International Journal of Scientific Engineering and Science
Volume 8, Issue 6, pp. 72-76, 2024. ISSN (Online): 2456-7361

Prediction of 20 KV Feeder Energy Losses and Time of Construction a New Feeder Based on Multiple Linear Regression

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Abstract*—The problem occur in the distribution feeders that have large loads and long conductors, causing voltage drops and increased energy losses. The solution is necessary: increasing the cross-sectional area of the conductor, balancing the phases, splitting the load to a new feeder or reconfiguration. This research discusses the prediction of energy losses in distribution feeders 20kV and determines the construction time for new feeders. The model is defined as a 20 kV distribution feeder system with parameters: feeder load, conductor specifications and line length. The multiple linear regression method is used to determine the predicted time for building a new feeder and predict the value of technical losses on the feeder. As the research object, the 20 kV feeder BWN11 UP3 Salatiga, Indonesia was determined. The results of the research show that the multiple linear regression method can be used to determine the predicted time for building a new feeder to break the load of the 20 kV BWN11 feeder, it is found in the 52nd month after the feeder was put into operation (July 2026) and get a predicted value of energy losses in the 52nd month of 216.4kW or in monthly units it is 155,808 kWh and will continue to increase all the time.*

Keywords*— Voltage drop, enery losses, reconfiguration,prediction and multiple linier regression.*

I. INTRODUCTION

The operating principle of the electric power system is the distribution of electric power by considering safety, reliability, quality and economic factors from the generation, transmission, substation to distribution systems [1]. Common problems often encountered in 20 kV feeders are voltage drops and energy losses. This is caused by increasing load growth and conductor length, thus causing an increase in the value of energy losses in the distribution network and resulting in voltage losses in the system [2]. The solution is to improve the drop voltage by dividing the load on the feeder or building a new feeder in order to break up the load to achieve a standard voltage, thereby resulting in minimum energy losses.

Several studies on energy drops and losses have been carried out, including: multiple linear regression prediction methods have been carried out, including: predicting long-term electrical energy needs [3], forecasting electrical energy needs [4], projecting electricity needs in the context of business strategy analysis [5] and short-term electrical energy needs [6]. None of the research that has been carried out using the multiple linear regression method has discussed the prediction of energy losses and the construction time for new feeders to break down the load on the feeders. This research focuses on predicting energy losses and determining the construction time for new feeders. As an object, the research was carried out on the 20 kV BWN11 feeder at UP3 Salatiga, central Java, Indonesia.

II. PROBLEM AND TEORI

The electric power system is a set of systems consisting of 4 (four) important parts, namely: generation, transmission, substation, distribution and customer units. All parts have their respective roles in the process of distributing electric power [7]. The Electric Power System diagram can be seen in Fig.1.

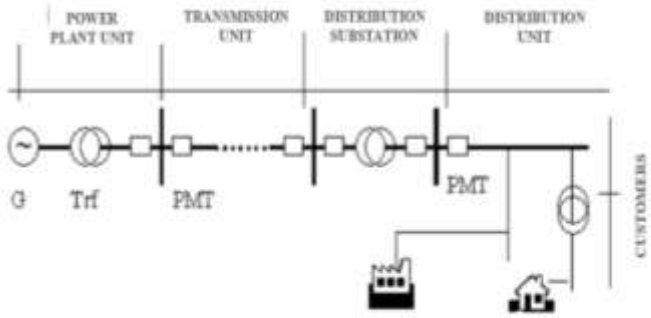

Fig. 1. Electric power system.

Electric power distribution uses a voltage of 20 kV which is called a 20 KV feeder whose function is to connect the high voltage substation and customers. The problem that occurs at the 20 kV feeder BWN11 Bawen, Salatiga, Central Java, Indonesia is the voltage drop due to increasing load and line length, this has an impact on energy losses. As the load increases, the voltage decreases and energy losses increase, so it is necessary to build a new feeder.

A. Electrical Power Quality

Electrical power quality is defined as a measure of the system's ability to provide electrical power services to users so that the equipment used by users can work according to the specifications of the equipment continuously [8].

