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A novel interactive technique for load current harmonic reduction for any randomly utilized household equipment

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ABSTRACT

Sustaining a stable level of power quality in the localized network is a growing challenge due to the increased use of power electronics. This paper proposes a novel interactive technique that reads the load current according to the connected loads. Whenever equipment is started running, the system is immediately read the distorted current for three cycles. The fundamental current can be estimated according to the system acquired readings. This system subtracts this estimated fundamental current from the sensor current reader to extract the total harmonic currents. According to the total harmonic currents the system uses suitable switching frequency Fs and modulation index Ma for generating anti-current source inverter (CSI) pulse width modulation (PWM) signal. Complete and comprehensive comparison between the system laboratory measurements using the Calmet TE30 power analyzer and the simulation model are presented. These results confirmed significant agreements between the proposed model and actual measurements at different loads. Furthermore, current and voltage sensors accompanied with a microcontroller read the load current the system realization. Finally, the measured currents of different loads are almost typically confirmed with the power analyzer's results. The reduced harmonics currents of the implemented model display the system validation.

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1. INTRODUCTION

Residential buildings require good power quality constantly for healthy operation. The power quality definition is the combination of voltage quality and current quality [1]. Power quality issues get affected by several external and internal factors such as poor power factor, electrical harmonics due to nonlinear loads, voltage instability, and imbalance impact on the efficiency of electrical equipment. This has several consequences including higher energy usage and costs, higher maintenance costs, and equipment instability and failure. This in turn reduces the lifetime of the equipment [2]. Voltage, current, active, and reactive power, and harmonic content are the most important characteristics of power quality [3]. Harmonics are a common power quality distortion of recent years and has different distorting impacts in many different applications. Harmonics are not existing in the electrical power systems having linear elements fed by a source having pure sinusoidal waveform with fixed amplitude and frequency. Harmonics are the sinusoidal element with a frequency of a periodic waveform that is multiple integers of the fundamental power frequency. Harmonics appear in voltage and current waveforms because of power electronics equipment that draws current in a non-linear way [4], [5]. Various household equipment such as refrigerators, mixers, hand blenders, microwaves, computers, and lamps which act as non-linear loads are a source of harmonics. Harmonics have different impacts on the effective performance of these types of equipment. Faulty operations occur in electronic and sensitive devices. Overheating is one of the negative results of harmonics due to the high-frequency components, and also negatively affects and disrupts the normal operation of devices. Absolute harmonic distortion can be determined by current and voltage total harmonic distortion factor (THD_v, THD_i) respectively [6]–[8]. Thus, to improve the performance of the end-user equipment and also the overall power system the problems caused by harmonics should be eliminated.

A relevant literature review of the power quality which is being affected by different household equipment operating in secluded and cumulative is a point of concern. For better performance of the system, it is necessary to reduce harmonic pollution. Several techniques are used, such as the active filter, passive filter, and other approaches. Harmonics reduction and mitigation methods are considered in different ways in various studies as follow: Alkhalifah and Habiballah [9] use ABB software called "PQF sizing application" to provide a solution for reducing the harmonics in the system network using an active harmonics filter (AHF). Voltage distortions without the active filter were 14.5% and after using the active filter the distortions were 1.5%. Current distortions without the active filter were 45.4% and after using the active filter the distortions were 4.9%. The study in [10] is a prefiltering technique based on a double second-order generalized integrator with a prefilter. The THD reduction is from about 22 % to less than 4.2 %. The three-phase four-wire shunt active power filter (SAPF) was developed to reduce the harmonic currents generated by nonlinear loads also is used in [11]. Nababan *et al*. [12] showed that the voltage and current harmonics are reduced after the installation of the capacitor. Obeidi *et al*. [13] shows that the active parallel filtering technique is used to compensate for harmonic currents of the nonlinear loads connected to networks. Mahmoud *et al*. [14] illustrate that the shunt active power filter (SAPF) is used to mitigate system harmonics of the distorted voltage source for unbalanced and nonlinear loads. The THD of the source current is improved from 45.45% to 3.13% complying with the harmonic limits given in the IEEE 519-1992 and IEC 61000-4-7 standards. Karekar [15] studies the method to design the passive filter and its impact on efficiency and energy usage. Another paper studied the effect of using UPS for providing power during blackouts and they proposed APF for improving the performance of the UPS system [16]. Using an active power filter THD was reduced from 46% to 1.4%. The shunt active power filter strategies [17] were also used for eliminating the harmonics.

2. PROBLEM DEFINITION

Harmonics has become a common problem nowadays due to spreading of the modern electronic equipment such as computers, laptops, microwaves, refrigerators, and others These types of nonlinear loads generate harmonics that highlight the importance of researching or proposing harmonic reduction techniques. However, huge numbers of articles and projects are proposed for harmonics elimination or reduction, most of them either active or passive elements have been designed based on a specific harmonic order elimination. In another word, most of these researches had been offered alternatives based on the individual harmonic orders elimination. For instance, one can use a filter to cancel either the 3^{rd} order, the 5^{th} order, or to cancel both the 5^{th} and 7^{th} harmonic orders together, and so on. In this research, a proposal novel interactive technique for the harmonic elimination independently its harmonics orders. The proposed system will be discussed and explored in the following paragraphs.

3. HOME GRID-DEPENDENT HARMONICS

The home grid harmonics are due to any of the nonlinear loads that generate the voltage and current harmonics distortion. These loads are nonlinear due to the reactive components of their impedance. The high-quality sinusoidal waveform generated by electrical utilities is distorted by the harmonics generated by the increased use of nonlinear loads [18]. This arises because the impedance of the equipment is not constant. The impedance, in fact, changes during each sine wave. So, a nonlinear device is one in which the current is not proportional to the applied voltage. Mostly, this load is represented by the device containing power electronics, which can be found in rectification frontends in motor drives, transformers, fluorescent lamps, personal computers or office equipment, and household electrical appliances [19]. Modeling of different household equipment that represents several different loads has been studied and analyzed in [20]. The harmonic effects of these loads on the power system have been elaborated [21]. Laptops, microwaves, desktop PC, refrigerators, vacuum cleaners, hand blenders are the most dominant household equipment in this study. The implemented algorithms of these techniques concern some specific harmonic orders [22]. That limits these techniques' reduction levels. However, many harmonics elimination methods are available nowadays, this paper proposes a novel technique for eliminating the harmonics independently on their orders. This technique reads whatever the withdrawing current and then calculates the fundamental to be subtracted for obtaining the all-current harmonics. These harmonics are current source inverter (CSI) pulse width modulated to be injected as a harmonic's compensator as shown in Figure 1. Furthermore, the system simulation will be implemented by using Simulink/MATLAB package as illustrated in the next paragraph.

