IDENTIFYING ENERGY EFFICIENCY IMPROVEMENTS AND SAVINGS POTENTIAL IN CROATIAN ENERGY NETWORKS

Tomislav BARICEVIC
EIHP – Croatia
tbaricev@eihp.hr

Minea SKOK
EIHP – Croatia
mskok@eihp.hr

Srdjan ZUTOBRADIC
HERA – Croatia
szutobradic@hera.hr

Lahorko WAGMANN
HERA – Croatia
lwagmann@hera.hr

EIHP - Energy Institute Hrvoje Pozar *HERA – Croatian energy regulatory agency*

ABSTRACT

Croatian ten year distribution network development plan (2016-2025) is characterised by peak driven network design in which the network is primarily developed and designed to meet peak demand in a safe and reliable manner and in which losses have been considered more as a consequence of design and operational management decisions, rather than and explicit development criteria. Faced with the requirement from the Article 15 of the Energy Efficiency Directive, in 2015 Croatian regulatory authority launched the vast study in order to examine the opportunities of making distribution network more energy efficient within the framework of the approved investments from 10-year plan. Based on the outcomes of the study, in this paper key measures for increasing energy efficiency and their energy efficiency potential are presented.

INTRODUCTION

Article 15 of the Energy Efficiency Directive (2012/27/EU) (EED) [1] targets specifically the transmission and distribution sector of electricity and gas and requires thus Member States (MS) to perform an assessment of the energy efficiency (EE) potential of their respective infrastructure. European associations report that most of their members have not yet been actively involved by MS in addressing the provisions of article 15.2. [2]; some MS are finalising their assessment, while others are working on the topic.

Faced with the above mentioned requirements, the Croatian regulatory authority (RA) launched, in 2015, a vast study to identify possible measures to reduce technical losses in transmission and distribution electricity networks and evaluate savings potential in 2015-2024 period. The study has been prepared by Energy Institute Hrvoje Pozar (EIHP) and finalized in 2016 [3].

Loss reduction is an important aspect of efficiency in electricity grids. In general, distribution networks present the highest losses and the highest EE potential and therefore are in the focus of this paper. In Croatian distribution network total losses (both technical and non-technical) in 2014 accounted for 8.14 % of energy injected into distribution network (1257 GWh), while in 2015 they accounted for 8.05 % (1295 GWh).

The Croatian RA has taken a pragmatic approach by focusing only on technical losses and taking gradual approach in assessing EE potential of HEP [4] networks. The first stage of assessment, the results of which are presented in the paper, focused on traditional (replacements/reinforcement) and networks management (operational) EE measures. Only replacement/investment programs already on-going and scheduled by the ten year distribution network development plan (TYDNDP [5]), adopted by RA for the period 2016-2025, have been assessed.

In general, loss reduction is considered as one of the variables of a larger investment optimization plan, but not the main driver for the investment. The loss reduction is the main driver for investment when there is a need to comply with regulatory requirements and standards (e.g. EcoDesign directive). The EED also considers that grid EE measures should go beyond loss reduction and also take into account planning/operational efficiency thanks to new "smart" measures allowing active grid management and exploiting flexibility of distributed energy resources (DER) and demand response (e.g. feed-in control). Measures which require the exploitation of DER have very limited diffusion in Croatia, as in many MS, often just at pilot level. Therefore assessment of these measures have been postponed to the following round of RA assessment.

In this paper, based on forecasted consumption and demand and scheduled investments from TYDNDP, qualitative and quantitative assessments of savings from technical loss reductions are presented.

CROATIAN DISTRIBUTION NETWORK

Entire Croatian distribution network is managed by the one distribution system operator (DSO), a limited liability company wholly owned by the state (via HEP d.d. [4]). Figure 1 and Table 1 illustrate the basic features of the HEP DSO and distribution network under its jurisdiction.

