STUDY ON EXTENSION METHOD BASED ON THE LOAD MODEL BASIC VECTOR

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1 Introduction

Load characteristics have important effects on dynamic performance of power system. The failure to represent loads in sufficient detail may produce results that miss significant phenomena. The existing load model was inadequate to simulate real process of power system, therefore development and use of more accurate dynamic load models is highly desirable.

To get load model for different physical loads in different places in large-scale power grid, measurement devices must be set to record the load dynamic characteristic. This has no problem in theory, but actually, with the power grid bigger and bigger, it's unacceptable in project to mount so many devices, for the cost on manpower, material resource and money.

At present， load model which used in Chinese power system simulation is rough, for example, load model in north-east grid is 50% static ZIP which is composed by constant impedance, constant power and constant current load, and 50% induction motor which represents the dynamic characteristic of load, load model in north China grid is 40% constant impedance load and 60% constant power load.

2 Research Background

The history of load modelling research is very long , load modeling began in the thirties of the 20th century, and have quickly developed in the sixties of the 20th century, and Measurement-Based Modeling Approach came into being in the eighties of the 20th century.

There are two methods of load modeling: Statistics -Based Modeling Approach and Measurement-Based Modeling Approach. Each has its own merit. Merit of Statistics -Based Modeling Approach is that visually statistical data, being easy to understand and with no complication of measure. The disadvantage is that it taking time, taking efforts and inaccurate. Merit of Measurement-Based Modeling Approach is for its credible data, simple procedure and easy operation

Different methods of load modeling have different advantages. This paper combine Statistics-Based Modeling Approach with Measurement-Based Modeling Approach. The results are applied in the actually power system practice.

3 The Structure of Load Model

Load model represents the relation between the power and voltage (frequency) and can be classified in many ways[1,2]. Load model can be classified static model which is described by algebra equation and dynamic model which is described by differential equation; or mechanism model and input/output model; linearity model and nonlinearity model; etc.

3.1 Static Load Model

(1) Exponential Model

$$
\begin{aligned}
P &= P_0 (V/V_0)^{np} \\
Q &= Q_0 (V/V_0)^{nq}
\end{aligned} \qquad (1)
$$

(2) Polynomial Model(“ZIP”Model)

$$
\begin{aligned}
P &= P_0[a_1(V/V_0)^2 + a_2(V/V_0) + a_3] \\
Q &= Q_0[a_4(V/V_0)^2 + a_5(V/V_0) + a_6]
\end{aligned} \qquad (2)
$$

(3) EPRI LOADSYN Model

$$
\begin{cases}
P = P_0\{P_{a1}(V/V_0)^{KPV1} \\
\qquad [1+KPF1(f-f_0)] + (1-P_{a1})(V/V_0)^{KPV2}\} \\
Q = P_0\{Q_{a1}(V/V_0)^{KQV1}[1+KQF1(f-f_0)] + \\
\qquad (Q_0/P_0 - Q_{a1})(V/V_0)^{KQV2}[1+KQF2(f-f_0)\}
\end{cases} \qquad (3)
$$

(4) EPRI ETMSP Model

$$
\begin{aligned}
P &= P(CI) + P(CMVA) + P(CZ) + P(V, f) \\
Q &= Q(CI) + Q(CMVA) + Q(CZ) + Q(V, f)
\end{aligned} \qquad (4)
$$

(5) PTI IEEE Model

$$
\begin{cases}
P_L = P_0\left(a_1 V^{K1} + a_2 V^{K2} + a_3 V^{K3}\right)\left(1 + a_4 \Delta f\right) \\
Q_L = Q_0\left(a_5 V^{K4} + a_6 V^{K5} + a_7 V^{K6}\right)\left(1 + a_8 \Delta f\right)
\end{cases} \qquad (5)
$$

3.2 Dynamic Load Model

(1) Non-mechanism Model

Non-mechanism model that developed from system identification theory has the advantage of generalizing a great deal of specific dynamic system and representing exactly the dynamic characteristics. Non-mechanism model has universal relevance because it lays stress on the representation of the dynamic characteristics but not on model's mechanism explain. There are various non-mechanism model: constant differential equation model, difference equation model, transfer function model, state space model, time domain disperse model, artificial neural network model, genetic arithmetic model and machine self-study model.

