Measurement and recognition of events in low voltage networks by using 2-bit SDMM

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***Abstract* – This article is a detailed presentation of the VMPCalc ver. 2.1 software, which is used to support the single phase power analyzer VMP20. Also, it briefly describes the measuring method used in VMP20. Two very significant cases from the end of 2016 have demonstrated the effectiveness of programs VMPCalc ver. 2.1 and VMP20 in recognition, qualification and quantification of events in the electricity grid (EG). The software VMPCalc ver. 2.1 is the BSC thesis of the first author.**

***Key words*–VMP20, VMPCalc ver. 2.1, SDMM**

I. INTRODUCTION

The stochastic digital measuring method (SDMM) has been published nineteen years ago [1]. Using this method, twenty one years ago has been produced the first production instrument: the single phase power analyzer VMP20. Regarding its metrological performances, it is still very competitive [2], [3], [4]. However, development in software methods and tools has significantly upgraded its applicability and actuality. VMPCalc ver.2.1, the central theme of this paper, is the third and most advanced version of the software for support. This program will be briefly described in this paper, with the emphasis placed on its actual applications in conjunction with the VMP20 instrument.

In the first case, the software VMPCalc ver. 2.1 and VMP20 have played a crucial part in a ruling in a dispute between a supplier and a user of some very sophisticated and expensive equipment within the warranty period. The supplier has acknowledged the inadequacy of the supplied version of the equipment, although he had previously claimed that the quality of the electricity is inadequate, and that the equipment is fine. The equipment simply did not tolerate short voltage dips, or activation of automatic restart (AR), in the framework of EN50160, to which it was required to.

In the second case, VMPCalc ver. 2.1 and VMP20 have proven the need to power sensitive and precise printing machines via UPS. Moreover, it was shown that the competent 20kV/0.4kV transformer station (TS) is connected to the same 110kV/20kV TS, where a third author has detected in 2008, by using the instrument VMP20 and a previous version of VMPCalc, an inadequacy of the quality of power suppled from the grid to a device for nuclear magnetic resonance (NMR), which caused its breakdown. It was concluded, that this 110kV/20kV TS does not provide adequate quality of power for highly sensitive and precise equipment.

Thanks to the VMP20 instrument and VMPCalc software, on the Department of Electrical Measurement of the Novi Sad Faculty of Technical Sciences already exists a respectable database of the quality of power supply from the public electricity grid in the city of Novi Sad and Bačka. In the examples shown, the expertizes where crucial in ruling in the disputes of order of 100 000 euros. Please note, that the instrument VMP20 and the software VMPCalc ver. 2.1 are fully a result of domestic development. They have enabled the research and better understanding of metrology problems in the public electricity grid, which has resulted in the development of new measurement methods and instruments [4], [5], [6].

II. SDMM METHOD

The key features of the 2-bit version of the SDMM method are very simple hardware and a very high sampling rate. Fig. 1 shows the basic schematic of measuring RMS voltage, current, electric power and energy - this is a measurement in the time domain.

Detailed theoretical and simulation analysis is given in [1] and [2], and its actuality is confirmed in [3]. Here we point out, that the method uses a 2-bit flash AD converter. The multiply and accumulate (MAC) operation is executed with only a few logic gates and an Up/Down counter. It is clear, that such a simple hardware implies a very small number of sources of systematic errors that are easily identifiable and their influence can be effectively suppressed [4].

Fig. 2. shows the basic schematic of measuring a single Fourier coefficient - the basic schematic of measuring in the frequency domain. Everything that is said for measurement in the time domain (Fig. 1), also applies to the frequency domain.