B. System Loss

Losses in the 20 KV distribution network based on the causes of their occurrence can be divided into two, namely technical and non-technical losses [9]. Electrical energy lost in distribution both in transmission lines and distribution channels is called technical losses or losses, as shown in (1).

$$P_{kond} = I^2 . R_{sal} \quad (1)$$

International Journal of Scientific Engineering and Science
Volume 8, Issue 6, pp. 72-76, 2024.
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with: P_{kond} = Power loss in the conductor (W), R_{sal} = conductor resistance (Ω), I = Average load current (A).

C. Voltage Drop

Voltage drop is a situation where the amount of voltage transmitted is not the same as the voltage received by the recipient (electrical load). The voltage drop on the line is the difference between the voltage at the sending end and the voltage at the receiving end of electric power [9], as shown in (2).

$$\Delta V = V_s - V_r \quad (2)$$

with: ΔV = Voltage drop (Volt), V_s = Transmitting end voltage (Volt), V_r = Receiving end voltage (Volt).

D. Prediction and Linear Regression Methods

Prediction is a process for predicting future events. Predictions based on time periods can be categorized into three, namely short term, medium term and long term [10].

E. Simple Linear Regression

Simple linear regression is a statistical method that functions to test the extent of the causal relationship between the independent variable (X) and the dependent variable (Y) as shown in (3) to (5) [8].

$$Y = a + bX \quad (3)$$

$$a = \frac{(\sum_{i=1}^{n} y_i - b(\sum_{i=1}^{n} x_i)}{n} \quad (4)$$

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \quad (5)$$

where: y = Response variable or dependent variable, x = predictor variable or independent variable, a = constant, b = regression coefficient (slope), n = number of data.

F. Multiple Linear Regression

The difference between simple and multiple linear regression is that when there is only one number of independent variables, it is called simple linear regression, while when there are more than one independent variables, it is called multiple linear regression [8], in accordance with (6) to (9).

$$Y = a + b_1 x_1 + \cdots + b_n x_n \quad (6)$$

$$b_1 = \frac{(\sum_{i=1}^{n} {X_2}^2)(\sum_{i=1}^{n} X_1 Y) - (\sum_{i=1}^{n} X_1 X_2)(\sum_{i=1}^{n} X_2 Y)}{(\sum_{i=1}^{n} {X_1}^2)(\sum_{i=1}^{n} {X_2}^2) - (\sum_{i=1}^{n} X_1 X_2)^2} \quad (7)$$

$$b_2 = \frac{(\sum_{i=1}^{n} {X_1}^2)(\sum_{i=1}^{n} X_2 Y) - (\sum_{i=1}^{n} X_1 X_2)(\sum_{i=1}^{n} X_1 Y)}{(\sum_{i=1}^{n} {X_1}^2)(\sum_{i=1}^{n} {X_2}^2) - (\sum_{i=1}^{n} X_1 X_2)^2} \quad (8)$$

$$a = \frac{(\sum_{i=1}^{n} Y) - (b_1 \sum_{i=1}^{n} X_1) - b_2 \sum_{i=1}^{n} X_2}{n} \quad (9)$$

A matrix is a scalar array ordered by rows and columns. Apart from the term matrix, there is a matrix determinant. The definition of a matrix determinant is an arrangement of numbers in the form of a square in the absolute value sign (two vertical lines). Matrix determinants only exist in square matrices (matrices with the same number of rows and columns [9]. Matrices and determinants are widely used in solving systems of linear equations and can be applied to multiple linear regression by arranging (10) to (15).

$$\begin{bmatrix} n & \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} X_2 \\ \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} {X_1}^2 & \sum_{i=1}^{n} X_1 X_2 \\ \sum_{i=1}^{n} X_2 & \sum_{i=1}^{n} X_1 X_2 & \sum_{i=1}^{n} {X_2}^2 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} Y \\ \sum_{i=1}^{n} X_1 Y \\ \sum_{i=1}^{n} X_2 Y \end{bmatrix} \quad (10)$$

$$a = \frac{detdet\ M_1}{detdet\ M}\ ;\ b_1 = \frac{detdet\ M_2}{detdet\ M}\ ;\ b_2 = \frac{detdet\ M_3}{detdet\ M} \quad (11)$$

$$M = \begin{bmatrix} n & \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} X_2 \\ \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} {X_1}^2 & \sum_{i=1}^{n} X_1 X_2 \\ \sum_{i=1}^{n} X_2 & \sum_{i=1}^{n} X_1 X_2 & \sum_{i=1}^{n} {X_2}^2 \end{bmatrix} \quad (12)$$

