Investigation of Supra-Harmonics through Signal Processing Methods in Smart Grids

Turgay Yalcin[1], Muammer Ozdemir[1]

[1]Ondokuz Mayis University, Electrical&Electronic Engineering Faculty, Samsun, TURKEY
turgay.yalcin@omu.edu.tr , ozdemirm@omu.edu.tr

Pawel Kostyla[2], Zbigniew Leonowicz[2]

[2]Wroclaw University of Technology Faculty of Electrical Engineering, Wroclaw, Poland
pawel.kostyla@pwr.wroc.pl, leonowicz@ieee.org

Abstract— **Nowadays supra-harmonic distortion studies are gaining attention day by day in power quality research area. When handling communication systems especially Power Line Carrier (PLC) systems in frequency range 2- 150 kHz, they are suitable for causing electromagnetic interference (EMI) to other systems. This study shows results of analysis employing advanced method called ensemble empirical mode decomposition (EEMD) to describe supra-harmonic distortion. Unlike the traditional method (short time fourier transform- STFT), EEMD gives extensive representation for supra-harmonic components**

Index Terms—ensemble empirical mode decomposition; power quality; short time fourier analysis; supra-harmonics;

I. INTRODUCTION

A novel and significance increasing day by day hazardous risk to smart grid systems called supra - harmonics or emissions in 2 kHz -150 kHz frequency band. This threat can affect capacitors, lose communication contacts with smart meters. The important single fault source operations from photovoltaic inverters (PVs). Naturally fuel cells, battery chargers also wind turbines, can produce this serious threat [1, 2, 3]. Supra-harmonics also disturb domestic appliances, semi-conductor manufacturing devices, medical equipments, security systems even transportation controls. PLC produces low-impedance for emissions in subharmonics frequency range. The highest levels are commonly by virtue of PLC. As a result, power grids are worked out to transfer power at 50 Hz however, line also carries 2 kHz- 150 kHz electromagnetic components [4, 5, 6, 7, 17]. In this study, National Instruments PWr cRIO Data Recorder was used to acquire distortions in power systems. Sampling frequency was selected 1 MHz for measurements. Table I. gives the information of PV systems components properties. Fig 1 shows PV System at the Faculty of Electrical Engineering Wroclaw University of Technology.

TABLE I. PV SYSTEM COMPONENTS PROPERTIES

	Monocrystalline c-Si	Polycrystalline p-Si	The panel thin-film CIGS
Efficiency	14,90%	15,50%	11,80%
Maximum power	190W	240W	90W
Maximum voltage	36,5V	30V	60,8V
Maximum current	5,2A	8A	1,48A
Dimensions	1580 × 808 × 35mm	1680 × 1040 × 35mm	1196 × 636 × 36mm
Weight	17,2 kg	20 kg	14,5 kg

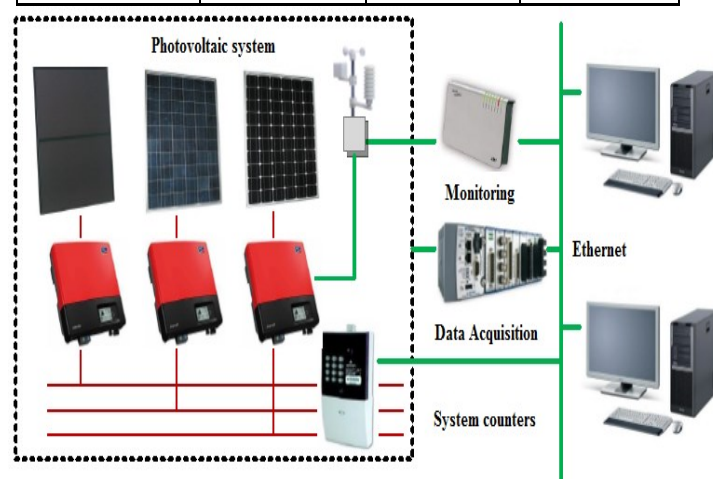| The angle of inclination to the horizontal	β =40⁰	β = 40⁰	β =40⁰
Azimuth	γ =135⁰	γ =225⁰	γ =135⁰

Fig 1. Photovoltaic System at the Faculty of Electrical Engineering Wroclaw University of Technology

