FACTA UNIVERSITATIS (NIŠ)
SER.: ELEC. ENERG. vol. 15, No. 3, Dec. 2002, 419-427

Load Modeling in Distribution Networks

Lidija Korunović and Dobrivoje Stojanović

Abstract: Experimental results of load model parameter determination on a substation middle voltage level are shown in this paper. This substation supplies residential load. The obtained parameters are different from literature data, because they depend on many factors such as climatic, economic and social ones. The measurements are performed for different day intervals and week days during winter. It is pointed out that real and reactive power sensitivities on voltage vary with voltage value. Mean polynomial static characteristics are presented, too. The obtained static characteristics are approximated by an exponential model with constant coefficients in the examined voltage range.

Keywords: load modeling, static characteristics, distribution networks

1 Introduction

Exact load flow calculation is necessary for successful exploitation, control and planning of distribution networks. The exactness of network condition calculation depends on the precision of input load parameter data. However, the value and component participation in the load, depends on the great number of factors: economic, social, climatic etc. Besides, distribution network loads vary during a day depend on a day of a week, season and change in the exploitation period.

Therefore, many authors have investigated load models and determined concrete load model parameters. Although, the number of papers and professional books, which consider this subject, is large, the fact is that the exact determination of load characteristic is practically impossible, having in mind the change of load composition in time and number of load components.

Manuscript received August 17, 2002.

The authors are with Faculty of Electronic Engineering, Beogradska 14, 18000 Niš, Yugoslavia, e-mails: `[lidijak, dstojanovic]@elfak.ni.ac.yu`.

According to the above mentioned facts, load modeling is very important, but also a rather complex job. Even if the load composition is known, it will not be practical to present every load component separately, because there are plenty of components in the total system load. Therefore, the total load is being aggregated [1, 2], and significant simplifications are being performed for load presentation [3, 4].

All load models can be divided into two groups, static and dynamic, and their application depends on concrete problem. Static models are used for steady-state condition calculations, but also for dynamic phenomena if the load bus encloses small part of electrical drives. Dynamic models are used for modeling of load that mostly consist of asynchronous and synchronous motors, air conditioners, as well as for research of lighting and thermostatically controlled load transients.

Most frequently used static models: exponential, polynomial and linear with neglected frequent dependence are considered in section 2 of this paper. Having in mind the fact that load model parameters differ very much for distribution network nodes [5-8], these are empirically determined and the results are shown in section 3. Furthermore, they can be extrapolated throughout the system for distribution network loads that supply consumers of similar composition. It is a basis of the measurement-based approach to determination of load characteristics.

2 Most Frequently Used Load Models

Static load models express load characteristics at a certain moment as the functions of voltage value and frequency. These load models can be divided into several groups: exponential, polynomial, complex, fuzzy logic model [6,8,9]. Here will be presented only most frequently used ones.

Traditionally, load dependence on voltage and frequency is presented by exponential model. Network voltage is commonly varied much more than frequency. Therefore, frequency dependence can be ignored:

$$P = P_n \left(\frac{U}{U_n} \right)^{k_{pu}}, \tag{1}$$

$$Q = Q_n \left(\frac{U}{U_n} \right)^{k_{qu}}, \tag{2}$$

where P and Q are real and reactive power at voltage U, P_n and Q_n are real and reactive power of load at nominal voltage U_n and, k_{pu} and k_{qu} are selfregulation coefficients for real and reactive power. When both exponents in the model (1) and (2) are equal to 0, 1 or 2, the load is of constant power, constant current or constant impedance type, respectively.

The selfregulation coefficients of this exponential model, k_{pu} and k_{qu}, show the percentage variations of real and reactive power, respectively, for the percentage of voltage change in the nominal voltage proximity [7]. Therefore, k_{pu} and k_{qu} can be named partial derivatives of real and reactive power with respect to voltage [1], or sensitivity coefficients [9].

