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Optimum Energy Loss Model for Evaluating Energy Generation Deficiencies of Thermal Power Stations in Nigeria

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Abstract

This study proposes an optimum energy loss model for evaluating energy generation deficiencies of thermal power stations in Nigeria. The formulated model was used to assess generation data from one of the leading power stations in Nigeria. The results obtained showed the maximum Energy not supplied $C_{t\ max}$ for 2011 with a time loss of 334hrs was 82807.59MWh. The average $C_{t\ max}$ of the station for ten years was computed to be 58651.52MWh with an average time loss of 216.8hrs for the period. 270.53MWh/hr of energy was lost or not supplied to the grid and for every quarter of an hour, about 42MWh was also not supplied due to inherent plant constraint. A validity test of the predicted parameters was carried out and the value of the F-test is statistically significant implying that the fitted model is applicable and the future behavior of the thermal station can be reliably predicted by the given model. From the above formulation the maximum energy lost due to poor generation and the time loss as it affects the grid demands can also be determined.

Keywords: *Energy not supplied, Time Loss Model, Average Load, Validity Test, Transit Period, Generating power*

1.0 Introduction

A power system, as any other system, consists of a set of components interconnected in some purposeful way. The object of a reliability study was to derive suitable measures of successful performance on the basis of component failure information and system configuration. Moreover, for generation system reliability study, the components of interest are the generating units and system configuration which are the specific units scheduled to serve the load. Bassey and Odesola 2020).According to Zhic (2019) the indices used to measure generation reliability are probabilistic estimates of the ability of a particular generation configuration to supply the load demand; These indices are better understood as estimates of system-wide generation adequacy and not as absolute measures of system reliability, Ery et al (2019). The indices are sensitive to basic factors like unit size and unit availability, and they are most useful when comparing the relative reliability of different generation configurations (Amal, (2020).

Managerial activities have proven more complex and it is necessary to make right decisions to avoid heavy losses. Whether it is manufacturing unit, or service organization, resources have to be utilized to their maximum in an efficient manner. Quantitative techniques adopt a scientific approach to decision- making. Application of scientific management and analysis is more appropriate when input values are steady. In such cases, a model can be developed to suit the problem which help us takes decisions faster. All simulation models like mathematical techniques are used to solve real- life problems with the aim of offering analytical solutions. In certain cases, it might not be possible to formulate the entire problem or solve it through mathematical models (Ivan and wang, 2019).

2.0 Literature Review

A model is a mathematical representation of a problem. A mathematical model is in form of expressions and equations that replicate the problem. This mathematical model enables us to identify and understand a real-time phenomenon. The models can be used to maximize the profit or to minimize the costs. The major advantage of mathematical model is that it facilitates decision making and helps to achieve more accurate results. The application of models are wide, such areas as linear programming model, integer programming, sensitivity analysis, goal programming, dynamic programming, non-linear programming, queuing theory, inventory management techniques, PERT/CPM (Network analysis), decision theory, transportation and assignment models (Estacle et al, 2008).

The simplest production cost deterministic model and approximated thermal plant failures are represented by their output levels as fractions of their maximum capacities. The Forced Outage Rate (FOR) of a plant determined the specific fraction of its total capacity that is counted as firm capacity. Under these representations, thermal plants could never fail at their forced outage rate-reduced capacities. Deterministic models treated hydro plants as thermal plants with FORs of zero, and they set hydro output levels to perfectly consume all available water in a given simulation period. This early genre of production models did not take into consideration the fact that when plants fail, their outputs drop to zero, leading to an under estimation of the need for generation to be more expensive from various generating units (Postnikov, 2018 and Finger, 1975).

The probabilistic production cost (PPC) models that followed treated thermal plant make outages prediction more realistic. Primarily developed by (Baleriaux, 1967) and reintroduced in English by (Booth, 1972) PPCs represented thermal plants using a two-state model. In the first state, the plant is available to generate electricity at its full capacity with probability $(1 - p)$. In the second state, the plant is not available to generate electricity (due to a forced outage) with probability p. By considering these two potential probabilistic states, Baleriaux/Booth created a new class of production cost models that were able to capture more accurately the effect of thermal plant outages (Nagralh and Kothari 2002).