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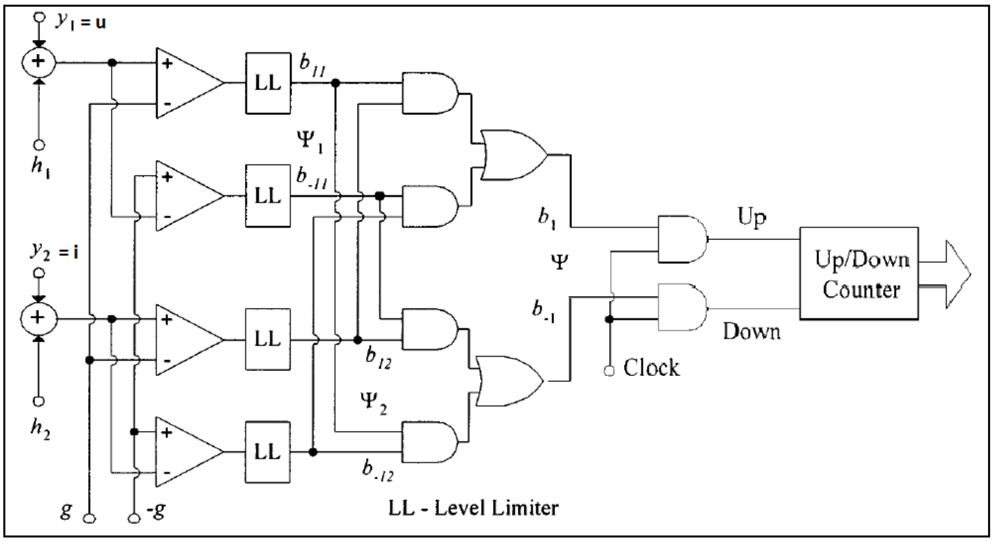

Fig. 1. Basic schematic of measuring RMS voltage, current, electric power and and energy-measurement in the time domain

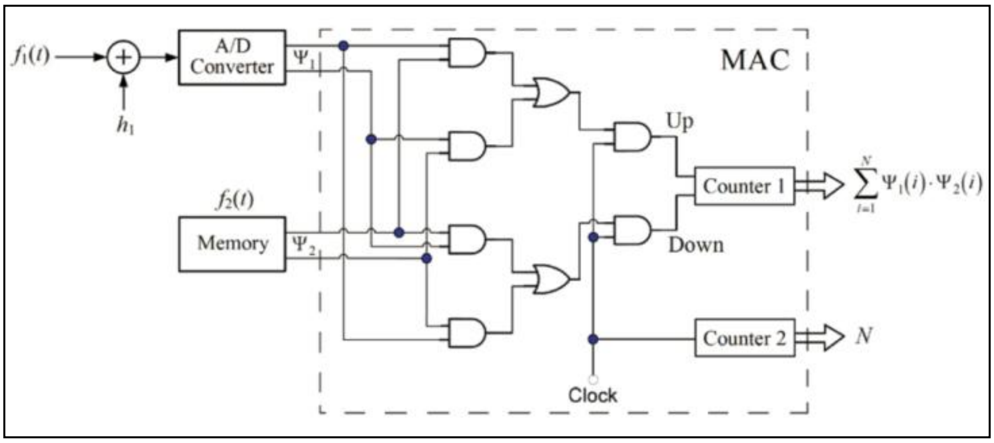

Fig. 2. Basic shematics of measuring a single Fouriere coefficient – measurement in the frequency domain

The time and frequency domains are completely equivalent [7]. In the frequency domain, it is possible to effectively measure very complicated electrical quantities, such as reactive power and energy [6].

The simple and very fast hardware of SDMM implies very reliable and accurate measuring, which was demonstrated during the years of implementation. To be able to carry out long-term, reliable and accurate expertizes, there was a need for a simple, robust and user friendly software. The developed software VMPCalc ver. 2.1 has expressed these required features.

III. The VMPCalc ver. 2.1 program

The VMPCalc ver. 2.1 program was developed on the Department of Electrical Measurement of the Faculty of Technical Sciences in Novi Sad by the author of this article. This is the latest version of the program, which began development in 2006. Over the years, the emergence of new needs in processing, new features and capabilities are added, and this trend will continue with all future versions.

The purpose of the VMPCalc ver. 2.1 program is the processing of data obtained by the VMP20 instrument, and their export from the database into a Microsoft Excel spreadsheet with charts.

