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Investigation of Harmonic Effects on Electrical Energy Measurement Devices Operations

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ABSTRACT

One of the power quality disturbances is harmonics which have a lot of disadvantages in power systems. One of the susceptible devices to voltage and current harmonic disturbances is energy measurement device (EMD). Therefore, their appropriate operations in harmonic conditions should be ensured. In this paper, a sample EMD is tested by constructing a sample tester. To investigate harmonic effects on EMD operation, interface software between tester and computer is written in Visual C which using this program, each waveform can be generated and applied to tester. In this study, different waveforms with various harmonic orders and amplitudes are generated and implemented on tester. To be ensured of harmonic content of voltage and current waveforms (to apply for EMD), spectrum frequency of these waveforms have been evaluated. For each test, power values measured by EMD have been obtained and after that it has been compared with real value. Therefore, from these two values, error of EMD can be specified in different harmonic conditions.

KEY WORDS: Power Systems Harmonics, Electrical Energy Measurement Devices and Measurement Error.

I. INTRODUCTION

Harmonics in distribution systems cause loss generation, inconvenient impact on relays operation (inappropriate operation or not operating when needed), and error in measurement devices (such as voltage, power and current) and so on which should be eliminated. Events such as switching in AC/DC converters, transformers B-H characteristics, electrical machines B-H characteristics which are existed in industrial factories are important sources to generate harmonics. EMDs operations can be affected in harmonic circumstances regarding their internal structure and their calculating algorithm. The question which comes to mind is that how in a real situation, EMDs operation can be evaluated in harmonic conditions and also whether these measurement devices are reliable enough or not. Moreover, there is a direct relation between accurate operations of devices in measuring electrical energy and economical cost in power networks. Therefore, their operations in harmonic conditions should be investigated. Different methods have been proposed to test power systems devices. One of the practical methods presented in most papers is using a digital simulator. Different waveforms can be generated by this simulator and then they can be implemented to relays in order to analyze its operation. [1-5]. Relay can be evaluated by two tests which are closed loop (real time) and open loop which in latter test, getting feedback from output is not possible [6-10].

In former test, a power system is simulated using power systems analyzing software's (EMTP, EMTDC and etc) and its results are implemented on relay. One of susceptible devices to voltage and current harmonic disturbances are EMDs. Nowadays, digital EMDs due to increasing microprocessor power and high accuracy in signal processing are being replaced with old and analog EMDs so fast. In distribution systems, EMDs are electrical energy measurement devices consumed by customers. EMDs have error in measuring energy in harmonic condition considering their structure and various algorithms. EMDs accurate operations are of great importance along with considering their variety. Consequently, an analyzer system to test their operations in harmonic conditions seems to be essential by which different waveforms with different harmonics are implemented to EMD and measurement error is determined in each case.

EMDs were electromechanical before which are still used by most customers. By adventure of electronic devices and microprocessors, digital devices are presented to energy market. In digital devices, electrical energy is calculated by sampling from voltage and current which can cause some measurement errors if there are harmonics in voltage and current waveforms. Considering the fact that sinusoidal function is non-linear. So, electrical energy will be a non-linear function. Hence, regarding these devices limitation in electrical energy measurement in distribution companies, their testing is proposed. In this paper, a system is designed and constructed to investigate voltage and current harmonics impacts on EMDs operations. Different harmonics are implemented to EMD and error values are obtained for each case. The structure of this paper is as follow: in part III, an introduction of SHEM switching method is presented. Equation between THD and m for different inverter operational modes is obtained in IV. Finally in part V, conclusion is given.

