

Power Quality Level Measurement and Estimation Issues

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Abstract—The paper presents a few power quality monitoring aspects on the interface between the power transmission network (TNE) and the power distribution network (DNE), 110 kV voltage level, considering both the current situation and the perspective. Monitoring the power quality indicators, performed via dedicated portable or fixed analyzers, facilitates compliance to standard limits and create the database required for the completion and correction of the standards. Implementing the monitoring system within all the Transelectrica's substations, several advantages are achieved. The efficiency is increasing; the decisions are able to be taken more accurately at all the involved levels.

Keywords—power quality; monitoring system; real power; reactive power; quality indicators; power market.

I. INTRODUCTION

Power quality is a complex and controversial issue, the complexity resulting from the multitude of factors that condition it, and the controversy from how different researchers understand and present it differently. In 1985, the European Commission Directive 85/374 EC [1] established that electricity is a 'product', that requires clear definition of features. The voltage and frequency maintenance within the admissible limits and a pure sinusoidal voltage curve, without 'noise', are the key elements for an ideal electricity supply.

The paper presents a few power quality monitoring aspects on the interface between the power transmission network and the power distribution network, at 110 kV voltage level, considering both the current situation and the perspective. Permanently or temporarily power quality monitoring is performed in the common connection point, where the system operator / provider has an obligation to provide electricity within the quality parameters of the contract. The supplier / consumer is required to limit the system perturbations transmitted in the Romanian Power System below the quota. Knowing the situation within the power transmission network buses and the disturbance sources, it is required a complex measurement program, using acquisition and processing equipment dedicated to the private Power Transmission Network - Power Distribution Network interface.

The problems specific to the common connection point result in the under-load of the power transmission network and the power distribution network. Also, difficulties in maintaining the voltage within the admissible range in the power transmission network are recorded. The incidents that

occur within the power transmission network cause large variations in voltage, gaps, short and long term power supply failures, leading to disturbances for the power supplied to consumers [2]. Power quality within the power distribution network is affected both by the voltage going out of the admissible range, and by the distortion of the voltage and power curves. In the power distribution network, power quality monitoring involves tracking it in the network buses and in the user common connection point, as well as establishing, for each connected user, the disturbance generated level.

The paper presents the structure of a power quality monitoring system, some experimental results and advantages obtained by using power quality monitoring system.

II. POWER QUALITY WITHIN THE ROMANIAN POWER GRID COMPANY TRANSELECTRICA

Within the Romanian Power Grid Company Transelectrica the power transmission activity is based on the transmission network. It includes substations and overhead lines. The transmission network represents a national and strategic interest, having the rated phase-to-phase voltage greater than 110 kV. The power facilities managed and operated by Transelectrica (the Romanian Transmission System Operator) are the following ones:

79 substations:

- 1 x 750 kV substation;
- 36 x 400 kV substations;
- 42 x 220 kV substations;

8931.6 km OHLs:

- 154.6 km - 750 kV;
- 4703.7 km - 400 kV;
- 4035.2 km - 220 kV;
- 38 km - 110 kV (tine-lines with the power systems of the neighbouring countries);

and 218 transforming units totalizing 37565 MVA.

To assure the fulfilment of the power quality requirements, the Company is undergoing a rigorous maintenance program to maintain the transmission network power facilities technical status. Its main goal is the following one: to improve the transmission network safety operation to avoid situations that could lead to dangerous unwanted events both for the transmission network and for the population or environment.

The implementation of a substation remote control and monitoring system represents a priority for the Romanian

Power Grid Transelectrica. The improvement of the power transmission service efficiency and quality, the reduction of the dangerous events and of the operation and maintenance costs are direct consequences of such system.

To achieve this goal, remote control and monitoring centre have been established at each transmission branch. Currently the following ones are operating: The Remote Control and Monitoring Center of Timisoara and The Remote Control and Monitoring Center of Sibiu (Figure 1).

Applying the monitoring system at Timisoara and Sibiu Subsidiaries, based on the obtained results, its expansion to the entire country level can be achieved. The results provided by the monitoring system are able to sustain several decisions regarding the upgrading all the electrical installations at Timisoara and Sibiu Subsidiaries. Also, an entire imagine is provided concerning the electrical

installations' upgrading for all the subsidiaries within Transelectrica.