II. SIGNAL PROCESSING METHODS

A. Short Time Fourier Transform

Traditionally STFT is applied to measured data from domestic appliances and Sunny Mini Central PV inverter. The results from the STFT are presented in a spectrogram. Spectrograms used for signal processing owing to show supra-harmonics. STFT has drawbacks about representation magnitude and frequency bands [8]. In algorithm we used STFT with hamming sliding window (5 ms) for decompositon. . Respectively fig 2 and 5 shows STFT spectrograms and 2 Hz - 120 kHz frequency band for current signals of domestic appliances LCD TV and Laser Printer.
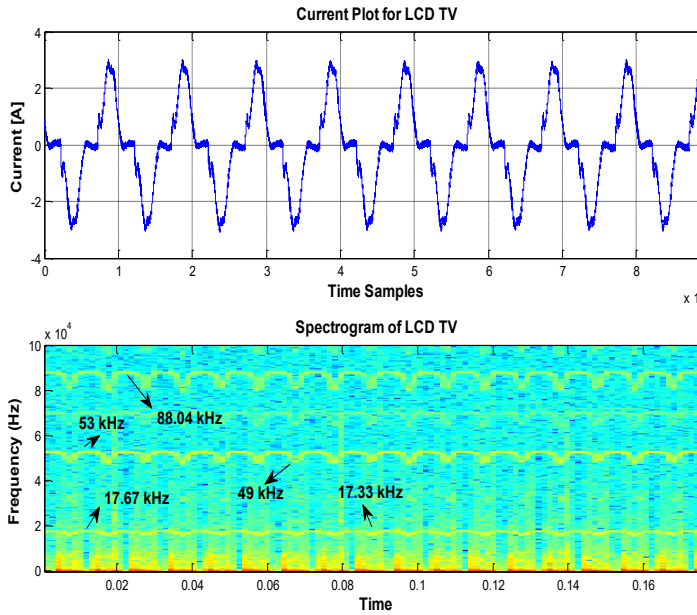
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Fig 2. Spectrogram of the current LCD TV

In figure 2 is illustrated constant or continuous frequency emissions at 17. 6 kHz, 53 kHz and 88 kHz bands.

B. Ensemble Emprical Mode Decomposition (EEMD)

EMD has been profitably performed for non-stationary signal processing. The EMD could decompose the complicated signal function into a number of Intrinsic Mode Functions (IMFs)[9,10,11]. The algorithm has major drawbacks of mode mixing, end effects and etc[12,13,14,15,16]. Therefore, in this work we performed EEMD method for generating IMFs in order to analyze supra-harmonics. We focused on pattern frequency band which is dominated in power grid.

The mathematical background of EEMD algorithm (Fig 3):

  i.   Add noise, $wn(t)$, to target signal $s_1(t)$. $s_2(t)=s_1(t)+wn(t)$.

  ii.   Used EMD [9, 10, 11, 12, 16] algorithm for decomposing the final signal $s_2(t)$.

  iii.   Continue steps (i) and (ii) till the trial numbers. When new imf combination $C_{ij}(t)$ is succeeded, predict the ensemble mean of the last intrinsic mode function (IMF). (Selected Nstd: 0 and Number of Ensemble: 1 we used EEMD like EMD.)
The aimed output:

$$EEMD[c_j(t)] = \sum_{i=1}^{tn} c_{ij}(t) \qquad (1)$$

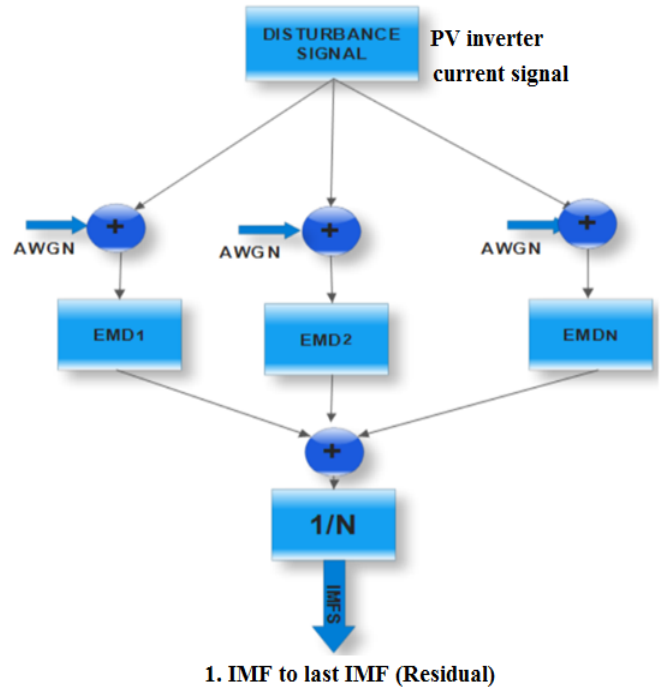*tn:* trial numbers, *i:* iteration number and *j:* imf scale [13, 14, 15].

