Possibilities of Surveying Electric Load and Daily Load Curves for the Profiling of Consumption in Public Energy Repartition and Distribution Systems

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***Abstract*— In actually conditions of our country, the survey and the outline of the load curves of supply electric energy consumers from repartition and distribution systems represent an essential instrument for substantiating the strategy of developing the infrastructure of the zonal distribution providers, a better knowledge of electric energy consumption characteristics of clients, optimizing the structure and the running states of these installations, the improvement of service quality, of forecasting the transactions and a varied offer of tariff packages for the energy delivered, but also of managing the electric energy consumption, in order to improve the competition level of electric energy repartition and distribution territorial units.**

***Index Terms*—survey, profiling, shape, typical load curves**

I. INTRODUCTION

Energy has represented in all ages and in all countries or geographical zones an essential problem as a factor of economical and social developing. The progress of a nation depends on its ability in using its own resources of energy in enforcing the economic competitiveness, in protecting the nature and in ensuring the national security. To elaborate a national strategy concerning a *durable development* it is essential to properly understand the complexity of this concept. Through time, the *durable development concept* developed and now it deals with many objectives of economical, social, ecological, a.s.o. matters [9], [13].

Among the last decades, *the World Energy Council* carefully examined the evolution of the world level in energy field, publishing two reports, entitled *Energy for Tomorrow's World.* The aim of this reports was to elaborate a new set of objectives of political energetic to obtain: *the elimination of lack energy anywhere on the globe, an improvement of the quality and the reliability of the energy delivered for consumers, a minimization of the negative impact on the environment and health, due to the development of the ways in which the electric energy is produced.*

Characterized by its strong inertia, the electric energy industry is going forward to a fundamental change in the last years. Even in different countries its organization takes different shapes, the energetic sector is mainly dominated by monopolies with a vertical structure. In this context, through opening the electric energy markets it was intended to remove the natural monopoly and to vertically integrate the energetic sector, replacing them with competitive mechanisms that allow the consumers the possibility of choosing, in a free way, the supplier.

In our country, in the years of 2000, the energetic sector was split after its nature of activity in: *Producers*: *Hidroelectrica* (hydroelectric), *Termoelectrica* (thermo-electric), *Nuclearoelectrica* (nuclear energy) and several other independent suppliers; *Dispatcher and Transport Operator* – Transelectrica, in which functions the *Commercial Operator*, ensuring the administration of electric energy market; *Distribution Operators* - Electrica, with its 8 zonal branches.

In the same time it took place *the license of the electric energy suppliers*, which ensure the commercial component of the link between the suppliers and consumers.

Regarding *the consumers*, they were split in two categories: *eligible consumers*, which can choose and negotiate the price with the supplier and *captive consumers*, which continue to receive the energy at regulated prices from the determined special provider. The energy market from our country totally opened in july 2007 and so the 8,5 millions of electric energy consumers of Romania, from which 8 millions home consumers, can choose the alternative providers based on supply and demand [4], [10], [18].

II. THE SURVEY OF REPARTITION AND DISTRIBUTION ELECTRIC ENERGY

By public electrical power supply system we understand the totality of: power distribution lines for a nominal voltage of 110 kV; 110 kV connection stations; 110 kV/medium voltage and medium voltage/medium voltage transforming stations; low and medium voltage power distribution lines; medium voltage/low voltage transforming stations. This systems supply energy to home and third-party receivers and consumers (i.e. commercial, social-cultural consumers, public services, small industrial and industrial-like consumers), located in a rural or urban habitable area.

The electric distribution networks represent over 88% of the whole network system in our country. The development of this networks and the reorganization of those that already exist acquire a great importance in the ensemble of the systems of electric energy due to the shift, in the past years, of the electric energy consumption to low and medium voltage. For a efficient exploitation of the distribution systems and a more rational technical and economic administration of the zonal distribution branches, one of the requests that must be fulfilled is the knoledgment of the power and energy demand, in terms, *where*, *when* and *how much*.

The medium voltage distribution networks and mainly the low voltage ones have a big number of components that are spread on large areas, have a relatively high density and are characterized, generally, by the absence of the technical possibilities in surveying their running. For example, even the low voltage distribution network ensure the distribution of the energy for more than 8 millions of consumers, the number of information gathered from these networks is poor. Because the necessary time for having them is long, the consumers are pretty unhappy with the quality of the energy delivered. On the other hand, many of the small consumers connected to the low voltage distribution network diminish the quality of the energy.

