UNIVERSITY OF CRAIOVA
FACULTY OF ELECTROTECHNICS

DOCTORAL DISSERATION

Theoretical contributions and experimentations on monitoring indicators of quality of electricity in a local energy system

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INTRODUCTION

Using computer equipments in the computerization of various industrial processes, has led the development, diversification and improvement of all components for such applications. The data acquisition system is the basis of the management applications for industrial processes. Electrical energetics, an area of special importance, has strongly developed, meaning the computerization of generation, transmission and distribution activities of electricity to consumers.

The conditions imposed to information systems in this area involve the existence of some open structures, ranked, allowing the distribution of functions in *functional knots*. Continuous monitoring of electric power quality parameters, has, on one hand, a preventive function of non-alteration of the network by the consumers and a function of objective control of the manner to respect the contractual obligations (for both sides) in order to establish measures to be taken, a basis for the penalty for irregularities.

CHAPTER 1. ELECTRIC POWER QUALITY

Developing digital measurement techniques, the expansion of pollutant receptors made that the actual operation conditions of electrical networks to be far from the stationary ones, requiring new techniques for estimating and measuring. In this respect, lately IEC and IEEE have promoted new ways of approaching the non-sinusoidal and / or non-symmetrical conditions. The quality of electricity should be monitored at each stage through which electricity passes: production, transport, distribution, consumption and has 3 main components:

- quality of voltage (compliance of voltage, frequency, the form of the curves of voltage and electric power, the non-symmetry of voltages and three phase voltages, overvoltages and superposition of remote signals)
- quality of supply (short interruptions and voltage gaps)
- quality contracting (relatively supplier - user)

Quality indicators of electricity

In order to allow the assessment of the quality level of electricity have been defined and are used the following main groups of indicators:

- Indicators regarding the power frequency voltage
- Indicators regarding the variation of voltage
- Indicators regarding the voltage gaps
- Indicators regarding the interruptions of electric network
- Indicators regarding the voltage fluctuations
- Indicators regarding the non-sinusoidal conditions of electric network
- Indicators regarding the inter-harmonics
- Indicators regarding the non-symmetry in electric networks
- Indicators regarding the overvoltages in electric networks

Methodology of measuring

The specific methodology specific to harmonics measurement concerns the instrumentation designated to the analysis of voltage components and electric power having the frequency field up to 2500 Hz. This includes both the instrumentation operating in the time field and the one operating in the frequency field. For statistical processing of the recorded data there are recommended the following time ranges:

Very short interval	Tvs = 3 s	Short interval	Tsh = 10 min
Long interval	T_L = 1 h	One day interval	T_D = 24 h
One week interval	T_{Wk} =7 days		

National regulations

The processing of the obtained results in the measurement process is made statistically in accordance with the present national regulations regarding the quality of electricity:

- Nominal voltages of low voltage public distribution of electrical networks; Harmonization documents SR HD 472.S1:2002; SR HD 472.S1: S1:2002/A1:2002
- Regulation for supplying and using the RFUEE electricity (PE 932 /93)
- Technical Code of the Electric Transportation Networks – ANRE : 51.1.112.0.01.27 /08 /04
- Technical Code of the Electric Distribution Networks – OUEM 63 / 28.12.1998

For the analysis of the non-sinusoidal and non-symmetrical conditions of electrical networks, IEC and IEEE have promoted new ways of approaching contained in the IEC 61000-4-7 standard as well as new indicators regarding the determination of the non-symmetrical condition.

CHAPTER 2. SOLUTIONS TO IMPROVE THE QUALITY OF ELECTRICITY

In accordance with the regulations in force, the deforming condition is defined as the permanent operation condition of alternative voltage electrical networks which supply distorting elements. The deforming element is a receiver that produces or increases the harmonic voltages. The deforming condition in electrical networks affects negatively the saving of the operation of the electrical energetics system as a whole and on components, such as:

- affects the operation of electronic, automation and control protection equipments;
- causes additional losses in the transmission and distribution of electricity;
- loads over the accepted limits the compensation static installations of reactive power;
- causes the decrease of the performance of electric engines, and so on.

Active filters filter a wide range of frequencies and can adapt to any kind of task. On the other hand, the nominal powers are reduced. Typical applications of active filters are:

- installations in the commercial area with a set of non-linear tasks representing less than 200 kVA (variable speed controller, non interruptible power supplies UPS-s, office equipments);
- installations where the electric power distortion must be reduced to avoid overloads

Active filter used to compensate the non-linear load is a three phase inverter. The active filter (SAF) is controlled by a PI type controller and a fuzzy controller. They are used to shape the electric power line to be in phase and of the same shape with the voltage supply.

Simulink models made in order to modelling the active power filters

In order to develop some performing algorithms of controlling the filters, especially for developing an algorithm for adjusting the voltage on the capacitor, there have been made a series of Simulink models, models presented in a graphic form.