II. INTRODUCTION OF SHEM SWITCHING METHOD

To evaluate EMD error in harmonic condition, real value of measured energy by EMD is required. Hence, this value should be obtained from specified equations. If current or voltage waveforms be non-sinusoidal, then power factor and power calculations face some difficulties. Because, many simplifications considered for AC analysis cannot be used and applied in this case. Three standard parameters related to power can be used which are defined as follow:

1) Apparent power (S): obtained from multiplying RMS voltage value by current

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2) Reactive power (Q): imaginary part of apparent power
3) Active power (S): Real part of apparent power

When voltage (current) is sinusoidal, active power can be expressed as following equation:

$$P = \frac{V_1 I_1}{2}\cos\theta_1 = V_{1rms} I_{1rms}\cos\theta_1 \tag{1}$$

Non-sinusoidal periodic voltage and current can be written as:

$$V(t) = V_{m1}\sin(\omega t) + V_{m2}\sin(2\omega t) + \ldots + V_{mn}\sin(n\omega t) \tag{2}$$

$$I(t) = I_{m1}\sin(\omega t + \theta_1) + I_{m2}\sin(2\omega t + \theta_2) + \ldots + I_{mn}\sin(n\omega t + \theta_n) \tag{3}$$

For these waveforms, active power can be determined by integrating from instantaneously power as:

$$\begin{aligned} P &= \frac{1}{T}\int_0^T V(t)I(t)dt \\ &= \frac{V_{m1}I_{m1}}{2}\cos\theta_1 + \frac{V_{m2}I_{m2}}{2}\cos\theta_2 + \ldots + \frac{V_{mn}I_{mn}}{2}\cos\theta_{n1} \end{aligned} \tag{4}$$

According to (4), active power will be equal to zero if voltage and current component in each harmonic or one of them be zero. Reactive power can be calculated as:

$$Q = \frac{V_{m1}I_{m1}}{2}\sin\theta_1 \tag{5}$$

Determination of P and S values is so important. Because, P is consumed energy value and S is defined as required capacity of power system in order to transfer P. As a result, Q is not actually so helpful solitary. Engineers pay attention to reactive power value in harmonic condition. Some researchers recommended that Q is conservative reactive component whereas a new parameter should be defined for non-conservative components. This new component is called distortion power (D). By this definition, Q includes sum of reactive power value in each frequency and D is determined by multiplying voltage and current values in different frequencies and it does not have an average value. Therefore, after determinations of S, P and Q values, D can be calculated as:

$$D = \sqrt{S^2 - P^2 - Q^2} \tag{6}$$

III. INTRODUCTION OF DIFFERENT SECTIONS OF CONSTRUCTED TESTER

Block diagram of EMD tester in harmonic conditions is shown in Fig. 1.

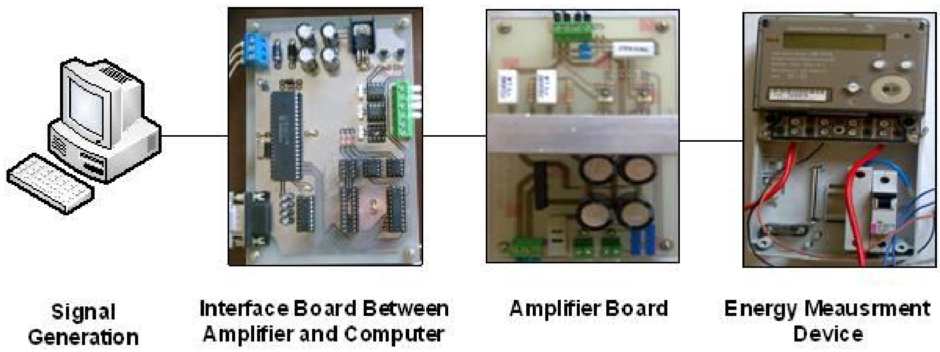
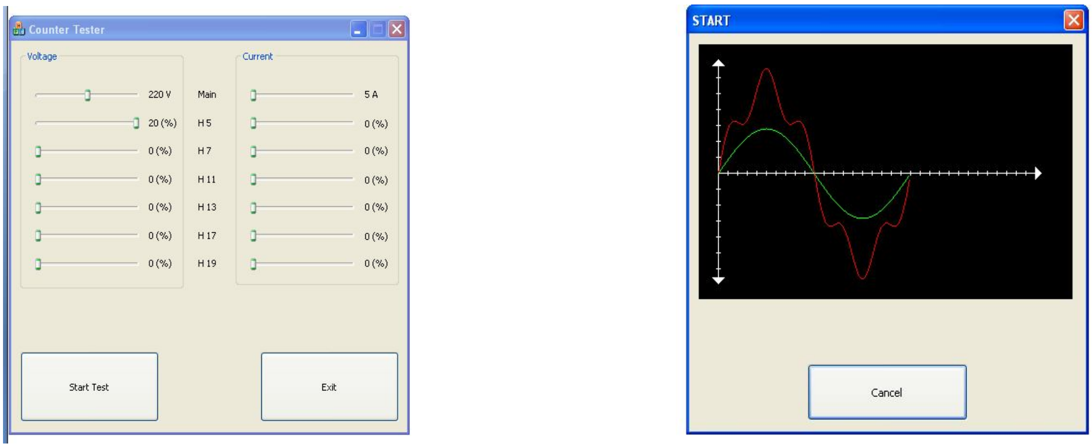


