XIX-th International Symposium on Electrical Apparatus and Technologies SIELA 2016
29 May - 1 June 2016, Bourgas, Bulgaria

ASSESSMENT OF ELECTRIC ENERGY LOSSES AIMING AT DETECTION OF THEFTS OF ELECTRICITY

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Abstract. The paper describes relations between technical, nontechnical and total electric energy losses in power systems and presents an innovative methodology for their accurate assessment aiming at detection of thefts of electricity in the distribution networks.

Keywords: active and reactive power losses, electric energy technical and nontechnical losses, electric power and energy measurements, theft of electricity.

INTRODUCTION

Main characteristics of sinusoidal power systems are the instantaneous values of the current flowing through each conducting element (measured in Amperes, A) and the voltages at the terminals of these elements (measured in Volts, V). They are complex quantities that are described by phasors. The current phasor and the voltage phasor at any point of the system determine the power for this moment, and the energy is the power integral for a certain period. The apparent power is the geometric sum of an active component measured in kW and a reactive component measured in kVAr. Respectively the active energy and the reactive energy are measured in kWh and in kVArh.

The power losses are defined as the difference between the instant electric powers measured in two real points or measured in two sets of real points in the electric power system [1, 2]. The electric energy losses are the integral of the electric power losses for the respective time period (with certain beginning and end). The losses occur both in the main equipment (power lines and transformers), and the measuring, control, protection and compensation devices during the steady state and the transient modes of operation. The losses shall be distinguished from the auxiliary consumption (needs) of the power plants or of the sub-stations.

One kind of (electric power) losses is caused by conductance of the power system's elements to the surrounding environment. They are called **transversal** or **idle** (running) losses (**TL**). Because they depend on the square of the voltage and very slightly on the transmitted current, sometimes they are also called constant losses. They can reach 1/3 of the total losses [3].

Another kind of losses is caused by the current, flowing through the conductors of the system elements (generators, transformers, power lines, etc.). These are the so called **longitudinal** or **distance** losses (**LL**). Because they depend on the square of on the flowing current, sometimes they are also called variable losses. Usually they comprise the main losses part, amounting at up to 2/3 of the total losses.

The two mentioned transversal, longitudinal and other types of losses form the category called technical (or physical) losses (**PL**). They are scattered in space because they arise at each of the system's elements. They shall be calculated or measured for these separate elements as a local phasor (complex value with active and reactive component). They are used to calculate the sums of the active and the reactive components for the entire grid. They are expressed in kW and kWh, respectively in kVAr and kVArh, but are often esteemed also as % of the grid input or output power or energy. They may also be expressed as a ratio to the maximum system load.

Apart from the clarified category called technical losses (**PL**), another category is the so called **non-technical** or **commercial** losses (**NTL**). In turn non-technical losses consist of two components. The first one comprises losses because of the imprecise estimation of the electricity consumption as a result of measurement errors including failures of electricity meters (**measurement errors losses** - **MEL**). The second one comprises the losses due to **thefts of electricity** (**TE**), i.e. energy which is consumed but is not measured because of illegal consumer connections or because of manipulation of electricity meters.

The invoicing errors as well as losses from correctly measured, calculated and invoiced, but unpaid electricity are commercial losses for the supply activities (retail commerce), which are not caused by loss of the commodity, therefore they are classified as separate financial loss, not related to power and energy losses.

The above may be summarized as follows:

Total losses = Injected power – Extracted power =

= PL+NTL = TL+LL+MEL+TE, kWh (I.1).

The subject of general interest is only the active power and energy losses because usually only the active energy is subject to payment. Calculation of the reactive loss components is significant for some applications, but hardly contributes to the detection of the thefts of electricity, so here it will not be further considered.

THEFTS OF ELECTRICITY

Thefts of electricity comprise a large part of the commercial losses of distribution companies. As an example 'For the first nine months of 2015 the thefts of equipment owned by CEZ, have caused damages to over 2.5 mil. BGN. In the period, the company has discovered also 4615 thefts of electricity as a result of which additional electricity quantity of only 24 mil. KWh was accounted, although the thefts may have lasted for years'.

'The electricity thefts and vandalism over energy equipment incur damages to the entire society. They divert from the company investment resource and prevent us from developing the grid as intensively as we would like in order to meet the needs of households and business' [4].