CHAPTER 3. SCADA SYSTEMS IN ELECTRICAL ENERGETICS

SCADA (Supervisory Control And Data Acquisition) is a technology that allows the user to take data from different terminals and send instructions to those terminals (acquisition, monitoring, control). A SCADA system allows the user, situated in a central position, to supervise and control a large number of system controllers at large distances. *The Remote Control* means to make decisions for the control of the evolution of a physical process located in a remote (large) location from the respective process.

The information system for operational and managerial management of an electrical network is an integrated system that contains the following information systems:

- The DMS/ SCADA system (Distribution Management System/ Supervisory Control And Data Acquisition), designated for operational management of electrical distribution networks. The database regarding the current condition of the components (facilities) of the network, monitoring and control of the processes distributed geographically is made with functions of SCADA type, and assisting dispatchers in making the best decisions on intelligence operations are carried out with features of DMS type;
- The Management Information System (MIS-Management Information System) designated for technical, economic and administrative activities within the distribution branches of electricity;

The current systems of DMS / SCADA type designated for the electrical of distribution tend to include also features for station automation, protection functions, monitoring of consumers, and so on, thus carrying out complex systems, known in literature as the Distribution Automation Systems (DAS-Distribution Automation System).

EMS (Energy Management System), DMS (Distribution Management System) and SCADA (Supervisory Control And Data Acquisition) represent structures based on digital equipments, used by energy dispatchers to assist them in the operation control of the energy complex systems. The base of the whole

system, which provides the supervision, control and monitoring of electrical equipments of the electrical power stations and networks, consists of the *acquisition and control equipments*. Among these equipments there is a close collaboration; practically, there can not be conceived the functions of the EMS or DMS systems without having available a SCADA system, which would provide both information the technological process and the possibility of remote control of this process.

CHAPTER 4. DISTRIBUTED SYSTEMS OF DATA ACQUISITION FOR THE HIGH AND MEDIUM VOLTAGE STATIONS

The equipment set by the author allows the acquisition and primary processing of 9 analog inputs (of alternating voltage or alternating current type) and 16 digital inputs (of contact type). On the base line there are connected the interfaces for IND digital inputs and INA analog inputs. These interfaces are handled by UCV-01 as a collection of ports, data, orders or status.

