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Two-Part Tariff Model Formulation for Bulk Sale of Energy by Depreciating the Plant Using Declining Value Method

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ABSTRACT: *The electric power sector may be aimed at making life meaningful and comfortable for man, but making profit while this is been done cannot be exempted. 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 this from the very start of the business. This paper shall develop a mathematical model the bulk electricity seller can use in fixing a two-part tariff that will be both profitable to himself and affordable to his customers. This model will be developed on the basis of depreciating the power generating plant by the diminishing value method of calculating depreciation. This model reveal how a 490MW power generating plant of $480 million installation cost with a life span of 42 years and a targeted $24 million profit at the end of the investment (the end of the plant useful lifetime) can be archived by using a two-port tariff. Testing of the developed model revealed tariffs of $6.4385/kWh and $0.0018/kWh as variable and fixed tariff respectively for the first to three years of plant life time. At the plant's last three years of existence, the energy bulk seller sells energy at variable energy tariff as $5.4882/kWh and $0.00882/kWh as fix energy tariff. With this, the investor can know how to set and vary energy tariff that can generate his expected profit at the end of the investment.*

Key word: *Model fixing two-port tariff.*

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' ($).
x	Rate of depreciation per annum.
n, g, h	1, 2, 3 ……. year.
V_n	Value of plant after nth year.
TI	Cash paid for tax and insurance per annum($).
r	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 ($).
M	Expected Miscellaneous expensive per annum ($).
P_T	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 ($)
Lf	Load factor

I. 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 selling energy 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.

(i) Ability/Willingness of the consumer to pay
(ii) Cost of generating and transmitting of the electric energy (which comprise of the fixing and running cost);
(iii) Quality of Services 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 the plant running healthy. 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, the plant will be depreciated using the declining value method. In this method, the value or worth of the plant at the end of the first year is taken as the worth of the plant at the beginning of the second year and so on.

1.1 ADVANTAGES OF THE DEPRECIATING THE PLANT BY DECLINING VALUE METHOD

1. The value of the plant at the beginning of every year is not taken as the initial or installation cost but as the value of the worth at the end of the preceding year.
2. This method gives higher tariffs at the initial stage of the business when the plant efficiency is high and encouraging to costumers.

1.2 DISADVANTAGES OF THE DEPRECIATING THE PLANT BY DECLINING VALUE METHOD

1. The method does not take appreciation of deposit made at early stages of the plant into consideration at the time when the plant will be salvaged.
2. This method is associated with high tariff at the initial stage of the business. It is bad to give more financial obligations to a new business with little customers by setting high initial tariff.
3. 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.

II. MODEL FOMULATION 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 'm' 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.

In this paper, the declining balance depreciation method will be used for computing monies to be set aside for cash reservation for the replacement of the plant at the end of its useful working years.

Using the declining balance depreciation method, the value of the plant at the end of the nth year is

$$V_n = (1-x)^n IC \qquad (1)$$

Where $x = 1 - \left[\frac{S}{IC}\right]^{\frac{1}{m}}$ (2)

Hence, the cash deposit to be made at the end of each year is

$$CD = V_k - V_{k-1} \qquad (3)$$

The deposited cash for any 3 consecutive years is,

$$CD_{k-3}^{k} = [V_k - V_{k-1}] + [V_{k-1} - V_{k-2}] + [V_{k-2} - V_{k-3}] \qquad (4)$$

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.

$$P_T = a\% \ of \ IC = \frac{a(IC)}{100} \qquad (5)$$

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.

$$Lf = \frac{expected\ average\ power\ demanded}{expected\ maximu\ power\ demanded} \quad (6)$$

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 at the beginning of a new the period of analysis from the preceding one (say 3 years as will be used in this paper).

III. 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,

$$CD_1^3 + 3TI + 3MC + \frac{3rIC}{100} + 3FC + 3M + 3SW + \frac{3aIC}{100m} = Lf \times MPD \times 3 \times t_1^3 \times 8.76 \times 10^3 + 3 \times 8.76 \times 10^3 K \quad (7)$$

The nest 3 years,

$$CD_4^6 + 3TI + 3.1MC + \frac{3rIC}{100} + 3.02FC + 3.1M + 3SW + \frac{3aIC}{100m} = Lf \times MPD \times 3 \times t_4^6 \times 8.76 \times 10^3 + 3 \times 1.3 \times 8.76 \times 10^3 \times K \quad (8)$$

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The last (k^th^) three years

$$CD_{k-2}^k + 3TI + 3MC + \frac{3xIC}{100} + 3\ldots FC + 3\ldots M + 3SW + \frac{3aIC}{100m} = Lf \times MPD \times 3 \times t_{k-2}^k \times 8.76 \times 10^3 + 8.76 \times 10^3 \times 3\ldots \times K \quad (k)$$

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The sum of the RHS of equations (7) 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.

$$Lf \times 3 \times MPD \times 8.76 \times 10^3 \times [t_1^3 + t_4^6 + \cdots + t_{k-2}^k] + 3 \times 8.76 \times 10^3 \times [K + 0.3K + \cdots + .. \times K] = IC + P_T \quad (9)$$