$$M_1 = \begin{bmatrix} \sum_{i=1}^{n} Y & \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} X_2 \\ \sum_{i=1}^{n} X_1 Y & \sum_{i=1}^{n} {X_1}^2 & \sum_{i=1}^{n} X_1 X_2 \\ \sum_{i=1}^{n} X_2 Y & \sum_{i=1}^{n} X_1 X_2 & \sum_{i=1}^{n} {X_2}^2 \end{bmatrix} \quad (13)$$

$$M_2 = \begin{bmatrix} n & \sum_{i=1}^{n} Y & \sum_{i=1}^{n} X_2 \\ \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} X_1 Y & \sum_{i=1}^{n} X_1 X_2 \\ \sum_{i=1}^{n} X_2 & \sum_{i=1}^{n} X_2 Y & \sum_{i=1}^{n} {X_2}^2 \end{bmatrix} \quad (14)$$

$$M_3 = \begin{bmatrix} n & \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} Y \\ \sum_{i=1}^{n} X_1 & \sum_{i=1}^{n} {X_1}^2 & \sum_{i=1}^{n} X_1 Y \\ \sum_{i=1}^{n} X_2 & \sum_{i=1}^{n} X_1 X_2 & \sum_{i=1}^{n} X_2 Y \end{bmatrix} \quad (15)$$

G. Suitability Evaluation Technique

The thing that needs to be considered in a prediction is measuring the suitability of the prediction results with the data that will be used. MAPE (Mean Absolute Percentage Error) is a method used to measure the accuracy of a prediction result, as shown in (16) [10].

$$MAPE = \frac{(A_t - F_t)}{A_t}\ x\ 100\% \quad (16)$$

dengan : A_t = actual data in the t period, F_t = Prediction data in the t period, $MAPE$ = *Mean Absolute Percentage Error.*
The analysis on MAPE value is as shown in Table 1 [8].

TABLE 1. MAPE value Range.

No	Range	Arti Nilai
1	<10%	Very Good Prediction Model Capability
2	10-20%	Good Prediction Model Ability
3	20-50%	Decent Prediction Model Capability
4	>50%	Poor Prediction Model Ability

H. ETAP (Electric Transient and Analysis Program)

ETAP is a software used to simulate electric power systems [11]. ETAP is used to calculate the value of energy losses on the 20 kV BWN11 feeder under maximum load condition and the length of the feeder from the prediction calculations.

III. RESEARCH MODEL

The feeder which is the object of research is BWN11 located in UP3 Salatiga, Bawen District, Semarang Regency, this feeder is connected to other feeders through the concept of a loop network configuration method. The feeders that can be connected to BWN11 are BWN1, BWN5, UGN8 and UGN7 as shown in Fig.2.

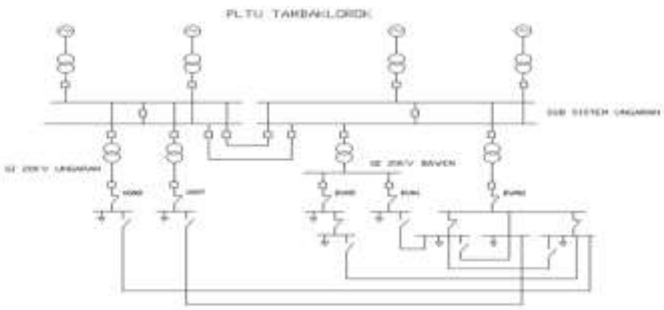

Fig. 2. Object of research

International Journal of Scientific Engineering and Science
Volume 8, Issue 6, pp. 72-76, 2024. ISSN (Online): 2456-7361

The research model in Fig.1 will then be made into an ETAP simulation design into Fig.2 a simulation design to calculate energy losses.