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

Timisoara Transmission Subsidiary contains:

- 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 is operating across the following six counties: Alba, Sibiu, Brasov, Mureş, Harghita and Covasna.

Sibiu Transmission Subsidiary contains:

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

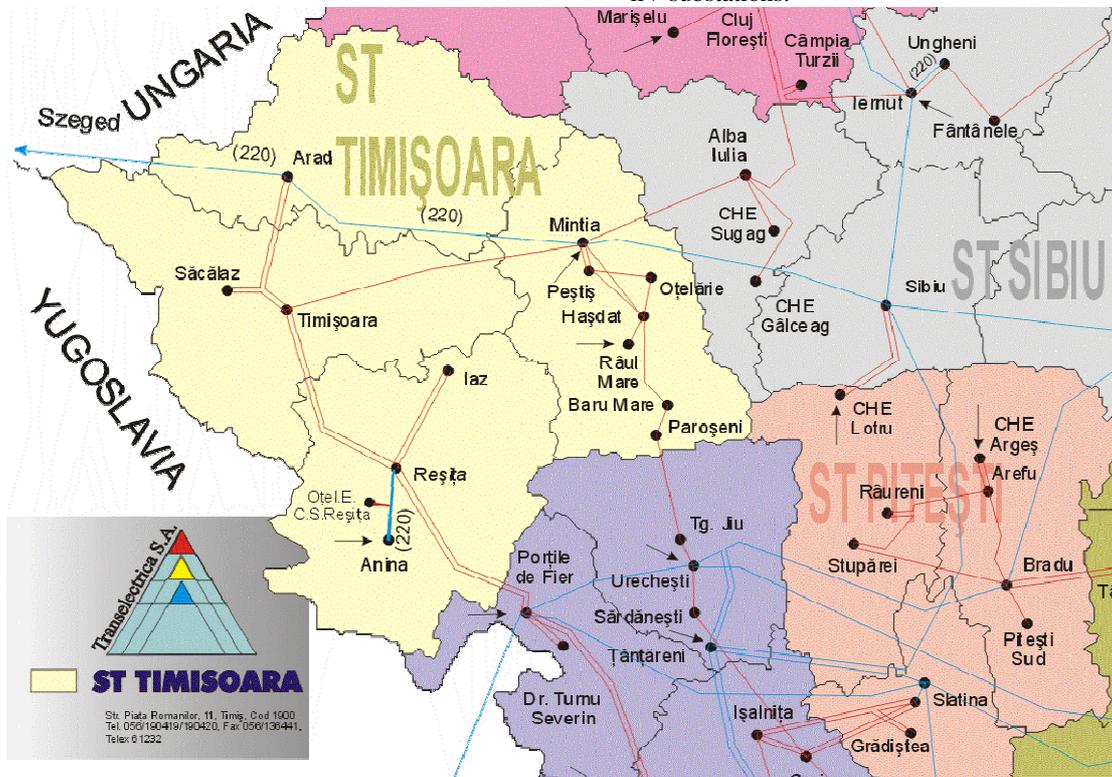


Figure 1. Timisoara and Sibiu's Remote Control and Monitoring Center

III. POWER QUALITY MONITORING SYSTEM

The system is composed of multiple devices and software presented synthetically in Table I. The "Analyzer CEE" equipment is in according to [2] - [5] standards.

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 1024 MB RAM, 120 GB SATA HDD. Auxiliary power is provided by UPS. Data Server has an LCD monitor 19", a multi color print A4. Fujitsu Siemens notebook communication with the server system is achieved by connecting the external modem described above, to the analogue telephone circuit.

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 stored on the database server can be accessed, on demand, in order to generate one's own programs to process the primary data and to print the data, the graphs or the reports. Implementing the system requires carrying out works on two levels: in each measuring cell of the substations and in the central point.