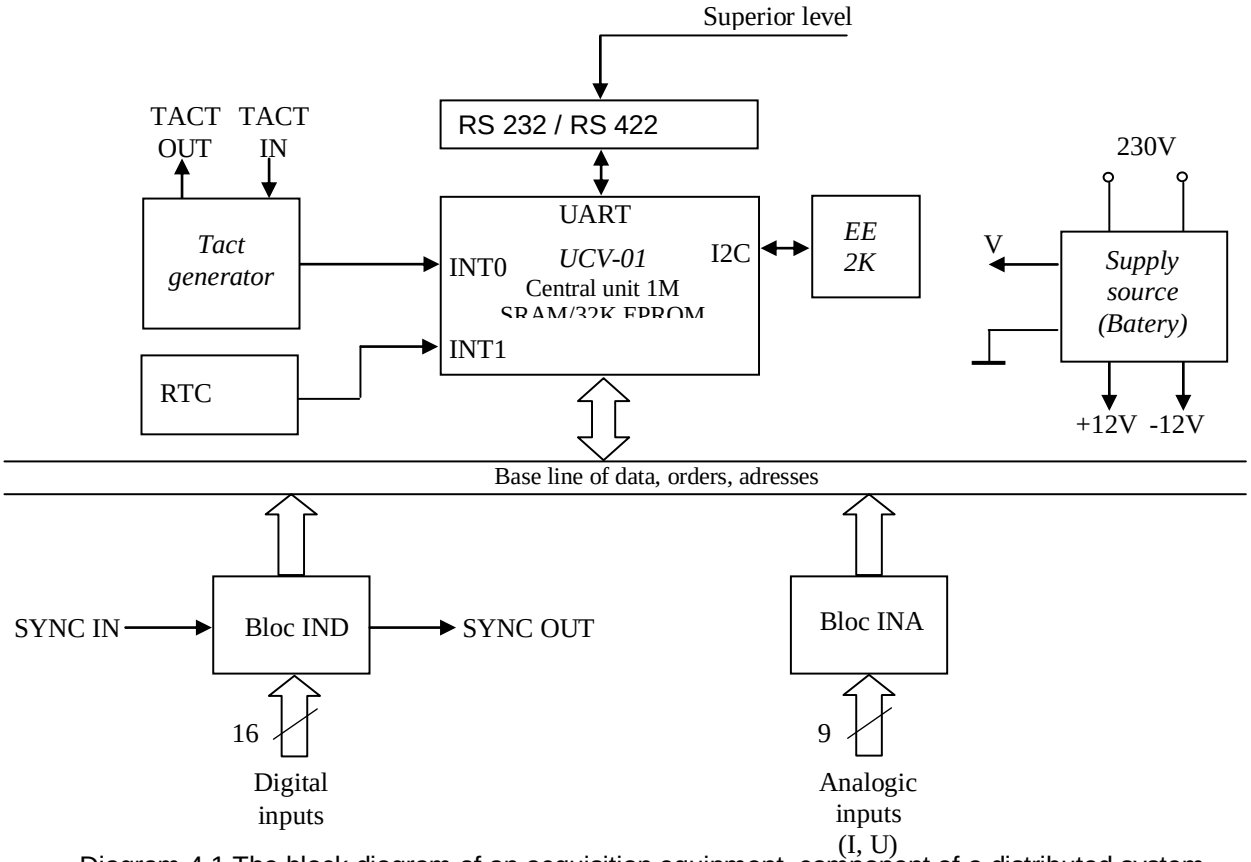


Diagram 4.1 The block diagram of an acquisition equipment, component of a distributed system

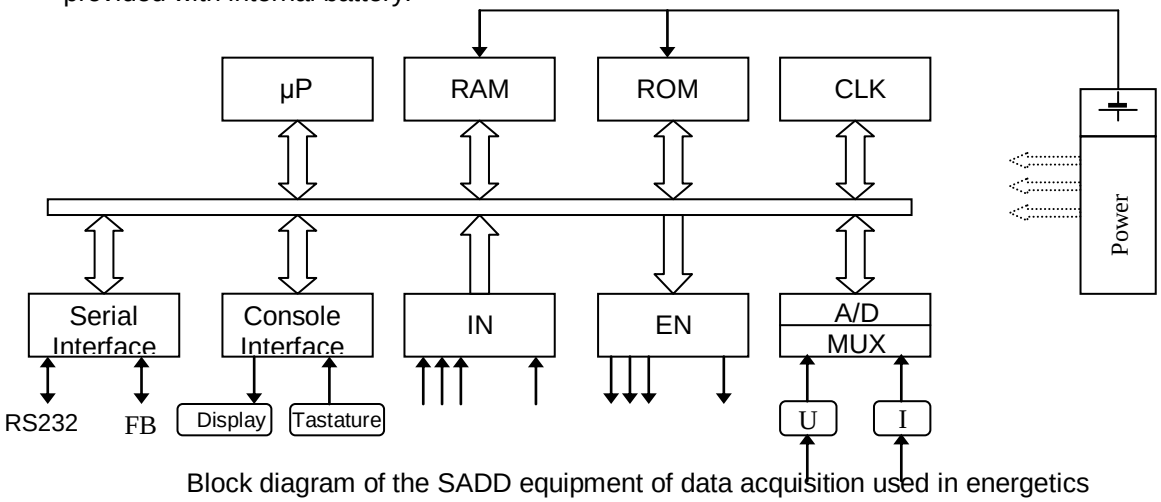
CHAPTER 5. SOLUTION STUDY; DISTRIBUTED SYSTEM FOR MONITORING THE ELECTRICAL AND QUALITIY PARAMETERS OF ELECTRICITY OF THE MEDIUM VOLTAGE INSTALLATIONS

The SAD system, developed by the author, is structured as a distributed data acquisition system, where the acquisition UAi units (standard 8- analogical input channels of voltage or electricity type, expandable modulo 8 to 32 analogical channels and 16 digital channels contact or voltage level type) are placed as close as possible to the area where the signals to be acquired are located.

The block diagram of the acquisition equipment contains the following elements:

- µP – microcontroller, which has the role to coordinate the operation of the equipment;

- RAM – static memory of CMOS type; the information can be also maintained when the equipment is not powered by energy (using an internal battery of the equipment);
- ROM – memory of EPROM type, useful to write the programs which ensure the operation of the equipment;
- CLK – clock/calendar, which is a real time precision clock, based on a quartz oscillator;
- local console (keyboard, local display) allowing the dialogue of the local operator with the equipment;
- IN – interface for digital inputs, with electric separation by optical couplers;
- EN – interface for order digital outputs, with electric separation by optical couplers;
- A/D – analogical – digital converter; MUX – analogical multiplexer;
- U – adapters for voltage inputs; I – adapters for electric power inputs;
- POWER SUPPLY – ensures the supply of the equipment from the internal services of the station, and contains the internal battery necessary to maintain the information in the RAM memory, respectively the operation of the clock in the absence of the supply voltage, when the circuits are not provided with internal battery.



