SOLUTIONS TO INCREASE THE ENERGY EFFICIENCY WITHIN THE ELECTRIC POWER DISTRIBUTION SYSTEM

Cătălin MIHAI[1,2], Ionel LEPĂDAT[2], Elena HELEREA[2]

[1] Transilvania SUD Electrica Distribution Network SA, 25 Pictor Luchian Str., Brasov, Romania
[2] Transilvania University of Brasov, 29 Eroilor Str. Brasov, Romania, helerea@unitb.ro

Abstract : **- Recent studies suggest as possible solutions to assure the electric power needs either to increase properly the generating capacities, or to diminish the power losses within the transportation and distribution system, as well as within the consumption network. The paper presents a comparative analysis of the solutions to reduce the losses in order to increase the power efficiency within the electric power distribution systems. The paper analyzes the losses of the distribution system components and conceives a flow chart for calculating losses in transformers. The case study comprises an analysis of the own technological consumption (OTC) of Electrical Distribution Network *Transilvania SUD* SA in order to establish solutions for modernization / refurbishment of 20.0/0.4 kV aerial distribution transformers, older than 30 years and still in operation. It was established a database on technical and functional characteristics of 20.0/0.4 kV transformers of distribution system. Based on proposed methodology for calculating the losses in transformers and taking into account two scenarios for their normal operating, a refurbishment solution has been elaborated: the replacing of old transformers with powers greater than 100 kVA, with new ones with lower losses.**

Keywords: *transformer losses, energy efficiency, electric power distribution network, scenarios*

1. POWER EFFICIENCY AND OWN TECHNOLOGICAL CONSUMPTION

Considering the current energy crisis, energy saving has become an issue of great importance on a global level. Studies show that reducing losses made in the electric power networks is much more economical than the corresponding increase in generation capacities, and energy efficiency is the cheapest resource of all.

Specialized technical literature emphasizes the new conditions to consider when debating the question of energy losses after the deepening of the energy crisis, both in relation to their cost and the need to save energy [1].

A situation regarding the number of distribution transformer stations relative to the average rated apparent power / transformer for different European countries is shown in Fig. 1 [2]. The situation corresponds to the year 2008.

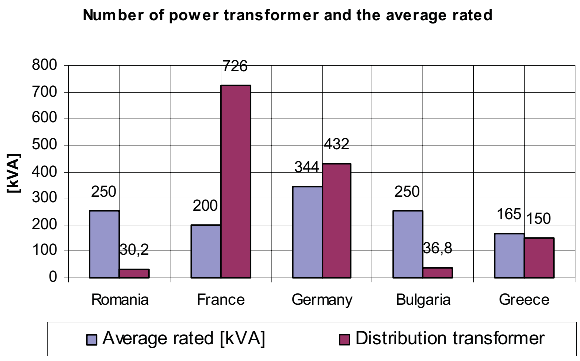

Figure 1: Distribution of the number of transformer stations relative to average rated apparent power for some European countries [2].

The Fig. 1 reveals that in Romania there are up to 30,200 transformer stations with an average rated value of apparent power of 250 kVA.

A great diversity of transformer units exists for other European countries:

- France: 726,000 transformer units with average rated value of apparent power of 200 kVA,
- Germany: 432,000 transformer units with average rated value of apparent power of de 344 kVA,
- Bulgaria: 36,800 transformer units with average rated value of apparent power of 250,000 kVA,
- Greece: 150,000 transformer units with average rated value of apparent power of 165 kVA [1], [2].

Energy efficiency has now become a priority for European and national energy policy [2].

Increasing energy efficiency and other objectives of European policy, can be achieved by reducing own technological consumption, by reducing distribution costs, by expanding transportation and distribution networks altogether with integration in smart grids and reduction of negative environmental impact.

Measures to reduce own technological consumption within transportation and distribution networks is grouped into several categories, after their applicability:

a. the implementation of new technologies with a long term vision;
b. the rational use of electrical installations;
c. improving the efficiency of energy equipment;

d. decentralization of low voltage networks based on installing small transformers, close to consumers, each transformer supplying 1-15 consumers, according to the load charging [2];
e. organizational/ management measures;
f. other measures.

Own technological consumption index is a characteristic parameter through which it can be analyzed the efficiency of technical and organizational measures meant to reduce energy losses.