In the following decades, many authors proposed iterations and refinements to the Baleriaux/Booth PPC model. Of these refinements, notably (Souza, 2012 and Conejos, 1992) developed an approach to incorporate hydrothermal coordination. More generally, the PPC techniques proposed by Conejo for optimal charging and discharging, as well as to determine the optimal merit order position to minimize system cost, applied to all limited energy plants (LEPs) (e.g., batteries, flywheels, compressed air storage)—not only hydro plants. As regulatory tools, derivatives of the Baleriaux/Booth PPC model have remained useful because they require relatively little computational effort, capture the discrete nature of plant failures, and directly convey a system’s reliability in terms of its ENSE and LOLP metrics.

Ogujor, et al (2005) did a study on bivarate analysis of the cost of electric energy not supplied (ENS), an attempt was made to formulate a model for the cost of energy not supplied (ENS) in Nigeria (1991 to 2003). The Average Energy Not Supplied (AENS) index was used to evaluate reliability at the customer level (MWh/customer/year). The choice of the index to be used for distribution system reliability is made based on the data available for evaluation. Since data for energy outage frequencies and durations was not available but load profiles for different customers within the system were, enabling the calculation of the total loss of energy over the year, the index AENS was used. While this past work focused on the energy not supplied from the distribution point of study this current work will look at the generation point of power generating system and come out with a model that will predicts the Energy Not Generated (ENG) or not supplied by the generating units and also predicts the time loss as a result of power demand from the grid (IKparnbese et al, 2014).

3.0 Materials and Methods

Generation is proportional to time and the generated mathematical model is a function of time. Data need to be collected for two fundamental Reasons; assessment of past performance and/or prediction of future system performance. In order to predict, it is essential to transform past experience into the required future prediction. Collection of data is therefore essential as it forms the input to relevant reliability models, techniques and equations. The data must be sufficiently comprehensive to ensure that the methods can be applied but restrictive enough to ensure that unnecessary data is not collected (Gupta, 2011 and Kleit and Terrell, 2001).

3.1 Model Formulation for The Cost Time Loss and Energy Not Supplied to Grid Due to Power Outage

These models were formulated to calculate the time loss due to plant power failure (i.e. forced or scheduled outage) or energy prediction per time that was supposed to have been supplied from a generating unit but not supply to the grid if there was a system shut down within a given period. The formulation is as stated thus:

Let the time duration for one of the units say steam or gas turbine of power generation being out of service = $\mathbf{T_S}$

Similarly, let $\mathbf{C_w}$ be the total energy in MW which is supposed to have been generated by the said "one" unit for this time period.

The cost of time lost say $\mathbf{L_g}$, throughout the waiting period is

= total energy supposed to have been generated × Time duration being out of service

$$\mathbf{L_g = C_w \times T_s} \qquad (1)$$

In addition, there is the cost generated by this delay. The size or numbers of the units is optional. It will be assumed that the time for servicing a unit $\mathbf{T_S}$ is inversely proportional to the size or number of unit and that the period cost or time interval $\mathbf{T_a}$ of servicing unit is also proportional to the size. Let the load demanded for one of these units of power generation from the grid; on outage in one time period equal $\mathbf{C_f}$. Then, the total time spent through these idle periods for a single unit as a result of this outage to offset the proposed load demand is given as,

$$Q_b = \frac{C_f}{T_s} \qquad (2)$$

The energy loss for a time interval say $\mathbf{T_a}$, will be the sum of energy supposed to be generated on this idle time period from one of this unit being out of service and the quantity of load demanded from the grid per the time period for the same unit and the total period of interval $\mathbf{T_a}$, (say ten years in this study).