Block diagram of the SADD equipment of data acquisition used in energetics

General technical characteristics of the SAD equipment

In terms of construction, the modular design of the SAD equipment allows the achievement of a family of measurement and data acquisition systems, portable and fixed:

- the acquisition of 8-32 analogical inputs of electric power or voltage type, which can be set upon request; 80 - 300 V, 5 A, 150 V. the acquisition of 16-64 digital inputs of relay contact type, 24/48V, real time clock
- sampling frequency of entries: 1000 Hz; 16 bits processing;
- Precision measurement: U, I…….....0,5%
  P, Q, S, D…….....1%
  Frequency…….....0,05%
  Active/reactive energy..... in accordance with the category 2 IEC1268
  Distortion factor I/U…..2%
  The errors introduced by the external transducers are not included;
- the nonvolatile storage of a finite number of records; storage capacity: 256 Ko ... 4Mo
- recording and storage cycles (locally, equipment):
  - 21.5 sec for very fast phenomena (damages),
  - 4 hours as normal registering instrument (normal technological operation,
  - 1 month with registration management;
  - more than a month by storing the data in the computer system
  - programming pre-damage, damage, post-damage cycles; triggering possibility;
- input for synchronization to an event of maximum 4 equipments of SADD type;
- the possibility to be integrated in a system of SCADA type
- the trigger of the records is made under the following conditions:

- upon the transition of one of the binary inputs (which can be programmed);
- at the programmed thresholds of the analogical inputs are exceeded (on the front or on the level, which can be programmed);
- by another equipment when driving the synchronization line at the event);
- from the hierarchically superior equipment (IBM-PC/AT computer) to which it is connected on a serial line
- manually by the operator;

- self-testing the good running condition and signaling the status of flaw (locally);

The memory strategies are established according to

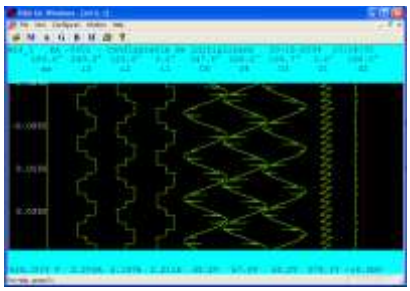
- the type of technological process (fast, slow)
- if there are triggered phenomena
- the triggering possibilities
- the possibility to change the cycles when appearing some phenomena needed to be examined (recovery of curve shapes)

Regarding the strategies we have in view different speeds for acquisition, registration, storage, data transmission to the top level. Also, we can associate different compound strategies: eg. in case of an electrical phenomenon, until the evidence of a damage, we record and store only those data which had an effective trend (we do not record those insignificant data, if the data is maintained in a defined level , we record only the inputs and outputs from the level. When emerging a damage phenomenon, the acquisition is made with the quota of maximum acquisition for those sizes required for an analysis. We have in view also the necessity to align the data compared to time (in order to make a relevant analysis. Usually, the data record is made in association with time).

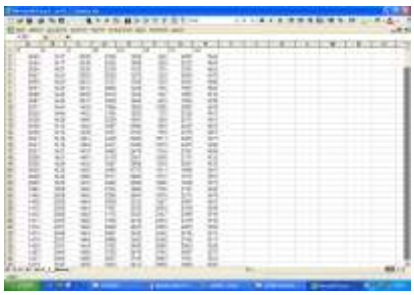
Used standars: IEC 61000-4-30/2007, IEC 61000-4-7-Ed.2/2002, En 61010 category III, IEC 60664, VDE 0110, UL 94, EN 60801, EN 50081-1, EN 50082-1, EN 61000-4-15, ANSI-IEEE 519, CEI 61000-2-4.4.