(2) Mechanism Model
Induction motor model is used by many papers to represent the dynamic characteristics because induction motor is the major component of dynamic load in power system. Induction motor has the equivalence circuit which has clear and definite physical meaning, therefore one (or two) high-capacity induction motor represents the dynamic load of one node (or substation) in power system.

3.3 Comprehensive Load Model

Comprehensive load model is being more and more accepted by researchers because the comprehensive load model consists of static load and dynamic load represent both static characteristic and dynamic characteristic[3,4,5,6,7]. It is general that comprehensive load model is represented by a induction motor and a static ZIP which is composed of constant impedance, constant power and constant current load.

4 Extension Method

There is a question of how to gain all load model from the measurement-based load model[8,9,10]. An extension method which we present in this chapter can solve this problem. Load model are classified to *m* types (industry; agriculture; commerce; resident and railway etc.) which respectively corresponds to *m* load model vectors.
There are *n* substations (transmission lines) which could get the load model through measurement. If $n \geq m$, the *m* load model vector radix can be obtained through the *n* load models based on measurement. Then load model in the other substations can be obtained by extension method through the m load model vector radix which are as follows[11]:

$$\left[r_s, X_s, X_m, r_r, X_r, T_j, A, B, K_{pm}, M_{lf}, P_Z, P_I, Q_Z, Q_I\right]$$

The simple form of the basic equation is:

$$A_{n\times m} \bullet X_{m\times 14} = \mathrm{B}_{n\times 14}$$

Where A is the load model coefficient matrix which can be further divided into winter and summer coefficient matrix; B is the load model parameter of measured substation which can be further divided into winter and summer parameters.
The basic equation is:

$$\begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,m-1} & a_{1,m} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,m-1} & a_{2,m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n-1,1} & a_{n-1,2} & \cdots & a_{n-1,m-1} & a_{n-1,m} \\ a_{n,1} & a_{n,2} & \cdots & a_{n,m-1} & a_{n,m} \end{bmatrix}_{n\times m} \bullet \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{m-1} \\ x_m \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_{n-1} \\ b_n \end{bmatrix}$$

$$x_i = \left[r_s, X_s, X_m, r_r, X_r, T_j, A, B, K_{pm}, M_{lf}, P_Z, P_I, Q_Z, Q_I\right]$$

$$b_i = \left[r_s, X_s, X_m, r_r, X_r, T_j, A, B, K_{pm}, M_{lf}, P_Z, P_I, Q_Z, Q_I\right]$$

Therefore

$$B_{n\times 14} = \begin{bmatrix} \mathrm{b}_{1,1} & \mathrm{b}_{1,2} & \cdots & \mathrm{b}_{1,13} & \mathrm{b}_{1,14} \\ \mathrm{b}_{2,1} & \mathrm{b}_{2,2} & \cdots & \mathrm{b}_{2,13} & \mathrm{b}_{2,14} \\ \vdots & \vdots & & \vdots & \vdots \\ \mathrm{b}_{n-1,1} & \mathrm{b}_{n-1,2} & \cdots & \mathrm{b}_{n-1,13} & \mathrm{b}_{n-1,14} \\ \mathrm{b}_{n,1} & \mathrm{b}_{n,2} & \cdots & \mathrm{b}_{n,13} & \mathrm{b}_{n,14} \end{bmatrix}_{\mathrm{n}\times 14}$$

Other unknown load models are obtained by extension method through the regional load model vector radix which is obtained through basic equation mentioned above.

$$\begin{bmatrix} M_1 \\ M_2 \\ \vdots \\ M_{x-1} \\ M_x \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,m-1} & a_{1,m} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,m-1} & a_{2,m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{x-1,1} & a_{x-1,2} & \cdots & a_{x-1,m-1} & a_{x-1,m} \\ a_{x,1} & a_{x,2} & \cdots & a_{x,m-1} & a_{x,m} \end{bmatrix}_{x\times m} \bullet \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{m-1} \\ x_m \end{bmatrix}$$

