

ANALYSIS OF TRANSMISSION LOSSES IN ELECTRICAL POWER NETWORK USING A LOSS FACTOR MODEL

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Abstract

Load factor (LD) is the ratio of average load to the peak load over a designated period of time while Loss factor (LS) is the ratio of the average loss to the peak loss over a designated period of time. The loss factor is used to eliminate energy losses for any part of the electric system where the current flowing is directly related to the system load. This paper develops an exponential loss factor model for the analysis of transmission losses in electrical power network in order to take care of the shortcoming of the previous models. The annual load and loss data from Ibadan distribution system were collected and analyzed using appropriate mathematical notations. An exponential curve fitting is used to develop an exponential loss factor model describing the relationship between the annual loss and load factor. The average value of the annual load and loss factors were then used to obtain constant coefficient of 3.2165 and 3.242 in the developed model which were further used to compute the loss factors from the respective annual load factors. The results of the developed model were validated by comparing with the results obtained from Buller and Woodrow model, Hoebel model and Gustafson model and they compared favorably well. The exponential loss factor model developed is capable of analyzing sub-transmission and distribution system losses because the values of the coefficient are very important in estimating losses, even for any system because each system has a different load profile which lead to different values.

Keywords: Transmission, Losses, Loss Factor, Model, Technical Losses, Woodrow Approach, Buller approach, Model, Hoebel Approach.

I. Introduction

Electrical losses occur at each stage of power distribution processes, beginning with the step-up transformer that connects power plants to the transmission system and ending with the customer wiring beyond the retail meter [11], [15], [17], [19]]. The system consists of several key components: step-up transformers, transmission lines, substations, primary voltage distribution lines, line or step-down transformer and secondary lines that connect to individual homes and businesses [6], [8]]. Losses occur in both transmission and distribution lines and in transformers, the fundamental components of the electricity distribution system or “the grid” some losses, called “core” or “no-load” losses are incurred to energize transformers in substations and on the distribution system. A large share is labeled “resistive” or “copper” losses; these losses reflect the resistance of the materials themselves to the flow of electricity. Core losses are typically 25 to 30 percent of total distribution losses and do not increase (or decrease) with changes in load. They are largely influenced by the characteristics of the steel laminations used to manufacture the core of transformers. Resistive losses are analogous to friction losses in the lines and transformers [9], [12], [14]]. As loads increase, the wires (including those in the transformers) get hotter, the material becomes more resistive and line losses increase. For this reason, resistive losses increase exponentially with the current on a line. At low-load periods, system losses are almost entirely core losses and may be as low as three percent. During peak electrical demand periods, however, resistive losses become dominant. At the highest load hours, average line losses increase into the 10-15-percent range, but marginal line losses (those that are avoided if load is reduced) may

increase to 20 percent or more. This concept is analogous to a freeway at rush-hour even a small reduction in traffic volumes can produce very large reductions in “friction” and improve traffic flow. At peak extremes, it can take five power plants operating to provide the end-use electricity normally provided by four. Line loss reduction is partly a function of system design and construction and is also heavily affected by operation of the underlying electrical loads and by how well peak loads are managed [[13], [15], [18]].

Technical Losses:

Technical losses in power system are caused by the physical properties of the components of the power system. The most obvious example is the power dissipated in transmission lines and transformers due to internal electrical resistance. Technical losses are naturally occurring losses (caused by action internal to the power system) and consists mainly of power dissipation in electrical system component such as transmission lines, power transformers, measurement system, etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads. Technical losses occur during transmission and distribution and they involve substation, transformer and line related losses. These include resistive losses of the primary feeders, the distribution transformer losses (resistive losses in windings and the core losses), resistive losses in secondary network, resistive losses in service drops and losses in kWh meter [[1], [2]].

The loss factor can be used to determine energy losses for those parts of the electric system where the current flowing is proportional to system load. A relationship between load factor and loss factor was proposed by Buller F.H and Woodrow C.A using an empirical approach which was later used by Hoebel.

Basic Approaches: The basic approaches include those of Buller and the Woodrow.

Assumptions made in Buller and Woodrow approaches

- Arbitrary and idealized case of a load curve consisting of a peak load for a time (t) and off-peak load for a time
- As the loss varies with square of the current, the loss varies with the square of the load.
- The loss curve has the same shape as that of the load curve.
- The load curve is the plot of the load variation as a function of time for a definite group of end- users. The loss curve is a plot of loss variation as a function of time.

Drawbacks of Buller and Woodrow Approach

The shortcomings of this approach include the following [[4], [7]]:

- It consists of so many unrealistic approximations
- The Load curve considered was an ideal one consisting of only peak and off peak whose average is a function of only peak and off peak, but the intermediate values affect the average

Hoebel Approach

Hoebell H.F developed a modified model from Buller and Woodrow’s model in terms of loss factor and load factor with an exponential coefficient. The commonly used exponential value is 1.6

Thus, the Hoebell Model developed is:

$$\text{Loss Factor} = (\text{loadfactor})^{1.6}$$

1

This is an exponential model with constant coefficient of 0.3 and an exponential coefficient of 1.6

Gustafson Approach

Gustafson M.W developed a quadratic model from Buller and Woodrow’s model to determine sub- transmission and distribution system losses. In his model, he revised the constant and exponential coefficients to be 0.08 and 1.912

respectively instead of 0.3 and 1.6. A constant term K was added representing the No-load losses. Thus, the model developed is [[3], [5], [20], [21], [23],[24], [25],[26]]:

$$\text{Loss Factor} = (\text{Loadfactor})^{1.912} + K \quad 2$$

II. Materials and Method

a. Model Development

In exponential curve fitting, any function is approximated as: $y = Pe^{Qx}$ 3

$$\log y = \log P + Qx \quad 4$$

The best-fit values are:

$$P = \frac{n \sum_{i=1}^n \ln y_i \sum_{i=1}^n x_i^2 - \sum_{i=1}^n x_i \ln y_i}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad 5$$

$$Q = \frac{n \sum_{i=1}^n x_i \ln y_i - \sum_{i=1}^n x_i \sum_{i=1}^n \ln y_i}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad 6$$

Where x_i and y_i are the sets of data, that must be fit in the required curve. Given that the relationship between the loss and load factor is of the form $LS_f = Pe^{qLD_f}$ 7

$$\text{Then: } \ln(LS_f) = \ln(p) + qLD_f \quad 8$$

In this case, $\ln(LS_f)$ can be plotted against LD_f . Thus, the general model will be of the form:

$$\ln(LS_f) = P + Q(LD_f) \quad 9$$

The values of the coefficients P and Q can be determined using equations (5) and (6) above.

The basic definition of loss factor can also be used to estimate the loss at any time.

$$LS_f = \frac{\text{Average loss}}{\text{Peak loss}} \quad 10$$

$$\text{Average loss} = LS_f \times \text{Peak Loss} \quad 11$$

Recall from equation (7);

$$LS_f = Pe^{qLD_f}$$

$$\text{Thus, Average loss} = Pe^{qLD_f} \times (\text{Peak Loss}) \quad 12$$

$$\text{Average loss} = P e^{qLDf}$$

13

Where $P = a \times \text{Peak Loss}$

Equation 13 is the developed load factor model.

With this relationship in equation (13), the average losses of the system can be calculated from the data collected. The model developed is validated by comparing the results with the results obtained from Buller and Woodrow model, Hoebel Model and Gustafson model.

The annual load and loss data from Ibadan distribution systems were collected over a period of ten years. The annual load and loss factors were computed using appropriate mathematical notations. The annual load and loss curves were then plotted. An exponential curve fitting is used to obtain a model describing the relationship between the annual loss and load factors. The average values of the annual load and loss factors were then used to obtain the constant coefficients in the developed model.

III. Discussion of Results

Figures 1 to 10 show the load curves of the network for Ibadan distribution system over a period of ten years.

In 2005, the load increased from 50kW to 70kW with a corresponding time increase from 2 hours to 4.6 hours. As the time increased progressively from 4.6 hours to 4.8 hours, the load decreased as well from 70kW to 15kW, thus establishing an inverse relationship between the two variables as seen in Figure 1.

In 2006, 53kW load was recorded in 4 hours. As the time increased to 6.2 hours, a total load of 68kW was also recorded thus suggesting a linear relationship between the two variables within this instance. After 0.3 hours, the load decreased to 66kW and this continued until 11.3 hours when the load was observed to have fallen to 53kW as seen in Figure 2.

The load increased from 55kW in 3 hour to 67kW in 4.3 hours with a linear relationship between them in 2007 as shown in Figure 3. The load later decreased from 70kW in 4.3 hours to 46kW in 8.5 hours with an inverse relationship existing between the two parameters. After this time, the load then increased to 62kW in 10.2 hours.

Figure 4 shows the variation of the load with time. In 2008, the load increased from 45kW in 1.5 hours to 63kW in 4.3 hours. After this time, the load decreased gradually to 10 kW even though, the time increased proportionately to 9.3 hours.

