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Original Article

Load Forecasting Investigation for Efficient Photovoltaic Design in Owerri Metropolis

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***Abstract** - The quest towards achieving an alternative power supply in Nigeria to augment the depleted conventional fossil fuel source that is environmentally hostile and which never satisfies the energy needs of consumers necessitated this research. This paper focuses on load forecasting investigation for efficient photovoltaic design within the Owerri metropolis for ten years projected period (2020-2030). Two load forecasting techniques, linear regression and exponential smoothing, were adopted during the load forecasting investigation and simulated with the Matlab program. The results were compared to select the most suitable technique for forecasting long-term load. The investigations showed that the exponential smoothing technique could not be applied because of its unstable behaviour, which does not accurately represent system performance for long-term load forecasting. The satisfactory performance of the least square technique (linear regression) with an increase in value of the forecasted load 13692kW in the year 2020 to 13702kW in 2030, respectively, makes it most appropriate for the analysis and hence was adopted.*

***Keywords** - Exponential smoothing, Hybrid method, Least square regression, Load forecast, Solar sizing.*

1. Introduction

Over decades, the Nigerian power industry has faced constant erratic power supply, adversely affecting the nation's economic growth. Less than 5,000 MW of power is transported to the grid [1]. This capacity is grossly inadequate for Africa's most populated black nation, requiring about 180,000 MW to stabilize its power sector. Besides, the country's current power generation sources are highly dominated by conventional fossil fuel that has already been depleted and accounts for a substantial amount of environmental pollution and greenhouse gas emissions. There is an urgent need to explore the natural gift of abundant renewable energy resources in Nigeria to tackle this age-long power shortage, primarily solar energy as an alternative power source.

To achieve an efficient and effective photovoltaic system design, it is essential to carry out a detailed load forecasting investigation. The intent of this work is centred on load forecasting investigation for efficient photovoltaic design within the Owerri metropolis for ten years projected (2020-2030). Load forecasting is a method used in power systems to predict the amount of power needed to meet the future energy needs of consumers. It involves the accurate prediction of both the magnitudes and geographical locations of electric load over the different periods of the planning prospect [2]. It is also vital for the sustainable development of the electric power industry [3]. The exactness of load forecasting is paramount for power system expansion plan, controlling and scheduling. Load forecasting helps an electric utility make rightful decisions, especially regarding electricity generation, procurement, load switching, and equipment development. It also minimizes utility risk by predicting future power consumption transmitted or delivered by the utility industry. Load forecasting is classified into the following types [4]-[13]:

a) Very short-term load forecasting (VSTLF): This type of load forecasting does not exceed one hour period.
b) Short-term load forecasting (STLF): This forecasting period is one hour to one week. It guides power system planners in decision-making that prevents system overloading.

c) Medium-term load forecasting (MTLF): It ranges from one week to one year and is usually adopted for fuel scheduling supplies and management.
d) Long-term load forecasting (LTLF): This span beyond a year. Power system analysts apply this category while predicting future generation expansion, equipment procurement and labour hiring.

The long-term load forecasting was carried out using the Least Square Regression (LST) and Exponential Smoothing Technique (EST). The most suitable technique from the LST and EST comparative analysis would be selected for long-term load forecasting. The forecasted load values remain vital in designing and sizing solar PV components [14].

The design steps include the determination of load and energy estimation (Watts and Wh), determination of size and choice of components (their voltage current and power ratings), determination of the battery size (their number, capacity, and Ah ratings), computation of the PV module size (their number, power rating voltage and current) and the size of wires and fuses ("mm and A").

2. Owerri Distribution Network

Transmission Company of Nigeria (TCN) Owerri work centre has an installed capacity of 160MW fed through a 132kV double circuit transmission line passing from Alaoji to Owerri, extended to Ahoada in Rivers State [15-17]. The total allocated power supply from Alaoji Generation Company (GenCO) to the work centre ranges from 50-80MW against the installed capacity. This unveils that the demand is much higher than the supply. It has been estimated that about 86% of households in Imo State depend on fuel and wood as their energy source [15-17].

Considering the prevailing challenges, the adoption of grid-connected PV technology as an alternative to augment the shortfall in the industry necessitated the study. As of 26th November 2022, the national generation capacity was 4,068.80 MW. Out of this amount generated, the allocation to the Enugu distribution company was 314MW [16, 18].

