Expert System used for Power Quality and Environmental Impact Assessment

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Abstract—**This paper presents an expert system used for power quality monitoring, transferred from power generation sector up to power delivery within the Romanian power market. First of all, the system allows the analysis of methods and means for making all maintenance works within substations, belonging to TRANSELECTRICA S.A., the National Company for Power Transmission, at high efficiency. Secondly, the system allows the high voltage facilities environmental impact assessment. Using a fuzzy logic based algorithm, it provides efficient measures in order to ensure the environmental parameters' quality, both local and regional. As a case study, a representative power substation within the Romanian Power System (Brasov Substation) is used.**

Keywords-expert system; fuzzy logic; power quality; monitoring; environment; power market.

I. INTRODUCTION

Electricity is one of the greatest discoveries of mankind. It is now used in almost all areas of activity: agriculture, industry, medicine, scientific research etc. In electricity, there are, among others, highly topical issues such as:

- Sustainable use of energy resources;
- Quality of electricity supplied;
- Efficient use of generated electricity;
- Reducing the power facilities environmental impact of.

The implementation of a remote control and monitoring system represents a priority for the Romanian Power Grid Transelectrica. To achieve this goal, remote control and monitoring centres have been established at each transmission branch (Figure 1). Currently the following ones are operating: Remote Control and Monitoring Centres in Timisoara and Sibiu.

Timisoara Transmission Subsidiary is operating across four counties: Timis, Arad, Caras-Severin and Hunedoara. Timisoara Transmission Subsidiary contains:

- 400 kV substations: Arad, Mintia, Nada;
- 220 kV substations: Arad, Baru Mare, Calea Aradului, Hasdat, Iaz, Mintia, Otelarie, Paroseni, Pestis, Resita, Sacalaz, Timisoara.

Sibiu Transmission Subsidiary is operating across the following six counties: Alba, Sibiu, Brasov, Mureş, Harghita and Covasna. It contains:

- Brasov, Darste and Iernut 400 kV substation;
- Alba Iulia, Fantanele, Gheorgheni, Ungheni, Iernut 220 kV substations.

This paper presents the structure of an expert system used for power quality monitoring, some experimental results (for Brasov Substation) and advantages obtained by using the expert system. Also the 110 kV, 220 kV and 400 kV power facilities environment impact can be studied.

Using this expert system, optimal upgrading decisions have been able to be taken for all power substation. The additional transmission network losses, due to perturbations affecting the power quality, have been mitigated [1]-[2].

II. EXPERT SYSTEM USED FOR POWER QUALITY AND ENVIRONMENTAL PARAMETERS MONITORING

The system is composed of multiple devices and software synthetically presented in Table 1.

Electric field is determined by measuring the potential gradient (electric field intensity) in kV / m, using the ICEMENERG gradient meter. It is part of the floating potential measuring type apparatus, the detector being included within the measuring probe. The measuring probe is a plane parallel dipole and is therefore made as a parallel plate probes isolated from them according to the IEC Standard 833 – "Measurement of the industrial frequency electric fields". The ICEMENERG gradient meter, according to the IEC 61786/1998 Standard is part of the single axe sensor measuring instruments, for measuring the human body electric field exposure.

Magnetic field is determined by measuring the maximum induction B in mT, for the points established using Tesla device monitor. The measuring device is part of the magnetic field measurement using a coil probe calibrated in a uniform magnetic field created by a solenoid with a suitable size to ensure the uniformity of the field. Measuring device complies with IEC 61786/1998 – "Measurement of electric and magnetic fields regarding the human exposure. Special requirements for measuring devices and rules".

The power quality analyzer is 7650TM type, considering the current regulations and standards [3]-[7].

The PSTN modem is "U.S. Robotics Courier 56 K Business type for dial-up telephone line switchable. Selected communication speed is 19200 baud / s. This type of modem keeps its settings in case of accidental interruption of the supply voltage.