Nowadays more and more information from the distribution networks is necessary and for having them there must be to installed new measuring equipments, new transmitting lanes of these information, computers, a.s.o. The lack of this information determines the zonal branches not to be able to perform a complete and correct analysis of the running states, an estimation of the shape of the distribution network, a consumption forecast, a.s.o. If, speaking about large power consumers, their loads can be determined because most have power meters, the situation is changed in the case of small consumers, which generally are captive. But the latter represents the largest amount in a distribution network. That's why their survey is important. For an efficient exploitation of the electric energy distribution systems we have to continuously *survey* these. The process consists in surveying some systems, installations, or parts of them to identify, during running, the variation of the parameters from the normal values. The survey functions means the control of the system, the observation of the variation, the send of the observation to the point of command and the elaboration of decisions. Depending on the procedure the information is gathered, there are two types of survey: *local survey* and *centralized survey*.

The needed information are: the active and reactive power (energie), the power factor, the voltage, the currents, the coefficients of non-symmetry for voltage and currents, the harmonic content of the currents and voltages, the resistance of the ground wires, the temperatures of different connecting elements (clamps, thimbles a.s.o), the shape of the conductors a.s.o. To obtain such information, is necessary the existence of automatic measurers which next will be emplaced in distribution networks, such as: electronic counter three-phase Alpha, voltage and ammeter recorder, resistance bridge of dispersing at ground plates, megohmmetre, automatic measurer of temperature, automatic measurer of dimension, reclosers, signal devices of defects, transducers and transmission bloc of information to dispatcher.

As transmission ways of information from different points of distribution networks to a central point (dispatcher), can be mentioned: leader cable, fiber optic circuits included in conductor or independent, conductors of electric lines, telehonic lines, radio channels, radio channels trough satellite. For choosing one of these, we have to consider a series of factors: the cost price, geographical situation of networks location, networks density a.s.o.

The survey process of electric energy distribution systems have to assure the next performances: the reliability increase by preventing the flow points of networks; adaptation of distribution systems at energy market asks trough quality and quantity assurance asked by consumers; deviation pursuit which are provided in networks operating; the control of electric energy consumption at delimitation point with energy providers; the introduction of process computers for ensuring the operating of distribution systems in optimal conditions; the obtaining of necessary information of investments works and also contract clauses.

III. THE CONSUMPTION PROFILE IN THE ENERGY REPARTITION AND DISTRIBUTION SYSTEMS. DATABASE

It is well known that the energy market works on the basis of buying and selling offers sent by the Energy Stock Exchange for every IBD (Interval of Bond Discount), which in our country IBD is 1 hour (hourly levels). This hourly levels determine the knowledge of the electric energy consumption in every hour for every consumer. To take part at the energy stock exchange and for a complex analyze of the running states of the distribution networks, there two ways of approaching [4], [6], [7], [9], [12]:

- every consumer should have installed electronic meters that allow the record of the hourly levels of the load curves;
- maintain at the consumers the analog meters and model or recover the consumption profiles under hourly levels through the redistribution of the total energy consumption after a number of profiles or typical load curves, that are characteristic to every consumer.

Taking into account the existing situation from our country, the actual level of technology and the specific costs, for the captive consumers (residential, commercial a.s.o), the second way of approaching this situation is the most effective, economically speaking.

The *profiles* or *typical load curves* represent the probable variation of the (active/reactive) loads in a certain period of time, usually, in one day, and can be defined as a *model* of electric energy consumer. In our country, these profiles are made under 24 hourly levels, every one lasting one hour, the loads being express in relative units, divided to the average value of the loads taken from the registered and statistically analyzed curves. The active and reactive loads from the nodes of the public distribution networks are time aleatory functions, and their past or daily variations represent concrete achievements of these functions. In conformity with [1], [3], [5], [6], [7], [10], [15], for the public distribution networks, the active and reactive loads follow, in every fixed moment of the day, the normal distribution rule, which is characterized by two quantities, the *average value* and the *dispersion*.

