Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 100 (2015) 1247 – 1252

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Investigation Performance of Marine Equipment with Specialized Information Technology

Anton Zhilenkov, Sergei Chernyi*†

Kerch State Marine Technological University, 82, Orgenikidse St., Kerch, 298309, Russian Fedaration

Abstract

The paper explores new approach for the real-time identification of harmonic composition of the distorted signals (voltages and currents) of autonomous electric power systems with inconsistent frequency, phase and amplitude, and which can be greatly distorted. The identification of target non-stationary harmonics is made by adjustment of the parameters of the relevant function-prototype. The proposed method of tracking the parameters of any harmonic of the distorted signal makes possible to provide unique, stable and convergent solution of the non-linear dynamic system. The obtained algorithm provides the unique asymptotic trajectory, being periodical and lying in the vicinity of the approximated function – target harmonic of the signal. This method may be successfully applied in design of the multivariable systems for identification of external parameters in the water transport and in other autonomous electric power systems. The test of the developed system is performed in the medium Matlab and the algorithm's practical implementation by FPGA sources is proposed.

Peer-review under responsibility of DAAAM International Vienna

Keywords: information technology; adaptive filtration; control systems; intelectual system; FPGA

1. Introduction

For the limited power autonomous AC distribution systems, the power quality problem and the means of keeping it under control, is a growing concern. Generally, this is due to the increase in the number of non-linear power electronic equipment used in the presence of sensitive electronic equipment. Their non-linear characteristics cause

* Corresponding author. Tel.: +38-050-590-77-08
E-mail address: sergiiblack@gmail.com

Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.490

harmonic currents, which result in additional losses in distribution system equipment and interference with communication systems. Failure of sensitive electronic loads such as process control and other equipment connected to the power systems has become a concern as they could result in economic consequences.

Due to the wide use of non-linear power electronic loads, autonomous AC distribution systems have experienced high harmonic pollution. The control or mitigation of the power quality problems may be realized through the use of harmonic filters. Harmonic filters are designed to reduce the effects of harmonic penetration in power systems. Two ways have been proposed to reduce the effect of the harmonic distortion: active and passive filtering approach.

Shunt passive filters cannot adjust to changing load conditions; they are unsuitable at distribution level as they can correct only specific load conditions or a particular state of the power system. The increasing emphasis on overall distribution system efficiency has resulted in a continued growth of devices such as shunt capacitors for power factor corrections. In the circuit formed by line inductance and power factor correction shunt capacitors harmonic contamination excites resonance, which result in magnification of harmonic distortion levels.

In the active filters, the harmonic currents produced by the nonlinear loads are extracted, and their opposites are generated and injected into the power line using a power converter. Several active filtering approaches based on different circuit topologies and control theories have been proposed. Most of these active filter systems consist mainly of a single PWM power converter with a high rating which takes care of the harmonic components in the distorted signal. As we come to realization of a control system, active power filtering can be performed in time domain or in frequency domain. The main advantage of time domain is fast control response, but it cannot control individual harmonics separately or apply various weightings for different harmonic components. Also, it ignores the periodic characteristics of the distorted waveform and not learning from past experiences. Correction in frequency domain, which is mainly implemented by FFT, has the advantage of flexible control of individual harmonics (cancel selected harmonics). Its main disadvantage is in the rather burdensome computational requirements needed for a solution, which results in long response times [1].

There are few known approaches with such consideration, but they use adaptive filters or artificial neuron nets to track the system voltage and extract the fundamental component of the source voltage which is used as a synchronize signal for the regulation loop. In order to provide high-quality electricity, it is essential to accurately estimate or extract time varying harmonic components, both the magnitude and the phase angle, to mitigate them using active power filters. At the same time a great deal of ship's automation systems apply the line currents and voltages to form the reference signal. Thus, for example, an automatic voltage regulator (AVR) of ship's synchronous generators (SG) performs regulation by an average value of voltages and currents in the circuit. However, with the distorted form of the variable signals (that is caused by the presence of a wide range of highest harmonics) their average value increases and an AVR, correcting the error, decreases the exciting current of the synchronous generator that results in loss of voltage in the ship's electric power systems (SEPS). Consequently, decrease in relative value and increase in highest harmonics take place and so electromagnetic moment of non-synchronous motors decreases, the level of interferences influencing the systems of ship's automatic controls becomes higher, and losses in power supply lines enlarge. Practically such an error is corrected by adjustment of the voltage corrector (VC). However, as harmonic composition periodically varies depending on the regime of operation and the composition of load of the electric power station, the setting of the voltage corrector should be changed constantly [2, 3, 4]. This problem should be solved by measuring the level of the basic harmonics of the current and voltages of the ship's circuit. On the other side it is known that filter-compensating devices (FCD) are the most efficient means to increase the quality of electric energy in the ship's power supply systems at the moment. Their efficiency in higher harmonic suppression and compensation of their volt-ampere reactive may be provided only with the high accuracy of the calculation of parameters in the target harmonics of the line currents and voltages.