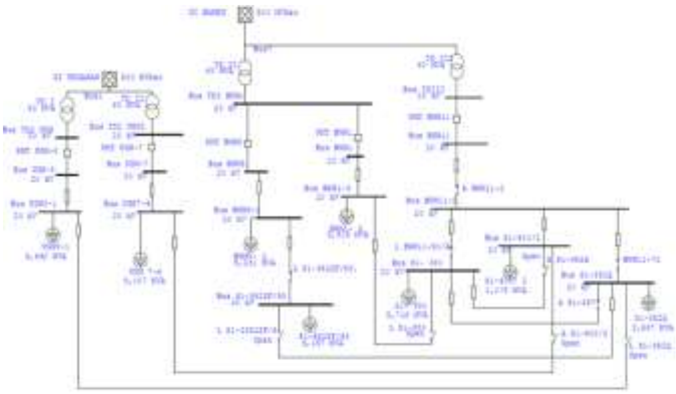

Fig. 2. ETAP Single Line Diagram

IV. RESEARCH PARAMETERS

The research parameters that will be used are data collection which is used as material in Table 2, results of load measurements for 3 phases of the BWN11 feeder and Table 3, conductor specifications.

TABLE 2. BWN11 Feeder Load Measurement

No	Bulan	Tahun	Rata-rata (A)	Jarak Penyulang (KMS)
1	April	2022	75	14,10
2	Mei	2022	76	14,10
3	June	2022	80	14,16
4	July	2022	82	14,16
5	August	2022	84	14,38
6	September	2022	88	14,38
7	October	2022	92	14,52
8	November	2022	95	14,52
9	December	2022	96	14,70
10	January	2023	99	14,70

TABLE 3. Conductor Specifications

No	Feeder	Feeder Length (KMS)	Keterangan
1	BWN11	15,12	1 kms (NYFGbY) 14,12 kms A3C 240mm^2
2	UGN8	7,55	1,1 kms (NYFGbY) 6,45 kms A3C 240mm^2
3	BWN1	5,07	0,9 kms (NYFGbY) 4,17 kms A3C 240mm^2
4	BWN5	43,18	0,9 kms (NYFGbY) 42,09 kms A3C 240mm^2
5	UGN7	12,20	1,2 kms (NYFGbY) 11,00 kms A3C 240mm^2

V. RESEARCH FLOW

The flow of the research carried out can be seen in Fig. 3 flowcharts.

VI. RESULTS AND DISCUSSION

Referring to Table 2, a multiple linear regression model will be created to simplify calculations in (10) to (15) and (6) to (9) to determine the multiple linear regression equation and look for the coefficient values a, variables b_1 and b_2 in Table 4.