This is equal to,

$$C_w\, T_S + \frac{C_f}{T_s}\, T_a \qquad (3)$$

We obtain the total energy loss for one time period **C_t**, by dividing the preceding by **T_a,**

$$C_t = C_w \frac{T_s}{T_a} + \frac{C_f}{T_s} \qquad (4)$$

The maximum energy loss per period is obtained by differentiating with respect to **T_s**and setting **C_t,** equal to zero;at the point of maximum energy loss:

$$\frac{dC_t}{dT_s} = 0 = \frac{C_w}{T_a} - \frac{C_f}{T_s^2} (5)$$

$$T_{s,\ maximum} = \sqrt{\frac{C_f T_a}{C_w}} (6)$$

And placing the value in (4) in equation (3)we have;

$$C_t T_a \left(\sqrt{\frac{C_f T_a}{C_w}}\right) = \frac{C_w C_F T_a}{C_w} + T_a C_f$$

This implies:

$$C_t = \frac{\frac{C_w C_F T_a}{C_w} + T_a C_f}{T_a\left(\sqrt{\frac{C_f T_a}{C_w}}\right)}$$

Squaring both side;

$$C_{t,\ maximum} = \mathbf{2}\sqrt{\frac{C_f C_w}{T_a}} \qquad (7)$$

It is important to note that **C_f** is the load demand in one time period of one unit on Mean Time to Failure (MTTF), if they are N total units on this stage instead of one from the same station.

Then,

The energy loss or not generated within a time in period for more units is given by the equation below:

$$C_t = C_w \frac{T_s}{T_s} + \frac{C_f N}{T_s} \qquad (8)$$

And equation (6) and (7) becomes

$$T_{s,\ maximum} = 2\sqrt{\frac{C_f T_a N}{C_w}} \qquad (9)$$

$$C_{t,\ \text{maximum}} = 2\sqrt{\frac{C_f C_w N}{T_a}} \qquad (10) \sqrt{\frac{L\,C_f\,T_a}{T_a}}\ \sqrt{\frac{L\,C_f\,T_a}{c_w}}$$

Equations (9) and (10) are the proposed models

In summary, the maximum time loss for a time period say one year can easily be calculated using equations 9 and 10 by assigning appropriate values to the model parameters thus:

C_f= the average load figure as demanded from the grid from a unit in a particular year

C_w = the actual generation at that particular year

T_a = the transit period of the unit or (MTBF) period

N = the total numbers of units generating power.

4.0 RESULTS AND DISCUSSION

Table 1: Optimum Time Loss and Energy not supplied Computed from the Data obtained from Sapele Thermal Power Station, Nigeria from 2011-2020

Year	**C_W (MWH)**	**C_f (MWH)**	**T_a= Sum of MTBF**	**Numbers of Unit in Operation (N)**	**T_s maximum (Hour)**	**C_t maximum (MWh)**
2011	1535744	1382938	6194.57	5	334	82807.59
2012	1383792	1303897	7700.69	5	381	68455.32
2013	1270980	1176030	4095.5	3	313	66178.32
2014	1339625	1252309	3096	3	186	80637.59
2015	1328653	1227902	7987	3	298	49509.26
2016	1167021	1093408	1302	3	121	34288.65
2017	904640	839476	2505	3	169	60315.48
201	100038	928904	2811	2	145	51426.2

8	9					
2019	490790	452180	1574	2	108	33585.06
2020	904640	835476	1727	2	113	59311.77