In 2009, the load was constant within the first eight intervals as illustrated in Figure 5. A constant load of 22kW was maintained between 1.55 hours and 2.70 hours. The load increased gradually to 24kW in 2.92 hours. The load pattern here is irregular until the load increased to 26kW in 5.15 hours.

Figure 6, shows an irregular pattern of the load curve. In 2010, the load was 20kW in 1.35 hours and 23 kW in 2.5 hours suggesting that as the time interval increased, the load interval was still irregular until a load of 24kW was obtained in 4.95 hours.

In 2011, the load pattern was fairly constant within the first seven intervals when 23kW of load was recorded in 1.65 hours and another 23kW was also recorded in 2.65 hours as shown in figure 7. A constant load of 27kW was equally recorded in 4.85 hours and 5.25 hours as illustrated in Figure 7

Figure 8 shows the load pattern in 2012. The load increased from 50kW in 1.9 hours to 65kW in 3.2 hours while it decreased along to 41kW in 7.4 hours until it finally increased to 57kW in 9.1 hours.

Figure 9 shows how the load varies with time in 2013. The load increased from 55kW in 3.5 hours to 75kW in 6.1 hours while it decreased to 73kW in 6.3 hours. This decrease trend was observed until after 11.3 hours when the load was 20kW.

In 2014, the load pattern maintained a definite trend within the first five intervals. The load increased from 52kW in 3.2 hours to 72kW in 5.8 hours. After this time, the load decreased rapidly until a load of 17kW was observed in 11.3 hours as illustrated in Figure 10.

Figures 11-20, show the annual loss curves for Ibadan distribution system from 2005 to 2014.

In 2005, the relationship between the per unit loss and time is illustrated in Figure 11. At a time of 2 hours, the per unit loss was 0.5 and a per unit loss of 0.91 was observed in 17 hours until a per unit loss of 0.39 was got in 36 hours.

Figure 12 shows that the variation of the per unit loss with time in 2006. The least per unit loss of 0.29 was observed in 40 hours while the highest per unit loss of 0.86 was observed in 12 hour suggesting that the per unit loss and time did not follow a definite pattern.

In 2007, the per unit loss increased within the first three intervals from 0.82 in 2 hours to 1.00 in 6 hours while between 6 hours and 12 hours, there was a drop in the per unit loss from 1.00 to 0.91 as shown in Figure 13. This sequential trend was maintained until at 40 hours when, 0.63 per unit loss was observed.

Figure 14 shows the variation of per unit loss with time in 2008. In 28 hours, a least per unit loss of 0.70 was obtained while a highest per unit loss of 1.00 was obtained in 10 hours..

Figure 15 illustrates how the per unit loss varied with time in 2009. At 2 hours, the per unit loss was 0.64 while at 40 hours, the per unit loss was 0.70.

In 2010, the variation of per unit loss with time is illustrated in Figure 16. In this case, the time increased throughout the interval even though, the per unit loss did not follow a definite sequential pattern. Thus, at 2 hours, the per unit loss was 0.84 while at 40 hours, the per unit loss was 0.89.

Figure 17 illustrates how the per unit loss varied with time for 2011. At 2 hours, the per unit loss was 0.69 while at 20 hours, the per unit loss was 0.78 and at 40 hours, the per unit loss was 0.75.

The correlation between the per unit loss and time is illustrated in Figure 18 for 2012. In 38 hours, the per unit loss was 0.44 which happened to be the least in this range while the highest per unit loss was 0.85 and it was recorded in 6 hours.

In 2013, the relationship between the per unit loss and time is illustrated in Figure 19. In 2 hours, the per unit loss was 0.35 while in 30 hours, the per unit loss was 0.45 and in 40 hours, the per unit loss was 0.32 which happened to be the least per unit loss in this range. The highest per unit loss was 0.82 in 14 hours.

Figure 20 shows the variation of the per unit loss with time in 2014. The least per unit loss of 0.19 was obtained in 40 hours even though; the highest per unit loss of 0.76 was obtained in 12 hours.

Figure 21 shows the actual loss factor curve over 10 years study period. In 2005, the actual loss factor was 8.5451 while in 2014; the actual loss factor was 8.7854. Observation shows that year 2006 witnessed the least actual loss factor of 7.5981 while the highest actual loss factor of 9.6452 was experienced in 2010 because some of the network feeder experienced intermittent outages during the time.

Figure 22 shows the variation of the actual load factor over the 10 years study period. The least actual load factor of 0.75211 was obtained in year 2005 while year 2010 experienced the highest actual load factor of 8.9581.

Figure 23 shows the variation of both the actual loss factor and the actual load factor over the 10 years study period. It is observed that in 2005, the least value of actual load factor of 0.75211 was obtained while the highest value of actual loss factor of 9.6452 was obtained in 2010.

Figure 24 shows the comparison of loss factor from the three models over the ten years study period. For Hoebel model, the loss factor was 7.3515 in 2005, 6.5141 in 2006, 7.6152 in 2007, and 7.6183 in 2008 while the actual loss factors in 2005, 2006, 2007 and 2008 were 8.5451, 7.5981, 8.3851 and 8.3693 respectively and in 2014, the actual loss factor was 8.0854 while the loss factor from Hoebel model was 8.7854.

In the same vain, the loss factors from Buller and Woodrow models were 7.9363 in 2005, 6.5782 in 2006, 7.6341 in 2007 and 7.6524 in 2008 while the actual loss factors were 8.5451 in 2005, 7.5981 in 2006, 8.3851 in 2007 and 8.3693 in 2008 respectively. In addition, in 2014, the actual loss factor was 8.7854 while the loss factor from Buller and Woodrow model was 8.7716.

The loss factors from Gustafson model were 7.5752 in 2005, 6.2863 in 2006, 7.3825 in 2007 and 7.6564 in 2008 even though the actual loss factors were 8.5451, 7.5981, 8.3851 and 8.3693 respectively. In 2014, the actual loss factor was 8.0854 even though the loss factor from Gustafson model was 8.0943 which were very close.

Figure 25 shows the graph of the developed model over the ten years study period. It shows how the loss factor from the developed model varied over the ten years study period.

In 2005, the loss factor from the developed model was 6.8854. In 2006, it was 5.7963. In addition, the loss factor from the developed model was 6.7072 in 2007, 6.9385 in 2008, 8.5243 in 2009, 8.3462 in 2010, 7.5188 in 2011, 6.3896 in 2012, 7.2185 in 2013 and 7.3954 in 2014 even though the actual loss factors were 8.5451 in 2005, 7.54981 in 2006, 8.3851 in 2007, 8.3693 in 2008, 9.4731 in 2009, 9.6452 in 2010, 8.9553 in 2011, 8.6465 in 2012, 8.7892 in 2013 and 8.7854 in 2014.

Figure 26 shows the relationship between the three models developed over the ten years study period.

Figure 27 shows the actual average loss over the ten years study period.

The actual average losses were 4.0163kW in 2005, 4.1096kW in 2006, 4.7836kW in 2007, 4.073kW in 2008, 3.1329kW in 2009, 2.6312kW in 2010, 3.1094 in 2011, 3.4987kW in 2012, 4.4851kW in 2013 and 4.1387 in 2014.

A least actual average loss of 2.6312kW was noticed in 2010 while year 2007 witnessed the highest actual average loss of 4.7836kW.

The variations of the calculated average loss are shown in Figure 28. In 2005, the calculated average loss was 3.9561Kw. In 2006, it was 4.1446kW while in 2014, it was 4.089kW. Year 2010 witnessed the least calculated average loss of 2.6473kW while year 2007 witnessed the highest calculated average loss of 4.7266kW

Figure 29 illustrates the variations of the actual average loss and calculated average loss over the study period of ten years.

Year 2010 witnessed the least actual average loss and calculated loss of 2.6312kW and 2.6473kW respectively while year 2007 experienced the highest average loss and calculated loss of 4.7836kW and 4.7268kW respectively.