According to [6], in 2014 Croatian total (gross) consumption was 16.9 TWh, out of which 91.4 % consumed at distribution system (84 % by end-users) and 6.1 % at transmission system. In 2014 total electricity delivered to end customers amounted 14.9 TWh, out of which 5.9 % consumed at HV, 23.6 % at MV and 70.5 % at LV level. The average annual household consumption was 2796 kWh, which is below the European average.

In 2014 and 2015, 317 GWh and 687 GWh were delivered to distribution network by DERs respectively (with a tendency to further increase). In 2014 the installed capacity of DERs interconnected to the distribution network reached 116 MW and in 2015 270 MW. Share of power generation in distribution network amounted 2.2% and 4.6 % of total DSO end customers consumption in 2014 and 2015 respectively.

Table 1 HEP DSO basic data

Basic DSO data (2014)			Unit
Number of employees		7 627	
Distribution network length		135 749	km
Number of substations		25 881	
Installed capacity of all transformers		21 016	MVA
Number of metering points (customers)		2 373 711	
DGs connected to DN	Number	1 237	
	Installed capacity	116.1	MW
DN gross consumption		15 440	GWh
Electricity delivered to end customers		14 183	GWh
Distribution network losses		1 257	GWh
of DN gross consumption		8.14	%

DN – distribution network; DG – distributed generation

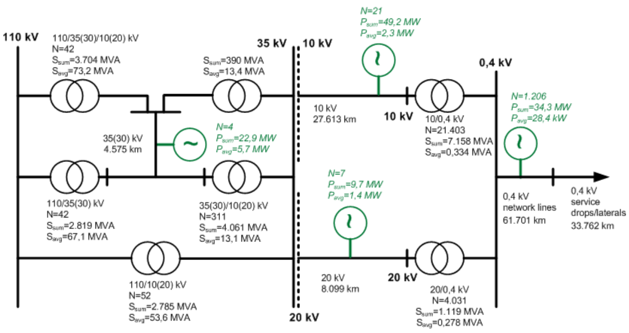

Figure 1 Block schematic of HEP distribution network

LOSSES IN THE HEP DSO NETWORK

Total losses are calculated as the difference between electricity received in the distribution network (from the transmission network and DERs interconnected to distribution network) and electricity delivered to the end customers. In percentage, total losses are calculated as the ratio between total losses and sum of total sale and total losses. Like the other DSOs, HEP DSO distinguishes between:

- technical losses,
- non-technical losses (theft, customers non-payment, unmetered supply, errors in meter reading, etc.).

As covered by EED, only measures aimed to improve technical losses in distribution networks shall be the consideration. Therefore the first stage of the study was to determine (as accurately as possible) the level of technical losses in total losses in 2014. In 2015 HEP DSO launched a comprehensive study of annual distribution system losses [7] based on:

- hourly data collected from a SCADA system (HV/MV, MV/MV transformers and MV lines),
- quarter-hourly load data from advanced metering infrastructure (AMI) for MV and LV customers with subscribed power > 30 kW,
- sales of electricity to LV customers with subscribed power ≤30 kW from billing system (LV commercial customers are read monthly, while households two times a year),
- technical data of distribution system assets,
- precise MV network models and analysis, and
- calibrated representative LV network models data.

