

SHORT-TERM ELECTRICITY LOAD FORECASTING SEASONAL PATTERN USING TIME SERIES REGRESSION (TSR) MODEL

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ABSTRACT

Electricity is a crucial component of modern life, where daily consumption fluctuates significantly. Uncertain electricity demand can lead to imbalances between supply and consumption, potentially causing energy wastage or power outages. To address this issue, a forecasting method capable of accurately predicting electricity load is essential. The Time Series Regression (TSR) model is applied for short-term electricity load forecasting by considering daily and weekly seasonal patterns. The forecasting results indicate that Monday and Tuesday have the highest electricity load, while Sunday has the lowest. When the Kolmogorov-Smirnov test is used to analyse the model, the p-value is 0.9608, which shows that the residuals have a normal distribution. The model's accuracy is assessed with a Root Mean Square Error (RMSE) value of 378.0069 MW, which is relatively high for a small dataset. Given the considerable forecasting error, further improvements such as hybrid models are recommended to enhance accuracy. The implementation of these forecasting results can help optimize electricity management and improve power distribution efficiency.

Keywords: Time Series Regression, electricity load, short-term forecasting, seasonal pattern, PLN.

1. INTRODUCTION

Electrical energy is an essential component of modern life, important in various sectors such as household, industry, business, and public. The availability of stable electrical energy is a crucial factor in supporting the daily activities of the community and the industrial sector. However, fluctuating electricity demand is often a challenge in power load management by electricity provider companies such as PT PLN (Persero). The ever-increasing demand for electrical energy along with population growth and industrial development leads to the need for effective strategies in electricity load forecasting to ensure optimal electricity availability and avoid waste or power shortages.

One of the main challenges in power system management is balancing the availability of electrical power (supply) with consumer demand (demand). If the supply of electricity exceeds the demand, there will be a waste of energy that can cause losses for electricity providers. Conversely, if the demand for electricity is greater than the supply, it can result in power outages that have a negative impact on economic activities and the social life of the community. In the context of Medan City, there are frequent power outages caused by various factors such as lack of electricity supply, electricity infrastructure maintenance, and extreme weather disturbances. This imbalance emphasizes the importance of accurate electricity load forecasting so that PLN can better anticipate power demand.

Electricity load forecasting is one of the approaches used to optimize the use of electrical energy and avoid imbalances between electricity production and consumption. This forecasting allows PLN to prepare a more efficient and economical operational strategy in the distribution of electricity. In the operation of the power system, electricity load forecasting is used as a basis for planning, scheduling, and evaluating the performance of the power system. Accurate forecasting can help in reducing operational costs, increasing the efficiency of electricity supply, and ensuring the availability of power for the community.

Three forms of power load forecasting can be distinguished based on the time period: short-term, medium-term, and long-term forecasting. Long-term forecasting is generally used to determine the need for electric power within an annual period and is often used in planning the development of electric power infrastructure. Medium-term forecasting is usually concerned with scheduling electrical loads on a monthly or weekly scale to ensure power adequacy during a certain period. Meanwhile, short-term forecasting is done to estimate electrical loads on a daily or hourly scale and is instrumental in real-time power system operations.

In this research, short-term electric load forecasting is the main focus because it has a direct impact on efficient electric power management. Short-term electricity load forecasting can help PLN in optimizing the distribution of electricity on a daily basis and reduce the risk of blackouts due to unpredictable demand spikes. One method that can

be used in short-term electricity load forecasting is the *Time Series Regression* (TSR) Model, which is able to capture seasonal data patterns as well as trends in electricity load data.

Based on the linear relationship between the independent and dependent variables in a time series, the TSR model is a statistical technique for predicting a variable's value. Due to its ability to adapt to changes over time, this model is appropriate for energy load data that exhibits seasonal patterns and trends. Furthermore, TSR enhances prediction accuracy by enabling the use of dummy variables to identify weekly and daily seasonal patterns in electrical load data.