This available capacity represented 9% of the energy generated and was shared across Abia State, Anambra State, Ebonyi State, Enugu and Imo State. The line diagram of the structure of the Transmission Company of Nigeria Owerri work centre is shown in Figure 1.

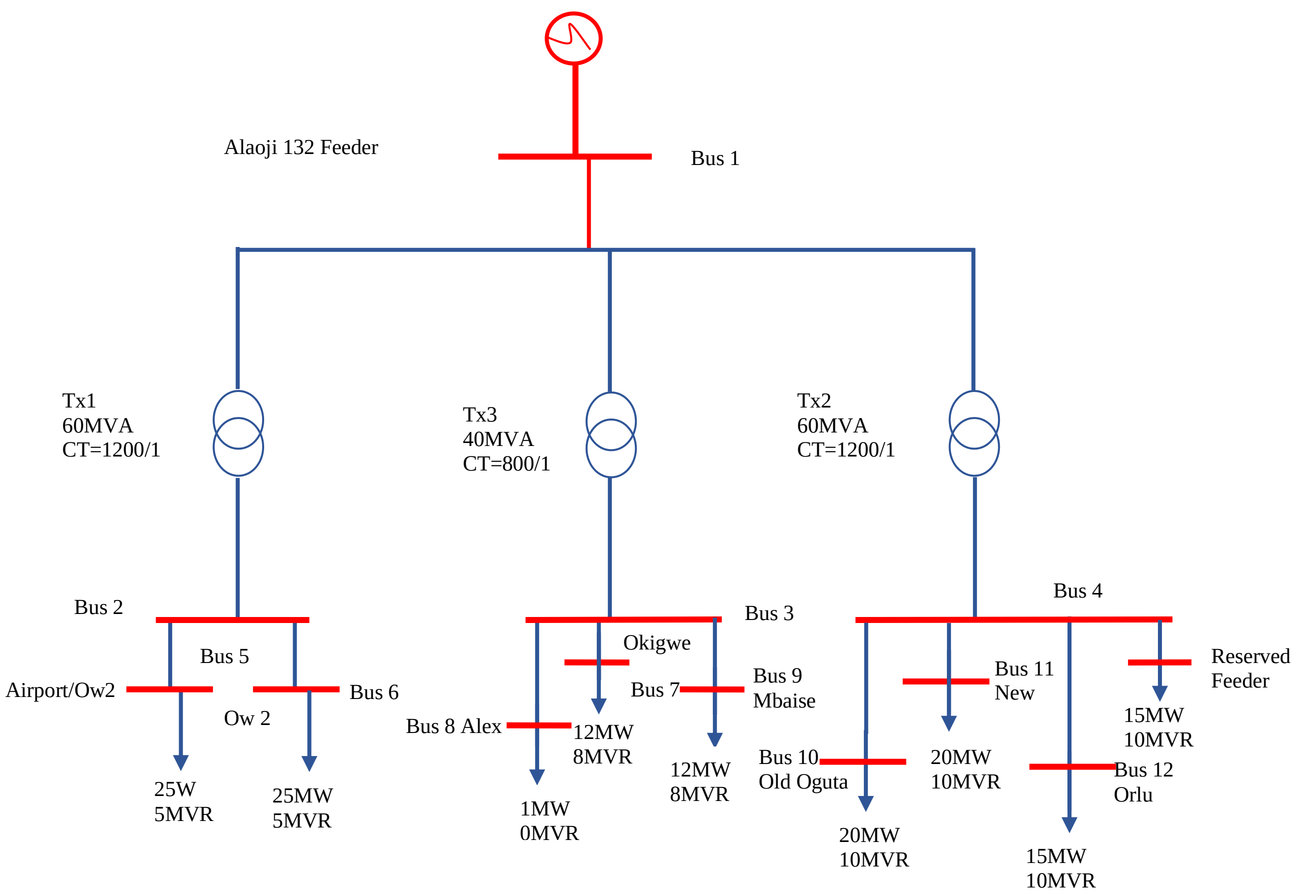

Fig. 1 Diagram of owerri transmission sub-station [16]

3. Methods

The study was conducted in Owerri Municipal Local Government Area of Imo state, which comprises various data sources of electricity consumers in the main cities of Douglas Road, Royce and Umezuruike axis with a total of 3984 consumers and load consumption of 8335 kW as of 25th November 2022. These data were sourced from the first and second-quarter electricity reports of the National Bureau of Statistics and Enugu Electricity Distribution Company (EEDC) [19].