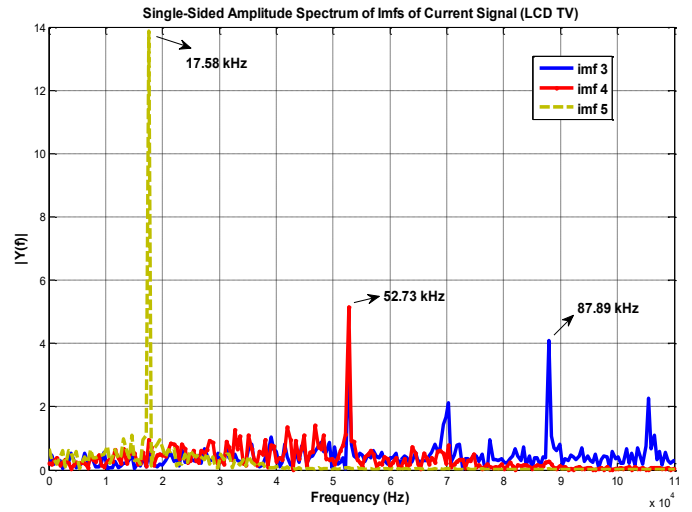**Fig. 3.** The representation of the EEMD algorithm[16]

Fig 4. Frequency IMFs components for current of LCD TV

Figure 4 shows the frequency spectrum of IMF 3- IMF 5. When we look for the spectrum it is clearly illustrated that IMF 3 represents the frequency component (17.58 kHz). Moreover, IMF 4 also shows frequency (52.73 kHz) band.
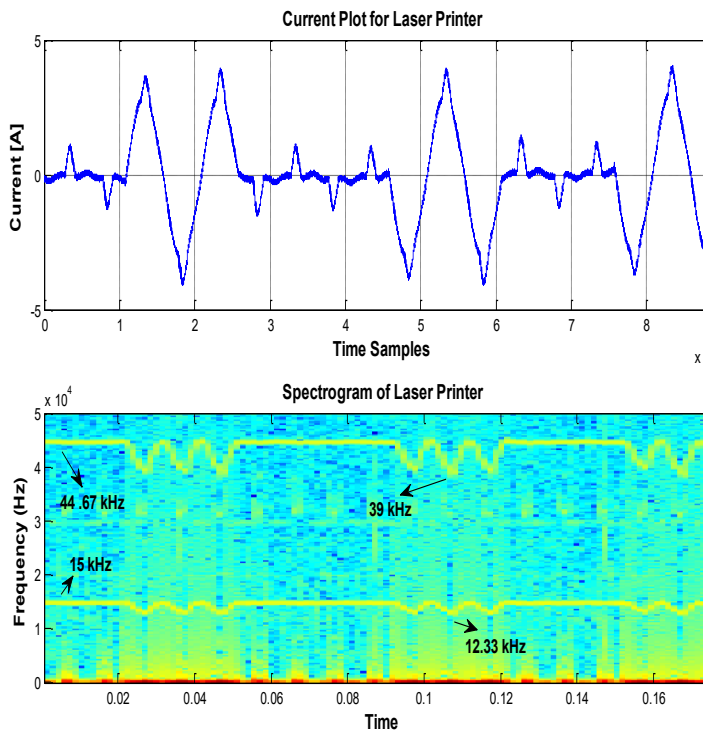
Fig 5. Spectrogram of the current Laser Printer

Fig 7. Spectrogram of the current power line with PV
(Sampling Frequency: 1 MHz)