Model, which is also frequently used for voltage dependence on load, is polynomial model. The second order polynomial model is most frequently used because the approximation with higher order polynomial does not contribute to more exact load modeling, because during experimental or calculation static characteristic determination, certain mistakes are made. Widely used polynomial model is

$$P = P_n\Big[p_1\left(\frac{U}{U_n}\right)^2 + p_2\left(\frac{U}{U_n}\right) + p_3\Big], \tag{3}$$

$$Q = Q_n\Big[q_1\left(\frac{U}{U_n}\right)^2 + q_2\left(\frac{U}{U_n}\right) + q_3\Big]. \tag{4}$$

The common name for this model is ZIP model, considering its composition of constant impedance (Z), constant current (I) and constant power (P) loads. If the total load is of constant impedance type, the coefficients are $p_1 = q_1 = 1$, while all other are equal to zero. Load type of constant current is modeled by means of $p_2 = q_2 = 1$ and constant impedance by means of $p_3 = q_3 = 1$, while other coefficients are equal to zero.

Linear load models can be obtained for small voltage variations:

$$P = P_n + \alpha(U - U_n), \tag{5}$$

$$Q = Q_n + \beta(U - U_n). \tag{6}$$

In the case of small voltage variations in (1) and (2) $\alpha = k_{pu}P_n/U_n$ and $\beta = k_{qu}Q_n/U_n$ [9].

3 Measurement Results

In order to determine load model parameters, field measurements are performed. Load static characteristics on 10 kV level of the transformer 110/10 kV (substation “Niš 13”) which feeds residential load are determined. Measurements of real power, current, power factor and impedance for voltage variations are performed by means of power analyzer D 5135 - "NORMA" during January 2001.

The frequency was not measured, because this variable changes in a narrow proximity of its nominal value. Therefore, it is considered that all real and reactive power changes are due to voltage variations. Every experiment is repeated several times, and static characteristics are obtained by the second order polynomial fitting using the least square method. The static characteristics are then approximated by exponential curves with the exponents that are equal to partial derivatives of real and reactive power with respect to voltage for nominal voltage value.

According to the fact that the load varies during a day, experiments of source voltage variations by means of load tap changer are performed in intervals with the smallest load oscillations. These intervals are found on the basis of the measured daily load curve and on the basis of the experience of distribution company workers. In Fig. 1, daily load curve is given as a histogram. According to that, morning peak occurs in the period between 8 and 9 o' clock, periods between 9 and 11 o' clock, and 3 to 5 p.m., are with almost constant load. Other day intervals have small load variations, and static real and reactive characteristics are recorded between 9 and 10 p.m., too. In the period between 11 p.m. to 5 a.m. there is a rapid load decrease, with the minimum between 4 and 5 o' clock.

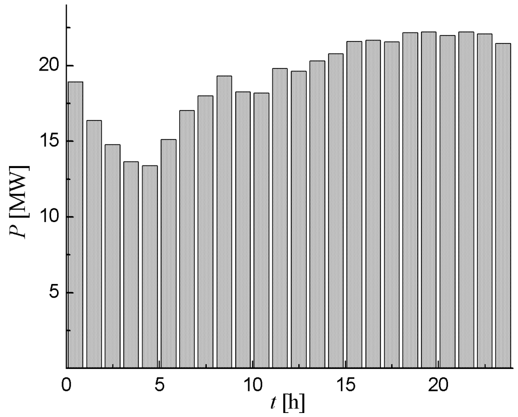


Fig. 1. Daily load curve of a working day.

This load diagram differs significantly from the typical one for residential load in our country. Low price of electric energy globally contributed to the increase of the load due to electric energy usage for home heating and cooking, as well as for load curve leveling, so there is no a characteristic night peak. Relation between real and reactive power was large during all day, i.e. the power factor is varied in narrow proximity of the value 0.987.