After that, a hybrid method was adopted in the analysis. The method involves computational techniques, namely least square regression and exponential smoothing. These two techniques will be compared to select the most suitable technique for the load forecast.

4. Mathematical Formulation

4.1. Linear Regression Technique

Load forecasting for ten years, from 2020–2030, was carried out using the exponential regression method [20-23]. This method is a non-linear model expected to fit the function to the set of data, expressed in Equation (1).

$$y=a^{bx} \tag{1}$$

A natural logarithm of both sides of equation (1) was implemented to linearize the equation, as shown in equation (2).

$$\log_e y = \log_e a + x\log_e b \tag{2}$$

Where a and b are regression parameters.

$$\begin{vmatrix} Y = \log_e y \\ A = \log_e a \\ B = \log_e b \end{vmatrix} \tag{3}$$

Transforming Equation (2) to a linear equation, we have

$$Y = A + B\mathcal{X} \tag{4}$$

Taking the summation of both sides in Equation (4), we have $\sum Y = A\sum 1 + B\sum x$

$$\sum Y = A\sum 1 + B\sum x \tag{5}$$

Where, $\sum 1 = n$

Then Equation (6) becomes

$$\sum Y = nA + B\sum x \tag{6}$$

Multiplying Equation (6) by "x" we have

$$\sum xY = A\sum x + B\sum x^2 \tag{7}$$

4.2. Exponential Smoothing Technique

It is a practical load forecasting approach in which future energy projections could be computed using exponentially weighted averages of previous examinations [24, 25]. The load at time t, y(t) is modelled using a proper function and is expressed in the form [26-30]. Equations (8) and (9) represent the exponential smoothing formula.

Table 1. Load demand and forecast of Owerri municipal from 2020-2030 using a linear regression technique

Year	x	x^2	Demand (y)	Y= $\log_e y$	xY= $x\log_e y$
2020	-5	25	13094	9.479	-47.399
2021	-4	16	12938	9.468	-37.872
2022	-3	9	12499	9.433	-28.300
2023	-2	4	12714	9.451	-18.901
2024	-1	1	13567	9.515	-9.515
2025	0	0	13591	9.517	0
2026	1	1	14579	9.587	9.587
2027	2	4	14436	9.578	19.155
2028	3	9	14510	9.583	28.748
2029	4	16	14000	9.547	38.187
2030	5	25	15000	9.616	48.079
	∑0	∑110	∑150927.9	∑104.774	∑1.769

$$F_t = \propto A_{t-1} + (1-\alpha)F_{t-1} \quad (8)$$

$$F_t = F_{t-1} + \propto (A_{t-1} - F_{t-1}) \quad (9)$$

For; $0 < \propto \leq 1$

Where:
F_t = Forecasted demand, $\propto$ = smoothing constant

A_{t-1} = previous period's actual demand, F_{t-1} = previous period's forecast demand.

5. Results

5.1. Limited Linear Regression analysis

Table 1 presents the load demand and forecast of Owerri Municipal from 2020-2030 using the Linear regression technique. From Table 1, Y= 104.774, n= 11, xY= 1.769 and x^2=110, the values of Equations (6) and (7) were substituted, which produced equations (10) and (11) with two unknown variables "A" and "B".

$$104.774 = 11A + B(0) \quad (10)$$

$$1.769 = A(0) + 110B \quad (11)$$

Substituting for the values of A and B from equations (10) and (11) gives;

A = 9.5249 and B = 0.0161

From equation (3), a is obtained as 13696.6, and b as 1.0162

Where, b = growth rate

$$\therefore y = 13697^{1.0162x} \quad (12)$$

$$Y = 13697 + 1.02x \quad (13)$$

Substituting Equation (13) with the values of "x" in Table 1, we have:

For the year 2020 Y1 = 13697+ 1.02(-5) = 13691.90
For the year 2021 Y2 = 13697+ 1.02(-4) = 13692.92
For the year 2022 Y3 = 13697+ 1.02(-3) = 13693.94
For the year 2023 Y4 = 13697+ 1.02(-2) = 13694.96
For the year 2024 Y5 = 13697+ 1.02(-1) = 13695.98
For the year 2025 Y6 = 13697+ 1.02 (0) = 13697.00
For the year 2026 Y7 = 13697+ 1.02 (1) = 13698.02
For the year 2027 Y8 = 13697+ 1.02 (2) = 13699.04
For the year 2028 Y9 = 13697+ 1.02 (3) = 13700.06
For the year 2029 Y10 = 13697+ 1.02 (4) = 13701.08
For the year 2030 Y11 = 13697+ 1.02 (5) = 13702.10

The straight-line graph of Figure 2 using the linear regression technique showed an increase in load demand from 13692kW in 2020 to 13702kW in 2030. Figure 3 shows the actual and forecasted load demand of Owerri municipal.