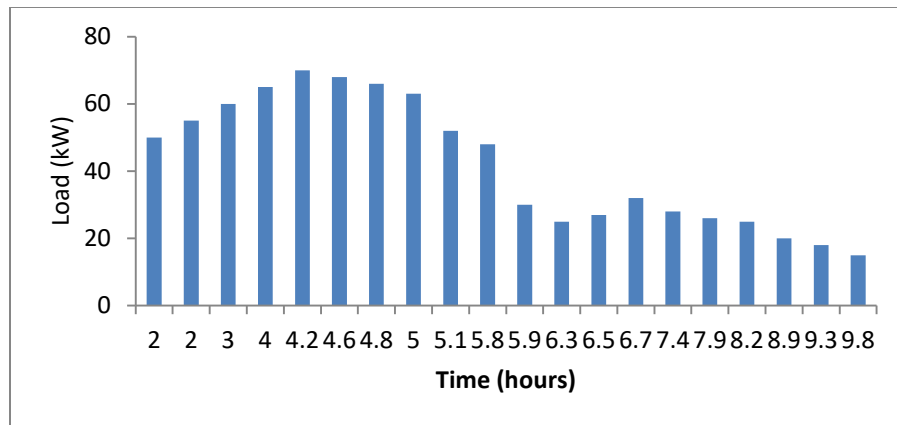


Figure 1: The Load Curve for Ibadan distribution system for year 2005

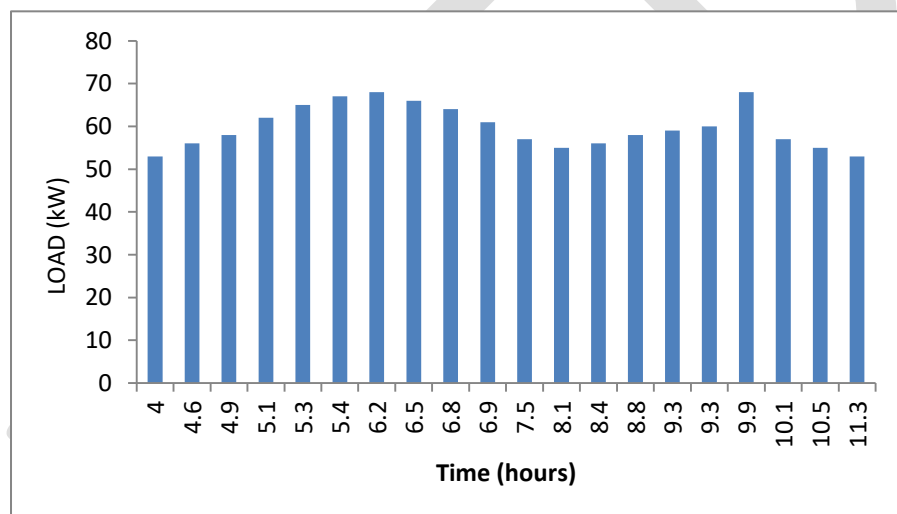


Figure 2: The Load Curve for Ibadan distribution system for year 2006

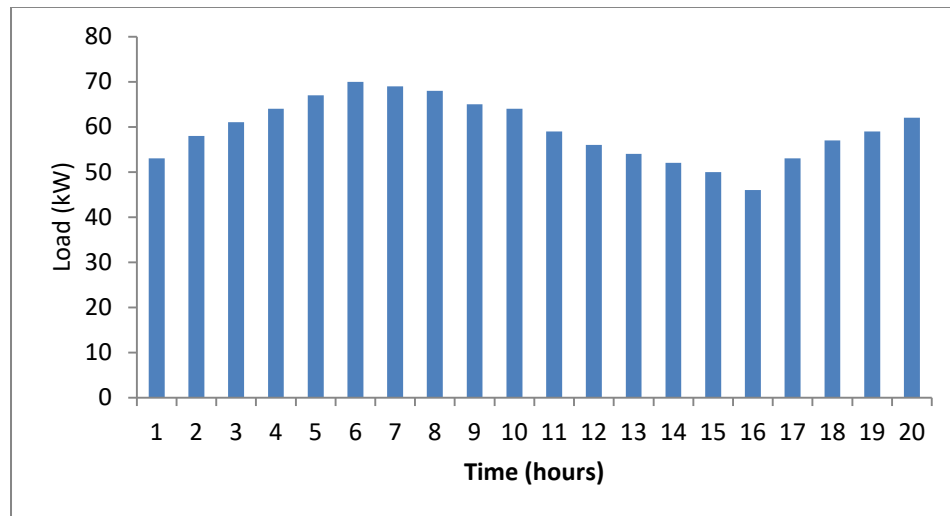


Figure 3: The Load Curve for Ibadan distribution system for year 2007

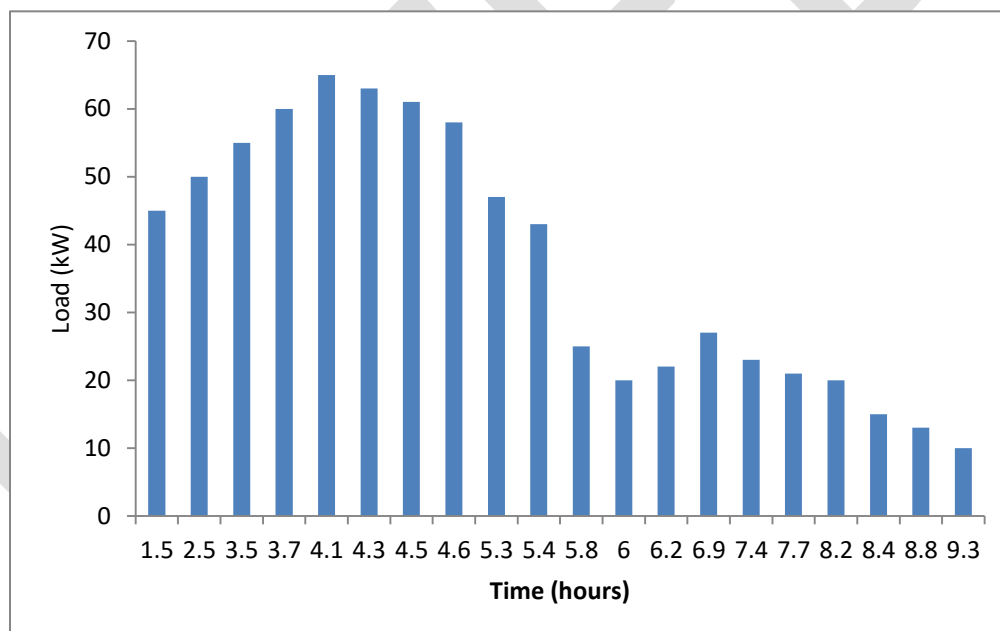


Figure 4: The Load Curve for Ibadan distribution system for year 2008

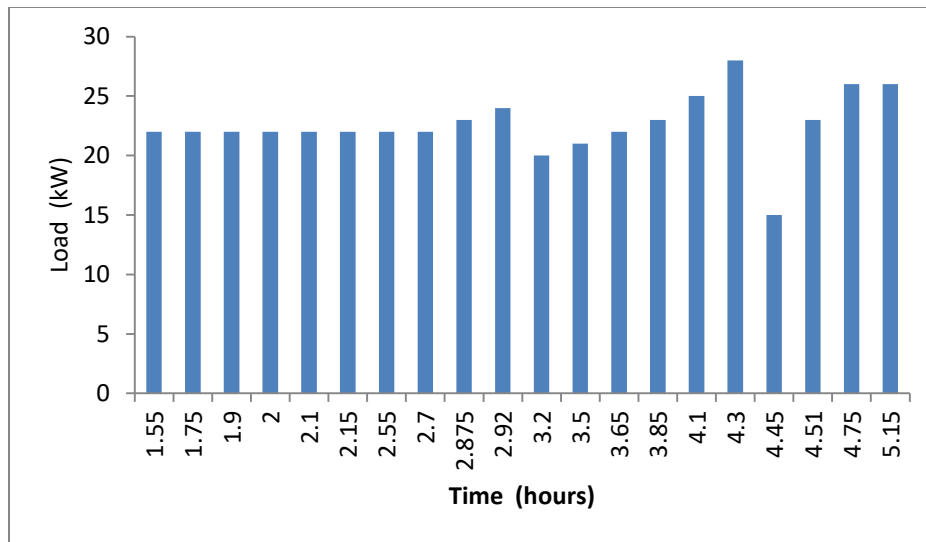


Figure 5: The Load Curve for Ibadan distribution system for year 2009