The data server is an HP personal computer Intel P4, 3 GHz. Due to large volume of data recorded for processing into various statistical forms, capacity is 1024MB RAM, 120GB SATA HDD. Auxiliary power is provided by UPS. Data Server has an LCD monitor 19", a multi colour print A4. Fujitsu Siemens notebook communication with the server system is achieved by connecting the external modem described above, to the analogue telephone circuit.

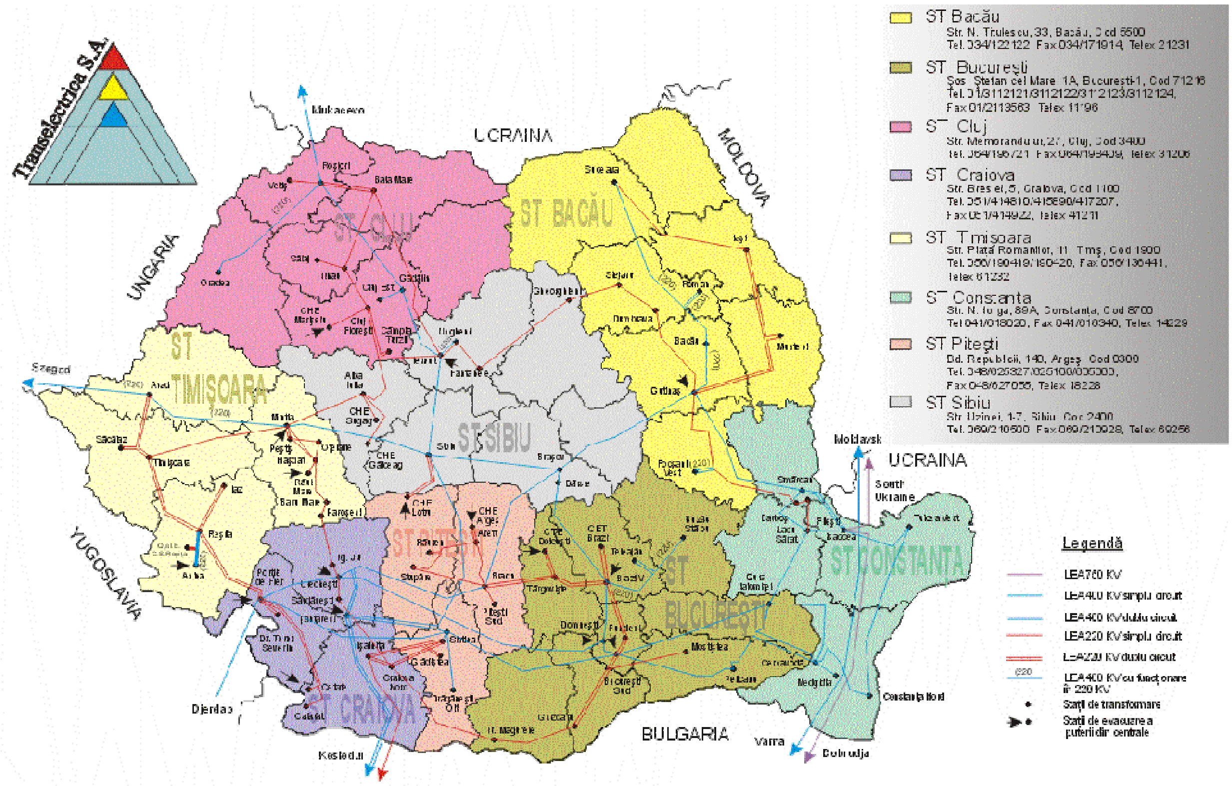

Figure 1. Transelectrica's Remote Control and Monitoring Centres

TABLE 1. EQUIPMENT USED FOR MEASUREMENTS

No.	Equipment	Made by	Type
1	Electric field measurement equipment	ICEMENERG	Gradientmetru
2	Magnetic field measurement equipment	Conrad Electronic	Tesla Monitor
3	Portable computer	Fujitsu Siemens	Procesor Pentium 4
4	Power quality analyzer	Power Measurement Canada	7650 ION™
5	PSTN modem	US Robotics	Courier 56K Bussines
6	Data server	Hewlet Packard	Procesor Pentium 4
7	Software license	Power Measurement Canada	ION Enterprise 5.5

Microsoft Windows NT operating system is used. On request, the data transmitted by the portable computer are automatically saved in a dedicated database. The system allows the external archiving of transmitted data on DVD RW and also their security.