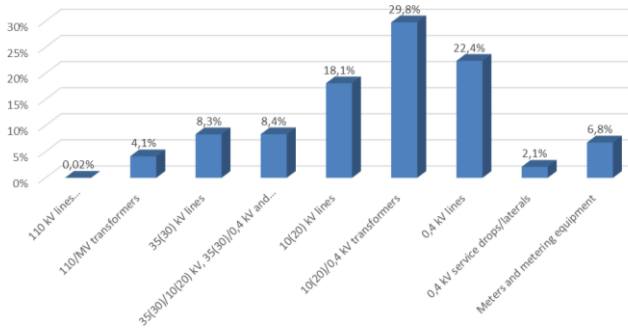

Figure 2 Structure of technical losses in HEP DSO network in 2014

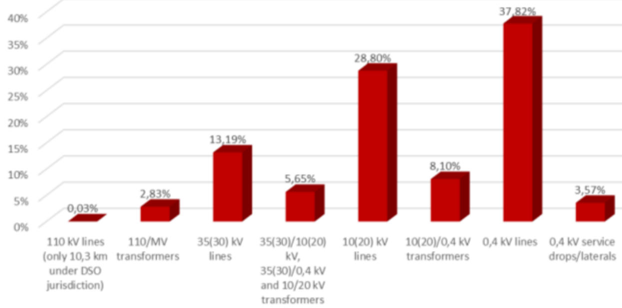

Figure 3 Structure of technical load losses (2014)

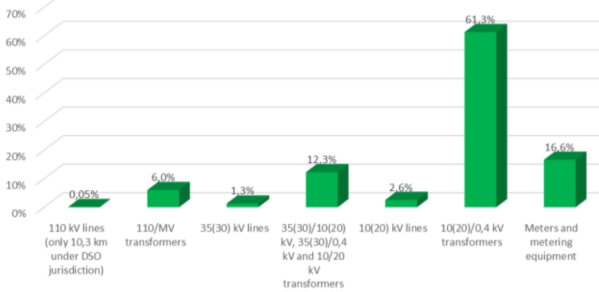

Figure 4 Structure of technical no-load losses (2014)

The DSO study on losses provides both background and insight on distribution network losses, as a precursor to determine EE potential of investments comprised in TYDNDP. The results in Figure 2-Figure 4 show the outcomes of the study on losses. In 2014 technical losses represented 643 GWh, 4.16 % of electricity delivered into distribution network (15.4 TWh), or 52.4 % of total losses. This value represents the base value of losses for the purpose of assessing the EE potential of distribution network. Non-technical losses represented 47,6 %. For a total of 643 GWh, load losses are 381 GWh (or 59.2 %), while no-load losses are 262 GWh of total technical losses (or 40.8 %). An examination of Figure 2 allows DSO to prioritise the stakes, the MV/LV transformers, particularly regarding iron (no-load) losses (i.e. 84 %), then the 0.4 kV and 10(20) kV distribution network lines.

CROATIAN APPROACH TO FULFILLING THE EED ASSESSMENT REQUIREMENT

Methodology

The potential for loss reduction in the observed period is defined as the difference between technical:

losses in the distribution network with realized TYDNDP investments/measures and losses in the baseline distribution network development scenario.

Therefore, while addressing loss reduction potential, it is important to anticipate the baseline distribution network development scenario. Retaining the current state of the network during the entire 10-year period cannot be considered as the baseline scenario, as the increase in load in the distribution network related to interconnection of new users on the specific locations necessitates certain investments in the network; e.g. construction of new lines, new substations, as well as strengthening the existing network in order to create conditions for interconnection. Such investments (aimed to connect new users or due to the increase of existing customers demand) are considered as an integral part of the baseline distribution network development scenario and, in that sense, neutral with regard to the EE potential.

In determining the potential of loss reduction it is necessary to take into account that there are significant differences in the accuracy of the analysis for different parts of distribution network, because of their complexity and the availability of the necessary data. Analyses of the primary distribution network (110 kV and 35(30) kV) are normally very accurate in terms of assessing the losses. The same applies to upgrading of 10 kV distribution network to 20 kV. In reference to the investments in 10(20) kV and 0.4 kV lines and MV/LV transformation, especially considering the fact that in the TYDNDP exact locations and investment parameters are defined only for the 1st year, while for the next 2 years only approximate, and for the remaining 7 years only indicative level of investments are given, it is far more complicated to determine the scope of the reference scenario. Therefore, analyses are reduced to model approach, with inherently less accurate results.

Finally, it should be noted that there might be an interdependency of investments with regard of impact on loss reduction. As independent could be regarded only those investments whose total integral potential for loss reduction is equal to the sum of the potential to loss reduction of each individual investment.