Several previous studies have shown that the TSR model has good performance in electricity load forecasting as well as various other fields. For example, research conducted by (Berliana & Mike, 2022) shows that the TSR method with dummy variables produces a smaller RMSE value compared to the ARIMA method in cement demand forecasting. In addition, research conducted by (Kartika, Sri & Memi, 2022) on modeling the share price of PT Telekomunikasi Indonesia Tbk also shows that TSR provides more accurate results than other methods. (Ardita & Sukma, 2021) also conducted research comparing the *Time Series Regression* and ARIMAX methods on clothing sales data in Boyolali City, where the results of the TSR method research produced a smaller RSME.

In the context of electricity load forecasting in Medan City, the use of the TSR model is expected to provide more accurate predictions of daily electricity consumption patterns. Thus, PT PLN (Persero) can optimize the electric power distribution strategy and reduce the possibility of frequent blackouts due to the imbalance between supply and demand. In addition, accurate forecasting can also help in operational planning of the power system, so that production costs can be reduced and power distribution efficiency can be improved.

In this study, daily electricity load data in Medan City over a certain period will be used to build a TSR model that can accommodate seasonal patterns in electricity consumption. The model will be evaluated using residual diagnostic method as well as model accuracy testing by calculating *Root Mean Square Error* (RMSE) value. It is anticipated that the findings of this study will offer a more thorough understanding of daily trends in electricity use and assist PT PLN (Persero) in creating a more effective electrical energy management plan.

Overall, this research aims to analyze and develop a short-term electricity load forecasting model in Medan City using the Time Series Regression method. By utilizing historical electricity load data and seasonal patterns that occur, the TSR model is expected to be able to provide more accurate predictions and support the strategic policies of PT PLN (Persero) in managing electricity. As well as knowing the equation model of short-term electricity load forecasting results (daily) *Seasonal Pattern Time Series Regression* (TSR) Model and knowing the level of accuracy through the percentage of error when using the TSR model.

Thus, the use of the TSR model in electricity load forecasting can be an effective solution in facing the challenges of power imbalance and ensuring stable electricity availability for the people of Medan City.

LITERATURE REVIEW

Electrical Load Forecasting

Forecasting in the field of electrical power is basically a forecast of electrical power load requirements. Both are often referred to as Demand and Load Forecasting. Load is a requirement for electrical energy whose size changes depending on the needs of consumers that must be supplied by PLN through electrical energy sources.

Broadly speaking, making a forecast of electrical power requirements can be divided into three stages, namely: Data collection and preparation, data processing and analysis, and determination of methods and model creation.

Time Series Regression (TSR) Model

Time Series Regression (TSR) is a time series model that can be used for modeling and forecasting, where the dependent variable and independent variables are time series with the assumption that the dependent variable is influenced by the independent variable. The TSR model is suitable for use on data that has a combined trend and seasonal pattern or one of them. If the time series does not have a trend or seasonal pattern, the forecasting results using the TSR model will be constant, there will be no increase or decrease.

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$$Y_t = T_t + S_t + \varepsilon_t \quad (1)$$

Seasonal TSR Model

Seasonal Pattern is a data pattern that repeats itself over a period of time. Seasonal fluctuations are often found in daily, weekly or monthly data.

$$Y_t = \beta_0 + \beta_1 M_{1,t} + \beta_2 M_{2,t} + \beta_3 M_{3,t} \dots + \beta_s M_{s,t} + \varepsilon_t \quad (2)$$

Parameter Estimation of the TSR (Time Series Regression) Model

Parameter estimation of TSR using the Ordinary Least Square (OLS) method. The OLS method is a method for finding regression parameter estimates by minimizing the sum of residual squares (SQS).

$$Y = X\beta + \varepsilon \quad (3)$$

Previous Research

Ardita Sukma (2021) also conducted research comparing the Time Series Regression and ARIMAX methods on clothing sales data in Boyolali City, where the results of the TSR method research produced a smaller RSME compared to the ARIMAX method itself, because the Time Series Regression method uses annual data dummy variables, calendar variation effects and trend dummies.

Berliana and Mike (2022) who predicted cement demand using Time Series Regression and ARIMA where the results of the analysis with the Time Series Regression model with dummy variables got better results by having the smallest RMSE value, compared to the ARIMA model.