One measurement circle of load tap change lasted for several minutes, and the curve obtained from every measurement circle has hysteresis shape, Fig. 2. Static load characteristic in a certain day interval is obtained as the result of several measurements. Correlation coefficients and standard deviations of these characteristics show the adequacy of applied polynomial regression. Therefore, correlation coefficients, R_P and R_Q, as well as standard deviations, SD_P and SD_Q, of real and reactive power characteristics, respectively, for different day intervals, are given in Table 1. Real and reactive power sensitivities on voltage for nominal voltage, $\partial P/\partial U$ and $\partial Q/\partial U$, are shown in the same table.

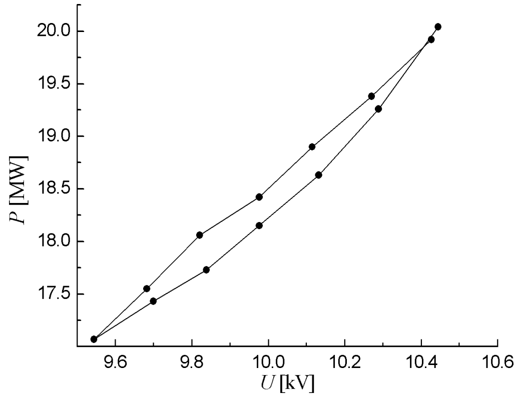
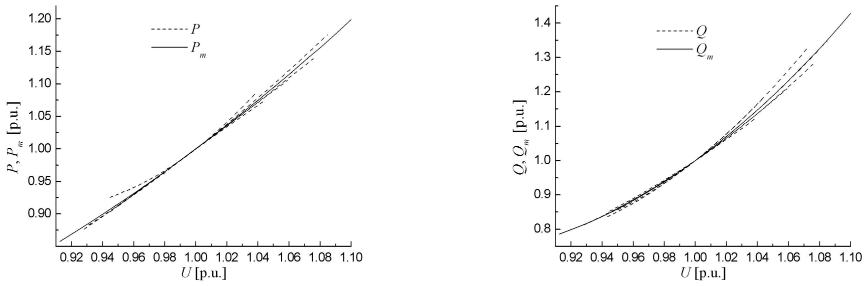


Fig. 2. Real power variations during one measurement circle.

Sensitivity coefficients of real power on voltage from the table for the working and weekend days differ less than 2.4% from the corresponding mean values. It means that for certain day intervals the mean value can be accepted: 1.753 for morning, 1.795 for afternoon and 1.817 for night. These values differ from 2 that corresponds to purely resistive load in the proximity of nominal voltage. Furthermore, all obtained static characteristics of real power for different day intervals and days in a week can be presented by mean static characteristic shown in Fig. 3a). Correlation coefficient (R_P) and standard deviation (SD_P) of this fitting curve are 0.9983 and 0.004, respectively, and real power sensitivity on voltage is 1.792. The curve sensitivity values differ less than 4.3% from this mean value. According to the figure all static characteristics are similar. This fact indicates that the load composition is almost the same in different day intervals, as well as in days of a week.

Table 1. Correlation coefficients and standard deviations of fitting curves, and real and reactive power sensitivities on voltage for U_n.

Day interval	Morning		Afternoon		Night	
Day	Working day	Weekend day	Working day	Weekend day	Working day	Weekend day
R_P	0.9962	0.9843	0.9881	0.9980	0.9843	0.9986
SD_P	0.0039	0.0079	0.0079	0.0043	0.0062	0.0037
$\partial P/\partial U$	1.716	1.791	1.767	1.812	1.861	1.774
R_Q	0.9855	0.9832	0.9808	0.9853	0.9346	0.9815
SD_Q	0.0156	0.0655	0.0182	0.0215	0.0223	0.0241
$\partial Q/\partial U$	3.565	3.616	3.135	3.169	2.962	3.138



(a) (b)

Fig. 3. (a) Static characteristics of real power P and mean characteristic P_m, (b) Static characteristics of reactive power Q and mean characteristic Q_m.