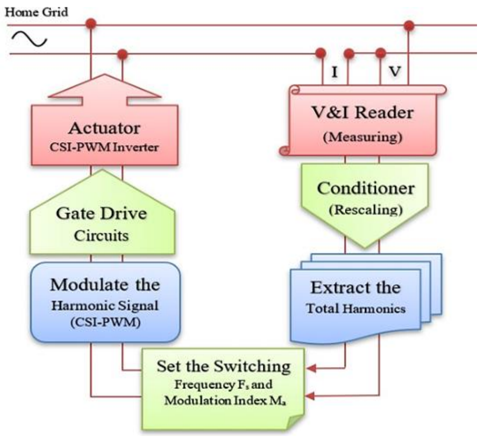


Figure 1. The system block diagram

4. THE PROPOSED MATLAB SYSTEM MODEL

The system model parameters are implemented in MATLAB/Simulink based on the real measured data which have been measured in the laboratory as shown in Figure 2. The model consists of a 220 V AC voltage source (grid) of 50 Hz frequency, network impedance, and the connected load. The implemented model is set to acquire the amplitude, frequency, and phase angle of a combination of home appliances currents. Voltage and current measurement tools have been used to measure voltage and current with the harmonic contents. Discrete total harmonic distortion blocks of the Simulink have been used to measure the total harmonic distortion (THD) of a periodic instantaneous voltage or current with the default parameters as shown in Figure 3.

However, the simulation voltage and the current measurements are achieved, the presented results concerned the detailed current results. This is due to significant current changes during the loads' operation. The instantaneous value of voltage and current can be expressed as:

$$v(t) = \sum_{n=1}^{\infty} v_n(t) = \sum_{n=1}^{\infty} \sqrt{2}\, v_n \sin(n\omega_1 t + \theta_n) \tag{1}$$

$$i(t) = \sum_{n=1}^{\infty} i_n(t) = \sum_{n=1}^{\infty} \sqrt{2}\, i_n \sin(n\omega_1 t + \delta_n) \tag{2}$$

where v_n and i_n are the instantaneous harmonic voltage and current of the order n, respectively with neglected DC component for simplicity. Also, ω_1 states the angular frequency of fundamental frequency. Lastly, the phase angles of voltage and current harmonics of the orders n are θ_n and δ_n, respectively. The related current and voltage r.m.s. values of an AC source obtaining nonlinear harmonic generating components are expressed as:

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} = \sqrt{V_1^2 + V_2^2 + V_3^2 + V_4^2 \dots \dots . V_n^2} \tag{3}$$

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = \sqrt{I_1^2 + I_2^2 + I_3^2 + I_4^2 \dots \dots . I_n^2} \tag{4}$$

$V_1, V_2, V_3 \dots \dots V_n$ in (3) are voltage value from the fundamental to higher order harmonic components. The current values are stated as $I_1, I_2, I_3 \dots \dots I_n$ in (4). One can then calculate the consumed power. By multiplying (1) and (2) the active power consumption of harmonic generating loads is calculated as (5).

$$P = \sum_{n=1}^{\infty} V_n I_n \cos(\theta_n - \delta_n) = \sum_{n=1}^{\infty} P_n \tag{5}$$

THD is one of the most widely used metrics in harmonic analysis of power systems, which evaluates the harmonic distortion on the related grid. It is necessary to evaluate the square root of the sum of the squares of the voltages and currents for all the order. It is well known that the magnitude of voltage and current tends to decrease with increasing harmonic orders and can be neglected after a certain value. So, the calculations were obtained up to19th order. The following formulations are given in the (6) and (7) for voltage and current, respectively [23]. So that this paper focused only on the current waveform distortion and its harmonic calculation and analysis.

$$THD_v = \frac{\sqrt{(\sum_{n>1}^{nmax} V_n^2)}}{V_1} = \frac{\sqrt{V_2^2+V_3^2+V_4^2 \ldots\ldots V_n^2}}{V_1} \quad (6)$$

$$THD_i = \frac{\sqrt{(\sum_{n>1}^{nmax} I_n^2)}}{I_1} = \frac{\sqrt{I_2^2+I_3^2+I_4^2 \ldots\ldots I_n^2}}{I_1} \quad (7)$$

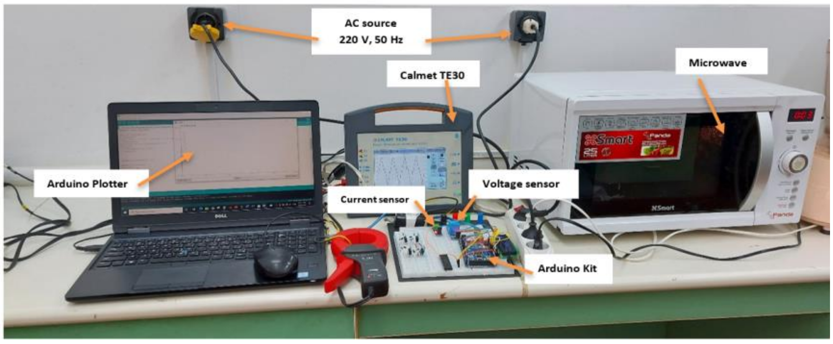


Figure 2. Microwave current waveform laboratory measurement using Arduino and Calmet TE30

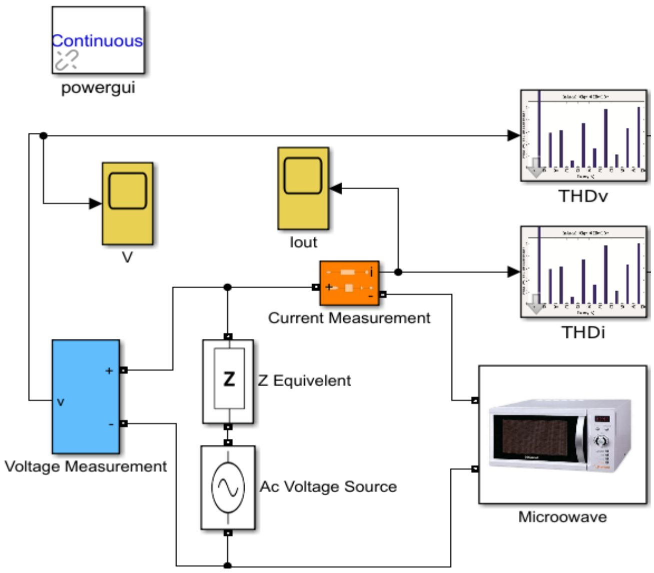


Figure 3. Simulink/MATLAB system model

5. COMPARATIVE STUDY OF THE SYSTEM DIFFERENT MEASUREMENTS

In this section, the experimental measurements have been carried out to be used for evaluating the simulated model for different residential equipment. The real-time load current of each equipment is measured and recorded using both the Calmet TE30 power analyzer. Voltage and current sensors accompanied with an Arduino mega kit as displayed in Figure 4 are used for measuring the load currents.

The AC power can be obtained according to the mathematical background (3); where power is a relationship between voltage and current [23]. The residential power voltage supply has a small distortion in the voltage waveform rather than the high-produced distortion due to the non-linear loads is in the current distortion. From all measurements done for several loads, the voltage waveform was within the standard distortion limits IEEE 519-2014 [24].

The real-time current sensor, laboratory power analyzer measurements, and simulation results of the current waveforms for different residential equipment are demonstrated. Figure 5 shows microwave current waveform (a) power analyzer (measured), (b) Arduino, and (c) MATLAB. The used microwave is a 25-liter capacity and 800 watts microwave of 5.2 A current waveform.

