# Analysis Of Energy Deficit On The Injection Substations Within Aba District Electricity Distribution Network

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***Abstract*— In this paper, analysis of energy deficit on the injection substations within Aba District electricity distribution network is presented. Basically, electrical energy deficit is the gap between the demand (required electrical energy by consumers) and the supply (the actual electrical energy supplied to the consumers). The datasets on the required electrical energy by consumers and the actual electrical energy supplied per injection substation on the power distribution network were obtained from the Aba District of the Enugu Electricity Distribution Company (EEDC) covering a period of five (5) years, from 2016 – 2020. Then, the yearly average daily energy deficit (MWH) for each of the five injection substations were computed along with the yearly energy deficit values obtained from all the injection substations on the power distribution. Specifically, a linear regression model with one lagged period was used for characterising the total of the Daily MWH energy deific per year. The model prediction results show that the yearly energy deficit values obtained from all the injection substations on the power distribution network was 268.0107 MWH in 2021, 270.4146 MWH in 2022 and 271.4513 MWH in 2023. In essence, the forecasted energy deficit for the entire power distribution network had increased in 2023 to about 183.4% of the base year (2016) energy deficit of 148.02 MWH. Also, the model performance parameter results were 21.39248 for Mean Absolute Deviation (MAD, 42.09131 for Root Mean Squared Error (RMSE) and 0.152927 for Mean Absolute Percentage Error (MAPE).**

***Keywords*— *Energy Deficit, Load Forecast, Injection Substations, Electricity Distribution Network***

## 1. Introduction

Adequate electrical energy supply is essential for sustainable development of any nation [1,2,3,4,5,6,7,8]. However, this has been the running challenge in most of the developing countries in Africa. In Nigeria for instance, about half of the population do not have access to electricity form the national grid [9,10,11]. Moreover, the percentage of the population that have access to the national grid are subjected to poor and irregular power supply [12,13,14,15]. This has result in self-help electric generating systems being adopted by many households and organisations. Notable alternative power systems in Nigeria includes fossil fuel electric generators [16,17,18], solar power [19,20,21, 22,23, 24, 25, 26, 27,28, 29,30, 31,32, 33,34, 35, 36] and wind power systems [37,38,39,40,41] with little installation count for hydro power sources [42,43,44,45].

In any case, before the installation of electric power distribution system in any locality, load demand assessment is usually conducted followed by projections of the load demand over the years ahead. It is expected that the installed electric power distribution system will make provision for the immediate load demand and the projected load demand. However, in many electric power distribution systems across Nigeria, the load demand is rarely satisfied [46,47,48]. As such, in this paper, analysis of energy deficit on the injection substations within Aba District electricity distribution network is presented. Basically, electrical energy deficit is the gap between the demand (required electrical energy by consumers) and the supply (the actual electrical energy supplied to the consumers). The datasets on the required electrical energy by consumers and the actual electrical energy supplied per injection substation on the power distribution network were obtained from the electricity power distribution company (EEDC) covering a period of five (5) years. Some statistical analysis metrics are used to assess the energy deficit in the injection substations within the case study power distribution system. The study will provide relevant information for proper enhancement planning of the case study power distribution system.

## 2. Methodology

### 2.1 The Case Study Area and dataset

The dataset utilised in the study was obtained from the Aba District of the Enugu Electricity Distribution Company (EEDC) covering a period of five (5) years, from 2016 – 2020. The primary area of the study was Aba District Electricity Distribution network comprising of five (5) 33 kV Injection Substations radiating from 132 kV Sub-transmission station at Alaoji's 330 kV / 132 kV / 33 kV system with the injection substations radiating into various 11 kV feeders that subsequently connect to consumer substations. The listed Injection substations which make up the Aba district distribution network are: Ogbor-Hill by 7Up Junction, Power Station (PS) by Nigerian Breweries, and Ovom by Opobo road, ECN (Electricity Corporation) of Nigeria off Port Harcourt road and Omoba in Isiala Ngwa South area.

The first set of data obtained (and shown in Table 1) includes the average daily load demand forecast in MWH, denoted as Daily MWH and the second set of data obtained expected supply duration per day in hours, denoted as Duration (Hrs). The second set of data obtained (and shown in Table 2) includes the average daily load demand forecast in MWH, denoted as Daily MWH and the expected supply duration per day in hours, denoted as Duration (Hrs).