The entire database saved on the server can be accessed on demand to generate the own primary data processing programs, data listing, graphical plots, reports.

The implementation of the system requires the magnetic and electric field measurement within the substations. It is followed by the transmission and storage of the measurements reports at the central point.

The environment impact assessment fuzzy based expert monitoring system provides the substation human operator and the one from the central monitoring point with the following important information:

- Electric field intensity value and magnetic induction values in case of each working area, within the substation territory;
- If the measured values are below or exceed the imposed ones by the regulations;
- A solution set for eliminating or limiting the disturbing effects, having as a goal human beings' health protection that are working within the substation.

Currently, the environment impact assessment system is fully implemented within the Brasov substation. Due to the advantages obtained using this expert monitoring system, its implementation for all the Transelectrica's substations is going to be realized.

The fuzzy logic based algorithm for environment impact parameters' evaluating within the substations is presented in Figure 2.

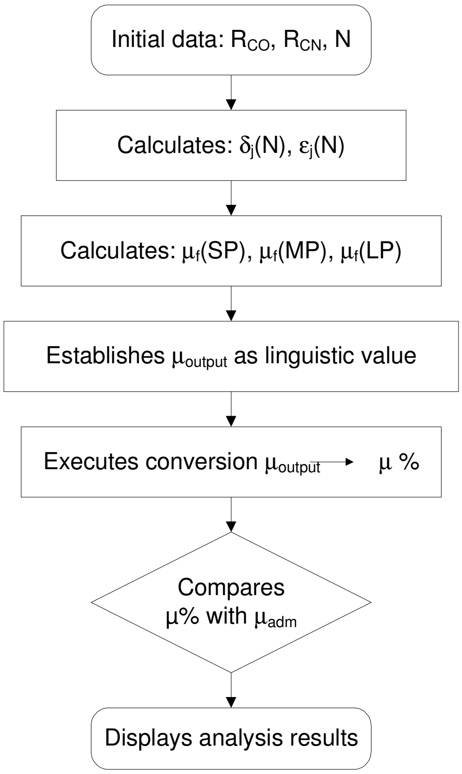

Figure 2. Block diagram of algorithm of establishing the environment impact parameters within the substations (R_{CO} – electric field intensity value or magnetic induction value corresponding to the last maintenance work within the substation installations; R_{CN} – electric field intensity value or magnetic induction value corresponding to measurement moment N; N – measurement number; $\delta_j(N)$ – rated error; $\varepsilon_j(N)$ – variation between two consecutive measurements; SP, MP, LP – fuzzy values; $\mu_f(SP)$, $\mu_f(MP)$, $\mu_f(LP)$ – fuzzy functions; μ_{output} – final fuzzy function having linguistic value; μ % – output function having numeric value; μ_{adm} – output function admissible value imposed by regulations)

The data obtained from the periodical measurements N and R_{CN} are used to calculate rated error $\delta_j(N)$.

$$\delta_j(N) = 1 - \frac{R_{CO}}{R_{CN}} \tag{1}$$

as well as the variation of this value between two consecutive measurements $\varepsilon_j(N)$

$$\varepsilon_j(N) = \delta_j(N) - \delta_j(N-1) \tag{2}$$

Placing $\delta_j(N)$ and $\varepsilon_j(N)$ in fuzzy multitudes of Figure 3 and linking them to fuzzy values SP, MP, LP, we can pass to the calculation of the final functions of output to a fuzzy multitude

$$\mu_j(SP) = \underset{x_i}{MAX}\left[MIN\left(\mu\left(x_i\right)\right)\right] \tag{3}$$

$$\mu_j(MP) = \underset{x_i}{MAX}\left[MIN\left(\mu\left(x_i\right)\right)\right] \tag{4}$$

$$\mu_j(LP) = \underset{x_i}{MAX}\left[MIN\left(\mu\left(x_i\right)\right)\right] \tag{5}$$