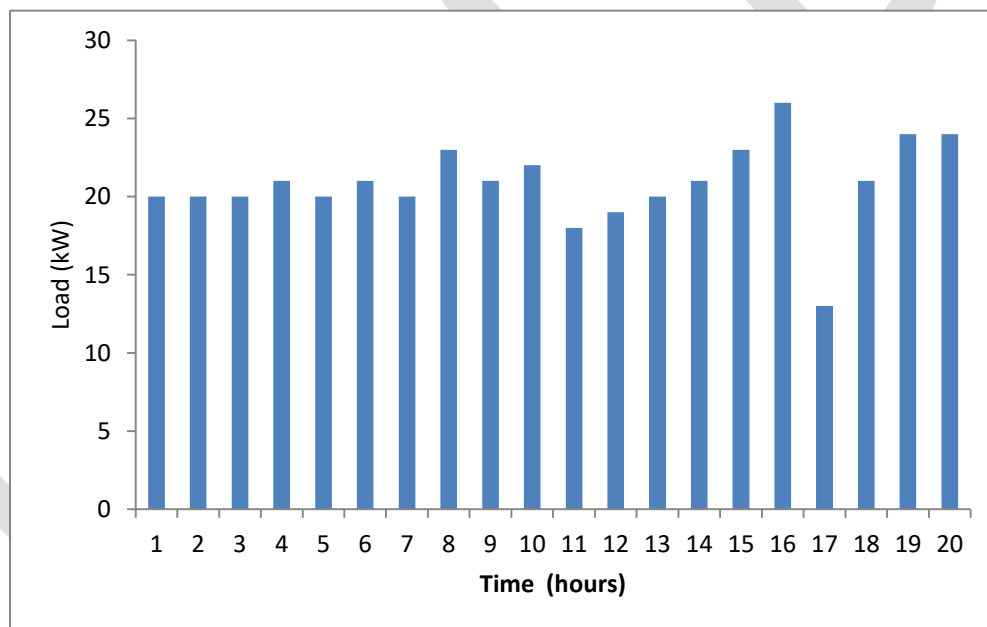


Figure 6: The Load Curve for Ibadan distribution system for year 2010

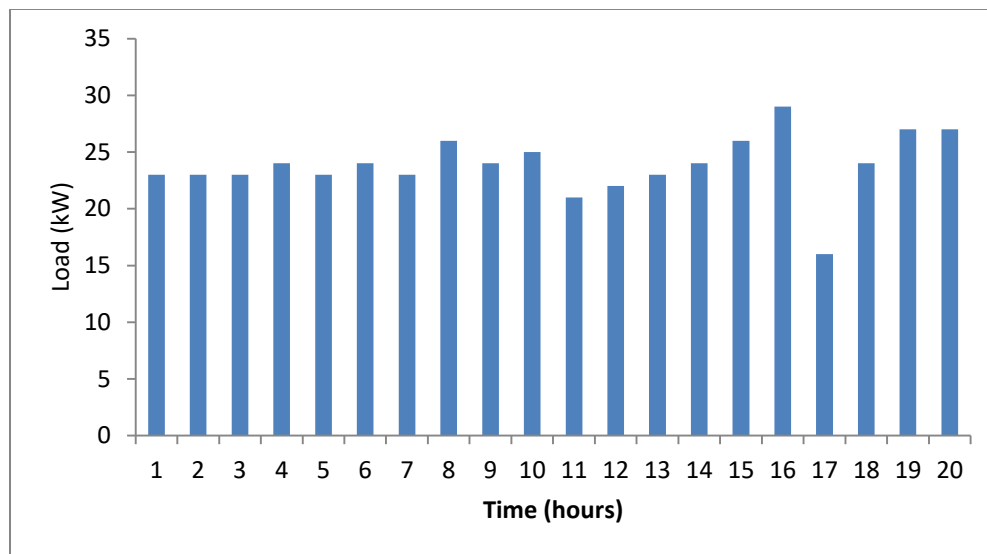


Figure 7: The Load Curve for Ibadan distribution system for year 2011

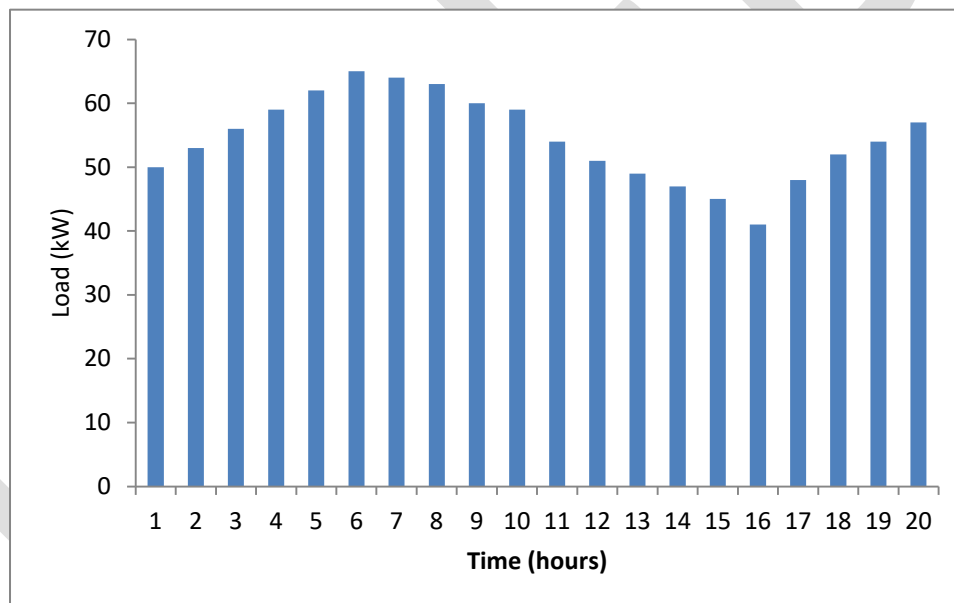


Figure 8: The Load Curve for Ibadan distribution system for year 2012

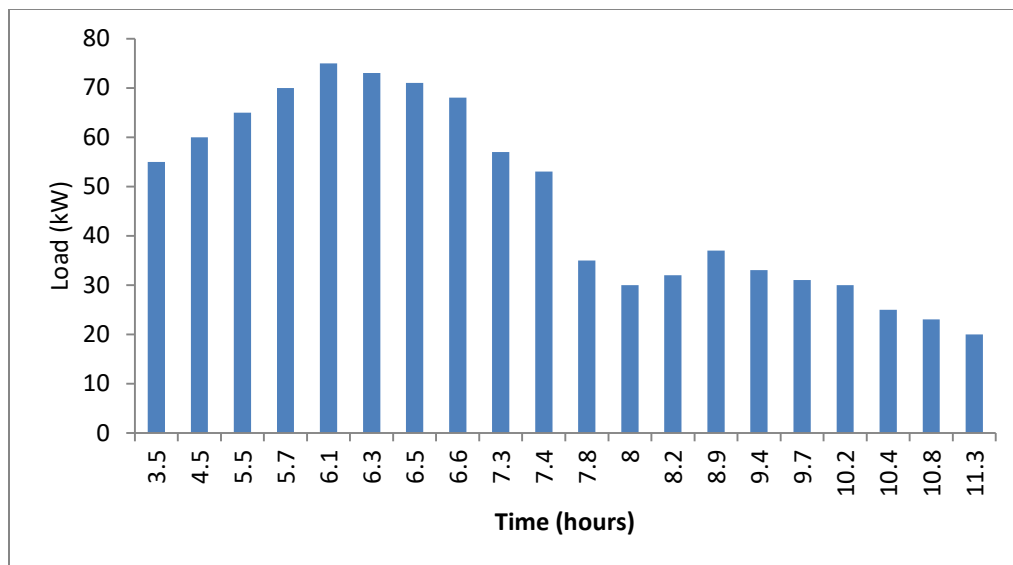


Figure 9: Load curve for Ibadan distribution system for year 2013

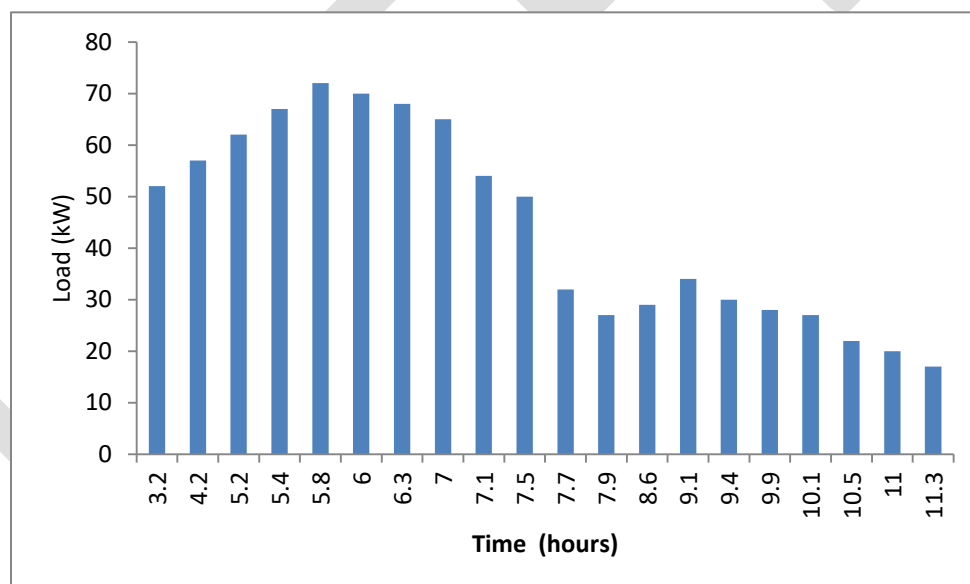


Figure 10: The Load Curve for Ibadan distribution system for year 2014

