Load Modelling by using Normal Operation Data

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Abstract – **This paper presents the results of load modelling obtained by using the data from normal operation of electric power system. Necessary data are stored by the computer which is the part of the equipment of transformer station TS 35/10kV. Voltage and real and reactive power data at the higher side of the station are analysed. The parameters of exponential load model are identified and grouped according to day periods and days of the week.**

Keywords – **Load modelling, Normal operation, Exponential load model.**

I. Introduction

The adequate load modeling is the base for electric power systems analysis of both steady-state operating conditions and transients. Therefore, load modelling is a very actual scientific theme and many papers concerning this matter have been published by now.

The parameters of low voltage devices can be determined on the basis of laboratory tests as explained in [1]. Much complicated task is determining of total load on medium voltage level. If the parameters of individual load components are known as well as its participation in total load, the task will be accomplished by the method of aggregation, i.e. by component based approach to load modelling [2]. Otherwise, measurement based approach to load modelling should be used [3]. The participation of load components in total load is very difficult to determine, since it varies during the day, changes depend on the day of the week and the season. Therefore, the second mentioned approach is the better one. It comprehends field measurements at selected buses of the network. Afterwards, the obtained load model parameters can be applied at the buses with similar load structure. However, measurement based approach is more complicated, since it implies permission of electrical distribution company, relatively expensive measuring equipment and participation of a group of people during the measurements.

The investigations regarding load modelling can be developed on those that are based on field tests and on the investigations based on continuous measurements. The field tests are allowed to be performed in time periods when they can not endanger electric power system operation. Furthermore, during the field tests, the changes of operating conditions are performed in a way that safety and the quality of a supply are bellow the limits [4]. Therefore, the ranges of the voltage changes during the tests are rather narrow [5]. Additionally, it becomes to be very difficult to get the permission for the field test in electric power system in the environment of electric energy deregulated market and generally in the market economy.

In the case of continuous measurements for load modelling, it is important to record the data in the time intervals when the disturbances in electric power system occur. For example, these are short-circuits or switching on/off large consumers [6]. Therefore, it is necassary to measure for a very long time to get relevant data, but despite that, this kind of investigations are usually based on the relativelly small number of valid data sets. Recording equipment used for continuous measurements should have much larger memory for data storage than the equipment used during field tests. Also, the recording equipment for continuous measurements very often have the possibility to proceed the data and sometimes even process the data by themselves [5], and by rule, it is very expensive.

This paper is the continuation of the research in the area of load modelling which results are collected in [4]. For this dissertation field tests were performed to obtain the load model parameters in distribution network of Nis. Due to the listed shortcomings of data gathering using field test, the paper deals with load modelling using continuous measurements. For this measurements microprocessor relays and the computer (so called station unit) which are the part of the remote control equipment in transformer station, are used instead of other expensive recording equipment.

The aim of the paper is to demonstrate the possibilities that the data stored by station unit enable in the domain of load modelling. Therefore, the results that relate to three week period during normal operation of the system are presented.

II. Normal Operation Data

Simplified principal schema of the equipment used for data storage, data transmission within the transformer station TS “Centar 1” and the transmission to other networking computers is presented on Fig. 1. The transformer station is equipped with microprocessor relays Siemens 7SJ63 that can send large number of variables. Near by relays are mutually connected with double optical cable and the first and the last one are also connected with the switch.

The computer in transformer station store the data from the relays, while remote terminal unit (RTU) communicate with the Control centre, that is equipped with supervisory control and data acquisition system (SCADA), over WAN (Wide Area Network) using Telekom router. In the case of

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interruption of this communication, alternative communication path is performed by the radio link.

The necessary data for load modelling are obtained from station unit in transformer station which is controlled by electric power distribution company „Jugoistok" Nis.

