Load Parameters in Low Voltage Distribution Networks

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***Abstract* – Results of the experimental load model parameter determination on low voltage of distribution networks are shown in this paper. Static characteristic parameters of typical representatives of resistive load, indoor and outdoor lighting are determined and compared with literature data. Equivalent parameters of residential load and outdoor lighting are also obtained by measurements and compared with parameters of examined devices and literature data. Correlation of real and reactive power sensitivities on voltage and voltage value is analyzed.**

***Keyword* – distribution network, load modeling, static characteristics**

I. Introduction

Exact load flow calculation is necessary for successful exploitation, control and planning of distribution networks. The accuracy 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 and 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.

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], and significant simplifications are being performed for load presentation [2].

All load models can be divided into two groups, static and dynamic, and their application depends on concrete problem.

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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 for certain low voltage devices and distribution network nodes [1, 3-8], these are empirically determined. Measurements are performed by means of power analyzer D 5135 - "NORMA".

II. Most Frequently Used Load Models

Static load models express load characteristics at a certain moment as the functions of voltage value and frequency. This load models can be divided into several groups: exponential, polynomial, complex, fuzzy logic model [7, 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:

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

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

where

P and Q - real and reactive power at voltage U,

P_n and Q_n - real and reactive power of load at nominal voltage U_n,

k_{pu} and k_{qu} - selfregulation coefficients of 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 [6]. 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:

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

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

The common name of 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.

III. Measurement Results

In order to determine load model parameters at 0.4kV voltage level, laboratory and field measurements that imply supply voltage variation are performed. The frequency was not measured, because this variable changed in a narrow proximity of its nominal value. Therefore, it was considered that all real and reactive power changes were 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 and network nominal voltage as base value. Then, partial derivatives of real and reactive power with respect to voltage, for different voltage values, are calculated.

Equivalent load static characteristics of one residential building and outdoor lighting are obtained. Also, components of these equivalent loads are chosen for experiments among plenty of low voltage devices. These are "typical" representatives of resistive load, indoor and outdoor lighting. Data of the devices are given in Appendix.

Static characteristic of single phase electric heater and hot plate real power are obtained in the voltage range $U \in [0.8 - 1.1\text{p.u.}]$:

$$P = -0.148 + 0.373 \cdot U + 0.775 \cdot U^2, \qquad (5)$$

$$P = 0.251 - 0.473 \cdot U + 1.222 \cdot U^2, \qquad (6)$$

and depicted in Fig. 1. These characteristics have dominant coefficient of square term. Fig. 2 shows partial derivatives of real powers with respect to voltage, i.e. real power sensitivities on voltage, $\partial P / \partial U$. Under nominal voltage these sensitivities are 1.92 and 1.97, respectively. In the literature [1, 3, 5-7], $\partial P / \partial U$ of resistive devices is specified as 2, which corresponds to constant impedance load type. Although the declinations of the sensitivities obtained by measurements from number 2 are mostly 4%, the results of these experiments show that constant impedance load type can not characterize even resistive devices.