The *profiles* or *typical load curves* are made for groups or categories of consumers that have certain common characteristics. In the same category of consumers, beside other influences of socio-economic nature, (endowment with equipments, installations or electric devices), other factors influence the shape of the profile, among these being the variations of the temperature from a day to another or from a season to another. In the classical approach, the methodology of modeling the *typical load curves* follows some principles. There are some steps to be followed. First, all the consumers are divided into categories, after certain criteria. After that, there are recorded the daily load curves for every category of consumers found at the first step, curves that cover a long enough period to individualize the specific behavior in every day of the week, in different seasons. The records can be achieved with the help of Alpha-meters, continuously for at least 7 consecutive days. For example, in Fig 1, 2 and 3, there are presented (active/reactive) load curves at low voltage bars level for transforming station which supplies home consumers, a hospital, end a hotel in January 2009. Same records have been effectuated with Alpha Power Plus counters in 2000, 2005, end for data acquisition it was used a computer connected at Alpha counters, data transfer being made with Power Quality Inspector program. Data acquisition have been continuously accomplished for at least 7 consecutive days, for a big number of transforming station and niches of consumers from public distribution networks, in different calendaristic days and months, among the year [7], [9], [11], [12].

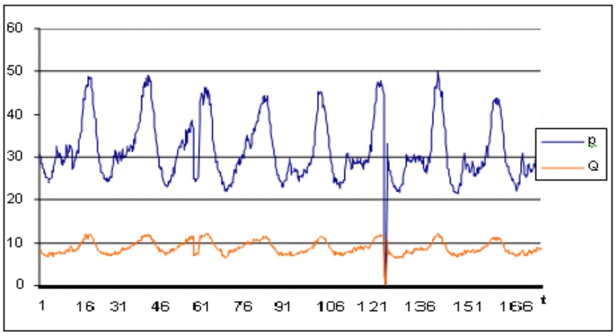

Fig. 1 Active and reactive load graphs recorded with the ALPHA counters, for a consumer of the "home consumers" type, in the period 12.01.09 – 20.01.09

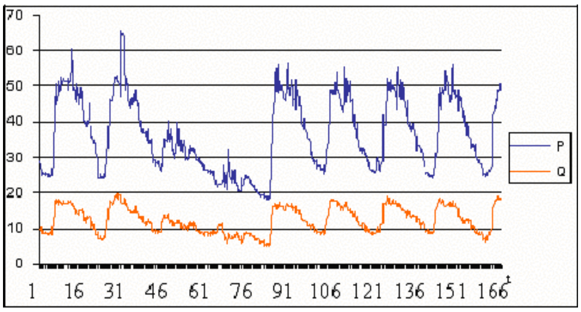

Fig. 2 Active and reactive load graphs recorded with the ALPHA counters, for a consumer of the "hospital" type, in the period 12.01.09 – 20.01.09

The next step is the effectively model of the typical load curves. For this, for every characteristic day from a certain season it is computed an average of the recorded load curves, hour by hour, for every category of consumers. The result is a unique load curve that is *typical* for that category, for the considered characteristic day, in that season. Applying this procedure, for every category of consumers, for certain characteristic days and certain seasons *profiles* or *typical load curves* are obtained. For example, in Fig. 4 – 7, there are presented *active and reactive typical load curves* for urban home consumption, hotel, hospital and universal shop, in working days of Tuesday, Wednesday and Thursday for winter cold season in 2009.

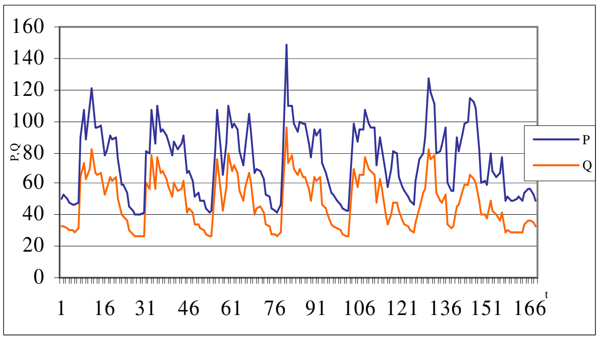

Fig. 3 Active and reactive load graphs recorded with the ALPHA counters, for a consumer of the "hotel" type, in the period 12.01.09 – 20.01.09

