ASPECTS OF FREQUENCY AS SYSTEM PARAMETER – LOW VOLTAGE MEASUREMENT CASE STUDY

Dan APETREI - ELECTRICA S.A., Romania[1]
Ioan SILVAS – ELECTRICA S.A., Romania[2]
Valentin RASCANU – FELIX IT SA, Romania[3],
Carmen STANESCU, CNTEE Transelectrica, Romania
Dorel STANESCU, Electrica S.A., Romania
Alin NICOARA, Electrica S.A.,Romania

SUMMARY

Usually we take for granted the frequency as a system parameter. Sort of common sense judgment leads to that. After Romanian system was UCTE integrated, frequency parameters greatly improved. The paper presents a practical approach analysis to a low voltage frequency survey made for over a year in three low voltage locations. Custom designed device allowed the measurement and storage of the values every half cycle for a long period of time. The measurements are made according to IEC 61000-4-30 class A requirements. The huge amount of data was validated and then the data in coincident measurement periods of time extracted and compared.

After a short introduction on the frequency in power systems, common standards (EN50160, IEC 61000-4-30) on measurement and survey in distribution networks are presented. Next, the measurement system is presented and the measurement results. The time synchronization problem is emphasized. Instead of conclusion, some consideration for the next step in analysis and measurement of this parameter are issued.

Key words: frequency measurement, IEC 61000-4-30, stationary signal

[1] str. Grigore Alexandrescu, nr. 9, sector 1, Bucureşti, telefon: 2085250, e-mail: dan.apetrei@electrica.ro;
[2] str. Grigore Alexandrescu, nr. 9, sector 1, Bucureşti, telefon: 2085202, e-mail:ioan.silvas@electrica.ro;
[3] str.ing.C.Constantinescu, nr.2-4, sector 2, Bucureşti, telefon: 2422120, e-mail: vrascanu@ice.felix.ro;

INTRODUCTION

Frequency is a measure of the number of occurrences of a repeating event per unit time. According to IEV (International Electrotechnic Vocabulary), the definition (101-14-08) states that *frequency is the reciprocal of the period*. The same source defines period (101-14-107) as the *smallest difference between two values of the independent variable at which the values of a periodic quantity are identically repeated*. Related to the power system, the definition is: number of complete cycles of a periodic wave in a unit of time. The frequency of electrical quantities such as voltage and current is expressed in hertz (Hz).
The analysis of frequency variation depends heavily on the timescale of the problem being analyzed. Figure 1 shows the principal power system dynamic performance areas displayed on a logarithmic timescale ranging from microseconds to days. The lower end of the band for a particular item indicates the smallest time constants that need to be included for adequate modeling. The upper end indicates the approximate length of time that must be analyzed. It is possible to build a power system simulation model that includes all dynamic effects from very fast network inductance and/or capacitance effects to very slow economic dispatch of generation.
Frequency of the system will vary as load and generation change. Increasing the mechanical input power to a synchronous generator will not greatly affect the system frequency but will produce more electric power from that unit. During a severe overload caused by tripping or failure of generators or transmission lines the power system frequency will decline, due to an imbalance of load versus generation as could be seen in Figure 2. Loss of an interconnection, while exporting power (relative to system total generation) will cause system frequency to rise. AGC (automatic generation control) is used to maintain scheduled frequency and interchange power flows.

