ijecs
open access www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 7 July 2015, Page No. 13169-13175

Running Costminimization Of An Electric Power Sector

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Abstract – The electric power sector like any other sector provides services to the public with one of its aim as making profit; this ensure that human and material resources involve in running the business are well taken care of so as to keep the business on and improve on customer satisfaction. This can be achieved by maximizing profit without placing exorbitant tariff on customers. Hence, reducing the cost of running the system will be a source of maximizing profit. This paper shall consider how the running of the system can be reduced in the generation stage- reducing the total fuel burnt in generating a specific amount of power in the system per hour. This paper shall consider only part of the Nigeria electric power sector as a case study, precisely the Niger-Delta region of Nigeria. We shall assume that the power generated by the plants in the region is also consume there. Research shows that for a total power demand/generation of $2170MW$ by all generating units in the region, a total of $752{,}435 \times 10^4 cal/hr$ of fuel will be burn. But with the system of running cost minimization developed in this paper, about $578{,}130 \times 10^4 cal/hr$ of fuel will be burnt in generating that same quantity of power demanded resulting a net savings of $174{,}305 \times 10^4 cal/hr$.

Key Words: Running Cost Minimization Power Sector

NOMENCLATURE

f_i	Fuel burned byi^{th} plant per hour (in kcal/hr)
P_{Gi}	Power generated/hour by i^{th} plant (in MW).
b_i	Constant (for the i^{th} plant)
c_i	Constant (for the i^{th} plant)
a_i	Constant (for the i^{th} plant)
d_i	Constant (for the i^{th} plant)
F_T	Total fuel burned by all generating plants in theregion under analysis (in kcal/hr).
P_D	Total power demand (in MW).
P_L	Total power loss (in MW).
P_{SP}	Spare capacity (in MW).
B_{ij}	Transmission network power loss B coefficients
$IC_i(\lambda_i)$	Incremental fuel cost of i^{th} plant (in ₦/MWh).
L_i	Penalty factor of the i^{th} plant
λ	Common incremental fuel cost of all plant (₦/MWhr)

1.INTRODUCTION

The Nigeria power system operates as a grid system where several generating units (running as parallel alternators) feed the national grid. The cost optimizationor reduction of the Nigerian power system can be archived by supplying the total load demanded with the cheapest possible cost. It can also be achieved by minimizing the power lossincurred along transmission lines. This paper will investigate how power plants running in the Nigeria grid can be optimized to generate the required load with the cheapest cost.

For simplicity, only a region of the Nigeria Power system shall be considered – the Niger-Delta region. At the moment, there are 9 (nine) functional power plants in the region and their generating capacity is given in the table below.

Power station	Location	Type	Capacity	Status	Year completed
Aba Power Station	Aba Abia State	Simple cycle gas turbine	140 MW	Operational (120MW)	2012
Afam IV-V Power Station	Afam Rivers State	Simple cycle gas turbine	726 MW	Partially Operational (213MW)	1982 (Afam IV)- 2002 (Afam V)
Afam VI Power Station	Afam Rivers State	Combined cycle gas turbine	624 MW	Operational (600MW)	2009 (Gas turbines) 2010 (Steam turbines)
Alaoji Power Station(NIPP)	Abia state	Combined cycle gas turbine	1074 MW	Partially operational (225MW)	2012-2015 Abiastate.
Okpai Power Station	Okpai	Combined cycle gas turbine	480 MW	Operational (470MW)	2005
Omoku Power Station	Omoku	Simple cycle gas turbine	150 MW	Operational (140MW)	2005
Sapele Power Station	Sapele	Gas-fired steam turbine and Simple cycle gas turbine	1020 MW	Partially Operational (135 MW)	1978 – 1981
Sapele Power Station(NIPP)	Sapele	Simple cycle gas turbine	450 MW	Operational (420MW)	2012
Delta - Ughelli Power Station	Ughelli	Simple cycle gas turbine	900 MW	Partially Operational (360 MW)	1966-1990

Table 1: LIST OF POWER PLANTS IN THE REGION OF NIGERIA UNDER ANALYSIS

Data collected from respective power plants' data book shows the energy or fuel burnt in generating a corresponding amount of power and it is given in the table 2 below.