**Table 1 Average Daily Load Forecast per Injection Substation in Aba District (2016 – 2020)**

| | Injection Substation | ECN | Ovom | Power Station | Ogbor Hill | Omoba | Total per year for the 5 injection substations |
|---|---|---|---|---|---|---|---|
| 2016 | Daily MWH | 143.61 | 36.58 | 102.80 | 70.46 | 31.57 | 385.02 |
| | Duration (Hrs) | 15.00 | 13.00 | 16.00 | 15.00 | 11.00 | 70.00 |
| | Average Daily MW | 9.57 | 2.81 | 6.43 | 4.70 | 2.87 | 26.38 |
| 2017 | Daily MWH | 149.20 | 38.05 | 106.90 | 73.20 | 32.80 | 400.15 |
| | Duration (Hrs) | 15.00 | 13.00 | 16.00 | 15.00 | 12.00 | 71.00 |
| | Average Daily MW | 9.95 | 2.93 | 6.68 | 4.88 | 2.73 | 27.17 |
| 2018 | Daily MWH | 190.23 | 48.45 | 136.17 | 93.33 | 41.82 | 510.00 |
| | Duration (Hrs) | 18.00 | 15.00 | 18.00 | 17.00 | 14.00 | 82.00 |
| | Average Daily MW | 10.57 | 3.23 | 7.57 | 5.49 | 2.99 | 29.84 |
| 2019 | Daily MWH | 212.83 | 54.21 | 152.35 | 104.42 | 46.79 | 570.60 |
| | Duration (Hrs) | 20.00 | 16.00 | 20.00 | 16.00 | 15.00 | 87.00 |
| | Average Daily MW | 10.64 | 3.39 | 7.62 | 6.53 | 3.12 | 31.29 |
| 2020 | Daily MWH | 220.88 | 56.26 | 158.11 | 108.37 | 48.56 | 592.18 |
| | Duration (Hrs) | 20.00 | 16.00 | 20.00 | 16.00 | 15.00 | 87.00 |
| | Average Daily MW | 11.04 | 3.52 | 7.91 | 6.77 | 3.24 | 32.48 |
| | Average MWH per injection substation for the period 2016 to 2020 | 183.35 | 46.71 | 131.27 | 89.96 | 40.31 | 491.59 |
| | Average MW per injection substation for the period 2016 to 2020 | 10.35 | 3.18 | 7.24 | 5.67 | 2.99 | 29.43 |

**Table 2 Actual Daily Load Delivery per Injection Substation (2016 – 2020)**

| | Injection Substation | ECN | Ovom | Power Station | Ogbor Hill | Omoba | Total per year for the 5 injection substations |
|---|---|---|---|---|---|---|---|
| 2016 | Daily MWH | **86.20** | **23.26** | **66.30** | **40.44** | **20.80** | 237.00 |
| | Duration (Hrs) | 10.00 | 9.00 | 10.50 | 10.00 | 8.00 | 47.50 |
| | Average Daily MW | 8.62 | 2.58 | 6.31 | 4.04 | 2.60 | 24.16 |
| 2017 | Daily MWH | 98.50 | 29.30 | 74.50 | 43.20 | 23.00 | 268.50 |
| | Duration (Hrs) | 11.50 | 8.00 | 12.00 | 11.00 | 8.50 | 51.00 |
| | Average Daily MW | 8.57 | 3.66 | 6.21 | 3.93 | 2.71 | 25.07 |
| 2018 | Daily MWH | 106.00 | 31.32 | 79.60 | 50.08 | 25.60 | 292.60 |
| | Duration (Hrs) | 12.00 | 9.00 | 12.00 | 11.50 | 9.00 | 53.50 |
| | Average Daily MW | 8.83 | 3.48 | 6.63 | 4.35 | 2.84 | 26.15 |
| 2019 | Daily MWH | 114.50 | 33.00 | 84.38 | 53.96 | 26.86 | 312.70 |
| | Duration (Hrs) | 14.00 | 10.00 | 15.00 | 12.00 | 9.50 | 60.50 |
| | Average Daily MW | 8.18 | 3.30 | 5.63 | 4.50 | 2.83 | 24.43 |
| 2020 | Daily MWH | 120.20 | 36.00 | 90.24 | 56.84 | 27.00 | 330.28 |
| | Duration (Hrs) | 14.60 | 11.00 | 15.00 | 12.50 | 10.00 | 63.10 |
| | Average Daily MW | 8.23 | 3.27 | 6.02 | 4.55 | 2.70 | 24.77 |
| | Average MWH per injection substation for the period 2016 to 2020 | **105.08** | **30.58** | **79.00** | **48.90** | **24.65** | 288.22 |
| | Average MW per injection substation for the period 2016 to 2020 | 8.49 | 3.26 | 6.16 | 4.27 | 2.74 | 24.91 |

Based on the given data items, Daily MWH and Duration (Hrs) in Table 1, the average daily required power forecast in MW (denoted as Average Daily MW) for the respective Injection Sub-stations are obtained as:

$$\textbf{Average Daily MW} = \frac{\textbf{Daily MWH}}{\textbf{Duration (Hrs)}} \qquad (1)$$

Where,

Daily MWH, as shown in Table 1 and Table 2 is the average daily load (energy) forecast for a period of five years for the respective Injection substations.