Table 1 Frequency control process and events time scale

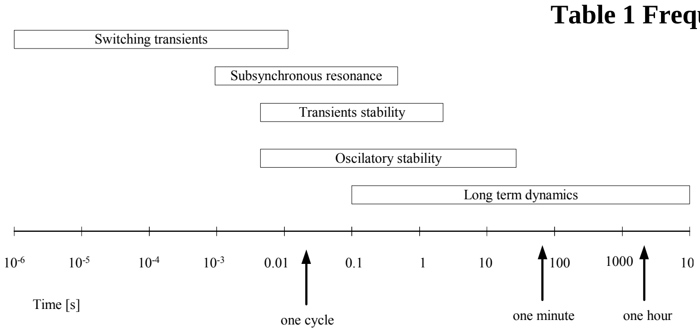


Figure 1 Power system events timescale

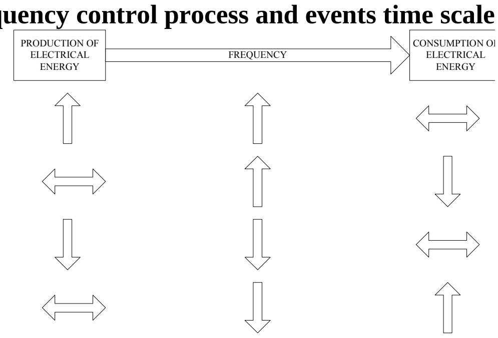


Figure 2 Frequency control process

Frequency protection relays on the power system network sense the decline of frequency and automatically initiate load shedding or tripping of interconnection lines, to preserve the operation of at least part of the network. Small frequency deviations (i.e.- 0.5 Hz on a 50 Hz or 60 Hz network) will result in automatic load shedding or other control actions to restore system frequency.
Smaller power systems, not extensively interconnected with many generators and loads, will not maintain frequency with the same degree of accuracy. Where system frequency is not tightly regulated during heavy load periods, the system operators may allow system frequency to rise during periods of light load, to maintain a daily average frequency of acceptable accuracy.
Frequency could vary around nominal value because of the continous change of the load. Frequency control is responsability of UCTE (**U**nion for the **C**oordination of **T**ransmission of **E**lectricity). One of the parameters used to analyse slow variations of frequency is (Δf):

$$\Delta f = f_N - f \tag{1}$$

Where : f_N is the nominal frequency and f – is the real frequency. Frequency error is expressed by:

$$\varepsilon_f\,[\%] = \frac{f - f_N}{f_N}.100 \quad [\%] \tag{2}$$

At least for electrical clocks based on system frequency, it is important to count the difference to a reference clock. The syncronicity condition is expressed by:

$$I_f = \int_0^{24} \Delta f \cdot dt = 0 \tag{3}$$

Network dispatch has to maintain frequency within limits. Limits are usually established in order to avoid damage of the devices connected to the network. Usually there is an interval of ± 1Hz (± 2%) accepted for common applications.

FREQUENCY MEASUREMENT

Frequency as characteristic of voltage is regulated by SREN 50160 and CEI 61000-4-30 among others. This couple of standards makes a good combination of threshold prescription and measurement methods.

SREN 50160

This standard gives requirements for the main characteristics of the voltage at the customer's supply terminals in public low voltage and 'Medium voltage electricity distribution systems. The standard is used under normal operating conditions. The object of the standard [2] is to define and describe the characteristics of the supply voltage concerning: frequency; magnitude; wave form; symmetry of the three phase voltages. Regarding frequency, it is stated that it has to be 50Hz. Under normal conditions, the values measured during a 10s interval has to be within:

- 50 Hz ± 1% (meaning 49,5 Hz-50,5 Hz) during 99,5% of a year;
- 50 Hz +4%/–6% (meaning 47 Hz-52 Hz) during 100% of time;

These characteristics are subject to variations during the normal operation of a supply system due to changes of load, disturbances generated by certain equipment and the occurrence of faults which are mainly caused by external events.
The Annex A of the standard gives a comment about the "Special nature of electricity":
"Electricity as delivered to the customers has several characteristics which are variable and which affect its usefulness to the customer.[...] In practice, there are many factors which cause departures from this. In contrast to normal products, application is one of the main factors which influence the variation of "characteristics".

CEI 61000-4-30

This standard defines the methods for measurement and interpretation of results for power quality parameters. Measurement methods are described for each relevant type of parameter in terms that will make it possible to obtain reliable, repeatable and comparable results. The power quality parameters considered in this standard are power frequency, magnitude of the supply voltage, flicker, supply voltage dips and swells, voltage interruptions, transient voltages, supply voltage unbalance, voltage and current harmonics and interharmonics, mains signaling on the supply voltage and rapid voltage changes.