Herni, Yunita, Subanar, Abdurakhman, and Gunardi (2019) in research on Electricity Load Forecasting in the Special Region of Yogyakarta with the Singular Spectrum Analysis (SSA) Method where this research uses monthly data on electricity loads where data characteristics contain seasonal patterns and trends. When using the SSA method, it gets a large error value in the out-sample of 5.61%.

Kartika, Sri, and Memi (2022) in this study researchers modeled the share price of PT Telekomikasi Indonesia Tbk using the TSR model. The data used is in daily form where there is a small error value using the TSR Method because it uses daily data which is better than annual data.

Melisa and Andrea (2021) who forecast the number of United States airline passengers using Time Series Regression (TSR) where the researchers used monthly data with dummy variables.

METHOD

This research uses a quantitative approach with a time series analysis method to perform short-term electricity load forecasting. The data used in this research is secondary data obtained from PT PLN (Persero) Medan City, which includes daily electricity load usage data for a certain period. The data is analyzed using the *Time Series Regression* (TSR) Model to identify seasonal patterns contained in daily electricity consumption. The TSR model was chosen because it has the ability to capture seasonal patterns and trends that occur in time series data. In this study, the variables used consist of independent variables in the form of dummy variables for the day of the week and dependent variables in the form of observed daily electricity load.

The research process begins with the collection of secondary data from PT PLN (Persero) which records daily electricity usage in Medan City. After then, the collected data is divided into two categories: in-sample data and out-of-sample data. A forecasting model is constructed using the in-sample data, and its accuracy is evaluated using the out-of-sample data. In order to preserve seasonal patterns and trends in the analysis, this separation is accomplished by preserving the temporal sequence. While the out-of-sample data includes more recent data to assess the predictive power of the resulting model, the in-sample data spans the first period to the majority of the historical data.

Plotting the time series data to identify patterns is the next stage in an exploratory examination of the data after it has been classed. These plots are used to see trends and seasonal patterns in the daily electricity load data. Based on the observed patterns, a TSR model was developed using dummy variables to capture the influence of certain days of the week on the electricity load. These dummy variables are used to represent the seasonal pattern in the data, where each day of the week is assigned a value of 1 if the data is from that day and 0 otherwise.

After the TSR model is formed, parameter estimation is performed using the Ordinary Least Squares (OLS) method. The residual diagnostic test is used to assess whether the model's residuals satisfy the white noise assumption. The OLS method is used to find the value of the regression coefficient that minimises the sum of the squares of the difference between the observed value and the predicted value.

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The significance of the parameters is then tested to make sure that the variables in the model have a significant impact on the daily electricity load. The Ljung-Box test is employed in this investigation to determine whether the model's residuals are random and devoid of any particular pattern. Furthermore, one of the crucial presumptions in time series regression models is that the residuals are normally distributed, which is checked using the Kolmogorov-Smirnov test.

Following validation of the model, the developed TSR model is used to forecast electricity loads. The accuracy of the model is assessed by comparing the forecasted results with the actual data. The Root Mean Square Error (RMSE) value is the metric used to evaluate the correctness of the model. To determine how much the model prediction error differs from the actual value, RMSE is computed. The model that has the smallest RMSE value is considered the best model in predicting the short-term electricity load in Medan City.

By applying this method, this research aims to provide more accurate electricity load forecasting results and assist PT PLN (Persero) in developing a more efficient electric power management strategy. It is anticipated that the findings of this study will aid in the operational planning of the power system and optimise power distribution to more steadily and systematically supply the community's electricity needs.