The program, based on measurement data, calculates the following RMS values in a given time interval:

a) the reactive power (*Q*), the apparent power (*S*), the power factor (*cos φ*), the impedance (*Z*),

b) the mean, the minimum, the maximum, and the standard deviation of the:

- voltage (*U*) (*Usr Umin Umax Usdv* in V),
- current (*I*) (*Isr Imin Imax Isdv* in A),
- true power (*P*) (*Psr Pmin Pmax Psdv* in W),
- reactive power (*Q*) (*Qsr Qmin Qmax Qsdv* in VAr),
- apparent power (*S*) (*Ssr Smin Smax Ssdv* in VA),
- frequency (*F*) (*Fsr Fmin Fmax Fsdv* in Hz),
- power factor (*cos φ*) $(_{sr},\ _{min},\ _{max},\ _{sdv})$;
- impedance (*Z*) (*Zsr Zmin Zmax Zsdv* in Ω);

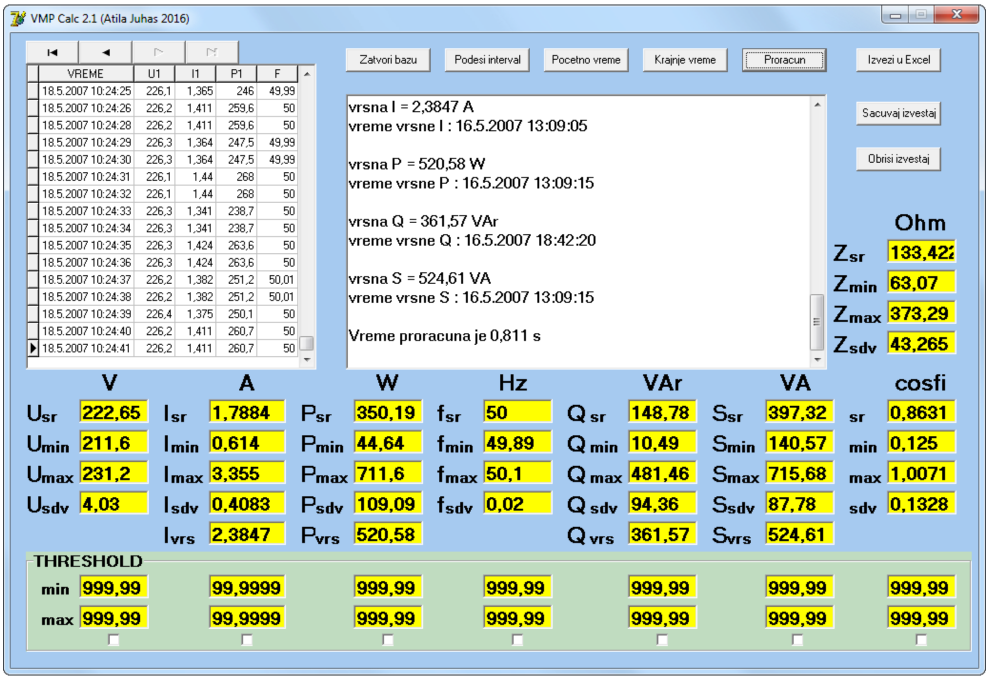

Fig. 3 VMPCalc ver. 2.1 user interface

c) the maximum average value in a fifteen minutes sub interval for the processing interval of the:

- true power (*Pvrs* in W),
- reactive power (*Qvrs* in VAr),
- apparent power (*Svrs* in VA),
- current (*Ivsr* in A).

Fig. 3 shows the user interface of VMPCalc ver. 2.1.

Below the title bar are the following commands:

„Otvori bazu“ – opens the database and performs a tabular presentation of the entire database in a window located on the left side.

„Pocetno vreme“ i „Krajnje vreme“ – set the time limits of the processing interval.

„Podesi interval“ – prepares the dataset of the set time interval for processing. After setting the interval, the name of the command changes to „Resetuj interval“, with which the interval boundaries can be returned to the initial state.

