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Analysis of the Application of Linear Interpolation and Quadratic Interpolation in Electrical Distribution Performance

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Abstract

The electricity distribution network is an important component that distributes electricity from substations to end consumers. Monitoring voltage across the network is critical, but direct measurement at all points is often impractical due to resource limitations. This research uses linear interpolation and quadratic interpolation to estimate stress at unmeasured points. Voltage measurement data at several points is used as a basis for interpolation. With the help of MATLAB, the voltage at unmeasured points can be estimated quickly and accurately. The results of the interpolation of distance on electricity consumption show that electricity consumption decreases as distance increases. At a distance of 5 km (Ds. Galih), electricity consumption was recorded at 1,237.5 kWh, while at a distance of 15 km (Ds. Triharjo) electricity consumption was reduced to 1,232.5 kWh. Furthermore, at a distance of 25 Km (Wungurejo District), electricity consumption was recorded at 1,227.5 kWh, and at a distance of 35 Km (Tejorejo District) electricity consumption decreased again to 1,222.5 kWh. This method enables more comprehensive monitoring of network performance, helps identify areas that require special attention, and supports decisions in network maintenance and repair. In conclusion, linear interpolation is an effective method for estimating voltages in electrical distribution networks, making an important contribution to improving the reliability and efficiency of electrical power distribution. Assists in monitoring and analyzing the performance of the electricity distribution network, thereby enabling more targeted maintenance and repair actions.

Keywords:
Linear Interpolation, Distribution Networks, Matlab

1. Introduction

The electric power distribution system is a system used to distribute electrical energy from input to output [1]. The electricity distribution network is an important part of the electric power system [19], and its task is to transmit electricity from the substation to the end user. Disturbances in electricity distribution in the distribution network can result in losses and the inability to distribute electrical energy as expected [2]. To improve the quality of customer service, the performance of the distribution network system is a primary concern as an important measure to maintain continuity of distribution in serving customer needs [3]. The reliability and efficiency of a distribution network are highly dependent on the ability to monitor and manage voltage throughout the network. Uncontrolled voltage fluctuations can cause equipment damage, reduce power quality, and cause consumer dissatisfaction [12].

Measuring voltage at various points in the distribution network is crucial for monitoring network performance. However, in practice, measuring voltage at every point is often not possible due to limited resources and costs [14]. Therefore, an effective method is needed to estimate stress at points that cannot be measured directly. One simple and efficient

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method that can be used is linear interpolation and quadratic interpolation.

This research aims to compare linear interpolation and quadratic interpolation techniques to estimate voltage at unmeasured points in the electricity distribution network. By utilizing voltage measurement data at several known points, this interpolation makes it possible to estimate the voltage between those points. It is hoped that the results of this interpolation can provide more comprehensive learning regarding voltage distribution throughout the network, as well as support decision-making for network maintenance and repair.

This research uses voltage measurement data from several predetermined points in the electricity distribution network. This data is then used as a basis for interpolation to estimate the stress at points between measurements. The linear interpolation method applied is a method that connects the two closest data points with a straight line, and then estimates the stress value along that line. It is also similar to LSTM (Long Short-Term Memory) algorithm and can achieve better accuracy and less error rate[18].

Interpolation on unmeasurable data enables smooth transitions between samples while still allowing accurate reconstruction and the generation of new data points in the input space.[16] This is the same as regression, which is a statistical analysis method used to predict the relationship between independent variables (influencing factors) and dependent variables (measured results).[17] Some of the main reasons for choosing this method are:

1. Linear interpolation is a simple method that only requires two data points to produce estimates. Quadratic interpolation, although more complex, offers higher accuracy by considering three data points. Both methods can be easily implemented using software such as MATLAB, resulting in fast and efficient calculations.
2. The proposed method allows stress estimation without the need for additional data, which is very useful in conditions where direct measurement is not possible. Linear interpolation is suitable for data that tends to be linear, while quadratic interpolation provides more accurate results on data with curved patterns.
3. The use of a combination of linear and quadratic interpolation for voltage analysis in electricity distribution networks provides a comparative approach to solving voltage estimation problems. According to the experimental result, the proposed method can decrease electricity consumption based on distance from the substation as a basis for monitoring distribution network performance.