The calculation of functions $\mu_f(SP)$, $\mu_f(MP)$ and $\mu_f(LP)$ is realized on the basis of Table 2 and Table 3. The following step consists of determining belonging function μ_{output} from the algorithm presented in Figure 2 in relations

$$\mu_{output} = MAX\left[\mu_f\left(SP\right), \mu_f\left(MP\right), \mu_f\left(LP\right)\right] \tag{6}$$

Through the conversion of the linguistic value of μ_{output} into a numerical value μ % and comparing the latter with μ_{adm}.

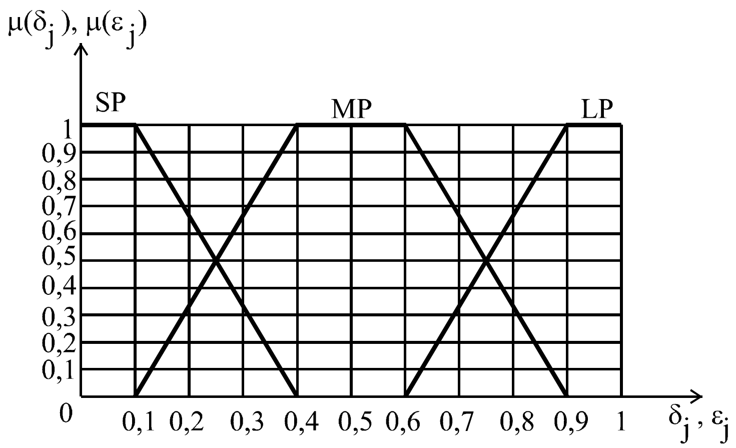

Figure 3. Fuzzy multitudes and belonging functions

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TABLE 2. FUZZY RULES

δ_j \ ε_j	SP	MP	LP
SP	SP	MP	MP
MP	MP	MP	LP
LP	LP	LP	LP

TABLE 3. DECISION TABLE OF FUZZY MULTITUDES AND BELONGNING FUNCTIONS

x_i	input	output			x_i	input	output		
	$(\delta_j, \varepsilon_j)$	$\mu(x_i, SP)$	$\mu(x_i, MP)$	$\mu(x_i, LP)$		$(\delta_j, \varepsilon_j)$	$\mu(x_i, SP)$	$\mu(x_i, MP)$	$\mu(x_i, LP)$
x_1	(SP,SP)	1	0.5	0	x_6	(MP,LP)	0	0.5	1
x_2	(SP,MP)	0.5	1	0.5	x_7	(LP,SP)	0	0.5	1
x_3	(SP,LP)	0.5	1	0.5	x_8	(LP,MP)	0	0.5	1
x_4	(MP,SP)	0.5	1	0.5	x_9	(LP,LP)	0	0.5	1
x_5	(MP,MP)	0.5	1	0.5					

The fuzzy logic based algorithm for evaluating the environment impact parameters within the substations is in patent phase. More details regarding this algorithm are going to be offered ion the future, once the patent phase is finished.

Experimental results from each point of measurement will be presented:

- Schedule normal operation of the substation for electricity conversion;
- Location point for measuring the delimitation of the area dotted element network;
- Continuity in the supply measurement point;
- Maintain the analyzer PQ mounted at the measurement point;
- Graphical representation of weekly analysis of the PQ indicators;
- Representation of numerical analysis for the annual PQ indicators;
- Nonframing indicators analysis within the limits allowed by their reflection in the real and reactive load curves;
- Reports measuring the electric field and magnetic, containing the following data: the test, test name, date of test, technical prescriptions, test results in table;
- Classification analysis / nonframings the values measured in the admissible limits.