„Proračun“ – processes and displays the data, and generates the report in the right side frame.

„Izvezi u Excel“ – the dataset of the set interval is exported into an Excel spreadsheet.

„Sacuvaj izvestaj“ – saves the processing report as a text file.

„Obrisi izvestaj“ – erases the contents of the report frame.

The calculated values are displayed organized into columns under the displayed tables and reports.

Below these values, there is a frame with settings various threshold values. This can eliminate data from the dataset which are smaller than the minimum, or larger than the maximum threshold. After setting the threshold, the dataset for processing is prepared by clicking „Podesi interval“.

„Export to Excel“ option can function only if the computer is running the Microsoft Office software package.

IV. Examples of Measurement and Recognition of Events

The usage of VMPCalc ver. 2.1 has shown the real capabilities of the SDMM method in measurement of electrical quantities and recognition of events in the electrical grid from the perspectives of the distributors of electricity, and the consumers. Based on years of measurements performed in a large number of industrial consumers and power grid facilities in different locations, we made a selection of typical events or disturbances and faults, which we use to illustrate the capabilities of the SDMM method for their detection and identification.

Example 1: Detection of Voltage Drop and AR Activation

This example shows the detection of a voltage drop (short power interruption) and the activation of AR in one of the power phases.

Measurements were carried out using the single-phase instrument VMP20 at the pumping station in Kamendin. The three phase input voltages of the pump stations electric drive were recorded successively on three successive days.

In the morning of 07/17/2015, voltage in the phase T has within a time interval of 2 seconds dropped to 190.7V, which is well below the permissible. That means, there was a voltage drop.

As the voltage before and after this time period had the same value, it means that all the electric equipment at the facility was operating nominally before and after the voltage drop. This voltage drop has the typical picture of AR activation: when the AR is triggered, the voltage drops to zero.

Based on the expertise that follows, the activation time that the AR is set will be calculated.

Activation of the AR, when the voltage drops to zero is shown in Fig. 4.

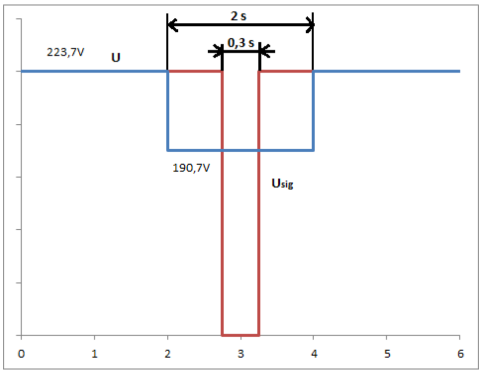

Fig. 4. Graphical representation of the medium voltage and voltage drop

DATUM	VREME	U1	I1	P1	F
17.7.2015	06:16:04	223,5	0,0000	0,042	49,99
17.7.2015	06:16:05	223,7	0,0000	0,042	49,99
17.7.2015	06:16:06	223,7	0,0000	0,042	49,99
17.7.2015	06:16:07	223,8	0,0000	0,042	49,99
17.7.2015	06:16:08	223,7	0,0000	0,042	49,99
17.7.2015	06:16:09	223,7	0,0000	0,042	49,99
17.7.2015	06:16:10	223,5	0,0000	0,042	49,99
17.7.2015	06:16:11	223,5	0,0000	0,042	49,99
17.7.2015	06:16:12	223,7	0,0000	0,021	49,99
17.7.2015	06:16:13	223,7	0,0000	0,021	49,99
17.7.2015	06:16:14	190,7	0,0000	3,208	50
17.7.2015	06:16:15	190,7	0,0000	3,208	50
17.7.2015	06:16:16	223,7	0,0000	0,042	50
17.7.2015	06:16:17	223,7	0,0000	0,042	50
17.7.2015	06:16:18	223,7	0,0000	0,021	49,99
17.7.2015	06:16:19	223,7	0,0000	0,021	49,99
17.7.2015	06:16:20	223,7	0,0000	0,042	50
17.7.2015	06:16:21	223,7	0,0000	0,042	50
17.7.2015	06:16:22	223,7	0,0000	0,042	50
17.7.2015	06:16:23	223,7	0,0000	0,042	50
17.7.2015	06:16:24	223,7	0,0000	0,021	49,99
17.7.2015	06:16:25	223,7	0,0000	0,021	49,99