Fig. 1: block diagram of EMD tester inharmonic condition

In this figure, first, test signals which should be applied to EMD are created by software. This program schematic is shown in Fig. 2a by which each harmonic amplitude can be determined. In the power system, considerable harmonics are 6n±1; n=1, 2,…,∞. Output of this program is specified in Fig. 2b. This figure includes 5th harmonic with amplitude of 20% fundamental component amplitude. Then, these signals are sent to voltage and current amplifier board which is one of the key sections of this tester.

In this paper, signals with low amplitude and power are amplified and reached to a level at which they can be applied to EMD. The inputs of EMDs are voltage and current. Range of input voltage is 220 V and current can be varied up to 15 A. Hence, amplifier part should be able to create voltage and current with desired harmonics from 6n±1; n=1, 2,…, ∞ in power systems.



(a) (b)

Fig. 2: a) Interface software to set the harmonic coefficients b) Generated voltage and current waveform

IV. EXPERIMENTAL RESULTS

To investigate experimental results, a sample digital EMD is used to test. These tests are conducted under different voltage and current harmonic conditions.

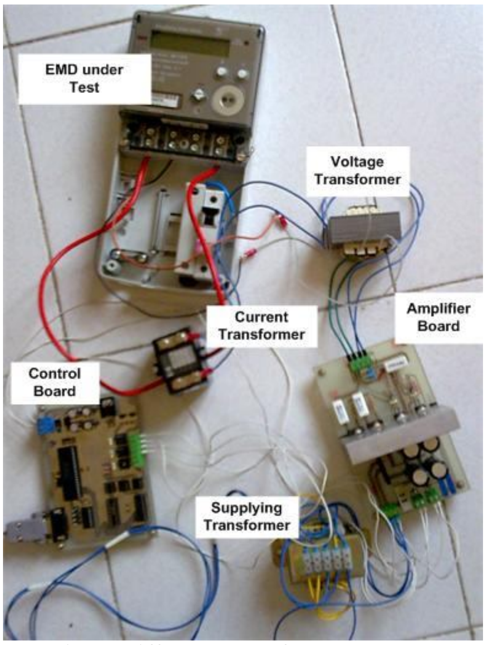


Fig. 3: Different parts of EMD tester

These tests are listed in table.1 in which harmonics up to 19th order are considered. It should be noted that test number can be so high (this test can be done so many times) but some of them are carried out in this study. Amplifier transformer frequency response is one of the notes which should be taken into account in amplifier designing part. In other words, it should be in a way that it can flow different frequency spectrums through itself. In this tester, a transformer with iron core is used which is able to flow 19th harmonic without disturbing waveform. However, at higher harmonic orders, transformer will be a little hot which should be cooled by a fan. Current generation is done using a current transformer or a CT. Different section of this tester is shown in Fig. 3.

According to obtained results from test, harmonic effects on electrical energy measurement can be evaluated. For various cases, different harmonics are added to fundamental component of voltage and current and then these signals are applied to EMD.

