3}\times3\times t_{40}^{42}\times8.76\times10^{3}+3\times8.76\times10^{3}\times4.9\times K \quad (15)$$

and

$$460\times10^{3}\times8.76\times10^{3}\times[0.896\times(t_1^3+t_4^6+t_7^9+\ \ldots .+t_{28}^{30})+0.850\times(t_{31}^{33}+\cdots+t_{40}^{42})]+10\times8.76\times10^{4}\times K[1+1.3+1.6+1.9+\ \ldots .4.9]=IC+P_T \quad (16)$$

Finding the solution to these fifteen set of equations (11 – 25) using MATLAB gives the following values:

Table 2: Obtained Variable and Fix Tariffs For Stages Of Plant

t_1^3	4.2439
t_4^6	2.4841
t_7^9	2.1433
t_{10}^{12}	1.9953
t_{13}^{15}	1.9132
t_{16}^{18}	1.8617
t_{19}^{21}	1.8268
t_{22}^{24}	1.8020
t_{25}^{27}	1.7837
t_{28}^{30}	1.7700
t_{31}^{33}	1.6691
t_{34}^{36}	1.6613
t_{37}^{39}	1.6553
t_{40}^{42}	1.6506
K	0.0006

Table 3: Tariff For Periods Under Analysis

S/N	PERIOD (YEAR)	VARIABLE TARIFF ($/kWh)	FIX TARIFF ($/kWh)	TOTAL TARIFF ($/kWh)
1	1 – 3	4.2439	0.00060	4.2445
2	4 – 6	2.4841	0.00078	2.4849
3	7 – 9	2.1433	0.00096	2.1442
4	10 – 12	1.9953	0.00114	1.9964
5	13 – 15	1.9132	0.00132	1.9145
6	16 – 18	1.8617	0.00150	1.8632
7	19 – 21	1.8268	0.00168	1.8285
8	22 – 24	1.8020	0.00186	1.8039
9	25 – 27	1.7837	0.00204	1.7857
10	28 – 30	1.7700	0.00222	1.7722
11	31 – 33	1.6691	0.00240	1.6715
12	34 – 36	1.6613	0.00258	1.6639
13	37 – 39	1.6553	0.00276	1.6581
14	40 – 42	1.6506	0.00294	1.6535

6. ASSUMPTIONS MADE IN THE SYSTEM ANALYSIS.

1. Dollar rate of 2003 was used in the analysis.
2. An assumed Interest rate of 8% was used for the analysis.
3. A life span of 42 years was used as the actual 30 years was for when the plant 24 hours per day for its entire life time which is practically impossible as a result of shunt down during maintenance, e.t.c.
4. The fuel here is a by-product of petroleum exploration; hence, no increase over the years was taken into account as most part of the fuel cost is the capital cost of the gas line from the flow station where the petroleum exploration is taking place to the gas plant.
5. A profit of 5% of capital cost of the project was assumed to be targeted by investor.
6. It was assumed that the fixed tariff will be increasing at a rate of 30% at the end of every 10 years.

7. DISCUSSION OF RESULTS

As observed, the energy tariff at the first three years was highest with total tariff at $4.2445/kWh ($4.2439/kWh and $0.0006/kWh for variable and fix charges respectively). The investor's plant operates at its highest efficiency at this stage and therefore provides the best services to energy buyers; his product will therefore be highly demanded and will get good patronage at that price. As time goes on, say between sixteen to eighteen years, the efficiency of the plant will not be as in the first three years, there will be more frequent turn around maintenance resulting to more regular frequent outage. The investor tries to keep his business and costumers by crashing his energy tariff to a total of $1.8632/kWh ($1.8617/kWh and $0.0015/kWh for variable and fix charges respectively). The tariff continue declining as systematically planed until the last three years of the plant when the tariff becomes a total of $1.6535/kWh consisting of variable energy tariff as $1.6506 kWh and $0.00294/kWh as fix energy tariff. With this, the investor is fully aware that at the end of the 42-year period, he will make a total profit of 5% of the installation cost of the project. He also knows how to place his tariff at any particular time throughout the plants so as to make his desired profit.

8. SUMMARY

By using this model, a proper plan can be made by any investor of how he can fix his energy tariff from the start of the power plant working life to the end its end that will generate the extract or desired profit the investor wishes to make. The implication of using this model in a country like Nigeria is that energy tariff may rise unless governments will as usual subsidence it for her citizens.

9. RECOMMENDATION

Reccomendation is made that private and public owners of commercial power plant find a strategic way of fixing tariffs even before the business actually commence. This will give an insight of how the business will run at any stage of its lifetime. The model developed in this paper will be a useful tool in putting this to practice.

10. CONTRIBUTIONS TO KNOWLEDGE

Before now (and even till date), power generation companies, for example the Independent power plant (IPP) Okpai used in runs with tariffs fixed at will, this is why twice in two years in some cases while at other cases tariff remain unchanged for three consecutive years. This is as a result of the lack of knowledge of a strategic way of fixing tariff. This paper has therefore contributed to the knowledge of a systematic way of fixing tariff for a power generation business even before the commencement of the business to the end of that business.

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