Journal of Electrotechnology, Electrical Engineering and Management (2021) Vol. 4: 1-6 DOI: 10.23977/jeeem.2021.040101
Clausius Scientific Press, Canada ISSN 2560-6697

# *Parameter identification of static load model in power system of refinery and chemical enterprise*

**Qi Qi[1, 2, *], Yi Wang[1]**

[1]*China Electric Power Research Institute, Beijing 100192, China*

[2]*Sinopec Luoyang Branch, Luoyang 471012, Henan, China*

*Corresponding author: qiqieee@163.com

***Keywords:*** Static load model, Least squares optimization, Parameter identification

***Abstract:*** The load modeling of the power system of a refining and chemical enterprise is an important basic research, and the establishment of a load model is an important part of the analysis of the stability of the enterprise's internal power grid. Based on the data measured on site, the error function is established to optimize, and the unknown parameters of the polynomial model of the static load and the power function model are identified. The evaluation index of the fitted curve proves that the static load model established by the steady-state test method is feasible and effective.

## 1. Introduction

The power system is a high-order multi-dimensional nonlinear system, and the main tool for its safety and stability analysis is power system simulation. The accuracy of the load model is directly related to the quality of the simulation results. The use of inaccurate models in the analysis, planning and control of the power system will cause the results to be inconsistent with the actual situation or even diametrically opposite things, which will cause the power system to be under construction Increase unnecessary investment or there are potential dangers in operation. The static model of the load needs to be used in many occasions, such as planning at the beginning of the power system design, analysis and control after the power system is put into operation, and specific application scenarios such as power flow calculation and voltage under the steady-state conditions of the power system. Analysis of stability, reactive power compensation layout, etc.

The medium handled by refining and chemical enterprises is flammable and explosive, the production environment is high temperature and high pressure, and the safe and reliable operation of the enterprise's internal power grid is the basis of production and operation activities.

The methods of power system static load modeling mainly include steady-state test method, online measurement and identification method and statistical synthesis method [1], [2], [3]. The power system of a refining and chemical enterprise has the characteristics of various voltage levels and high load density. The statistical synthesis method requires a lot of statistical work, and the online test and defense method needs to increase investment. Comprehensive considerations, this article uses the steady-state test method to carry out static load in a refining and chemical enterprise Model building work.

## 2. Mathematical description of static load model

The load model in the power system is a functional relationship that describes the change of port power with voltage and frequency [4]. There are mainly two types of models, static and dynamic. The static load model is suitable for the application scenarios of the power system under steady-state conditions. There are mainly two basic models: polynomial and power function. Other static load models are mainly based on the combination or deformation of these two models. The power system of a refining and chemical enterprise is generally interconnected with a large power grid, and the frequency changes very little, which cannot be identified in the steady state test method. Ignoring the influence of frequency, the static load model expression is as follows:

Polynomial model [5]:

$$\begin{cases} P = P_0\left[a_p\left(\frac{U}{U_0}\right)^2 + b_p\left(\frac{U}{U_0}\right) + c_p\right] \\ Q = Q_0\left[a_q\left(\frac{U}{U_0}\right)^2 + b_q\left(\frac{U}{U_0}\right) + c_q\right] \end{cases} \tag{1}$$

This model is also called the ZIP model, where $P, Q,$ and $U$ are the actual active power, reactive power, voltage and frequency of the load, respectively; $P_0, Q_0,$ and $U_0$ are the initial operating values; $a_p, b_p, c_p$ respectively represents the voltage square term load, the voltage primary term load, and the voltage independent term load in the total active load; $a_q, b_q, c_q$ respectively represent the voltage square term load, voltage primary term load, and voltage independent term in the total reactive load. The proportion of the load satisfies the constraint conditions $a_p+b_p+c_p = 1$, $a_q+b_q+c_q = 1$.

Exponential model [5]:

$$\begin{cases} P = P_0(\frac{U}{U_0})^{p_u} \\ Q = Q_0(\frac{U}{U_0})^{q_u} \end{cases} \tag{2}$$

In the formula, $P, Q, U,$ $P_0, Q_0,$ and $U_0$ have the same meaning as in formula (1). $p_u, q_u,$ are the active voltage characteristic coefficient and the reactive voltage characteristic system respectively.

Polynomial model and exponential model are two different description forms of static load, so these two models can be converted to each other.