In figure 5 is illustrated continuous and fluctuant frequency emission at 15 kHz and 44.67 kHz bands. Figure 6 shows the frequency spectrum of IMF 3- IMF 5. When considering the spectrum it is comprehensively shown that IMF 3 represents the frequency component (15.14 kHz). Furthermore, IMF 4 also shows frequency (44.92 kHz) band.
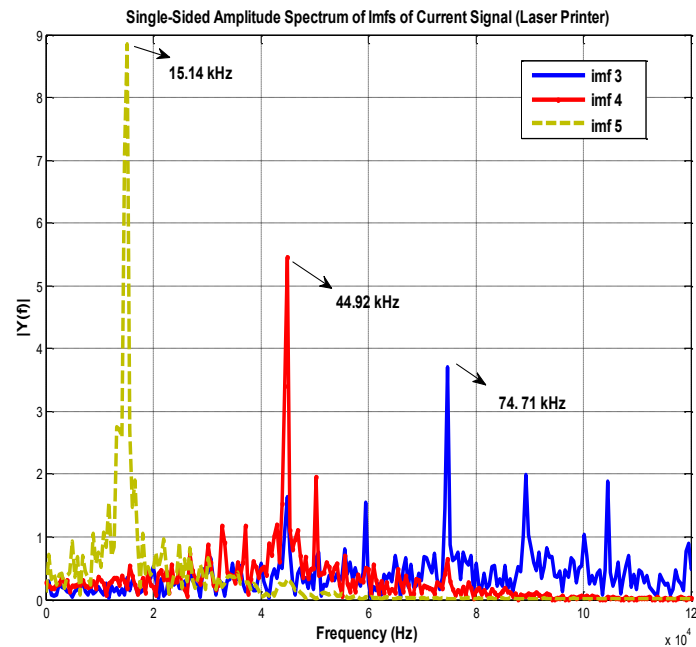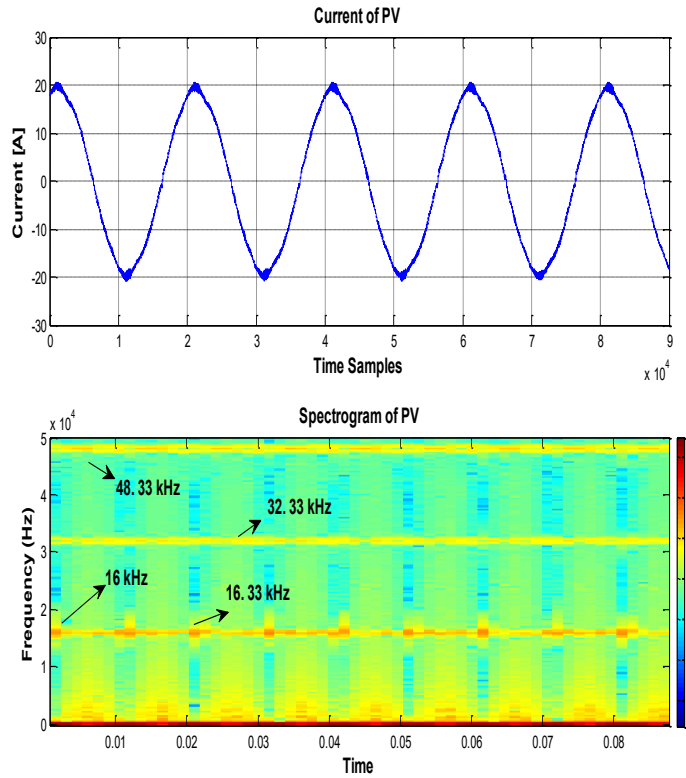
In figure 7 is illustrated Continuous and fluctuant frequency emissions at 16 kHz output PLC frequency and Daylight emission at 32 kHz PV inverter signature bands.
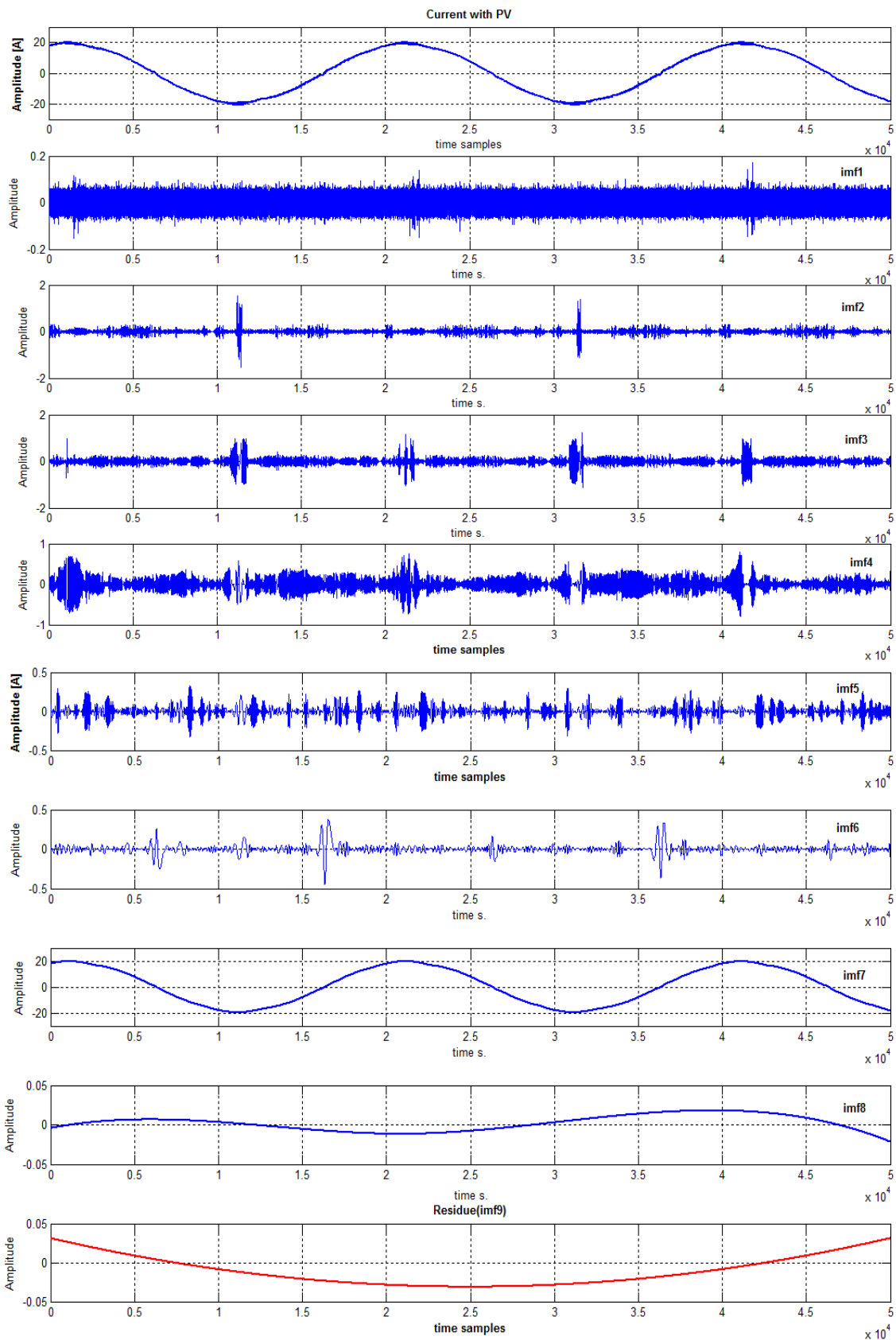