TABLE I. EQUIPMENT USED FOR MEASUREMENTS

No.	Equipment	Manufacturer	Type
1	Analyzer CEE	Power Measurement Canada	7650 ION™
2	Modem PSTN	US Robotics	Courier 56K Bussines
3	Server de date	Hewlet Packard	Procesor Pentium 4
4	Software license	Power Measurement Canada	ION Enterprise 5.5

Figure 2 shows the system architecture in a simplified version that includes only one on-field location and the central point. As seen in the figure, the analyzers have been installed in fixed assembly, on the metering closet pertaining to the monitored cell. The database server and the dedicated application have been installed in the central point

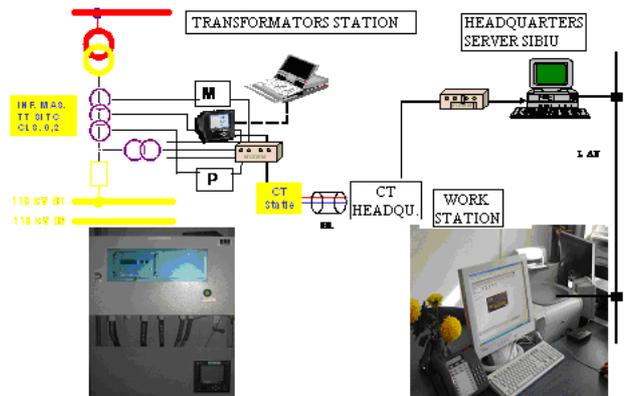


Figure 2. Implementing the system

IV. 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).

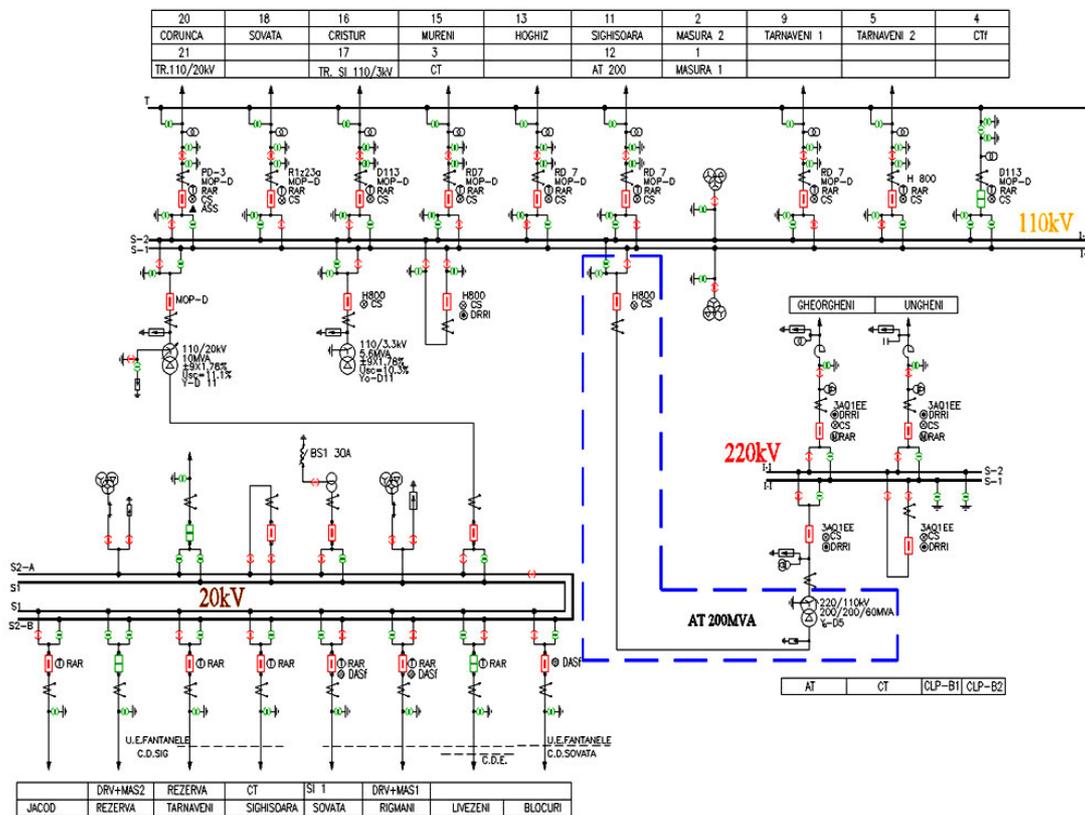


Figure 3. Fantanele substation one-line operating scheme

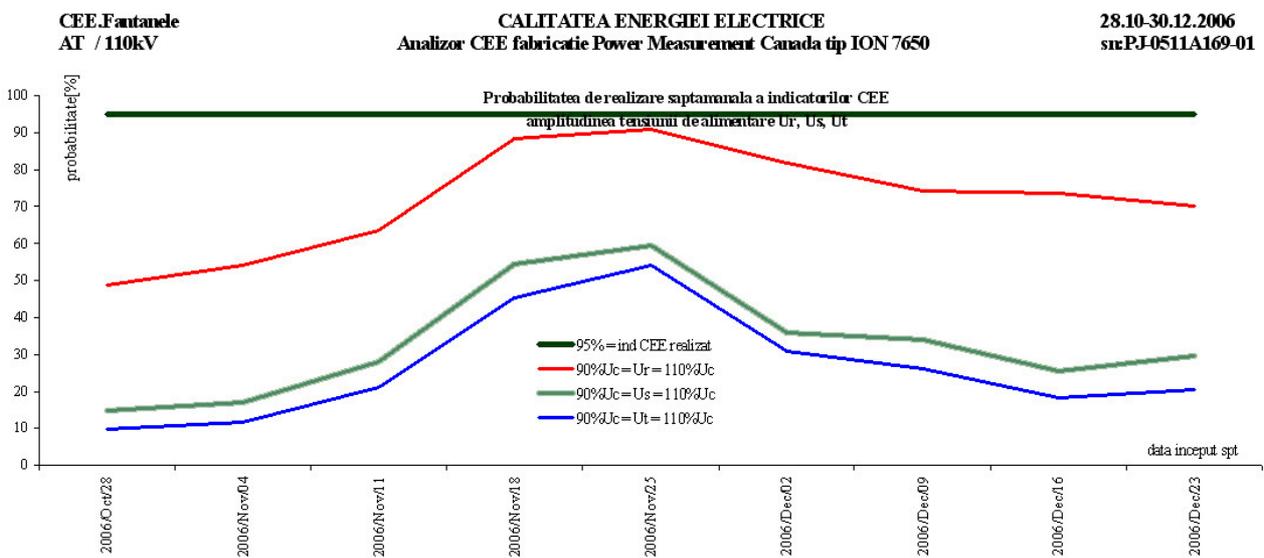
Part of the experimental determinations has been previously presented in other references such as [6]-[9].

In the following, only the experimental results corresponding to the 220 / 110 / 20 kV Fantanele Substation are presented (Figure 3).