Bulgarian distribution companies appeal for intolerance to such acts that harm the electricity consumers and disrupt the normal rhythm of life of a large number of households. All types of fraud aim at payment of less electricity than actually consumed. The illegal manipulation of electric meters and hidden electricity consumption favors single consumers but has detrimental impact on the electricity grid of entire regions and harms the honest electricity consumers.

Electricity thefts are performed in many diverse ways: through connection before the electric meter, shunting the electric meter, manipulation of the electric meter so as to report less energy. Seals, as one of the means for protection against interference on the electric meter, are not an efficient obstacle against modern crooks.

Upon detection of electricity thefts in many Northern American states the legal practice is to charge a payment based on the maximum power (or current), for which the electric meter is sized, for the entire reporting period, most often a month. In Bulgaria the charges paid are based on only the one third of the maximum current of the electric meter for eight hours a day (ten hours for non-householed consumers) from the date of identification of the incorrect/imprecise measurement or failure to measure - back to the date of installation of the electric meter or to its previous check, but not for more than 90 days. In case of missing electric meters the maximum current is determined by half of the flow capacity of the consumer outlet wiring.

In Bulgaria thefts are prevented through replacement of electric meters and their placement at the border of owned real estates. In residential areas with increased thefts it is widespread to locate the electric meters at high poles. This results not only in lowering of the thefts and increasing the reported electricity, but also in load decrease, which also reduces the losses in the grid.

Also, ad hoc checks of loads, of cabinets and of consumer's outlet wiring are applied for theft detection.

The theft of electricity is a phenomenon that is difficult to be traced and unveiled. In order to discover the thefts the distribution companies run campaigns. Gradually, these campaigns should be replaced with efficient supervision/monitoring of the load on the power lines in real or extended real time, as described hereinafter.

MEASURING AND/ OR CALCULATION OF LOSSES

Some of the described types and categories of losses may be both measured and calculated, which enables mutual estimation of precision in the two approaches. Others may only be calculated, which means that the estimation precision is determined by the errors and assumptions in the relevant models. Apart from the error magnitude, concerning the feasibility estimation, it is important to ensure the registration of the initial data in order the final results could be proved if necessary, by means of repeated calculations and/or measurements.

The huge variety of electric installations and equipment already more than 130 years has caused and continues to cause development of approaches and methods to calculate the losses of power and energy in the respective grid elements. In parallel runs the reverse process for decrease of the calculation cases through simplifying the phenomena or grouping of impact factors or typifying of the equipment by types of transformers, power lines middle voltage, and power lines low voltage. Initially, as a result of insufficient measured data, only the losses of power during the peak periods were calculated, and the energy losses were determined according to the duration of the peak loads.

The increase of the electricity thefts in many countries changed the priority of the problems related to electricity losses. The problem for detection and liquidation of the non-technical losses became priority for the distribution companies. Its effective solution is possible due to the development of electric meter and communication technologies. The modern "smart" electric meters enable sufficiently precise and effective measurement of the injected and extracted energies along all branches in the distribution grids, and calculation of the total losses by sections as a difference between the measured energies. However, this does not repeal the problem for calculation of the technical losses, because the non-technical losses are not subject to direct calculation or measurement and also because ‘The distortion of loads under the impact of the non-technical losses distorts the calculation of the technical losses caused by the actual loads, and renders the results no-good, untrue.’[5].

The only acceptable and worldwide utilized approach for the estimation of non-technical losses is the following:

1) determination of total losses as the difference between the supplied/injected and extracted measured energies,

2) determination of the technical losses with the maximum possible accuracy using the available measured energies and computational models,

3) determination of non-technical losses as the difference between the estimated at stage 1) total and at stage 2) technical losses.

The mathematic description of this approach is as follows:

NTL = Supplied energy – Extracted energy – PL, kWh (I.2).

In its turn the NTL are a total of the measurement errors losses and the theft losses:

NTL = MEL+TE, kWh (I.3).

This enables the theft losses to be determined as a difference between the non-technical losses and the losses from measurement errors:

TE = NTL –MEL, kWh (I.4).

The overall analysis of these expressions shows that the efforts of the distribution companies to reduce the losses by means of errors elimination and thefts detection should be directed to the following objectives:

1) improving the accuracy of measurement of the injected and extracted energies.

