VOLTAGE DIPS ANALYSIS USING VIRTUAL INSTRUMENTS

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Abstract – The paper presents a virtual instrument proposed by the authors for voltage dip analysis. The main characteristics of voltage dip are theoretical presented and the corresponding LabView diagrams are explained. In order to test the virtual instrument, a voltage dip is then generated using a mathematical signals generator and the results obtained by the virtual instrument are presented. Measurements were performed in a 220/110 kV substation using classical measurement equipment and the recorded data corresponding to voltage values are used afterward like input files for the virtual instrument. The results are graphically presented in the paper.

Keywords: voltage dip, signal generator, virtual instrument, measurement system, electrical network.

1. INTRODUCTION

The voltage dips (called also *sags*), defined as a decrease in root mean square (RMS) voltage at consumers' terminals are one of the important power quality disturbances that have been focus considerable research in recent years [1]. The level of RMS voltage drop, to be considered as voltage dip, is from 0.1 to 0.9 pu of nominal voltage, for duration from 0.5 cycles to 1 minute. The duration of voltage dip is defined as the time measured from the moment the RMS voltage drops below 0.9 pu of nominal voltage to when it rises above this level [2].

The voltage dips can cause major problems in several types of equipment, especially electronic equipment, or adjustable-speed drives, very sensitive to such perturbations. Acquiring of a less sensitive equipment is, of course, more expensive, so the designers have to know the dip characteristics on the distribution buses to make a good decision concerning the compromise between equipment cost and it's supplying solutions [3].

On the other side, the network operators need to estimate the effects of voltage dips on the load connected to the distribution buses to make appropriate settings of the protection and automation devices. Harmless voltage dips can be the origin of system load loss due to the protection device sensitivity [4]. Consequently, it is necessary to obtain accurate information about voltage dips characteristics.

Voltage dips characteristics can be estimated either by field data processing or by simulation tool based on a time-domain technique. The increasing of the recorders number located through distribution system make the first alternative to became more attractive.

However, when we consider the large amount of data that may be collected in a given power system, the manual inspection and extraction of information about the events is no longer a practical option. Therefore, it is necessary to have automatic analysis tools, integrated with the monitoring systems, for automatic analysis and classification of voltage dips and others power quality events. This information is important for identifying the parameters of the voltage dips occurred at a specific bus.

In this context, the present paper, describes a procedure applied using virtual instruments for data processing of the field information, recorded during voltage dips, to highlight the parameters of the voltage dips.

Using field recorded instantaneous values of the phase-to-neutral voltages during system perturbations, the processing algorithm computes rms voltages, identifies duration of the voltage dip, establish it amplitude, phase angle shift and point on wave.

Virtual Instrumentation refers the use a computer and dedicated input and output devices in order to simulate the characteristics and operating functions of a measurement instrument or data acquisition device.

Virtual instruments make use of transducers and sensors to get in touch with the physical amounts measured by any system of signal conditioning and analog-digital conversion circuits [5].

The advantage against the classical measurement systems is that this time all of the processing and analysis functions of measured values, the storage of this information and their transmission to the human user are made by computer and not by dedicated equipments.

The software performs these functions in most of the cases and graphic user interface having the same look as the front panel of a meter are used. That's why these applications are called virtual instruments.

LabVIEW programs are called virtual instruments because by their form and their mode of operation looks like classical measurement and control devices. A virtual instrument has an interactive user interface, a source code equivalent, and supports a hierarchy along with other virtual instruments. However they are identical to functions in conventional programming languages, and sometimes are integrated into these [6].

Virtual instruments can be easily adapted for the use for a wide range of applications in smart grids. In [7] a virtual measurement instrument is used for detection and analysis of power quality disturbances in voltage supply using wavelets. Monitoring and analysis of power quality parameters in industrial systems using LabView are also presented in [8] and [9].