Own technological consumption losses include specific components:

- Losses in lines and cables – losses through Joule effect, which are dependent of load, Corona effect losses, which are dependent of voltage and environment conditions, dielectric losses in insulation of cables, transformers and other components;
- Losses in transformers – dependent of load (short circuit or winding losses) and independent of load (in the magnetic core)
- Losses in electrical appliances - including loses in the counters, fuses, measuring instruments.

There are several procedures to evaluate the power losses in the elements of power distribution system. A calculation model of power losses in transformers is described in the following paragraph.

2. PROCEDURE TO EVALUATE THE POWER LOSSES IN TRANSFORMERS

Active and reactive power losses in transformers are determined by losses in the transformer's core (independent of load) and losses in the transformer's windings (variable with load). Active power losses in the transformer's core depend on the magnetic induction in the core, therefore on the supply voltage. They are determined by the no-load testing ΔP_o of the transformer. Active power losses in transformer's windings depend on the square of power (load) in rate regime, being determined through the short circuit test ΔP_{sc}. [3], [4], [5].

Total active power losses in the transformer will be:

$$\Delta P = \Delta P_0 + \alpha^2 \cdot \Delta P_{SC} \quad (1)$$

where:

$$\alpha = \frac{I}{I_n} = \frac{S}{S_n} \quad (2)$$

I_n – curentul nominal al transformatorului,
I – curentul de sarcina al transformatorului,
α - is transformer's load factor,
S_n – apparent power of the transformer,
S – apparent power of transformer load.

The values of active power and energy losses are influenced both, by the flow of reactive power and reactive power losses. Reactive power losses generate a reactive current which is phasorially composed with the load current value.

The resulting current of a greater value creates additional active power losses.

In the case of power transformers, the total active power losses taking into account the contribution of the reactive component of power losses in the transformer can be expressed by the formula:

$$\Delta P_T = \Delta P + k_e \cdot \Delta Q \quad (3)$$

where, the significance of quantities are:
ΔP_T - active power losses due to power circulating through the transformer;
ΔQ- reactive power losses in transformers when it is compensated by capacitors.
k_e- energetic equivalent of reactive power losses, representing the contribution of reactive power losses into active power losses, in kW/kVar,
$k_e \cdot \Delta Q$ - additional active power losses due to circulation of reactive power losses in the power transformer, in kW [3].

In [3] there are presented the values of active power losses in power transformers manufactured in the country with energy equivalent consideration.

According to the normative NTE 401/03/2000 the type of losses can be determined through the formula written below.

Having in view the period of time for calculating energy losses as:

$$\tau = T_{SM} \frac{10000 + T_{SM}}{27520 - T_{SM}}, \quad (4)$$

where: T_{SM}=2686 hours (in PE 132 /2003), and it is obtained:

$$\Delta W_{Ta} = \Delta P_0 \cdot 8760 + \alpha^2 \cdot \Delta P_{sc} \cdot \tau, \quad (5)$$

where:
ΔW_{Ta} – annual energy losses in transformers;
T_{SM} – average of annual duration of using maximum power;
τ- duration of maximum losses.

In the case of a great number of different rated power transformers differently loaded, the assessment of energy losses is a difficult and laborious process.

Specific software and methodologies are presented in specialized papers. [6] – [10].

Fig. 2 presents the flow chart proposed for evaluating the losses in the case of a group of *n* power transformers of different types and different loads.

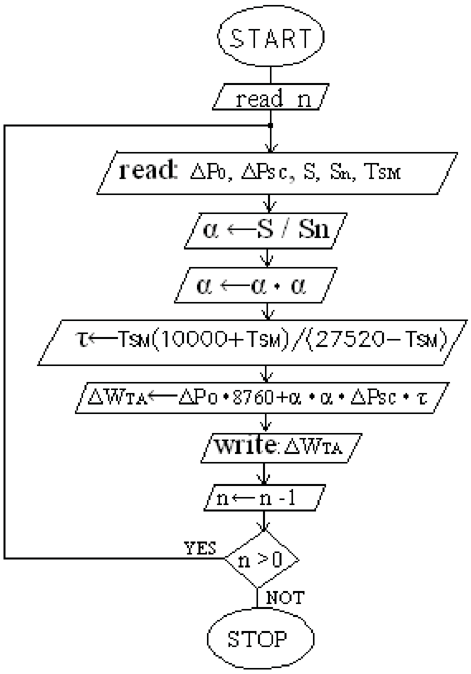

Figure 2: Flow chart proposed for evaluating the losses in case of a group of *n* power transformers.