2) establishment of a practice for calculation of the technical losses.

3) improving the practices for measurement of the energy through decreasing the failures of the electric meters, reduction of the number and magnitude of the measurement errors and reduction of errors arising in the process of data input and treatment.

4) implementation of an automated system for surveillance of the losses due to measurement errors and theft losses.

Distribution companies in Bulgaria lack methodology and organization potential, as well as means for daily surveillance of the technical and the non-technical losses. We propose the methodology described in the following section in order to cover a part of this deficit.

METHODOLOGY FOR DETERMINATION OF LOSSES

1. Purposes

The general purpose of the Methodology is to provide a method, tools and activities by means of which the distribution company could calculate and analyze all the kinds of electric active power and energy losses with acceptable accuracy. This accuracy is determined by the intended use of the calculated values as part of the process of supervision and network operation control. Depending on the loss integration interval the methodology distinguishes between hourly, daily, monthly and annual calculation and analyzing of all types of losses of active energy. Depending on the scope of the grid elements the methodology distinguishes between losses in a separate device, in a separate electric line, in the grid supplied by a sub-station, in the grid of one operation center or in the grid of the entire company. The methodology considers the constraints concerning the availability and reliability of the relatively constant parameters for the grid and the constantly changing regime data: voltages, currents, loads. The methodology envisages the start with actually possible activities and gradual development and increase of the company potential for the more difficult problems.

Under the present conditions, the methodology may and shall provide the following activities:

The first activity is the everyday determination of the total energy losses for each hour of the day.

The results of this problem are necessary to settle the company liabilities to the public supplier and to the balancing market. The same results, together with the data concerning the temperature of the air and other environmental indices, as well as other factors that impact the common losses, will be archived and used for forecasting the schedule of the hourly losses for the following day.

The second activity/objective is the calculation of technical losses for each of the hours of the past day. The results are used for calculation of non-technical losses as the difference between total and technical losses.

The third activity is the determination of the losses due to erroneous measurements for each hour of the past day and using the results to certify the non-reliable measurements, and after that – for calculation of the thefts of electricity as a difference between the non-technical losses and the losses from erroneous measurements.

The described objectives/activities shall not be considered as a renouncement of the activities that perform theft checks through various other means and algorithms. For example the individual statistics of each consumer enables the current data to be checked for correlation with the data from a similar historical period. The small correlation is a sign for looking for the reason of the changed consumption. Other activities are the analyses of the automatic signals for manipulation of the electric meter, the carried out periodic and ad-hoc checks, public exposure of proven electricity thieves etc.

2. Contents, scope and cyclicity of the activities

The first activity, i.e. the daily calculation of the difference between the injected flows and extracted hourly energies, assumes improvement of the existing process for calculation of the monthly total losses according to formula I.1.

The improvement involves acceleration of the automatic registering of the hourly electric metering data and the other auxiliary electric meter data for each border point of the company, submission of these values into the central database, their certification, recording and provision to use. This determination of the total losses of the company for each hour of the past day may be performed within a day-and-night cycle (after expiry of the entire past day-and-night). However, upon introducing the intra-day market, the distribution companies will be interested to determine the total losses within a shorter cycle, at best hourly. Until they reach such a good practice, a six-hour cycle may be used as a compromise.

So far the smallest set of equipment, for which the companies may calculate the total losses independently, is the grid supplied by one sub-station 110kV/middle voltage, but even this distinction is not applied. Instead, all power lines around all sub-stations within one Operation center (OC) are considered as a whole.

The electric meters at all sub-stations on the territory of a given Operation center (OC) shall be considered as a common border point for calculation of the injected/extracted energy on the border between the Electricity system operator (ESO-EAD) and this OC. The electric meters at the distribution sub-stations and border kiosk switchgears shall be considered as a common border point for calculation of the injected/extracted energy on the borders between the remaining OC or between other companies and this OC. The electric meters on the inlet connecting terminals of the power producers represent the third interface border point for calculation of the injected/extracted energy (on the border between the company and the power producers). The electric meters on the consumers/prosumers outlet connecting terminals constitute the forth equivalent border point for calculation of the extracted/injected energy at the border between the company and the consumers/prosumers.