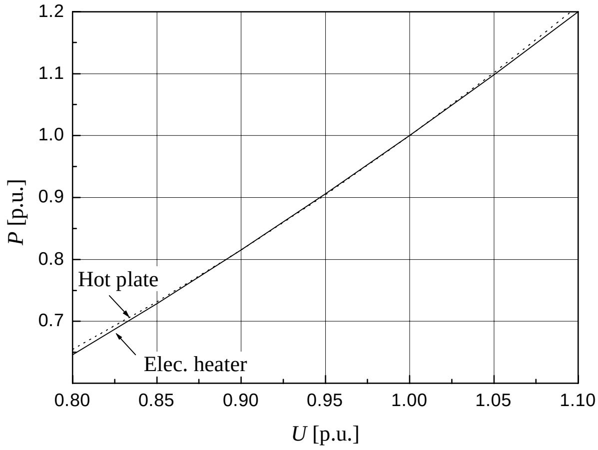

Fig. 1. Static characteristics of resistive load

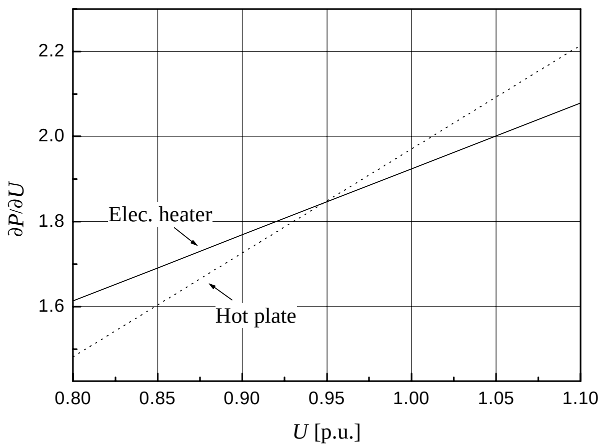

Fig. 2. Real power sensitivity on voltage of resistive load

Real power sensitivity on voltage of both devices changes with voltage variations, because their resistance changes with temperature. Thus, with voltage variation from 0.8 to 1.1p.u., sensitivity changes within the range 1.61-2.08 for electric heater and 1.48-2.21 for hot plate. This fact may be important when exponential load model, Eqs. (1) and (2), is used in the wide voltage range and therefore cause calculation mistakes.

Fluorescent lamp static load characteristics are

$$P = -0.102 + 0.511 \cdot U + 0.592 \cdot U^2, \qquad (7)$$

$$Q = 3.495 - 9.574 \cdot U + 7.081 \cdot U^2 \qquad (8)$$

in the voltage range $U \in [0.8 - 1.1\text{p.u.}]$. These are depicted in Fig. 3. On the basis of these polynomials, real and reactive power sensitivities on voltage are 1.69 and 4.67, respectively, in the close proximity on nominal voltage. These values are close to data specified in [2] for fluorescent lamp, but totally different from other literature values. For example, 0.96 and 7.4 are specified in [5]. According to the first derivative of Eq. (7) real power sensitivity coefficient changes from 1.46 to

1.82 with voltage variation from 0.8 to 1.1p.u. Reactive power sensitivity on voltage changes significantly, from 1.45 to 6.32 for the same voltage variation, owing to the larger square term coefficient. Declination of 1.45 from reactive power sensitivity on voltage in the proximity of U_n is even 69%.

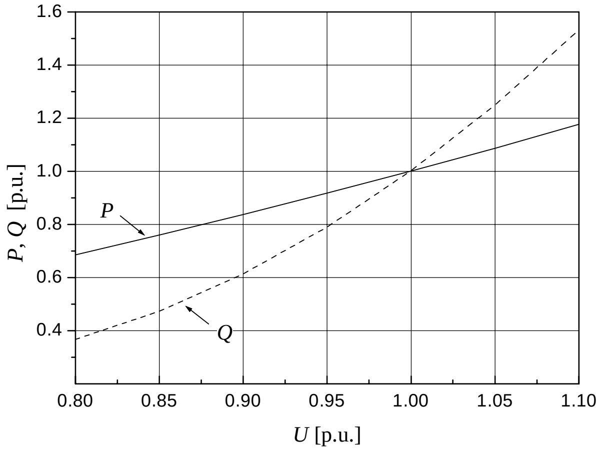

Fig. 3. Fluorescent lamp
real and reactive power dependence on voltage

The experiments are also carried out on mercury lamps for outdoor lighting of 125 and 250W rated power. These are denoted as lamp 1 and lamp 2, respectively. Static characteristics are specified in Table I and depicted in Fig. 4.

TABLE I

MERCURY LAMP STATIC CHARACTERISTICS FOR $U \in [0.85-1.1\text{p.u.}]$

Lamp Type	$P = F_1(U)$	$Q = F_2(U)$
Lamp 1	$-0.831+1.254\cdot U+0.577\cdot U^2$	$0.914-3.212\cdot U+3.299\cdot U^2$
Lamp 2	$-2.027+3.769\cdot U-0.741\cdot U^2$	$-0.015+0.719\cdot U+1.302\cdot U^2$

It may be noted that graphics of lamp 1 and 2 static characteristics are mutually similar. According to real power static characteristics of the lamps, linear term is dominant, and the dependence on voltage is approximately straight line. In the Eqs. of reactive power static characteristics, third term coefficient is greatest and the curves have parabolic shape.