Duration (Hrs), as shown in Table 1 and Table 2 is the time duration in hours proposed for power availability or the actual time power was available within a day.

It is also to be noted that the load allocation/delivery system are dependent on the station capacity and the nature of its coverage areas in terms of economic/social activities.

Now, considering ECN, for the year 2016 in Table 1, Daily MWH = 143.61 and Duration (Hrs) =15.00, hence, average MWH = 143.61 /15.00 = 9.57.

Again, considering ECN in Table 1 for the 5 years period, the average MWH (forecast, considering Table 1) is obtained as follows:

Forecast Average MWH

$$= \frac{(143.61+149.20+190.23+212.83+220.88)}{5}$$

= 183.35 MWH

Similarly,

Forecast Average Duration (Hrs)

$$= \frac{(15.00 + 15.00 + 18.00 + 20.00 + 20.00)}{5}$$

$$=17.6\ Hrs$$

$$\text{Forecast Average MW} = \frac{(9.57+9.95+10.57+10.64+11.04)}{5}$$

= 10.35 MW

Alternatively,

Forecast Average MW $= \frac{183.35\, MWH}{17.6\, Hrs}$ = 10.35 MW

Therefore, based on the given load forecast dataset in Table 1, 183.35MWH or 10.4MW daily average load forecast corresponds to a projected 17.6 hours of operation per day.

In the same way, considering ECN in Table 2 for the 5 years period, the average in MWH (actual daily load delivery) is thus obtained as follows.

Actual Average MWH

$$= \frac{(86.2+98.5+106.0+114.5+120.2)}{5}$$

= 105.08 MWH

Actual Average Duration (Hrs)

$$= \frac{(10.00 + 11.50 + 12.00 + 14.00 + 14.60)}{5} = 12.4\ Hrs$$

Actual Average MW $= \frac{105.08}{12.4}$ = 8.5 MW

The computations for the other Injection substations follow the same sequence as contained in Tables 1 and Tables 2.

### 2.2 The time series regression model for characterising the total of the Daily MWH energy deific per year

The focus of this paper is to characterise the overall (that is, the total) yearly energy deficit in the entire case study power distribution network. In this case, instead of looking at the energy deficit on each injection substation, the total of the yearly energy deficit obtained from all the injection substations on the power distribution network is considered.

Specifically, the electrical energy deficit is the gap between the demand (required electrical energy by consumers) and the supply (the actual electrical energy supplied to the consumers). Let the actual value of the total of the Daily MWH energy deific per year in the year t obtained for the five injection substations be denoted as $Y_{a(t)}$ and the corresponding predicted value for the year t be denoted as $Y_{p(t)}$, then;

$$Y_{a(t)} = \text{Actual Average MWH}(t) - \text{Forecast Average MWH}\ (t) \quad (2)$$

In this study, a linear regression model with one lagged period is used for characterising the total of the Daily MWH energy deific per year and it is defined as follows:

$$Y_{p(t)} = a + b(t) + c\left(Y_{a(t-1)}\right) \quad (3)$$

Where t is the year index, while a, b and c are the model constants which in this paper are determined using the MS Excel Solver tool, $Y_{p(t)}$ is the value of the total Daily MWH energy deific per year in the year with year index value of t, and $Y_{a(t-1)}$ is the value of the total Daily MWH energy deific per year in the year with year index value of t-1. The value of t is obtained as,

$$t = Year\ - year\ before\ the\ base\ year \quad (4)$$

For instance, in the dataset used in this study (as presented in Table 1 and Table 2), the base year is 2016, hence the year before the base year is 2015. Therefore, in this study, t is computed as follows;

$$t = Year\ - 2015 \quad (5)$$

### 2.3 The performance parameters used to evaluate the model

Let the prediction error associated with $Y_{a(t)}$ and $Y_{p(t)}$ be denoted as $e_{(t)}$, then.

$$e_{(t)} = Y_{a(t)} - Y_{p(t)} \quad (6)$$

Let the mean of $Y_{a(t)}$ be $\overline{Y_a}$ and n be the number of data items considered, then

$$\overline{Y_a} = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(Y_{a(t)}\right)\right) \quad (7)$$