The most numerous are the electric meters on the low voltage power network branches. A great part of them are not suited for automatic submission of the data to the central data base, especially during a day-an-night cycle. Therefore, the methodology envisages temporary utilization of historical data taken from previous similar day-and-nights and similar seasons for each of these consumers and its subsequent substitution with the actual data after their registration in the central data base, depending on the existing actual opportunity for reporting and registration of the data from each non-automatized electric meter.

The second activity means use of the hourly electric meter data for each of the power lines medium and low voltage (the electric meters at the sub-station outlets, at the distribution sub-stations and kiosk switchgears, at the producers, at the consumers and prosumers) for calculation of the non-technical losses according to formula (I.2) utilizing prior calculation of the technical losses at every section of each power line low voltage, each transformer station and each power line medium voltage on the basis of the established in advance models.

Unfortunately, with the existing approach for measurement of the power injected by the transmission system operator sub-stations, it is not possible to calculate non-technical losses for each of the outgoing power lines and their sections, and as a result the total losses are available by Operation centers, not by separate power lines. Therefore, the calculated technical losses for the power lines of a given OC shall be summed and this sum shall be deducted from the OC total losses, in order to obtain an aggregate value for the non-technical losses on the territory of each OC. The accuracy of the so calculated non-technical losses for the operation centers will be low, and the losses will not be addressed according to the location where they occur.

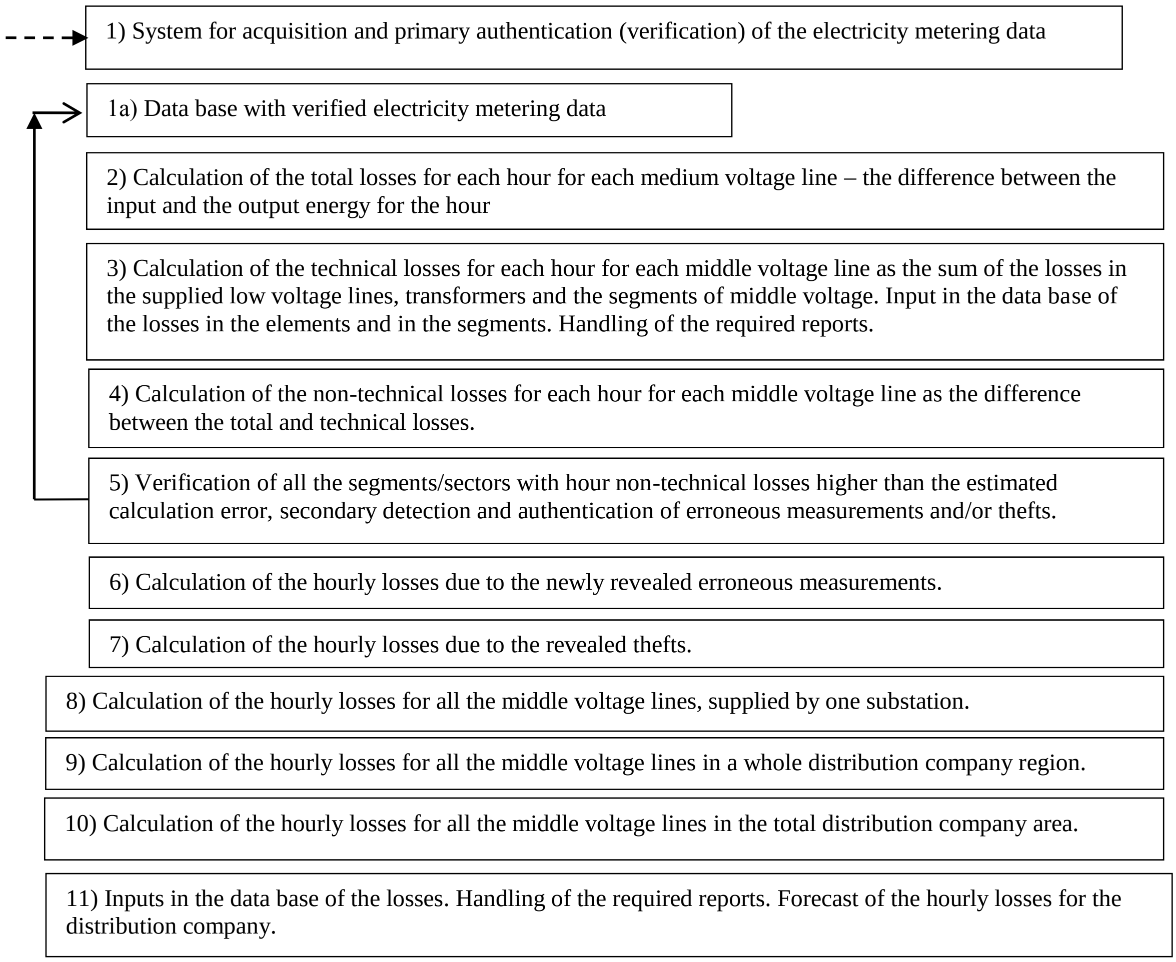
The third activity comprises calculation of losses as a result of the energy thefts along each section of the power lines medium and low voltage as a difference between the non-technical losses and the losses from erroneous measurements for each hour of the past day-and-night according to formula (I.4).