2. Related Works

1) BASIC THEORY OF LINEAR INTERPOLATION

There are four types of interpolation [15]. These include linear interpolation, quadratic interpolation, Lagrange interpolation, and Newton interpolation [4]. Linear interpolation is a mathematical method used to calculate the value between two known data points by drawing a straight line connecting the two points [5]. Linear interpolation is used so that each input value can be known for the difference in value [6]. If two points are known, then the point between the two points uses a straight-line approach $(x_0, f(x_0)), and\ (x_1, f(x_1))$ can be calculated based on the straight line equation [7]:

$$f(x) = f(x_0) + \frac{f(x_1) - f(x_0)}{x_1 - x_0} \cdot (x - x_0) \quad (1)$$

Where x is a point between x_0 and x_1 whose value is to be estimated [13]. This method is commonly used in various scientific and technical applications for data interpolation. It is considered simple because it connects two data points with a straight line [8]. Essentially, linear interpolation is a very basic form of interpolation, where two data points are connected by a straight line [9].

2) THEORY OF QUADRATIC INTERPOLATION
Quadratic interpolation is a method that uses a second-degree (quadratic) polynomial to estimate values between two or more known data points. A second-degree polynomial has the general form as follows:

$$p(x) = ax^2 + bx + c \tag{2}$$

$$\begin{cases} p(x) = ax_0^2 + b_0 + c \\ p(x) = ax_1^2 + b_1 + c \\ p(x) = ax_2^2 + b_2 + c \end{cases} \tag{3}$$

Here, a, b, and c are coefficients that must be determined based on the given data points. Quadratic interpolation is more complex than linear interpolation but can provide more accurate values, especially when the data exhibits a pattern that closely matches the desired shape.

3. Proposed Method

This research uses linear and quadratic interpolation approaches to estimate voltage at unmetered points in the electricity distribution network. The proposed method involves the following stages:

1. Problem Identification: At this stage, the main problems in measuring voltage in the electricity distribution network are identified. Direct measurements at all points are not possible due to cost and resource limitations. Therefore, estimation methods are needed to complement unmeasured data.
2. Literature Study: A literature study was carried out to understand the relevant interpolation methods, namely linear and quadratic interpolation. These two methods were chosen based on their ability to provide simple (linear) or more accurate (quadratic) estimation results.
3. Data Collection: Voltage data at several measurement points in the distribution network is collected. This data is used as a basis for interpolation. The measurement points cover a certain distance from the substation, for example:
    - 0 km (Ds. Kedunggading)
    - 10 km (Ds. Kedungasri)
    - 20 km (Ds. Ringinarum)
    - 30 km (Ds. Ngerjo)
    - 40 km (Ds. Wungurejo)
4. Application of the Interpolation Method
5. a. Linear Interpolation
    - This method connects the two closest data points with a straight line. The stress at the point between these two points is calculated based on the straight-line equation:

$$f(x) = f(x_0) + \frac{f(x_1) - f(x_0)}{x_1 - x_0} \cdot (x - x_0)$$

Where y1 and y2 are the voltage values at the data points, while x1 and x2 are the positions of the data points.

b. Quadratic Interpolation
   - This method uses a second-degree polynomial which is formulated as:

$$p(x) = ax^2 + bx + c$$

Coefficients a, b, and c are calculated based on a system of equations formed from the three closest data points. This method provides more accurate results for data patterns that show non-linear changes.

6. Implementation in MATLAB
   - MATLAB was used to implement both interpolation methods.
   - The interp1 function is used for linear interpolation, while the quadratic equation is calculated using MATLAB algebraic functions for systems of equations.
   - Results are calculated efficiently and visualized for further analysis.
7. Analysis of Results
   - Stresses at unmeasured points are calculated using both methods.
   - Interpolation results are compared to evaluate the effectiveness of both approaches.

Reasons for Selecting Methods

- Linear Interpolation is chosen for its simplicity, computational speed, and efficiency, especially for nearly linear data.
- Quadratic Interpolation was chosen because of its ability to capture data patterns that show non-linear changes, thereby providing higher accuracy under certain conditions.

With this approach, this research offers a practical, efficient, and flexible solution for estimating voltages in electricity distribution networks, better-supporting maintenance and network optimization decisions.

4. Experimental Setup

1) Data Collection
The collected data includes voltage measurements in several villages along the power distribution network. Voltage measurements were taken in the following locations: Ds. Kedunggading at a distance of 0 km, Ds.Kedungasri at a distance of 10 km, Ds.Ringinarum at a distance of 20 km, Ds.Ngerjo at a distance of 30 km, and Ds.Wungurejo at a distance of 40 km from the substation.