For calculation of energy losses, for each transformer it is considered the technical data, load factor and period of operation.

3. CASE STUDY

The case study is conducted on Electrical Distribution Network *Transilvania SUD* SA, for whose 20.0/0.4 kV aerial distributions transformers, older than 30 years and still in use, modernization /refurbishment solutions are proposed.

A database for the 2365 distribution transformers of 20.0/0.4 kV comprising their technical and functional characteristics have been developed.

No-load or iron transformer losses and short-circuit or copper transformer losses for older than 30 years transformers have been calculated with relations (1) – (3), and there are shown in Table 1.

S_n [MVA]	Number of transformers [pcs]	ΔP_o [MWh]	ΔP_{sc} [MWh]
345.97	2365	15,095.49	40,478.79

Table 1: No-load transformer losses and short-circuit transformer losses for older than 30 years transformers

No-load transformer losses represent only 37.29 % of total losses; the greater value of short-circuit losses is due to the variation of transformer load.

In Fig. 3 is graphically shown the distribution transformer losses depending of rated power of PTA from FDEE-EDTS.

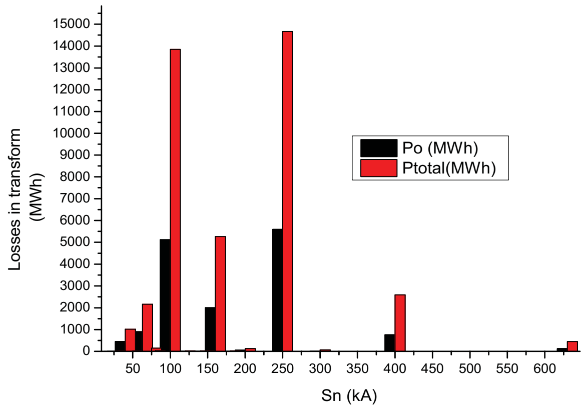

Figure 3: Distribution transformer losses depending of rated power of PTA from FDEE-EDTS.

Fig. 4 shows distribution of older than 30 years aerial transformers in the distribution branches - subsidiaries of Electrical Distribution Networks Transilvania SUD SA.

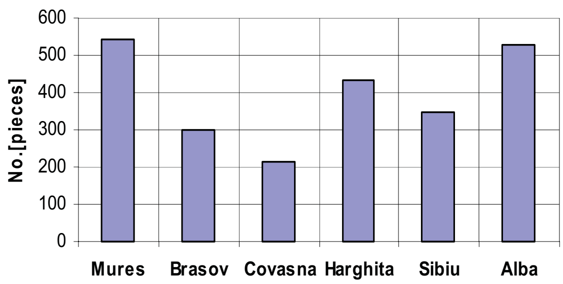

Figure 4: Branch distribution of aerial transformers older than 30 years of *Transilvania SUD* SA.

In the subsidiaries of Electrical Distribution Network *Transilvania SUD* SA there are also included non-standard transformers, i.e. 30 kVA, 47 kVA, 50 kVA, 75 kVA, 80 kVA, 120 kVA, 140 kVA, 150 kVA, 180 kVA , 200 kVA, 300 kVA.

The case study considers these transformers to be replaced with others of similar standardized apparent power since they have no correspondence in new transformers ranges.

Transformers were grouped according to their apparent power and their number, as shown in Fig. 5 and Fig. 6.

Annual energy losses in the 2365 transformers are calculated with the relations (1)-(5), using the procedure described in Fig. 2. The obtained value of total energy losses corresponding (for MV) to the own technological consumption (OTC) is of 18,847.85 MWh.