Therefore in the RA study, while evaluating EE potential of HEP DSO distribution networks infrastructure, all TYDNDP investments have been divided into two groups:

1. investments that lead to "principal" EE potential:
   a. include investments in primary distribution (i.e. HV/MV and MV/MV transformers, 35(30) kV lines and increase of system voltage from 10 kV to 20 kV, and 10(20) kV lines that are built when integrating new 110/10(20) kV or 35(30)/10(20) kV substation into the network,
   b. evaluation of EE potential for these investments can be done with satisfactory accuracy,
   c. low interdependency of investments with regard of impact on losses can be observed,
2. investments that lead to "possible additional" EE potential:
   a. include investments in reconstruction and revitalization and of new 10 (20) kV and 0.4 kV lines, replacement of old inefficient 10/0.4 kV transformers that pre-date 1970, and new 10(20)/0.4 kV substations,
   b. evaluation of EE potential for these investments cannot be done with high level of accuracy and precision,
   c. possibility of high interdependency of investments with regard of impact on losses should be regarded.

Forecasting

For the assessment of EE potential of the electricity infrastructure one of the important factors is the estimation of future demand in the areas to which the specific investments apply. According to [5], in the 2005-2008 period distribution system has recorded a steady increase in consumption, and afterwards (due to a recession) decline can be observed up until 2015 (figures for 2015 show app. 3.5 % increase compared to 2014).

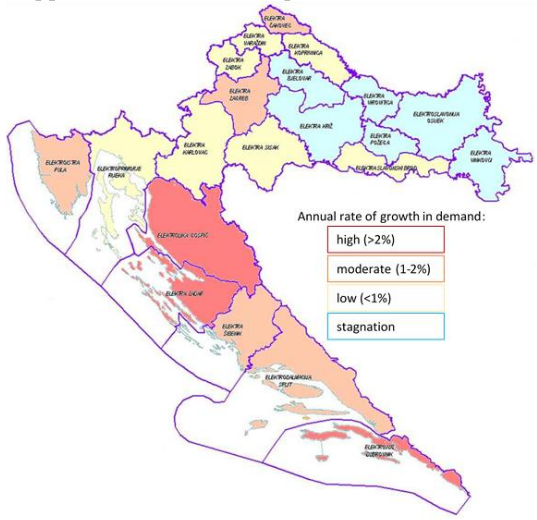

Figure 5 Forecasted average annual rate of demand growth in 21 Croatian distribution supply areas [5]

The RA study of EE potential adopted forecasts of average annual rate of demand growth from TYDNDP [5] (Figure

5). These overall forecasts referring to large areas have been adjusted for specific local use associated to feeding area of specific investment (e.g. supply area associated to an individual substation or a feeder). Adjustments were based on background information, e.g. DSO billing files with information on existing and past consumptions as well as discussions with the appropriate local area-planning authority, revealing parts of areas where more rapid load growth may occur (e.g. predicted industrial and housing developments, development in coastal areas due to tourism), and also areas with decreasing demand (e.g. depopulation or industry decay). In this way, in the study average annual rates in the range between 0 % and 2.5 % have been applied.

Analysed investments

Assessing the potential for loss reduction in the distribution network has been carried out for investments already realized in 2015 and planned investments from TYDNDP in 2016-2025 period (Table 2). Blue coloured rows correspond to investments that yield "principal" and orange coloured to investments that yield "possible additional" EE potential. Planned investments until 2025 are 860 million € (recovered from distribution charge) and around 460 million € (covered by connection charge) [4].

