# Trends and Directions for Energy Saving in Electric Networks

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## 1. Introduction

The existing grids are one-way systems for the delivery of electricity without the self-healing, monitoring and diagnostic capabilities essential to meet demand growth and new security challenges facing us today.

Increasing the efficiency of existing distribution and consumption equates to making additional power available at lower cost. Such efficiencies reduce the need for constructing new generation plants and associated transmission facilities. Smart Grid can provide the communications and monitoring necessary to manage and optimize distributed and renewable energy resources and to maximize the environmental and economic benefits.

The term "smart grid" is hyperbole that seems to imply a future when the grid runs itself absent human intervention. The smart grid concept in many ways suggests that utility companies, executives, regulators and elected officials at all levels of government will indeed face a brutal "pass/fail" future with regard to electric service, a driving force of the U.S. world-leading economy (IEA, 2001).

Intelligent distribution systems are an inevitable reality for utilities as they replace aging infrastructure, deal with capacity constraints and strive to meet the demands of an increasingly sophisticated end-use customer. The benefits of a real-time, single-platform smart distribution network are clear.

The business case must take into account the cost-effectiveness, operational improvements and return on investment of specific initiatives and must consider community-wide benefits. A proactive incremental implementation of smart distribution systems can have a dramatic impact on system improvements and customer satisfaction. A proactive review of smart grid strategy is vital: the utility leadership landscape will reward those who move early.

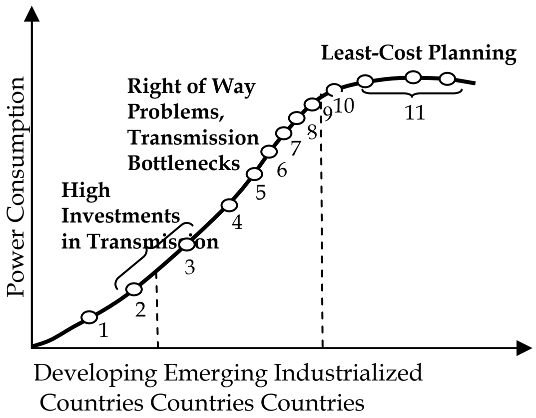
The essence of the smart grid lies in digital control of the power delivery network and two-way communication with customers and market participants. This intelligent infrastructure will allow for a multitude of energy services, markets, integrated distributed energy resources, and control programs. The smart grid is the essential backbone of the utility of the future (IEA, 2001).

In the nearest future we will have to face two mega-trends. One of them is the demographic change. The population development in the world runs asymmetrically: dramatic growth of population in developing and emerging countries, the population in highly develops countries is stagnating (Breuer et al., 2007).

This increase in population (the number of elderly people in particular) poses great challenges to the worldwide infrastructure: water, power supply, health service, and mobility and so on.

The second mega-trend to be mentioned is the urbanization with its dramatic growth worldwide. In less than two years more people will be living in cities than in the country.

Depending on the degree of development (developing, emerging, industrialized countries) different regions have very different system requirements, Fig. 1.




**1. Introduction of Higher Voltage Levels**
**2. Insolated Small Grids**
**3. Decentralized Power Supplies**
**4. More Investments in Distribution**
**5. Lifetime Extension, Monitoring**
**6. Increased Automation**
**7. Demand for Power Quality**
**8. System Interconnections**
**9. Long – Distance Transmission**
**10. Use of New Technologies**
**11. High Energy Imports**

Fig. 1. Development of Power Consumption and System Requirements (Breuer et al., 2007)

Thus, in developing countries, the main task is to provide local power supply. Emerging countries have a dramatic growth of power demand. During the transition, the newly industrialized countries need energy automation, life time extension of the system components, such as transformers and substations. Higher investments in distribution systems are essential as well. At the same time, the demand for a high reliability of power supply, high power quality and, last but not least, clean energy increase in these countries. In spite of all the different requirements one challenge remains the same for all: sustainability of power supply must be provided.

Taking into account these aspects, the energy saving has become a major problem in the worldwide. Numerous studies have indicated that reduction of the power/energy losses in the electric networks is much easier than the increase of generating capacities, and energy efficiency represents the cheapest resource of all. The worldwide experience shows that in utilities with high network loss level, 1 $ expended for loss reduction saves 10 - 15 $ to the utility (Raessar et al., 2007).

But, in evaluation of the energy losses from the electric distribution systems is necessary to know the loads from nodes of the system. Because, in distribution system, except the usual measurements from substations, the feeders and the loads are not monitored, there is few information about the network state. In this situation a modern technique, based on fuzzy set model, it can provide a good operating solution. The core of this technique is the fuzzy correlation model (Cârţină et al., 2003). The combination of the fuzzy approach with the system expert leads to an efficient and robust tool.

## 2. Strategies for power/energy saving in electric distribution networks

### 2.1 Minimization of the power/energy losses

Nowadays, power/energy saving has become a major problem in the worldwide. Numerous studies have indicated that reduction of power/energy losses in the electric networks is much easier than the increase of generating capacities, and energy efficiency represents the cheapest resource of all.

Energy losses throughout the world's electric distribution networks vary from country to country between 3.7% and 26.7% of the electricity use, which implies that there is a large potential for improvement. The distribution networks in most countries in the world were significantly expanded during the late 1960s and early 1970s, with different nominal voltages. For example, in distribution networks from Romania there are three levels of voltage: 6, 10, and 20 kV. The 6 kV level is the first who was developed and the availability of this in urban centres and other areas of concentrated demand for power is still quite high. Perspective to maintain the level of 6 kV is full of difficulties because the networks are very old, some distributors are loaded close to maximum capacity and energy losses are very high. The electric equipments installed in these networks now approach the end of their useful life and need to be replaced. But after replacing, the lifetimes of primary components are long and the networks built today will still be in use after several decades. The same problems in electric distribution networks are occurring during past years all over the world. The 20 kV level appeared later and covered the rest of urban and rural distribution areas. The 10 kV level included still very small areas of urban networks (Grigoraş et al., 2010c, 2010d). Thus, in the Figs. 2 and 3, the location by components of energy losses in the electric networks of a Distribution Company from Romania is presented. From Fig. 2 it can observe that a major part of the energy losses of a distribution system are the energy losses in the 6 kV distribution networks. It should be noted that energy losses in the 6 kV networks have about the same percentage as the 20 kV networks (1.25 % vs. ≈ 1 %), Fig 2, even if their total length is much smaller (report lengths, respectively the number of transformers is about 1 to 3). Another issues relates to the energy losses from the 6 kV cables that are very high compared with those on the 20 kV cables, and from the iron of the power transformers.

In the power transformers, the energy losses fall into two components: no-load losses or iron losses (constant, resulting from energizing the iron core; this phenomenon occurs 24 hours per day, 7 days per week, over the lifetime of the transformer, 30 years in average) and load losses (variable, arising when providing power to a user, from the resistance of the coils when the transformer is in use, and for eddy currents due to stray flux) (Eiken, 2007; European Commission, 1999; Grigoraş et al., 2010a).