Fig 6. Frequency IMFs components for current of Laser Printer

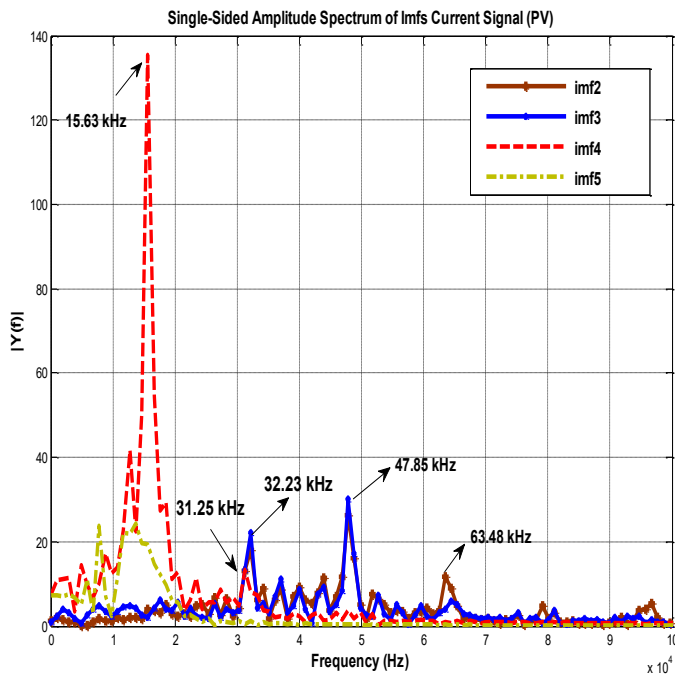**Fig 8.** IMF components of PV current signal