This paper presents a virtual instrument realized by the authors for voltage dip analysis and is organized as follows: Section 2 proposes the structure of the virtual instrument based on the theoretical approach of voltage dip analysis, Section 3 presents a testing procedure of the virtual instrument using a voltage dip generated by a signal generator, Section 4 presents a study case for a voltage dip recorded in an electrical substation, while Section 5 reports the conclusions.

2. VIRTUAL INSTRUMENT DESIGN FOR VOLTAGE DIP ANALYSIS

The following is the algorithm used to voltage dips analysis and the software solution developed in LabView.

Residual voltage is the main characteristic of a voltage dip and it represents the minimum value of the voltage RMS during the dip [10]. The following method is used for the voltage RMS determination.

The power voltage is sampled N times/cycle which results in a sampling frequency of *50*N* Hz. The RMS voltage is computed using (1).

$$V_{RMS}(k)=\sqrt{\sum_{i=k-N}^{N}(v(i))^2} \qquad (1)$$

Here, $v(i)$ is the i^{th} sample (one of the last N^{th} samples). The last N samples are used to compute the actual RMS voltage. Consequently, a three-phase system triples the work to be done.

The duration of a voltage dip is the time in which the voltage is below a threshold [10]. In some cases it can be used two thresholds: one for dip starting (typically 90% of nominal voltage) and one for dip ending (typically 92% of nominal voltage).

For voltage dip analysis is first to determine the RMS value of the voltage for each signal period available depending on sampling rate. RMS values so determined are then reported to the RMS value of the rated voltage. LabView diagram for this sequence program is presented in Fig.1.

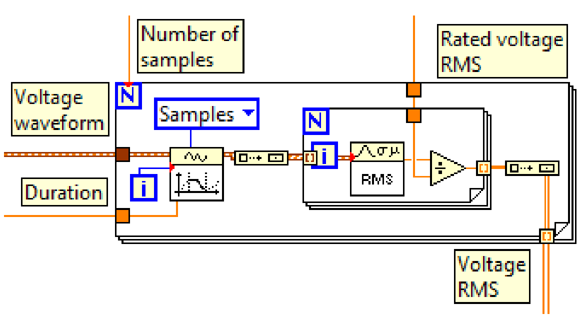

Fig.1. RMS voltage computing

Two important characteristics of voltage dip are the *amplitude* and *duration* of the dip. The corresponding computing procedure in LabView is presented in Fig.2.

To detect the main characteristics of voltage dip, first it must to be used a trigger to detect the start and the end of the dip. The trigger uses two thresholds: one for dip starting (90% of nominal voltage) and one for dip ending (92% of nominal voltage). By “Dip begin” and “Dip end” was determined the number of samples recorded during voltage dip. The number of samples recorded during the dip is divided to the sampling rate in order to obtain the dip duration. The “Dip amplitude” represents the minimum RMS voltage between “Dip begin” and “Dip end”.

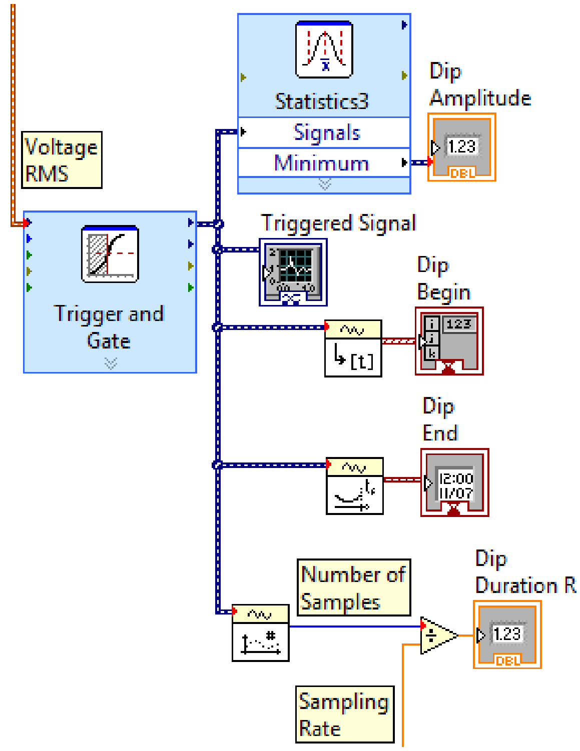

Fig.2. Amplitude and duration computing

One of the particularities of the waveforms during voltage dip is *phase shift*, term used in [10], [11] (other authors [12] use the term *phase angle jump*). Through the phase angle jump it is understood the difference between the phase angle before and during the dip.