Table 2 TYDNDP investments [5]

Type of investment	No. (km)	Aggregated data
New TS 110/10(20) kV	15	
New TS 110/30(20) kV	1	
New TS 35(30)/10(20) kV	3	
New TR 110/10(20) kV	7	
Reconstruction of TS 35/10 kV into 110/10(20) kV	9	
New TR 35(30)/10 kV	1	
Replacement of TR 110/10(20) kV	2	
Replacement of TR 110/35 kV	4	
Replacement of TR 110/35 kV with 110/10(20) kV	4	
Replacement of TR 35/10 kV	17	
New 35 kV lines in 2015-2018 period	8 (59,9)	
New 35 kV lines in 2019-2024 period		61 km within 6 yrs
Reconstruction of 35 kV lines in 2015-2018 period	7 (65,6)	
Reconstruction of 35 kV lines in 2019-2024 period		474 km within 6 yrs
Increase of system voltage: 10 kV to 20 kV		900 km/yr
New 10(20) kV lines in 2015-2018 period		217 km/yr
New 10(20) kV lines in 2019-2024 period		213 km/yr
Reconstruction of 10(20) kV lines in 2015-2018 period		166 km/yr
Reconstruction of 10(20) kV lines in 2019-2024 period		192 km/yr
New TS 10(20)/0.4 kV		248 units/yr
Replacement of TR 10(20)/0.4 kV in 2015-2020 period*		300 units/yr
Replacement of TR 10(20)/0.4 kV in 2021-2024 period*		300 units/yr
New 0.4 kV lines		97 km/yr
Reconstruction of 0.4 kV lines		188 km/yr

TR – transformer; TS – substation

* *The EU Directive – 2009/125/EC – mandates the adoption of Ecodesign transformers in two phases, from 2015 and 2020. Therefore different specifications for new transformers have been applied in the study for the 2015-2020 and 2021-2024 period. Old distribution transformers that pre-date 1970 have been observed for replacement.*

RESULTS

By valuing the impact of each TYDNDP investment, taking into account the year of commissioning and also the forecasted load growth in the associated feeding area of each specific investment, the RA study determined annual potential to reduce technical losses. Figure 6 comprises total EE potential divided into "principal" and "possible additional" and differentiated by types of investments. Besides it comprises yearly EE potential values. The following could be observed for the 2015-2024 period, with regard of:

- *principal* technical loss reduction potential: in total 252.8 GWh savings can be expected, or an average of 25.3 GWh per year, which corresponds to 4.1% of the technical losses in 2014,
- *possible additional* technical loss reduction potential: in total 171.5 GWh savings can be expected, or an average of 17.2 GWh per year, which corresponds to 2.8% of the technical losses in 2014.

With an average cost of losses 45 €/MWh (from tenders for procurement of grid losses in Croatia), estimated "principal" savings from technical loss reductions in the future decade are estimated to 11.4 million €, and "additional potential" savings to 7.7 million €.

Some of the key outcomes and insights of the RA EE study are summarized below:

- the measure, which yields high savings potential is upgrading the 10 kV network to 20 kV,
- investments in primary distribution network, especially in 110/10(20) kV (i.e. elimination of transformation steps), frequently lead to reduction of technical losses,
- advantageous impact has reconstruction of MV lines, since they usually include replacement of overhead lines with cables and accompanied use of larger conductors,