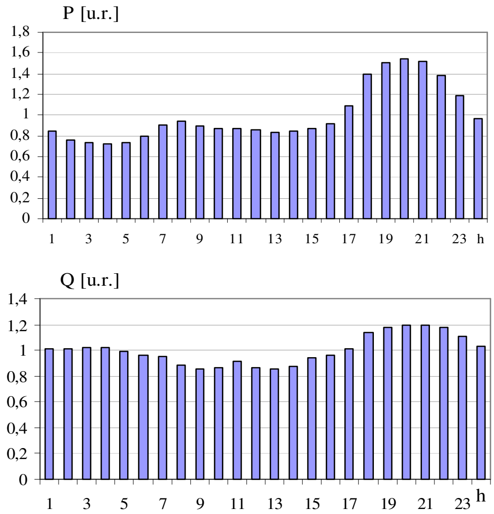

Fig. 4 Active and reactive typical load curves for a consumer of the "urban home" type, in January, in working day Tuesday, Wednesday and Thursday

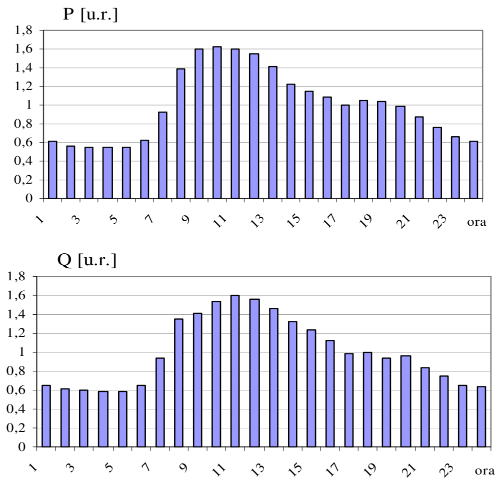

Fig. 5 Active and reactive typical load curves for a consumer of the "hospital" type, in January, in working day Tuesday, Wednesday and Thursday

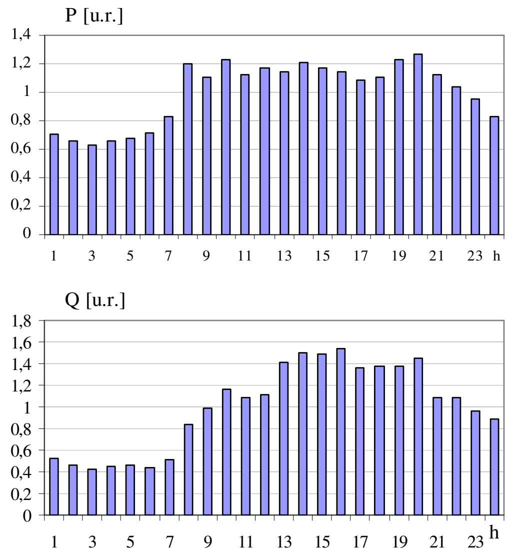

Fig. 6 Active and reactive typical load curves for a consumer of the "hotel" type, in January, in working day Tuesday, Wednesday and Thursday

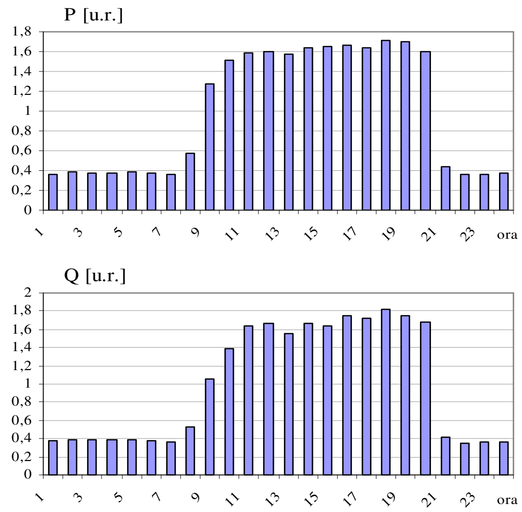

Fig. 7 Active and reactive typical load curves for a consumer of the "universal shop" type, in January, in working day Tuesday, Wednesday and Thursday

In principle, there can be modeled hundreds of typical load curves but, from practice, it was observed that many consumers have common patterns of their profiles. Thus, every zonal branch of distribution has a certain number of typical load curves, gathered in a *database* [6], [8], [10], [11]. The most important aspects that must be taken into account when choosing a load curve to be a typical load curve, are: the typical load curves are modeled after a record of at least one year; every typical load curve must represent a relatively homogenous number of consumers and must be distinct in comparison with other typical load curves; the set of typical load curves must cover a large number of small consumers (of second and tertiary kind), which generally are captive consumers; when using the sampling after the consumption criterion, the criteria after which a certain typical load curve is associated with a certain type of consumer must be very clearly mentioned, in order to facilitate a simple use in practice; the number of the typical load curves that inter in the database must be relatively small.