Fig. 5. Voltage drop in Excel spreadsheet

Before and after the voltage drop, the measured voltage was 223.7V (shown in Fig. 5). During the two second time interval, when the voltage drop occurred, the voltage value measured by the instrument was 190.7V. Change in mean values of RMS voltage during this period, compared to the previous and next interval, was: $\Delta\overline{U} = 33V$. Let's assume, that the time of switching the AR (l) is less than 2 seconds. It is then, based on Fig. 4,

$$l = 0.295s \approx 0.3s \qquad (1)$$

The analysis shows that the time of activation of the AR is 0.3s, which is equivalent to the default setting. By checking in the relevant electrical utility company, it was found that on 17/07/2015, in the transmission line, which supplies power to the pumping station, at 06:16:14 hours, an AR activation occurred for a period of 0.3s. This confirmed the correctness and accuracy of the recording, as well as the assumptions about the activation of the AR.

Measurements were made from 07/16/2015 15:16:42 in the same way as the measurement of the previous two phases. Table 1 shows the VMPCalc generated report.

In the selected time period (**07/16/2015 15:16:42**) to (**07/17/2015 20:42:51**) there are **102842** records		
Usr	**223.98**	**V**
Umin	**190.7**	**V**
Umax	**228**	**V**
Udev	**1.97**	**Hz**
fsr	**50**	**Hz**
fmin	**49.78**	**Hz**
fmax	**50.08**	**Hz**
fdev	**0.02**	**Hz**
Processing time	**0.355**	**s**

Table 1. VMPCalc report

It was found that the voltage is within legal boundaries except for a time of 2 seconds, on 17/07/2015. from 06:16:14 to 06:16:16 when the voltage has dropped to 190.7V, which is below the legal limit. At that time the activation of the AR was detected at a higher voltage level for a period of 295ms, which is about the default time of 300ms.

Since this is the only irregularity during the recording, from the standpoint of the power supply company, this is a regular event in the broader sense, so that the power supply voltage is within the legal limits of the EN 50160 standard.

EXAMPLE 2: DETECTION OF OVERVOLTAGE AND FREQUENCY DIP USING THE VMP20 INSTRUMENT

This example shows the detection of overvoltage and frequency dip in an industrial facility.

The measurements were carried out on the low-voltage power supply line to a printing office in Novi Sad from 05/07/2016 at 22:21:50 to 08/07/2016 at 09:37:45 hours. All three phases were measured successively.

On 07/07/2016 at 14:59:10 and 14:59:11 in phase T, a voltage of 238.1V was detected for a total duration of 2 seconds. The graph of the event is shown on Fig. 6. The table view of data during the overvoltage is shown on Fig. 7.