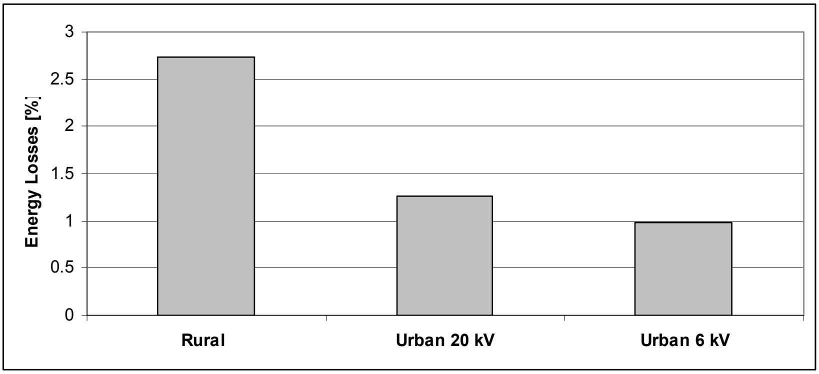



Fig. 2. The total energy losses in electric networks of a distribution company (expressed in percentage of total energy circulating in network)

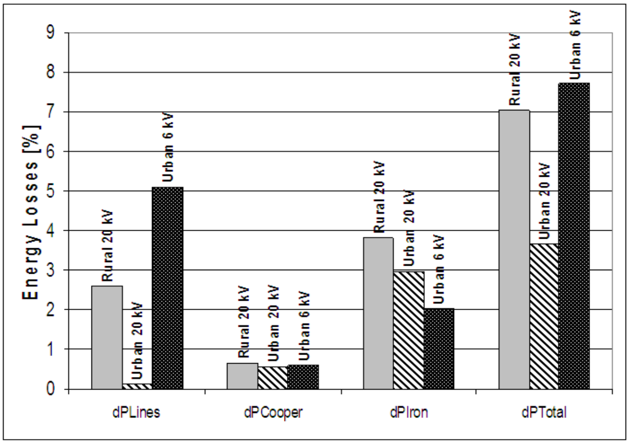



Fig. 3. The total energy losses in a subsidiary of the distribution company (expressed in percentage of energy circulating in the every type of network)

The variable losses depend on the effective operating load to the transformer. The energy consumed in meeting these losses is dissipated in the form of heat, which is not available for the consumers to use.

No-load loss (iron loss) is the power consumed to sustain the magnetic field in the transformer's steel core. Iron loss occurs whenever the transformer is energized; iron loss does not vary with load. These losses are caused by two factors: hysteresis and eddy current losses.

Load loss (copper loss) is the power loss in the primary and secondary windings of a transformer due to the resistance of the windings. Copper loss varies with the square of the load current. The maximum efficiency of the transformer occurs at a condition when constant loss is equal to variable loss. For distribution transformers, the core loss is 15% to 20% of full load copper loss. Hence, the maximum efficiency of the distribution transformers occurs at a loading between 40% – 60%. For power transformers, the core loss is 25% to 30% of full load copper loss. Hence, the maximum efficiency of the power transformers occurs at a loading between 60% – 80%. The efficiency of the transformers not only depends on the design, but also, on the effective operating load.

A policy for the reduction of losses can contain short and long term actions, (Grigoraş et al., 2010a; Raesaar et al., 2007). The some short term measures are following:

- Identification of the weakest areas in distribution network and improve them;
- Reduction the length of the distribution feeders by relocation of distribution substation/installations of additional transformers, and so on.

The long term measures may relate to:

- Mapping of complete distribution feeders clearly depicting the various parameters such as nominal voltage, the length, installed transformation capacity, the number of the transformation points, the circuit type (underground, aerial, mixed), load being served etc.
- Replacement of the 6 kV or 10 kV voltage level with 20 kV voltage level;
- Replacement of the old power transformers with the efficient transformers;
- Compilation of data regarding existing loads, operations conditions, forecast of expected loads etc.

For further development of plans of energy loss reduction and for determination of the implementation priorities of different measures and investment projects, an analysis of the nature and reasons of losses in the system and in its different parts must be done.

From these measures, we will refer only to replacement of the voltage of 6 kV level to 20 kV and the old power transformers with the efficient transformers.

The replacement of the voltage of 6 kV level to 20 kV can be done in order to improve reliability and to minimize power losses in electrical distribution networks. On the other hand, most of the electric distribution infrastructure in urban areas is underground, so if excavation work is done to lay new distribution feeders, it makes much more economic sense to deploy 20 kV distribution lines that have about three times the capacity of 6 kV lines. Other solution that can be applied to minimize the power losses, correlated with the above is the use of efficient transformers. The distribution power transformer is the most important single piece of electrical equipment installed in electrical distribution networks with a large impact on the network's overall cost, efficiency and reliability. Selection and acquisition of distribution transformers which are optimized for a particular distribution network, the utility's investment strategy, the network's maintenance policies and local service and loading conditions will provide definite benefits (improved financial and technical performance) for both utilities and their customers (Amoiralis et al., 2007)

For most electric distribution networks in Europe consist of aged network assets that have reached the end of their original amortized life. Fig. 4 shows a typical asset age profile of such assets and suggests that if original replacement times were to be exercised the majority of gear would have to be replaced in a short interval (Northcote-Green & Speiermann, 2010).

Thus, for an electric utility (Distribution Company) that has numerous distribution transformers in its network, there is an opportunity to install high efficient distribution transformers that have less total energy losses than less efficient transformers, so they pollute the environment less.

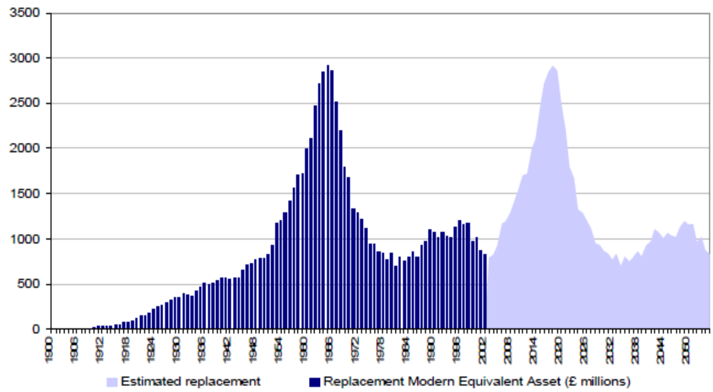



Fig. 4. Typical Electrical Power Distribution Network Asset Age Profile (Northcote-Green& Speiermann, 2010)

## 2.2 Energy performance standards for power transformers

Worldwide there are programs on Minimum Energy Performance Standard (MEPS) for to reduce energy losses associated with transformer operation in the electricity distribution system. Since the original MEPS levels were specified there has been significant development in transformer efficiency standards and requirements in other countries including the USA, European Union, Canada, Japan, China, Mexico and India. Thus, in Fig. 5 it presents a comparison of the requirements of international standards in terms of performance transformer oil at a loading of 50% (Ellis, 2003).

HD 428 standard imposed by European Union specific levels of energy losses in the transformer core for three different classes: A', B' and C' (C' having the lowest level of energy loss and A' the highest level). Also energy losses in the windings for three categories: A, B and C (C being the lowest level of losses and type A has the highest level of losses) (Ellis, 2003; European Commission, 1999). Some states have used the category of transformers the most efficient C-C' as a necessity while others use transformers less efficient by category B-B′. C-C′ category present iron and copper losses of low values compared with other types of categories, presented in Table 1 (Ellis, 2003).

Several European projects have shown the interest in acquiring efficient transformers. A project initiated in collaboration with European Commission from 1999 estimated that energy efficient transformers could save approximately 22 TWh per year by means of C-C′ units; amorphous core transformers could save even more. The Prophet project continued this task in 2004 and arrived at similar conclusions; furthermore, it showed a rising trend in the installation of amorphous transformers in Japan and China, and India and USA install them too. In USA, 10% of new transformer sales are amorphous transformers (about 100,000 new amorphous transformers per year); 15% of new pole transformer sales in Japan are amorphous transformers (about 350,000 amorphous transformers were in service in 2003 (Frau&Gutierrez, 2007). Today, another EU project is working to highlight energy efficiency on Distribution Transformers. The SEEDT project represents one of the projects in the Intelligent Energy Europe programme. The aim of this project is to promote the use of energy-efficient distribution transformers, which can be profitable for investors, and, by contributing to European Community energy savings, may help to fulfil EU energy policy targets (Polish Copper Promotion Centre & European Copper Institute, 2008).