The real and reactive energy is flowing in both directions through the measurement point being recorded by the PQ analyzer, but also by the metering system. This meter has been installed by the electric energy remote-metering within the wholesale market, providing a superior accuracy measurement PQ analyzer. The data recorded by the remote-metering of the electric energy within the wholesale market have been used in the following analysis. It has been developed a software dedicated for this analysis and it was represented the monthly real and reactive power evolution. Excel application is used to represent load curves (Figure 5), containing an area that allows the selection of alphanumeric interval analyzed. It also contains a graphical area plotting the time evolution of energy through the network. The user is requested to select the month from the list of options, which will be represented in the chart at the top, power flow evolution. A set of buttons is available for detailed analyses that allow the change of the interest area (green rectangle in the chart above), representing it within the chart at the bottom. This is the effect of the “magnifying glass” that allows the simultaneous observation of the development of both monthly and the interest area.

Starting from the in-depth analyses of the recorded events, the effective causes that are leading to power quality indicators mitigation have to be determined. Also, this analysis has to be correlated with the operation data from the substations and electric networks including the ones archived in SCADA systems. The power quality indicators’ admissible limits’ overpass analysis has been performed only within the Brasov substation measuring point. This case study has been chosen due to the fact that the supplied voltage magnitude had a spectacular evolution.

3. EXPERIMENTAL RESULTS

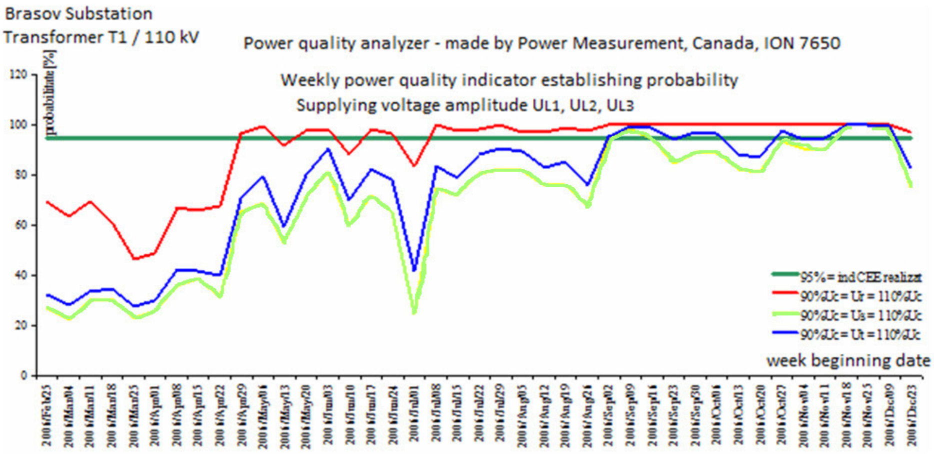
Several experimental determinations have been performed within the following locations:

- Timisoara Transmission Subsidiary (400 kV substations: Arad, Mintia, Nadab; 220 kV substations: Arad, Baru Mare, Calea Aradului, Hasdat, Iaz, Mintia, Otelarie, Paroseni, Pestis, Resita, Sacalaz, Timisoara);
- Sibiu Transmission Subsidiary (400 kV substations: Brasov, Darste and Iernut; 220 kV substations: Alba Iulia, Fantanele, Gheorgheni, Ungheni, Iernut).

Part of the experimental determinations has been previously presented in other references such as [1]-[2] and [8]-[9].

In the following, only the experimental results corresponding to the 400 / 110 kV Brasov Substation are presented.