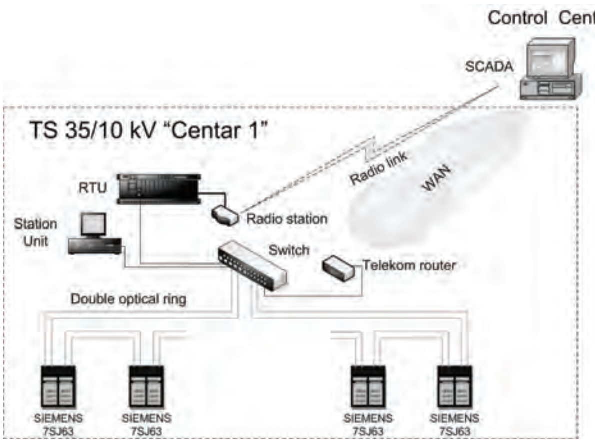

Fig. 1. Principal schema of the equipment for storage and transmission of data

Electrical simplified single-phase schema of TS "Centar 1" during the measurements is presented on Fig. 2. Two lines that are fed from TS "Nis 3" supply the transformer station which consists of two transformers 35/10kV. The station delivers the electric energy to the center of Nis trough 12 feeders. Since the aim of load modelling was to determine the parameters of the total load at 35kV voltage level, some of variables were selected to be stored in station unit every second. These are: three line voltages at 35kV bus, three-phase real and three-phase reactive power of both transformer T_1 and transformer T_2.

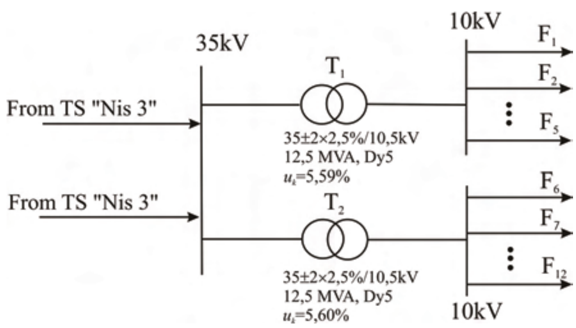

Fig. 2. Simplified single-phase schema of TS "Centar 1"

The data were recorded during three weeks every second, from Thursday 21st October to Wednesday 10th November in 2010. During this period the abrupt voltage changes that are characteristic of normal operation of the system were tracked. These changes are caused by electric power system regulation and/or disturbances and they are used for modelling of real and reactive power.

During 21 day period there were two days without any abrupt voltage change - Sunday and Monday, 24th and 25th October. Also, there were the days with several abrupt voltage changes. For example, Fig. 3 presents the voltage vs. time diagram recorded on Saturday 30th October when three abrupt voltage changes occurred.

The first voltage change is typical for most of the concerned days. It is the voltage decrease after the midnight when the voltage reaches pretty high value due to load decrease in electric power system and the decrease is the result of power system regulation that tend to keep the voltage under acceptable limits. This voltage decrease is for 1.268% of rated voltage value (U_n) and in other days it has similar amount.

The second abrupt voltage change from the figure is the voltage increase for 2.612% of U_n. It occurred at 20:25. In most of examined days, the voltage increase of approximately 1.3% of rated voltage happened earlier, from 16:30 to 18:30. This increase was the results of power system regulation, since in this time interval the voltage reached the lowest values.

The third abrupt voltage change from Fig. 3 is the voltage decrease for 1.345% of U_n at 23:20 also caused by the voltage regulation. Such kind of the voltage change before the midnight happened only five times during three week period. It is more usual that the voltage decrease appear after the midnight.

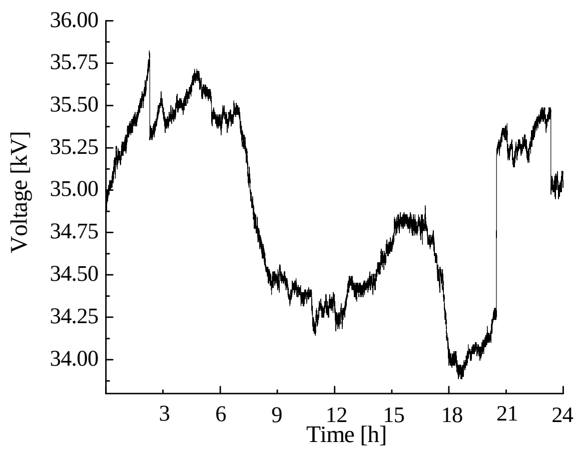

Fig. 3. The voltage diagram on Saturday 30th October

In concerned three week period 41 abrupt voltage changes occurred and all of them are considered in load modelling process. These changes are grouped according to time intervals of a day and days of the week and their number in considered intervals and days is presented in Table I. Most of the voltage changes occurred in the periods from 0 to 6h and from 12 to 18h - totally number 25, while per 8 changes happened from 6 to 12h and from 18 to 24h.