The Mean Absolute Deviation (MAD) is given as;

$$MAD = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left|Y_{a(t)} - \overline{Y_a}\right|\right) \quad (8)$$

The Mean Squared Error (MSE) is given as;

$$MSE = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(e_{(t)}\right)^2\right) \quad (9)$$

The Root Mean Squared Error (RMSE) is given as;

$$RMSE = \sqrt[2]{\left[\left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(e_{(t)}\right)^2\right)\right]} \quad (10)$$

The Mean Absolute Percentage Error (MAPE) is given as;

$$MAPE = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(\frac{Y_{a(t)} - Y_{p(t)}}{Y_{a(t)}}\right)\right) \quad (11)$$

Mean Percentage Error (MPE) is given as;

$$MPE = \left(\frac{100}{n}\right)\left(\sum_{t=1}^{n}\left(\frac{Y_{a(t)} - Y_{p(t)}}{Y_{a(t)}}\right)\right) \quad (12)$$

### 4. Result and Discussions

The results of the computed expected or forecasted average daily load demand (MWH) per year for each of the five injection substations are presented in Table 3 and Figure 1. The results in Table 3 and Figure 1 show that the ECN injection substation is expected to carry the highest load in the power distribution network while Omoba injection substation is expected to carry the lowest load. Also, the load demand in the ECN injection substation is expected to increase much faster than the load in any of other injection substations.

Table 3 The Computed Expected or Forecasted Average Daily Load Demand (MWH) per year for each of the five injection substations

| Year | t (Year index) | ECN Injection Substation Expected or forecasted Average Daily Load Forecast (MWH) | Ovom Injection Substation Expected or forecasted Average Daily Load Forecast (MWH) | Power Station Injection Substation Expected or forecasted Average Daily Load Forecast (MWH) | Ogbor Hill Injection Substation Expected or forecasted Average Daily Load Forecast (MWH) | Omoba Injection Substation Expected or forecasted Average Daily Load Forecast (MWH) | TOTAL Expected Daily Load Expected or forecasted (MWH) for all the Injection Substations |
|---|---|---|---|---|---|---|---|
| 2016 | 1 | 143.61 | 36.58 | 102.8 | 70.46 | 31.57 | 385.02 |
| 2017 | 2 | 149.2 | 38.05 | 106.9 | 73.2 | 32.8 | 400.15 |
| 2018 | 3 | 190.23 | 48.45 | 136.17 | 93.33 | 41.82 | 510 |
| 2019 | 4 | 212.83 | 54.21 | 152.35 | 104.42 | 46.79 | 570.6 |
| 2020 | 5 | 220.88 | 56.26 | 158.11 | 108.37 | 48.56 | 592.18 |

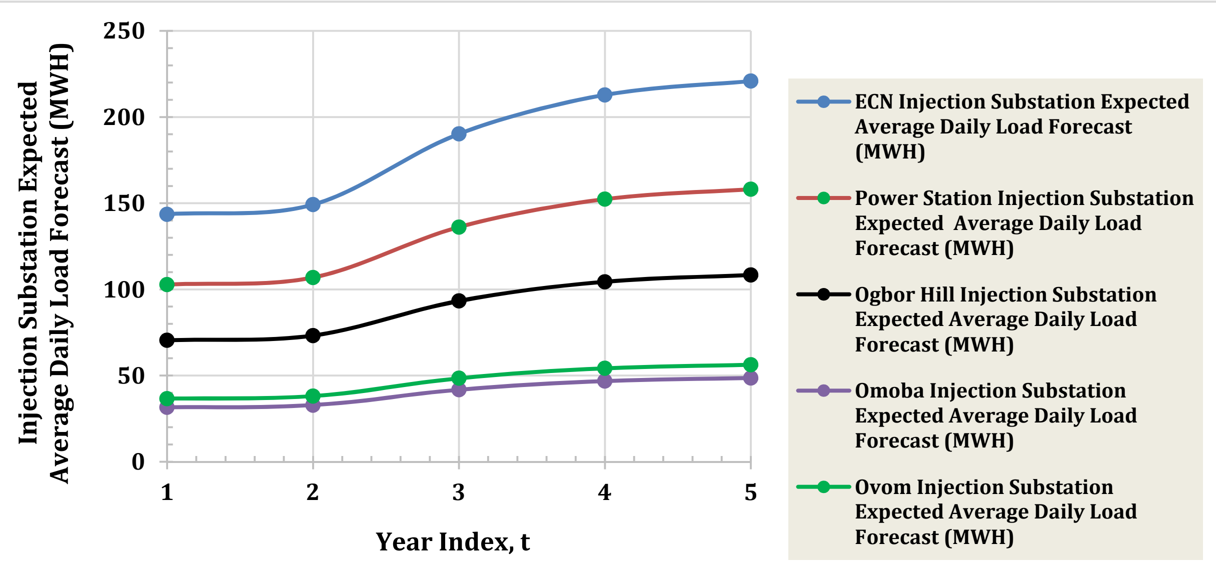


Figure 1 The graph of the computed expected or forecasted average daily load (MWH) (demand) per year for each of the five injection substations