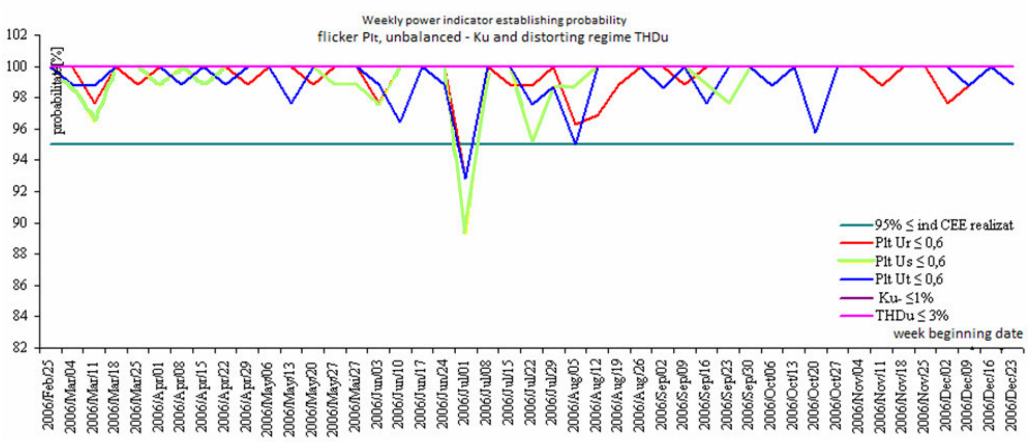
Within Brasov Substation the measurements have been performed between 25.02-30.12.2006. It contains the greatest number of 110 kV power supplies from all the analyzed substations: 21 OHLs (overhead lines) and 2 transformers. Concerning the other network elements, the greatest real energy quantity transported in 2006 is noted, according to Table 4. The load curve variation corresponding to the maintenance period between 03-14.07.06 is presented in Figure 5. The power quality indicator synthesis is presented in Figure 4.



a)

No.	Temporary overvoltage magnitude	Temporary overvoltage number with respect to magnnitude and duration								
		U_{L1}			U_{L2}			U_{L3}		
		Δt < 1 s	1 s ≤ Δt < 1 min	1min ≤ Δt	Δt < 1 s	1 s ≤ Δt < 1 min	1min ≤ Δt	Δt < 1 s	1 s ≤ Δt < 1 min	1min ≤ Δt
1	110 % Uc < U < 120 % Uc	12	36	700	39	52	907	34	150	1199
2	120 % Uc ≤ U < 140 % Uc	0	0	0	0	0	0	2	1	0
3	140 % Uc ≤ U < 160 % Uc	0	0	0	0	0	0	0	0	0
No.	Voltage sag magnitude	Voltage sag number with respect to magnitude and duration								
		U_{L1}			U_{L2}			U_{L3}		
		100 ms ≤ Δt < 100 ms	100 ms ≤ Δt < 500 ms	500 ms ≤ Δt < 1 ms	10 ms ≤ Δt < 100 ms	100 ms ≤ Δt < 500 ms	500 ms ≤ Δt < 1 ms	10 ms ≤ Δt < 100 ms	100 ms ≤ Δt < 500 ms	500 ms ≤ Δt < 1 ms
1	10 % Uc < ΔU< 15 % Uc	3	1	0	1	2	0	6	3	0
2	15 % Uc ≤ ΔU < 30 % Uc	6	3	0	8	2	0	4	5	0
3	30 % Uc ≤ ΔU < 60 % Uc	1	6	0	1	2	0	0	1	0
4	60 % Uc ≤ ΔU < 99 % Uc	0	0	0	0	2	0	0	0	0
No	Measurement period	Short and long period voltage sag number with respect to their duration								
		U_{L1}			U_{L2}			U_{L3}		
		Δt < 1 s	1 s ≤ Δt < 3 min	3min ≤ Δt	Δt < 1 s	1 s ≤ Δt < 3 min	3min ≤ Δt	Δt < 1 s	1 s ≤ Δt < 3 min	3min ≤ Δt
1	25.02-30.12.2007	12	2	15	9	2	16	0	0	0

b)



c)

Figure 4. T1 transformer 110kV Brasov Substation power quality indicator synthesis (a, b and c)

TABLE 4. T1 TRANSFORMER 110 KV BRASOV SUBSTATION OPERATING CONDITIONS

Network element	Transformer tap ratio	Rated power	Tap	Current transformer tap ratio	Voltage transformer tap ratio
T1 Autotransformer corresponding to 2006 year operating conditions	400 / 110kV	250MVA	8 and 7	1200 / 5A	110000 / 100V
	Out of service	Average loading level	Real energy transmitted to 110 kV network	Real energy received from 110 kV network	Power factor
	03-14.07.06 23-25.10.06 09.12.06	25.9 %	570.3 GWh	0 GWh	99.23