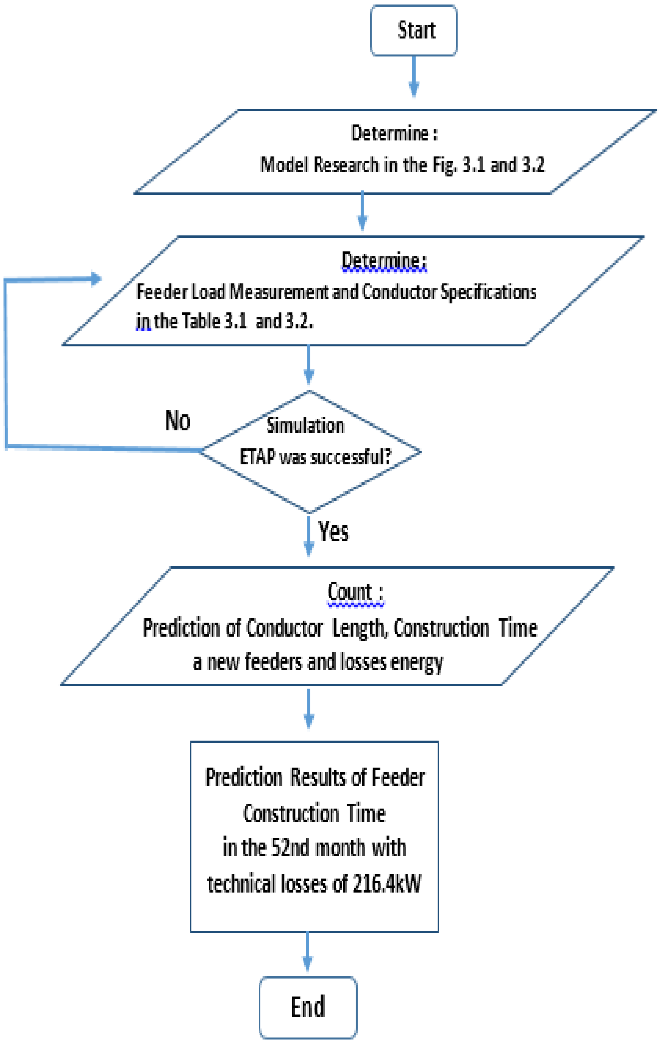

Fig. 3. Flowchart

TABLE 4. Multiple Linear Regression Table Modeling

No	Y (Month)	X_1 (A)	X_2 (KMS)	X_1Y	X_2Y	X_1X_2	X_1^2	X_2^2
1	1	75	14,10	75	14,1	1057,5	5625	198,81
2	2	76	14,10	152	28,2	1071,6	5776	198,81
3	3	80	14,16	240	42,48	1132,8	6400	200,5056
4	4	82	14,16	328	56,64	1161,12	6724	200,5056
5	5	84	14,38	420	71,9	1207,92	7056	206,7844
6	6	88	14,38	528	86,28	1265,44	7744	206,7844
7	7	92	14,52	644	101,64	1335,84	8464	210,8304
8	8	95	14,52	760	116,16	1379,4	9025	210,8304
9	9	96	14,70	864	132,3	1411,2	9216	216,09
10	10	99	14,70	990	147	1455,3	9801	216,09
JML	55	867	143,72	5001	796,7	12478,12	75831	2066,041

Apply equation (10) with the result data in Table 4.

$$\begin{bmatrix} 10 & 867 & 143,72 \\ 867 & 75831 & 12478,12 \\ 143,72 & 12478,12 & 2066,041 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} 55 \\ 5001 \\ 796,7 \end{bmatrix}$$

Find the determinant of M by applying (12) and the resulting data in Table 4.

$$M = \begin{bmatrix} 10 & 867 & 143,72 \\ 867 & 75831 & 12478,12 \\ 143,72 & 12478,12 & 2066,041 \end{bmatrix} ; \det M = 195,5042$$

Find the determinant of M_1 by applying (13) and the resulting data in Table 4.

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$$M_1 = \begin{bmatrix} 55 & 867 & 143{,}72 \\ 5001 & 75831 & 12478{,}12 \\ 796{,}7 & 12478{,}12 & 2066{,}041 \end{bmatrix}$$

det M_1 = -9.756,4036

Find the determinant of M_2 by applying (14) and the resulting data in Table 4.

$$M_2 = \begin{bmatrix} 10 & 55 & 143{,}72 \\ 867 & 5001 & 12478{,}12 \\ 143{,}72 & 796{,}7 & 2066{,}041 \end{bmatrix}$$; det M_2 = 57,9066

Find the determinant of M_3 by applying (14) and the resulting data in Table 4.

$$M_3 = \begin{bmatrix} 10 & 867 & 55 \\ 867 & 75831 & 5001 \\ 143{,}72 & 12478{,}12 & 796{,}7 \end{bmatrix}$$

det M_3 = 404,3399997271

Equation (11) is applied after the determinant value is known.

$$a = \frac{-9.756{,}4036}{195{,}5042} = -49{,}90380565$$

Applying (6) with results a, b_1 and b_2 produces (17) the multiple linear regression equation determines the construction time of the new feeder.

$$Y = -49{,}90380565 + 0{,}296191079X_1 + 2{,}068190861X_2 \quad (17)$$

Equation (17) is applied to find MAPE with Table 4 column number 6, X_1 = 88 dan X_2 = 14,38.

$$Y = -49{,}90380565 + 0{,}296191079(88) + 2{,}068190861(14{,}38)$$

$$Y = 5{,}90159388$$

Equation (17) is used to calculate the prediction error value.

$$MAPE = \frac{6-5{,}90159388}{6} \, x \, 100\% = 1{,}64\%$$

VII. Simple Linear Regression Results And Energy Loss Predictions

Simple linear regression is used to predict the length of the BWN11 feeder using the model in Table 5.