In these tests, current and voltage fundamental component amplitudes are respectively 2 A and 220 V. Nevertheless, they can be changed up to 15 A and 240 V. The case at which there is no harmonic in current and voltage signals is considered as reference power value measured by EMD which is equal to 379 W according to Table.1. Table results show that voltage and current values measured by EMD are different from previous values by adding voltage and current harmonics. For instance, for test number I_1, I_5, I_7, I_{11} and I_{13} are respectively equal to 10, 7, 5 and 3 percents of current fundamental component amplitude and EMD voltage has no harmonics. Measured power value is about 404 W which in comparison with reference value (379 W) it has about 25 w or 66% error. Error value can be calculated as:

$$K_{error} = \left| \frac{404 - 379}{379} \right| \times 100 = 6.6\% \tag{7}$$

Table. 1: Different done tests on the EMD and their results

THD (%) (Mode I)	Measurement Value			Test Current							Test Voltage							Calculated Power	Error (%)
	V_o	I_o	P_o	I_1	I_5	I_7	I_{11}	I_{13}	I_{17}	I_{19}	V_1	V_5	V_7	V_{11}	V_{13}	V_{17}	V_{19}		
509.37	221.4	1.9	379	100	0	0	0	0	0	0	100	0	0	0	0	0	0	379	0
338.7	222.2	1.9	398	100	0	0	0	0	0	0	100	20	0	0	0	0	0	379	4.8
266.47	220.9	2.1	451	100	20	0	0	0	0	0	100	20	0	0	0	0	0	394.16	12.6
223.66	220	2.1	404	100	20	0	0	0	0	0	100	0	0	0	0	0	0	379	6.2
194.27	221.4	2.1	411	100	10	10	10	0	0	0	100	10	10	10	0	0	0	390.37	5
172.22	220	1.9	385	100	0	0	0	0	0	0	100	5	5	5	5	0	0	379	1.6
154.74	222.2	2	417	100	5	5	5	5	0	0	100	5	5	5	5	0	0	382.79	8.2
140.38	225.2	2.5	536	100	20	20	20	20	0	0	100	20	20	20	20	0	0	439.64	18
127.26	221.5	2.1	408	100	0	20	0	0	0	0	100	0	0	0	0	0	0	379	7.1
116.79	223.5	2	404	100	0	0	0	0	0	0	100	0	20	0	0	0	0	379	6.2
107.46	221.5	2	404	100	10	7	5	3	0	0	100	0	0	0	0	0	0	379	6.2
98.51	220.5	2	407	100	0	0	0	0	0	0	100	10	7	5	3	0	0	379	6.9
90.89	219.5	1.8	357	90	0	0	0	0	0	0	100	0	0	0	0	0	0	379	6.2
83.4	221	1.8	364	90	0	0	0	0	0	0	100	10	0	0	0	0	0	379	4.1
76.37	222.3	1.8	360	90	10	0	0	0	0	0	100	10	10	0	0	0	0	382.79	6.3
70.26	222.6	1.8	367	90	10	0	0	0	0	0	100	10	10	10	0	0	0	382.79	4.3
63.94	222.8	1.8	370	90	10	0	0	0	0	0	100	10	10	10	10	0	0	382.79	3.5
57.43	220.7	1.8	364	90	10	0	0	0	0	0	100	0	0	0	10	0	0	379	4.1
51.5	221	1.8	357	90	0	0	0	0	0	0	100	10	0	0	0	0	0	379	6.2
45.6	221	1.8	351	90	10	0	0	0	0	0	100	0	0	0	0	0	0	379	8
90.89	219.9	1.8	360	90	10	10	0	0	0	0	100	0	0	0	0	0	0	379	5.3
83.4	221.4	1.8	370	90	10	10	10	0	0	0	100	0	0	0	0	0	0	379	2.4
76.37	219.8	1.8	370	90	10	10	10	10	0	0	100	0	0	0	0	0	0	379	2.4
70.26	219.2	1.9	364	90	10	10	10	0	10	0	100	0	0	0	0	0	0	379	4.1
63.94	219.4	1.8	367	90	0	0	0	0	0	20	100	0	0	0	0	0	0	379	3.3
57.43	219.5	1.9	364	90	0	0	0	20	5	0	100	0	0	0	0	0	0	379	4.1
51.5	219.5	2	370	90	10	10	10	10	10	10	100	0	0	0	0	0	0	379	2.4

