110 kV NETWORK TECHNICAL LOSSES ASSESSMENT. REAL DISTRIBUTION SYSTEM CASE STUDY

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Abstract - The paper is focusing on evaluating the technical losses within a real distribution network. The study was conducted for a distribution system operator within the Romanian Power System. The analysed area is represented by a real part of the Romanian Power System. It is modelled in a computer aided power system analysis tool. Several power system operating conditions are analysed. Power system optimization measures are provided having as a goal to reduce the technical losses' value. Values obtained based on the field measurement are compared to the ones provided by computer simulations. These conclusions are very useful for the distribution network operator.

Keywords: technical losses, overhead line, optimization.

1. INTRODUCTION

The paper has been developed based on a research project between a distribution system operator within the Romanian Power System and Politehnica University Timisoara. The work is focusing on technical losses evaluation in case of 110 kV real distribution network. The influence of several factors is taking into consideration for technical losses' assessment: voltage level, 110 kV distribution network configuration, 400 kV transmission network and renewable sources.

Load variation very often takes place within the distribution networks. Thus, the losses reduction problem comes in the front [1]. It is very important to estimate the technical losses from the both operation and economical point of view. This may be achieved by network topology reconfiguration. If it is applied very often, it could lead to transient problems. In [1] a solution is proposed considering a restrained number of network topologies that remain unchanged for a given horizon of time. In [1] this goal is fulfilled applying hybrid genetic algorithms. The approach is continued in [2]. The authors are proposing a reconfiguration process for the distribution network based on optimal power flow (OPF) computing. Initially, all the branches are closed. According to the OPF results it is established witch branch is going to be open, operating a single switch.

For technical losses estimation new concepts, such as loss factor and equivalent hours are introduced in [3]. To prove the efficiency of the proposed algorithm real data are used correspond to load curves within the Brazilian power system. The authors are describing the use of average demands and loss coefficient having as a goal to improve the loss estimation process (better cable selection, loss estimation in case of transformers, etc.).

In [4] the authors are proving that the energy losses are computed more accurately, dividing the corresponding mathematical relation into three parts. The 1st set of results is provided by the power flow computing. The following parts are enabling the methodology to be applied in care of distribution networks where no measurements are provided.

In [5] and [6] there are presented other factors that are influencing the technical losses value, such as the leakage current (in case of polluted insulators) and corona discharge. Such aspects are also addressed within our paper.

The following methods for technical losses computing have been used within the paper:

- parallel metering, achieved by installing the electrical network analysers supplied from the voltage and current transformers (managed by the owner);
- electrical resistances have been daily adjusted, according to the environment temperatures (measurements' period).

Following the introduction already presented, the 2nd section refers to the technical losses evaluation algorithm. The electrical network used as case study is described within the 3rd section. The 4th section is focusing on measurements (acquisitions) performed on the field. The technical losses are computed within the 5th section. Finally, the conclusions are synthesized.

2. MATHEMATICAL MODEL

A. *Electrical load dependent technical losses*

Step 1. The length and parameters of each OHL segment (having the same characteristics) are established.

Step 2. The temperature influence on the OHL resistance variation is determined. The daily resistances (R_d) are computed for each day of the analysed period.

Step 3. The monitored quantities matrix is prepared. It is formed by the apparent power flow (S), line voltage (V). 559 samples have been recorded for each monitored quantity. 15 min sampling interval has been used.

Step 4. The measuring error (ε_T) is computed.

$$\varepsilon_T = 100\% + AC_{ENA} + \varepsilon_V + \varepsilon_I - \\ - 0.0291 \cdot \tan(\arccos(\varphi)) \cdot (\delta_V - \delta_I) \quad (1)$$

where: AC_{ENA} – electrical network analyzer accuracy class, ε_V – voltage transformer error; ε_I – current transformer error; $cos(\varphi)$ – power factor, δ_V – voltage transformer error, δ_I – current transformer error.

Step 5. The energy losses due to the asymmetrical currents (ΔW_{assym}).

$$\Delta W_{asymm} = 1 + k_{I-}^2 + k_{I0}^2 \qquad (2)$$

where: k_{I-} – negative asymmetric current factor, k_{I0} – homopolar asymmetric current factor.

Step 6. The energy losses to the harmonic operating condition (ΔW_{HD}) are computed.

$$\Delta W_{HD} = 1 + (THD_I)^2 \qquad (3)$$

where: THD_I – current total harmonic distortion coefficient.

Step 7. The electric load dependent energy losses (ΔW_L) are computed.

$$\Delta W_L = \sum_{i=1}^{N-1} \left[k_c \cdot R_d(i) \cdot \left(\frac{S_i}{V} \right)^2 \cdot \Delta W_{asymm} \cdot \Delta W_{HD} \cdot k_t \right] \cdot \varepsilon_V \qquad (4)$$

where: N – samples recorded for each monitored quantity, k_c – resistance increase coefficient, k_t – hourly sampling interval.