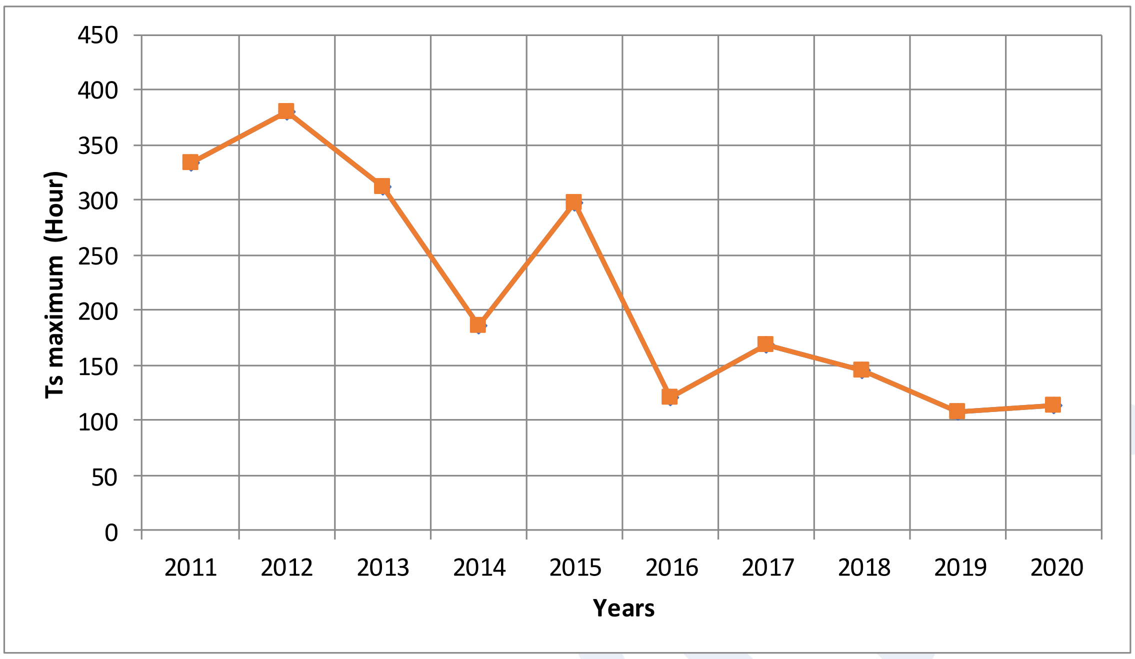

Fig 1: Graph Showing Maximum Time Loss per Period for the Duration

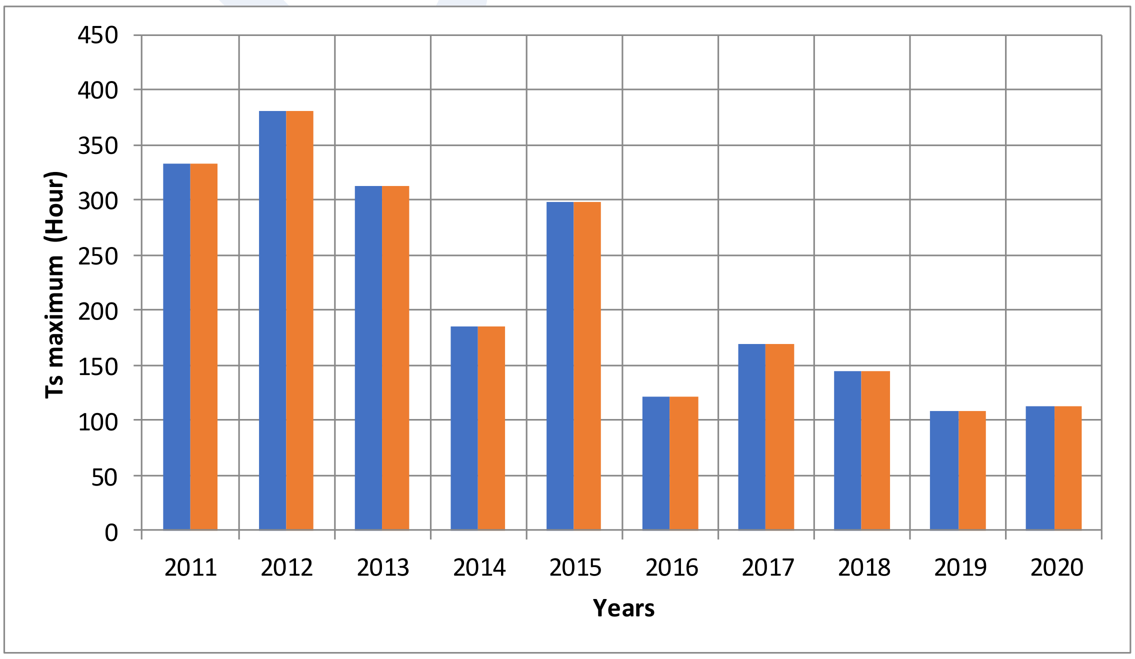

Fig 2: Bar Chart Showing Maximum Time Loss per Period for the Duration

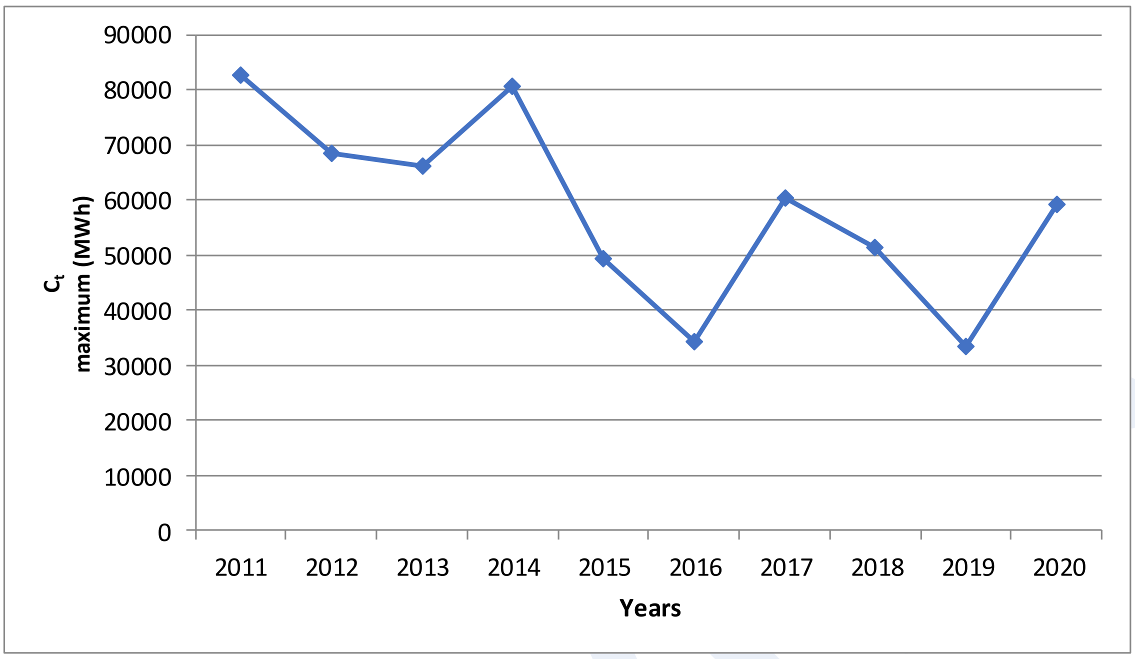

Fig 3: Graph Showing Maximum Energy Loss per Period for the Duration

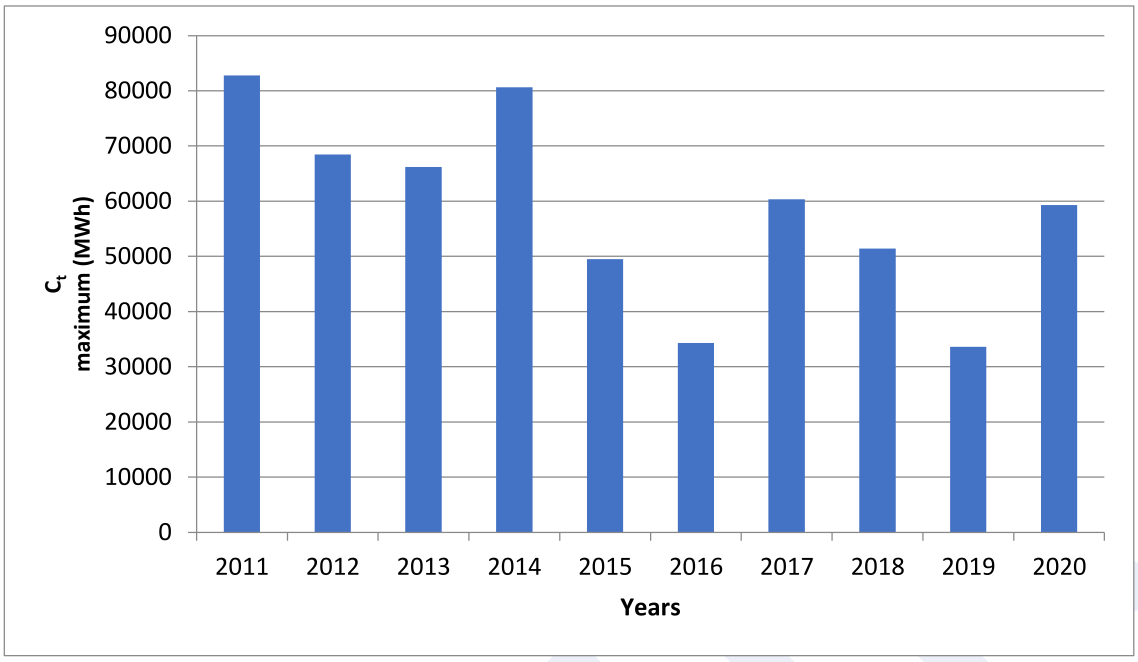

Fig 4: Bar Chart Showing Maximum Energy Loss per Period for the Duration

Fig 1-4 depicts the maximum time loss and maximum energy loss for the period respectively. These show that the maximum time loss and the maximum energy loss decreases with time for the period under review. The decrease is due to many failures recorded for the period. These failures maybe due to ageing from the units of power generation. Some of the points with relative rise in power generation maybe as a result of the maintenance carried out on the plant to increase its generation efficiency.