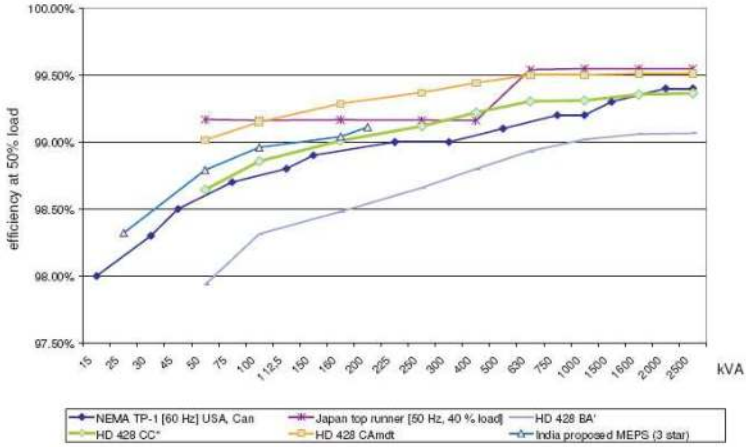



Fig. 5. Requirements of international standards in terms of performance transformer oil at a loading of 50% (Ellis, 2003)

| $S_n$ [kVA] | Power losses (Transformers with standard HD428 (<20kV)) | | | | | |
|---|---|---|---|---|---|---|
| | A [W] | A′ [W] | B [W] | B′ [W] | C [W] | C′ [W] |
| 50 | 1100 | 190 | 1350 | 145 | 875 | 125 |
| 100 | 1750 | 320 | 2150 | 260 | 1475 | 210 |
| 160 | 2350 | 460 | 3100 | 375 | 2000 | 300 |
| 250 | 3250 | 650 | 4200 | 530 | 2750 | 425 |
| 400 | 4600 | 930 | 6000 | 750 | 3850 | 610 |
| 630(4%) | 6500 | 1300 | 8400 | 1030 | 5400 | 860 |
| 630(6%) | 6750 | 1200 | 8700 | 940 | 5600 | 800 |
| 1000 | 10500 | 1700 | 13000 | 1400 | 9500 | 1100 |
| 1600 | 17000 | 2600 | 20000 | 2200 | 14000 | 1700 |
| **2500** | **26500** | **3800** | **32000** | **3200** | **22000** | **2500** |

Table 1. Power losses in transformers according with standard HD 428

There are a number of factors that will enable the achievement of higher efficiencies and support the increase in the current minimum efficiency performance standards levels (Blackburn, 2007):

- Better use of traditional materials to achieve loss reduction and improvement of efficiency;
- Better computer-aided design of transformers to reduce losses and improve efficiency;
- Use of low loss core materials such as amorphous metals;
- New lower loss core configuration designs such as the "Hexaformer";
- Improved operational applications of transformers to optimize energy efficiency in operation;
- Consideration of total life cost of transformers: purchase cost plus operational energy losses;
- The effect of increasing harmonic levels from non-linear loads in increasing losses and reducing efficiency;
- Increased transformer life resulting from lower operating temperature with more efficient transformers.

The savings brought about by loss reduction not just about the monetary value of the energy saved: the released capacity of the system can serve to delay a costly expansion and reduce ageing of the components.

In the past there was little concern for lowering losses in transformers. This was mainly due to the fact that when compared to motors and other electrical devices, transformers were considered to be very efficient.

Thus, low loss transformers can be called"efficient transformers". Operating losses are less causing less heat generation and effecting longer life. One of the prime components of losses is the no-load loss which can be drastically reduced by better design and using superior grades of electrical steels. The other components of losses are the load loss. Load loss can be reduced by using thicker conductors. With use of superior grades of electrical steels and thicker conductors for the windings, the losses of transformers may be brought down to minimum.

The conventional transformer is made up a silicon alloyed iron (Grain oriented) core. The iron loss of any transformer depends on the type of core used in the transformers. However, the latest technology is to use amorphous material for the core. The expected reduction in energy loss over conventional (Si Fe core) transformers is roughly around 70%, which is quite significant. Electrical distribution transformers made with amorphous metal cores (high efficiency transformers) provide an excellent opportunity to conserve energy right from the installation. Though these transformers are costlier than conventional iron core transformers, the overall benefit towards energy savings will compensate for the higher initial investment.

It must be underline if now for us the objective is replacements of old transformers by efficient transformers, (EU, Fig. 6), in Japan the objective the passing to high efficient transformers (Amorphous).

Thus, the technical solutions exist to reduce transformer losses. Energy-efficiency can be improved with better transformer design (selecting better, lower-core-loss steels; reducing flux density in a specific core by increasing the core size; increasing conductor cross-section to reduce current density; good balancing between the relative quantities of iron and copper in the core and coils; and so on.), or by the adoption of amorphous iron transformers world-wide (distribution transformers built with amorphous cores can reduce no-load losses by more than 70% compared to the best conventional designs).

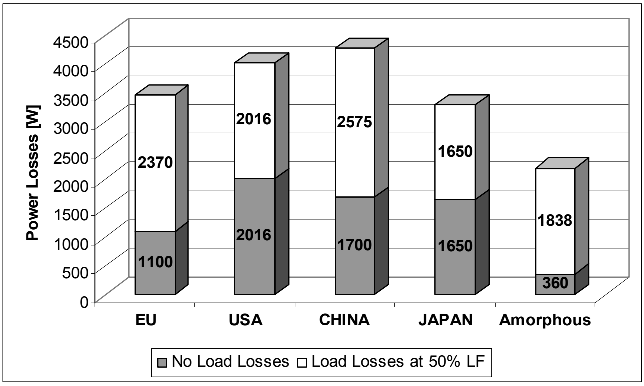



Fig. 6. 1000 kVA Transformers losses from fabrication Norms for several countries (Eiken, 2007; European Commission, 1999)

## 3. Fuzzy modeling in energy losses determination

### 3.1 Fuzzy modeling

In the last few years, research in the area of the optimal operation and planning of the electric networks is in expansion. Many papers and reports about new models have been published in the technical literature, due mostly to the improvement of the computer power availability, new optimization algorithms, and greater uncertainty level introduced by the power sector deregulation.

A considerable part of the information is uncertain, i.e. it is vague, fuzzy, and even ambiguous. Uncertainty of the information in distribution planning, as example, is caused by errors in measurements as well as inevitable errors in estimation of future forecasts. Furthermore, since most of the data used for the planning tasks are not based on the direct measurements, the degree of information uncertainty may be quite high. From the descriptive viewpoint, all the initial information may be categorized into the following several classes (Neimane, 2001):

- Deterministic (voltage levels, sites for new substations etc).
- Probabilistic (existing loads, reliability data for the network components, power quality indices etc).
- Fuzzy (information in linguistic form: large, average small, etc). The fuzzy information is often very subjective and is usually based on expert judgment; however it can be a huge aid during the Decision-Making (DM) process.

Since its first presentation in 1965 by L. A. Zadeh, the Fuzzy Techniques (FT) have had an unexpected growth and success. The broad development of mathematical theory especially in areas of Possibility Theory, Fuzzy Control, Artificial Neural Networks, and Pattern Recognition provided the basis for different applications. They finally became the driving force of FT that today is reflected in many different software and hardware products.

The basic idea of FT is to model and to be able to calculate with uncertainty. Mathematical models and algorithms in distribution systems aim to be as close to reality as possible. The required human observations, descriptions, and abstractions during the modeling process are always a source of imprecision, Fig. 7.