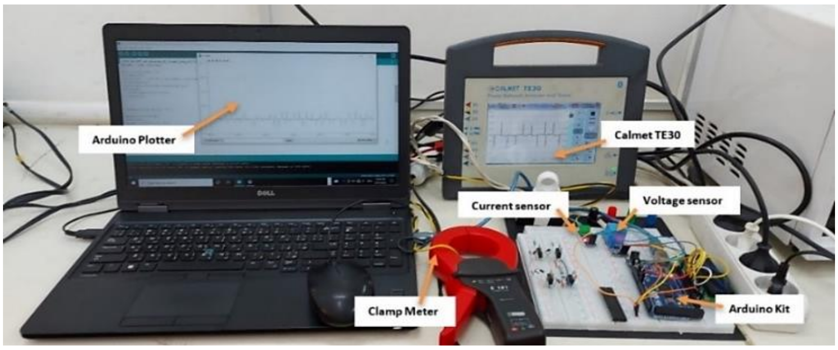


Figure 4. The capture of the laptop laboratory measurements

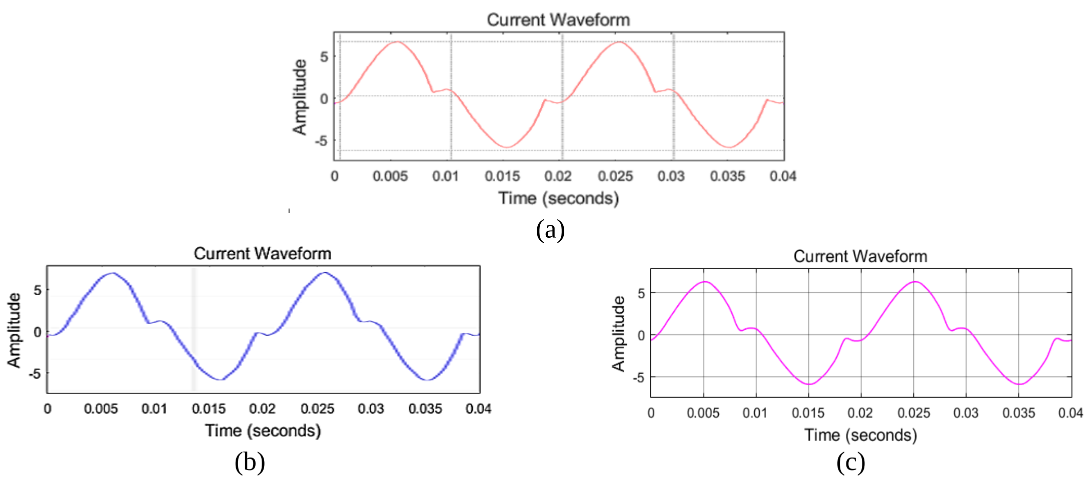


Figure 5. Microwave current waveform (a) power analyzer (measured), (b) Arduino, and (c) MATLAB

The real measurements are the measured using the power analyzer that shows the very similarity with both the measured current using controller (Arduino) as well as the simulated current using the MATLAB. Satifactory agreement beteewn the model and the measured results is depicted in Figure 5. Moreover, the measured current using the arduino is used for estimating the fundmental current. Figure 6 shows laptop current waveform (a) power analyzer (measured), (b) arduino, and (c) MATLAB. The laptop has capacity of 65 watts with 0.33 A current waveform and has a huge distortion.

Figure 6 describes the 65 watts laptop's 0.33 A current waveform with different schemes. A small difference between the controller measured current using Arduino and the other two figures, the measured current with Power analyzer (measured), and the MATLAB simulated current with MATLAB. The differences may be due to the sampling number of the measured current waveform. Next, Figure 7 describes the refrigerator current waveform: (a) power analyzer (measured), (b) Arduino, and (c) MATLAB. Using the three methods the refrigerator with 238 liters capacity and 0.88 A current waveform distortion is compared.

Figure 7 illustrates the 238 liters capacity refrigerator 0.88 A current waveform with about 180 watts. The real measurements of the Power analyzer (measured) show very similarity with both the controller measured current as well as the simulated current. However, small differences between the current peaks of the three different current cases are due to the three different platforms, the experimentally measured (power analyzer and Arduino) are very close together. Finally, Figure 8 illustrates the two-desktop current waveform: (a) power analyzer (measured), (b) Arduino, and (c) MATLAB. The measurement of the two-desktop current waveform distortion also contains a large amount of distortion.

Figure 8 shows the two desktop PC's 0.86 A current waveform with the power consumption between 40 and 85 watts. The power analyzer measured current waveform in (a) power analyzer (measured) is a little different with both the Arduino controller measured current and the MATLAB simulated current. However, the current peaks of the two other current cases are approximately similar due to the different platforms and number of reading samples.

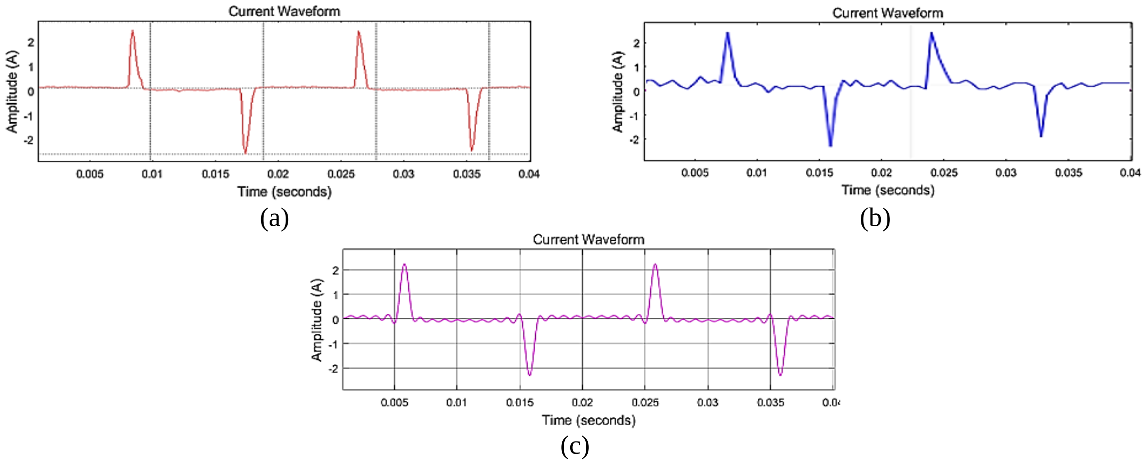


Figure 6. Laptop current waveform (a) power analyzer (measured), (b) Arduino, and (c) MATLAB

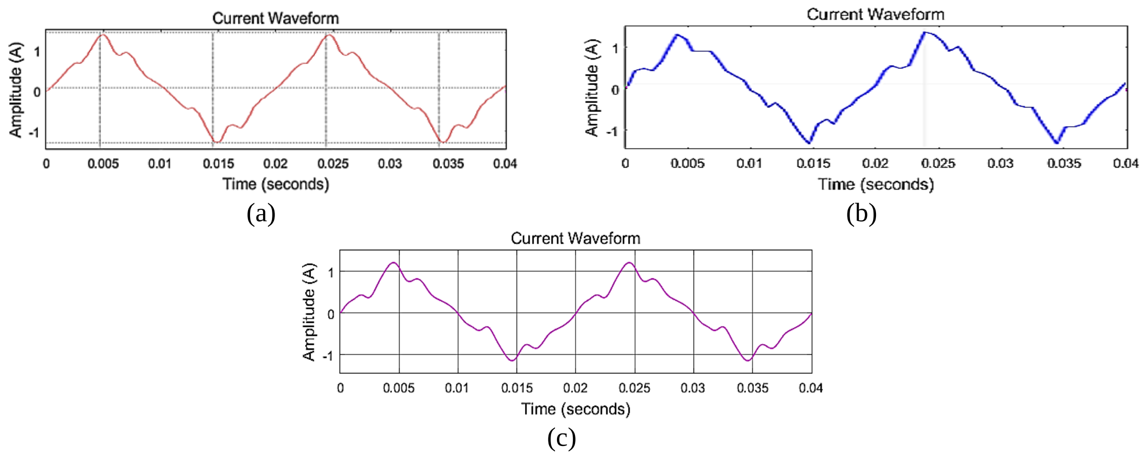


Figure 7. Refrigerator current waveform (a) power analyzer (measured), (b) Arduino, and (c) MATLAB