Real power sensitivity on voltage in the proximity of nominal voltage is 2.41 and 2.29, for mercury lamp 1 and 2, respectively, and these values are close to the value specified in [3]. This coefficient is larger than the sensitivity of fluorescent lighting. Reactive power sensitivities in the proximity of rated voltage are 3.38 and 3.32 and significantly are higher than value in [3]. Real power sensitivities weakly change and opposite, reactive power sensitivities significantly change with voltage due to static characteristic shapes – nearly straight lines and parabolas. Power factors of mercury lamps are 0.55 and 0.58 because examined lamps operate without capacitor. Power factor of fluorescent lamps is significantly greater - 0.87. It was observed that power factor of both lamp types increases with voltage reduction and vice versa.

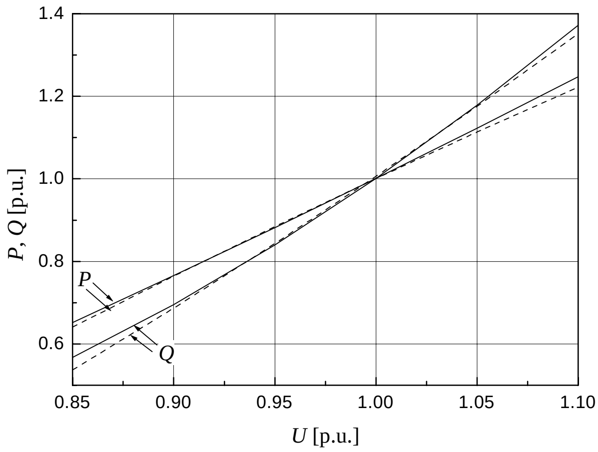

Fig. 4. Real and reactive power dependence on voltage
of mercury lamp 1 (———) and 2 (- - - - - -

Real and reactive power sensitivities show that none of examined devices belongs to the constant power, constant current or constant impedance load type. Also, the analysis reveals that these sensitivities are not constants and vary with voltage.

In next paragraphs, the experiment results of equivalent load static characteristics determination at 0.4kV voltage level are presented.

The measurements of total load of one residential building are performed during summer working day noon. This building also includes five offices. The voltage was varied by means of load tap changer at 110/35/10kV supply transformer station (Sarajevo 2).

Obtained static characteristics, in the voltage range $U \in [0.9-1.1\text{p.u.}]$ are

$$P = -0.575 + 1.324\cdot U + 0.2506\cdot U^2 , \qquad (9)$$

$$Q = 5.0815 - 13.068\cdot U + 8.986\cdot U^2 . \qquad (10)$$

These are presented in Fig. 5. Real and reactive power sensitivities on voltage in the proximity of nominal voltage are 1.83 and 3.81, respectively and power factor of the examined load is 0.979. In [5], for residential load class during summer are specified totally different values, $\partial P/\partial U = 1.2$, $\partial Q/\partial U = 2.9$ and $\cos\varphi = 0.9$. This may be explained by significant variety of load composition in different distribution networks that depends of economic, social, climatic and other factors. For example, in many countries, usage of air conditioners in summer increases. Their participation in total load influence on equivalent parameters and decrease them because typical parameters of window type air conditioner are $\partial P/\partial U = 0.468$, $\partial Q/\partial U = 2.5$ and $\cos\varphi = 0.82$ [5].

Experimentally obtained values of real power sensitivity on voltage and power factor, 1.83 and 0.979, confirm that non-resistive load participate in equivalent load. In the range 0.9-

$1.1U_n$, real power sensitivity on voltage changes from 1.78 to 1.88. Reactive power sensitivity varies in the wide range from 2.18 to 5.43 that exceeds ±42% of 3.81.