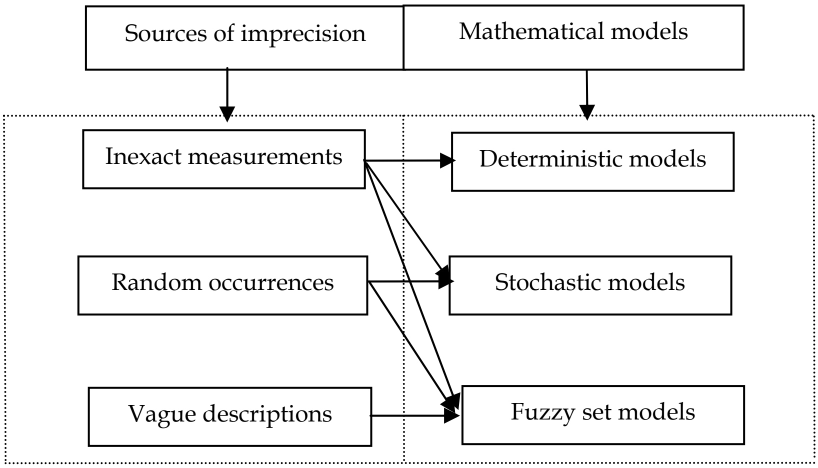



Fig. 7. Mathematical models for imprecision (Steitz et al., 1993)

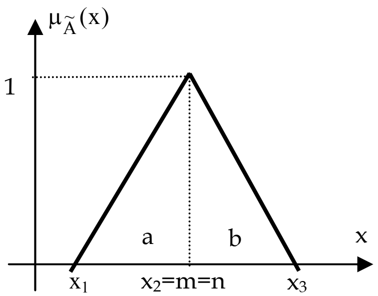
While the two sources of imprecision have long since led to suitable mathematical models, the last one came in our mind only a few decades ago, although we use it instinctively in our everyday life, e.g.: *The reliability of this component is very high*. Most of linguistic descriptions such as *Small*, *Medium or High* are in nature fuzzy. These vague descriptions are as well part of modeling process and the algorithm. The system analyzer has to differ between classes, e.g., when classifying system operation states according to certain operational aspects (Steitz et al., 1993; Cârțină et al. 2003).

Uncertainty in fuzzy logic is a measure of nonspecifically that is characterized by possibility distributions. This is, somewhat similar to the use of probability distributions, which characterize uncertainty in probability theory. Linguistic terms, used in our daily conversation, can be easily captured by fuzzy sets, for computer implementations. A fuzzy set is a set containing elements that have varying degrees of membership in the set. Elements of fuzzy set are mapped to a universe of a membership function.

Fuzzy sets and membership functions are often used interchangeably. There are different ways to derive membership functions. Subjective judgment, intuition and expert knowledge are commonly used in constructing membership function. Even though the choices of membership function are subjective, there are some rules for membership function selection that can produce well the results. The membership values of each function are normalized between 0 and 1.

The uncertain of the load level, the length of the feeders or loading of the power transformers and so on will be represented as fuzzy numbers, with membership functions over the real domain $\Re$. A fuzzy number can have different forms but, generally, this is represented as trapezoidal or triangular fuzzy number, Figs. 8 and 9.

In the case of triangular and trapezoidal representations, a fuzzy number $\tilde{A}$ is usually represented by its breaking points (Cârțină et al., 2003).



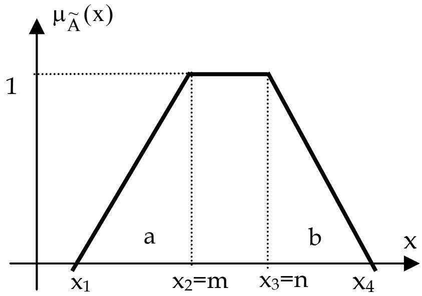




Fig. 8. Triangular fuzzy number Fig. 9. Trapezoidal fuzzy number

$$\tilde{A} \Leftrightarrow (x_1, x_2, x_3) = [m, a, b] \tag{1}$$

$$\tilde{A} \Leftrightarrow (x_1, x_2, x_3, x_4) = [m, n, a, b]$$

The usual algebraic operations with numbers can be extended to fuzzy sets:

$$\tilde{A} = \left\{ \left( x_1, \mu_{\tilde{A}}(x_1) \right), x_1 \in X \right\} \tag{2}$$

$$\tilde{B} = \left\{ \left( y_1, \mu_{\tilde{A}}(y_1) \right), y_1 \in X \right\} \tag{3}$$

$$\tilde{A} + \tilde{B} = \left\{ \left( z_1, \mu_{\tilde{A}+\tilde{B}}(z_1) \right), z_1 \in X \right\} \tag{4}$$

$$\mu_{\tilde{A}+\tilde{B}}(z_1) = \max_{z_1 = x_1 + y_1} \{\min[\mu_{\tilde{A}}(x_1), \mu_{\tilde{B}}(y_1)]\} \tag{5}$$

$$\tilde{A} \cdot \tilde{B} = \left\{ \left( z_1, \mu_{\tilde{A}\cdot\tilde{B}}(z_1) \right), z_1 \in X \right\} \tag{6}$$

$$\mu_{\tilde{A}\cdot\tilde{B}}(z_1) = \max_{z_1 = x_1 \cdot y_1} \{\min[\mu_{\tilde{A}}(x_1), \mu_{\tilde{B}}(y_1)]\} \tag{7}$$

$$c \cdot \tilde{A} = \left\{ \left( x_1, \mu_{c\cdot\tilde{A}}(x_1) \right), x_1 \in X \right\} \tag{8}$$

$$\mu_{c\cdot\tilde{A}}(x) = \mu_{\tilde{A}}(c \cdot x) \tag{9}$$

If for three factors $\tilde{A},\tilde{B},\tilde{C}$, defined as fuzzy variables, we accept the trapezoidal form, represented by breaking points, Fig. 9:

$$\tilde{A} = [m_1, n_1, a_1, b_1],\ \tilde{B} = [m_2, n_2, a_2, b_2],\ \tilde{C} = [m_3, n_3, a_3, b_3] \tag{10}$$

the resulting expressions for addition and multiplication are (11), respectively, (12):

$$\tilde{A} = \tilde{B} + \tilde{C} = [m_2 + m_3,\ n_2 + n_3,\ a_2 + a_3,\ b_2 + b_3] \tag{11}$$

$$\begin{gathered}\tilde{A} = [m_1, n_1, a_1, b_1] = \tilde{B} \cdot \tilde{C} = \\ [m_2 m_3,\ \ n_2 n_3,\ \ m_2 a_3 + m_3 a_2 - a_2 a_3,\ n_2 b_3 + n_3 b_2 + b_2 b_3]\end{gathered} \tag{12}$$

In particular case of the triangular fuzzy number representation, m = n, Fig. 8, and from (11) and (12), we have:

$$\tilde{A} = \tilde{B} + \tilde{C} = [m_2 + m_3,\ a_2 + a_3,\ b_2 + b_3] \tag{13}$$

$$\tilde{A} = [m_1, a_1, b_1] = \tilde{B} \cdot \tilde{C} = [m_2 m_3,\ m_2 a_3 + m_3 a_2 - a_2 a_3,\ m_2 b_3 + m_3 b_2 + b_2 b_3] \tag{14}$$

In certain conditions, it is necessary to define the radical operation for a fuzzy number. Considering the triangular representation:

$$m_3 = m_2,\quad a_3 = a_2,\quad b_3 = b_2 \tag{15}$$

(14) becomes:

$$\tilde{A} = [m_1, a_1, b_1] = [m_2^2,\ 2m_2 a_2 - a_2^2,\ 2m_2 b_2 + b_2^2] \tag{16}$$