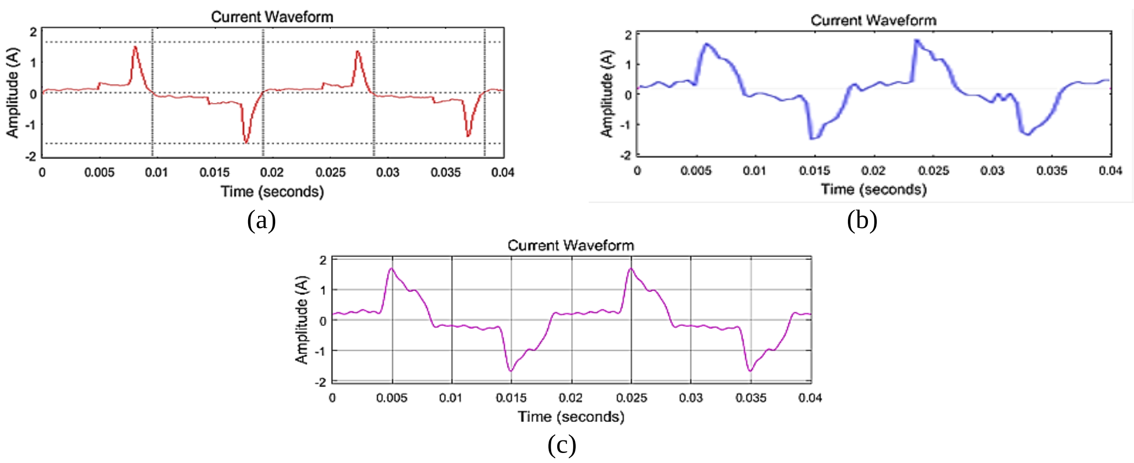


Figure 8. Two desktop current waveform, (a) power analyzer(measured), (b) Arduino, and (c) MATLAB

6. SYSTEM HARMONIC ANALYSIS

Figure 9 illustrates the laboratory measurement for a different type of equipment. The measurements done with individual device and other with compound devices. In the following subsections, the results of the simulation model will be calculated and discussed as follows.

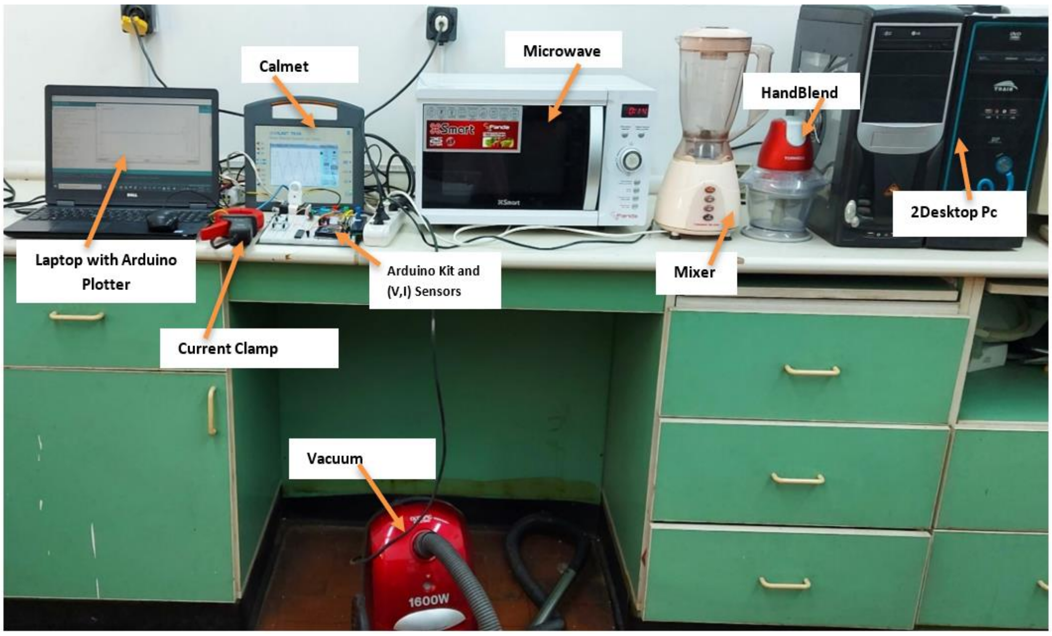


Figure 9. Different types of equipment laboratory measurements setup

6.1. 800 W microwave

In the case of the microwave, the current waveform and fast fourier transform (FFT) analysis are displayed in Figure 10. It can be noticed that the THD_i is about 22.35% and the 3rd harmonic order is higher than the other lower harmonic orders as it is about 20.38% of the fundamental. The 5th and 7th harmonic orders are about 7.4% and 3.9 % respectively or less. The microwave current waveform distortion is mainly due to the 3rd harmonic order.

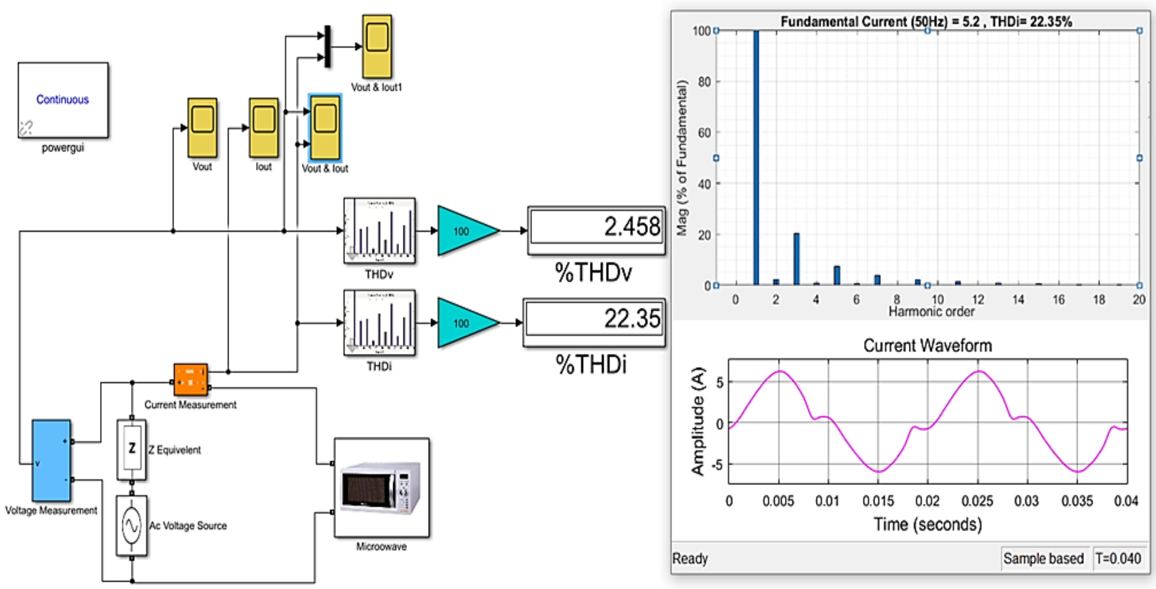


Figure 10. Microwave model and output waveform with the spectrum

6.2. 65 W laptop and 180 W refrigerator

The laptop and refrigerator equipment current waveform and FFT analysis/(bar graph) according to the proposed model are displayed in Figure 11. It was noticed that the THD_i of the current waveform is about 54.71%. Because of the presence of the laptop, most of the frequency harmonics component is found. By including up to the 19th harmonic orders the 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, and 19th harmonic orders; they are about 32.15%, 22.27%, 16.38%, 17.97%, 16.46%, 14.37%, 13.83%, 10.76%, and 8.76% respectively.