Since this paper is dealing with frequency measurement, we will briefly present the requirements for this type of measurement. There are two classes of performance for voltage measurement: class A and class B. The following rule must be applied for class A measurement:

The frequency reading shall be obtained every 10-s. As power frequency may not be exactly 50 Hz within the 10-s time clock interval, the number of cycles may not be an integer number. The fundamental frequency output is the ratio of the number of integral cycles counted during the 10-s time clock interval, divided by the cumulative duration of the integer cycles. Before each assessment, harmonics and interharmonics shall be attenuated to minimize the effects of multiple zero crossings. The measurement time intervals shall be non-overlapping. Individual cycles that overlap the 10-s time clock are discarded. Each 10-s interval shall begin on an absolute 10-s time clock, ±20 ms for 50 Hz. Over the range of influence quantities, and under the conditions described in [3] the measurement uncertainty Δf shall not exceed ±10 mHz.

For class B performance, the manufacturer shall indicate the process used for frequency measurement. The manufacturer shall specify the uncertainty Δf over the range of influence quantities,

Measurement time intervals are aggregated over 3 different time intervals. The aggregation time intervals are: 3s interval (150 cycles for 50 Hz nominal), 10-min interval, 2-h interval.

Aggregations are performed using the square root of the arithmetic mean of the squared input values. Three categories of aggregation are necessary:

- <u>Cycle aggregation</u> - the data for the 150 cycle time interval shall be aggregated from 15 10-cycle time intervals; This time interval is not a "time clock" interval; it is based on the frequency characteristic;
- Because the time interval is not a "time clock" interval, a cycle to time-clock aggregation is needed. According to the standard, the 10-min value shall be tagged with the absolute time (for example, 01H10.00). The time tag is the time at the end of the 10-min aggregation. If the last 10-cycle value in a 10-min aggregation period overlaps in time with the absolute 10-min clock boundary, that 10-cycle value is included in the aggregation for this 10-min interval.
- On commencement of the measurement, the 10/12-cycle measurement shall be started at the boundary of the absolute 10-min clock, and shall be re-synchronized at every subsequent 10-min boundary. This implies that a very small amount of data may overlap and appear in two adjacent 10-min aggregations.
- <u>Time-clock aggregation</u> -the data for the “2-h interval” shall be aggregated from twelve 10-min intervals.

MEASUREMENT DESCRIPTION

For the measurements the MOT-103B/BG equipment was used. This is a custom designed, made in Romania measurement system. The system was designed to meet SREN 50160 requirements even for long term surveys. There are four versions of the system depending on the front panel and number of inputs. In order to be connected to a higher processing level, MOT has factory configurable serial interfaces (RS-232 or RS-422/485) treated with MODBUS protocol. MOT is treated as a MODBUS slave. As could be seen in figure 3, MOT has dedicated internal blocks for:

- power supply;
- input voltage monitoring;
- rms value recording;

- frequency measurement;
- operator console;
- processing and storage;
- clock and synchronization.

The equipment has dedicated inputs for voltage to be monitored, time synchronization and dedicated bidirectional interfaces for communication.