From (16), we have the calculation expressions for $m_2$, $a_2$ and $b_2$:

$$m_2 = \sqrt{m_1} \tag{17}$$

$$a_2 = \sqrt{m_1} \pm \sqrt{m_1 - a_1} \geq 0,\ \ a_2 \leq \sqrt{m_1} \tag{18}$$

$$b_2 = -\sqrt{m_1} \pm \sqrt{m_1 + b_1} \geq 0 \tag{19}$$

Then, for radical operation we can write:

$$\sqrt{\tilde{A}} = [\sqrt{m_1},\ \sqrt{m_1} - \sqrt{m_1 - a_1},\ -\sqrt{m_1} + \sqrt{m_1 + b_1}] \tag{20}$$

Similarly, for division operation, from (14), we can write the equations system:

$$m_2 m_3 = m_1 \tag{21}$$

$$m_2 a_3 + m_3 a_2 - a_2 a_3 = a_1 \tag{22}$$

$$m_2 b_3 + m_3 b_2 + b_2 b_3 = b_1 \tag{23}$$

where from the values of $m_3$, $a_3$, $b_3$ are:

$$m_3 = \frac{m_1}{m_2} \tag{24}$$

$$a_3 = \frac{a_1 - \frac{m_1}{m_2} a_2}{m_2 - a_2} \geq 0 \tag{25}$$

$$b_3 = \frac{b_1 - \frac{m_1}{m_2} b_2}{m_2 + b_2} \geq 0 \tag{26}$$

Considering the significance of the parameters, Fig. 8, the conditions (25) – (26) can be written:

$$\frac{a_1}{a_2} > \frac{m_1}{m_2}\ ;\ \frac{b_1}{b_2} > \frac{m_1}{m_2} \tag{27}$$

For defuzzification process, the most used method is the center of gravity (CG) method. According to this method, the crisp value is calculated with relation:

$$\text{Crisp} = \frac{\sum_{i=1}^{4} x_i \cdot \mu(x_i)}{\sum_{i=1}^{4} \mu(x_i)} \tag{28}$$

### 3.2 Fuzzy modeling in determination of the energy losses

In electrical distribution networks, except the usual measurements from stations, there is few information about the state of network. The loads are not usually monitored. As a result, there is at any moment a generalized uncertainty about the power demand conditions and therefore about the network loading, voltage level and power losses. The effects of the load uncertainties will propagate to calculation results, affecting the state estimation and the optimal solutions of the various problems concerning the operation control and development planning.

Therefore, the fuzzy approach may reflect better the real behavior of a distribution network under various loading conditions. For modeling of the loads, two primary fuzzy variables are considered: the loading factor $K_L$ (%) and power factor cosφ, so that the representation of the active and reactive powers result from relations:

$$P = \frac{K_L}{100} \cdot S_n \cdot \cos\varphi, \quad Q = P \cdot \tan\varphi \tag{29}$$

where $S_n$ is the nominal power of the distribution transformer from the distribution substations.

Thus, the hourly loading factor of a particular distribution transformer can be employed to approximate the nodal load. And, because the most utilities have not historical records of feeders, it is proposed to use linguistic terms, usually used by dispatchers, to describe the uncertain hourly loading factor. These linguistic terms are defined in function by the loading of the transformers at the peak load. Each loading level represented by a linguistic variable is described by a fuzzy variable and its associated membership function.

The loading factor $K_L$ and the power factor cosφ were divided into five linguistic categories with4 the trapezoidal membership function, Table 2 (Cârțină et al., 2003; Grigoraş et al., 2010b).

The fuzzy models used in this case for the loading factor and power factor correspond to urban residential loads. Also, active power and power factor must be correlated as it is shown in Fig. 10 (Cârțină et al., 2003).

| Linguistic Categories | | x | | Linguistic Categories | | x | |
|---|---|---|---|---|---|---|---|
| | | $K_L$[%] | cos φ | | | $K_L$[%] | cos φ |
| VS | $x_1$ | 10 | 0.75 | M | $x_3$ | 55 | 0.87 |
| | $x_2$ | 10 | 0.77 | | $x_4$ | 65 | 0.89 |
| | $x_3$ | 15 | 0.79 | H | $x_1$ | 55 | 0.87 |
| | $x_4$ | 25 | 0.81 | | $x_2$ | 65 | 0.89 |
| S | $x_1$ | 15 | 0.79 | | $x_3$ | 75 | 0.91 |
| | $x_2$ | 25 | 0.81 | | $x_4$ | 85 | 0.93 |
| | $x_3$ | 35 | 0.83 | VH | $x_1$ | 75 | 0.91 |
| | $x_4$ | 45 | 0.85 | | $x_2$ | 85 | 0.93 |
| M | $x_1$ | 35 | 0.83 | | $x_3$ | 95 | 0.95 |
| | $x_2$ | 45 | 0.85 | | $x_4$ | 95 | 0.97 |

Table 2. Values of the primary variables for each linguistic loading level

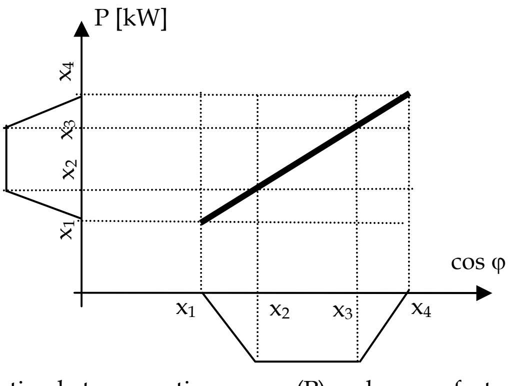



Fig. 10. Fuzzy Correlation between active power (P) and power factor (cos φ)

For estimation of the annual energy losses in the distribution networks, the following empirical formula can be used:

$$\Delta W_T = \left(\Delta P_{Cable} + \Delta P_{Tr\,Co}\right) \cdot LF \cdot 8760 + \Delta P_{Tr\,Ir} \cdot 8760 \quad (30)$$

where:

$\Delta P_{Cable}$ – the power losses at the peak load in the cable;

$\Delta P_{Tr\,Co}$ – the cooper losses at the peak load in the transformers;

$\Delta P_{Tr\,Ir}$ – the iron losses in the transformers;

LF – loss factor.

The values of the $\Delta P_{Cable}$, $\Delta P_{Tr\,Co}$, and $\Delta P_{Tr\,Ir}$ are calculated as fuzzy variables using the modeling presented above.

Determination of the loss factor (LF) can be done for each distribution feeder, using the following formulae (Albert&Mihailescu, 1998; Grigoraş et al., 2010d):

$$LF = \left(0.124 + \frac{T_{max}}{10000}\right)^2 \quad (31)$$

$$T_{max} = \frac{\sqrt{W_P^2 + W_Q^2}}{S_{max}} \quad (32)$$

where:

$W_P$ - active power measured during a period T (usually a year), (kWh);

$W_Q$ - reactive power measured during a period T (usually a year), (kVAr);

$S_{max}$ - peak load of the distribution feeder, (kVA);

$T_{max}$ - peak load hours.

## 4. Case study

### 4.1 Technical analysis

In this paragraph it's presented as example a strategy for energy saving based on the replacement of the 6 kV voltage level with 20 kV voltage level, in correlation with the extent of using efficient transformers. Thus, it considered an urban distribution network with 8 electric stations (110/20/6 kV), which supplies 102 distribution feeders (52 feeders by 6 kV and 50 feeders by 20 kV). The characteristics of this urban distribution network are presented in the Tables 3 and 4.