B. Non electrical load dependent technical losses

Step 1. OHL modeling: support, conductor section, geometrical distances between the OHL conductors, conductor radius.

Step 2. Corona discharge losses computing.

$$V_{cr} = E_{cr} \cdot k_1 \cdot k_2 \cdot \delta_{air} \cdot r \cdot \ln\left(\frac{D}{r} \right) \qquad (5)$$

where: V_{cr} – critical voltage corona discharge, E_{cr} – critical voltage air ionization (21.1 kV/cm), k_1 – coefficient for conductor surface polishing, k_2 – coefficient taking into consideration the meteorological conditions ($k_1 = k_2 = 0.8$), δ_{air} = 1.263 kg/m^3 – air relative density (0°, H = 165 m, 20 % humidity), r – conductor radius, D – average geometrical OHL distance.

Step 3. Leakage current losses computing

$$\Delta W_0 = g_0 \cdot L_{OHL} \cdot k_{weather} \cdot V_l^2 \cdot T \qquad (6)$$

where: L_{OHL} – OHL length, $g_0 = 7.1 \cdot 10^{-8}$ S/km – leakage current specific conductance, $k_{weather}$ – factor depending on the meteorological conditions (it has been considered equal to 6 for the current approach), V_l – line voltage, T – analysis period.

3. INTEREST AREA DESCRIPTION

The power system used as case study is operated by an important distribution system operator within our country. It is modelled based on the Southern part of the Romanian Power System.

Several operating conditions have been analysed. The presented results are referring to the peak-evening-winter operating condition. The real consumed power is 1314.7 MW and reactive consumed power is 400.8 MVAr. The real generated power is 1327.45 MW.

For the base case, without renewable sources, the technical losses are ranging around 12.75 MW (0.97 % from the consumed power).

The 220 kV and 400 kV transmission network one-line diagram is presented in fig. 1

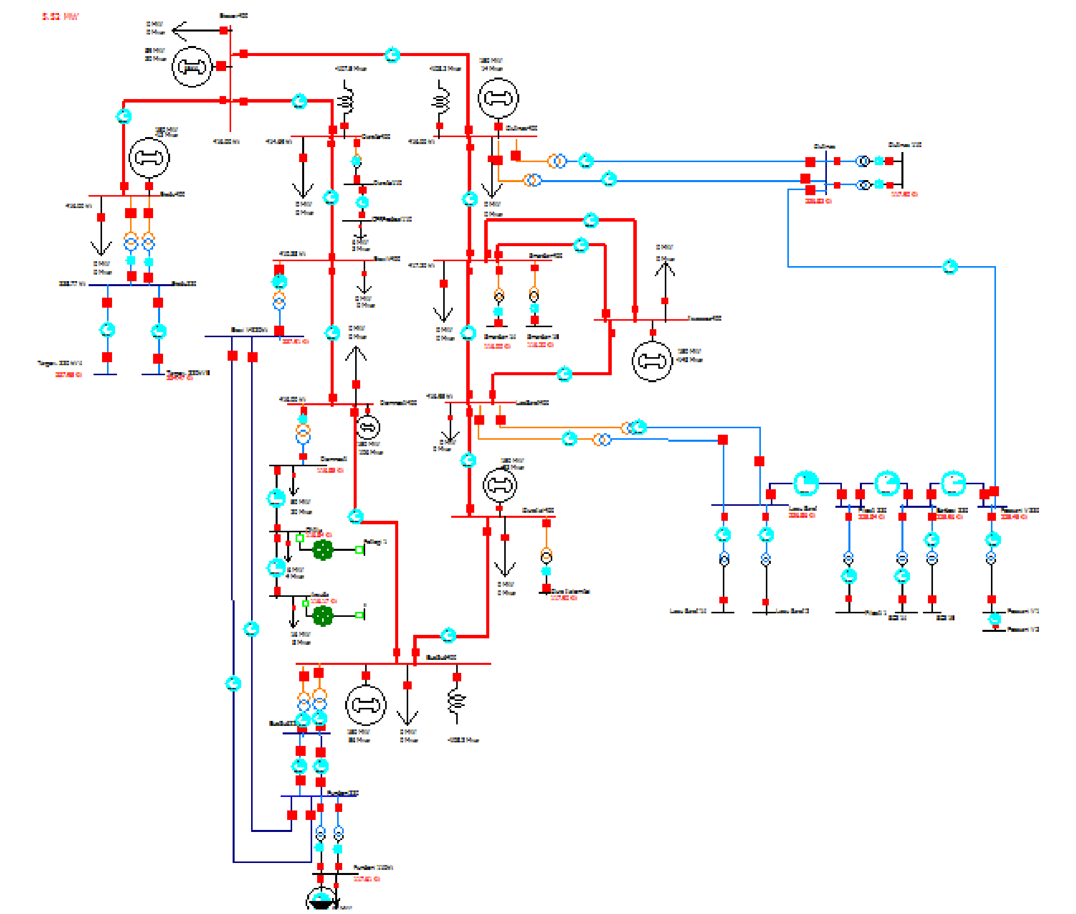

Fig. 1. 220 kV and 400 kV transmission network

The 110 kV distribution network is divided into 6 areas. These ones are presented in the following (figs. 2-7). The real consumed power values have been considered according to the data provided by the distribution system operator for each area.