Over 50 % of the 220 kV and 400 kV total overhead lines (OHL) length (987 km), within Sibiu Subsidiary, are located on mountain areas, with difficult access. These OHLs are operating in special environment conditions, high requests from the maintenance and operation point of view. The power produced within the major power plants is transmitted through these OHLs: Lotru, Mintia and Iernut. Within

Fantanele substation, additionally, even it has been partially upgraded, power quality indices unsatisfied values have been recorded. The negative aspects refer to the supplied voltage magnitude: U_R , U_S , U_T .

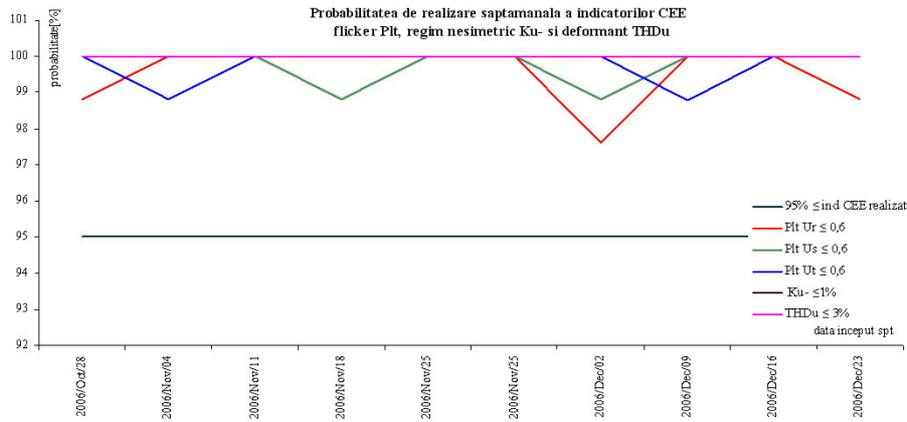
Within Fantanele Substation the measurements have been performed between 28.10-30.12.2006. The very short measurement period is due to several difficulties in establishing the communication between the measurement point and the central one. The greatest real energy quantity received from 110 kV network is noted (according to Table II) being an important characteristic for 110 kV autotransformer.