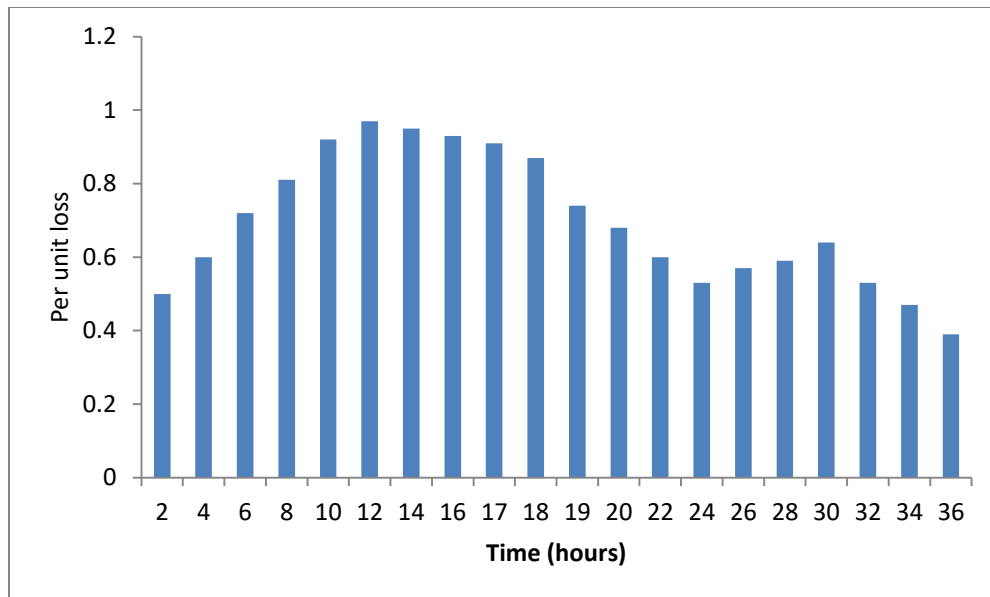


Figure 11: The Loss curve for Ibadan distribution system for year 2005

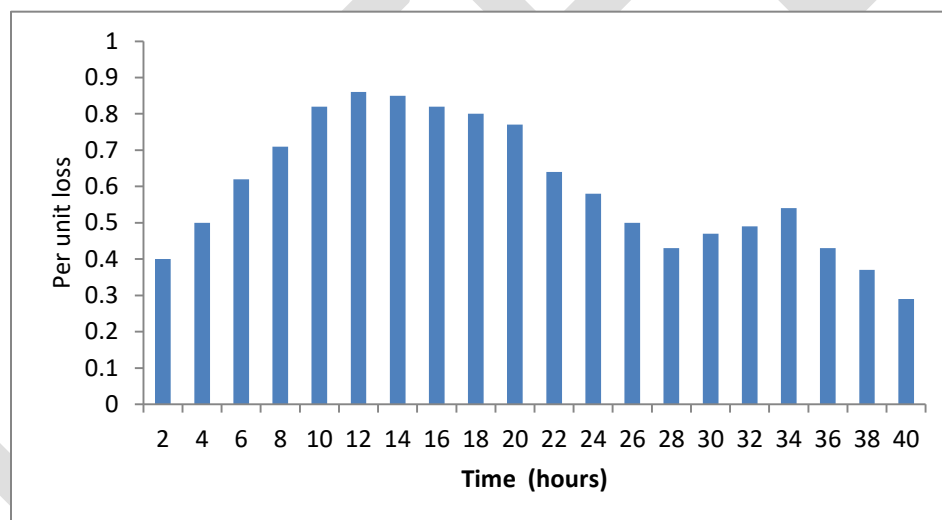


Figure 12: Loss Curve for Ibadan distribution system for year 2006

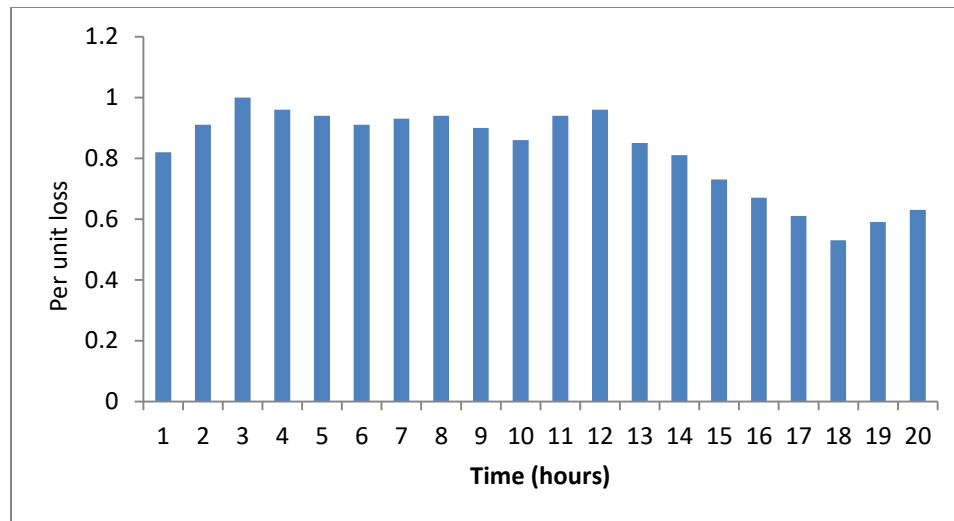


Figure 13: Loss Curve for Ibadan distribution system for year 2007

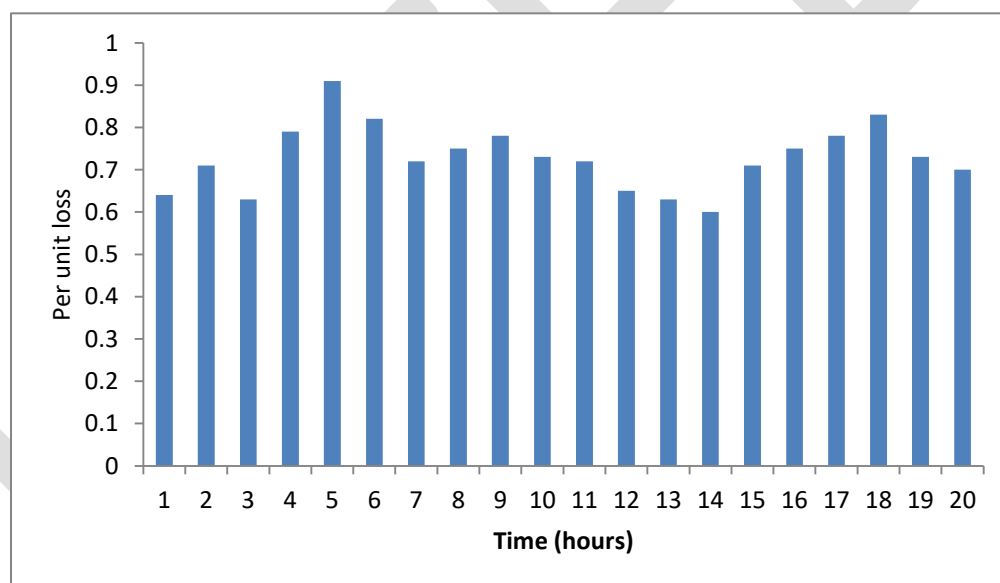


Figure 14: Loss Curve for Ibadan distribution system for year 2008

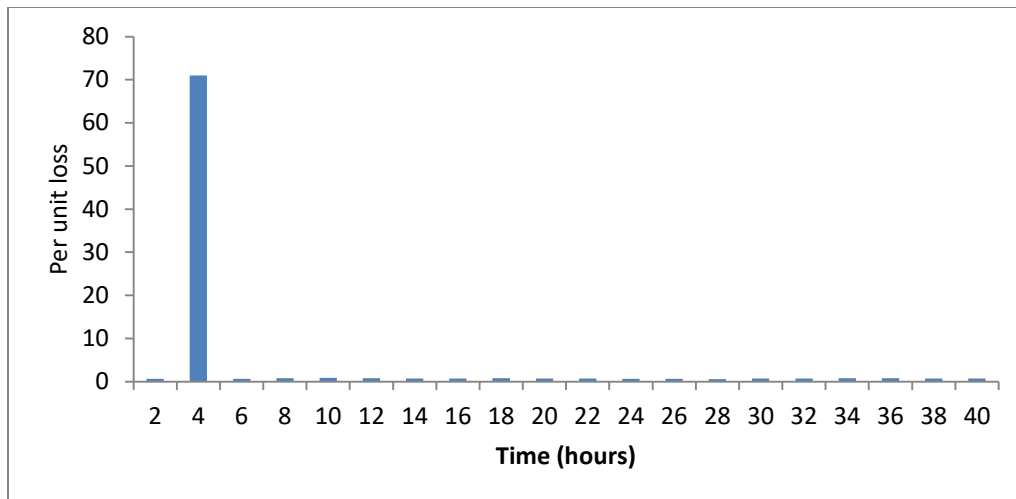


Figure 15: Loss Curve for Ibadan distribution system for year 2009