CHAPTER 6. DIAGNOSING THE FLAWS OF ELECTRICAL GENERATORS TAKING INTO ACCOUNT THE ANALYSIS OF ELECTRICITY QUALITY

Made and used equipments



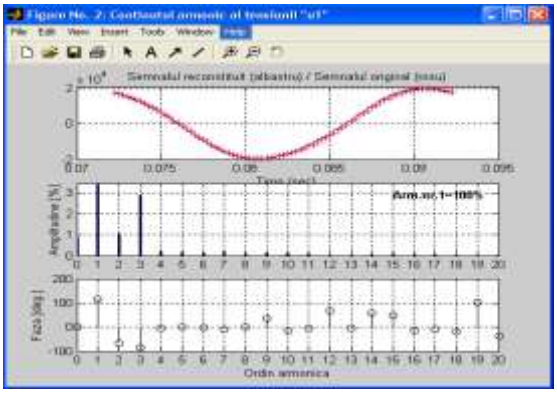
Records of stimulus sizes



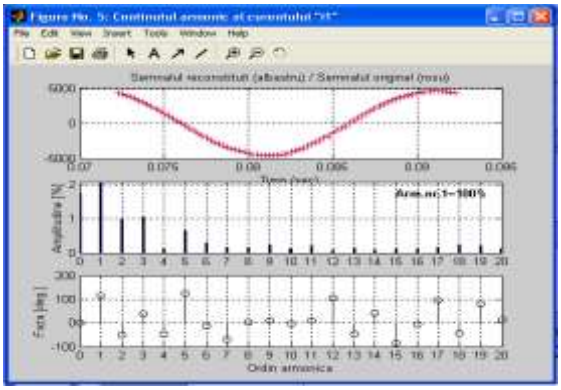
The calculation program for assessing the status has in view the acquisition of the sizes of electrical nature from the stator of the main generator, from the rotor of the main generator (after the rectifier ordered by thyristors), from the stator of the auxiliary generator (before the rectifier ordered by thyristors). Also, there can be determined various quality parameters of normal and abnormal operation of an energy group, powers circulating between the various components of the energy group, as well as with the energy system. The acquired sizes, as well as those determined after the subsequent digital processing, is stored, thus enabling the creation of a database which would allow making some optimal decisions from those who use the database in terms of maintenance works).

The analysis program of visualized wave forms allows the determination of several sizes, including the circulating powers between the different parts of the energy group ("the movement of power between the different parts of the energy group), comparing with the values from the normal functioning of the various components of the energy group, in this way giving the possibility to make a proper decision on the

maintenance works. Thus it could be detected in due time the emergence of some flaws (such as short circuits between the spires of the stimulus winding of the main generator), which have the effect of shortening the life cycle of the main generator and the eventual shut-down of the energy group. The detecting in proper time of these flaws has as a consequence the making of proper maintenance works, at the appropriate time, so that in the surrounding areas not to be felt the side effects of their occurrence. The equipment was tested for records of electric sizes from the auxiliary generator of an energy group from Turceni Energy Complex, in order to register curve shapes of the voltage and stator electric power of the auxiliary generator stator and the curve shapes corresponding to the voltage and stimulus electric power. From the processed data it was considered necessary the decomposition up to harmonica 40, according to the European regulation (it may disintegrate even up to harmonica 50, according to the ANSI-IEEE519 / 1992 standard). The existence of the harmonics of rank seems to lead us towards two causes: measurement errors and / or non-symmetry of voltage. Analyzing the causes we detected the short circuit between the spires of the rotor winding. The continuing component may also occur from the calibration of the data acquisition system or from an error when recording.



Harmonic content of “U1” voltage



Harmonic content of “I1” electric power

Theoretically, the deviations from the real values of the electric power are more important than those of the voltage, given their greater variability, which is visible also practically from the examination of the charts. The harmonic content is presented for the decomposition of electrical quantities in a number of 40 harmonics, in accordance with IEC 61000-4-30/2007, IEC 61000-4-7 standards, Ed.2/2002. Based on the harmonic decompositions of the voltages and electric power, the software developed allows the determination of the quality parameters of the sizes of electric nature.

Conclusions

The system has greater influence on electric power (are less distorted). The voltages are at the terminals of the generator, not those from the energy system. The presence of the harmonics of rank 2 / 3 in the curves of the voltages / powers show a non-symmetrical operation, although the share of the harmonics of rank 2 are not very high. There are ascertained both voltages and electric power of rank 3, which shows the possibility of movement of the harmonic electric power, multiple of 3. The differences in the read powers and those calculated shows that:

- it is possible that the generator to deliver to the energy system the active power on the fundamental harmonics and on harmonics.
- the generator does not change with the system a reactive power on the fundamental harmonics (the read reactive power), in exchange it may assign reactive power on the harmonics.

The distortion coefficients of the voltage from the terminals of the generator and the stator electric power of values sensitively equal show a stable electrical energy system.

Similar to the described methodology, there can be processed digital records and processing of wave shapes (voltages, electric power) of the stator and the rotor of the main generator. By the simultaneous recording of the wave shapes of the electric quantities before and after the rectifier fully commissioned with thyristors, there can be made a complete monitoring of the energy group.

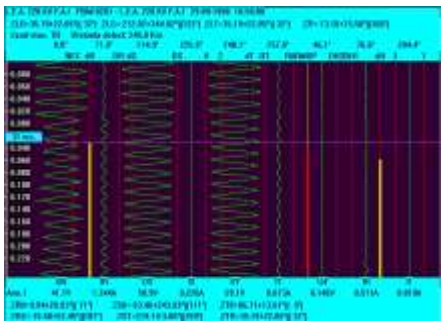
CHAPTER 7. SYSTEM FOR MONITORING THE QUALITY OF ELECTRICITY

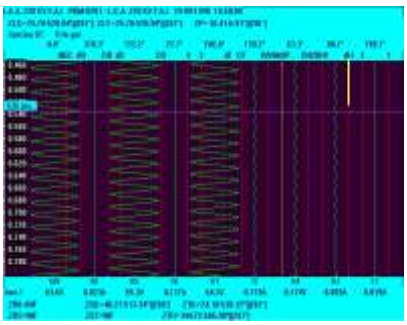
The acquisition and registration systems of electric events are installed in medium and high voltage stations within the national power system. These structures are useful in post-crash analysis and to identify the weak points of electrical networks. The package of programs, is addressed, in particular, to the PRAM personnel serving the electrical installations.