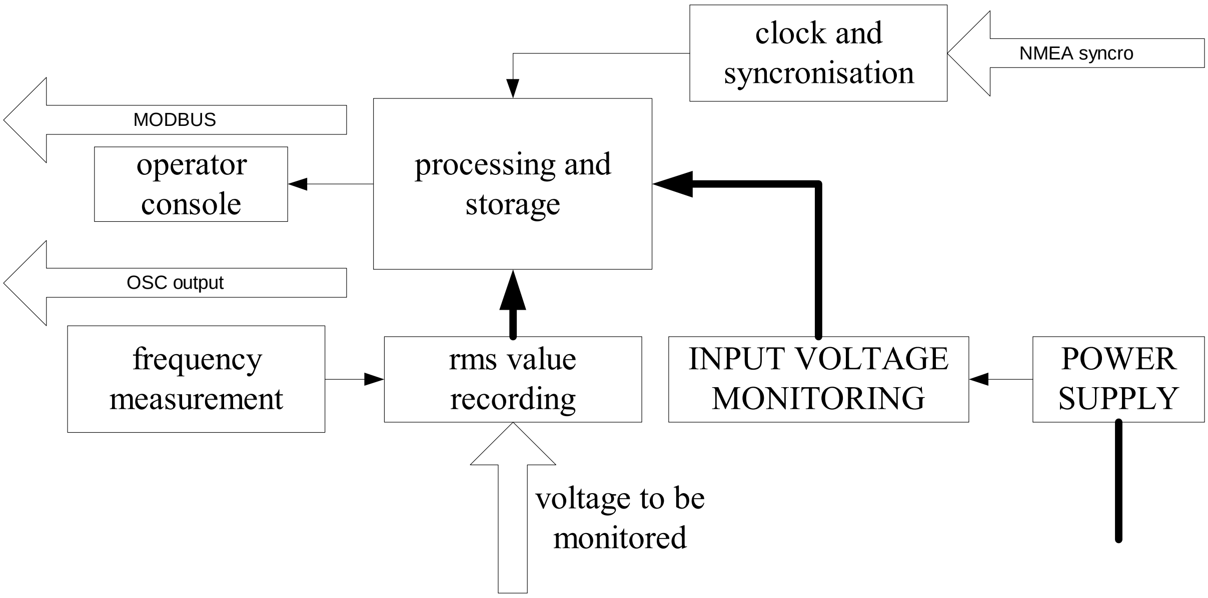


Figure 3 MOT internal blocks

Besides voltage monitoring according to SREN50160, the equipment can give on OSC output the RMS value of the voltage and the duration of the half cycle, every half cycle. This secondary function is used for the study presented in this paper. The configuration of the system dedicated is presented in figure 4.
As could be seen there is a Windows XP - PC runnig a dedicated piece of software.

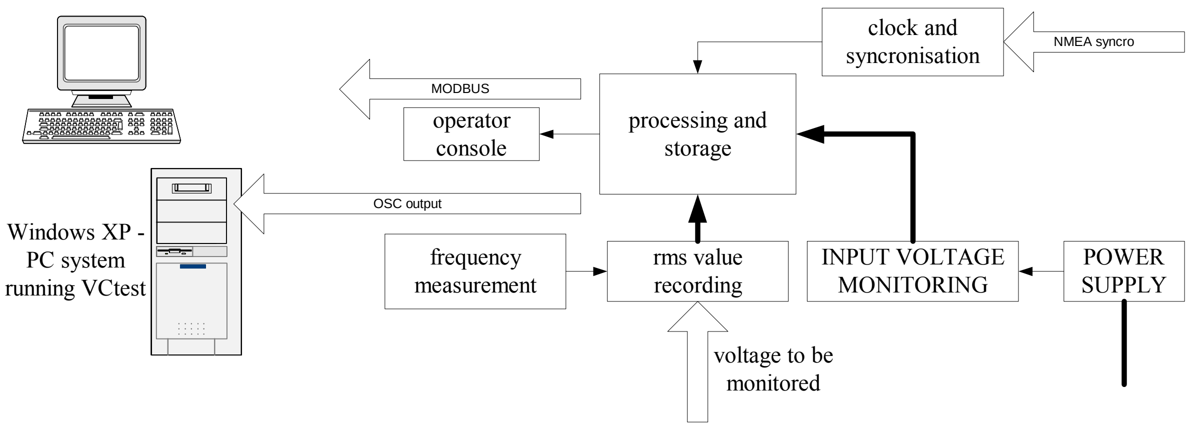


Figure 4 VCtest configuration

The software used is called VCtest. It realizes the link between computer and MOT through serial interface. Since the equipment doesn't have dedicated memory for half cycle measurement storage, the computer must be continuously connected during the data acquisition. Figure 5 presents the measurement points. As could be seen on the map, there were three locations: Bucuresti; Cluj; Sibiu where recordings were made during one year. The results are stored and then processed. Analysis of the data is not an easy process since low voltage environment is more polluted than high voltage environment.