Table 1 shows the application of the proposed models (equations 9 and 10) to evaluate the power generation data of Sapele Thermal Power Station in Nigeria. The following results were obtained from the assessment of the Thermal Power station: $C_{t\ max}$ for 2011 with a time loss $T_{s\ max}$ of 334hrs was 82807.59MWh, C_t for 2012 is 68455.32 at $T_{s\ max.}$ 381hrs; C_t for 2013 is 66178.32MWh at $T_{s\ max}$ 313hrs; C_t for 2014 is 80637.59MWh at $T_{s\ max}$ 186hrs; for 2015 C_t is 49509.26MWh at $T_{s\ max}$ 298hrs;for 2016 C_t is 34288.65MWh at $T_{s\ max}$ 121hrs; for 2017 C_t is 60315.48MWh at $T_{s\ max}$ 169hrs; for 2018 C_t is 51426.2MWh at $T_{s\ max}$ 145hrs; for 2019 C_t is 33585.06MWh at $T_{s\ max}$ 108hrs; for 2020 C_t is 59311.77MWh at $T_{s\ max}$ 113hrs. An average of $C_{t\ max}$ of 586515.24/ 10 is 58651.52MWh in a ten years-time frame, with an average time loss of 216.8hrs. This implies that for an average of every one hour (1hr); 270.53MWh of energy is not supplied to the grid demand. For ¼ hrs, 42MWh was not also supplied. These models verify the downward movement of Maximum Time Loss and maximum energy loss as depicted in fig 1-4

Table 2: Statistical Tests of Model Reliability and Validity

Model		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
1	Regression	857846259324.569	1	857846259324.569	2506.906	.000[b]
	Residual	2737545663.831	8	342193207.979		
	Total	860583804988.400	9			

a. Dependent Variable: CW (MWH); b. Predictors: (Constant), $\mathbf{C_f}$ (MWH)

Table 2 shows the predictive validity of the fitted model using the analysis of variance F-test. The value of the F-ratio is highly significant which shows that the fitted model is valid and this implies that the future behaviour of the dependent variable can be reliably predicted by the proposed model.

Table 3: R-Square Model Determination of Validity Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.998[a]	.997	.996	18498.465

a. Predictors: (Constant), Cf (MWH)

The results of the R^2 test of model determination as given in Table 3 supports the results obtained in Table 2 above.