Taking into account the mentioned aspects, every distribution zonal branch can realize its own database formed by *profiles* or *typical load curves,* that is most adapted to the specific kind of activities performed in the area. These database have a relatively small dimension if, in the statistic analysis, where these load studies are included, the rational design of the sample of the analyzed consumers plays an essential role, in order to generate profiles or typical load curves generally valid for the whole population.

In this way, a very used method is the *stratified sampling*, which, usually, is applicable for a population with asymmetric density. This method divides the whole studied population into many independent under- populations, named *layers.* The aim is the obtaining, with the help of the available information, of sets of under- populations, as much as possible homogenous, [2], [14], [16]. In [4], [7] it is proposed an alternative approach, which gives a less importance to the pre-established classification, leaving the liberty to the procedure of classification to extract as many categories of consumption as it seems to be necessary, inside a pre-established level. In this alternative, the main classification criterion is the shape of the daily active and reactive recorded loads. We have to mention that this procedure belongs to the so named category of *self-organizing algorithm.* There is a large variety of self-organizing algorithms, but the best that suits the given situation concerning the daily load curves is the *Self Organizing Feature Maps*, applied on the *Kohonen neuronal networks.*

IV. THE MODEL OF THE LOAD CURVES FROM THE NODES OF THE DISTRIBUTION NETWORKS

Having at disposal a database with typical load curves, the daily active and reactive loads curves from the nodes of the distribution network, in characteristic annually states (summer-warm, respectively winter-cold, for the standard days) can be modeled through an association made between some information from the network to the typical load curves of the supplied consumers and to the load structure from the nodes. The information that can be recorded is [4], [6], and [8]:

1. The current from a node at a daily variable hour

In this case, the active and reactive load, at hour t from the daily load curves, which are allocated to the node, are determined with relations (1):

$$P_{n,j}(t) = \sqrt{3}\cdot U_n \cdot I_{n,j}(k)\cdot \cos\varphi_j^T(k)\frac{P_j^T(t)}{P_j^T(k)},$$

$$Q_{n,j}(t) = \sqrt{3}\cdot U_n \cdot I_{n,j}(k)\sqrt{1-\cos^2\varphi_j^T(k)}\,\frac{Q_j^T(t)}{Q_j^T(k)}, \qquad (1)$$

$$t = \overline{1{,}24}$$

where:

- $P_{n,j}(t)$, $Q_{n,j}(t)$: the active, respectively the reactive power from node n, in the state j, at hour t;
- $I_n(k)$: the current measured in node n, in the state j, at hour k;
- $P_j^T(t)$, $P_j^T(k)$, $Q_j^T(t)$, $Q_j^T(k)$: the average value of the active and reactive load from the typical curves that correspond to the state j, at hour t, respectively k;

- $\cos\varphi_j^T(k)$: the value of the power factor that corresponds to the typically active and reactive load curves from the state j, at hour k;
- U_n: the nominal voltage of the network.

2. The active energy that flows in 24 hours through the node

In this case, the active and reactive load, at hour t from the daily load curves, which are allocated to the node, are determined with relations (2):

$$P_{n,j}(t) = \frac{W_{n,j}}{24} P_j^T(t),$$
$$Q_{n,j}(t) = P_{n,j}(t) \cdot \sqrt{\frac{1}{\left[\cos\varphi_j^T(t)\right]^2} - 1}, \qquad t = \overline{1,24} \tag{2}$$

where:
- $W_{n,j}$: the active energy that flows in 24 hours through the node n, in the state j;
- $\cos\varphi_j^T(k)$: the value of the power factor that corresponds to the typically active and reactive load curves from the state j, at hour k.