Equation (4) can be rewritten as (8). Active power consists of two parts: first part Pr which is related to fundamental component active power and second part Ph which is related to harmonic component active power:

$$P=\overbrace{\frac{V_{m1}I_{m1}}{2}\cos\theta_1}^{P_r}+\overbrace{\frac{V_{m5}I_{m5}}{2}\cos\theta_5+\frac{V_{m7}I_{m7}}{2}\cos\theta_7+\ldots+\frac{V_{m,6n\pm1}I_{m,6n\pm1}}{2}\cos\theta_{6n\pm1}}^{P_h}\quad n=1,2,\ldots,\infty \tag{8}$$

For the case that 5th, 7th, 11th and 13th harmonic amplitude in voltage and current waveforms is 20% of voltage and current fundamental component amplitude (test number 8), active power value can be written as:

$$P=\underbrace{1\cos\theta_1}_{P_r=379W}+0.04\cos\theta_5+0.04\cos\theta_7+0.04\cos\theta_{11}+0.04\cos\theta_{13} \tag{9}$$

This equation includes two active power parts: fundamental component active power which is equal to 379 W and harmonic component active power which will be equal to:

$$P_h=0.16P_r=0.16*379=60.64\ W \tag{10}$$

Considering that θ_5 to θ_{13} angels are almost close to zero. Therefore, total power calculated from this equation in this case is:

$$P_{total}=P_h+P_r=60.64+379=439.64\ W \tag{11}$$

Whereas total power measured by EMD according to Table. 1 is equal to 536 W. So, EMD error value is calculated as:

$$K_{error}=\frac{536-439.64}{536}\times100=17.97\% \tag{12}$$

This is relatively high value. This error value which is difference between real value and measured value by EMD can be calculated for each case which is presented in last column of Table. 1. Although error value is so high in test number 8, these harmonics may not be existed in network. If mentioned harmonic amplitude is decreased from 20% to 5%, then measured power by EMD is 417 W and calculated power is 382.79 W. consequently, error value will be decreased from 17.97% to 8.2%. According to results of Table.1, if there is harmonic in voltage or current, there will be error in measured power value. But the point is that, if both signals contain harmonic, error value will be significantly increased. For instance, two tests of 6 and 7 are studied. At case 7 in which both voltage and current signals contain harmonics, error value is 8.2%. Nonetheless, at case 6 which only voltage signal contains harmonic, error value is 1.6%. As a result, latter case has less error value; however it is still considerable.

V. INVESTIGATIONS OBTAINED WAVEFORMS FROM TESTS

Voltage waveform measured by oscilloscope is plotted in Fig. 4. It is expected that this waveform contains 5th, 7th, 11th and 13th harmonics about 10% in voltage. To prove this, frequency spectrum obtained from measured data and PSpice software is plotted in Fig. 5.

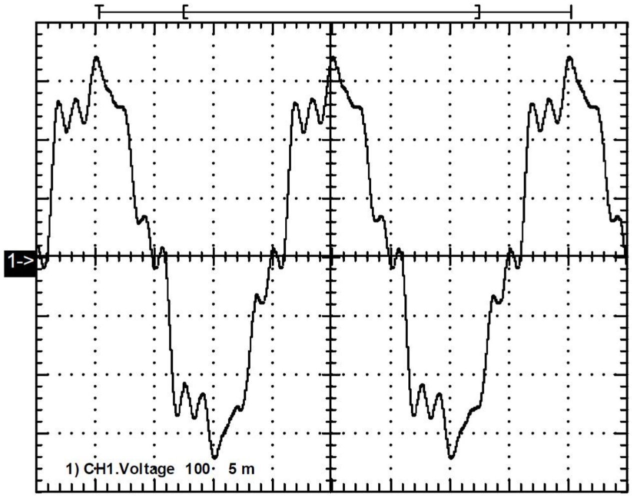


Fig. 4: Tester output voltage (to EMD voltage supply) with 10% of 5th,7th, 11th and 13th harmonics