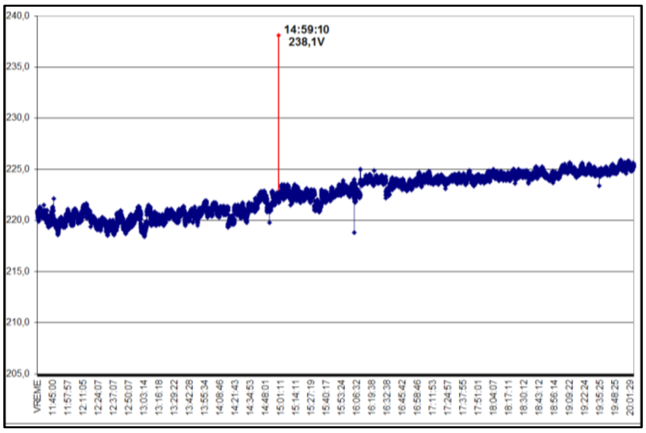

Fig. 6. Overvoltage in phase T

DATUM	VREME	U1	I1	P1	F
7.7.2016	14:59:04	222,3	0,0000	0,042	49,98
7.7.2016	14:59:05	222,3	0,0000	0,042	49,98
7.7.2016	14:59:06	222	0,0000	0,021	49,99
7.7.2016	14:59:07	222	0,0000	0,021	49,99
7.7.2016	14:59:08	222,1	0,0000	0,021	49,98
7.7.2016	14:59:09	222,1	0,0000	0,021	49,98
7.7.2016	14:59:10	238,1	0,0000	0	49,99
7.7.2016	14:59:11	238,1	0,0000	0	49,99
7.7.2016	14:59:13	222,1	0,0000	0,021	49,99
7.7.2016	14:59:14	222,1	0,0000	0,021	49,99
7.7.2016	14:59:15	222,1	0,0000	0,021	49,99
7.7.2016	14:59:16	222,1	0,0000	0,021	49,99
7.7.2016	14:59:17	222	0,0000	0,021	49,99
7.7.2016	14:59:18	222	0,0000	0,021	49,99

Fig. 7. Table with data in phase T during overvoltage

The voltage of phase T has in 14:59:10 hours jumped to 238.1V for 2 seconds. As the voltage before and after the jump was 222.1V, it is assumed that the overvoltage was caused by a voltage surge within the time interval. This voltage surge is a pulse of random nature: its duration and amplitude are unknown. It is necessary to analyze the characteristics of this voltage pulse, to determine whether the change in the voltage is in accordance with the regulations.

Since the pulse is of random nature, it can be assumed that it has a Gaussian distribution with standard deviation *σ*. Then, this voltage pulse is defined by

$$U_{eff}(t) = U_m \cdot p(t) \qquad (2)$$

$$p(t) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{t^2}{2\sigma^2}} \qquad (3)$$

$$\Phi(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{\tau^2}{2\sigma^2}} d\tau \qquad (4)$$

$$\Phi(-\frac{T}{2}) - \Phi(\frac{T}{2}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\frac{T}{2}}^{\frac{T}{2}} e^{-\frac{\tau^2}{2\sigma^2}} d\tau \qquad (5)$$

$$\Phi(3\sigma) - \Phi(-3\sigma) \approx 0.9973 \approx 1 \qquad (6)$$

On the basis of (6) it can be assumed that the practical duration of the Gaussian pulse is

$$T = 6\sigma \, . \qquad (7)$$

The mean of the RMS value of the Gaussian shaped voltage pulse is, based on (5), (6) and (7), is

$$\overline{U_{eff}} = \frac{U_m}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} p(t)dt = \frac{U_m}{T} \qquad (8)$$

The maximum value of the RMS voltage of the pulse is at the moment *t*=0, and then, based on (2), (3) and (7) is

$$U_{\max} = U_{eff}(0) = \frac{U_m}{\sigma\sqrt{2\pi}} = \frac{6 \cdot U_m}{\sqrt{2\pi} \cdot T} \qquad (9)$$

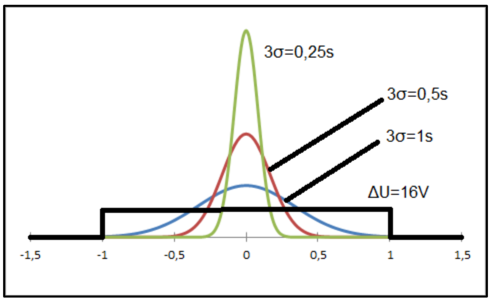

Fig. 8. Graphs of the mean value of the overvoltage and voltage pulse

Because the method for measuring the RMS value of the voltage using the SDMM method, implemented in the VMP20, we know that the measured RMS value is correct, regardless of the waveform of the measured voltage. Fig. 7. shows that the value of the voltage before and after the voltage jump is $U = 222.1$V. Thus, the measured mean value of the RMS value of the voltage jump during this period was

$$\overline{\Delta U_{eff}} = 238.1V - 222.1V = 16V \qquad (10)$$

The measured duration of the voltage jump is $T_m = 2s$, what is shown in the table on Fig. 7. Let's assume, that the duration of the voltage pulse is $T = 6\sigma$ and $T \le T_m$. Based on (8) and (10) is obtained

$$\overline{\Delta U_{eff}} = \frac{\overline{U_{eff}} \cdot T}{T_m} = \frac{U_m}{T_m} = 16V \qquad (11)$$

Based on (11) is obtained

$$U_m = 32Vs \qquad (12)$$

If we accept the above assumptions, it is possible to determine the amplitude of the Gaussian pulse as a function of the pulse duration (9).