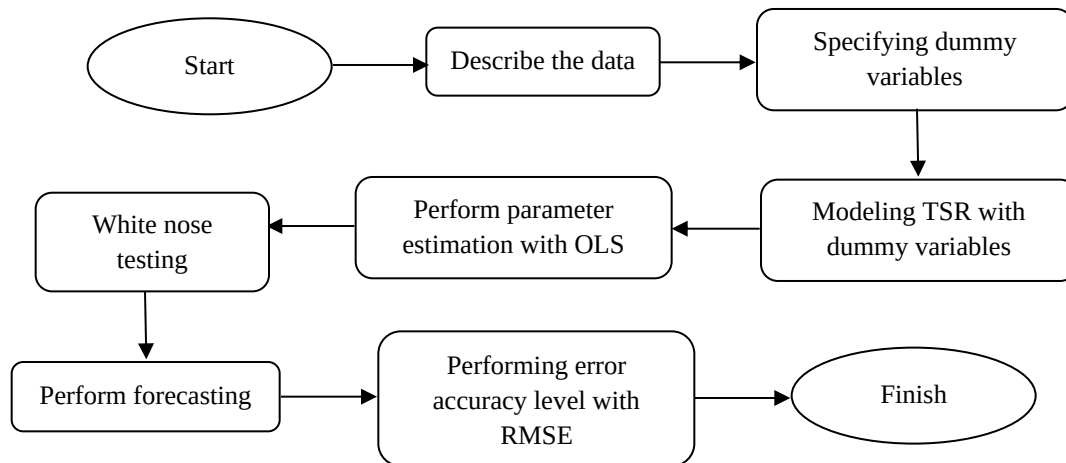


Fig 1. Flow Chart

4. RESULT

Data Collection

The data used in this study is secondary data from PT PLN (Persero) Medan City, which records daily electricity load consumption in Megawatts (MW) for the period April 1, 2024 to June 30, 2024. This data is categorized into two parts:

- In-sample: Data from April 1 to June 23, 2024 was used to build the forecasting model.
- Out-sample: Data from June 24 to June 30, 2024 was used to test the accuracy of the model.

Table 1 Electricity Load Usage		
Date	Day	Load Data (MW)
01-Apr	Monday	2295
02-Apr	Tuesday	2291
03-Apr	Wednesday	2393
...	...	...
29-Jun	Saturday	2511
30-Jun	Sunday	2215

Figure 2 shows a plot of the electricity load data over the study period. From this visualization it can be seen that the electricity load has a weekly seasonal pattern, with repeated increases and decreases.

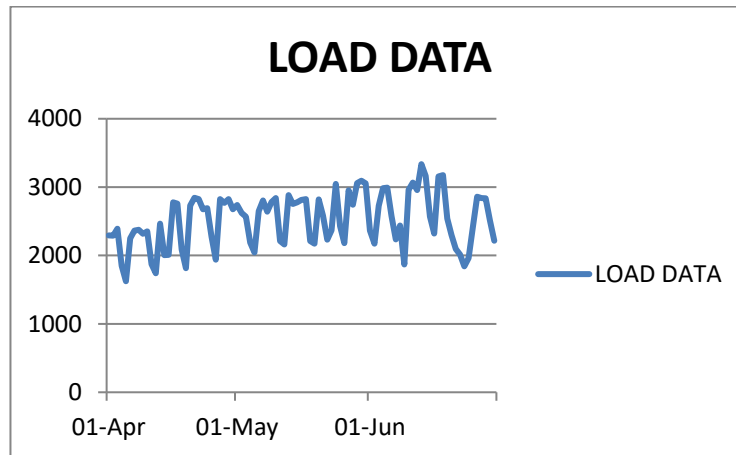


Fig. 2 Load Data Plot

Time Series Regression (TSR) Modeling

Determining In-sample and Out-sample Data

The selection of in-sample and out-sample data is done by maintaining the time sequence so that the seasonal pattern is preserved. This division ensures that the TSR model can be trained with historical data and tested with recent data.

- In-sample: April 1 - June 23, 2024
- Out-sample: June 24 - June 30, 2024

Table 2 In-Sample and Out-Sample Data

Date	Day	Load Data (MW)
01-Apr	Monday	2295
...	...	...
23-Jun	Sunday	1841
24-Jun	Monday	1964
...	...	...
30-Jun	Sunday	2215

Defining Dummy Variables

Since the electricity load has a weekly seasonal pattern, a *dummy variable* is used for each day of the week. The TSR model will regress the electricity load data against these *dummy variables* to capture the weekly pattern.