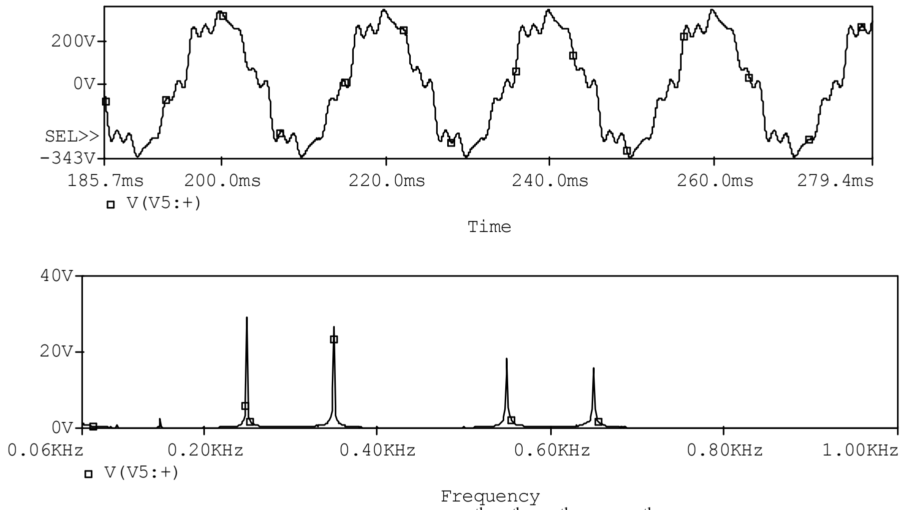


Fig. 5: Tester output voltage (to EMD voltage supply) with 10% of 5th, 7th, 11th and 13th harmonics and its spectral frequency obtained using PSpice software

This waveform has 5th, 7th, 11th and 13th harmonics in voltage. It verifies that generated waveform can be used to test EMD due to its high efficiency. Current waveform which contains 20% harmonic of 13th and 5% of 17th harmonic is shown in Fig. 6.

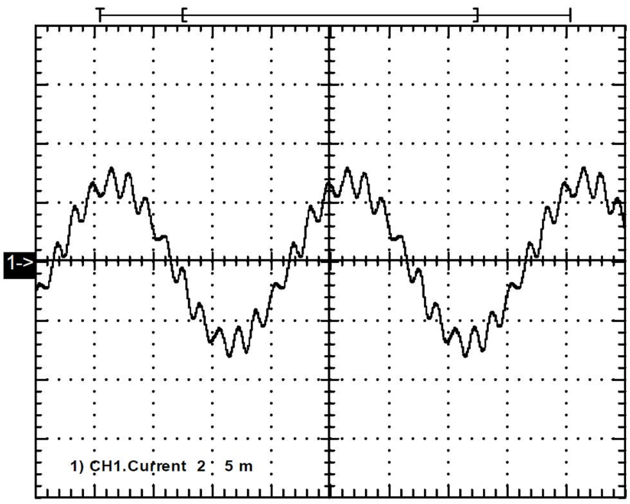


Fig. 6: Tester output current (to EMD current supply) with 20% of 13th and 5% of 17th harmonic