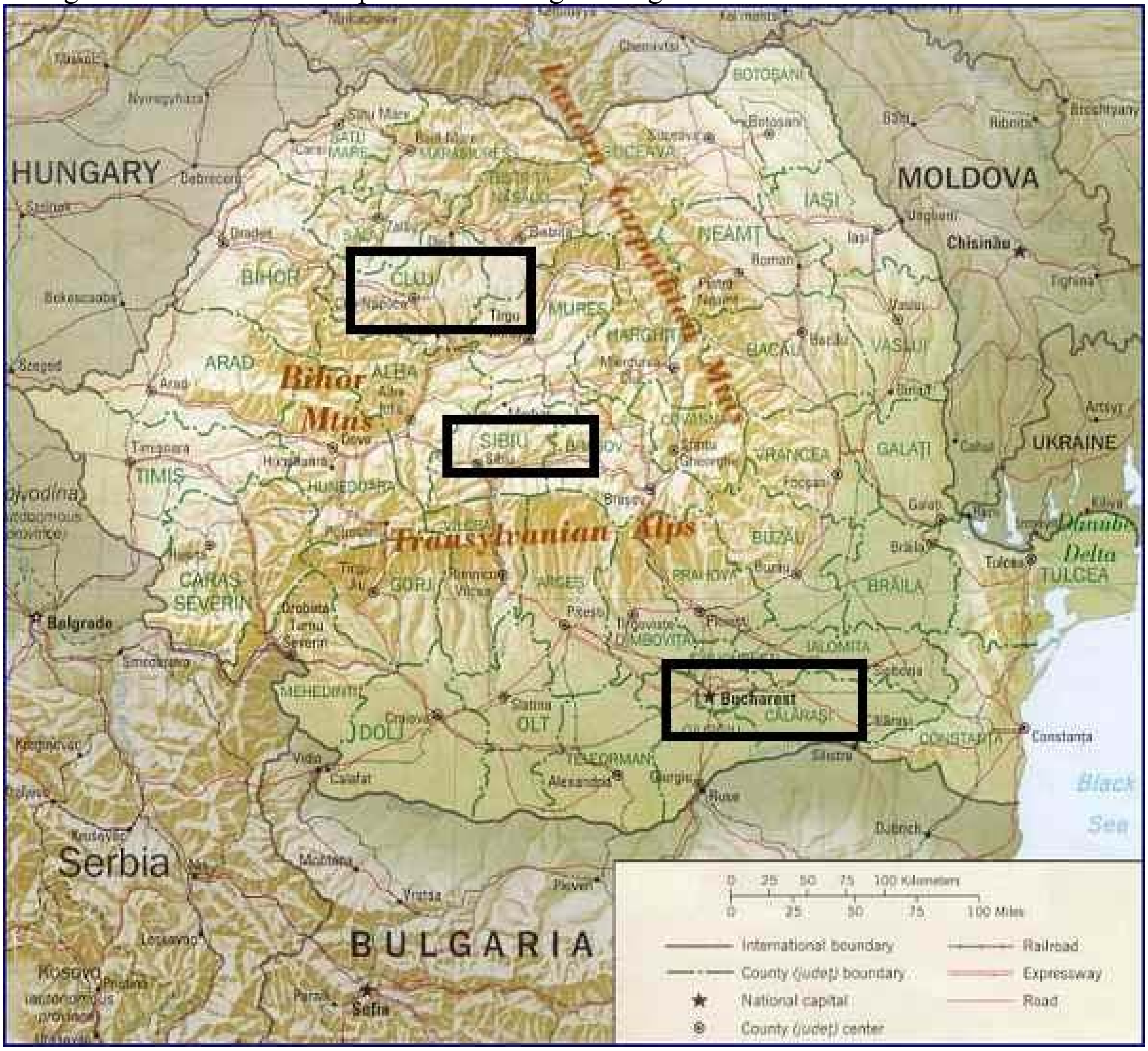


Figure 5 Measurement points location

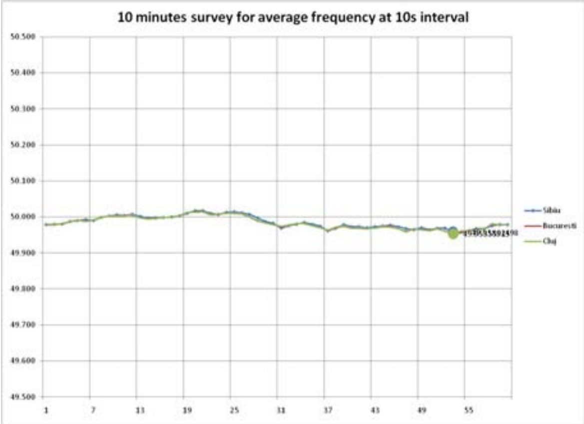
From the data measured, we have selected one ten minutes interval containing 60.000 recordings. There was a recording for every half cycle.

MEASUREMENT RESULTS

The interval selected for analysis is on 10th of April from 11:00 till 11:10. For this time interval 60000 values of the duration of the half cycle are stored for every metering point under survey. According to the standard, ten seconds average of measurements is presented in Figure 6 and Figure 7. Figure 6 shows the data recorded in the measurement points at the scale established by EN 50160 +/-1%. On the chart in Figure 7 the same data is presented at a different scale. The limits of the frequency scale are 50,020Hz and 49,950Hz. This means [+0,04% ; -0,10%] limits compared to nominal value of frequency.

As could be seen, the chart in figure 7 clearly defines different functioning regimes of the power system. Since 11 o'clock is among the morning peak hours the average frequency during the ten minutes survey period is under nominal value.

As could be seen the curves are correlated and the difference between measurements is under accuracy requirements of the standard.