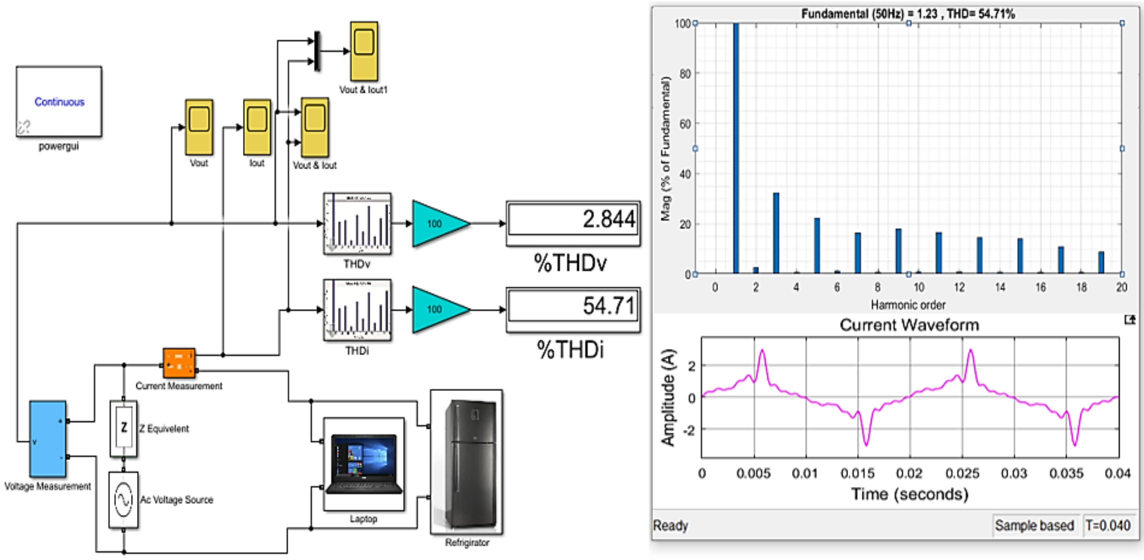


Figure 11. Laptop and refrigerator model and output waveform with the spectrum

6.3. 800 W microwave, 65 W laptop, and 1500 W vacuum cleaner

When simulating households, it is necessary to combine different equipment to simulate the total household current and calculate the total harmonic distortion. The microwave, laptop, and vacuum cleaner equipment current waveform and FFT analysis according to the proposed model are displayed in Figure 12. Also, the main contributors to this load current distortion are the 3rd,7th, 9th, and 11th harmonic orders. The THD_i is about 33.63% and the 3rd,7th, 9th, and 11th harmonic orders are 32.89 %,3.29%,4.82%, and 2.36% of the fundamental current. The rest of the other harmonic orders are less than 1% of the fundamental current.

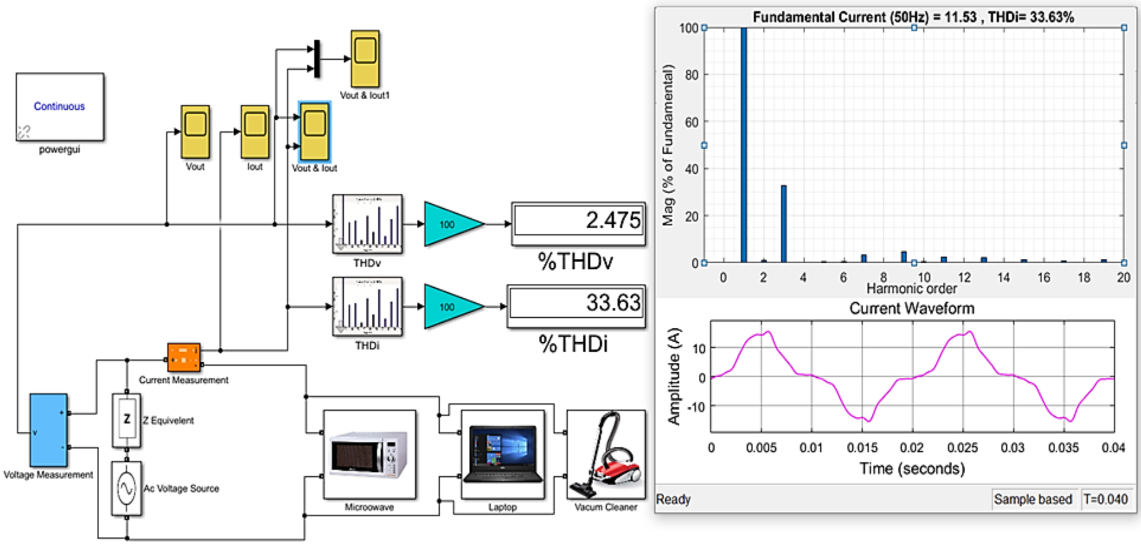


Figure 12. Microwave, laptop, and vacuum cleaner model and output waveform with the spectrum

The previous simulation models are verified by the first performing current measurements and FFT analysis on the selected home appliances. It has an almost full agreement with the laboratory-measured current of the same cases as shown in the next section. This validates the simulation model to be implemented for the control/compensation model.

7. THE RESIDENTIAL GRID-INTERACTIVE HARMONIC REDUCTION TECHNIQUE

According to the grid-connected equipment, several orders of harmonics will deform the source current waveforms. Indeed, the harmonic orders are difficult to be estimated at any specific instant or even for a long time. Real-time harmonic measurements are a key factor for implementing the proposed technique. The system subtracts the clean fundamental current from the total measured current for obtaining the total harmonic signal waveform. One can use this harmonic signal as a modulating reference signal for generating a compensating CSI-PWM [25]–[27]. This signal is used to fire grid-connected CSI. The Control scheme is depending on the distorted current measurement via system microcontroller. The peak value of the measured current is used for eliminating the fundamental according to sinusoidal distribution and the switching frequency (1 kH) of the PWM. The inverter configured of a full bridge G15N60 IGBT, two IR2112 gate drive circuits, and the smoothing current inductor of 35 mH. The current source has an advantage of the independence of the connected voltage magnitude. The voltage source inverter requires that the PWM voltage has the same magnitude, frequency, and phase angle are the same with the connected grid. A simplified block diagram for the proposed system with connected two desktop load is depicted in Figure 13.