Also, the generating units injecting power into the 110 kV network have been considered. Regarding the status of each 110 kV branch, the normal operating scheme has been taken into consideration.

110 kV bus voltage variation is presented in fig. 8. All the values are ranging between the admissible limits.

In case of power flow branches there have not been highlighted any special situations (such as congestions or inadequate operating conditions).

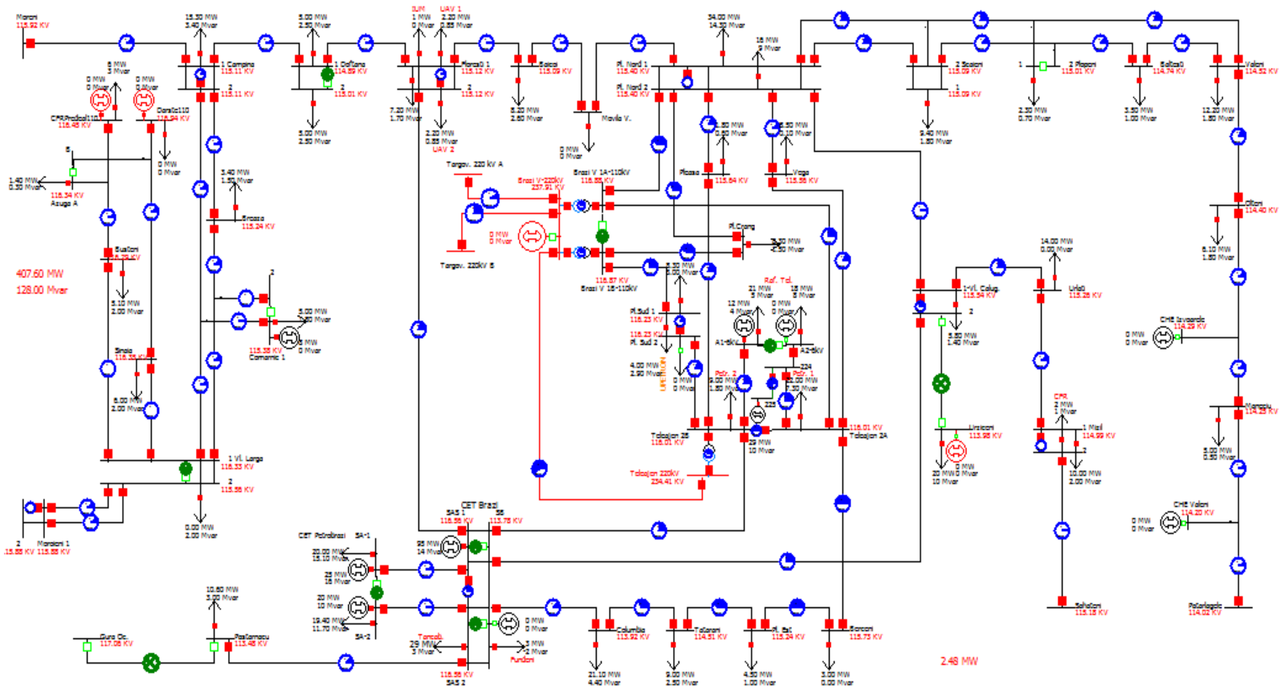

Fig. 2. Area 1one-line diagram