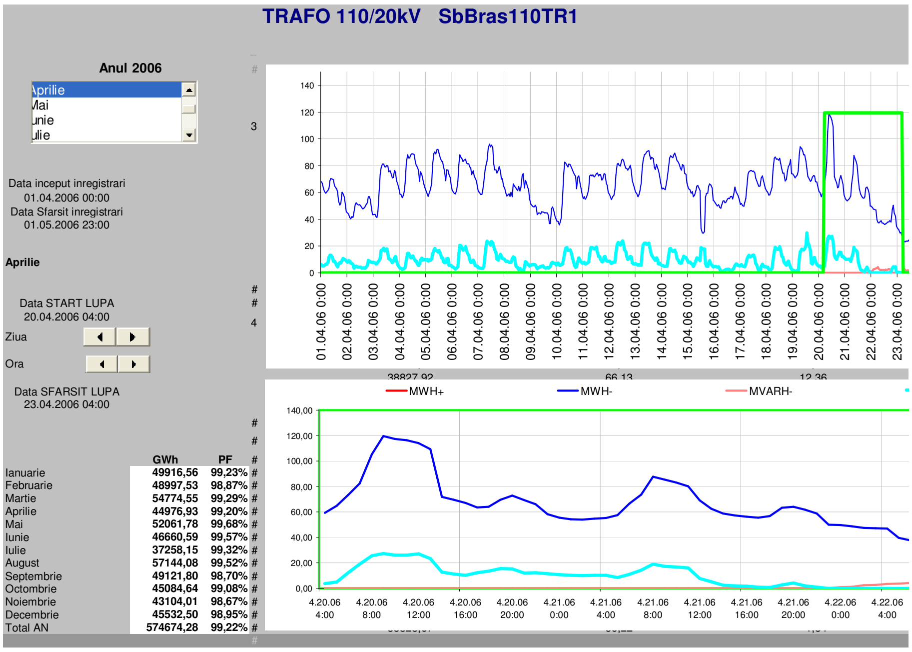


Figure 5. T1 transformer 110 kV Brasov Substation load curves

According to this figure the phase L1, L2, L3 supplied voltage magnitude and the long period flicker level Plt have not fitted between the admissible limits. The T1 transformer (type TTUS-FS 400 kV ± 8*12.5 % / 121 kV) is provided with the possibility of primary circuit voltage control by the under-load tap changer type T-III-1000, made by Reinheisen. It has been set on 8 position within the 25.02-21.04.2006 period and on 7 position between 21.04-30.12.2006. The tap changing is also highlighted by the supplied voltage magnitude rapid variation and also by the reactive energy before and after the commutation.

Starting with 2006 year, an upgrading process, for all the voltage levels, has been started within the substation. Obviously, the upgrading process is based on the recorded values. Several economical advantages have been obtained (the accidental events' number has been reduced, also the operation expenses).

CENELEC - Project ENV European standard 50166-1, Human exposure to low frequency electromagnetic fields (0 - 10 kHz) and the General rules of safety set by the Ministry of Labor and Social Protection and the Ministry of Health in Romania provide that the maximum permissible intensity of the electric field E = 10 kV / m for a time of 8 hours a day. In the conditions under which staff are exposed to E > 10 kV / m is recommended reducing the waiting time in the electric field using the formula t = 80 / E, where t is time in hours.

The E [kV / m] electric field measurement results, within the 400 kV Brasov substation, are synthesized within Table 5 (only few of the measured values are highlighted). Measurements in 148 points have been performed. In 92 points values greater the 10 kV / m have been found. In these areas with E > 10 kV / m necessary measures to protect staff in accordance with international and domestic rules. To protect human beings' health within the Brasov substation, the installation of several protection screens has been performed. Their role is to reduce the electric field intensity values in case of the main working areas. Also, have reduced work-time for the intense electric field areas.