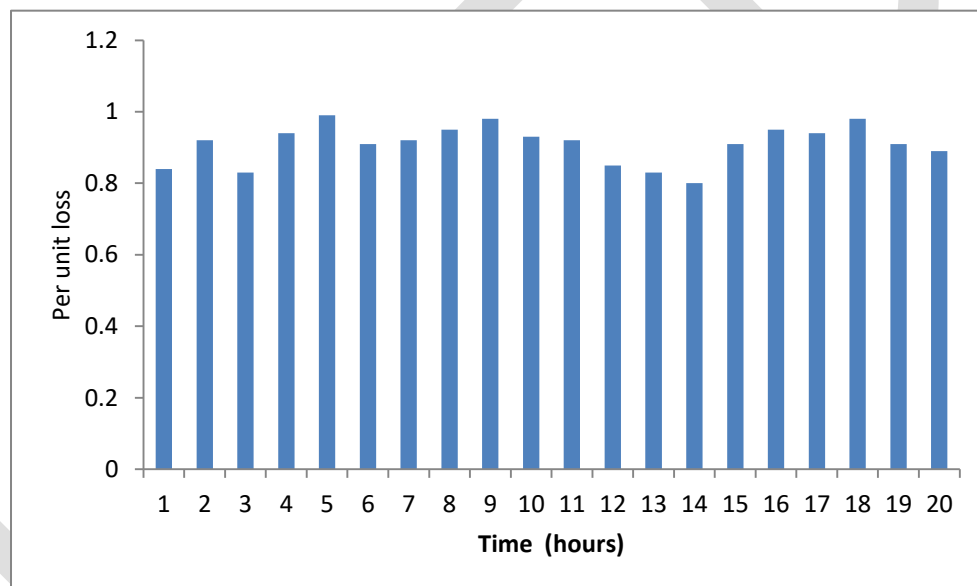


Figure 16: Loss Curve for Ibadan distribution system for year 2010

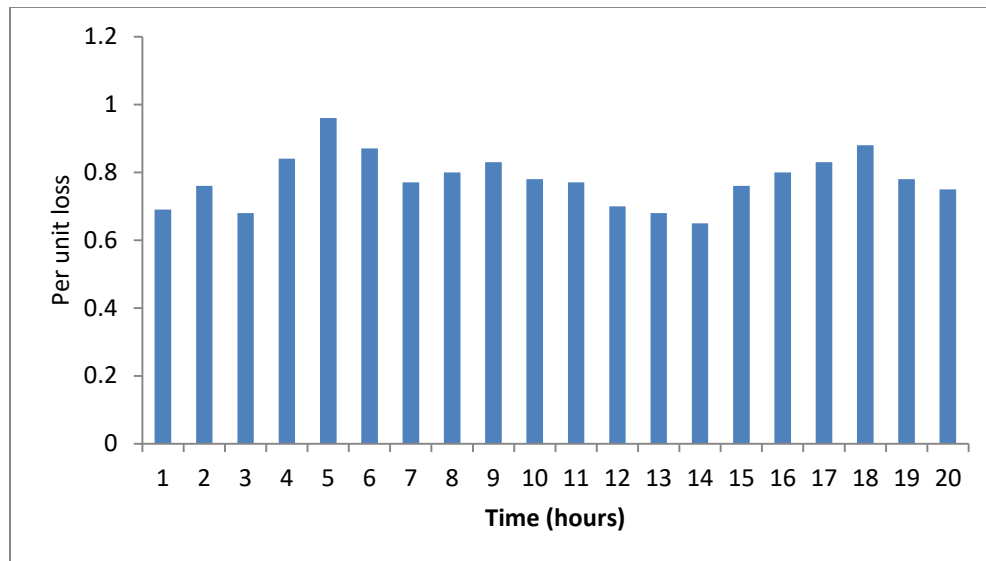


Figure17: Loss Curve for Ibadan distribution system for year 2011

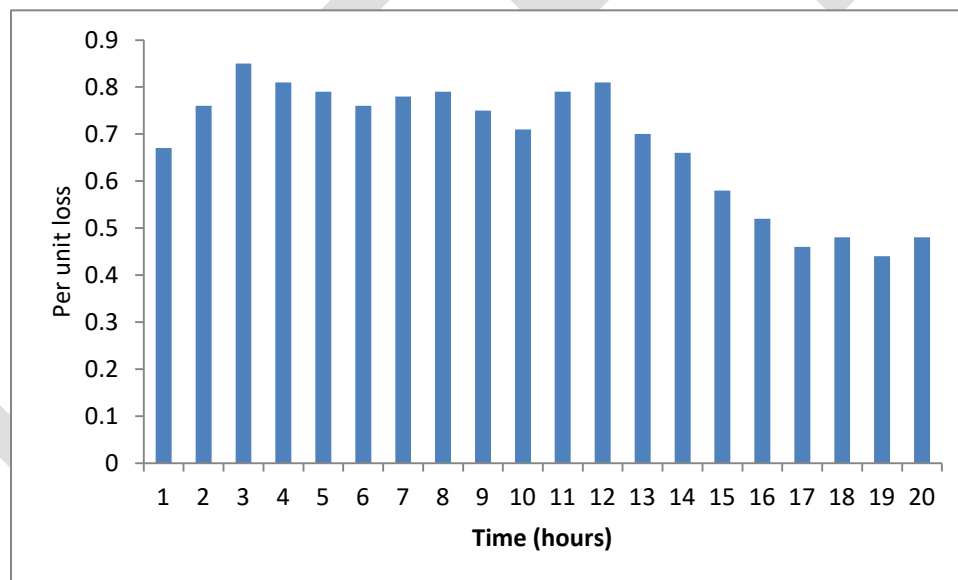


Figure 18: Loss Curve for Ibadan distribution system for year 2012

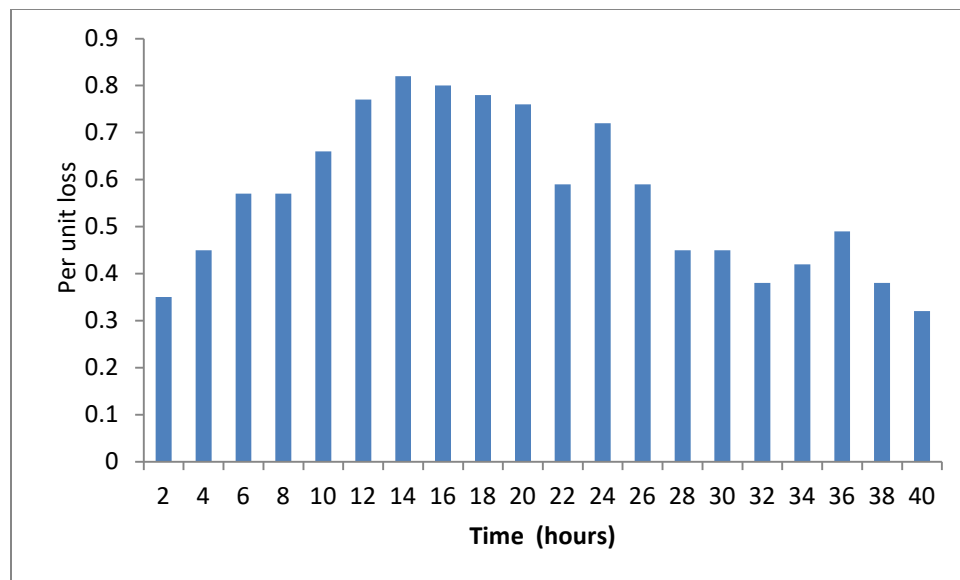


Figure 19: Loss Curve for Ibadan distribution system for year 2013

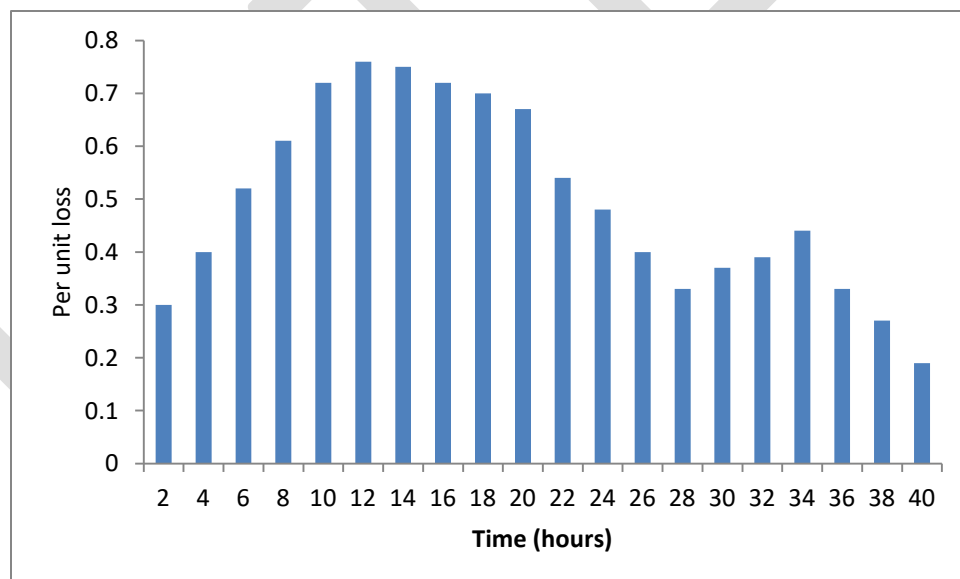


Figure 20: Loss curve for Ibadan distribution system for year 2014