## 3. Steady state test

The field test was carried out on the 35kV busbar of a 110kV substation of a refining and chemical enterprise. There are generally several methods for adjusting the voltage of the load node: 1. Switching on and off the reactive power compensation device; 2. Changing the reactive power output of the generator; 3. Adjusting the on-load transformer gear. This actual test is to adjust the 35kV system voltage by adjusting the taps on the high voltage side of the main transformer (110kV/35kV) of the substation. It should be noted that the voltage adjustment range of the 35kV side busbar should be within 95%~105%, and it should be noted that the lower-level 6kV system voltage cannot exceed the range required by the production process. The on-site measurement time is scheduled at night, the device production is stable, and the process operation is not adjusted.

The test data should be timely and accurate. Timely is required to shorten the test time as much as possible to prevent the system voltage from affecting the test results due to external waveforms or production adjustments. The voltage adjustment interval during the actual test is 2 to 3 minutes; the accuracy is that the data records of the variables are required to be synchronized. This substation has power system integration. The automation system and real-time recording device can ensure that the data of voltage, active power, and reactive power are recorded at the same time. Table 1 shows the data recorded during the actual test, where the voltage is the standard unit value.

*Table 1: Test data*

| Time | Voltage/pu | Active power/MW | Reactive power/MVar |
|---|---|---|---|
| 19:45 | 0.9620 | 16.46 | 7.74 |
| 19:48 | 0.9689 | 16.59 | 7.83 |
| 19:51 | 0.9769 | 16.37 | 7.99 |
| 19:53 | 0.9783 | 16.41 | 8.15 |
| 19:56 | 0.9880 | 16.58 | 8.22 |
| 19:58 | 0.9906 | 16.68 | 8.31 |
| 20:01 | 1.0029 | 16.71 | 8.48 |
| 20:04 | 1.0154 | 16.82 | 8.72 |
| 20:07 | 1.0243 | 16.91 | 8.81 |
| 20:10 | 1.0334 | 16.94 | 9.02 |
| 20:13 | 1.0406 | 16.99 | 9.19 |
| 20:16 | 1.0480 | 17.07 | 9.27 |

## 4. Model parameter identification

The system identification theory provides a powerful theoretical basis and analysis tool for the overall measurement and identification method. Classical identification methods mainly include step response method, spectrum analysis method, least square method and so on. The least square method is the most basic method in the system identification theory. Because its principle is concise, easy to understand, and very effective, it is widely used in parameter estimation, so it is also the most familiar and commonly used method for engineering and technical personnel.

The least square method can be used to obtain the fitted model with the smallest variance with the measured data. Suppose the output variable is y, and the input variable is an n-dimensional variable $\boldsymbol{X} = (x_1, x_2, \cdots, x_n)$, and there is a linear relationship between them, as follows:

$$y = \theta_1 x_1 + \theta_2 x_2 + \cdots \theta_n x_n \tag{3}$$

In the formula, $\boldsymbol{\theta} = (\theta_1, \theta_2, \cdots \theta_n)$ is the set of constant parameters to be estimated. It is hoped that $x_1(i), x_2(i), \cdots, x_n(i)(i = 1,2, \cdots, m)$ and $y(i)$ to represent the measured data, the following $m$ linear equations can be obtained:

$$y(i) = \theta_1 x_1(i) + \theta_2 x_2(i) + \cdots \theta_n x_n(i) \quad i = 1,2, \cdots, m \tag{4}$$

Formula (4) is called the regression equation, and $\theta_i(i = 1,2, \cdots, m)$ is called the regression coefficient. Formula (4) can be organized into a simple matrix form:

$$\boldsymbol{Y} = \boldsymbol{X\theta} \tag{5}$$

Where $\boldsymbol{Y} = [y(1), y(2), \cdots, y(m)]^T$, $\boldsymbol{\theta} = [\theta_1, \theta_2, \cdots \theta_n]^T$,

$$\boldsymbol{X} = \begin{bmatrix} x_1(1) & \cdots & x_n(1) \\ x_1(2) & \cdots & x_n(2) \\ \vdots & \cdots & \vdots \\ x_1(m) & \cdots & x_n(m) \end{bmatrix}$$

When $m > n$, $\boldsymbol{\theta}$ can be estimated, but it is not the only $m$ equation that accurately satisfies the formula (4), because there may be model errors or measurement noise in the data.