Let's consider a few cases for the pulse duration *T*:

i) If $T = 2s$, based on (9) follows, that

$$U_{\max} = \frac{96}{\sqrt{2\pi}} V = 38.3V ,$$

and then the maximum value of the overvoltage is

$$U = 222.1V + 38.3V = 260.4V .$$

This is the best possible case for a realistic assumption, such as the Gaussian shape of the overvoltage pulse.

ii) If $T = 1s$, then

$$U_{\max} = \frac{192}{\sqrt{2\pi}} V = 76{,}6V ,$$

and then the maximum value of the overvoltage is

$$U = 222.1V + 76.6V = 298.7V .$$

iii) If $T = 0.5s$, then

$$U_{\max} = \frac{384}{\sqrt{2\pi}} V = 153{,}2V ,$$

and then the maximum value of the overvoltage is

$$U = 222.1V + 153.3V = 375.3V .$$

Looking at the voltage surge based on i), ii) and iii), it can be seen, that this is a typical short-term ground fault in one of the remaining two phases at a higher voltage level.

Fig. 9 shows the graph of the frequency drop detected.

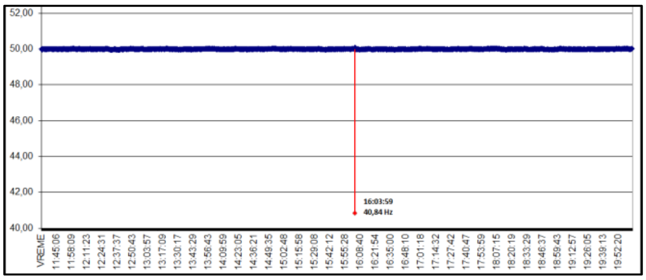

Fig. 9. Graph of the frequency drop in phase T

On 07/07/2016 at 16.03:59 the detected frequency was 40.84 Hz, what is outside of the regulated boundaries. Since the value of the voltage was the same before and after this event, the frequency drop in a 1 second period is an indication of a transitional regime in the network and requires a separate analysis, if it had an impact on the operation of the machines in the printing facility.

V. Discussion

In the two examples of expert application given above, the combination of the power analyzer VMP20 with a personal computer running the VMPCalc ver. 2.1 program has proven to be extremely robust, reliable, accurate and precise. It allows further investigations of the behavior of the public electric grid. Just recently, it has pointed out a possibility of a construction of a new, extremely accurate and precise electricity meter [4]. The design applies a 2-bit SDMM, and its functioning is based on the statistical data of the behavior of the public electric grid. The simple, robust, reliable and user friendly software VMPCalc ver. 2.1, which uses current software methods and tools, allows easy handling of the above combination, easy access and analysis of measurement data. It provides a very large number of derived parameters of power and generates very transparent reports in two levels:

a) first level - a simple and very informative document, where at first glance can be seen if the power supply is in accordance with EN 50160,

b) second level - in which it is extremely simple and intuitive to find the parameter that is not in accordance with EN 50160 and may be precisely quantified.

VI. Conclusion

The paper describes the VMPCalc ver. 2.1 software, which supports the VMP20 single-phase power analyzer. The paper describes its structure and basic functions, and shows its practical application in two current and very important cases. It is simple, robust, reliable and user friendly. It allows not only commercial expertise in the public power grid, but it speeds up very time-consuming and complex statistical research of behavior of the public electrical grid, and significant research of the behavior of measuring equipment.

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