Table 3 Dummy Variables for TSR Model

Date	Day	Load Data (MW)	D_Monday	D_Tuesday	D_Wednesday	D_Thursday	D_Friday	D_Saturday	D_Sunday
01-Apr	Monday	2295	1	0	0	0	0	0	0
02-Apr	Tuesday	2291	0	1	0	0	0	0	0
03-Apr	Wednesday	2393	0	0	1	0	0	0	0
...	...	...	...	...	...	...	...	...	...

Parameter Estimation with Ordinary Least Squares (OLS)

The Ordinary Least Squares (OLS) approach was used to assess the TSR model. The resulting model equation is:

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$$Y_t = \beta_0 + \beta_1 D_{selasa} + \beta_2 D_{rabu} + \beta_3 D_{kamis} + \dots + \beta_6 D_{minggu} + \epsilon_t \quad (1)$$

Where:

- Y_t : Electricity load at time t (dependent variable).
 D_{hari} : Dummy variable for each day (1 if it is a day, 0 if it is not).
 $\beta_0, \beta_1, \dots, \beta_6$: Regression parameter to be estimated.
 ϵ_t : Expected errors (residuals) fulfill the assumption of white noise

Table 4 Parameter Estimation of TSR Model

Variables	Coefficient (β)	p-value
Intercept (Monday)	2707.17	-
Tuesday	29.83	0.47
Wednesday	-29.58	0.53
Thursday	-209.83	0.02
Friday	-295.00	0.01
Saturday	-315.92	0.03
Sunday	-477.83	0.002

These results show that the electricity load on Friday and Sunday is significantly lower than on Monday ($p < 0.05$)

Then the model parameter estimation equation is

$$\hat{y} = \beta_0 + \beta_1 D_{selasa} + \beta_2 D_{rabu} + \beta_3 D_{kamis} + \dots + \beta_6 D_{minggu} + \epsilon_t \quad (2)$$

$$\hat{y} = 2707.16667 + (29.83333)D_{selasa} + (-29.58333)D_{rabu} + (-209.83333)D_{kamis} + (-295.00000)D_{jumat} + (-315.91667)D_{sabtu} + (-477.83333)D_{minggu} + \epsilon_t$$

TSR Model Evaluation

a. Residual Diagnostics

The Ljung-Box test was conducted to evaluate the *white noise* assumption in the model residuals. The test results show that the residuals have no significant pattern, indicating a fairly good model.

In addition, The residuals' normality was tested using the Kolmogorov-Smirnov test, and the results showed that they are normally distributed with a p-value of 0.9608.

```
> ks.test(residuals_model, "pnorm", mean(residuals_model), sd(residuals_model))

Asymptotic one-sample kolmogorov-smirnov test

data: residuals_model
D = 0.055083, p-value = 0.9608
alternative hypothesis: two-sided
```

Fig 3. RStudio Result of Kolmogorov-Smirnov Test

b. Error accuracy level using RMSE value

The accuracy of the TSR model is measured using the Root Mean Square Error (RMSE).

$$RMSE = \sqrt{MSE} \quad (3)$$

First calculate the MSE value:

$$MSE = \frac{1}{2} \sum_{i=1}^n (\hat{y}_i - y_i)^2 \quad (4)$$

$$MSE = \frac{(1964 - 2707.167)^2 + (2417 - 2737)^2 + \dots + (2215 - 2229.333)^2}{2}$$

$$MSE = \frac{552297,1899 + 102400 + \dots + 205,434889}{2}$$

$$MSE = 142889,3$$

After the MSE value has been calculated then calculate the RMSE:

$$RMSE = \sqrt{142889,3}$$

$$RMSE = 378,0069$$

The calculation results show an RMSE value of 378.0069 MW, which is relatively high for a small dataset. With this RMSE value, PLN needs to conduct further optimization to reduce forecasting errors and improve the efficiency of electric power.