Table 4: Spearman's Measures of Reliability

			CW_(MWH)	Cf (MWH)
Spearman's rho	CW_(MWH)	Correlation Coefficient	1.000	.997**
		Sig. (2-tailed)	.	.000
		N	10	10
	Cf (MWH)	Correlation Coefficient	.997**	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

The results in Table 4 show the spearman's measure of reliability with coefficient 0.997. Since the range of the reliability coefficients is from 0 to 1; we can conclude based on the value of r_{xy}= 0.997, that the relationship between the variables in the fitted model is very strong and highly reliable. This means that the data supports the predictive power of the proposed model.

5.0 Conclusion

This study proposed an optimum energy loss model for evaluating energy generation deficiencies of thermal power stations in Nigeria. The formulated model was used to assess the generation data from one of the leading power stations in Nigeria. The analysis shows a maximum of 82807.59MWh loss of energy that was not supplied to the grid for 2011, while in the year 2015, 49509.26MWh was also not supplied; and in the year 2020, 59311.77MWh was notsupplied to the grid. Furthermore, the analysis of the Thermal Power Station showed an average of $C_{t\,max}$ of 58651.52MWh was not supplied for a period of ten years with an average time loss of 216.8hrs. Also, the analysis showed that for every one hour (1hr), an average of 270.53MWh of energy is not supplied tothe grid; for ¼ hrs, 42MWh was not also supplied to the grid. Using these formulated models, we can obtain the forecasts of the maximum energy not supplied to the grid by any power generating plant as well as maximum time that is lost due to any subsequent plant failures.

6.0 References

Amal E.l.B. (2020). Reliability analysis of Gas turbine power plant based on failure data, International Journal of Mechanical and mechatronics Engineering Egypt, 29(2): 13-25

Baleriaux, H., Jamoulle, E. and Linard, G F.(1967) Simulation del'explotation d'un parc de machines thermiques de poduction d'éelectrictée coupléeàa des statons de pompage. Societée Royale Belge des Electriciens, 7:225–245.

Bassey, J. B. and Odesola I. (2020). Effect of grid instability on power generation systems' reliability, Journal of Engineering research and Reports

Booth R .R. (1972) Power System Simulation Model Based On Probability Analysis.

Booth-Baleriaux Probabilistic Simulation

Conejo, A. (1992). Equivalent Load Production Cost Models for Thermal Dominated Electric Energy Systems. PhD Thesis, Universidad Pontificia Comillas.

Ery,S., Imaz, Y. Devrim, P. (2019). Reliability Engineering and Safety 185

Estache A. et al (2008). How efficient are African Electricity Companies? Evidence from the south Africa country energy policy, 36(6)

Finger, S (1975) Modeling Conventional and Pumped Hydro-Electric Energy Using

Gupta, S. and Tenarri, P. C. (2011), Simulation modeling in a Availability Thermal Power Plane. Journal of Engineering Science and Technology Review 4(2) 110 – 117

IKparnbese, K. K, Akaaza J. N and Tortson A. (2014). Performance Evaluation of Gas Turbine Power Station Omotosho Phase I, international journal Engineering Research and Science & Technology vol 3.

Ivan P. (2020). Analysis of reliability of heat supply from hybrid energy source based on WPP and CHPPi E35 web of conferences, 216:01057 DOI: 10.1051/e35conF/202021601057

Kleit, A.N. and Terrell, D. (2001). 'Measuring potential efficiency gains from deregulation of electricity generation a Bayesian Approach' Review of Economics and Statistics pp S23 – 530

Nagralh I. J. and Kothari, D. P. (2002). Modern Power System Analysis. Tata migraw – Hill publishing company limited New Delh. Pg 1 – 13, 222 – 225

Ogujor E. A, Apeh, S. E. and Kuate P. A. (2005). Bivarate Analysis of the cost of electricity energy not supplied (international Journal of Science and Technological research vol 2 No 1 & 2)

Postnikov, I., Stennikov, V., Mednikova, E. and Penkouskii, A. (2018). Applied Energy 227

Souza, G. F. M. (2012), thermal power performance Analysis of Gas Turbine Bucket, Engineering failure Analysis vol 10 pp 559

Wang, F., Jchen, B. and Xu, Z. (2019). Applied Energy 251

Zhic, Z and Song T. (2019). Electrical power and Energy systems 113