Table 1. Measurement Data

Distance from Substation (Km)	Electricity Distribution (kWh)
0 Km (Ds. Kedunggading)	1.240
10 Km (Ds. Kedungasri)	1.235
20 Km (Ds. Ringinarum)	1.230
30 Km (Ds. Ngerjo)	1.225
40 Km (Ds. Wungurejo)	1.220

Table 1 presents measurement data on electricity distribution in kilowatt-hours (kWh) for several villages located at varying distances from the substation. This data illustrates how electricity consumption varies with increasing distance from the substation.

2) Solution Using Linear Interpolation

Linear interpolation is used to estimate the voltage values between the existing measurement points. We want to determine the voltage at Ds. Galih, which is located 5 km away, Ds.Triharjo at 15 km, Ds.Wungurejo at 25 km, and Ds.Tejorejo at 35 km from the substation.

Calculation

- *Using the linear interpolation formula*

$$f(x) = f(x_0) + \frac{f(x_1) - f(x_0)}{x_1 - x_0} \cdot (x - x_0)$$

a. Distance 5 km (Ds. Galih)

Nearest point : $x_0 = 0\ km, f(x_0) = 1.240\ kWh$, $x_1 = 10\ km, f(x_1) = 1.235\ kWh$

$f(x) = 1.240 + \frac{1.235 - 1.240}{10 - 0}(5 - 0)$

$= 1.240 + \frac{-5}{10}(5)$

$= 1.240 + (-2,5)$

$= 1.237,5\ kWh$

b. Distance 15 km (Ds. Triharjo)

Nearest point : $x_0 = 10\ km, f(x_0) = 1.235\ kWh$, $x_1 = 20\ km, f(x_1) = 1230\ kWh$

$f(x) = 1.235 + \frac{1.230 - 1.235}{20 - 10}(15 - 10)$

$= 1.235 + \frac{-5}{10}(5)$

$= 1.235 + (-2,5)$

$= 1.232,5\ kWh$

c. Distance 25 km (Ds. Wungurejo)

Nearest point : $x_0 = 20\ km, f(x_0) = 1.230\ kWh, x_1 = 30\ km, f(x_1) = 1.225\ kWh$

$f(x) = 1.230 + \frac{1.225 - 1.230}{30 - 20}(25 - 20)$

$= 1.230 + \frac{-5}{10}(5)$

$= 1.230 + (-2,5)$

$= 1227,5\ kWh$

d. Distance 35 km (Ds. Tejorejo)

Nearest point : $x_0 = 30\ km, f(x_0) = 1.225\ kWh, x_1 = 40\ km, f(x_1) = 1.220\ kWh$

$f(x) = 1.225 + \frac{1.220 - 1.225}{40 - 30}(35 - 30)$

$= 1.225 + \frac{-5}{10}(5)$

$= 1.225 + (-2,5)$

$= 1.222{,}5\ kWh$

So, the voltage at each distance you want to calculate is

$5\ km = 1.237{,}5\ kWh$

$15\ km = 1.232{,}5\ kWh$

$25\ km = 1227{,}5\ kWh$

$35\ km = 1222{,}5\ kWh$

1) Using Quadratic Interpolation

a. Distance 5 Km (Ds. Galih)

- Data Points:
  (0 Km, 1240 kWh) → Kedunggading
  (10 Km, 1235 kWh) → Kedungasri
  (20 Km, 1230 kWh) → Ringinarum
- Form a System of Equations

$$\begin{cases} 1240 = a(0)^2 + b(0) + c \\ 1235 = a(10)^2 + b(10) + c \\ 1230 = a(20)^2 + b(20) + c \end{cases}$$

$$= \begin{cases} 1240 = c \\ 1235 = 100a + 10b + c \\ 1230 = 400a + 20b + c \end{cases}$$

- Solve Systems of Equations

$1235 = 100a + 10b + 1240 \Rightarrow 100a + 10b = -5$

$1230 = 400a + 20b + 1240 \Rightarrow 400a + 20b = -10$We solve this linear system to get the values for a and b:

$400a + 20b = -10$

$100a + 10b = -5$

By solving, we get:

$400a + 20b = -10$

$100a + 10b = -5 \Rightarrow a = 0\,, \qquad b = -0{,}5$

- Quadratic Polynomials:
  Substitute a, b, and c into the polynomial:

$f(x) = 0x^2 - 0{,}5x + 1240$

$f(5) = -0{,}5(5) + 1240 = 1237{,}5\ kWh \rightarrow Distribusi\ listrik\ Desa\ Galih$

b. Distance 15 Km (Ds. Triharjo)

- Data Points:
  (10 Km, 1235 kWh) → Kedungasri
  (20 Km, 1230 kWh) → Ringinarum
  (30 Km, 1225 kWh) → Ngerjo
- Form a System of Equations

$$\begin{cases} 1235 = a(10)^2 + b(10) + c \\ 1230 = a(20)^2 + b(20) + c \\ 1225 = a(30)^2 + b(30) + c \end{cases}$$

$$= \begin{cases} 1235 = 100a + 10b + c \\ 1230 = 400a + 20b + c \\ 1225 = 900a + 30b + c \end{cases}$$

- Subtract the second equation from the first

$(400a + 20b + c) - (100a + 10b + c) = 1230 - 1235$
$300a + 10b = -5$
$30a + b = -0{,}5 \ldots\ldots\ldots (1)$
Subtract the third equation from the second:
$(900a + 30b + c) - (400a + 20b + c) = 1225 - 1230$
$500a + 10b = -5$
$50a + b = -0{,}5 \ldots\ldots\ldots (2)$
Subtract equation (2) from (1):
$(50a + b) - (30a + b) = -0{,}5 - (-0{,}5)$
$20a = 0$
$a = 0$
Substitute an into equation (1):
$30(0) + b = -0{,}5$
$b = -0{,}5$

Substitute a and b into the first equation:
$1235 = 100(0) + 10(-0{,}5) + c$
$1235 = -5 + c$
$c = 1240$
Quadratic polynomial:
$f(x) = 0x^2 - 0{,}5x + 1240$
$f(15) = -0{,}5(15) + 1240 = 1232{,}5\ kWh$
$\rightarrow Triharjo\ Village\ electricity\ distribution$

c. Distance 25 Km (Ds. Wungurejo)

- Data Points:
  (20 Km, 1230 kWh) → Ringinarum
  (30 Km, 1225 kWh) → Ngerjo
  (40 Km, 1220 kWh) → Wungurejo
- Form a System of Equations
  $$\begin{cases} 1230 = a(20)^2 + b(20) + c \\ 1225 = a(30)^2 + b(30) + c \\ 1220 = a(40)^2 + b(40) + c \end{cases}$$
  $$= \begin{cases} 1230 = 400a + 20b + c \\ 1225 = 900a + 30b + c \\ 1220 = 1600a + 40b + c \end{cases}$$
- Subtract the second equation from the first
  $(900a + 30b + c) - (400a + 20b + c) = 1225 - 1230$
  $500a + 10b = -5$
  $50a + b = -0{,}5 \ldots\ldots\ldots (1)$
  Subtract the third equation from the second:
  $(1600a + 40b + c) - (900a + 30b + c) = 1220 - 1225$
  $700a + 10b = -5$
  $70a + b = -0{,}5 \ldots\ldots\ldots (2)$
  Subtract equation (2) from (1):
  $(50a + b) - (30a + b) = -0{,}5 - (-0{,}5)$
  $20a = 0$
  $a = 0$

Substitute an into equation (1):
$50(0) + b = -0,5$
$b = -0,5$
Substitute a and b into the first equation:
$1230 = 400(0) + 20(-0,5) + c$
$1230 = -10 + c$
$c = 1240$
Quadratic polynomial:
$f(x) = 0x^2 - 0,5x + 1240$
$f(25) = -0,5(25) + 1240 = 1227,5kWh$
$\rightarrow Wungurejo\ Village\ electricity\ distribution$

d. Distance 35 Km (Ds. Tejorejo)