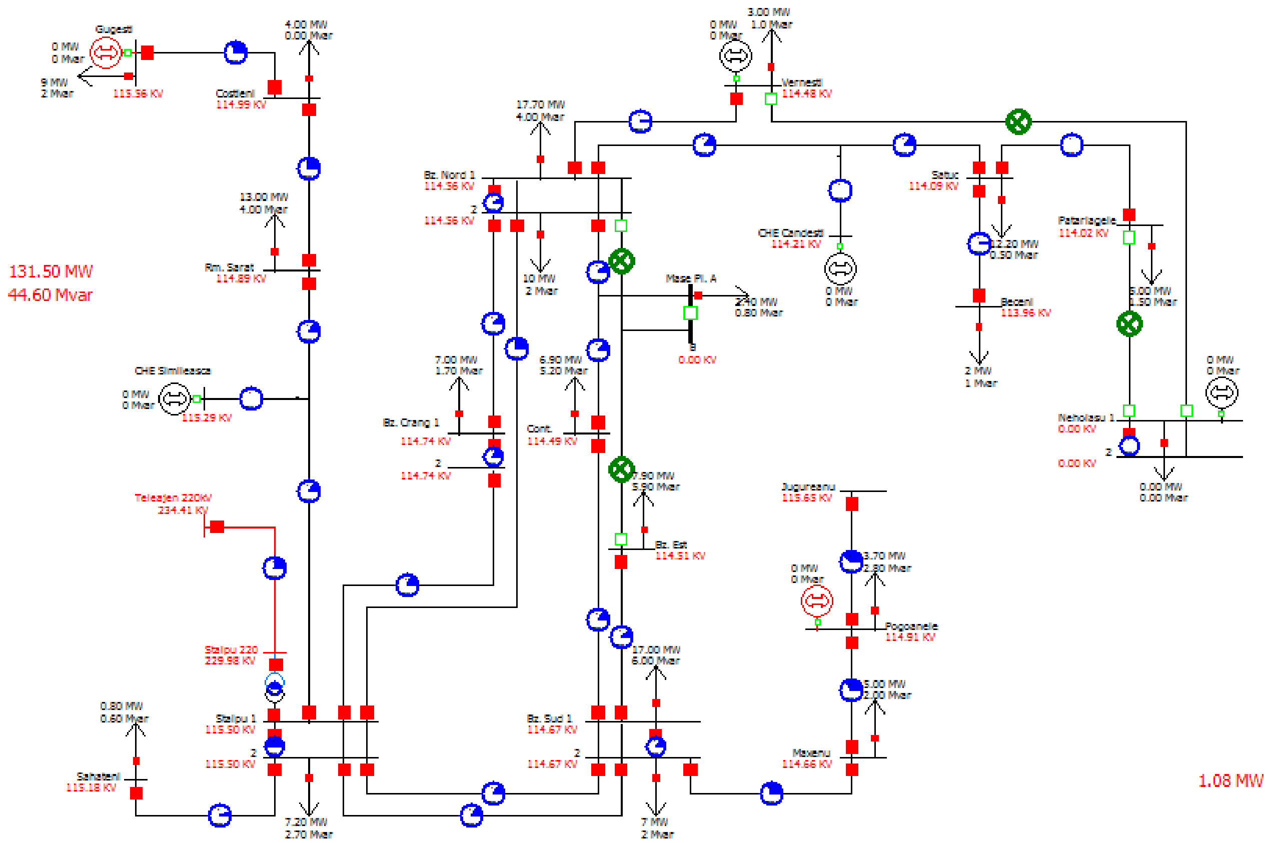

Fig. 3. Area 3 one-line diagram

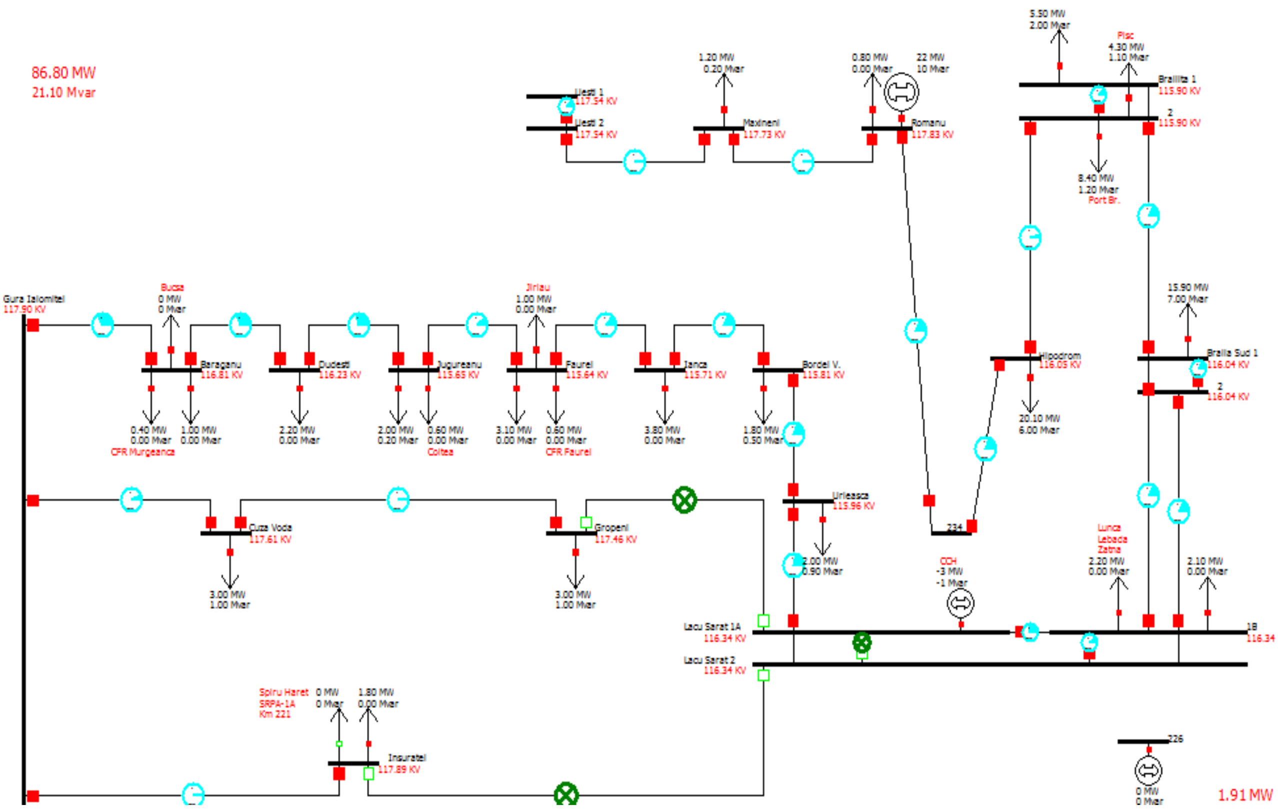

Fig. 4. Area 2 one-line diagram

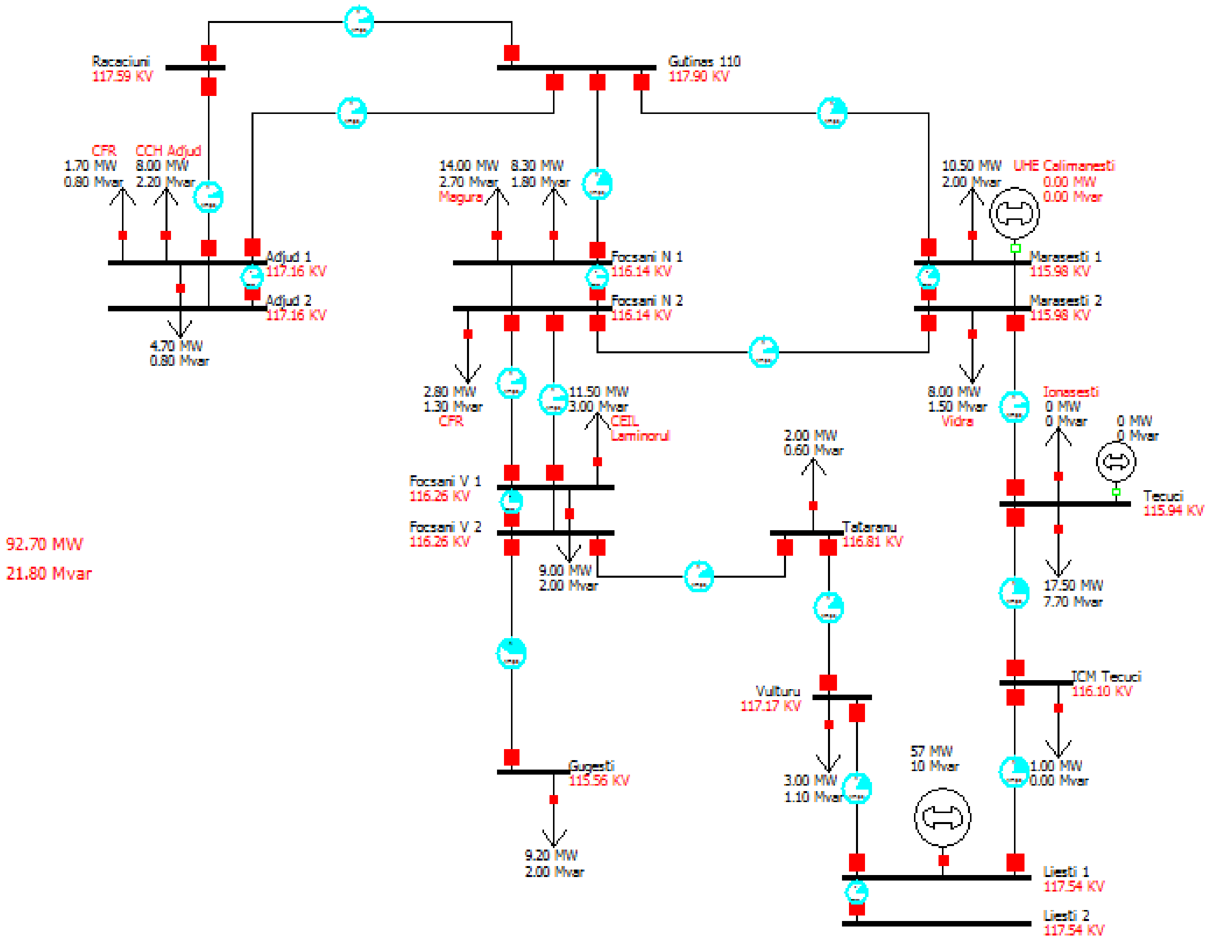

Fig. 5. Area 4 one-line diagram

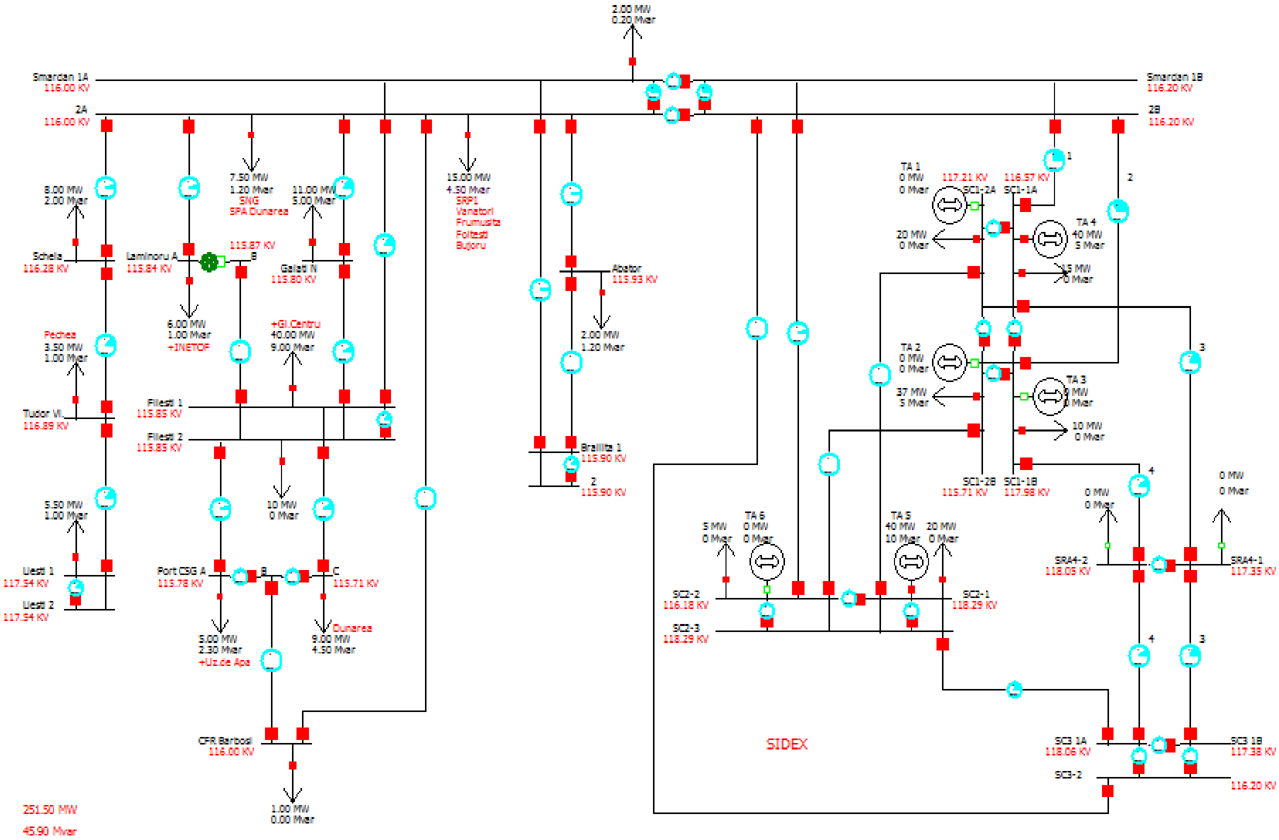

Fig. 6. Area 5 one-line diagram

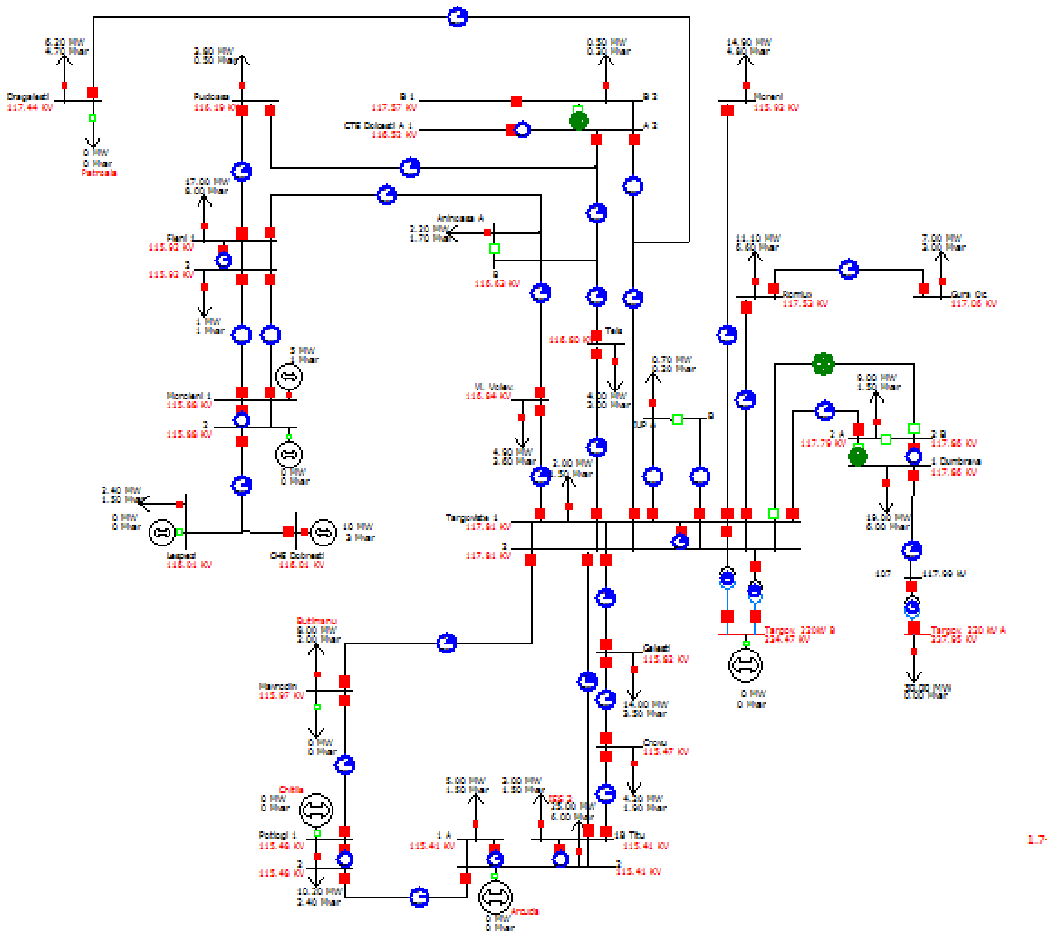

Fig. 7. Area 6 one-line diagram

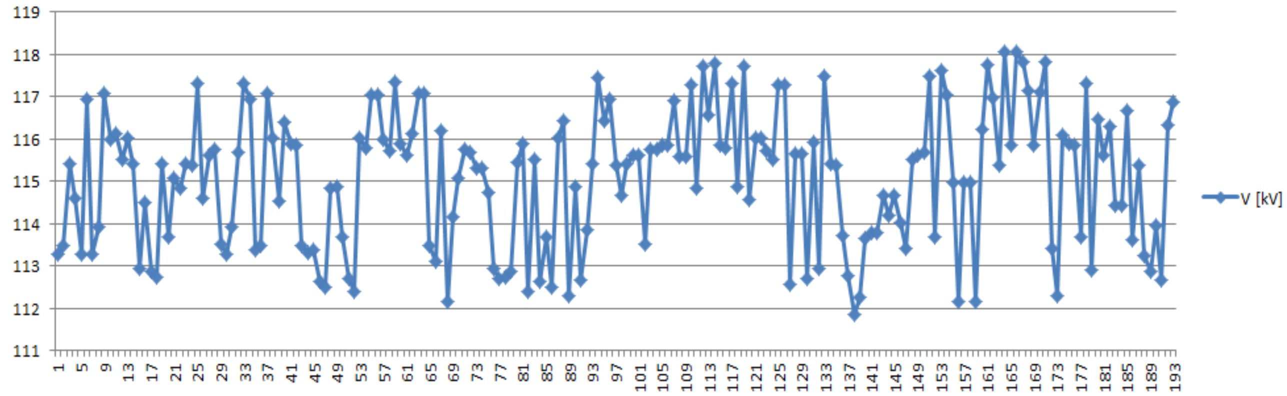

Fig. 8. Bus voltage variation

4. RESULTS AND DISCUSSIONS