The results of the computed actual average daily load delivery (MWH) per year for each of the five injection substations are presented in Table 4 and Figure 2. The results in Table 4 and Figure 1 show that the ECN injection substation is actually delivering the highest volume of energy in the power distribution network while Omoba injection substation is delivering the lowest volume of energy.

The results of the computed yearly average daily energy deficit (MWH) for each of the five injection substations are presented in Table 5 and Figure 3 while the computed total of the yearly energy deficit values obtained from all the injection substations on the power distribution network are presented in Table 6 and Figure 4.

Table 4 The Computed Actual Average Daily Load Delivery (MWH) per year for each of the five injection substations

| Year | t (Year index) | ECN Injection Substation Actual Daily Load Delivery (MWH) | Ovom Injection Substation Actual Daily Load Delivery (MWH) | Power Station Injection Substation Actual Daily Load Delivery (MWH) | Ogbor Hill Injection Substation Actual Daily Load Delivery (MWH) | Omoba Injection Substation Actual Daily Load Delivery (MWH) | TOTAL Actual Daily Load Delivery (MWH) for all the Injection Substations |
|---|---|---|---|---|---|---|---|
| 2016 | 1 | 86.2 | 23.26 | 66.3 | 40.44 | 20.8 | 237 |
| 2017 | 2 | 98.5 | 29.3 | 74.5 | 43.2 | 23 | 268.5 |
| 2018 | 3 | 106 | 31.32 | 79.6 | 50.08 | 25.6 | 292.6 |
| 2019 | 4 | 114.5 | 33 | 84.38 | 53.96 | 26.86 | 312.7 |
| 2020 | 5 | 120.2 | 36 | 90.24 | 56.84 | 27 | 330.28 |