In the situation in which for that specific node it is known only the average load of the transformer, the active and respectively the reactive load for the state j, at the hour t, can be computed with equations (3):

$$P_{n,j}(t) = \overline{k}_{zj_P} \cdot S_n \cdot P_j^T(t),$$
$$Q_{n,j}(t) = \overline{k}_{zj_Q} \cdot S_n \cdot Q_j^T(t), \qquad t = \overline{1,24} \tag{3}$$

where:
- $P_j^T(t)$, $Q_j^T(t)$: the average value of the active and reactive load from the typically load curves, in the state j, at the hour t, corresponding to the main branch of the distribution network;
- $\overline{k}_{zj_P}$, $\overline{k}_{zj_Q}$: the statistical average values of the load coefficients of the transformers from the transformation points, at a medium daily active, respectively reactive, load, in the state j;
- S_n: the nominal apparent power of the transformer from the transformation point.

If the model of the daily load curves from the nodes of the distribution network is realized after (3), depending on the average load coefficient $\overline{k}_{zj} = M_i / N_i$ and on the standard deviation, which is computed with the following equation $\sigma = \sqrt{\frac{1}{N_i - 1}\left[S_i - N_i\left(\overline{k}_{zj}\right)\right]^2}$, the values of the load coefficients $\overline{k}_z$ must fulfill the following restriction:

$$\overline{k}_z \le \overline{k}_{zj} + 3\sigma_j \tag{4}$$

where:
- $\overline{k}_{zj}$: the average load coefficient for the typical load curve from the state j;
- M_i: the sum of the load coefficients for a number N_i of nodes;
- σ_j : the standard deviation of the load coefficient from the typical load curve in the state j;
- S_i: the sum of the squares of the load coefficients for a N_i number of nodes, in the state j.

For the case in which the nodes have a mixed structure of loads, the typical active and reactive load curves associated to them are established depending on the typically load curves of the categories of supplied consumers and on their weight in the structure of consumption of the respective nodes.

To increase the accuracy of modeling the active and reactive loads from the nodes of a distribution network, the load curves can be amended, taking into account that the hourly active power balance, on every branch of the analyzed network, must be fulfilled, for every hour t from a day:

$$\gamma_{P,j} \cdot P_j(t) - \sum_{n=1}^{m} P_{n,j}(t) = 0, \quad t = \overline{1,24} \tag{5}$$

where:
- $\gamma_{P,j}$: a coefficient that is influenced by the active power losses from the lines and transformers, in the analyzed network;
- $P_j(t)$: the active power injected in the network, in the state j, at the hour t;
- $P_{n,j}(t)$: the active load modeled with (1), (2), or (3), in the node n, for the state j, at the hour t;
- m: the total number of the nodes from the analyzed network.

Generally, (5) is not fulfilled and there must be made corrections on the active loads modeled in the nodes, which are as the kind:

$$\Delta P_{n,j}(t) = \frac{\left[\gamma_{n,j} \cdot P_j(t) - \sum_{n=1}^{m} P_{n,j}(t)\right] \cdot P_{n,j}(t)\left[1 - \omega_{n,j}(t)\right]}{\sum_{n=1}^{m} P_{n,j}(t)\left[1 - \omega_{n,j}(t)\right]} \tag{6}$$
$$t = \overline{1,24}$$

where:
- $P_{n,j}(t)$: the active load allocated to the node n, in the state j, at the hour t;
- $k_j(t)$: coefficient of proportionality corresponding to the state j, at the hour t;
- $\omega_{n,j}(t)$: coefficient of veridicality.

All the three possibilities above mentioned concerning the model of the active and reactive loads from the nodes of distribution network lead to errors low than 2.5%. Applying the corrections to the nodal loads, in order to satisfy the active and reactive balance of powers, the modeled nodal loads curves lead to the real ones, the errors being under 1%.

V. CONCLUSION

In actually context of our country, through opening the electric energy market it was intended to remove the natural monopoly and to vertically integrate the energetic sector, replacing them with competitive mechanisms, specific to market economy.

The public electric energy repartition and distribution systems represent over 88% of the whole transmission and distribution networks which supply with electric energy 8,5 millions consumers (captive consumers) of Romania, which can choose the alternative providers based on supply and demand. Further, the development of this networks and the reorganization of those that already exist acquire a great importance in the ensemble of the systems of electric energy due to the shift, in the past years, of the electric energy consumption to low and medium voltage.