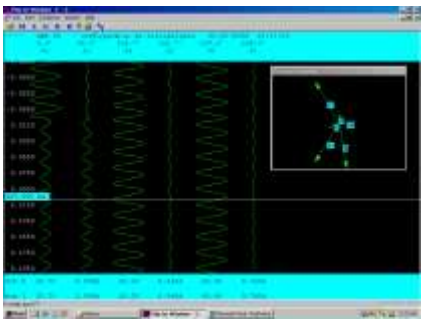
The equipments are useful also during the works for the operation of electrical equipments (transformers, coils, and so on), allowing rapid determination of errors filtered into secondary electrical circuits. For this purpose there have been made portable acquisition and recording equipments. These systems have also proved to be useful in identifying the parameters characteristic to electrical lines of medium voltage, in order to deal properly the neutral, with coil and resistor.

Equipment

Extended variant equipment , in the system







Records of the event analysis

The software package for monitoring and recording allows:

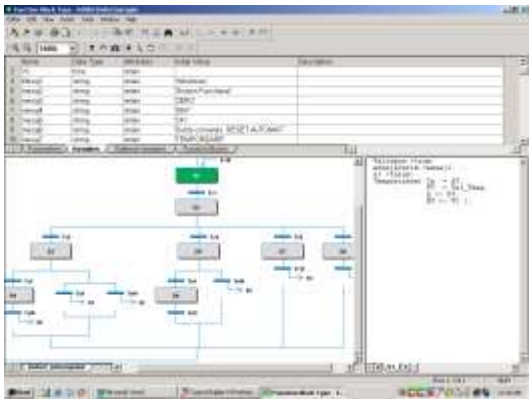
- the monitoring of system connected to a PC; the transfer of records from the equipment to a PC;
- the measurement of analogical quantities (actual values, angles of alteration of phase to a reference size, spectral analysis) and binary;
- calculations in three-phase regarding:
  - impedances, reactances, the resistances of phases and earth; active and reactive powers;
  - the direct, positive and negative components and of zero sequence of the voltages and electric powers;
  - the distance to the flaw; determining the work schedule of the supervised item (load condition, idle running, lack of tension – short-circuit type, and so on).
  - records management; • control/programming of the disturbance recorders from the respective system;
- viewing and inspection of the archive.

The equipment was installed in the system at SC Electrica Oltenia SA

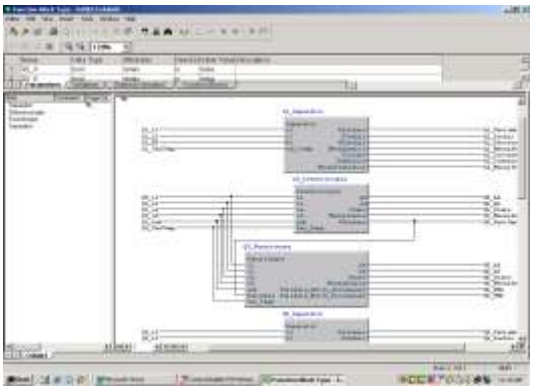
CHAPTER 8. APPLICATIONS

8.1 Monitoring and control system for medium voltage power stations

The aim of the paper: Acquisition and registration system of electric sizes from the cells of 20kV and 0,4kV, as well as the teleoperation of the installation from HMI and DET.



Flaw detection function.



Function Cell 01

For maximum portability, there have been created specific libraries of electrical symbols, that made – automatically - the connection with the function implemented in the PLC. The program system contains the following applications:

- Connection to the PLC by OPC; library symbols; configuration own system operator;
- Databases with events, damages and joint; the window control, automatic switch
- Window confirmation and validation of the order; operation surveillance PLC