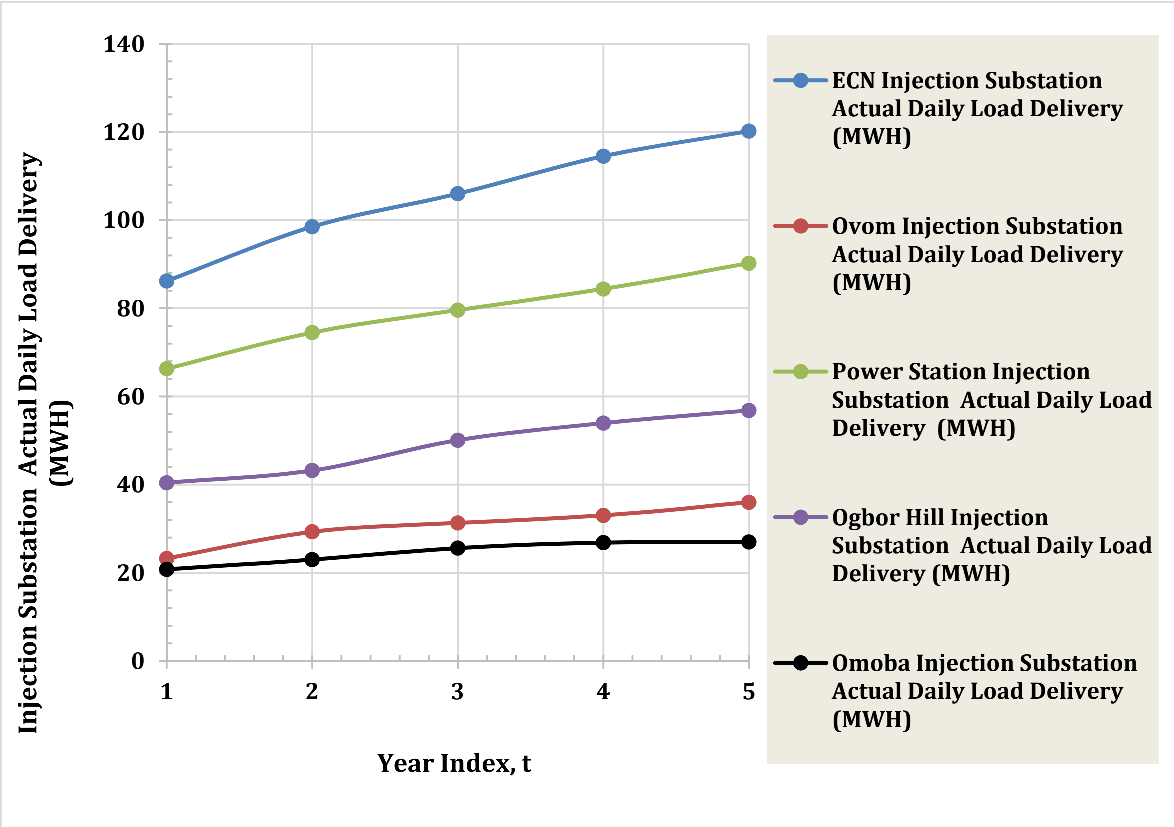


Figure 2 The graph of the computed actual average daily load delivery (MWH) per year for each of the five injection substations

Table 5 The results of the computed Yearly Average Daily Energy Deficit (MWH) for each of the Five Injection Substations

| Year | t (Year index) | ECN Injection Substation Average Daily Energy Deficit (MWH) | Ovom Injection Substation Average Daily Energy Deficit (MWH) | Power Station Injection Substation Average Daily Energy Deficit (MWH) | Ogbor Hill Injection Substation Average Daily Energy Deficit (MWH) | Omoba Injection Substation Average Daily Energy Deficit (MWH) | Total Average Daily Average Daily Energy Deficit (MWH) for all the Injection Substations |
|---|---|---|---|---|---|---|---|
| 2016 | 1 | 57.41 | 13.32 | 36.5 | 30.02 | 10.77 | 148.02 |
| 2017 | 2 | 50.7 | 8.75 | 32.4 | 30 | 9.8 | 131.65 |
| 2018 | 3 | 84.23 | 17.13 | 56.57 | 43.25 | 16.22 | 217.4 |
| 2019 | 4 | 98.33 | 21.21 | 67.97 | 50.46 | 19.93 | 257.9 |
| 2020 | 5 | 100.68 | 20.26 | 67.87 | 51.53 | 21.56 | 261.9 |