- Data Points:
  (30 Km, 1225 kWh) → Ngerjo
  (40 Km, 1220 kWh) → Wungurejo
  (20 Km, 1230 kWh) → Ringinarum
- Form a System of Equations
  $$\begin{cases} 1225 = a(30)^2 + b(30) + c \\ 1220 = a(40)^2 + b(40) + c \\ 1230 = a(20)^2 + b(20) + c \end{cases}$$
  $$= \begin{cases} 1225 = 900a + 30b + c \\ 1220 = 1600a + 40b + c \\ 1230 = 400a + 20b + c \end{cases}$$
- Subtract the second equation from the first
  $(1600a + 40b + c) - (900a + 30b + c) = 1220 - 1225$
  $700a + 10b = -5$
  $70a + b = -0,5 \dots\dots\dots (1)$
  Subtract the third equation from the second:
  $(400a + 20b + c) - (900a + 30b + c) = 1230 - 1225$
  $-500a - 10b = 5$
  $-50a - b = 0,5 \dots\dots\dots (2)$
  Subtract equation (2) from (1):
  $70a + b - 50a - b = -0,5 + 0,5$
  $20a = 0$
  $a = 0$
  Substitute an into equation (1):
  $70(0) + b = -0,5$
  $b = -0,5$
  Substitute a and b into the first equation:
  $1225 = 900(0) + 30(-0.5) + c$
  $1225 = -15 + c$
  $c = 1240$
  Quadratic polynomial:
  $f(x) = 0x^2 - 0,5x + 1240$

$$f(35) = -0{,}5(35) + 1240 = 1222{,}5kWh$$
$$\rightarrow Tejorejo\ Village\ electricity\ distribution$$

2) Implementation in Matlab

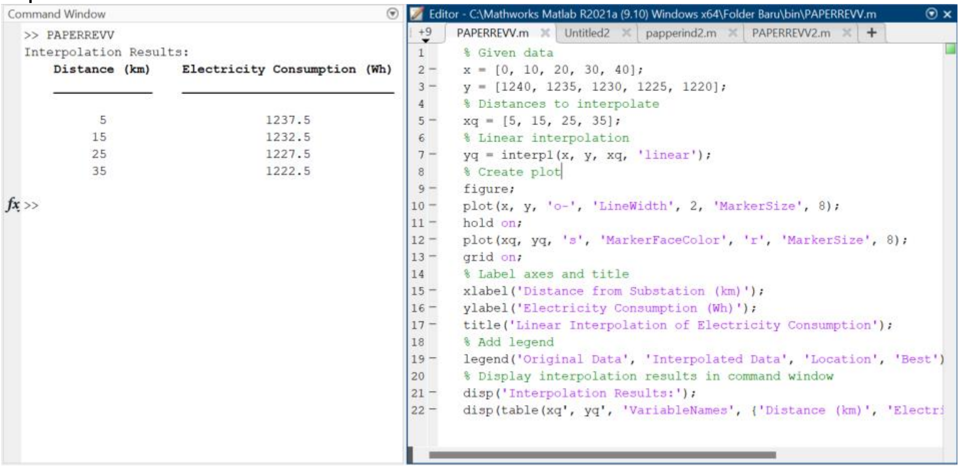

Figure 1. Matlab implementation of the Linear Interpolation Method

Figure 1 shows the implementation of a linear interpolation method using Matlab to estimate electricity consumption at a certain distance from a substation that is not in the original data. The “interp1” function is used to perform linear interpolation. x and y are the original data, x is the interpolated point, and 'linear' is the interpolation method used.

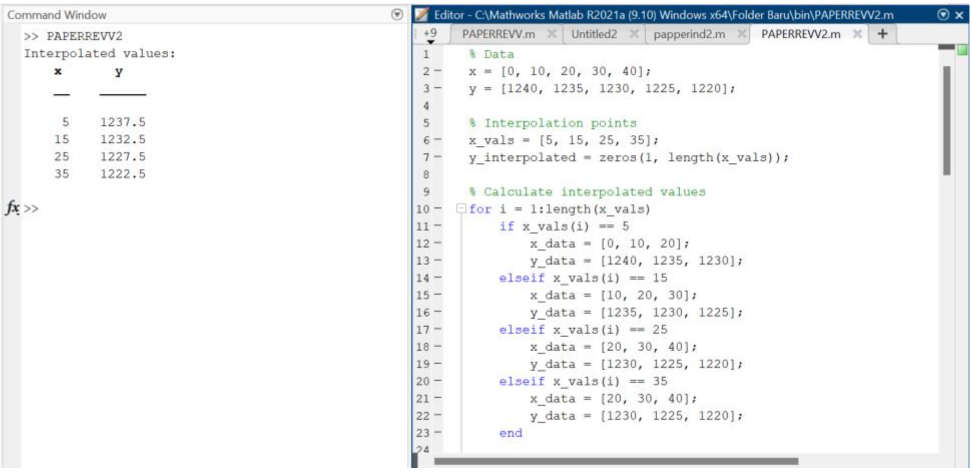

Figure 2. Matlab implementation of the Quadratic Interpolation Method

Figure 2 shows the implementation of the quadratic interpolation method using Matlab, which is displayed in two parts: the output results in the Command Window and the Matlab program code used.