CENELEC - Project ENV European standard 50166-1, Human exposure to low frequency electromagnetic fields (0 - 10 kHz) and the General rules of safety set by the Ministry of Labor and Social Protection and the Ministry of Health in

Romania in Romania provide that the maximum allowable induction of the magnetic field B = 0.5 mT on exchange of work (for 8 hours daily). In the conditions under which staff are exposed to B = 5 mT duration of exposure will be less than 2 hours on the exchange work.

The B [mT] magnetic field measurement results, within the 400 kV Brasov substation, are synthesized within Table 6 (only few of the measured values are highlighted). All values measured induction B are much lower than the maximum allowable B = 0.5 mT and therefore are not necessary measures to protect personnel action against the magnetic field.

TABLE 5. 400 KV BRASOV SUBSTATION ELECTRIC FIELD INTENSITY VALUES

No.	**Measurement point**	**Electric field intensity E [kV / m]**		
		L_1	**L_2**	**L_3**
Transformer 2 cell – 400 / 220 kV				
1	IO circuit breaker	11	9	12.5
2	Circuit breaker triggering mechanism	16	12.5	16
3	S B_2 T_2 insulating switch	18	18	18
400 kV transfer bus-bar cell				
13	Bus-bar insulating switch 1	13.5	12.5	16
14	Circuit breaker triggering mechanism	16.5	11	12.5
15	Bus-bar insulating switch 2	18	16	18

TABLE 6. 400 KV BRASOV SUBSTATION MAGNETIC FIELD VALUES

No.	**Measurement point**	**Magnetic induction B [mT]**		
		L_1	**L_2**	**L_3**
1	Transformer cuve T_2	0.069		
2	Circuit breaker triggering mechanism – T_2	0.018	0.022	0.016
3	Bus-bar insulating switch 2	0.013	-	0.02
4	Relays cabin	0.05		

4. CONCLUSIONS

For all the measuring points, the supplied voltage magnitude U_R, U_S, U_T, overpasses the imposed limits 99-121 kV, stipulated within the Electrical Transmission Network Technical Code [10]. The upper limit has been exceeded for a 95 % period of the week. The revision of the Electrical Transmission Network Technical Code has been proposed considering the technical equipment characteristics installed within 110 kV electrical installations and the experience achieved. The upper limit voltage magnitude variation from 121 kV to 123 kV has been proposed.

For a 95 % of the analyzed period, long term flicker has not been framed within the limits imposed by the IEC 61000-4-15:2003 [11].

The feasibility study conducted for this expert system stresses that its implementation will ensure rapid access to information needed FOR all the responsible factors. It is necessary to establish concrete measures designed for reducing electromagnetic disturbances and to diminish the following effects:

- Further losses' reduction within power transmission networks and consumers, mainly by reducing the level of harmonics, voltage unbalances and current;
- Proper equipment operation, for those cases when their functions and performance are affected by the harmonics' presence and voltage unbalances and / or current;
- Reducing the operation expenses for the equipment preventive or corrective maintenance, for those cases when they are affected by disturbances that damage the power quality;
- Increasing the efficiency of the generating units, processing units, lines and electric motors (including the ones for the substations' ancillary services) etc.;
- Reducing the costs of power generation / power transmission and, in general, reducing the investment within the National Power System. It would result from the need of over sizing the network elements to cover the effects of electromagnetic disturbance with offences against limits;
- Reducing the damages to consumers caused by voltage (the violation of the rated value, voltage gaps and short term interruptions);
- Establishment of concrete protecting measures to protect the operating personnel from 110 kV, 220 kV and 400 kV installations against the electric and magnetic fields, based on the literature study.

Using this expert system, optimal upgrading decisions have been able to be taken for Brasov substation. The additional transmission network losses, due to perturbations affecting the power quality, have been mitigated.

Currently, a profitability index Pi = 2.8 has been obtained. It represents the ratio between the sum of the yearly updated benefits and the sum of the yearly updated expenses, along the considered study period. Consequently, the system implementation had an important advantage compared to other systems describer within the literature [12]-[14].

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