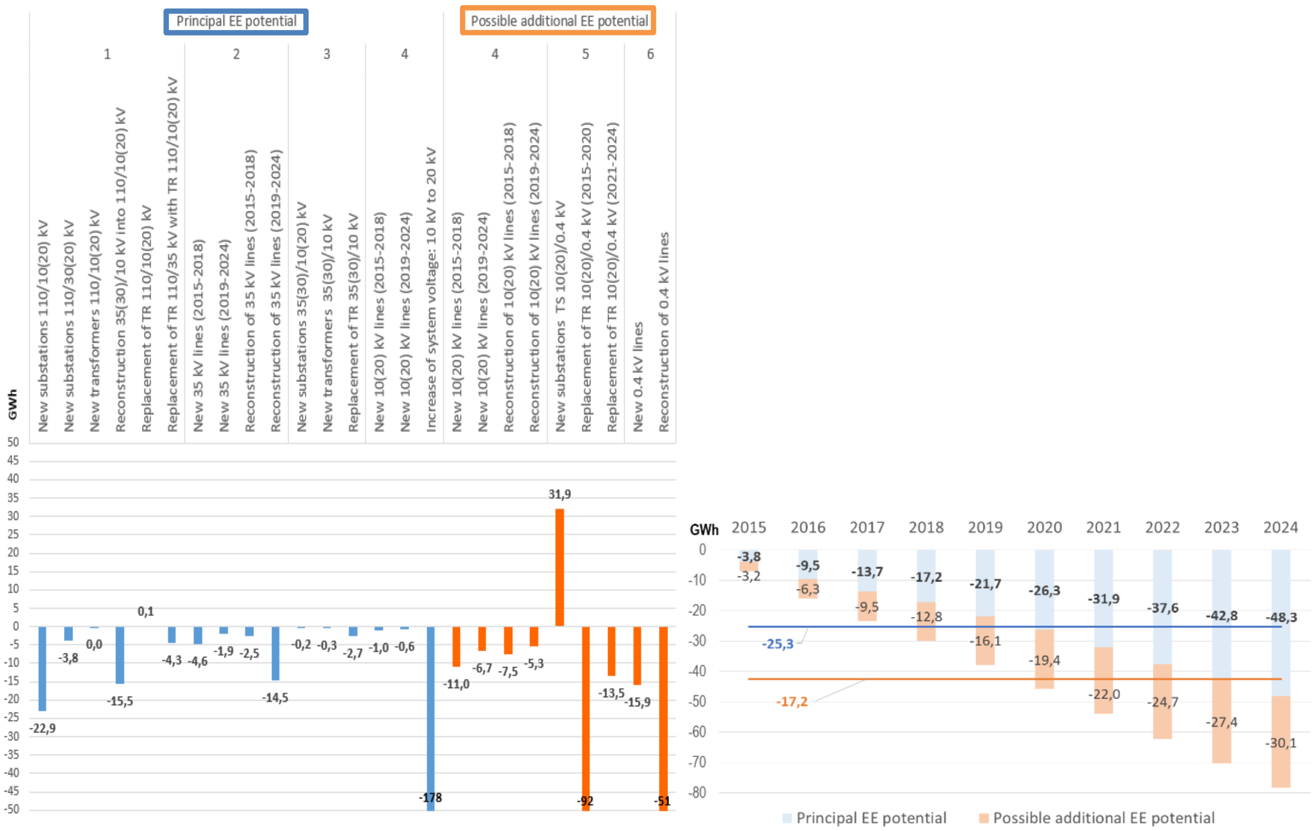

Figure 6 Total and annual EE potential of HEP distribution network in 2015-2024 differentiated by types of investments

- very beneficial is the replacement of old transformers with more EE ones, and generally transformers switching out at twin transformer substations at times of low load,
- in the context of "possible additional" loss reduction potential, so called integral management of 10(20)/0.4 kV transformation is beneficial; i.e. replacement of old transformers accompanied by interpolation of the new 10(20)/0.4 kV substations (leads to reduction of LV feeders length), the reconstruction and revitalization of the LV network, replacement of overhead lines with small conductors (i.e. 25 and 35 mm^2) with cables, and relocation of existing transformers in order to optimize their utilization,
- most of investments lead to loss reduction, but there are investments that lead to increase of losses (primarily new network components).

CONCLUSIONS

The EE study has been undertaken by the Croatian RA in order to examine the opportunities of making distribution network more energy efficient within the framework of the TYDNDP approved investments. The study relies on the results of other more comprehensive study launched by Croatian DSO at about the same time and which provides both background and insight on existing distribution network losses. The EE study estimated the "principal" technical loss reduction potential of 252.8 GWh in 2015-2024 period, and "possible additional" potential of 171.5 GWh, which corresponds to average yearly loss reduction of 4.1 % and 2.8 % of the value of technical losses in 2014 respectively. The future work shall focus on expanding the knowledge and experience, and thus to evaluate the potential of the new "smart" measures allowing active grid management and exploiting flexibility of DER and demand response.

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