To this end, apart from the technical losses calculated from the past activities, losses from erroneous measurements shall also be calculated, which in its turn is derived from detection of all erroneous measurements for each of the hours of the past day-and-night.

Because of the lack of electric meter measurements for each middle voltage line outlet of the sub-stations 110kV/middle voltage, presently the companies may calculate the total amount of thefts for each of the OCs, but they may not identify the locations of these thefts, because they cannot be calculated by power lines and even less – by sections.

The described methodology activities are illustrated with the block scheme on Fig.I.

Fig. **I. Block scheme of the methodology algorithm**



The implementation of the methodology is not sufficient. The distribution companies have to develop effective and continuously updated plans for reduction of the electric energy losses including the reduction of the thefts. The plans shall not be considered only by the companies. The plans shall attract as partners all consumers through stimulation of consumption-related measures. These plans will be obsolete, if they are based only on the well-known classical measures but do not envisage modernization of the grids and use of innovations both in power distribution technologies and in the state-of-the-art information and control systems merging with the grid. In the next section we propose our concept for the contents of an indicative plan.

PLAN FOR THE DEVELOPMENT OF THE POTENTIAL OF THE DISTRIBUTION COMPANIES

Proposed contents of a plan to develop the potential of the distribution company to reduce electricity losses

1. Abolishing the use of electric meters that do not comply with the requirements under Recommendation 2012/148/EC and Recommendation 2014/724/EC and launching the sole utilization of electric meters that meet these requirements.

2. Modernization of the system for collection and processing of electric meter information.
3. Initiating a shift in the approach for energy calculation on the borders with ESO-EAD (the transmission system operator) and installation of electric meter on each middle voltage line, outgoing from sub-stations 110/middle voltage.
4. Installation of “redundant” electric meters in the consumer cabinets with many individual electric meters, as well as in the transformer stations (middle/low voltage) and in distribution sub-stations.
5. Elaboration of individual calculation models for each power line medium voltage, for each transformer station (middle/low voltage) and for each distribution sub-station, for each power line low voltage, incl. the outlet terminals connecting the consumers.
6. Establishing of a methodology and measurement of the passive parameters of the power lines medium and low voltage, in order to check the faithfulness of the individual computation models built on the basis of producers’ and catalog data.
7. Design, elaboration or purchase of a computing system that uses the electric meter data and the computation models for hourly calculation of the total, technical and non-technical losses.
8. Investigation of the commercial proposals to establish a state-of-the-art grid control system and comparison with scenarios for improvement of the existing information and computing systems.
9. Setting of medium and long-term objectives and planned activities for transition to smart grids.

CONCLUSIONS

The permanent relevance of the tasks related to the reduction of thefts and technical losses in distribution networks, as well as the inevitable transition to smart grids, necessitate public authorities and distribution companies to concentrate their activities on creating methodological, organizational and resources potential for automated control over the functioning of networks, including the control on all types of electricity losses.

ACKNOWLEDGEMENTS

The authors thank to the Board of Management of CEZ Distribution Bulgaria AD for the support to the here presented research and to the Ministry of Education and Science, and to the Scientific and Research Sector of the Technical University of Sofia for the support of the PhD student research project № 152ПД0036-01, entitled “Pricing models for smart distribution and transmission networks”.

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