The voltage changes are also grouped according to days of the week. It is found that 30 changes appeared during working days (Table I), i.e. averagely 6 changes per one day - Monday to Friday. During three Saturdays and three Sundays in the period of 21 days, only 6 and 5 changes occurred, respectively. It shows the necessity of the further research in the longer time periods in order to capture much more abrupt voltage changes during weekends.

TABLE I
THE NUMBER OF ABRUPT VOLTAGE CHANGES

Time interval [h]	Number of changes	Day of the week	Number of changes
0-6	16	Monday - Friday	30
6-12	8		
12-18	9	Saturday	6
18-24	8	Sunday	5

III. ADOPTED LOAD MODEL

Exponential load model is one of the most frequently used static load models:

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

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

In this model P and Q denote real and reactive load power at voltage U, P_n and Q_n are real and reactive load power at rated voltage, respectively, k_{pu} and k_{qu} denote voltage exponent of real and reactive power.

In the vicinity of rated voltage, the parameters k_{pu} and k_{qu} represent partial derivatives of real and reactive power with respect to voltage [7]

$$k_{pu} = \frac{\partial P}{\partial U} , \tag{3}$$

$$k_{qu} = \frac{\partial Q}{\partial U} , \tag{4}$$

or real and reactive power sensitivities on voltage [8]. These parameters practically show the value of real and reactive power change in percents for one percent of voltage change in the vicinity of rated voltage [9]. If both voltage exponents in model (1) and (2) are 0, 1 or 2, the load is of constant power, current or impedance type, respectively.

The model (1)-(2) describes the changes of real and reactive power for voltage variations around the rated voltage. The analysis of all abrupt voltage changes during concerned three week period shows that almost all voltage changes are pretty small. Even 38 changes were smaller than 1.5% of U_n, two were around 2.6% of U_n and only one was 5.46% of rated voltage. Previous researches [8, 10] showed that exponential load model can be applied in relatively wide voltage range, somewhat smaller than the range 0.95-1.1pu with acceptable mistakes - up to 5%. Therefore, exponential load model is used for modelling of examined load.

However, most of the abrupt voltage changes during power system normal operation are not so close to rated voltage value. Therefore, another variant of exponential load model is applied. It uses initial real and reactive power values, P_0 and Q_0, at initial voltage U_0, instead of P_n and Q_n at U_n [11]. Thus, the parameters of exponential load model for small voltage deviations and therefore small power deviations are calculated as:

$$k_{pu} = \ln\left(\frac{P}{P_0}\right) \Big/ \ln\left(\frac{U}{U_0}\right) \approx \frac{(P - P_0)/P_0}{(U - U_0)/U_0} , \tag{5}$$

$$k_{qu} = \ln\left(\frac{Q}{Q_0}\right) \Big/ \ln\left(\frac{U}{U_0}\right) \approx \frac{(Q - Q_0)/Q_0}{(U - U_0)/U_0} . \tag{6}$$

IV. ANALYSIS OF THE RESULTS

The station unit stored the data averaged every second. According to these data, the power changes "momentary" with the voltage to its new value. One of these power responses to voltage change recorded on 23rd October at 3:30 is depicted in Fig. 4 through *P-U* and *Q-U* characteristics. These characteristics demonstrate the power changes for small voltage change (only 0.884% of U_n in examined case) that finish within 1 second. The data from these characteristics are enough for determining of the exponential load model parameters according to formulae (5) and (6). Thus, identified parameters from the voltage change from Fig. 4 are: k_{pu}=1.383 and k_{qu}=4.081.