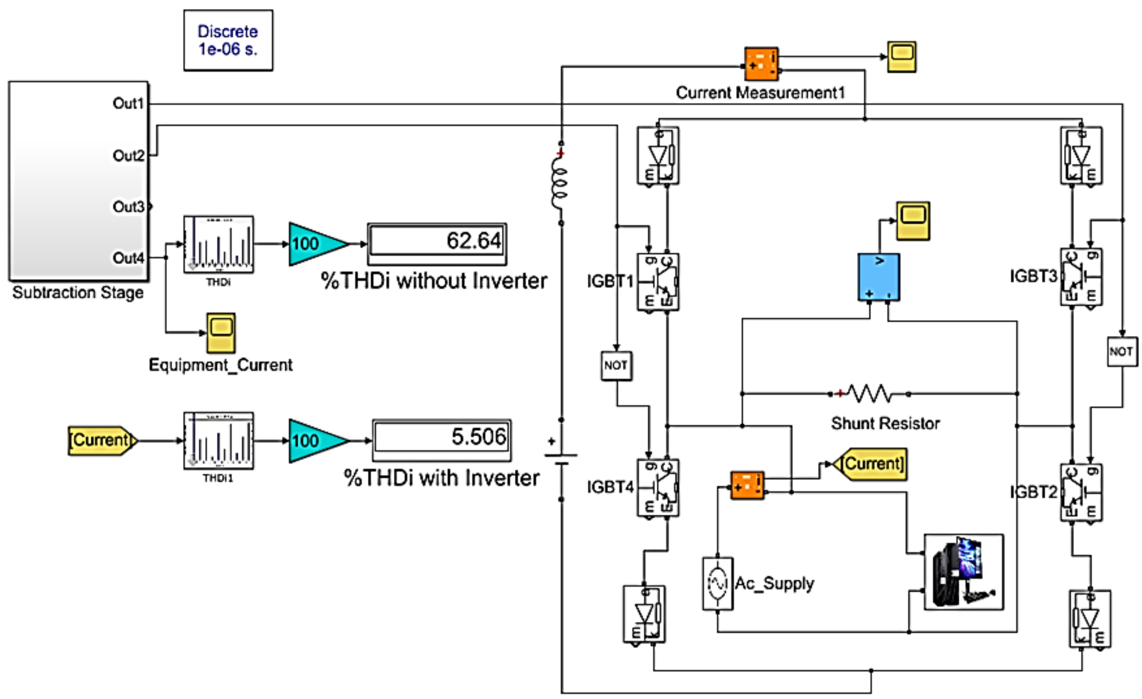
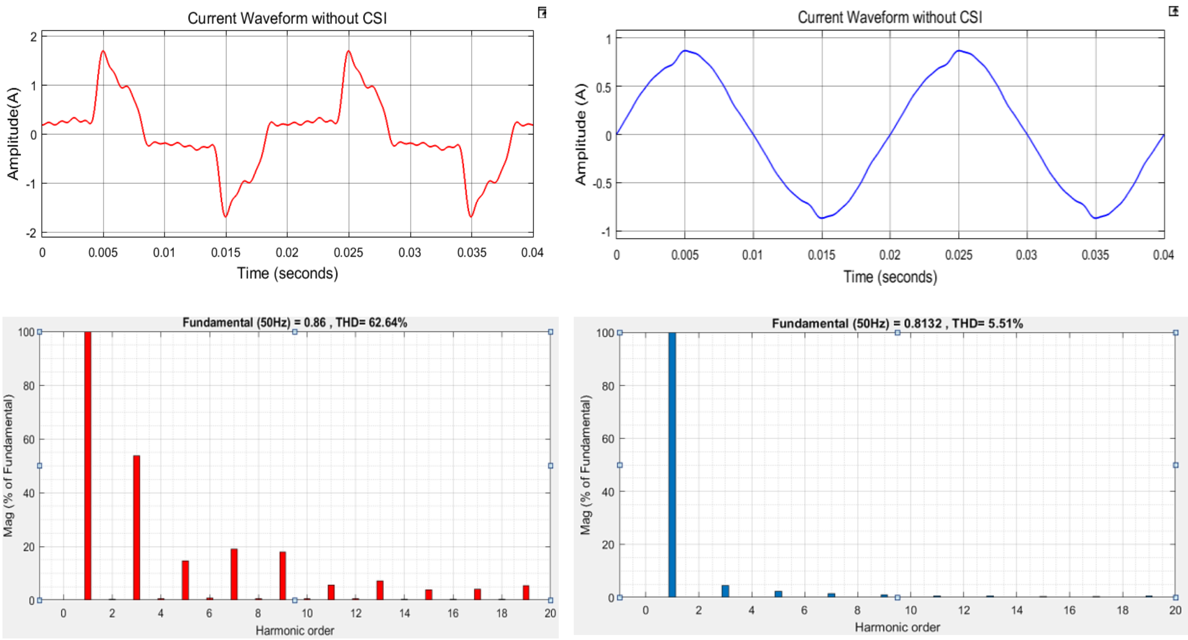


Figure 13. Two desktop system model with the current source inverter

Figure 14 shows the two-desktop current waveform and THD_i (a) without CSI and (b) with CSI. The distorted waveform contains large THD_i with 62.64%. The compensated waveform is obtained by using the proposed PWM-CSI. The enhanced model can improve the inverter output waveform and significantly reduce THD_i which have been reduced from 62.64% to 5.506 % with the nearly clean current waveform.

In Figure 15 shows the block diagram of different three connected loads. The three loads are two desktops, microwave, and vacuum cleaner. The THD_i of the connected loads result without inverter was 32.48%. This value will be improved using the proposed system. By applying the proposed system for the three connected loads; two desktops, microwave, and vacuum cleaner as depicted in Figure 15.



(a) (b)

Figure 14. Two desktop current waveform and THD_i (a) without CSI and (b) with CSI