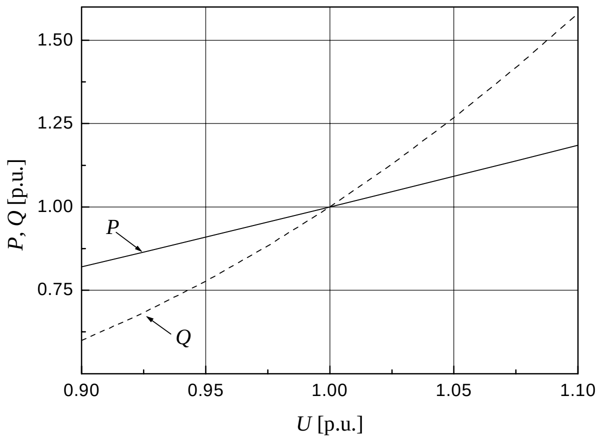

Fig. 5. Static characteristics of residential building load

The outdoor lighting load was simulated by 13 mercury lamps of 400W at each phase. These lamps are used as indoor lighting of IRCE High Voltage Laboratory in Sarajevo. The obtained static characteristics are

$$P = -1.630 + 2.572 \cdot U + 0.058 \cdot U^2, \qquad (11)$$

$$Q = 0.629 - 3.354 \cdot U + 3.725 \cdot U^2, \qquad (12)$$

and depicted in Fig. 6. Real and reactive power sensitivities on voltage for nominal voltage are 2.69 and 4.1, respectively, and power factor of the lighting is 0.7. Since real power characteristic is nearly straight line, real power sensitivity on voltage changes in narrow range from 2.68 to 2.7 for supply voltage from 0.9 to $1.1U_n$. Reactive power sensitivity on voltage changes from 3.35 to 4.84, i.e. declination from 4.1 is approximately 18%.

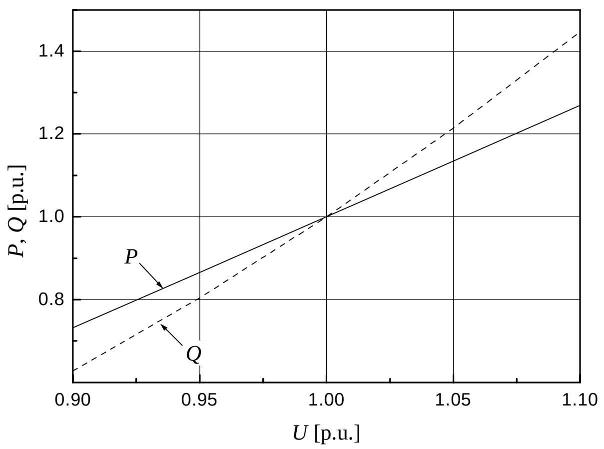

Fig. 6. Static characteristics of outdoor lighting

IV. Conclusion

The results of the paper show that none of the examined low voltage electric devices – representatives of resistive load, indoor and outdoor lighting belongs to the constant power, constant current or constant impedance load type. Real and reactive power sensitivities on voltage of these devices, of equivalent residential load and outdoor lighting, load differ from literature data. This points out the necessity of experimental load parameter determination and afterwards their incorporation in distribution network calculation. Also, real and reactive power sensitivities on voltage vary with voltage value and in some cases this variation is significant. It may cause larger calculation errors when exponential load model is used.

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Appendix

Resistive devices:

1. electric heater: type БДС 2099-85, P_n =1,6 kW, U_n =220 V, f_n=50 Hz, ЕЛВА КВАРЦ – Bulgaria,
2. hot plate: type PR13, P_n =700 W, U_n =220 V, f_n=50 Hz, FVUE FERIZAJ – Urosevac, Serbia & Montenegro.

Lighting:

1. fluorescent lamps: type FC 40 W, DS 6500°K , U_n =220 V, f_n =50 Hz, TESLA – Pancevo, Serbia & Montenegro,
2. mercury lamps:
   - HPL-N 125 W, PHILIPS, Made in Belgium,
   - HPL-N 250 W, PHILIPS, Made in Belgium.