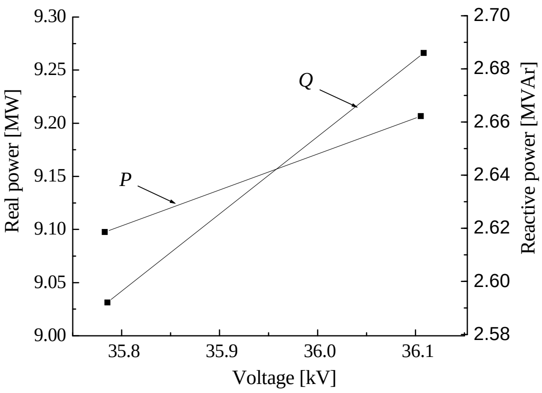

Fig. 4. *P-U* and *Q-U* characteristic

Table II presents exponential load model parameters grouped according to time intervals. Mean values and standard deviations of the parameters are given in this table. The value of k_{pu} slightly increases from the first time interval to the third one, but is close to 1. In the last analysed time interval of the day, 18-24h, k_{pu} increases significantly that indicates that the usage of resistive load devices increases. These load devices have parameter k_{pu} that is approximately 2 [12].

Variation of parameter k_{qu} is most likely the consequence of the change of the voltage values in the investigated time intervals. Mean value of k_{qu} varies in the range from 2.281 in time interval 12-18h when the voltage values are the lowest, to the value 3.993 in the interval 0-6h when the voltage reaches its maximum. That is because higher network voltages affect the saturation of 35/10kV transformer and 10/0.4kV distribution transformers known to have highly nonlinear reactive power–voltage characteristics.

Load model parameters are also grouped according to days of the week: working day, Saturday and Sunday. Mean values and standard deviations of identified parameters are given in Table III. Both parameters vary in relatively narrow range: mean value of k_{pu} changes from 1.070 on working days to 1.338 on Saturday, while mean value of k_{qu} varies from 3.150 during working days to 3.635 on Sunday. It approves that the load parameters, i.e. load composition, vary rather with day periods than with the days of the week.

TABLE II
MEAN VALUES AND STANDARD DEVIATIONS OF THE PARAMETERS GROUPED ACCORDING TO TIME INTERVALS

Parameter	Time interval [h]	Mean	Standard deviation
k_{pu}	0-6	0.970	0.278
	6-12	0.966	0.313
	12-18	1.177	0.376
	18-24	1.511	0.353
k_{qu}	0-6	3.993	1.409
	6-12	3.112	0.986
	12-18	2.281	1.426
	18-24	2.787	0.972

TABLE III
MEAN VALUES AND STANDARD DEVIATIONS OF THE PARAMETERS GROUPED ACCORDING TO DAYS OF THE WEEK

Parameter	Day of the week	Mean	Standard deviation
k_{pu}	Monday - Friday	1.070	0.361
	Saturday	1.338	0.447
	Sunday	1.160	0.357
k_{qu}	Monday - Friday	3.150	1.236
	Saturday	3.334	1.851
	Sunday	3.635	1.816

At the end it should be emphasized that the paper demonstrates what a powerful tool for load modelling electric power distribution company has got. It is the station unit that stores the huge amount of data from microprocessor relays. The results of load modelling on the bases of data from normal operation during three weeks show the applicability of presented procedure for parameter identification. The small number of abrupt voltage changes in some day intervals and during weekend, and consequently significant values of standard deviations approve the necessity of further data processing in order to obtain even more reliable results as well as the parameters in other seasons.

V. CONCLUSION

The paper presents the procedure of load modelling using the station unit - computer which is the part of the remote control equipment in transformer station. Exponential load model parameters are obtained from normal operation data during three weeks in autumn. The parameter k_{pu} shows the significant increase from nearly 1 to the value 1.511 that is reached in the period from 18 to 24h as the result of the increase of the usage of resistive load devices. The values of k_{qu} vary predominantly as the consequence of transformer saturation, from 2.281 in the afternoon to 3.993 after the midnight. The investigation can be continued in order to obtain the parameters in other seasons.

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