The performed analyses for a large variety of operating conditions (peak-evening-winter, unloaded-night-summer) have led to the following elements that are influencing the technical losses' value:

- 110 kV network voltage level;
- 110 kV network configuration (meshed or unmeshed);
- injected power structure from the 400 kV network.

Each of these aspects is discussed in the following.

4.1. 110 kV network voltage level influence

Several operating conditions have been analysed starting from the base case, the differences being generated by the 110 kV voltage level. They have been obtained by changing the 220 / 10 kV transformer ratios.

A synthesis of the obtained results is presented in the following.

The 110 kV voltage is ranging between 112-118 kV, for the base case. The technical losses are 12.747 MW, meaning 0.97 % from the consumed power.

If the voltage is ranging between 109 and 117.5 kV then the technical losses are 13.238 kV, meaning 1.01 % from the consumed power (4 % increase).

Once the voltage is changing and set to be between 106 and 117 kV, then the technical losses are 14.028 MW, meaning 1.07 % from the consumed power (9.3 % increase).

In case of 10 kV voltage ranging between 01-116 kV, then the technical losses are 16.026 MW, meaning 1.22 % from the consumed power.

For the last operating condition, when the voltage is ranging between 111 and 121 kV, then the technical losses are 12.485 MW, meaning 0.95 % from the consumed power (2.1 % increase).

If the voltage is increased continuously, then it would exceed the admissible limits and secondly, the technical losses are increasing due to the fact that the reactive power flow is changing.