The sensitivity values of reactive power for morning are significantly larger than for other day intervals. This can be explained by saturation of distribution transformers. Mean values of reactive power sensitivity for morning, afternoon and night are: 3.59, 3.152 and 3.05, respectively. Deviations from these values are less than 2.9% for certain day intervals. Static characteristics of reactive power on voltage variations for different day intervals and days, as well as mean static characteristic are shown in Fig. 3.b). Correlation coefficient (R_Q) and standard deviation (SD_Q) of this mean curve are 0.9972 and 0.0098, respectively, and reactive power sensitivity on voltage for nominal voltage is 3.264. The values of reactive power sensitivity from the table differ less than 10.8% from this number. The mean curve approximates static characteristics relatively well in the range from 0.95 to 1 p.u. of the voltage, giving 6% lower sensitivity. At higher part of the curve, for the voltage from 1 to 1.05 p.u., the sensitivity of the mean curve differs up to 18% from those that are obtained by measurements. This shows that the slope of reactive power characteristic significantly varies, so, selfregulation coefficient in the wide range, from 1.6 to 6, can be found in literature [6].

The sensitivities of real and reactive power on voltage are similar to those from literature [6] for residential load during winter, but also, totally different values can be found in literature [5, 8]. This shows that every region has different load composition even for the same load class. Therefore, it is necessary to obtain concrete static characteristics, and incorporate them in further calculations and investigations.

Mean static characteristics of real and reactive power in the voltage range $U \in [0.915 \div 1.1 p.u.]$ are

$$P = 1.12 - 2.032U + 1.912U^2, \tag{7}$$

$$Q = 7.486 - 16.27U + 9.784U^2. \tag{8}$$

Once the mean static characteristics are obtained, the approximation with exponential curves can be done and this is shown in Fig. 3. The mistakes made by these approximations are less than 1.1% for real power, and less than 6% for reactive power for the margins of the examined voltage range.

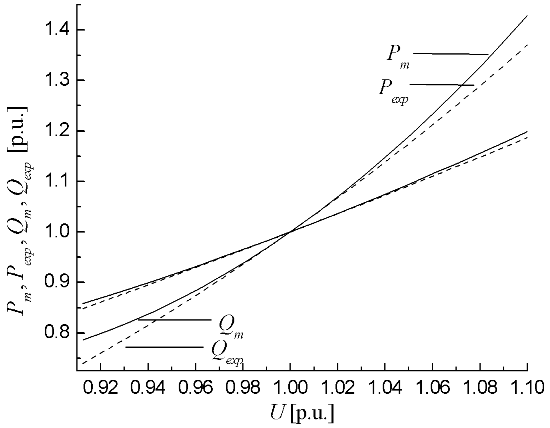


Fig. 4. Mean polynomial and exponential static characteristics of real and reactive power.

4 Conclusion

On the bases of the measured static characteristics on transformer 10 kV level it is shown that the load during winter is mostly resistive with small participation of asynchronous motors and lighting. This confirms the fact that the power factor is close to 1. Load curve and static characteristics show that economical and social factors influence the component participation in total load and should be taken into account for determination of load static characteristic in the component based approach.

In the examined case, static characteristics of real power for different day periods and week days can be replaced by mean characteristic causing the real power sensitivity mistake less than 5%. Reactive power sensitivity varies more among curves obtained in different day intervals. Mean static characteristics can be approximated well by exponential curves with constant coefficients in the examined voltage range.

Beside the prediction of a daily load curve, further investigations should be connected with determination of static characteristics of distribution network nodal loads with industrial and commercial load, as well as with their application for power and energy loss reduction by voltage regulation.

Acknowledgment

The authors would like to thank "JP Elektrodistribucija - Niš" for allowing field measurements in the substation.

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