5 Application

To give an example, the load models in Heilongjiang province grid are divided into 4 types (industry; agriculture; resident; the other) which respectively correspond to 4 load model vector. There are 10 measured transmission lines (Qingtai line; Xiyao line; Xigujia line; Xiwan line; Qingshajia line; Jizhang line; Qinghuayi line; Qinglajia line; Jiguangjia line; Xijiao line) which respectively correspond to 10 load models, so m=4 and n=10.The winter load model and summer load model are discussed as follows:
Winter load model coefficient matrix is

$$A1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0.97 & 0 & 0.03 & 0 \\ 0.95 & 0.02 & 0.03 & 0 \\ 0 & 0.8 & 0.2 & 0 \\ 0.9 & 0 & 0.1 & 0 \\ 0.1 & 0.8 & 0 & 0.1 \\ 0.5 & 0 & 0.4 & 0.1 \\ 0.12 & 0 & 0.37 & 0.51 \\ 0.3 & 0.03 & 0.5 & 0.17 \end{bmatrix}$$

Summer load model coefficient matrix is

$$A2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0.97 & 0 & 0.03 & 0 \\ 0.95 & 0.02 & 0.03 & 0 \\ 0 & 0.8 & 0.2 & 0 \\ 0.9 & 0 & 0.1 & 0 \\ 0.1 & 0.8 & 0 & 0.1 \\ 0.5 & 0 & 0.4 & 0.1 \\ 0.12 & 0 & 0.37 & 0.51 \\ 0.3 & 0.03 & 0.5 & 0.17 \end{bmatrix}$$

the winter load model parameter is

$$B_1 = \begin{bmatrix} 0.079176 & 0.155373 & 3.263529 & 0.021255 & 0.198980 & 0.450588 & 0.615686 & 0.695686 & 0.611176 & 0.570980 & 0.207922 & 0.750431 & 1.929412 & -1.176471 \\ 0.071765 & 0.127804 & 2.571765 & 0.036078 & 0.215216 & 0.667059 & 0.604706 & 0.973333 & 0.31 & 0.497255 & 0.073412 & 0.784510 & 2.4 & 1.772549 \\ 0.079451 & 0.229137 & 2.508235 & 0.050353 & 0.214314 & 1.283529 & 0.929412 & 0.913725 & 0.758627 & 0.721569 & 0.073412 & 0.558353 & 3.749020 & -3.372549 \\ 0.079725 & 0.228392 & 2.677647 & 0.023176 & 0.242275 & 0.384706 & 0.774118 & 0.877647 & 0.504510 & 0.614902 & 0.054196 & 0.617216 & 0.549020 & -2.0211765 \\ 0.077804 & 0.147176 & 2.818824 & 0.022078 & 0.177333 & 1.264706 & 0.673725 & 0.720784 & 0.422941 & 0.636863 & 0.025373 & 0.765922 & 1.427451 & -3.498039 \\ 0.032235 & 0.209020 & 3.397647 & 0.056392 & 0.241373 & 1.194118 & 0.918431 & 0.984314 & 0.165686 & 0.658824 & 0.480784 & 0.651294 & 2.525490 & 0.862745 \\ 0.044039 & 0.098 & 3.397647 & 0.020431 & 0.172824 & 1.26 & 0.880784 & 0.700392 & 0.200196 & 0.592941 & 0.075333 & 0.8 & -3.498039 & 2.274510 \\ 0.056118 & 0.200824 & 2.352941 & 0.024275 & 0.197176 & 0.94 & 0.792941 & 0.872941 & 0.353922 & 0.533333 & 0.108 & 0.784510 & 3.498039 & -2.211765 \\ 0.070392 & 0.088314 & 2.261176 & 0.020431 & 0.214314 & 0.991765 & 0.728627 & 0.847843 & 0.325686 & 0.541176 & 0.111843 & 0.719451 & -3.152941 & 1.929412 \\ 0.076157 & 0.097255 & 3.517647 & 0.022078 & 0.242275 & 1.382353 & 0.741176 & 0.902745 & 0.165686 & 0.500392 & 0.394314 & 0.601725 & -1.521569 & 2.023529 \end{bmatrix}$$