POWER STATION	ENERGY (FUEL) BURNT/HOUR [(cal) $\times 10^4/hr$]	PLANT OUTPUT POWER (MW)
Aba Power Station	2.3	0
	9,200	80
	11,430	90
	13,900	100
	16,600	110
Afam IV-V Power Station	3.1	0

POWER STATION	ENERGY (FUEL) BURNT/HOUR [(cal) $\times 10^4/hr$]	PLANT OUTPUT POWER (MW)
	22,500	150
	28,560	170
	35,345	190
	42,840	210
Afam VI Power Station	2.8	0
	254,000	500
	285,145	530
	295,925	540
	329,460	570
Alaoji Power Station(NIPP)	4.2	0
	36,725	180
	40,857	190
	45,205	200
	47,462	205
Okpai Power Station	3.3	0
	163,200	400
	175,548	415
	195,350	438
	219,950	465
Omoku Power Station	2.1	0
	8,885	80
	14,810	105
	18,200	117
	21,580	128
Sapele Power Station	4.0	0
	8,725	80
	13,505	100
	15,140	106
	19,330	120
Sapele Power Station(NIPP)	3.2	0
	147,200	400
	150,865	405
	158,330	415
	161,360	419
Delta - Ughelli Power Station	5.1	0

POWER STATION	ENERGY (FUEL) BURNT/HOUR [(cal) $\times 10^4/hr$]	PLANT OUTPUT POWER (MW)
	102,000	300
	105,385	305
	115,845	320
	134,385	345

Table 2: ENERGY RELEASE IN GENERATING POWER BY EACH PLANT
(Source: respective power station).

2.METHODOLOGY

We shall assume that these plants feed only loads in the region. The method of equal incremental fuel cost for all power plants in the region (or network under analysis) shall be employed. Hence, we shall assume that all 9 (nine) plants run with equal incremental fuel cost.

3.MODEL FORMULATION

If some quantity of fuel burns for one hour librating an energy f, to generate a particular power output in that one hour, the relationship is

$$f_i = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \qquad (1)$$

For n plants in the system (9 in this case), the total fuel burnt by all plants is

$$F_T = \sum_{i=1}^{9}(a_{ki} + b_i P_{Gi} + c_i P_{Gi}^2)(2)$$

CONSTRAINTS

The minimization of the objective function (2) is subject to some constraints. These include equality and inequality constraints.

1. Real power balance: Real power in supply must be equal to real power in demand (plus real power losses).

$$\sum_{i=1}^{9} P_{Gi} - P_D - \sum P_L = 0(3)$$

2. Spare capacity constraint: Some load predictions at load centers are made in inaccurate; there are also sudden changes in load demand; there are also inadvertent losses of schedule generation in the Nigeria power system. The spare capacity constraint can be use to account for these and more. This ensures that the total generation available at any time should be in excess of total anticipated load demand and total system loss by an amount not less than a specific minimum, called the spare capacity.

$$\sum_{i=1}^{9} P_{Gi} = \sum P_L + P_{SP} + \sum_{I=1}^{9} P_{Di}(4)$$

P_L is calculated as

$$P_L = \sum_{i=1}^{9} \sum_{j=1}^{9} P_{Gi} B_{ij} P_{Gj}(5)$$

$$P_L = [B_{11}P_{G1} + B_{21}P_{G2} + \cdots + B_{91}P_{G9}]P_{G1} + \cdots + [B_{19}P_{G1} + B_{21}P_{G2} + \cdots + B_{99}P_{PG9}]P_{G9}(6)$$

Our task is therefore to minimize equation (2) subject to equations (3) and (4).