Similar analyses have been performed for other loading conditions, but the provided conclusions are suitable for these cases too.

The final recommendation, based on the performed analyses, refers to the fact that the 110 kV voltage should range between 114 and 121 kV.

4.2. 110 kV network configuration influence

The analyses have been stated from the 110 kV normal operating scheme. From the distribution network operator the meshing / unmeshing possibilities have been discussed. Several situations have been analysed when the 110 kV distribution network is meshed and unmeshed operated. The conclusions are synthesized in the following.

Connection or disconnection of 110 kV *A-B* overhead line (OHL) has a slight influence on the technical losses value – 12.767 MW compared with 12.747 MW. It is recommended that the decision concerning the operation status should be made based on other criteria (safety operation, easier network operation and control, etc.).

Connection or disconnection of 110 kV *C-D* OHL has a slight influence on the technical losses value – 12.765 MW compared with 12.747 MW. The same comments are suitable for this case too.

Closing the bus-bar coupling in station *S1* leads to a significant technical losses' increase – 13.345 MW compared with 12.747 MW. Thus, it is not recommend to be connected.

In case of the bus-bar coupling closing in station *S2* an insignificant technical losses' increase – 12.776 MW is recorded compared with 12.747 MW. It is recommended that the decision concerning the operation status should be made based on other criteria (safety operation, easier network operation and control, etc.).

In case of 110 kV *E-F* OHL connection or disconnection a slight influence on the technical losses' values is highlighted – 12.676 MW compared with 12.747 MW. Thus, a meshed operating scheme is recommended, without excluding the possibility of decision based on other considerations (safety operation, easier network operation and control, etc.).

Connection or disconnection of 110 kV *G-H* OHL has a slight influence on the technical losses value – 12.811 MW compared with 12.747 MW. The same comments, as the previous case, are suitable for this case too.

In case of 110 kV *I-J* OHL connection or disconnection an accentuated influence on the technical losses value – 19.991 MW – is highlighted. Thus, the unmeshed operating scheme is not recommended.

The most accentuated influence on the technical losses value – 21.472 MW – is recorded in case of 110 kV *K-L* OHL connection or disconnection. In this case too, the unmeshed operating scheme is not recommended.

Connection or disconnection of 110 kV *M-N* or *O-P* OHLs has a slight influence on the technical losses' value – 12.939 MW (simultaneously) or 12.806 MW, respectively 12.774 MW (individual disconnection).

4.3. Injected power structure from the 400 kV network influence

The injected power structure from the 400 kV network has been modified. Its influence on the 110 kV technical losses' value has been studied for the base case and also for other operating conditions. The conclusions are synthesized in the following.

50 MW increase in the 400 kV bus HV1 has as a consequence 50 % increase of technical losses. A reduction of the injected power considering the same value leads to 25 % decrease of technical losses. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

If the same scenario is applied for the case of 400 kV bus HV2 the same conclusions are suitable.

50 MW increase in the 400 kV bus HV3 has as a consequence 70 % increase of technical losses. A reduction of the injected power considering the same value leads to 10 % decrease of technical losses. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

50 MW increase in the 400 kV bus HV4 has as a consequence 50 % increase of technical losses. A reduction of the injected power considering the same value leads to 25 % decrease of technical losses. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

In case of the 400 kV bus HV5, 50 MW increase of the injected power has as a consequence 15 % decrease of technical losses. A reduction of the injected power considering the same value leads to 17 % increase of technical losses. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

The same comments are suitable in case of 400 kV HV6 injected power change.

50 MW increase in the 400 kV bus HV7 has as a consequence 15 % technical losses' decrease. A reduction of the injected power considering the same value leads to 40 % technical losses' increase. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

In case of the 400 kV bus HV8, 50 MW increase of the injected power has as a consequence 15 % decrease of technical losses. A reduction of the injected power considering the same value leads to 17 % increase of technical losses. In both cases the injected power from the other 400 kV buses has been adjusted accordingly.

Based on the provided analyses a "theoretical" combination of the 400 kV injected power structure may be as follows: HV1 – 100 MW, HV2 – 80 MW, HV3 – 20 MW, HV4 – 70 MW, HV5 – 270 MW, HV6 – 170 MW, HV7 – 90 MW, HV8 – 170 MW. Such a combination leads to 40 % technical losses' reduction.

5. CONCLUSIONS

The provided analyses are based on the entire 220 kV and 400 kV transmission network modelling within the interest area.

In the base case, the technical losses are ranging around 1 %. This is absolutely normal in case of a distribution network.

Depending of the voltage level within the 110 kV network the technical losses could increase till 1.22 %.

Several meshing / unmeshing possibilities have been studied (according to the network operator) to identify an optimal operating scheme. In these cases the technical losses are varying between 12.676 MW – 21.742 MW (compared with 12.747 MW).

Finally, the structure of the injected power from the 400 kV network has been analysed. An optimal configuration has been proposed leading to technical losses decreasing with around 40 %.

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