In this research, Matlab plays an important role in helping carry out linear interpolation calculations and analysis of the results. MATLAB software is a high-level programming language used by students to apply various numerical methods and optimization techniques. Through group-based projects, they gain hands-on experience with modern scientific computing, which helps them solve numerical problems effectively[10]. Matlab is also easy to use because in its solutions it uses familiar mathematical notation expressions [11]. Matlab provides a very efficient "interp1" function for linear interpolation. With this function, the voltage at unmeasured points can be estimated quickly and accurately. The implementation of linear interpolation in Matlab allows fast and efficient calculations based on available measurement data. The use of Matlab in linear interpolation calculations and analysis increases research efficiency and accuracy. Matlab allows researchers to run through large amounts of data quickly and produce consistent and reliable results.

By utilizing Matlab, this research succeeded in estimating voltage at unmeasured points in the electricity distribution network efficiently and accurately. Matlab not only helps in linear interpolation calculations but also provides tools for comprehensive visualization, data analysis, modeling, and simulation. Therefore, Matlab is a valuable tool in assisting this research and providing deeper learning regarding the performance of electricity distribution networks.

5. Result and Analysis

1) Result

Voltage measurement data at several points in the electricity distribution network has been taken and used as a basis for carrying out linear interpolation and quadratic interpolation. The following are the interpolation results:

Table 2. Interpolation Results

Distance (Km)	Electricity Consumption (kWh)
5 Km (Ds. Galih)	1.237,5
15 Km (Ds. Triharjo)	1.232,5
25 Km (Ds. Wungurejo)	1.227,5
35 Km (Ds. Tejorejo)	1.222,5

The table shown illustrates the results of linear and quadratic interpolation of electricity consumption at several points in the electricity distribution network. The data provided consists of the distance (in kilometers) from the measurement points and the electricity consumption (in kWh) at these points. Linear interpolation estimates values based on the two closest points, while quadratic interpolation uses second-degree polynomials for greater accuracy. As a result, electricity consumption tends to decrease with increasing distance, which can help in the analysis and optimization of electricity distribution networks.

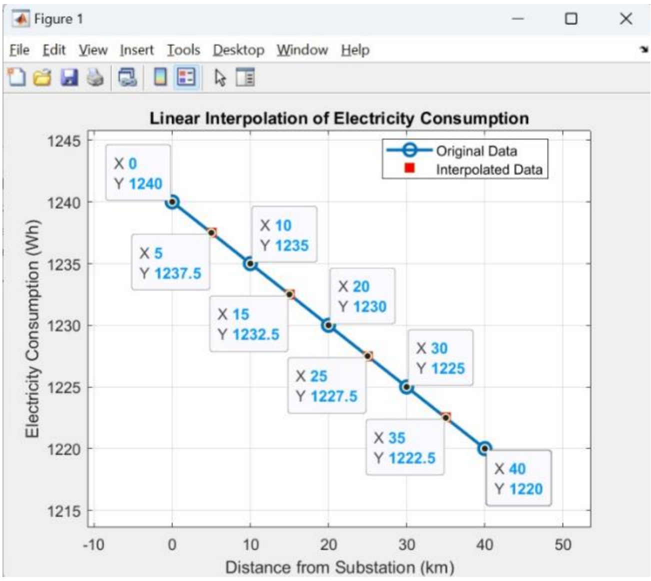

Figure 3. Results of Matlab Implementation of Linear Interpolation

Figure 3 shows the results of implementing linear interpolation to predict electricity consumption at several points along the distance from the substation using MATLAB. The x-axis represents the distance from the substation in kilometers (Km), while the y-axis represents electricity consumption in kilowatt-hours (kWh).