Equations (4) and (5) are applied with Table 5 to find the values of coefficient b and constant a.

$$b = \frac{10(12.478{,}12) - ((867) \times (143{,}72))}{10(75.831) - (867)^2}$$

$$= \frac{(124.781{,}2) - (124.605{,}24)}{(758.310) - (751.689)} == \frac{175{,}96}{6.621} = 0{,}026576$$

TABLE 5. Simple Linear Regression Modeling

No	Y (KMS)	X (A)	XY	Y²	X²
1	14,1	75	1057,5	198,81	5625
2	14,1	76	1071,6	198,81	5776
3	14,16	80	1132,8	200,506	6400
4	14,16	82	1161,12	200,506	6724
5	14,38	84	1207,92	206,784	7056
6	14,38	88	1265,44	206,784	7744
7	14,52	92	1335,84	210,83	8464
8	14,52	95	1379,4	210,83	9025
9	14,7	96	1411,2	216,09	9216
10	14,7	99	1455,3	216,09	9801
JML	143,72	867	12478,12	2066,041	75831

$$a = \frac{143{,}72 - (0{,}026576 \times 867)}{10}$$

$$= \frac{143{,}72 - 23{,}041392}{10} = \frac{120{,}678608}{10} = 12{,}0678608$$

Equation (3) can be applied after the values of a and b are known, becoming (18) the equation for finding the length of the conductor.

$$Y = 12{,}0678608 + 0{,}026576X \quad (18)$$

If the load is 220A, then the length of the conductor (18) can be known.

$$Y = 12{,}0678608 + 0{,}026576(220)$$

$$= 17{,}9145808 \approx 17{,}91 \, kMs$$

Equation (17) to determine the feeder construction time can be used once the conductor length is known.

$$Y = -49{,}90380565 + 0{,}296191079(220) + 2{,}068190861(17{,}91) = 52$$

If the BWN11 feeder is first operated in April 2022, then the 52nd calendar month will be July 2026.

To find out the value of energy losses in the 52nd month, it is simulated using Figure 2, the BWN11 feeder load is 220A and the feeder length is 17.91 KMS, shown in the results of Fig.4.

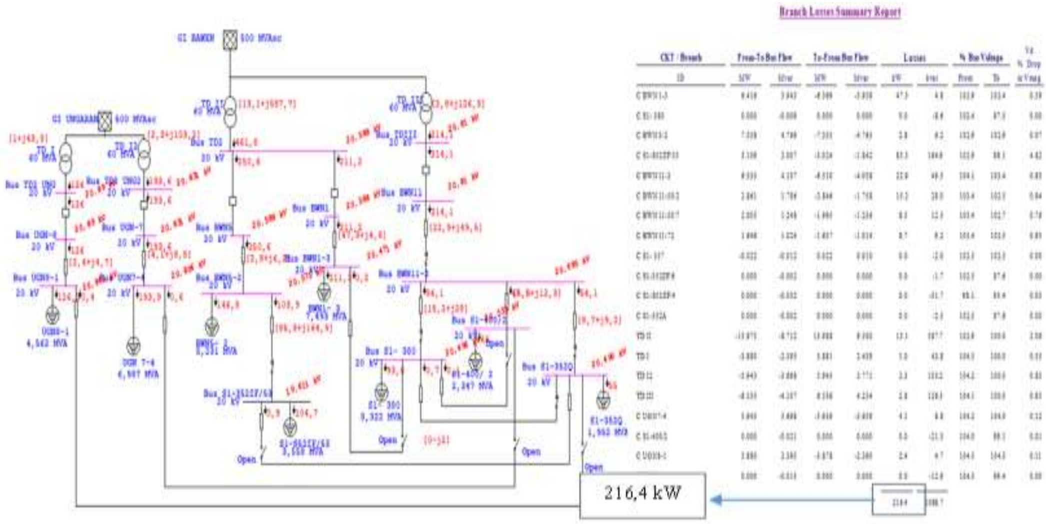

Fig. 4. Energy Loss Simulation and Results

Referring to Fig. 4 BWN11 energy loss value for the 52nd month was 216.4 kW. If the monthly unit is 155,808 kWh, the potential losses caused by the BWN11 feeder are likely to continue to increase, it is necessary to plan the construction of a new feeder in the 52nd month, it is July 2026.

VIII. CONCLUSION

The conclusion of the research is that using the multiple linear regression method is able to create a prediction equation determining the construction time of the new feeder in the 52nd month and predicting energy losses of 214.6 kW. With a prediction error value of 1.64% (very good prediction).

ACKNOWLEDGMENT

The authors are grateful to all the teacher, staff and students of Magister Program of Electrical Engineering Department, Universitas Islam Sultan Agung, Semarang, Indonesia

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