the 4 load model vector radix (industry; agriculture; resident and other) is

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} = \begin{bmatrix} 0.0667 & 0.2077 & 2.9302 & 0.0375 & 0.2215 & 0.7649 & 0.8164 & 0.8580 & 0.5342 & 0.6429 & 0.1816 & 0.6531 & 2.1268 & -1.3563 \\ 0.0649 & 0.1236 & 2.9232 & 0.0275 & 0.1869 & 1.0020 & 0.7045 & 0.8027 & 0.3191 & 0.5749 & 0.0341 & 0.7954 & 0.3119 & 0.3501 \\ 0.0717 & 0.1626 & 3.2025 & 0.0194 & 0.2294 & 1.8230 & 0.7043 & 0.9615 & 0.0210 & 0.4599 & 0.4440 & 0.6654 & 4.3720 & -2.9333 \\ 0.0627 & -0.0189 & 1.8392 & 0.0122 & 0.1990 & 0.5564 & 0.7880 & 0.7299 & 0.4011 & 0.5495 & -0.1005 & 0.7727 & -11.7506 & 7.9554 \end{bmatrix}$$

Heilongjiang grid's load model database is built by this extension method which is discussed in chapter 4.

6 Validity Analysis

To be simple, model vector radix can be described as the various typical load parameter vectors obtained by measurement-based method, such as typical industrial load parameter vector, typical agricultural load parameter vector, typical commercial load parameter vector and typical residential load parameter vector, etc. But load model vector radix is more applicative, more representative and has better time domain description than typical load parameter. This is verified in table 1 as follow:

Table 1-Comparison between load model vector and IEEE inductor's data

	Rs	Xs	Xm	Rr	Xr	Tj
Industrial vector	0.066	0.207	2.93	0.037	0.221	0.764
Big industry	0.013	0.067	3.8	0.009	0.17	3.0
Small industry	0.031	0.1	3.2	0.018	0.18	1.4
Residential vector	0.071	0.162	3.202	0.019	0.229	1.823
resident	0.077	0.107	2.22	0.079	0.098	1.48
Resident and industry	0.035	0.094	2.8	0.048	0.163	1.86

The validity of extension method is verified through the comparison between the extended load model and the measured load model. Taking Xishui line for example, the extension load model is :

[0.0669， 0.2063， 2.9383， 0.0369， 0.2217， 0.7967， 0.8130， 0.8611， 0.5188， 0.6374， 0.1894， 0.6535， 2.1941， -1.4036]

The dynamic characteristics are as follows:

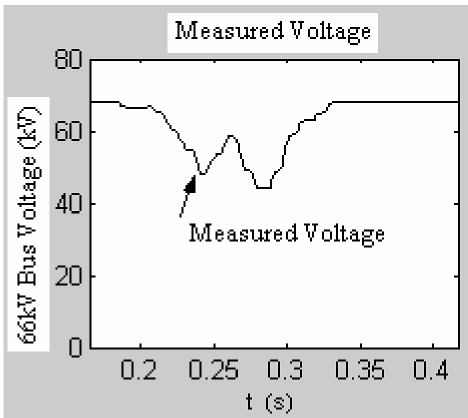

Fig1 Measured Voltage

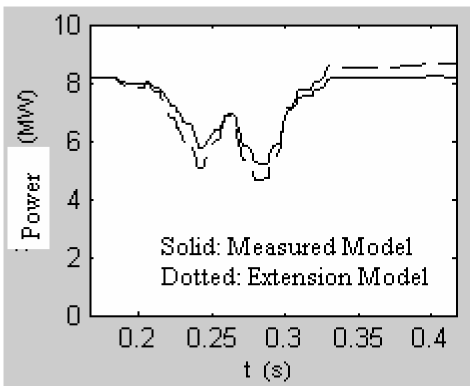

Fig2 Comparison between the extended model and the measured model

7 Conclusion

Extension method based on the load model basic vector radix is recommended in this paper, it has been applied to the Heilongjiang province power grid and gained large economic returns and social benefits. Ttransmission capacity limitation is increased in theory.

With the power grid bigger and bigger, it's unacceptable in project to mount so many devices, for the cost on manpower, material resource and money. Extension method has special advantage in large-scale power grid load modeling.

There are two problem in extension method. First, when computing load model vector radix, sometimes large number and negative number arise which have no physical explanation. Second, load model coefficient matrix is based on statistical data which have more random and subjectivity. To avoid these error, the extension method theory needs more research.

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