For a efficient exploitation of the distribution systems and a more rational technical and economic administration of the zonal distribution branches, one of the requests that must be fulfilled is the knowledge of the power and energy demand in all nodes of these systems.

The survey and the profile of the load curves belonging to the consumers from the distribution systems must be realized rigorously because they represents an essential instrument in proving the decisions and strategies of development of the infrastructure belonging to the zonal branches of distribution, of the running states optimization, of the diversification of the services offered to the clients and of the electric energy consumption management.

REFERENCES

[1] S. V. Allera, A. G. Horsburgh, "Load profiling for energy trading and settlements in the UK electricity markets", DistribuTECH Europe DA/DSM Conference, London, October 27 – 29, 1998.

[2] E. Bompard, E. Carpaneto, G. Chicco, R. Napoli, F. Piglione, ş.a, "Stratified sampling of the electicity customers for setting up a load profile survey", 1st RIMAPS Conference, Madeira, september 25 - 27, paper RUR-017, 2000.

[3] C. S. Chen, J. C. Hwang, Y. M. Tzeng, C. W. Huang, M. Y. Chow, "Determination of customer load characteristics by load survey system at Taipower", IEEE Transactions on Power Delivery, Vol. 11, No. 3, July 1996.

[4] M. Gavrilaş, M. Filimon. Tendinţe moderne în distribuţia energiei electrice, Editura AGIR, Bucureşti, 2001.

[5] Gh. Georgescu, A. Poeată, N. Poeată, ŢContribuţii la modelarea sarcinilor reţelelor de distribuţie urbaneŢ, Bul. Instit. Polit. Iaşi, Tom XXIX, fasc. 1-2, 1983.

[6] Georgescu Gh., Gavrilaş M., Cârţină Gh., "Aspects Concerning Power Distribution Networks Planning Using Artificial Intelligence", Proceedings of the 14th International Conference on Electricity Distribution, CIRED'97, Birmingham, 1997.

[7] Gh. Georgescu. Transportul şi distribuţia energiei electrice, Vol 1, 3, Editura Politehnium, Iaşi, 2000 and 2002.

[8] Gh. Georgescu, V. Varvara, ş.a, "Amplasarea optimă a surselor de putere reactivă în reţelele de distribuţie, folosind metode se simulare şi algoritmi evolutivi", Producerea, transportul şi distribuţia energiei electrice şi termice, nr. 5, Bucureşti, 2001.

[9] Gh. Georgescu. Sisteme de distribuţie a energiei electrice, vol. 1, Editura Politehnium, Iaşi, 2007.

[10] Gh. Georgescu, M. Istrate, V. Varvara. Sisteme de distribuţie a energiei electrice, vol. 2, Editura Politehnium, Iaşi, 2008.

[11] Gh. Georgescu, Al. Poeată, M. Gavrilaş, "Calculul pierderilor de energie în reţelele de distribuţie folosind descompunerea graficelor de sarcină în serii Fourier", Revista Energetica, seria B, nr. 5, Bucureşti, 1995.

[12] G. T. Ionescu, Olga Pop. Ingineria sistemelor de distribuţie a energiei electrice, Editura Tehnică, Bucureşti, 1998.

[13] A. Leca. Principii de management energetic, Editura Tehnică, Bucureşti, 1997.

[14] M. Newborough, P. Augood, "Demand-side management opportunities for the UK domestic sector", Proceedings Generation Transmission and Distribution, Vol. 146, No. 3, May 1999.

[15] Al. Poeată, Gh. Georgescu, "Conducerea automată a reţelelor de distribuţie", Revista ENERG, nr.3, Editura Tehnică, Bucureşti, 1987.

[16] M. Scutariu, G. Chicca, R. Napoli, ş.a., "Sistem de sondare a curbelor de sarcină ale consumatorilor în vederea stabilirii profilurilor tip", Energetica, nr. 7, 2001.

[17] *** Declaraţia CME 2000, raportul "Energie pentru lumea de mâine. Să acţionăm acum!" Editura AGIR, Bucureşti, 2002.

[18] ***Situl Autorităţii Naţionale de reglementare în domeniul Energiei – A.N.R.E, www.anre.ro.