Fig 9. Frequency components of IMFs

Figure 8 shows the IMF components of PV signal. For measurements for PV, fig 9 shows frequency spectrum of IMF 2- IMF 5. When we look for the spectrum it is clearly illustrated that IMF 3 has PLC frequency component (15.63 kHz). Moreover, IMF 4 also shows PV converter frequency (32.23 kHz) band.

Table II. shows the relationship between signal and the IMFs components. IMFs are sorted from higher frequency to lower. Algorithm routine stops till the end of getting monotonic function IMF 9 called residual IMF 7 (R=0.9998) strongly related with the signal.

TABLE II. CORRELATION COEFFICIENT BETWEEN SIGNAL AND IMFS

	R (correlation coefficient)
signal,imf1	0,0006
signal,imf2	-0,0014
signal,imf3	-0,0005
signal,imf4	0,0087
signal,imf5	0,0049
signal,imf6	0,0079
signal,imf7	**0,9998**
signal,imf8	0,0511
signal,imf9	0,1524

III. CONCLUSIONS

Instead of traditional methods such as STFT, EEMD gives more accurate results, determining the PV inverter and PLC frequency bands with high exactitude. It was shown that EEMD method can be used for spectral analysis of supra- harmonics and can be also applied for pattern recognition of supra-harmonics in smart grids with PV systems. With the help of the proposed method supra-harmonic analysis and pattern detection of them easily inquire into.

For future study, this results will discuss with another signal processing methods. Filter design for measuring supra-harmonics in smart grids will be investigated in the light of the analysis.

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Pawel Kostyla in 1998 was awarded the title of Doctor of Science at the Wroclaw University of Science and Technology. From 1999 until now he has been working as an Assistant Professor at the Department of Electrical Engineering. He holds the position of Laboratory Manager of the Theoretical Electrical Engineering. Author and coauthor of publications from the author's interest areas such as artificial neural networks and methods of digital signal processing in automation and electrical engineering, algorithms of digital signal processing and electrical measurements, development and testing of new methods of measuring electrical parameters, quality of electricity.

About the Authors

Turgay YALCIN received the B.Sc. Erciyes University (ERU), Kayseri, Turkey in 2006 and M.Sc. degrees in electrical engineering from Ondokuz Mayıs University (OMU), Samsun, Turkey, in 2010 and he is currently pursuing the Ph.D. degree in electrical engineering from Ondokuz Mayıs University (OMU). His areas of interest are Identification of Power Quality Disturbances, Signal Processing Methods and Machine Learning Algorithms.

Muammer OZDEMIR received the B.Sc. and M.Sc. degrees in electrical engineering from Black Sea Technical University (KTÜ), Trabzon, Turkey, in 1988 and 1991, respectively, and the Ph.D. degree in electrical engineering from The University of Texas at Austin (UT), Austin, TX, USA, in 2002.Currently, he is an Assistant Professor with the Department of Electrical and Electronics Engineering, Ondokuz Mayıs University (OMU), Samsun, Turkey. His areas of interest are power systems harmonics, power quality, and power system analysis.

Zbigniew Leonowicz (IEEE M'03–SM'12) became a Member (M) of IEEE in 2003 and a Senior Member (SM) in 2012. He received the M.Sc., Ph.D. and Habilitate Doctorate (Dr Sc.) degrees, all in Electrical Engineering, in 1997, 2001, and 2012, respectively. He has been with the Department of Electrical Engineering, Wroclaw University of Technology, since 1997 where he currently holds position of Associate Professor. His current research interests are in the areas of power quality, control and protection of power systems, renewables, industrial ecology and applications of signal processing methods in power systems.