5.2. Results Obtained using Exponential Smoothing

α= 0.2 since 0< α ≤ 1

$$(1-\alpha) = 1 - 0.2 = 0.8 \quad (14)$$

Substituting for the value of alpha in equation (14)

$$F_t = \alpha A_t + (0.8)F_t \quad (15)$$

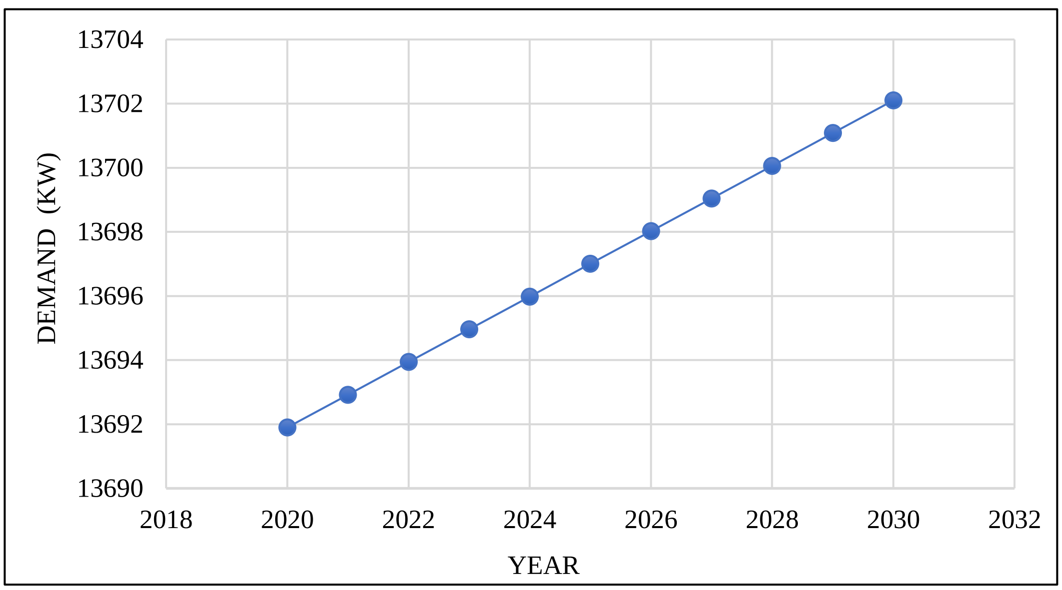

Fig. 2 Forecasted load of owerri using linear regression

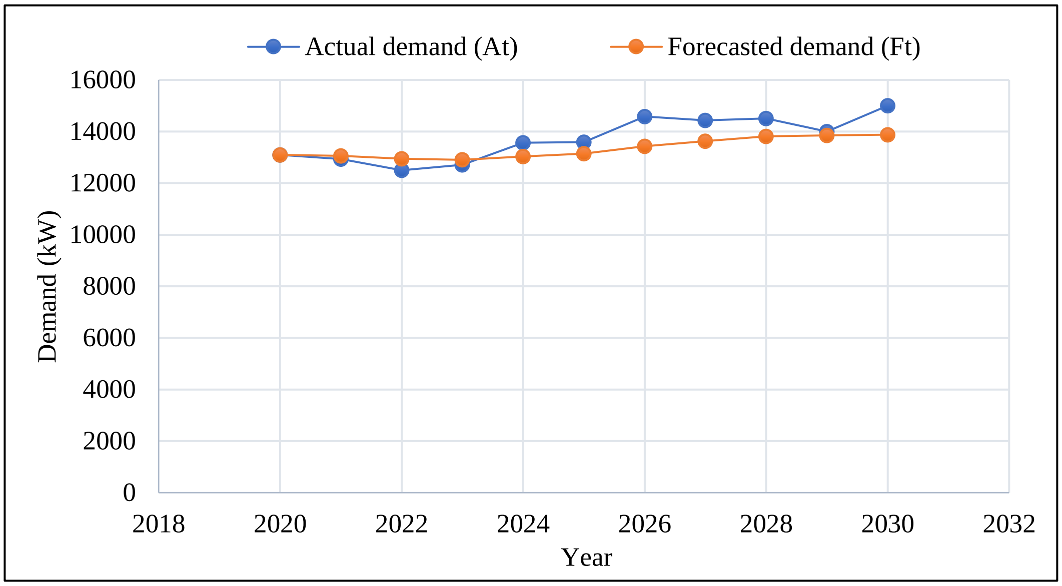

Fig. 3 Actual and forecasted demand using linear regression

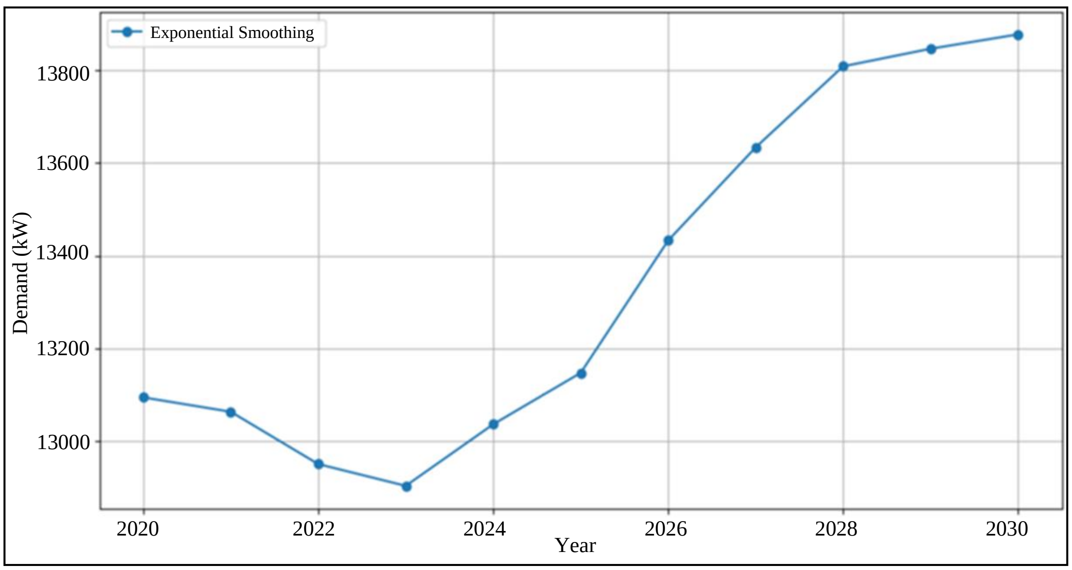

Fig. 4 Line graph forecasted load using an exponential smoothing technique

$F_1 = 13094$

$F_2 = 0.2(12938) + 0.8(13094) = 13062.80$

$F_3 = 0.2(12498.9) + 0.8(13062.8) = 12950.02$

$F_4 = 0.2(12714) + 0.8(12950.02) = 12902.80$

$F_5 = 0.2(13567) + 0.8(12902.80) = 13035.64$

$F_6 = 0.2(13591) + 0.8(13035.64) = 13146.70$

$F_7 = 0.2(14579) + 0.8(13146.70) = 13433.16$

$F_8 = 0.2(14436) + 0.8(13433.16) = 13633.73$

$F_9 = 0.2(14510) + 0.8(13633.73) = 13808.98$

$F_{10} = 0.2(14000) + 0.8(13808.98) = 13847.18$

$F_{11} = 0.2(15000) + 0.8(13847.18) = 14077.74$

Figure 4 represents the line graph of the forecasted load with the exponential smoothing technique. The instability of the line graph shows that the technique is unsuitable for long-term load forecasting. Table 2 represents the Load demand and forecast using the exponential smoothing technique. Table 3 shows the comparative results of linear Regression and exponential technique. It presents the load demand and forecast of Owerri Municipal from 2020-2030 using linear regression techniques and exponential smoothing. From Table 3, it can be deduced that exponential smoothing does not correctly handle trends. It is somewhat unreliable and gives an unstable result with distorted values, especially in 2022-2023.