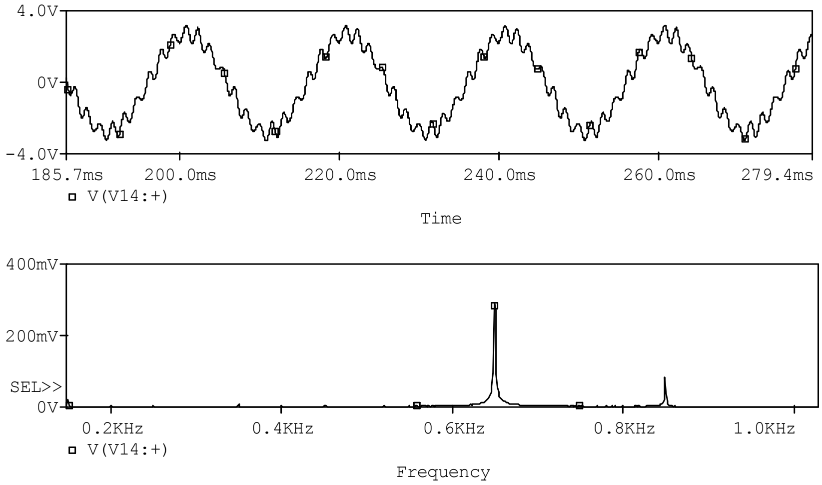


Fig. 7: Tester output current (to EMD current supply) with 20% of 13th and 5% of 17th harmonic and its spectral frequency obtained using PSpice software

In this case, voltage is sinusoidal. Also, frequency spectrum for this case is plotted in Fig. 7. According to this figure, firstly, there are only 13th and 17th harmonics in output current waveform. Secondly, 17th harmonic amplitude is approximately 25% of 13th harmonic amplitude. To show more efficiency, number of existed harmonics in current waveform is increased. For 5, 7,11,13,17 and 19 harmonics with the same amplitude of 10%, this waveform is measured in Fig. 8. According to frequency spectrum shown in Fig. 9, there are only mentioned harmonics in the output.

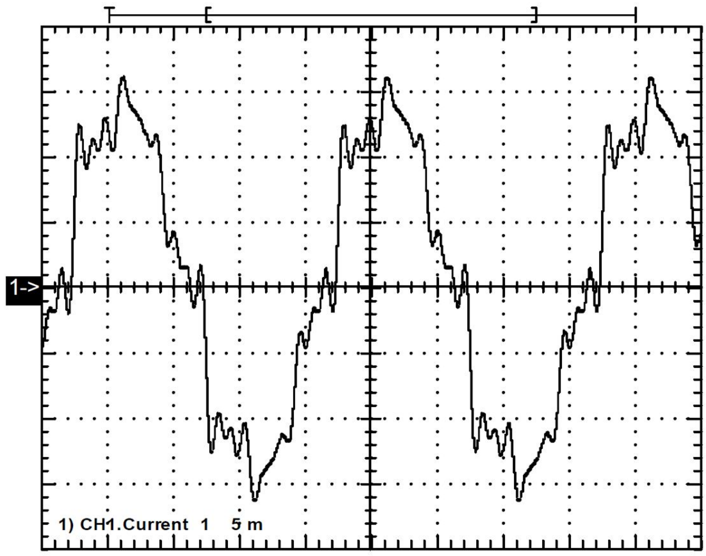


Fig. 8: Tester output current (to EMD current supply) with 10% of 5th,7th, 11th, 13th, 17th and 19th harmonics