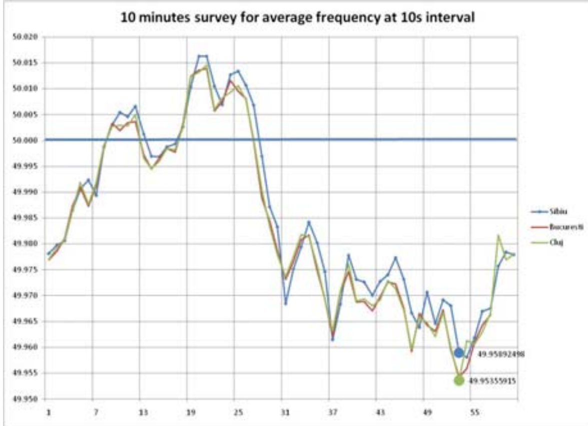
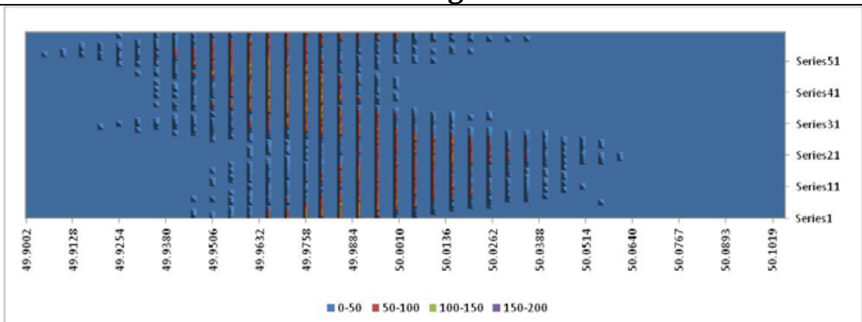
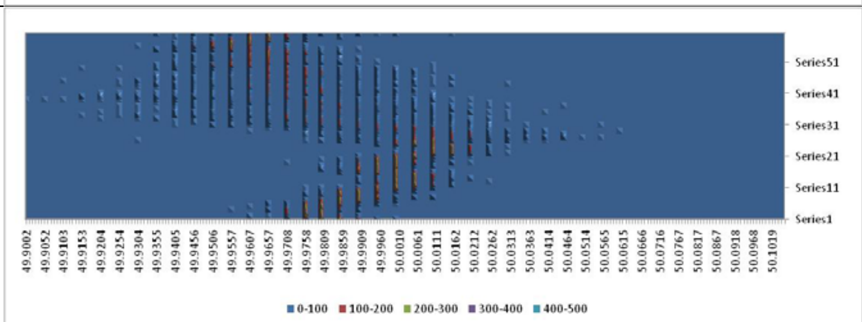
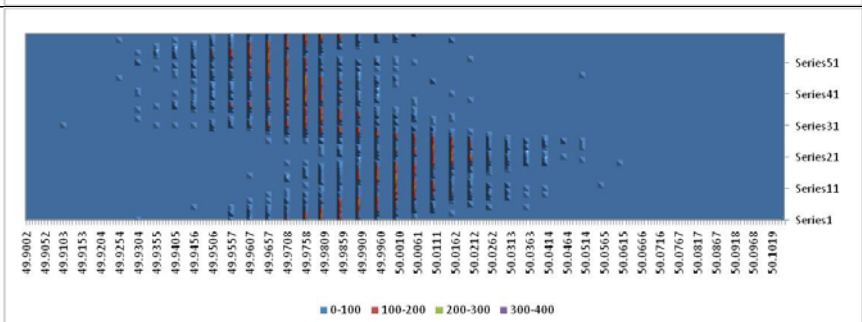


Figure 6 Frequency chart at 50Hz±1% scale

Figure 7 Frequency chart at 50Hz(+0.04%;-0.1%)

According to the data presented in figure 7, the frequency (at least the average during ten seconds of the frequency) is a system parameter.
The charts in Table 2 present the distribution of frequency for the three locations under survey. As could be seen, despite the fact average values are almost the same, the distribution of the values is different.

Table 2 Repartition of frequency on the 60 intervals of 10 seconds

Nb.	Location	Histogram
1	Cluj	
2	Bucuresti	
3	Sibiu	

The charts present the 60 series of values, each containing 1000 measurements as they contain frequency measurements in the interval 49,9002Hz to 50,1019Hz. There are multiple explanations for the different distribution of frequency in different areas. Among the causes could be:

- the noisy environment;
- the local unbalance between generation and consumption;

In order to establish a sound explanation for the charts in table 2, further investigation is necessary.

NEXT STEP IN MEASUREMENT OF FREQUENCY

Measurement condition at each site should be investigated. First step is to try a correlation analysis between voltage THD and frequency measurement distribution. Since the measurement method is based on zero crossing detection, noisy environment could lead to a wider distribution of the values measured.
In order to extend the analysis in time domain, good synchronization practice is necessary. Actual measurement conditions lead to an unsatisfactory synchronization level. As could be seen in the chart in figure 7, we have an important delay between the red line and the others. The causes of this lack of performance are multiple. It is necessary to investigate each one and to enforce corrective measures. The level of time accuracy of the common time source and time synchronization mechanism has to be fewer than 1ms to get comparable result.

BIBLIOGRAPHY

[1] William W. Price - Power System Dynamic Modeling -GE Energy
[2]EN 50160 Voltage characteristics of electricity supplied by public distribution systems, - CENELEC , 2003
[3]IEC 61000-4-30 Ed. 1: Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods, - CEI , 2003