In order to determine the phase angle jump, a sinusoidal signal with the same initial phase and frequency of the signal acquired is generated using LabView. Is then determined the phase shift between the two signals throughout the analysis. The procedure for determining the phase shift, shown in Fig.3, consider in which quadrant is placed each of the two phasors. Considering that in LabView the phasors gets values in the domain [-360 deg. ÷ 360 deg], the voltage phasors are brought in the domain [-180 deg. ÷ 180 deg.], according to generally accepted convention.

To compute the difference between the two signals we need to treat some particular cases. For example a particular case appear when the two signals are around 180 deg and one of them has a positive value (175 deg) and the second has a negative value (-175 deg). In this situation we need to adapt the computation process to obtain the correct result. All particular cases are treated by the mathematical model described in Fig.4.

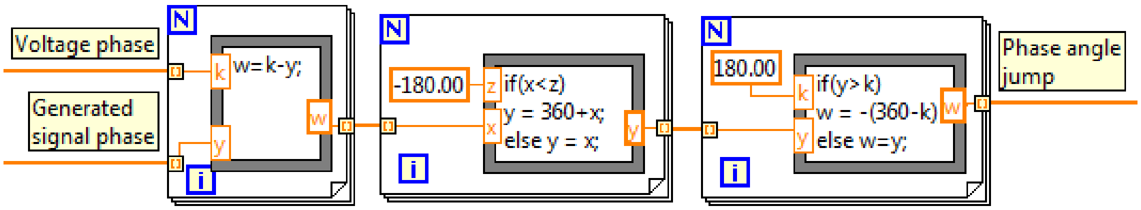

Fig.3. Phase angle jump computing

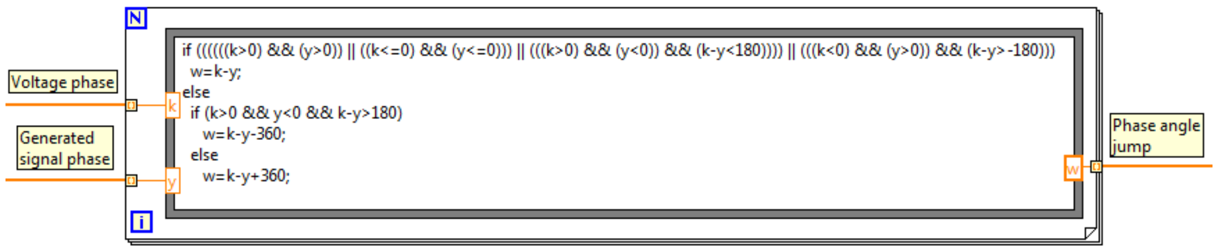

Fig.4. Mathematical function for phase angle jump correction

Another important parameter of the waveform is the *point on wave*, which represents the moment on the waveform when appears or ends the dip. In some materials [13] the authors considered that this parameter should be used to compute the voltage dip duration. Fig.5. presents the point on wave computing proposed in LabView. It's quite simple to detect the point on wave using a triggering system on the frequency measurement. Considering that the frequency is computed on the last cycle, the result must be respectively adjusted. This method can be used only when the voltage dip was clearly detected because the frequency can vary from many other reasons. In order to be sure that there is a voltage dip, the signal "Voltage Waveform" from Fig.5 it's collected from a buffer.