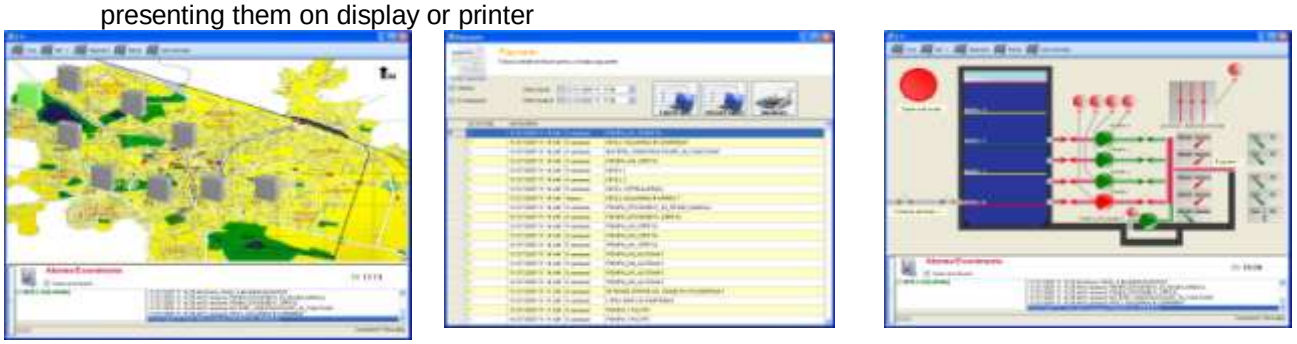
Reference: Transelectrica, The power station of 20 kV from Urechesti, Gorj county

8.2. Monitoring and control system of pump stations

The system ensures the acquisition from the transducers of the characteristic sizes of the operation of technological facilities from the pump stations of drinking water or sewage, self-diagnosis, displaying on display, processing the data acquired, transmission at the central dispatch level, tracking the operation of stations, developing the monitoring report, balance sheets of the stations and operational situations, transmission of data to decision makers.

Provided functions:

- Data acquisition - Pressure, flow, level, pumps' status, valves' positions, equipment's status
- Control of the pumps by inverters and / or soft-starters
- Warning in case of exceeding the work sphere, data storage; data transmission
- Analyses, reports
- Registration of changes of the process status in discharge event books
- Developing intelligence reports, of synthesis, using the data from the database and / or records and presenting them on display or printer



Screens' view

Reference: The system for Craiova Sanitation Agency, Simnic Pump Station.

8.3. Protections for digital hydrogenerators

The aim of elaborating the digital protections is to interrupt the injection of electricity in the lines of 20kV on which the hydrogenerators debit, when the voltage on the network increases, thus avoiding the occurrence of overvoltages and damage of SDFEE, the hydrogenerators. The digital protection equipment, monitoring and recording, for CHEmp, allows the monitoring of hydrogenerators' operation, performing the function of protection, registration and their disconnection from the electrical network.

The equipment is very useful especially in some cases of damage which lead to the supersaturation of the group or overvoltages on the generator's terminals.
In cases of damage, the equipment performs also the function of registration and storage of the monitored electrical quantities, in a sequence that can be accessed later, thus allowing the post-damage analysis of the event, in optimum knowledge conditions of the situation and especially the cases in which the damage was produced.

Diagram 8.6 Digital protection equipment

Reference: Hidroelectrica sa, Targu Jiu branch

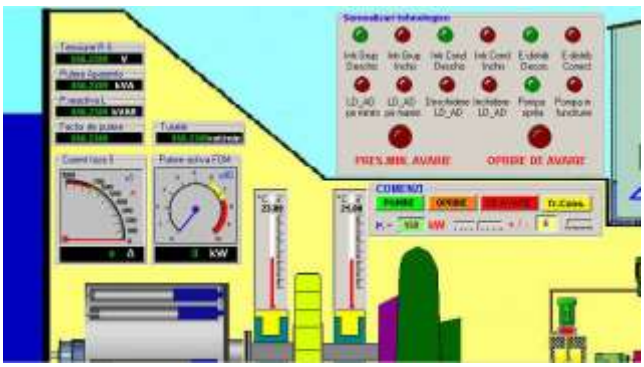
8.4. Monitoring system, remote management of **micro hydroelectric power station**

System's functions

- Acquisition, processing of input signals, processing the information taking into account an algorithm .
- Orders to the equipments afferent to the electrical installation MHC Valea lui Iovan.
- Optical signalization of the technological status fo the electrical installation's equipments; data recording Connection with the equipment of automatic synchronization. The connection decision in parallel with the system of the hydro plant unit will be taken by the synchronization equipment.

On / off functions / Protections :

- maximum voltage (instant action) and electric power (timed action);
- protection against acceleration (instant action);
- protection against the operation as an electrical engine, with a timed action;