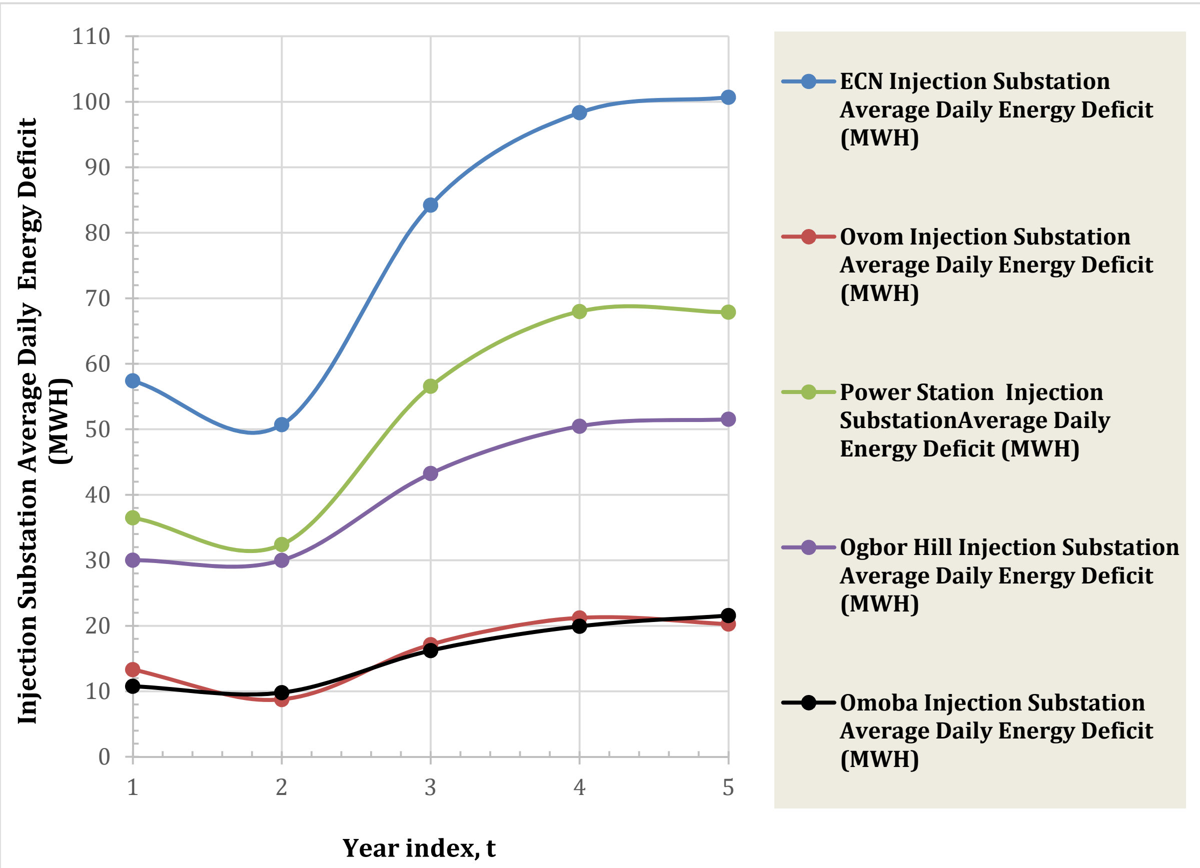


Figure 3 The graph of the computed Yearly Average Daily Energy Deficit (MWH) for each of the Five Injection Substations

Table 6 The results of the computed total of the yearly energy deficit values obtained from all the injection substations on the power distribution network

| Year | t (Year index) | Total forecasted Daily MWH per year for the 5 injection substations |
|---|---|---|
| 2016 | 1 | 385.02 |
| 2017 | 2 | 400.15 |
| 2018 | 3 | 510 |
| 2019 | 4 | 570.6 |
| 2020 | 5 | 592.18 |

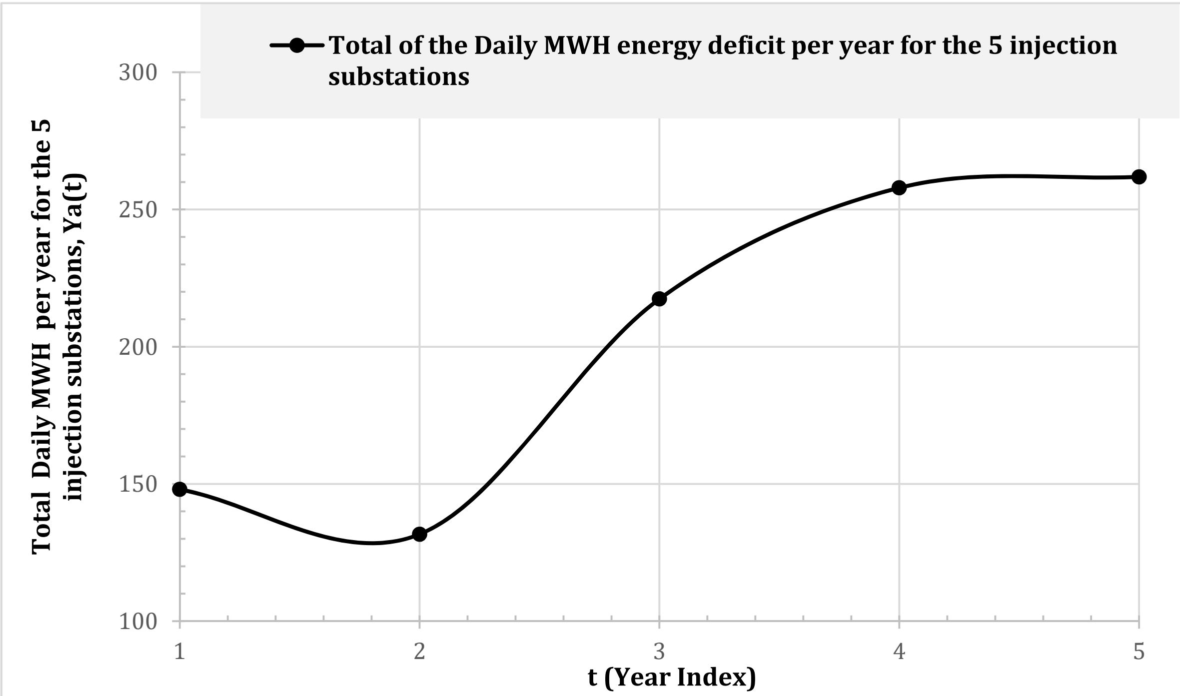


Figure 4 The graph of the computed total of the yearly energy deficit values obtained from all the injection substations on the power distribution network

The model parameter values obtained based on the case study dataset for the prediction of the yearly energy deficit values obtained from all the injection substations on the power distribution network are such that a =170.5086644, b = 0.15 and c= 0.368850751. Hence, the model obtained is given as;

$$Y_{p(t)} = 170.5086644 + 0.15t + 0.368850751Y_{p(t-1)} \quad \text{where } t > 1 \quad (13)$$

The results of the model prediction of the yearly energy deficit values obtained from all the injection substations on the power distribution network are given in Table 7 and Figure 5while Table 8 shows the results of the model prediction performance parameter values. The model prediction results show that the yearly energy deficit values obtained from all the injection substations on the power distribution network is 268.0107 MWH in 2021, 270.4146 MWH in 2022 and 271.4513 MWH in 2023. In essence, the forecasted energy deficit for the entire power distribution network has increased in 2023 to about 183.4% of the base year (2016) energy deficit of 148.02 MWH. Also, the model performance parameter results are such that value obtained for MAD is 21.39248, value obtained for RMSE is 42.09131 and value obtained for MAPE is 0.152927.