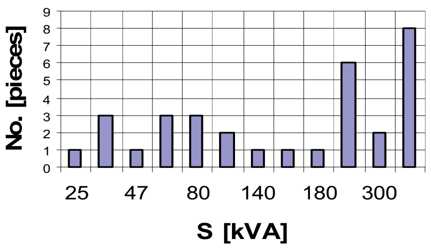

Figure 5: Number of transformers with their apparent powers: 25 kVA, 30 kVA 47 kVA, 50 kVA, 80 kVA, 120 kVA, 140 kVA, 150 kVA, 180 kVA, 300 kVA.

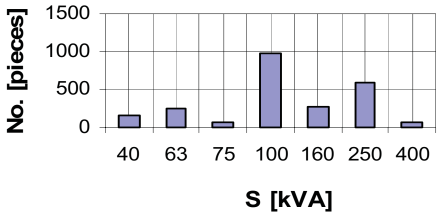

Figure 6: Number of transformers with their apparent powers: 40 kVA, 63 kVA, 75 kVA, 100 kVA, 160 kVA, 250 kVA, and 400 kVA, by their number.

In Table 2 the situation of total OTC in *Transilvania Sud* SA, at the levels of HV, MV (HV/MV transformers and MV network are included), LV (MV/LV transformers and LV network are included) in which the weigh losses of considered transformer is given.

Voltage level [kV]	2009 [MWh]	ΔW_{ov} [MWh]
HV	70,894.00	
MV	203,192.00	18,847.85
LV	458,033.00	
Total	732,118.00	

Table 2: Own technological total consumption OTC for 2009 in comparison with the annual energy losses for considered transformers.

Thus, in the year 2009, the annual losses for the 2365 transformers of MV taken in account represent 9.27 % of total annual energy losses in the medium voltage network (203,192.00 MWh/year).

In figures 7, 8, 9, and 10 there are shown the annual power losses of the aerial transformers older than 30 years, estimated, in comparison with the newer transformers, having lower losses.

In these figures, are also considered the aerial transformers with non-standard rated powers. It can conclude that by replacing these transformers with new ones with lower losses, energy losses decrease by 40.76 %.

To establish the optimal solution for reduction the annual energy losses in transformers belonging to Electrical Distribution Network *Transilvania SUD* SA two scenarios are proposed:

- Scenario I: to replace all transformers;
- Scenario II: to replace a part of old transformers.

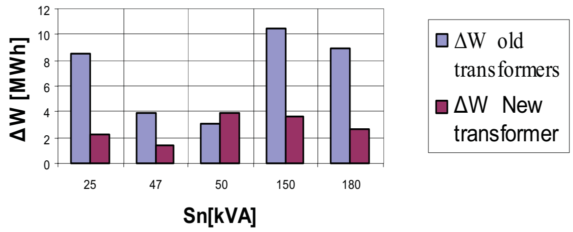

Figure 7: Comparison of annual energy losses in transformers with the apparent powers of 25 kVA, 47 kVA, 50 kVA, 150 kVA, 180 kVA and older than 30 years and new transformers with lower losses.

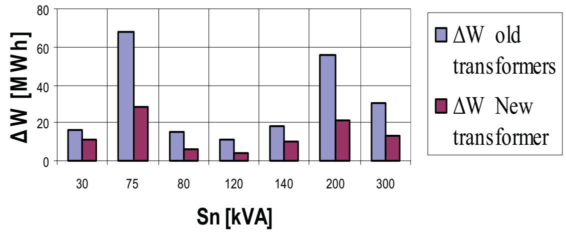

Figure 8: Comparison of annual energy losses in transformers with the apparent powers of 30 kVA, 75 kVA, 80 kVA, 120 kVA, 140 kVA, 200 kVA, 300 kVA and older than 30 years and new transformers with lower losses.

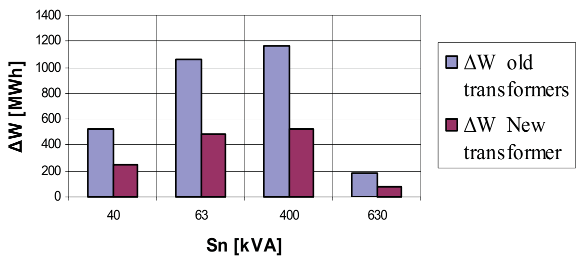

Figure 9: Comparison of annual energy losses in transformers with the apparent powers of 40 kVA, 63 kVA, 400 kVA, 630 kVA and older than 30 years and new transformers with lower losses.