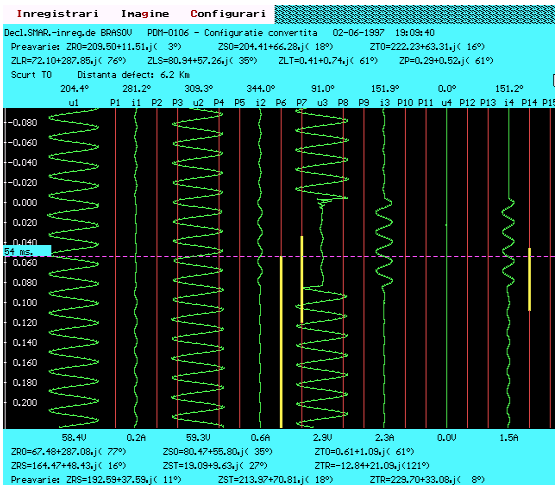


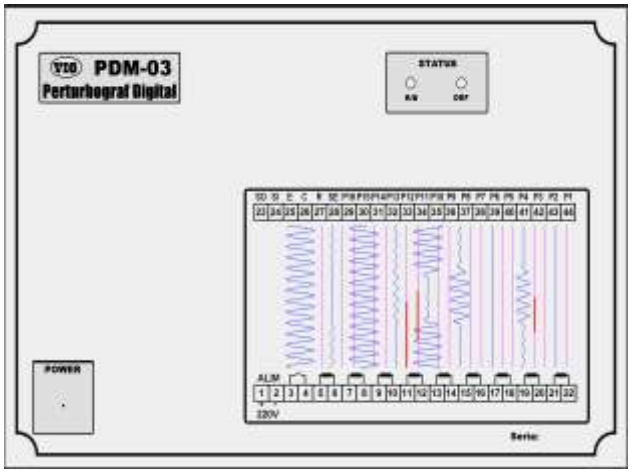
Display local dispatcher

Reference: Hidroelectrica sa, Targu Jiu branch, MHC Cerna,

8.5. Digital flaw registering instrument

The equipments from the series PDM are digital modules for the acquisition of analogical sizes (electric power, voltages, and so on) and binary (contacts, voltage levels, and so on) which allow the temporary storage of the acquired information and its transfer to a compatible calculation equipment IBM-PC/AT, in order to its subsequent storage and processing
(post-damage analyses, monitoring).





Registering instrument, screen

CHAPTER 9. CONTRIBUTIONS, CONCLUSIONS, PERSPECTIVES

The paper approaches and solves problems in the field of data acquisition systems, designated to the computerization of industrial processes applied in electrical energetics. The book had an applicative character, the author designing and producing a family of modules, equipments for the completion of distributed data acquisition systems applying in electrical energetics, with applications regarding the analysis of electricity's quality.

Contributions

- Analysis of the parameters which characterize the quality of electricity, defining and assessing the qualitative indicators of electricity;
- Solutions to increase the quality of electricity to large consumers, designing active filters
- Developing a distributed, ranked, modular data acquisition system for the high and medium voltage stations (hardware and software)
- Developing a family of module of functional knot type, dedicated to monitoring and recording the functional parameters of primary equipments from the medium and high voltage stations;
- Achieving the genuine solution of diagnosing the flaws of electrical generators using methods of analysis of the quality of electricity
- Implementation of some distributed SCADA systems type, designed and made and implemented by the author for data acquisition, in several medium and high voltage stations and electrical plants in the country, these systems provide monitoring of electrical parameters, the analysis of the parameters that characterize the quality of electricity and the detection and recording the cases of flaw, installations' control, informing the decision-makers as an operator guide.

From browsing the paper we can synthesize the following **conclusions:**

1. Continuous monitoring of the parameters of the electricity's quality, allows *the control of the manner of abiding the contracting obligations (seller of energy - the beneficiary) in order to establish the measures to be taken, a base for the penalty of the deviations.*
2. By the correlation of the analysis functions of electricity's quality and using the digital protection for the hydrogenerator, if MHC Cerna it was allowed the switching out of injecting of electricity in the

lines of 20KV on which the hydrogenerators debit, when the network voltage increases, thus avoiding the appearance of overvoltages and SDFEE deterioration, of the hydrogenerators.

3. Applying the acquisition and data analysis system from the main generator of an energy group within Turceni Power Plant , by post-damage analysis has allowed the deduction in case of certain events of operating and anomalies in electrical networks, as well as their localization.
4. By applying the system at Urechesti electrical power station, with the standard mathematical models for the static and dynamic operation of each device and the transmission in the network of the equipment's state and the input sizes, at any hierarchical superior level it can be rebuilt the real status, avoiding the occurrence of abnormal conditions that would lead to the alteration of the electricity;s quality.
5. Equipment for measuring and registration of energetic parameters that characterize the quality of electricity such as the flaws registering instrument as an equipment of energy data collection, in terms of structure, functionality, design, projection and their implementation, as well as the *solutions proposed by the author* are a *result of the studies performed by the author.*

Perspectives. In the following period, the author aims to

- develop the family sub-assemblies, modules and equipment of functional knot type, dedicated to monitoring the primary installations of electrical energetics; the increase of local processing speed by using micro-controllers with the data base line of 16-bits and the signal processors (DSP);
- the development of tools and applications for data analysis at the dispatcher's level, the development of predictive maintenance applications, development of equipment control, monitoring and driving for the passenger transportation that will lead to reducing the energy consumption in municipalities.

CHAPTER 10. SELECTIVE BIBLIOGRAPHY

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