a)

Nr crt	Amplitude of temporary overvoltages	Number of temporary overvoltages by amplitude and duration								
		U_R			U_S			U_T		
		$\Delta t < 1s$	$1s \leq \Delta t < 1min$	$1min \leq \Delta t$	$\Delta t < 1s$	$1s \leq \Delta t < 1min$	$1min \leq \Delta t$	$\Delta t < 1s$	$1s \leq \Delta t < 1min$	$1min \leq \Delta t$
1	$110\%U_c < U < 120\%U_c$	12	3	175	8	7	162	14	11	106
2	$120\%U_c \leq U < 140\%U_c$	0	0	0	0	0	0	0	0	0
3	$140\%U_c \leq U < 160\%U_c$	0	0	0	0	0	0	0	0	0
Nr crt	Amplitude of voltage gaps	Number of temporary voltage gaps by amplitude and duration								
		U_R			U_S			U_T		
		$10ms \leq \Delta t < 100ms$	$100ms \leq \Delta t < 500ms$	$500ms \leq \Delta t < 1ms$	$10ms \leq \Delta t < 100ms$	$100ms \leq \Delta t < 500ms$	$500ms \leq \Delta t < 1ms$	$10ms \leq \Delta t < 100ms$	$100ms \leq \Delta t < 500ms$	$500ms \leq \Delta t < 1ms$
1	$10\%U_c < \Delta U < 15\%U_c$	2	2	0	2	0	0	1	0	0
2	$15\%U_c \leq \Delta U < 30\%U_c$	1	2	0	6	2	0	0	1	0
3	$30\%U_c \leq \Delta U < 60\%U_c$	0	0	0	6	0	0	2	1	0
4	$60\%U_c \leq \Delta U < 99\%U_c$	1	0	0	12	14	4	8	3	0
Nr crt	Measurement interval (on-of) week	Number of short and long voltage breaks by duration								
		U_R			U_S			U_T		
		$\Delta t < 1s$	$1s \leq \Delta t < 3min$	$3min \leq \Delta t$	$\Delta t < 1s$	$1s \leq \Delta t < 3min$	$3min \leq \Delta t$	$\Delta t < 1s$	$1s \leq \Delta t < 3min$	$3min \leq \Delta t$
1	TOTAL	0	0	0	0	0	0	0	0	0

b)



c)

Figure 4. Synthesis of the PQ indicators of the Fantanele Substation (a, b and c)

TABLE II. AUTOTRANSFORMER 110 kV FANTANELE SUBSTATION OPERATING CONDITIONS

Network element	Transformer tap ratio	Rated power	Tap	Current transformer tap ratio	Voltage transformer tap ratio
Autotransformer corresponding to 2006 year operating conditions	220 / 110 kV	200 MVA	12	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
	02.06.06 11.07.06 16.08.06 16-20.10.06	9.33 %	162.802 GWh	11.7 GWh	88.86