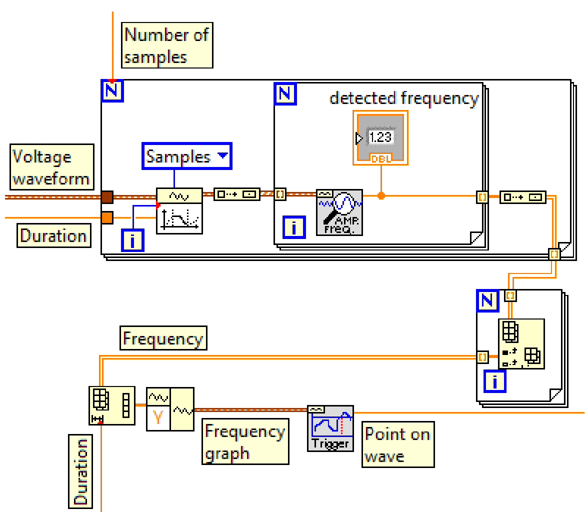

Fig.5. Point on wave computing

3. VIRTUAL INSTRUMENT TESTING

In order to test the virtual instrument proposed above, a signal generator for voltage dip was used [14].

The mathematical description of the practical problem could be summarized as follows: given the characteristics of the two phases (amplitudes A_1 and A_2, frequency f, phase shift φ), construct a continuous function that describes the voltage dip that occurs between the timestamps t_1 and t_2.

The mathematical model used is composed by 5 different equations. The first and the last equation describe the voltage waveforms for the normal operating condition (ante-perturbation and post-perturbation). The second and the fourth equations describe the transition segments between the normal operating conditions and the voltage during the dip. The third equation describes the voltage waveform during the dip.

$$y(t)=\begin{cases} A_1\cdot N(t)\cdot\sin(2\pi ft) & ,t\le t_1 \\ N(t)\cdot j_1(t)\cdot\dfrac{Y_2(t_1+\theta)-Y_1(t_1)}{j_1(t_1+\theta)-j_1(t_1)} & t_1<t\le t_1+\theta \\ A_2\cdot N(t)\cdot\sin(2\pi ft+\varphi) & ,t_1+\theta<t\le t_2 \\ N(t)\cdot j_2(t)\cdot\dfrac{Y_1(t_2+\theta)-Y_2(t_2)}{j_2(t_2+\theta)-j_2(t_2)} & t_2<t\le t_2+\theta \\ A_1\cdot N(t)\cdot\sin(2\pi ft) & ,t_2+\theta<t \end{cases}$$

Finally, the complete formula of the noise can be obtained using (2). In this relation is considered that the waveform is affected by noise composed from both solutions presented.

$$N(t)=1+\sum_i\frac{A_{in}}{A_1}\cdot\sin(2\pi f_{in}t+\varphi_{in})+ \\ +\frac{A_n}{A_1}\cdot\prod_i\sin(2\pi f_{jn}t+\varphi_{jn}) \qquad (2)$$

This noise is composed by two different models (the two members of the sum). The first one represents a harmonic distortion, modelled as a sum of sine waves of given amplitude A_{ih} (which is a fraction of the amplitude of the normal regime), given frequency f_{ih} and given phase shift φ_{ih}. The second member is composed by overlap of multiple distinct sinusoidal signals, having a common amplitude A_{1n} and having a given frequency f_{jn} and phase shift φ_{jn}.

As it can be remarked from Table I, in order to test the virtual instrument, it was generated a voltage dip having the following characteristics: the dip amplitude is 0.5 u.r., the dip duration is 346 ms (t_2-t_1+θ), and phase angle shift is 15 deg (φ in Table 1).

Table 1. The values of the parameters for the voltage dip generated to test the virtual instrument.