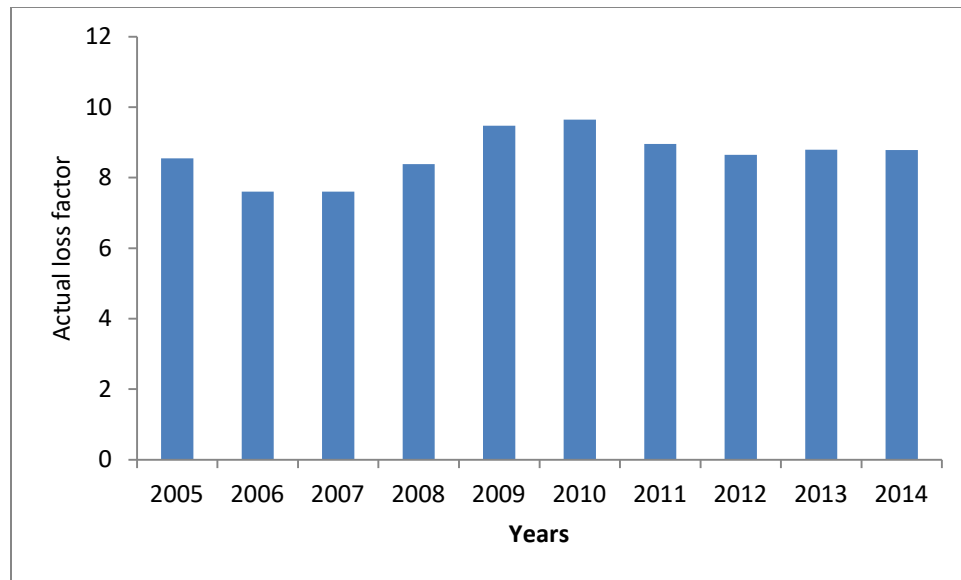


Figure 21: The curve of Actual loss against Years for Ibadan distribution system

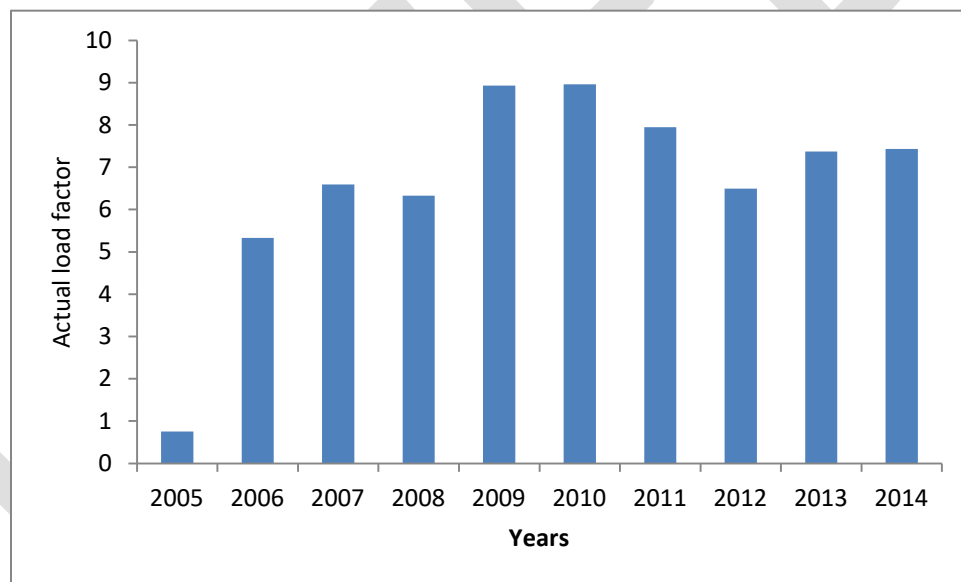


Figure 22: The curve of actual load factor against Years for Ibadan distribution system

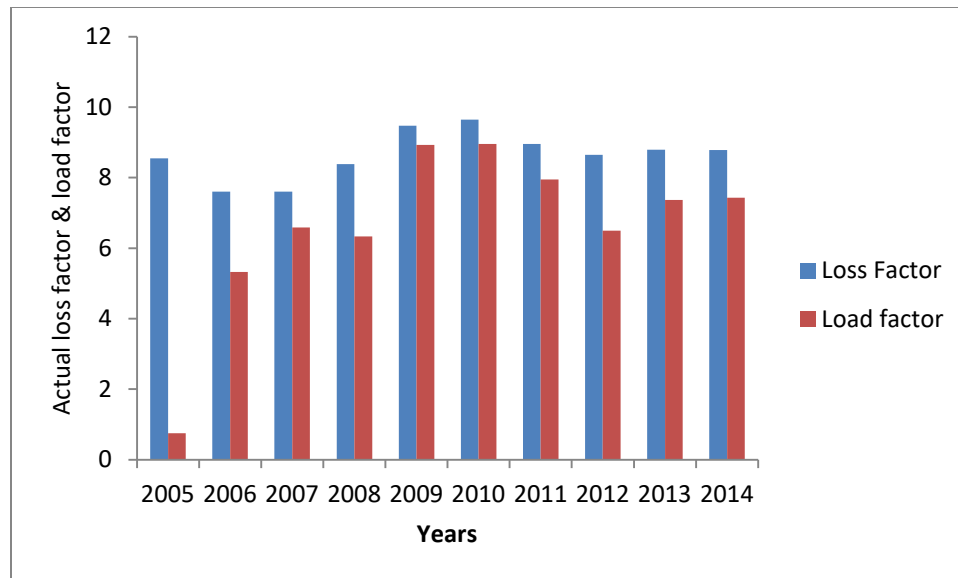


Figure 23: Actual Loss Factor and Load Factor Versus Years for Ibadan distribution system

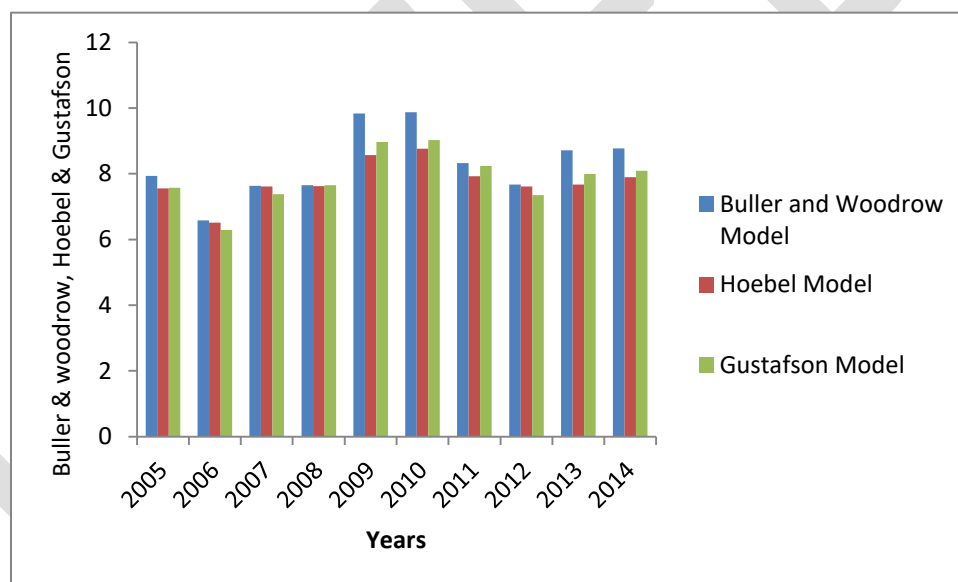


Figure 24: Buller and Woodrow, Hoebel and Gustafson Versus Years for Ibadan distribution system