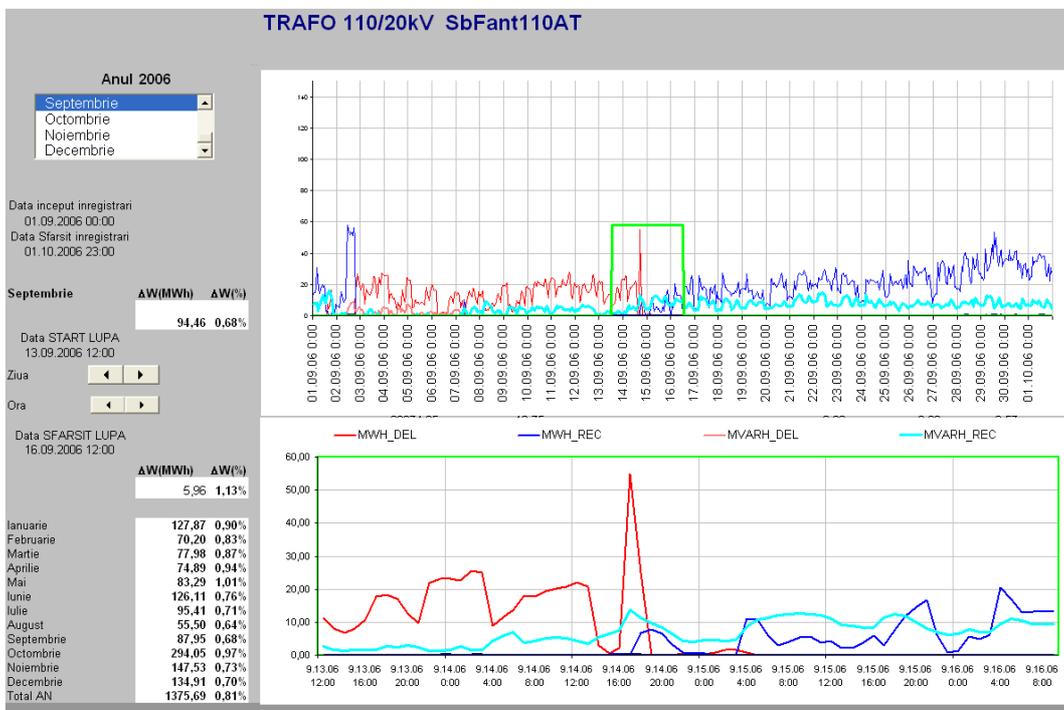


Figure 5. Autotransformer 110 kV Fantanele Substation load curves

The change of the real energy sense is followed by a significant reactive energy quantity. In specific cases the latter could overpass the real one (Figure 5). The 110 kV autotransformer power factor is 88.66 %, being the smallest in comparison to other analyzed network elements. The power quality indicator synthesis is presented in Figure 4. 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.

V. CONCLUSIONS

The supplied voltage magnitude power quality indicator is the most frequent overpass of the imposed limits for all the measuring points, due to its increased value over 110 % U_C . 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.

The feasibility study conducted for this system stresses that its implementation will ensure rapid access to information needed for all the responsible factors. It will therefore increase efficiency with regards to the establishment of concrete measures to reduce electromagnetic disturbances and to diminish their effects in order to:

- Reduce the additional losses in the power transmission network and for the consumers supplied directly from the power transmission network. It is achieved mainly by reducing the harmonics' level, voltage and power non-symmetries for this type of networks;
- Ensure the proper equipment operation with functions and performance affected by the harmonics and voltage and / or current non-symmetries presence;
- Reduce operation expenses for the preventive or corrective equipment maintenance that is affected by disturbances that damage power quality;
- Increase the life span of the power transmission network equipment and consumers supplied directly from the power transmission network, mainly by reducing the level of temporary over-voltages and the harmonic power and voltage on the network;
- Increase the generators, processing units, lines and electric motors efficiency;
- Reduce the costs of power generation / transmission and, in general, reduce investment in the Romanian Power System that would be necessary in order to cover the electromagnetic disturbances' effects caused by exceeding the admissible limits;
- Reduce the reactive power flow and reduce the reactive power exchanges between the power transmission network and the power distribution network;
- Reduce damage to consumers caused by voltage deviations from the rated value, by voltage gaps and by short term power supply failures.

The power quality monitoring system presented provides better results than the ones stipulated within the literature [10]-[13].

Implementing the monitoring system within all the Transelectrica's substations, several advantages are achieved. The efficiency is increasing; the decisions are able to be taken more accurately at all the involved levels.

Only limiting the advantages' evaluation at transmission network additional losses reduction, that affects the power quality, the following economic efficiency indices can be evaluated.

- Considering a 10 years period, the net updated revenue is $NUR = 628,489$ Euro. It presents the analyzed investment efficiency, for a considered study period and an update chosen rate. The limit condition the accept the investment is: $NUR > 0$.
- Profitability index $Pi = 2,612$. 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. To accept the investment this ratio has to be greater than 1.
- Internal return rate $IRR = 45,14$ %. It verifies if the investment is sensitive at greater updating rates, than the one chosen within the computing process.
- Updated recovery $UR =$ approximately 2.5 years from the first operation of the investment. It highlights the capacity of the objective to refund the invested capital for its achievement. It is refunded based on the operation benefices, respectively from the number of years necessary to equal the investment value.

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