An analysis of the information from the Table 3 indicates that the length of the distribution networks for two voltage levels is about the same, but the sections between 150 and 185 $mm^2$ predominates at the 20 kV. For the 6 kV level the length of the sections less than 150

$mm^2$ is close to that of sections between 150 and 185 $mm^2$. Regarding the number of transformers, Table 4, it can observed that the average installed power ($S_i$) of a transformer at the 6 and 20 kV voltage levels is about the same (510 vs. 550 kVA) for a ratio of about 2 to 3. More than eighty percent of the transformers have an installed power above 400 kVA.

| Level Voltage | Length, [km] | | | |
|---|---|---|---|---|
| | < 150 $mm^2$ | ≥150 $mm^2$ & ≤ 185 $mm^2$ | > 185 $mm^2$ | Total |
| 6 kV | 91.76 | 126.2 | 25.58 | 243.54 |
| 20 kV | 59.66 | 227.07 | 0 | 286.73 |

Table 3. The length of cables in function by section for the analyzed distribution network

| Level Voltage | < 400 kVA | | ≥ 400 kVA & ≤ 630 kVA | | > 630 kVA | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Transformers | | Transformers | | Transformers | | Transformers | |
| | No. [pcs] | $S_i$ [kVA] | No. [pcs] | $S_i$ [kVA] | No. [pcs] | $S_i$ [kVA] | No. [pcs] | $S_i$ [kVA] |
| 6 kV | 77 | 16536 | 254 | 124830 | 50 | 53000 | 381 | 194366 |
| 20 kV | 78 | 16569 | 358 | 178620 | 82 | 89800 | 518 | 284989 |
| Total | 155 | 33105 | 612 | 303450 | 132 | 142800 | 899 | 479355 |

Table 4. Distribution transformer populations for the analyzed distribution network

In order to check the technical profitability of the implementing the strategy, two variants were analyzed:

- Variant I – the 6 kV and 20 kV voltage levels with the old transformers;
- Variant II – the replacement of 6 kV voltage level with 20 kV, in correlation with the use of the efficient transformers.

The technical characteristics for the distribution (old and efficient) transformers (the cooper and iron power losses) are presented in the Table 5.

| Nominal power [kVA] | Cooper Losses | | Iron Losses | |
|---|---|---|---|---|
| | Old [W] | Efficient [W] | Old [W] | Efficient [W] |
| 100 | 2760 | 1475 | 600 | 210 |
| 160 | 3720 | 2000 | 890 | 300 |
| 250 | 5040 | 2750 | 1100 | 425 |
| 400 | 6850 | 3850 | 1470 | 610 |
| 630 | 9720 | 5400 | 1920 | 860 |
| 1000 | 13900 | 9500 | 2700 | 1100 |
| 1600 | 20200 | 14000 | 4350 | 1700 |

Table 5. Nominal power losses of the distribution transformers (Old vs. Efficient)

For appropriate loading level, Table 2, the power losses of the each feeder can be calculated. Using these power losses (in cables and distribution transformers) and the loss factors, the energy losses can be calculated with the relation (8). For example, in the Table 6 the crisp annual energy losses, as function of the linguistic loading level, for the urban feeders by 6 kV which leave from an electric station (electric station no. I), were presented.

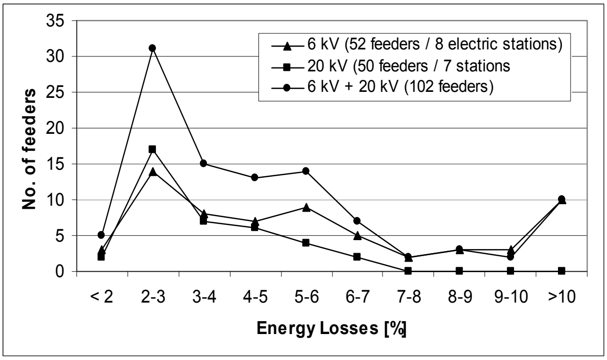



Fig. 11. Annually energy losses' variation in function by number of distribution feeders, variant I

| | Loading level | $dW_{cable}$ [MWh] | $dW_{Tr\ Co}$ [MWh] | $dW_{Tr\ Ir}$ [MWh] | $dW_{Tr}$ [MWh] | $dW_{Total}$ [MWh] |
|---|---|---|---|---|---|---|
| 1 | S | 0.77 | 2.75 | 88.98 | 91.73 | 92.49 |
| 2 | H | 17.24 | 35.51 | 133.31 | 168.82 | 186.06 |
| 3 | S | 2.40 | 12.57 | 101.83 | 114.40 | 116.79 |
| 4 | S | 2.00 | 13.97 | 110.53 | 124.50 | 126.50 |
| 5 | M | 8.39 | 23.40 | 149.69 | 173.09 | 181.48 |
| 6 | H | 1.34 | 18.48 | 63.28 | 81.76 | 83.10 |
| 7 | S | 1.75 | 11.88 | 105.78 | 117.66 | 119.41 |
| **Total** | | **33.89** | **118.56** | **753.39** | **871.95** | **905.84** |

Table 6. Crisp values of the energy losses on the feeders which leave from a distribution station, as function of the linguistic loading level, variant I

In the following, the results obtained by making the energy balance of 6 kV feeders/electric stations (crisp values) are presented in the Tables 7 – 9 and Figs. 12 – 16.

| ST | $dW_{cable}$ [MWh] | $dW_{Tr\ Co}$ [MWh] | $dW_{Tr\ Ir}$ [MWh] | $dW_{Tr}$ [MWh] | $dW_{Total}$ [MWh] | $dW_{cable}$ [%] | $dW_{Tr\ Co}$ [%] | $dW_{Tr\ Ir}$ [%] | $dW_{Tr}$ [%] | $dW_{Total}$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| I | 33.89 | 118.56 | 753.39 | 871.95 | 905.84 | 0.31 | 0.33 | 3.21 | 3.54 | 3.84 |
| II | 30.61 | 53.91 | 169.26 | 223.17 | 253.78 | 1.13 | 1.99 | 6.25 | 8.24 | 9.37 |
| III | 3639.70 | 522.65 | 950.82 | 1473.46 | 5113.11 | 6.73 | 0.97 | 1.76 | 2.73 | 9.46 |
| IV | 1538.50 | 228.09 | 1103.89 | 1331.98 | 2870.52 | 3.13 | 0.46 | 2.25 | 2.71 | 5.85 |
| V | 292.79 | 87.17 | 443.50 | 530.67 | 823.46 | 1.40 | 0.42 | 2.12 | 2.54 | 3.94 |
| VI | 313.81 | 58.58 | 368.70 | 427.28 | 741.09 | 2.31 | 0.43 | 2.71 | 3.14 | 5.44 |
| VII | 21.20 | 65.83 | 268.73 | 334.55 | 355.75 | 0.23 | 0.70 | 2.87 | 3.57 | 3.80 |
| VIII | 706.10 | 119.13 | 837.38 | 956.51 | 1662.60 | 1.93 | 0.33 | 2.29 | 2.62 | 4.56 |
| **Total** | **6576.60** | **1253.92** | **4895.67** | **6149.57** | **12726.15** | **3.16** | **0.58** | **2.33** | **2.91** | **6.07** |

Table 7. The total annually energy losses of 6 kV feeders/electric stations, Variant I

| ST | $dW_{cable}$ [MWh] | $dW_{Tr\ Co}$ [MWh] | $dW_{Tr\ Ir}$ [MWh] | $dW_{Tr}$ [MWh] | $dW_{Total}$ [MWh] | $dW_{cable}$ [%] | $dW_{TrCo}$ [%] | $dW_{Tr\ Ir}$ [%] | $dW_{Tr}$ [%] | $dW_{Total}$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| I | 3.66 | 30.92 | 322.59 | 353.51 | 357.17 | 0.02 | 0.13 | 1.40 | 1.53 | 1.55 |
| II | 15.91 | 26.30 | 68.00 | 94.30 | 110.21 | 0.59 | 0.97 | 2.51 | 3.48 | 4.07 |
| III | 240.34 | 264.84 | 428.94 | 693.78 | 934.12 | 0.44 | 0.49 | 0.79 | 1.28 | 1.73 |
| IV | 86.46 | 97.40 | 499.11 | 596.52 | 682.98 | 0.18 | 0.20 | 1.02 | 1.21 | 1.39 |
| V | 21.80 | 51.79 | 190.50 | 242.29 | 264.19 | 0.10 | 0.25 | 0.91 | 1.16 | 1.27 |
| VI | 10.50 | 19.93 | 164.72 | 184.65 | 195.15 | 0.08 | 0.15 | 1.21 | 1.36 | 1.43 |
| VII | 1.63 | 30.52 | 112.36 | 142.89 | 144.51 | 0.02 | 0.33 | 1.20 | 1.52 | 1.54 |
| VIII | 34.97 | 60.86 | 503.85 | 564.70 | 599.67 | 0.10 | 0.17 | 1.38 | 1.55 | 1.64 |
| **Total** | **415.25** | **582.56** | **2290.07** | **2872.64** | **3287.99** | **0.20** | **0.28** | **1.09** | **1.37** | **1.57** |