Table 5 Forecasting Results and Errors (Residuals)

Date	Day	Load Data (MW)	TSR Prediction (MW)	Residuals
01-Apr	Monday	2295	2707.167	-412.167
02-Apr	Tuesday	2291	2737.000	-446.000
...	...	...	...	...
30-Jun	Sunday	2215	2229.333	-14.333

Perform TSR Forecasting

First : Adding dummy variables for the *out-sample* data. To capture seasonal patterns, create dummy variables (D_j) according to the number of seasons.

Second : Scouting $\hat{Y}$ is calculated by :

$$\hat{Y} = Z \cdot \hat{\beta} \quad (5)$$

Where:

Z : independent variable data matrix (including constant column for intercept).

$\hat{\beta}$: coefficient vector of OLS estimation result.

$$\hat{Y} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 2707.16667 \\ 29.83333 \\ -29.58333 \\ -209.83333 \\ -295.00000 \\ -315.91667 \\ -477.83333 \end{bmatrix}$$

$$\hat{Y} = \begin{bmatrix} 2707.16667 \\ 2737.000 \\ 2677.583 \\ 2497.333 \\ 2412.167 \\ 2391.250 \\ 2229.333 \end{bmatrix}$$

Electricity load forecasting results tend to be higher on Monday with a load of 2707 MW and decreased on Sunday with a load of 2229 MW.

DISCUSSIONS

The regression equation obtained from the analysis of electricity load data is as follows:

$$\hat{y} = \beta_0 + \beta_1 D_{selasa} + \beta_2 D_{rabu} + \beta_3 D_{kamis} + \dots + \beta_6 D_{minggu} + \epsilon_t \quad (6)$$

With the model parameter estimation results:

$$\hat{y} = 2707.16667 + (29.83333)D_{selasa} + (-29.58333)D_{rabu} + (-209.83333)D_{kamis} + (-295.00000)D_{jumat} \\ + (-315.91667)D_{sabt} + (-477.83333)D_{minggu} + \epsilon_t$$

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The resulting regression equation describes the relationship between daily electricity load and day of the week using dummy variables. The intercept of 2707.16667 indicates the average electricity load on Monday, which is used as the baseline. The coefficient of the dummy variable indicates the difference in electricity load on each day compared to Monday. For example, the average electricity load on Tuesday is higher by 29.83 units, while on Wednesday it is lower by 29.58 units. The decrease in electricity load starts to be significant from Thursday to Sunday, with the largest decrease occurring on Sunday by 477.83 units compared to Monday. This reflects the weekly seasonal pattern, where electricity loads tend to be higher at the beginning of the week and decrease at the end of the week, which is likely due to a decrease in industrial or commercial activity.

The Kolmogorov-Smirnov test results show a D value of 0.055083 with a p-value of 0.9608. This high p-value indicates that the model residuals are not significantly different from the normal distribution, so the assumption of residual normality is met.

The Root Mean Square Error (RMSE) value of 378.0069 provides an overview of the average model prediction error in units of electricity load data. The high RMSE value can be caused by the complexity of the data pattern or the limited amount of data used, which makes the model less able to capture all patterns optimally. For small datasets, model variability tends to be higher, making the RMSE value more difficult to interpret.

CONCLUSION

In the forecasting results where Monday and Tuesday have the highest electricity load of 2737 mw and produce an RMSE of 378.0069 the variability of the error model tends to be higher. This may result in a loss for PT PLN (Persero) Medan City. Because if the error rate is smaller, there will be an advantage for PT PLN (Persero). Overall, this research provides insight into how electricity load forecasting can assist PLN in more efficient power management. By continuing to develop and refine the forecasting model, PLN can ensure a more stable and optimal electricity distribution for the people and industries in Medan City.

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Finally, the author realizes that this research still has many limitations and shortcomings. Therefore, constructive criticism and suggestions are highly expected for the improvement of future research. Hopefully this journal can provide benefits for the development of science, especially in the field of electricity load forecasting, and can be a useful reference for further research. The author hopes that the results of this research can make a real contribution to PT PLN (Persero) in optimizing the distribution of electric power and increasing the efficiency of the power system in Medan City.

The author wishes to humbly convey his sincere appreciation to everyone who has contributed to this study effort. Hopefully all forms of assistance and support provided will be rewarded and beneficial to all interested parties.

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