Define the error vector $\varepsilon = [\varepsilon_1, \varepsilon_2, \cdots \varepsilon_m]^T$, and set

$$\boldsymbol{\varepsilon} = \boldsymbol{Y} - \boldsymbol{X\theta} \tag{6}$$

Choose a set of $\hat{\theta}$ such that the objective function

$$J = \sum_{i=1}^{m} \varepsilon_i^2 = \boldsymbol{\varepsilon^T \varepsilon} \tag{7}$$

Make the objective function minimum. Combining formula (6) and formula (7), then $J$ can be expressed as

$$J = (\boldsymbol{Y} - \boldsymbol{X\theta})^{\boldsymbol{T}}(\boldsymbol{Y} - \boldsymbol{X\theta}) = \boldsymbol{Y^T Y} - \boldsymbol{\theta^T X^T Y} - \boldsymbol{Y^T X^T \theta} + \boldsymbol{\theta^T X^T X \theta} \tag{8}$$

Differentiate $J$ with respect to $\theta$ and set it to zero, then an estimate $\hat{\theta}$ that minimizes $J$ can be obtained

$$\frac{\partial J}{\partial \boldsymbol{\theta}}|_{\theta=\hat{\theta}} = -2\boldsymbol{X^T Y} + 2\boldsymbol{X^T Y \hat{\theta}} = 0 \tag{9}$$

Therefore

$$\hat{\boldsymbol{\theta}} = (\boldsymbol{X^T X})^{-\boldsymbol{1}} \boldsymbol{X^T Y} \tag{10}$$

Then $\hat{\boldsymbol{\theta}}$ is called the least square estimate of $\boldsymbol{\theta}$, and $\boldsymbol{\varepsilon}$ is called the residual.

According to the data in Table 1, using the least square method, the static load model identification results of active power and reactive power are as follows:

Active power polynomial model:

$$P = 16.67(1.367U^2 - 2.291U + 1.924)$$

Active power exponential model:

$$P = 16.69U^{0.4578}$$

Reactive power polynomial model:

$$Q = 8.445(-1.579U^2 + 5.274U - 2.695)$$

Reactive power exponential model:

$$Q = 8.427U^{2.089}$$

In the above formula, $U$ is the standard unit value.

The parameters in the polynomials of the active and reactive power models above all have negative values. The reason is that the load of refining and chemical enterprises is relatively complex, especially the use of a large number of thyristors in the power system, so that the load model is no longer just constant impedance, constant current, and constant Power is a combination of three types of loads. Therefore, it is reasonable for the parameters to have negative values in the identification results. If the constraint that the parameters are positive is added in the optimization process, although there are estimated values, the result error will increase.

The comparison between the identification result and the test data is shown in Figure 1 and Figure 2:

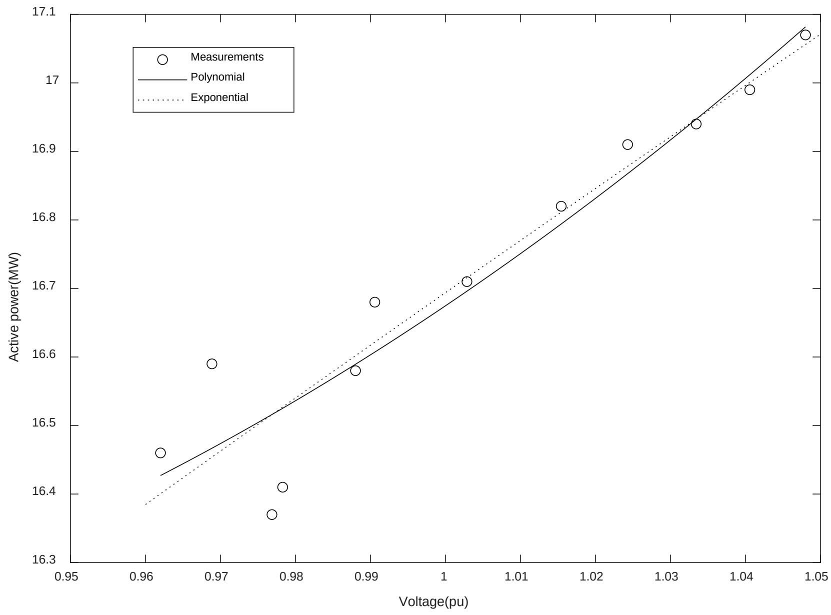


*Figure 1: Fitting curve of active power*

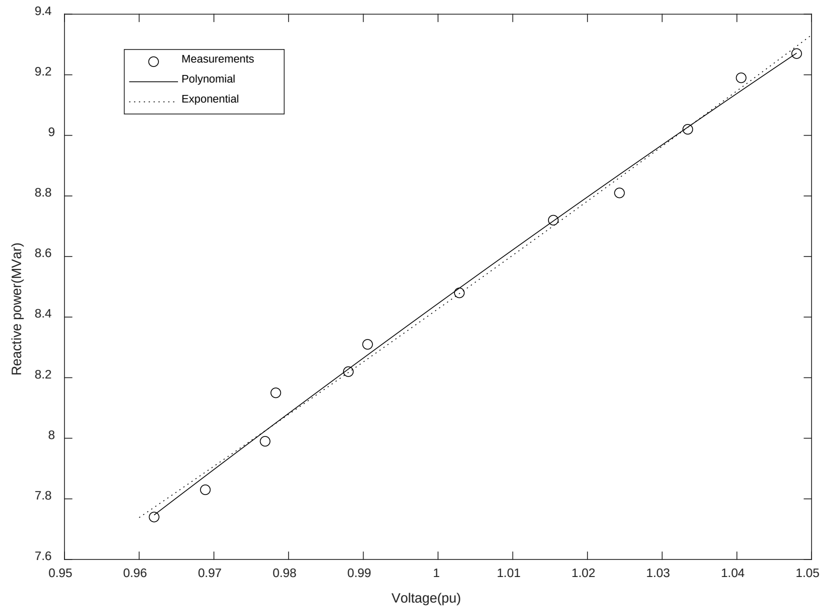


*Figure 2: Fitting curve of reactive power*

*R-square* and *RMSE* are two indicators to measure accuracy, and they are also important scales for evaluating models. R-square is the coefficient of determination, which is the ratio of the *SSR* of the difference between the fitted data and the mean of the experimental data to the *SST* of the difference between the fitted data and the mean (*SSR/SST*). The value range is [0 1], The closer it is to 1, the better the model expresses the experimental data. *RMSE* is the root mean square error, which is the square root of the ratio of the sum of the squares of the deviation of the fitted data and the experimental data to the number of trials $N$. The value range is [0 $\infty$]. The closer to 0, the better the accuracy of the model and the experimental data. Table 2 is the evaluation index of the identified static load model.

*Table 2: Load model evaluation index*

| Evaluation index | Active power load model | | Reactive power load model | |
|---|---|---|---|---|
| | polynomial | exponential | polynomial | exponential |
| $R - square$ | 0.9029 | 0.8982 | 0.9933 | 0.9925 |
| $RMSE$ | 0.0814 | 0.0790 | 0.0474 | 0.0476 |

Through Figure 1, 2 and Table 2, it shows that the fitting of the polynomial model and the exponential model of the static load model based on the field test data has reached a relatively high accuracy.

It should be noted that in low-voltage systems such as 380V bus, it can also be carried out simultaneously with the actual measurement process to establish a static load model under the low-voltage bus. As for the static load model at the 110kV bus, the static load model at the 35kV bus can be integrated with the branch reactance of the 110kV/35kV transformer, and the static load model at the 110kV bus can be obtained. This process belongs to comprehensive statistics. Method, the calculation process is very simple, related topics are described in the literature, this paper will not be expanded here.

## 5. Conclusions and Discussion

According to the characteristics of the power system of the refining and chemical enterprises, this paper adopts the steady-state test method to establish the static load polynomial model and the exponential model, and analyzes the fitting results to provide guidance for the relevant work of the refining and chemical enterprises.

## References

*[1] H. Renmu , M. Jin, and D. J. Hill, "Composite load modeling via measurement approach," IEEE TRANSACTIONS ON POWER SYSTEMS PWRS, vol. 21, no. 2, p. 663, 2006.*

*[2] A. H. A. Bakar, S. Yusof, M. Satchiananda , and S. Mekhilef, "Load response towards voltage in tnb power system using the measurement approach," in 2006 IEEE International Power and Energy Conference.IEEE, 2006, pp. 318–323.*

*[3]Y. Baghzouz and C. Quist, "Determination of static load models from ltc and capacitor switching tests," in Power Engineering Society Summer Meeting, 2000. IEEE, vol. 1. IEEE, 2000, pp. 389–394.*

*[4] M. Eremia and M. Shahidehpour, Handbook of electrical power system dynamics: modeling, stability, and control. John Wiley & Sons, 2013,vol. 92.*

*[5] A. Dixit and S. K. Jain, "Genetic algorithm based optimal placement of phasor measurement units for harmonic source identification," 2016 7th India International Conference on Power Electronics (IICPE), Patiala,2016, pp. 1-6.*