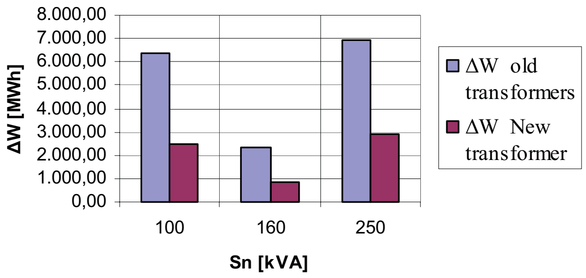

Figure 10: Comparison of annual energy losses in transformers with the apparent powers of 100 kVA, 160 kVA, 250 kVA and older than 30 years and new transformers with lower losses.

For each scenario, the following cases are considered:

a. Aerial distribution transformers are replaced with lower losses transformers of standardized rated powers having in view the rate regime of operation;

b. Aerial distribution transformers are replaced with lower losses transformers of standardized rated powers having in view the variable loading.

Technical and functional characteristics of all transformers of 20.0 / 0.4 kV were considered those of standard EN - 50 464.

The non-standard transformers were replaced with standard power transformers of similar apparent power. In doing so, the total number of transformers remained the same while the power was adjusted.

Tables 3, 4 and 5 show the result of this operation of grouping the transformers, energy losses divided on groups of transformers and total energy losses.

Energy losses have been calculated with the model presented above.

Scenario I results:

- In case *a,* the annual amount of energy losses in transformers are of 7,682.85 MWh and represents 3.78 % of the medium voltage network losses, amounting to 203,192.00 MWh in 2009. By reducing losses in distribution transformers the own technological consumption of the medium voltage network drops by 5.49 %.
- In case *b* is suggested to introduce aerial distribution transformers with lower losses transformers of standardized rated powers and taking account the load optimizer required by the transformer.

In case *b* the annual amount of energy losses in transformers is 8,535.91 MWh and represents 4.20% of the medium voltage network losses, in 2009.

By reducing energy losses in distribution transformers the own technological consumption of the medium voltage network drops by 5.07%.

Table 3 and 4 shows the result of the operation of grouping the transformers and the energy losses.

No. of groups	S_n [kVA]	No. of transformers [pcs]	ΔW_{Ta} [MWh]
1	40	171	259.75
2	63	276	528.79
3	100	976	2,459.99
4	160	280	902.81
5	250	582	2,928.57
6	400	72	517.96
7	630	8	84.99
Total		2365	7,682.85

Table 3: Energy losses in Scenario I, case *a*.

No. of groups	S_n [kVA]	No. of transformers [pcs]	ΔW_{Ta} [MWh]
1	16	17	21.19
2	25	60	83.25
3	40	227	329.44
4	63	316	544.15
5	100	863	3,177.35
6	160	291	1,016.68
7	250	460	2,427.60
8	400	117	796.11
9	630	11	97.61
10	1000	3	42.53
Total		2365	8,535.91

Table 4: Energy losses in Scenario I, case *b*.

Scenario II results:

The total losses of transformers smaller than 100 kVA represents only 10.26% of the total losses calculated for the 2365 transformer distributions.

For this reason in the scenario II it was proposed to study only transformers with power exceeding 100 kVA. The number of these transformers is 1918, for which the own technologic consumption OTC is 17,148.1 MWh.

The annual amount of energy losses corresponding to the 1918 new transformers is 6,894.31 MWh.

By reducing energy losses (10,253.79 MWh) in distribution transformers the own technological consumption of the medium voltage (203,192 MWh) network drops by 5.04%.

No. of groups	S_n [kVA]	No. of transformers [pcs]	ΔW_{Ta} [Mwh]
1	100	976	2,459.99
2	160	280	902.81
3	250	582	2,928.57
4	400	72	517.96
5	630	8	84.99
	Total	1918	6,894.31

Table 5: Energy losses in Scenario II.

Comments:

Proposed scenario	No of Trafo [pcs]	Old trafo ΔW_{Ta} [MWh]	New trafo ΔW_{Ta} [MWh]	Reduc-tion of OTC [MWh]
Scenario Ia	2365	18,847.8	7,682.8	11,165.0
Scenario Ib	2365	18,847.8	8,535.9	10,311.9
Scenari0 II	1918	17,148.1	6,894.3	10,253.7

Table 6: Comparison of scenarios regarding the reduction of own technologic consumption OTC.