Table 7 The results of the model prediction of the yearly energy deficit values obtained from all the injection substations on the power distribution network

| Year | t, Year Index | Actual total of the Daily MWH energy deific per year, $Y_{a(t)}$ | Forecasted total of the Daily MWH energy deific per year , $Y_{p(t)}$ | Error, $e_{(t)}$ | Error^2 |
|---|---|---|---|---|---|
| 2016 | 1 | 148.02 | 148.02 | 0 | 0 |
| 2017 | 2 | 131.65 | 225.406 | -93.756 | 8790.179 |
| 2018 | 3 | 217.4 | 219.5179 | -2.11787 | 4.485355 |
| 2019 | 4 | 257.9 | 251.2968 | 6.603182 | 43.60202 |
| 2020 | 5 | 261.9 | 266.3853 | -4.48527 | 20.11767 |
| 2021 | 6 | | 268.0107 | | |
| 2022 | 7 | | 270.4146 | | |
| 2023 | 8 | | 271.4513 | RMSE | 42.09129 |

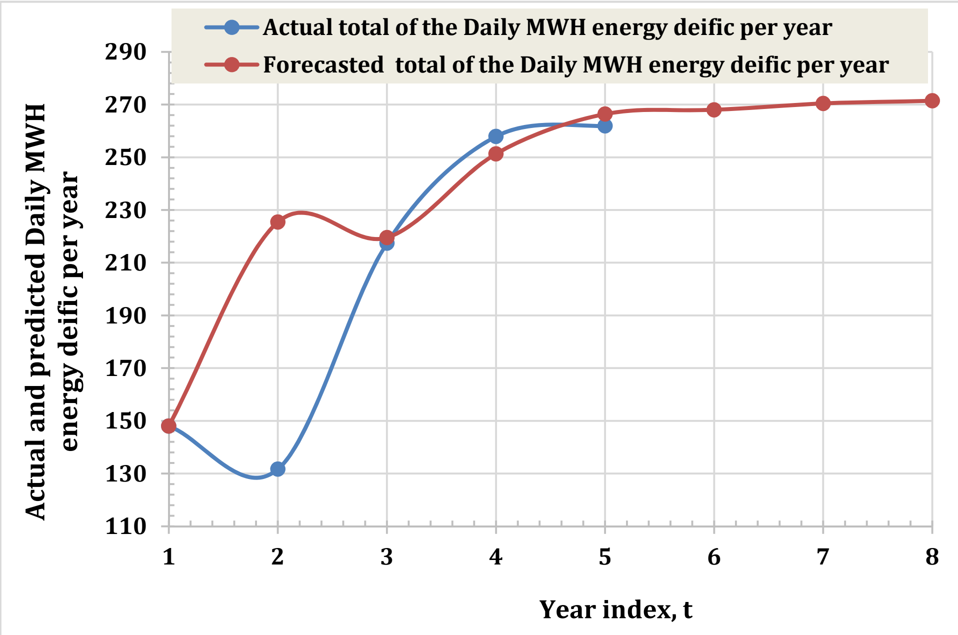


Figure 5 The graph of the model predicted yearly energy deficit values obtained from all the injection substations on the power distribution network

Table 8 The results of the model prediction performance parameter values

| S/N | Performance Parameter Description | Performance Parameter Value |
|---|---|---|
| 1 | MAD: | 21.39248 |
| 2 | MSE: | 1771.679 |
| 3 | RMSE: | 42.09131 |
| 4 | MAPE: | 0.152927 |
| 5 | MPE: | -0.14269 |

## 4. Conclusion

The energy demand and actual delivered energy datasets for the injection substations in the Aba District Electricity Distribution Network are studied. The two datasets , which were for five years records (from 2016 to 2020) were used to determine the yearly energy deficit in each of the injection substations and also the total yearly energy deficit for all the injection substations in the power distribution network. A time series regression model was used to characterise the total yearly energy deficit for all the injection substations in the power distribution network. In all, the results show that by the year 2023, the energy deficit for the entire power distribution network would have increased to about 183.4% of the base year (2016) energy deficit.

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