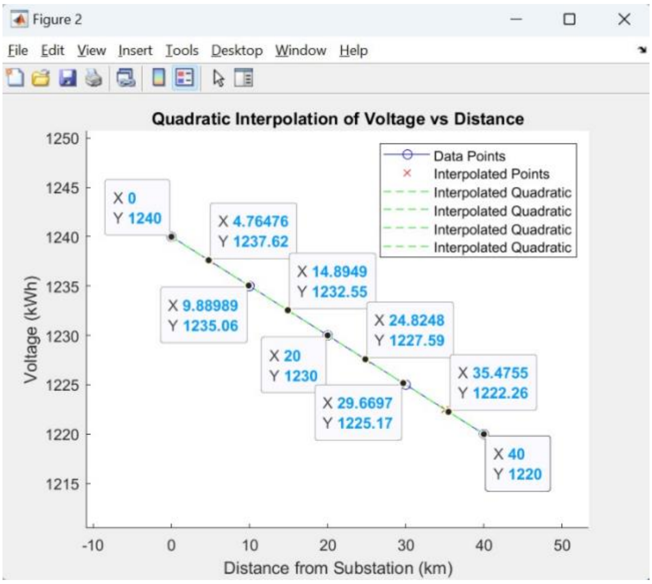

Figure 4. Results of Matlab Implementation of Quadratic Interpolation

Figure 4 shows the results of implementing quadratic interpolation to predict electric voltage at various points along the distance from the substation using MATLAB. The x-axis represents the distance from the substation in kilometers (Km), while the y-axis represents the voltage in kilowatt-hours (kWh).

2) Analysis

The linear and quadratic interpolation methods used provide results that are in accordance with the existing measurement data. The estimated voltage for the unmetered points is within a reasonable range of values and follows the expected voltage drop pattern in an electricity distribution network. This shows that linear interpolation is a simple but effective method for estimating voltage at unmetered points in a distribution network.

The advantage of using this method is that it helps network operators monitor electricity distribution performance more comprehensively by predicting voltage at unmeasured points. With a better understanding of the voltage at various points in the network, operators can identify areas that require more attention, such as points where the voltage is too low or too high.

Although linear interpolation gives good results in this case, this method has limitations. Linear interpolation only considers the two closest points and assumes that the change in voltage between the two points is linear. In field situations, stress variations can be more complex and require more sophisticated interpolation approaches, such as more accurate quadratic interpolation for data that has curvature due to considering three points. Can capture more complex changes in data. When compared with the regression method, it will provide slightly different values because it takes into account the element of non-linearity.

The results of this interpolation can be used to support electricity distribution network maintenance decisions. With more complete voltage data, operators can plan preventive maintenance actions on parts of the network that show performance degradation. In addition, interpolated data also has the potential to assist in the development of more precise network simulation models, which are useful for planning network expansion or optimizing power distribution efficiently.

6. Conclusion

This research successfully applies interpolation techniques to estimate voltage at unmeasured points in the electricity distribution network. The following are the main points from the conclusions of this research, including the calculation results:

a) Linear interpolation provides a simple and effective way to estimate stress at unmeasured points, by utilizing measured stress data.
b) Voltage measurements are carried out at distances of 0 km, 10 km, 20 km, 30 km, and 40 km from the substation. Based on linear interpolation, the voltage at the points between measurements is calculated as follows:
    a. Distance 5 km (Ds. Galih): 1.237,5 kWh
    b. Distance 15 km (Ds. Triharjo): 1.232,5 kWh
    c. Distance 25 km (Ds. Wungurejo): 1.227,5 kWh
    d. Distance 35 km (Ds. Tejorejo): 1.222,5 kWh

   The results of this interpolation show that the estimated voltage at unmeasured points is within a reasonable range of values and is in accordance with the expected voltage drop pattern in the electricity distribution network.
c) By using interpolation, grid operators can monitor electricity distribution performance more comprehensively, identifying areas that require special attention, such as points with voltages that are too low or too high.
d) Interpolated data can support decisions in network maintenance, enabling preventive action on network parts that show performance degradation.

e) In this research, MATLAB was used to carry out interpolation calculations and analysis of the results. Using MATLAB makes the calculation process and data visualization easier, increasing the efficiency and accuracy of research.

Therefore, this research makes a major and important contribution to the management and monitoring of electricity distribution networks, helping to improve the reliability and efficiency of electric power distribution.

Linear interpolation is suitable for situations where speed and simplicity are priorities, as well as when the analyzed data is nearly linear. Quadratic interpolation is more suitable for data that exhibits curvature, providing more accurate results although it is more complex in calculations. The choice of method depends on the specific requirements of accuracy and complexity desired in data analysis.

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