This gives the incremental fuel cost of all power plants as

$$IC_i \times L_i = \lambda \qquad (7)$$

Hence,

$$IC_1 L_1 = IC_2 L_2 = \cdots = IC_9 L_9 = \lambda \qquad (8)$$

This means that the incremental fuel cost of all nine (9) plants running in the Niger-Delta region must be on the same to ensure optimal/minimal effective cost of generation of totalgeneration.

Hence, the incremental fuel cost of the ith plant is given by

$$\frac{\partial f_i}{\partial P_{Gi}} . L_i = [d_i P_{Gi} + b_i] . L_i = \lambda(9)$$

Or

$$[d_1 P_{G1} + b_1] L_1 = [d_2 P_{G2} + b_2] L_2 = \cdots . . [d_9 P_{G9} + b_9] L_9 = \lambda(10)$$

Our task is now to find the incremental cost which the eight plants will be running on to give this optimum/economic dispatch of the generators.

First, we must find the penalty factor for each generator,

$$L_i = \frac{1}{\left[1-\frac{\partial P_L}{\partial P_{Gi}}\right]} \quad (11)$$

and

$$\frac{dP_L}{dP_{Gi}} = 2B_{ii}P_{Gi} + \sum_{j=1,j\neq i}^{9} B_{ji}P_j + \sum_{j=1,j\neq i}^{9} B_{ij}P_j \quad (12)$$

However, if the losses are not considered, the cost of running the system when incremental costs of the plants are the same will be

$$\frac{\partial f_i}{\partial P_{Gi}} = [d_i P_{Gi} + b_i] = \lambda (13)$$

4.SYSTEM ANALYSIS

The quantity of energy (or quantity of fuel burned) by each plant when generating and delivering power is given on the table in 2. From the table, the values of the plant constant- a_i, b_i, c_i for each plant can calculated and their approximate values are given below:

Power station	a_i	b_i	c_i	Fuel Eqn× 10^4
Aba Power Station	2.3	19	1.2	$2.3 + 19P_G + 1.2{P_G}^2$
Afam IV-V Power Station	3.1	15	0.9	$3.1 + 15P_G + 0.9{P_G}^2$
Afam VI Power Station	2.8	8	1	$2.8 + 8P_G + {P_G}^2$
Alaoji Power Station(NIPP)	4.2	6	1.1	$4.2 + 6P_G + 1.1{P_G}^2$
Okpai Power Station	3.3	8	1	$3.3 + 8P_G + {P_G}^2$
Omoku Power Station	2.1	15	1.2	$2.1 + 15P_G + 1.2{P_G}^2$
Sapele Power Station	4	5	1.3	$4 + 5P_G + 1.3{P_G}^2$
Sapele Power Station(NIPP)	3.2	8	0.9	$3.2 + 8P_G + 0.9{P_G}^2$
Delta - Ughelli Power Station	5.1	10	1.1	$5.1 + 10P_G + 1.1{P_G}^2$

Table 3: Energy equation for various power Plants in the region as a Function of their power Generated

Their incremental fuel cost is given below:

Power station	$\lambda(P_G, L_i)$	$\frac{\lambda}{L_i}(P_G)$
Aba Power Station	$[19 + 2.4P_G]L_1$	$19 + 2.4P_G$
Afam IV-V Power Station	$[15 + 1.8P_G]L_2$	$15 + 1.8P_G$
Afam VI Power Station	$[8 + 2P_G]L_3$	$8 + 2P_G$
Alaoji Power Station(NIPP)	$[6 + 2.2P_G]L_4$	$6 + 2.2P_G$
Okpai Power Station	$[3.3 + 2P_G]L_5$	$3.3 + 2P_G$
Omoku Power Station	$[15 + 2.4P_G]L_6$	$15 + 2.4P_G$
Sapele Power Station	$[5 + 2.6P_G]L_7$	$5 + 2.6P_G$
Sapele Power Station(NIPP)	$[8 + 1.8P_G]L_8$	$8 + 1.8P_G$
Delta-Ughelli Power Station	$[10 + 2.2P_G]L_9$	$10 + 2.2P_G$