Table 2. Load demand and forecast using an exponential smoothing technique

Year	Actual demand (A_t)	Forecasted demand (F_t)
2020	13094	13094
2021	12938	13063
2022	12499	12950
2023	12714	12903
2024	13567	13036
2025	13591	13147
2026	14579	13433
2027	14436	13634
2028	14510	13809
2029	14000	13847
2030	15000	14078

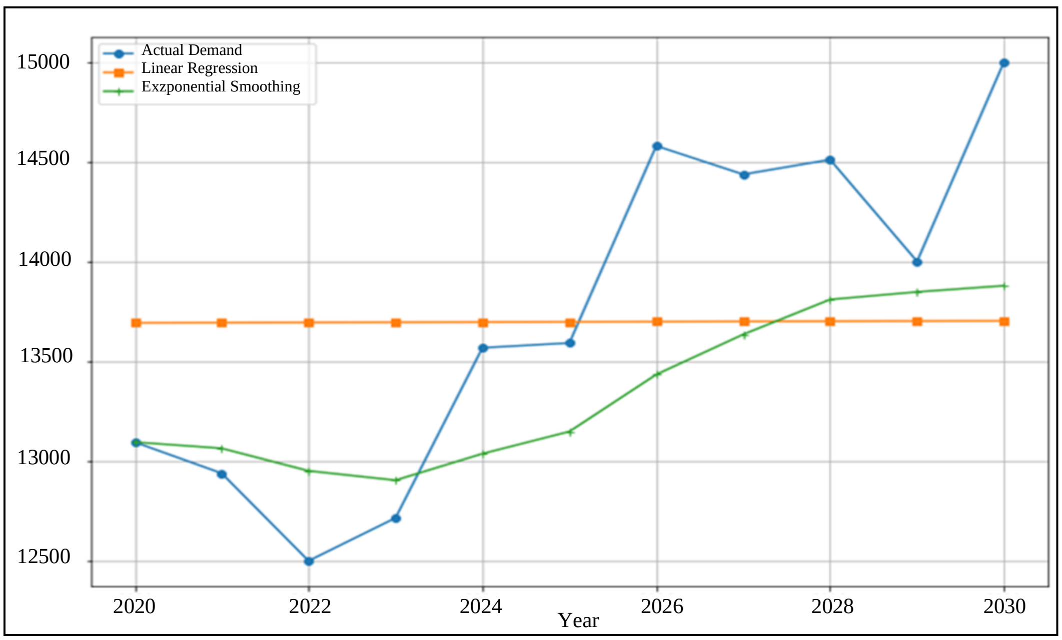

Fig. 5 Comparison of the least square vs exponential smoothing

The least square method is considered most suitable and was selected as the best fit for a set of variables required for the projected future energy demand of the study area, as shown in Figure 5.

The line graph comparison of the least square and exponential smoothing techniques is shown in Figure 5. It could be deduced that the linear regression method shows a steady rise in load demand from 13692kW in 2020 to 13702kW in 2030.

The remarkable rise in the value load is an explicit confirmation that it is most suitable for handling long-term forecasting. At the same time, exponential smoothing gave unstable values of load demand, confirming that the technique is only suitable for short-term load forecasting.

Table 3. Comparison of linear regression and exponential smoothing

Year	Actual Demand (kW)	Forecasted (Y) with Linear Regression (kW)	Forecasted (Y) with Exponential Smoothing (kW)
2020	13094.00	13691.90	13094.00
2021	12938.00	13692.92	13063.00
2022	12498.90	13693.94	12950.00
2023	12714.00	13694.96	12903.00
2024	13567.00	13695.98	13036.00
2025	13591.00	13697.00	13147.00
2026	14579.00	13698.02	13433.00
2027	14436.00	13699.04	13634.00
2028	14510.00	13700.06	13809.00
2029	14000.00	13701.08	13847.00
2030	15000.00	13702.10	14078.00

6. Conclusion

A load forecasting investigation for efficient photovoltaic system design in Owerri metropolis for a projected period of ten years from 2020 to 2030 was conducted with exponential smoothing and linear regression techniques, with a view of comparing and selecting the most suitable technique. The study identified the linear regression technique as the most suitable technique compared with the exponential smoothing for the computation of long-term load forecast for future electricity expansion plans in Owerri Municipal. The result of the investigation showed a trend of maximum load demand increment of 13692kW to 13702kW for the year 2020 to 2030, respectively. The forecasted result showed that load demand cannot exceed 15000kW (15 MW) at the end of 2030, which helped design and size an effective solar energy system.

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