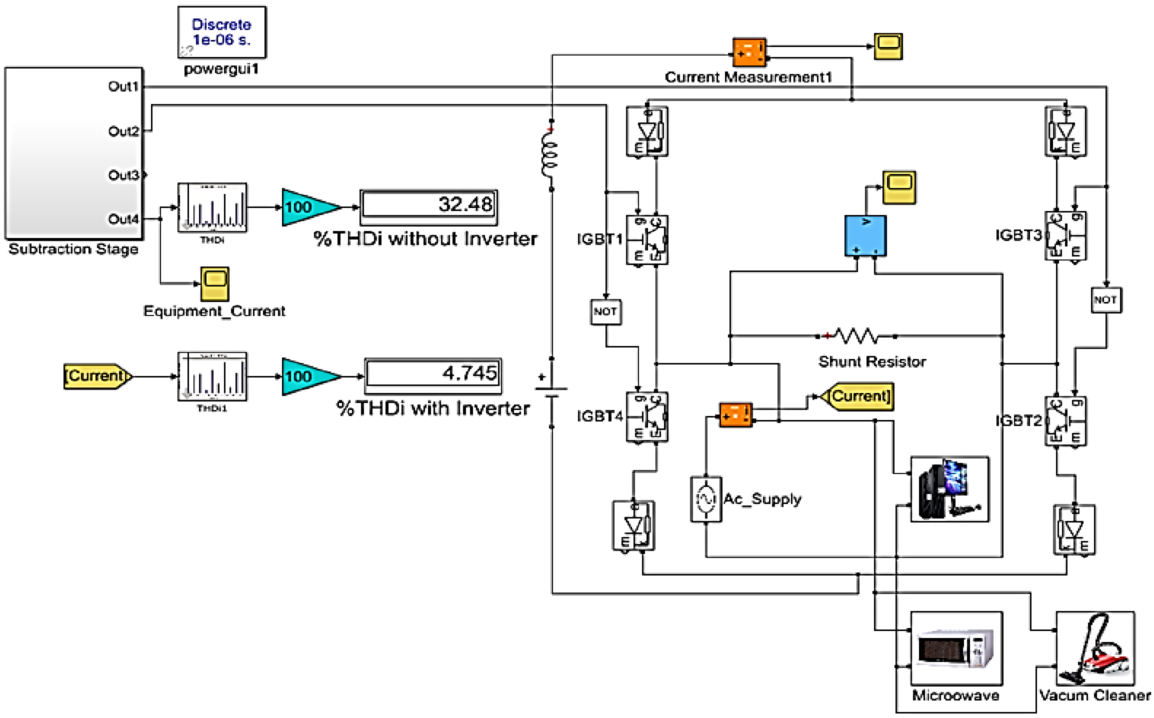
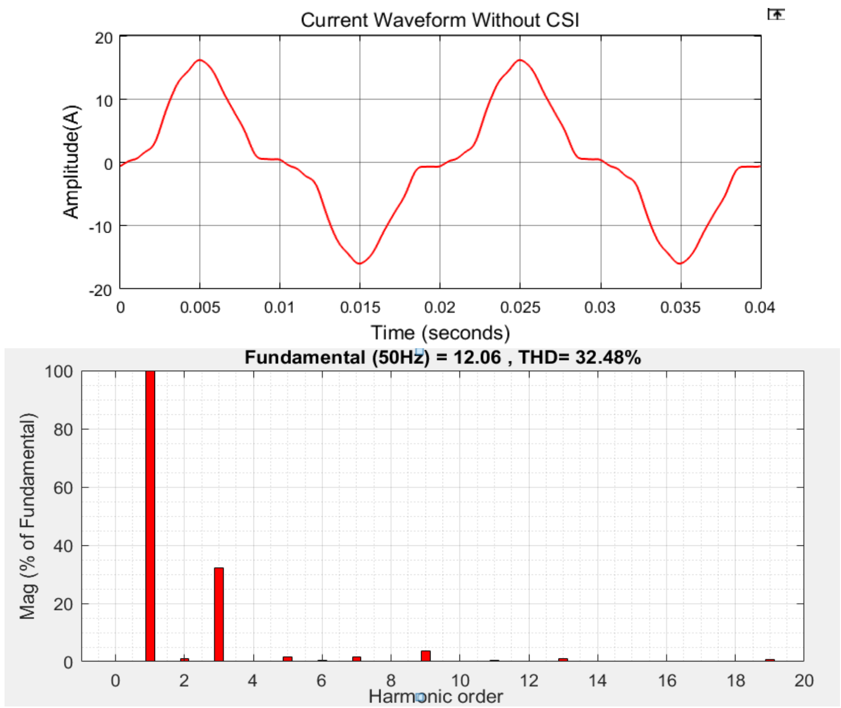
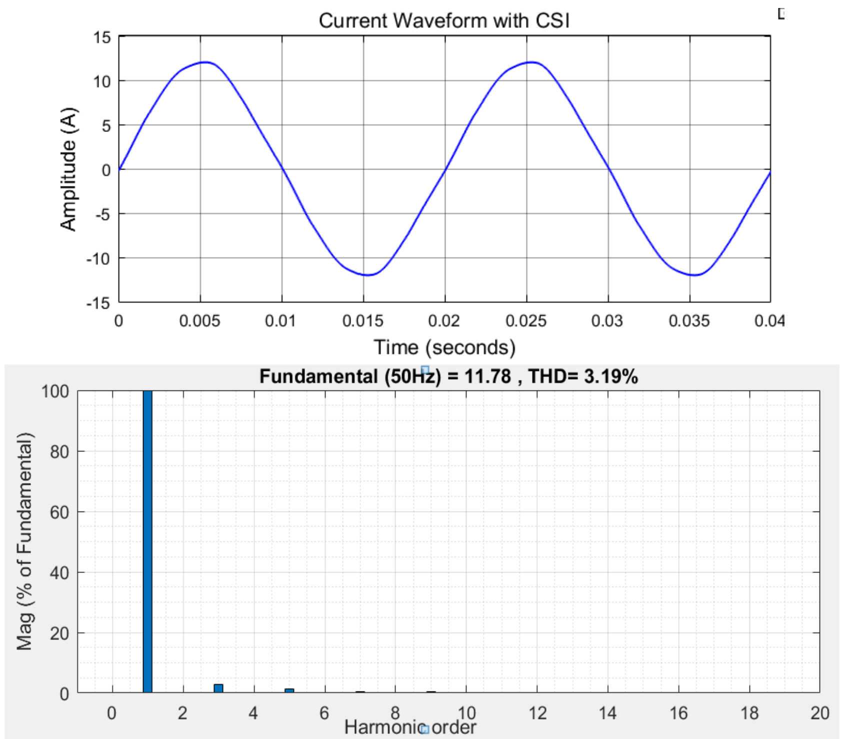


Figure 15. Two desktop, microwave, and vacuum cleaner system model with the current source inverter

Figure 16 illustrates the two desktops, microwave, and vacuum cleaner current waveform and THDi (a) without CSI and (b) with CSI. In Figure 16(a) the waveform was distorted with THD_i 32.48%. The enhanced model using CSI can improve the inverter output waveform and significantly reduce THD_i. As shown in Figure 16(b) THD_i have been improved to 3.19% for the three connected loads.



(a)



(b)

Figure 16. Two desktop, microwave, and vacuum cleaner current waveform and THD_i:
(a) without CSI and (b) with CSI

8. CONCLUSION

A smart novel interactive model for real instantaneous reading of the all connected load currents has been proposed, implemented, and successfully tested. The simulation model has been designed based on extracting the total harmonics signals to be the reference current of a PWM-CSI. The PWM switching frequency has been selected according to the highest harmonic order that are must be eliminated. Three grid cycles are the maximum delay between equipment running and the harmonic reduction activation and running. According to the total harmonic currents the system uses a 1 kHz switching frequency and unity modulation index for generating anti-PWM-CSI firing signals. A CSI inverter has been modeled and derived by these anti-PWM-CSI signals. A completer and comprehensive comparison between the system laboratory measurements using the Calmet TE30 power analyzer and the proposed simulation model has been presented. These results confirmed significant agreements between the proposed model output and actual measurements at different connected loads. Finally, the experimental system measured currents of different loads are almost typically confirmed with the power analyzer's results. The reduced harmonics currents of the implemented model display the system's suitability and validation.

REFERENCES

[1] S. V. Kulkarni, S. Gatade, N. Samanvita, and D. N. Gaonkar, “Comprehensive strategy for power quality improvement of inverter based distributed generation systems,” *Emerging Research in Computing, Information, Communication and Applications*, vol. 790, pp. 185-195, 2022, doi: 10.1007/978-981-16-1342-5_14.

[2] Z. Hameed, M. R. K. Sial, A. Yousaf, and M. U. Hashmi, “Harmonics in electrical power systems and how to remove them by using filters in ETAP,” *Proceedings 3rd International Conferences Engineering and Emerging Technologies (ICEET)*, 2016.