Table 4: Incremental Fuel Cost of various power Plant in the region

From table 2, let us consider the case when total power generated by all the power is 2170MW.From eqn (3) and neglecting the losses, if all plants are running with equal incremental fuel cost, then

$$\sum_{i=1}^{9} P_{Gi} = 2170 (a)$$

$$19 + 2.4P_{G1} = \lambda (b)$$

$$15 + 1.8P_{G2} = \lambda (c)$$

$8 + 2P_{G3} = \lambda$(d)

$6 + 2.2P_{G4} = \lambda$(e)

$3.3 + 2P_{G5} = \lambda$(f)

$15 + 2.4P_{G6} = \lambda$(g)

$5 + 2.6P_{G7} = \lambda$(h)

$8 + 1.8P_{G8} = \lambda$(i)

$10 + 2.2P_{G9} = \lambda$ (k)

Solving equations 'a' to 'k'simultaneously with MATLAB, the energy consume and power generated by each plant can be obtained and it is given on the table below (when the plants are run with equal and with unequal incremental fuel cost.

WITH DEMAND LOAD OF 2,170 [MW] (or $\sum_{i=1=}^{9} P_{Gi} = 2,170MW$)

POWER STATIONS	WITH UNEQUAL INCREMENTAL FUEL COST		WITH EQUAL INCREMENTAL FUEL COST	
	Fuel Burnt per Hour [× 10^4Cal/hr]	Plant Output Power [MW]	Fuel Burnt per Hour [× 10^4Cal/hr]	Plant Output Power [MW]
Aba Power Station	9,200	80	56,788	209.7628
Afam IV-V Power Station	22,500	150	75,756	281.9060
Afam VI Power Station	254,000	500	68,220	257.2154
Alaoji Power Station(NIPP)	36,725	180	62,026	234.7412
Okpai Power Station	163,200	400	68,221	257.4295
Omoku Power Station	8,885	80	56,816	211.4295
Sapele Power Station	8,725	80	52,486	199.0118
Sapele Power Station(NIPP)	147,200	400	75,800	285.7949
Delta-Ughelli Power Station	102,000	300	62,013	232.9231
TOTAL	**752,435**	**2170**	**578,130**	**2,170**

5.DISCUSSION OF RESULT

With a total power of 2,170MW generated by all 9 (nine) generating units in the region, the total energy used each hour by all 9 (nine) plants in the generation of this power is $\mathbf{752,435} \times \mathbf{10^4}\boldsymbol{cal/hr}$with the plants running on their respective incremental fuel cost. However, when the plants ran with the same incremental fuel cost, the total energy used by all 9 (nine) plants to generate that same total of 2,170MW power each hour is $\mathbf{578,130} \times \mathbf{10^4}\boldsymbol{cal/hr}$. This implies that a total of$\mathbf{174,305} \times \mathbf{10^4}\boldsymbol{cal}$(or $\mathbf{7.296} \times \mathbf{10^9}\boldsymbol{Joules}$) of energy is saved each hour.This value converted to kWh gives $\mathbf{2.027} \times \mathbf{10^3}\boldsymbol{kWh}$ as the energy saved each hour. With energy sold at ₦18/kWh in Nigeria, a total of **₦36,486** will be saved each hour. This means that a total of **₦319,617,360** will be saved per annum.

6.CONCLUSION

With all power plants in the region running under equal incremental fuel cost, more generation task is given to those plants whose cost of generating power is relatively low (provided their generation capacity is not exceeded). With this, the same quantity of total power is generated with a relatively lower cost; this can be regarded as comparative cost advantage. As seen above, a total of over ₦300 million is saved annually when all plants in the region analyzed are run with equal incremental fuel cost. This saved money can be used to build more power plants, expand transmission capacities or used for other capital projects in the country.

7.ACKNOWLEDGEMENT

I wish to acknowledge the assistance given to me by the operations department of the listed power plants for providing me with the necessary data used for the systemanalysis of this paper.

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