Data of Table 6 show that Scenario II offers a greater reduction of own technological consumption, of 10,253.7 MWh.

4. CONCLUSIONS

For satisfying the energy need the reducing losses in electric networks is much more economically than the increasing the generation capacity. The energy efficiency is the cheapest of all existing resources. Losses reduction means efficient use of energy, means energy saved, means less energy generated. All these lead to the rational use of resources, i.e. to a sustainable energy development policy. Increasing energy efficiency can be achieved by reducing annual energy losses in aerial distribution transformers.

The case study of aerial transformers from Electrical Distribution Network *Transilvania SUD* SA shows the possibility to replace only transformers with power exceeding 100 kVA, for which the greatest decreasing of the losses in the distribution transformers of the electric energy network is obtained.

This proposal is in accordance with the "European Climate Changes Programme", approved by Decision 1600/2002/EC, for replacing transformers with big internal energy losses - translated into the own technological consumption indicator – with new transformers having low operating losses. This proposal has an important positive impact on the environment.

Such a project may qualify for accessing European funds in Priority Axe 4 - Increasing energy efficiency and security of supply in the context of combating climate change, Area of intervention 4.1 - Improving energy efficiency, Operation 2 – Efficient and Sustainable Energy (improving energy efficiency and sustainable development of the energy system from the environmental point of view).

References

[1] P. Paitsios, G. Dimitrakakis P. Ioannos, *Transformers of reduced losses and evaluation of their repair*, Journal of Materials Processing Technology, no. 161, 2005, pp. 204–209.

[2] M. Lupescu, A. Leca, *Increasing the energy efficiency in distribution electric networks through losses reduction (*in Romnian: *Cresterea eficientei energetice in retelele electrice de distributie prin reducerea pierderilor,* Regional Forum of Energy, FOREN 2008, Neptun, 15 – 19 June, pp. 204-209.

[3] H. Albert, A. Mihailescu, *Losse power and energy în electrical distribution system (*in Romnian: *Pierderi de putere si energie in retelele electrice*) Editura tehnica Bucuresti, 1997.

[4] L. Popescu, S. Căciulă, Mihaiescu, V. Gulinschi, M. Iliuta, *Considerations on energy equivalent of reactive power in transformers* (In Romanian: *Consideratii asupra echivalentului energetic al pierderilor de putere reactiva pentru transformatoare)*, , Regional Forum of Energy, FOREN 2008, Neptun, 15-19 June 2008, pp. 1-8.

[5] J. Triplett, S. Rinell, J. Foote, *Evaluating distribution system losses using data from deployed AMI and GIS systems,* Conference Papers, 2010 IEEE, 10 (C1):p.C1-C8.

[6] J. C. Olivares, Y. Liu, J. M. Cañedo, R. Escarela-Pérez, J. Driesen, P. Moreno, *Reducing Losses in Distribution Transformers,* IEEE Transactions on Power Delivery, vol. 18, no. 3, July 2003, pp. 821-826.

[7] D. A. Koppikar, S. V. Kulkarni, P. N. Srinivas, S. A. Khaparde, R Jain, *Evaluation of flitch plate losses in power transformers,* IEEE Transactions on Power Delivery, Vol. 14, No. 3, July 1999, pp. 996-.1001.

[8] J. C. Olivares, Y. Liu, J. M. Cañedo, R. Escarela-Pérez, J. Driesen, P. Moreno, *Reducing Losses in Distribution Transformers,* IEEE Transactions on Power Delivery, vol. 18, no. 3, july 2003, pp. 821- 826.

[9] S. V.Kulkarni and S. A. Khaparde, *Stray loss evaluation in power transformer—a review,* IEEE Power Eng. Soc. Winter Meeting, Paper no.0.7803-5938-0/00, Singapore, Jan. 2000, pp. 2269–2274.

[10]C. Yongbin, Y. Junyou, Y. Hainian, and T. Renyuan, *Study on eddy current losses and shielding measures in large power transformer*, IEEE Transactions on magnetism, vol. 30, Sept. 1994, pp. 3068–3071.