[3] F. T. Noori and T. K. Hassan, “Reactive power control of grid-connected photovoltaic microinverter based on third-harmonic injection,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 4, pp. 2169–2181, 2021, doi: 10.11591/ijpeds.v12.i4.pp2169-2181.

[4] T. Thentral, R. Rathakrishnan, V. Anbalagan, K. Dhandapani, U. Sengamalai, and P. Ramasamy, “Mitigation of current harmonics in multi-drive system,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 1, pp. 113–121, 2022, doi: 10.11591/ijpeds.v13.i1.pp113-121.

[5] Ł. Michalec, M. Jasiński, T. Sikorski, Z. Leonowicz, Ł. Jasiński, and V. Suresh, “Impact of harmonic currents of nonlinear loads on power quality of a low voltage network—review and case study,” *Energies*, vol. 14, no. 12, 2021, doi: 10.3390/en14123665.

[6] Y. Bhujbal and P. N. Korde, “Analysis of tuned filters for mitigation of harmonic current distortion of residential,” International journal of innovations in engineering research and technology, vol. 2, no. 11, pp. 1–10, 2015, ISSN: 2394-3696.

[7] V. M. Lopez-Martin, F. J. Azcondo, and A. Pigazo, “Power quality enhancement in residential smart grids through power factor correction stages,” IEEE Trans. Ind. Electron., vol. 65, no. 11, pp. 8553–8564, 2018, doi: 10.1109/TIE.2018.2813965.

[8] M. Sabarimuthu, N. Senthilnathan, A. M. Monnisha, V. KamaleshKumar, S. K. Sree, and P. M. Sundari, “Measurement and analysis of power quality issues due to electric vehicle charger,” *IOP Conference Series: Materials Science and Engineering*, vol. 1055, no. 1, p. 012131, 2021, doi: 10.1088/1757-899x/1055/1/012131.

[9] A. Alkhalifah and I. O. Habiballah, “Harmonics effect to the network–practical case,” *European International Journal of Science and Technology*, vol. 9, no. 11, pp. 1–8, 2020.

[10] S. Kalkoul, H. Benalla, K. Nabti, and R. Abdellatif, “An adaptive harmonic compensation strategy for three-phase shunt active power filter based on double second-order generalized integrator with prefilter,” *Electrical Engineering & Electromechanics*, no. 3, pp. 58–64, 2020, doi: 10.20998/2074-272x.2020.3.09.

[11] M. Dellahi, H. Maker, G. Botella, E. Alameda-Hernandez, and A. Mouhsen, “Three-phase four-wire shunt active power filter based on the SOGI filter and Lyapunov function for DC bus control,” *International Journal of Circuit Theory and Applications*, vol. 48, no. 6, pp. 887–905, 2020, doi: 10.1002/cta.2778.

[12] S. Nababan, Supriyatna, A. Natsir, and N. M. Seniari, “Simulation of effect of capacitor on power distribution system harmonics with one nonlinear load,” *International Journal of Applied Engineering Research*, vol. 15, no. 6, pp. 581–587, 2020.

[13] N. Obeidi, B. Belmadani, and E. Bounadja, “Harmonic filter in its experimental environment,” *Journal of Science & Technology*, vol. 02, no. 01, pp. 83–90, 2020.

[14] M. O. Mahmoud, W. Mamdouh, and H. Khalil, “Source current harmonic mitigation of distorted voltage source by using shunt active power filter,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 4, pp. 3967–3977, 2020, doi: 10.11591/ijece.v10i4.pp3967-3977.

[15] S. Karekar, “Analysis, comparison and study on mitigation of harmonics by using active and passive harmonics filters by using MATLAB simulation,” *JOJ Material Science (JOJMS)*, vol. 4, no. 1, pp. 1-9, 2018, doi: 10.19080/JOJMS.2018.04.555628.

[16] M. Kumar, Z. A. Memon, M. A. Uqaili, and M. H. Baloch, “An overview of uninterruptible power supply system with total harmonic analysis & mitigation: an experimental investigation for renewable energy applications,” *IJCSNS International Journal of Computer Science and Network Security*, vol. 18, no. 6, pp. 25–36, 2018.

[17] E. Hernández, E. Dueñas, R. Iracheta, H. J. Cortina, and M. A. Hernández, “Implementation of a shunt active power filter for power quality improvement: harmonic compensation and power factor correction,” *International Journal of Research in Engineering and Innovation (IJREI)*, vol. 2, no. 2, pp. 162–172, 2018.

[18] I. Ahmed, M. Z. Shames, Md. M. Alam, “An overview of harmonic sources in power system,” *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, vol. 7, no. 3, pp. 01–03, 2013, doi: 10.9790/1676-0730103.

[19] N. Singh, N. K. Sharma, and P Tiwari, “Harmonics: sources, effects and control techniques,” *NIET Journal of Engineering & Technology (NTJET)*, vol. 1, no. 1, pp. 34–37, 2012.

[20] M. J. H. Rawa, D. W. P. Thomas, and M. Sumner, “Experimental measurements and computer simulations of home appliances loads for harmonic studies,” *2014 UKSim-AMSS 16th International Conference on Computer Modelling and Simulation*, 2014, pp. 340-344, doi: 10.1109/UKSim.2014.12.

[21] H. Farooq, C. Zhou, and M. E. Farrag, “Analyzing the harmonic distortion in a distribution system caused by the non-linear residential loads,” *International Journal of Smart Grid and Clean Energy*, vol. 2, no. 1, pp. 46–51, 2013, doi: 10.12720/sgce.2.1.46-51.

[22] S. Elphick, P. Ciufo, and S. Perera, “Laboratory investigation of the input current characteristics of modern domestic appliances for varying supply voltage conditions,” *Proceedings of 14th International Conference on Harmonics and Quality of Power-ICHQP 2010*, 2010, pp. 1-7, doi: 10.1109/ICHQP.2010.5625397.

[23] A. Çiçek, A. K. Erenoğlu, O. Erdinç, A. Bozkurt, A. Taşcıkaraoğlu, and J. P. S. Catalão, “Implementing a demand side management strategy for harmonics mitigation in a smart home using real measurements of household appliances,” *International Journal of Electrical Power & Energy Systems*, vol. 125, p. 106528, 2021, doi: 10.1016/j.ijepes.2020.106528.

[24] "IEEE recommended practice and requirements for harmonic control in electric power systems," in *IEEE Std 519-2014 (Revision of IEEE Std 519-1992)*, pp.1-29, Jun. 2014, doi: 10.1109/IEEESTD.2014.6826459.
[25] A. A. Saleh, R. K. Antar, and H. Al-Badrani, "Design of new structure of multilevel inverter based on modified absolute sinusoidal PWM technique," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 4, pp. 2314–2321, 2021, doi: 10.11591/ijpeds.v12.i4.pp2314-2321.
[26] M. Samy, M. Mokhtar, N. H. Saad, and A. A. El-Sattar, "Modified hybrid PWM technique for cascaded MLI and cascaded MLI application for DTC drive," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 1, pp. 47–57, 2022, doi: 10.11591/ijpeds.v13.i1.pp47-57.
[27] D. N. Quy, D. B. Phu, and N. K. Trung, "The new approach minimizes harmonics in a single-phase three-level npc 400 hz converter for airplanes," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 3, pp. 1738–1750, 2021, doi: 10.11591/ijpeds.v12.i3.pp1738-1750.

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