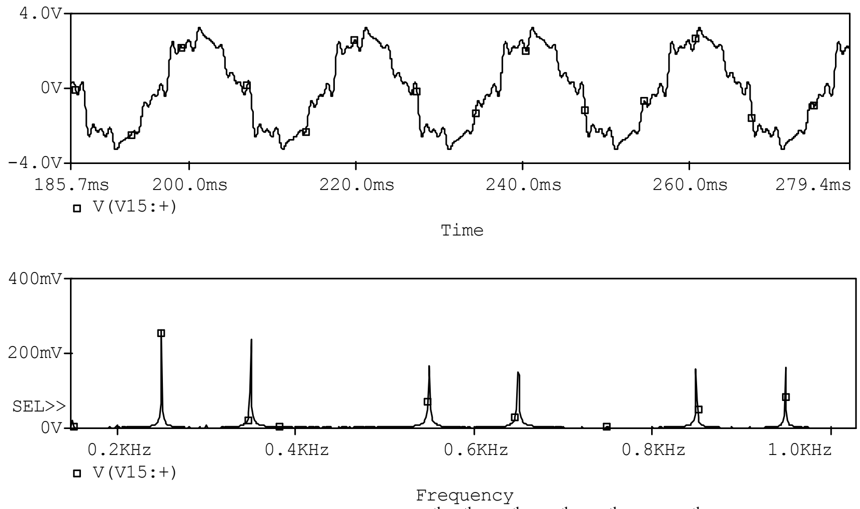


Fig. 7: Tester output current (to EMD current supply) with 10% of 5th,7th, 11th, 13th, 17th and 19th harmonics and its spectral frequency obtained using PSpice software

VI. CONCLUSION

In this paper, harmonic effect on EMD operation has been investigated. For this purpose, a tester has been designed and constructed. Different voltage and current waveforms with various harmonic amplitudes and orders have been applied to EMD by this tester and a program written in Visual C and measure values have been obtained. To verify its accurate operation created voltage and current harmonics, frequency spectrum for several cases have been obtained by measure values and PSpice software. Obtained results have shown that waveforms had relatively good quality in order to test EMDs. To better comparing the values and also to evaluate EMD operation in harmonic condition, measured value by EMD in sinusoidal current and voltage with 220 V and 2 A amplitudes has been considered as reference value and obtained values have been compared with this value. Results have shown that EMD in harmonic conditions has error and this error value depends on harmonics amount. Another important result obtained in this study is that there is relatively high error when both voltage and current signals contain harmonic.

VII. REFERENCES

[1] M. Kezunovic, "Digital simulator performance requirements for relay testing," IEEE Trans. Power Delivery, vol. 13, pp. 78–84, Jan. 1998.

[2] M. Kezunovic et al., "Distance relay application testing using a digital simulator," IEEE Trans. Power Delivery, vol. 12, pp. 72–82, Jan. 1997.

[3] M. Kezunovic and Z. Galijasevic, "An advanced PC-based digital simulator for protective relay testing," in Proc. 2nd Int. Conf. Digital Power System Simulators-ICDS'97, Montreal, Canada, May 1997, pp. 9–14.

[4] M. Kezunovic, A. Abur, Lj. Kojovic, C. W. Foreman, and D. R. Sevcik, "DYNA-TEST simulator for relay testing—Part I: Design characteristics," IEEE Trans. Power Delivery, vol. 6, pp. 1423–1429, Oct. 1991.

[5] "DYNA-TEST simulator for relay testing—Part II: Performance evaluation," IEEE Trans. Power Delivery, vol. 7, pp. 1097–1103, July 1992.

[6] D. Jackominich, R. Krebs, D. Retzmann, and A. Kumar, "Real-time digital power system simulator design considerations and relay performance evaluation," IEEE Trans. Power Delivery, vol. 14, pp. 773–780, July 1999.

[7] O. Devaux, L. Levacher, and O. Huet, "An advanced and powerful real-time digital transient network analyzer," IEEE Trans. Power Delivery, vol. 13, pp. 421–426, Apr. 1998.

[8] M. Kezunovic, J. Domaszewicz, V. Skendzic, M. Aganagic, J. K. Bladow, and D. M. Hamami, "Design, implementation and validation of a real-time digital simulator for protective relay testing," IEEE Trans.Power Delivery, vol. 11, pp. 158–164, Jan. 1996.

[9] P. G. McLaren, R. Kuffel, R. Wierckx, J. Giesbrecht, and L. Arendt, "A real time digital simulator for testing relays," IEEE Trans. Power Delivery, vol. 7, pp. 207–212, Jan. 1992.

[10] M. E. Agudo,W. Young, B. Kasperek, and S. I. Thompson, "End-to-end relay tests use secondary injection," IEEE Comput. Appl. Power, vol. 13, pp. 32–37, July 2000.