Table 8. The total annually energy losses of new 20 kV feeders/ electric stations, Variant II

| ST | $\Delta dW_{cable}$ [MWh] | $\Delta dW_{Tr\ Co}$ [MWh] | $\Delta dW_{Tr\ Ir}$ [MWh] | $\Delta dW_{Tr}$ [MWh] | $\Delta dW_{Total}$ [MWh] | $\Delta dW_{cable}$ [%] | $\Delta dW_{Tr\ Co}$ [%] | $\Delta dW_{Tr\ Ir}$ [%] | $\Delta dW_{Tr}$ [%] | $\Delta dW_{Total}$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| I | 66.89 | 44.38 | 418.88 | 463.27 | 530.15 | 0.29 | 0.19 | 1.81 | 2.01 | 2.30 |
| II | 14.71 | 27.61 | 101.26 | 128.88 | 143.58 | 0.54 | 1.02 | 3.74 | 4.76 | 5.30 |
| III | 3399.36 | 257.81 | 521.88 | 779.68 | 4178.99 | 6.29 | 0.48 | 0.97 | 1.44 | 7.73 |
| IV | 1452.04 | 130.69 | 604.77 | 735.45 | 2187.55 | 2.96 | 0.27 | 1.23 | 1.50 | 4.46 |
| V | 270.99 | 35.38 | 253.00 | 288.37 | 559.27 | 1.30 | 0.17 | 1.21 | 1.38 | 2.68 |
| VI | 303.30 | 38.65 | 203.98 | 242.63 | 545.94 | 2.23 | 0.28 | 1.50 | 1.78 | 4.01 |
| VII | 19.57 | 35.31 | 156.36 | 191.67 | 211.24 | 0.21 | 0.38 | 1.67 | 2.05 | 2.25 |
| VIII | 671.14 | 58.26 | 333.53 | 391.81 | 1062.93 | 1.84 | 0.16 | 0.91 | 1.07 | 2.91 |
| **Total** | **6198.00** | **628.08** | **2593.67** | **3221.76** | **9419.65** | **2.96** | **0.30** | **1.24** | **1.54** | **4.50** |

Table 9. The energy saving in case of Variant II

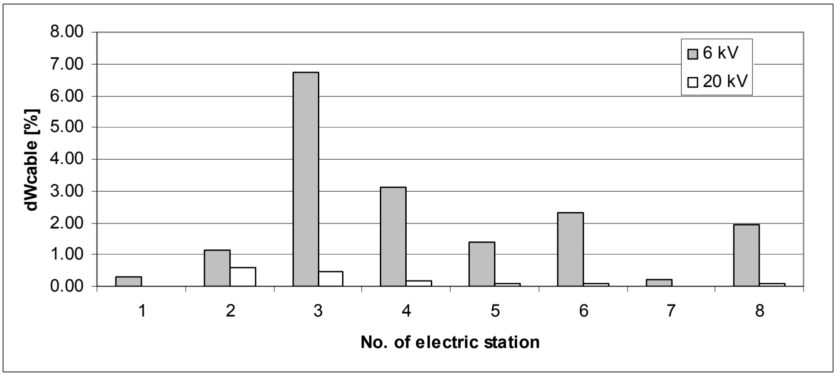



Fig. 12. The annually total energy losses in the cables/electric stations

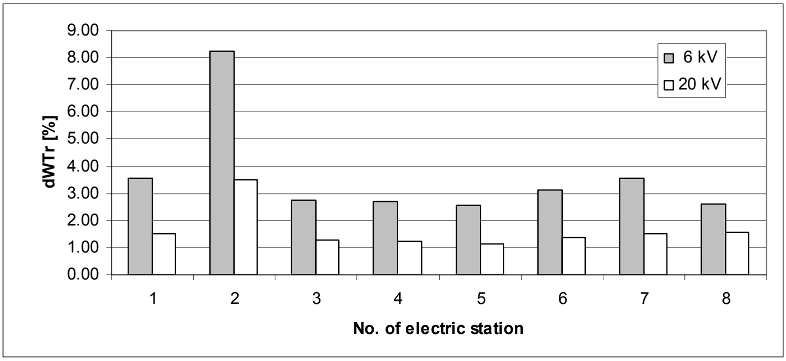



Fig. 13. The annually total energy losses in the transformers/electric stations

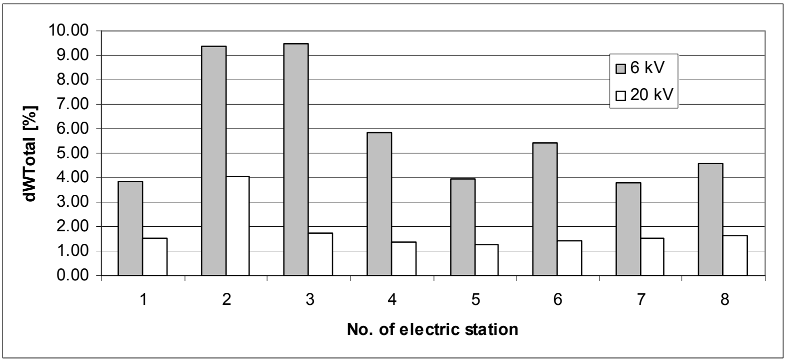



Fig. 14. The annually total energy losses/electric stations

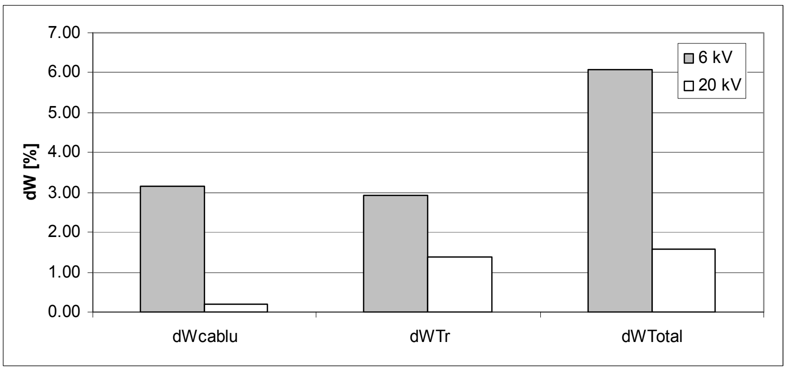



Fig. 15. The annually total energy losses/network elements (cables and transformers)