Parameter	Value	Parameter	Value
A_1	89653	*timestep*	0.0001
A_2	0.5*89653	θ	0.001
f	50	A_{1h}	2689
φ	Pi/12	A_{2h}	2689
t_1	0.207	A_{3h}	2689
t_2	0.552	f_{1h}	150
A_{1n}	896	f_{2h}	250
f_{1n}	123	f_{3h}	350
f_{2n}	1063	φ_{1h}	1
φ_{1n}	0.5	φ_{2h}	3
φ_{2n}	1.5	φ_{3h}	2

When virtual instruments are used, the results are shown by an interface which is called front panel. Many display possibilities are available in LabView, but, for our application, the most practical is the graphic display.

Fig.6 presents the voltage waveform generated by the mathematical signal generator in order to test the virtual instrument. The voltage corresponds to a phase to neutral voltage of a three phase level 110 kV.

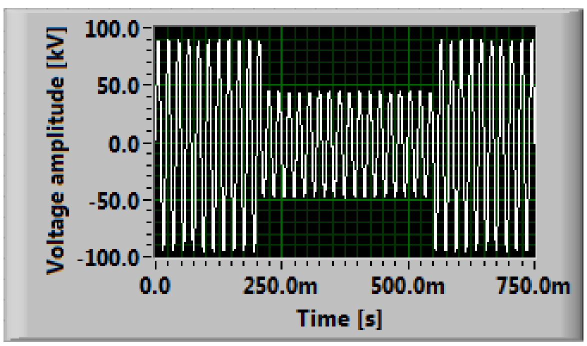

Fig.6. Generated voltage waveform

The voltage RMS corresponding to the generated signal is computed using (1) and is presented in Fig.7.

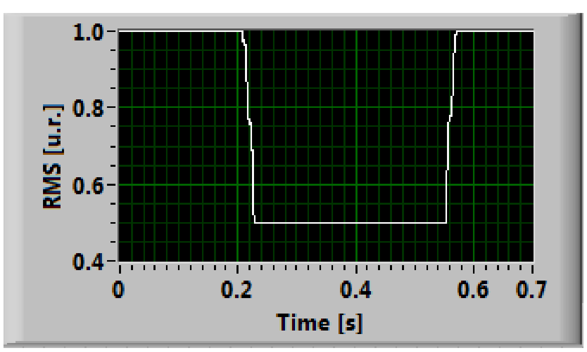

Fig.7. Voltage RMS

The value of the RMS voltage during the dip is 0,5 u.r., for the generated signal (Table 1), but on the zoom presented in Fig. 8, it can be seen a very small difference (about 0.1%) due to the noise that affect the signal. So we can say that the instrument can be used in noisy environment.

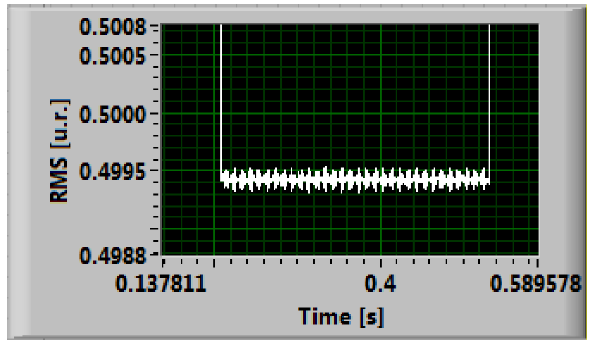

Fig.8. Zoom on the voltage dip RMS

The voltage dip duration from LabView is 351.5 ms, and the generated voltage sag duration is 346 ms. The difference is due to the fact that in LabView the voltage dip duration is computed as the difference between the moment when the RMS decreases below 0.9 and the moment when the RMS increases over 0.92.

The phase shift of the signal due to the perturbation is 15.05 deg computed as difference between the voltage phases before and during the perturbation. This value can be observed on the phase graph for the dip duration in Fig. 9. For a better observation a zoom is presenting in Fig. 10. This value almost is identical with the value (φ) indicated in Table 1.