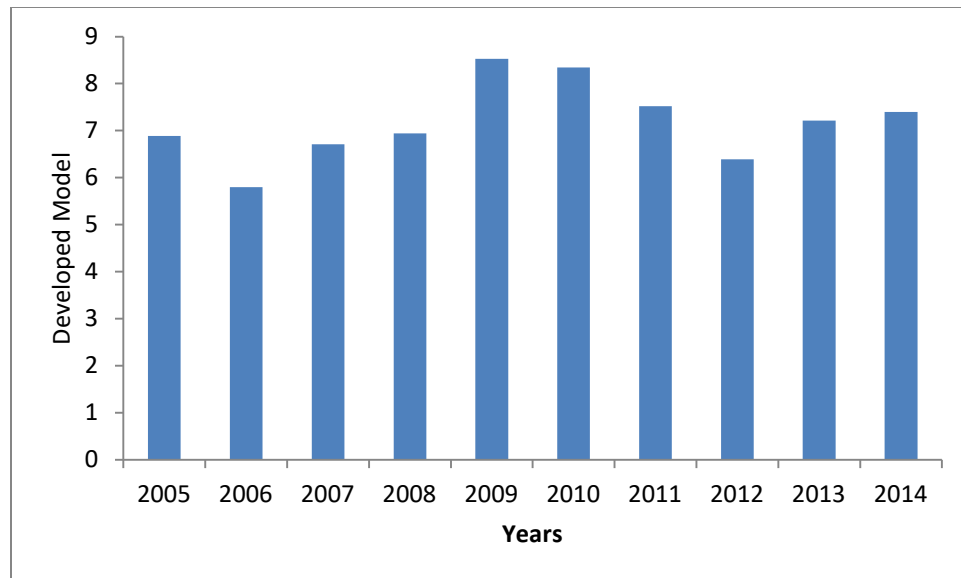


Fig 25: Developed Model versus Years for Ibadan distribution system

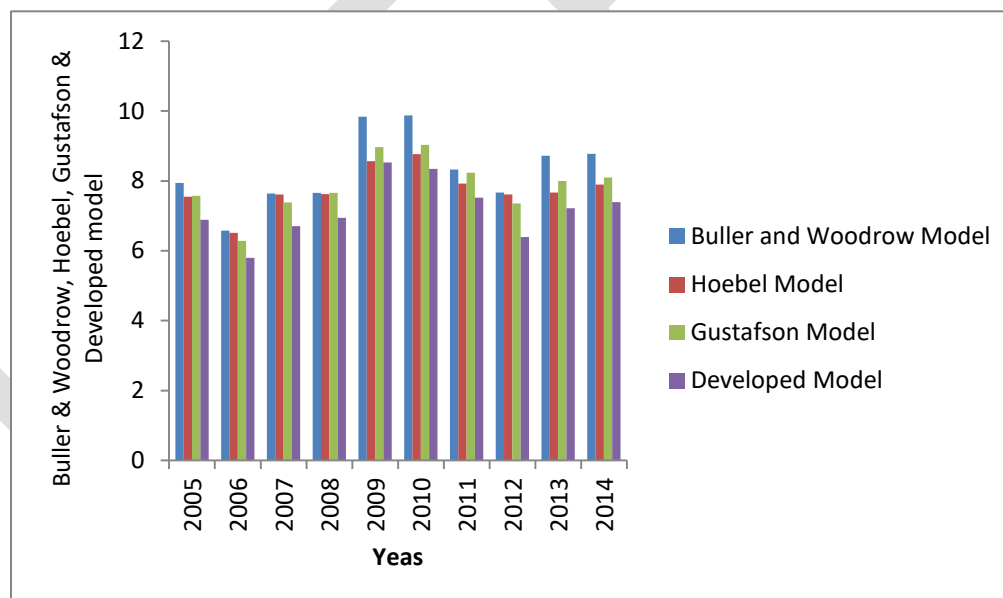


Fig 26: Buller and Woodrow, Hoebel, Gustafson and Developed Model versus Years for Ibadan distribution system

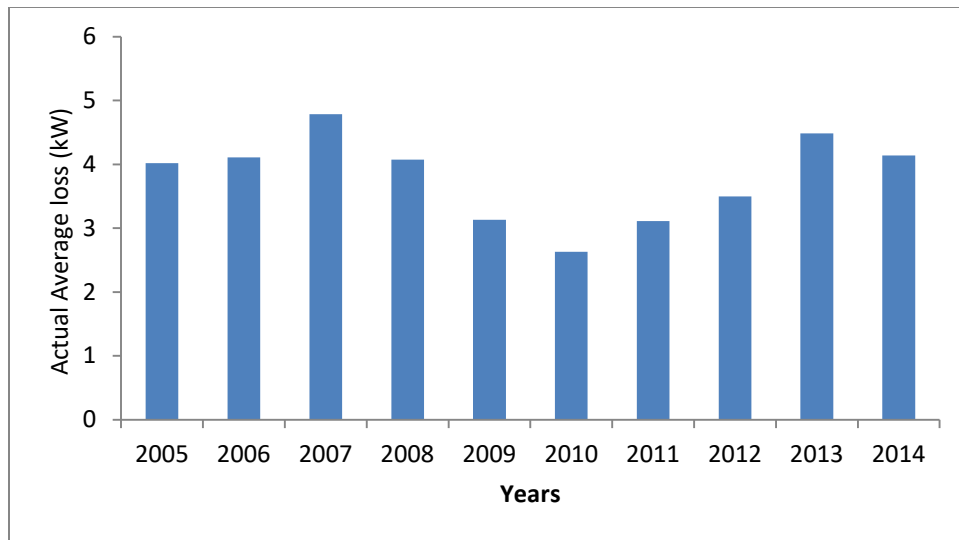


Figure 27: Actual average loss versus Years for Ibadan distribution system

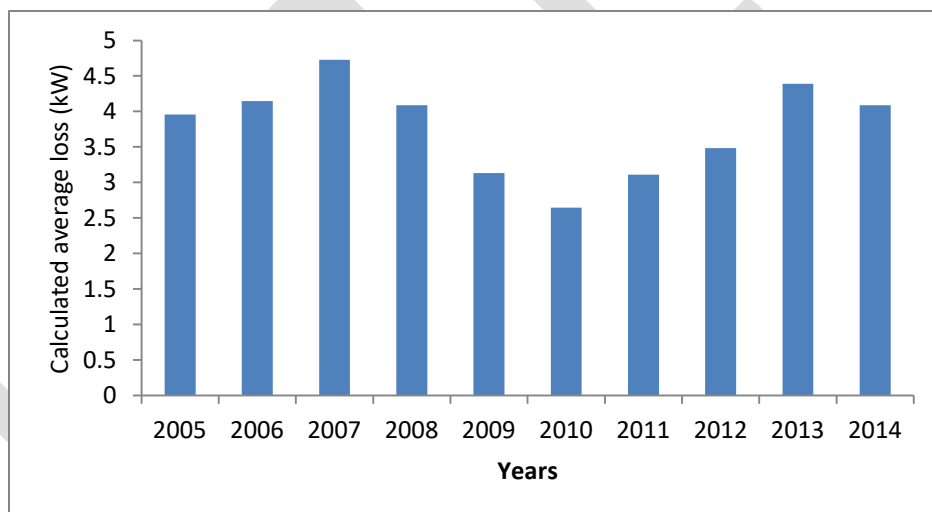


Figure 28: Calculated average loss versus Years for Ibadan distribution system

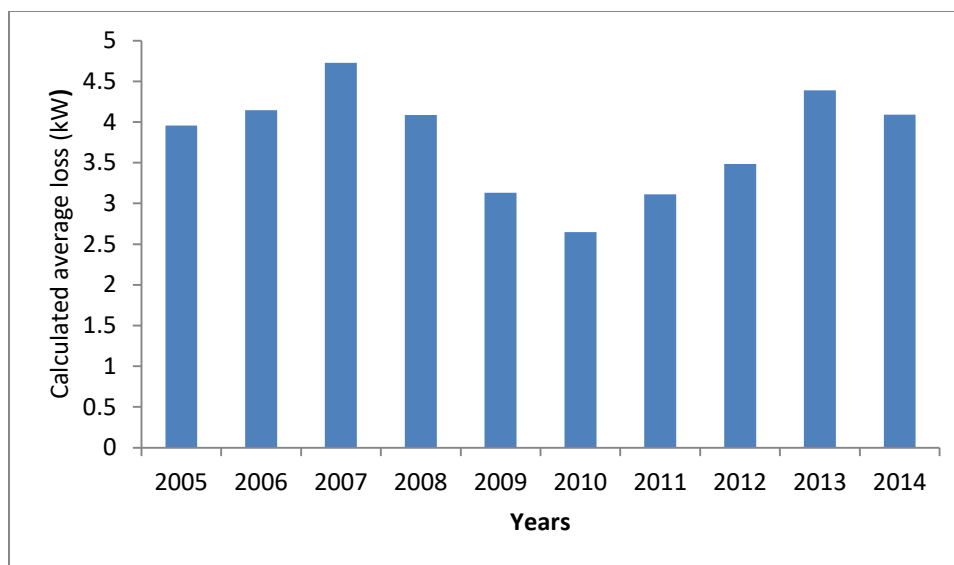


Figure 29: Actual average loss and calculated average loss versus Years for Ibadan distribution system

IV. Conclusion

A loss factor model for the analysis of transmission system losses in electrical power network has been developed.

The model development started with the computation of annual load and loss factors using the annual load and loss data information from Ibadan distribution systems over a period of ten years. An exponential loss factor model is obtained using the curve fitting analysis to establish a relationship between the loss factor and the load factor. A constant coefficient of 0.7321 was determined for the model from the average value of the annual load and loss factors. The coefficients of the developed model were calculated as 3.2165 and 3.242 which were further used to compute the loss factors from the respective annual load factors.

The result of the developed model is validated by comparing with the results obtained from Buller and Woodrow model, Hoebel model and Gustafson model and they compared favorably well.

The exponential loss factor model developed can be used to analyze sub-transmission and distribution system losses since the values of the coefficient are very significant in estimating losses, despite the fact that they cannot be generalized for any system since each system has a separate load profile; which given rise to different coefficient values.

V. References

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