IV. ASSUPTIONS 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.

V. MODEL TESTING

The model developed in this paper shall be tested with Nigeria's first ever Independent Power Plant (IPP), capable of generating 490MW 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,

$$x = 1 - \left[\frac{S}{IC}\right]^{\frac{1}{m}} = 0.064 \qquad (10)$$

The cash deposits for every three years is given below

TABLE 2: COMPUTED CASH DEPOSIT TO BE MADE IN STATED PERIODS

PERIOD (YEAR)	CASH DEPOSIT (\$)
1 – 3	86.39
4 – 6	70.83
7 – 9	58.10
10 – 12	47.63
13 – 15	39.07
16 – 18	32.03
19 – 21	26.27
22 – 24	21.54
25 – 27	17.66
28 – 30	14.12
31 – 33	11.88
34 – 36	9.74
37 – 39	7.99
40 – 42	6.55

The plant tariff model for first to three years is

$$CD_1^3 + 3 \times 25{,}000 + 3 \times 50{,}000 + \frac{3 \times 0.08 \times 480 \times 10^6}{100} + 3 \times 1{,}200 + 3 \times 100{,}000 + 3 \times 200{,}000 + \frac{3 \times 0.05 \times 480 \times 10^6}{100 \times 42} = 0.896 \times 460 \times 10^3 \times 3 \times t_1^3 \times 8.76 \times 10^3 + 3 \times 8.76 \times 10^3 \times K$$

(11)

Tariff model for 4th to 7th years is

$$CD_4^7 + 3 \times 25{,}000 + 3 \times 1.2 \times 50{,}000 + \frac{3 \times 0.08 \times 480 \times 10^6}{100} + 3 \times 1{,}200 + 3 \times 1.2 \times 100{,}000 + 3 \times 1.05 \times 200{,}000 + \frac{3 \times 0.05 \times 480 \times 10^6}{100 \times 42} = 0.896 \times 460 \times 10^3 \times 3 \times t_4^6 \times 8.76 \times 10^3 + 3 \times 8.76 \times 10^3 \times 1.3 \times K \quad (12)$$

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$$CD_{40}^{42} + 3 \times 25{,}000 + 3 \times 3.6 \times 50{,}000 + \frac{3 \times 0.08 \times 480 \times 10^6}{100} + 3 \times 1{,}200 + 3 \times 3.6 \times 100{,}000 + 3 \times 1.65 \times 200{,}000 + \frac{3 \times 0.05 \times 480 \times 10^6}{100 \times 42} = 0.850 \times 460 \times 10^3 \times 3 \times t_{40}^{42} \times 8.76 \times 10^3 + 3 \times 8.76 \times 10^3 \times 4.9 \times K$$
(24)

and

$$460 \times 10^3 \times 8.76 \times 10^3 \times [0.896 \times (t_1^3 + t_4^6 + t_7^9 + \ldots + t_{28}^{30}) + 0.850 \times (t_{31}^{33} + \cdots + t_{40}^{42})] + 10 \times 8.76 \times 10^4 \times K[1 + 1.3 + 1.6 + 1.9 + \ldots 4.9] = IC + P_T$$
(25)

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

TABLE 3: OBTAINED VARIABLE AND FIX TARIFFS FOR STAGES OF PLANT

t_1^3	6.4385
t_4^6	6.2925
t_7^9	6.1752
t_{10}^{12}	6.0809
t_{13}^{15}	6.0061
t_{16}^{18}	5.9467
t_{19}^{21}	5.9003
t_{22}^{24}	5.8644
t_{25}^{27}	5.8371
t_{28}^{30}	5.8133
t_{31}^{33}	5.5048
t_{34}^{36}	5.4958
t_{37}^{39}	5.4905
t_{40}^{42}	5.4882
K	0.0018

Using these results, the tariffs for the respective periods can be formulated as given in table 4.

TABLE 4: TARIFF FOR PERIODS UNDER ANALYSIS

S/N	PERIOD (YEAR)	VARIABLE TARIFF ($/kWh)	FIX TARIFF ($/kWh)	TOTAL TARIFF ($/kWh)
1	1 – 3	6.4385	0.00180	6.4403
2	4 – 6	6.2925	0.00234	6.2948
3	7 – 9	6.1752	0.00288	6.1781
4	10 – 12	6.0809	0.00342	6.0843
5	13 – 15	6.0061	0.00396	6.0101
6	16 – 18	5.9467	0.00450	5.9512
7	19 – 21	5.9003	0.00504	5.9053

8	22 – 24	5.8644	0.00558	5.8700
9	25 – 27	5.8371	0.00612	5.8432
10	28 – 30	5.8133	0.00666	5.8200
11	31 – 33	5.5048	0.00720	5.5120
12	34 – 36	5.4958	0.00774	5.5035
13	37 – 39	5.4905	0.00828	5.4988
14	40 – 42	5.4882	0.00882	5.4970

VI. ASSUMPTIONS MADE IN THE SYSTEM ANALYSIS.

1. Dollar rate of 2003 was used in the analysis.
2. An assumed Interest rate of 8% of the capital 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.

VII. DISCUSSION OF RESULTS

As observed, the energy tariff at the first three years was highest with total tariff at $6.4403/kWh ($6.4385/kWh and $0.0018/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 frequent outage. The investor tries to keep his business and costumers by crashing his energy tariff to a total of $5.9512/kWh ($5.9467/kWh and $0.0045/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 $5.4970/kWh consisting of variable energy tariff as $5.4882/kWh and $0.00882/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.

VIII. 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.

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