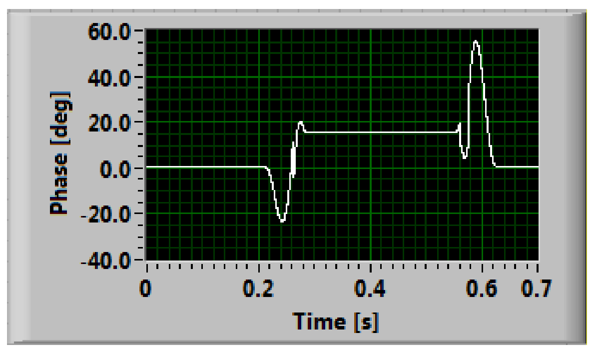

Fig.9. Phase shift

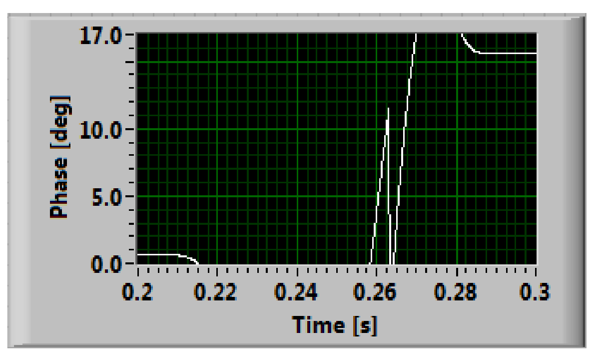

Fig. 10. Zoom for phase shift

The point on wave is found using a trigger on the frequency graph. For this example the frequency is exactly 50 Hz during the normal operating conditions and also during the dip (Fig. 11). Thus, a threshold value of 2% (49 Hz or 51 Hz) can be chosen and the corresponding point on wave is detected, Fig.12.

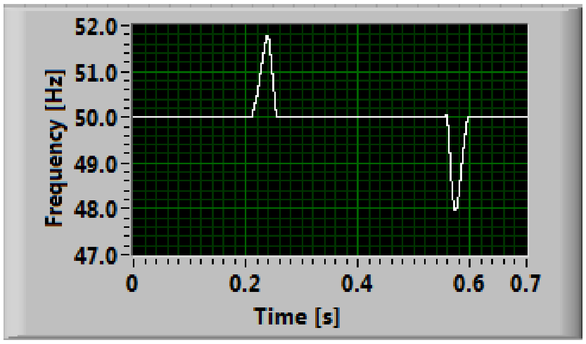

Fig.11. Point on wave

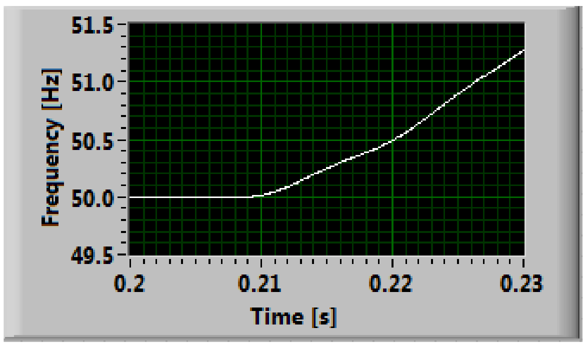

Fig. 12. Zoom for point on wave

As it observed in the case presented above, the virtual instrument operates correctly. In these conditions, the next paragraph will use this tool to determine the parameters of a voltage dip recorded in reality.

4. CASE STUDY

Measurements were performed at the secondary side of a voltage measurement transformer from a 220/110 kV substation. For the virtual instrument described above, the file containing the recorded data is used like input file.

One of the voltage dips recorded by the measurement system during the monitoring period is analysed in this section. Voltage dip characteristics described above are presented. The voltage waveform containing the dip is presented in Fig. 13.