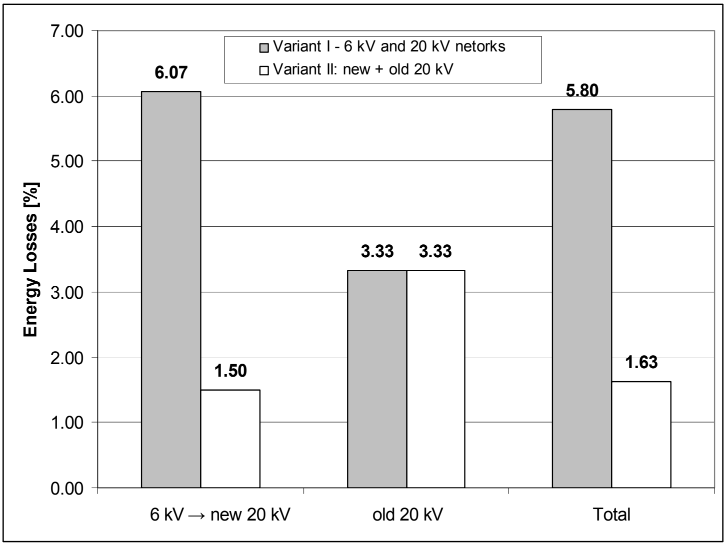



Fig. 16. The annually total energy losses/voltage levels

From the analysis of the results it can be seen that by implementing this strategy, a reduction in losses (which translates into energy savings) of about 9420 MWh /year (4.5% from total energy that entering in the 6 kV network) was obtained. Total energy losses (old and new networks by 20 kV) in the whole analyzed network decrease from 5.8 to 1.63 %, as can be seen in Fig. 16. In this figure, the energy losses for every voltage level and whole distribution network were calculated in percents from the total energy that entering in the every voltage level, respectively from the circulating total energy in network.

## 4.2 Economic analysis

For economic analysis of the strategy for energy saving, the payback time method can be used. This method is quite simple. The relationship for calculating the payback time of investments is:

$$P_T = \frac{N_{tr} \times C_{tr} + L_{line} \times C_{km}}{W_S \times C_{kWh}} \text{ , (years)} \qquad (33)$$

where:

$W_S$ – energy savings realized fom the replacement of the lines and transformers, [kWh];

$N_{tr}$ – number of efficient transformers;

$C_{tr}$ – price of an effcient transformer, (euro);

$L_{line}$ – the length of the cable, (km);

$C_{km}$ – price/km of the cable, (euro);

$C_{kWh}$ – price of a kWh, (euro);

At today's commodity prices (low loss magnetic steel 2 500 - 3 000 euro/tonne, copper 6 000 - 7 000 euro/tonne) the indicative transformer price for AC' class 100 kVA typical distribution transformer is around 3 000 euro, 400 kVA is around 7 000 euro and 1 000 kVA around 12 000 euro. The price/rating characteristics can be roughly described as (Eaton Corporation, 2005):

$$C_1 = C_0 \cdot \left( \frac{S_{in}}{S_{0n}} \right)^x \quad (34)$$

where:

$C_i$ - is cost of transformer "i"

$C_0$ - is cost of transformer "0"

$S_{in}$ - is rated power of transformer "i"

$S_{0n}$ - is rated power of transformer with the nominal power by 100 kVA;

x - exponent (cost factor).

The x factor is about 0.4 to 0.5. For more efficient units this factor has a tendency to increase up to 0.6 or even higher.

Also, the price for one km of electric cable with section of 150 mm$^2$ was considered 4700 euro/km, and for a section of 185 mm$^2$, the price is 5900 euro/km.

In Table 10, the payback times of investment, in the case of the urban distribution network with 8 electric stations (110/20/6 kV) considered in the above paragraph, are presented.

The payback times of investment vary different from one to another distribution feeder in function by the loading level, power installed and the length. In Fig. 17, the variation of the payback time of investment in function of energy savings is shown.

| ST | Energy losses/voltage level [MWh] | | $W_S$ [%] | $P_T$ [years] |
|---|---|---|---|---|
| | 6kV | 20 kV | | |
| I | 905.84 | 357.16 | 60.57 | 6.91 |
| II | 253.78 | 110.20 | 56.57 | 12.87 |
| III | 5113.1 | 934.11 | 81.73 | 2.37 |
| IV | 2870.52 | 682.97 | 76.21 | 4.82 |
| V | 823.45 | 264.08 | 67.93 | 9.46 |
| VI | 741.09 | 195.15 | 73.66 | 4.78 |
| VII | 355.75 | 144.51 | 59.37 | 2.56 |
| VIII | 1662.6 | 446.23 | 73.16 | 9.26 |
| **Total** | **12726.13** | **3134.41** | **75.37** | **6.63** |

Table 10. Energy saving and the payback time of the investment/electric stations

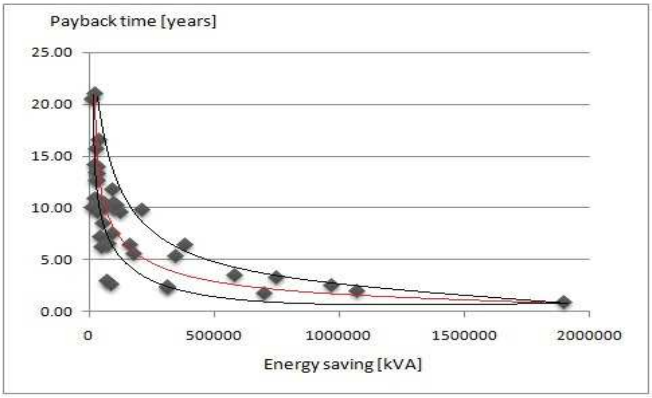



Fig. 17. The payback time of investment in function by saving energy

From the figure it can be seen that the distribution feeders with high energy saving have a payback time more reduced than the feerders with the small values of the energy saving.

## 5. Conclusions

Power/energy losses have a considerable effect on the process of transport and distribution of electrical energy and thus the strategies for saving energy are a concern to electrical companies in the country and abroad. In this chapter, a strategy for energy saving based on the minimization of the power/energy losses in electric networks, especially by replacement of the 6 kV voltage level with 20 kV voltage level in correlation with using efficient transformers, is presented.

This strategy can lead to increased capacity of electric distribution lines (by switching from 6 kV to 20 kV), to increase network reliability and minimize energy losses (the annually energy saving is about 9400 MWh, 2.67% from the circulating total energy in network). In terms of the environmental impact, the strategy can have a control and management of energy use not entailing the use of supplementary resources.

The economic analysis revealed that the payback time of initial investment in the network elements (lines and transformers) is on average 10 years, depending on the loading level, power installed and the length.

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**Management of Technological Innovation in Developing and Developed Countries**

Edited by Dr. HongYi Sun

ISBN 978-953-51-0365-3
Hard cover, 312 pages
**Publisher** InTech
**Published online** 21, March, 2012
**Published in print edition** March, 2012

It is widely accepted that technology is one of the forces driving economic growth. Although more and more new technologies have emerged, various evidence shows that their performances were not as high as expected. In both academia and practice, there are still many questions about what technologies to adopt and how to manage these technologies. The 15 articles in this book aim to look into these questions. There are quite many features in this book. Firstly, the articles are from both developed countries and developing countries in Asia, Africa and South and Middle America. Secondly, the articles cover a wide range of industries including telecommunication, sanitation, healthcare, entertainment, education, manufacturing, and financial. Thirdly, the analytical approaches are multi-disciplinary, ranging from mathematical, economic, analytical, empirical and strategic. Finally, the articles study both public and private organizations, including the service industry, manufacturing industry, and governmental organizations. Given its wide coverage and multi-disciplines, the book may be useful for both academic research and practical management.

**How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Gheorghe Grigoraş, Gheorghe Cârţină and Elena-Crenguţa Bobric (2012). Trends and Directions for Energy Saving in Electric Networks, Management of Technological Innovation in Developing and Developed Countries, Dr. HongYi Sun (Ed.), ISBN: 978-953-51-0365-3, InTech, Available from: http://www.intechopen.com/books/management-of-technological-innovation-in-developing-and-developed-countries/trends-and-directions-for-energy-saving-in-electric-networks

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