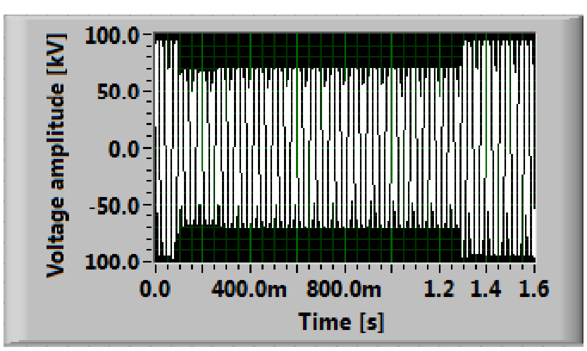

Fig.13. Recorded voltage waveform

The RMS voltage corresponding to the recorded waveform is computed using (1) and is presented in Fig. 14. For this case we remark a voltage dip of about 0.7 u.r., the duration of the dip being of more than 1 sec.

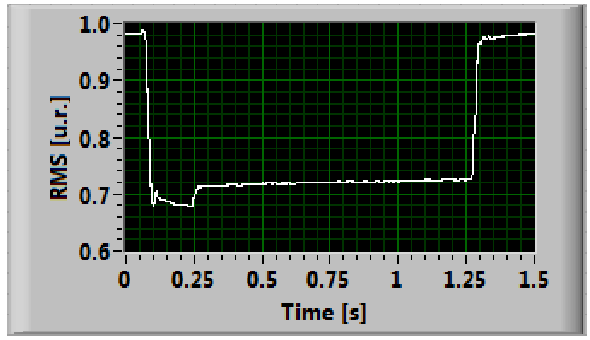

Fig.14. Voltage RMS

Regarding the phase angle jump, in Fig.15 it's observed that there is a phase shift of about -20 deg., before the dip and during the dip.

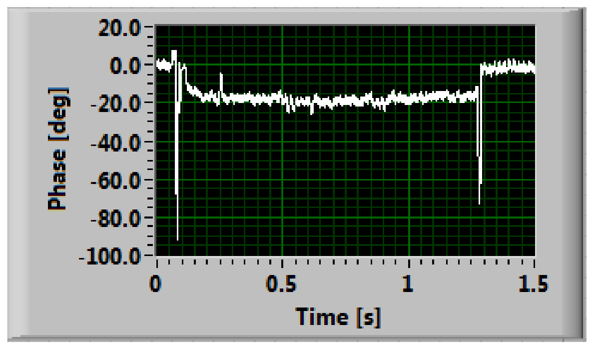

Fig.15. Phase shift

The point on wave is presented in Fig.16.

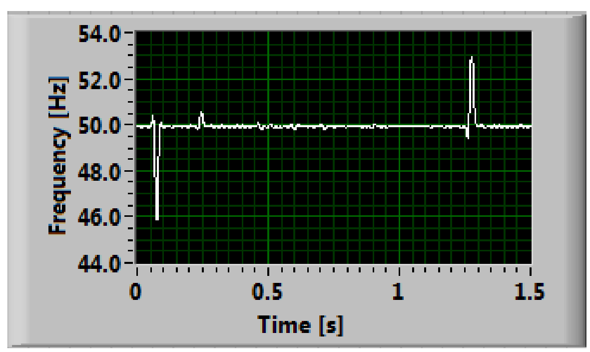

Fig.16. Point on wave

5. CONCLUSION

First of all, the paper proves that virtual instrument represent a very useful tool for signal analysis. Virtual instrumentation refers the use a computer and dedicated input and output devices in order to simulate the characteristics and operating functions of a measurement instrument or data acquisition device. The advantage against the classical measurement systems is that this time all of the processing and analysis functions of measured values, the storage of this information and their transmission to the human user are made by computer and not by dedicated equipments. The software performs these functions in most of the cases and graphic user interface are used.

In the field of power system it can be easy implemented for measurements and monitoring the operating conditions. Graphical representations of different amounts are very intuitive for the user.

In this paper the virtual instrument is designed for voltage dip analysis. A mathematical signal generator is used to test the virtual instrument. It's observed that the results obtained for the voltage dip characteristics are those expected.

Afterwards, measurement values obtained from a 110/220 kV substation were introduced like input data for the virtual instrument. The analysis is realized considering the voltage dip characteristics proposed in the literature and the results are presented in the paper.

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