The fundamental frequency tracking capability is an important feature for successful active harmonic filtering. One of the common problems with FTT is the spectral leakage effect resulting from the deviation in the fundamental frequency. A fundamental frequency offset of 0.4 Hz produces an error of 10% in the amplitude of the 5th harmonic [2]. To overcome this problem, a variety of algorithms have been developed for frequency measurement. One of them is the zero crossing technique. This technique is simple but it has long measurement times. Both the Kalman filter and FFT may use zero crossing as an external algorithm to measure the fundamental frequency. However, the adaptive algorithms are modified by combining the fundamental frequency tracking with adaptive-based harmonic analyse.

2. Results and discussion

The shape of the phase voltages of the synchronous generator can be rebuilt by the harmonic series consisting of several harmonics, and in the ideal case by one - the fundamental one. When there is the noise in the signal, its harmonic content will include higher-order harmonics .The proposed filter (fig.1) is based on the elements of the theory of extreme systems and adaptive systems. Proposed devices approximate the desired signal, generating a linear combination of the set of subsidiary functions that are generated from the parent function h(t). Parameters of the elements can be optimized by the least mean square function of decrementing the estimated energy function E in time. Since approximated, the signal is close to the sine curve and its parameters are approximately known (for example 380V, 50Hz for European standards), then as a parent you can assume the function sin(t). Physically, the filter in each channel can determine the magnitude, phase and frequency of corresponding phase voltage signal.

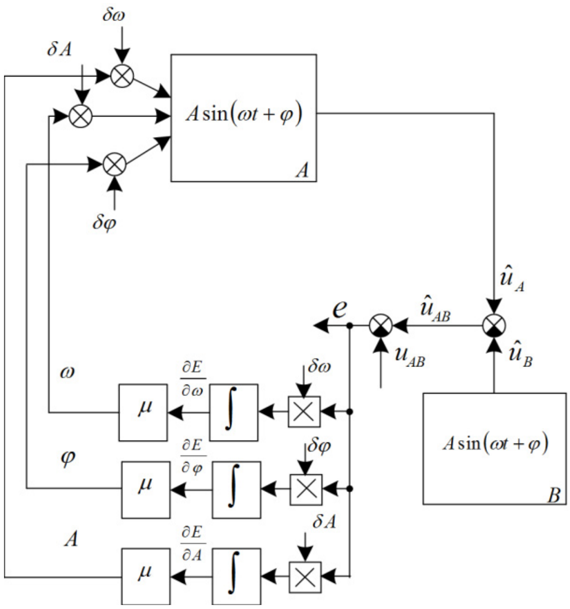

Fig. 1. Adaptive harmonic approximation.

Identification of the target non-stationary harmonics of the distorted signal is made by adjustment of the parameters of the relevant function-prototype (FP). In its general form the input signal y(t) of the identification system being a signal proportional to the circuit current or voltage in the ship's electric power system may be described by Fourier's series [4,5]:

$$y(t) = \sum_{k=1}^{N} a_k(t)\sin\left(k\omega_k(t)t + \varphi_k(t)\right) = x(t) + \xi(t) \tag{1}$$

where ak(t) is amplitude, ωk(t) is a rate of phase change and φk(t) is a phase angle of k-harmonics, N is a number of harmonics (in general $N = \infty$), $\xi(t) = \sum_{k=2}^{N} a_k(t)\sin\left(k\omega_k(t)t + \varphi_k(t)\right)$ is a set of non-approximated (i.e. non-recoverable by the device being designed) harmonics.

Let's introduce the vector for the parameters $\phi(t) = \left[a(t), \omega(t), \varphi(t)\right]^T$, which belong to the space of parameters $\Phi(t) = \left\{\left[a, \omega, \varphi\right]^T\right\}$.

The approximation error is exhibited by the expression

$$\varepsilon = y - \hat{x}, \quad (2)$$

where $\hat{x}(t) = \hat{a}_1(t)\sin\left(\hat{\omega}_1(t)t + \hat{\varphi}_1(t)\right)$ is a recovered harmonic component. Moreover, it is evident that the more components ξ(t) of the function will be recovered by the relevant generators of the approximating functions the less error (2) will be.

And also let the energetic function of the error be exhibited by the mean square error

$$E = \frac{1}{2}\varepsilon^2. \quad (3)$$

The function (3) is the function of three variables, that is E(A, ω, φ) or E(ф). The task of the approximation is to seek such an algorithm of variation of elements of vector ф, with which minimization of the function (3) takes place, i.e. the search for such a value $\bar{\phi}$ of the vector ф, to which extreme value of the function E (minimum), where the condition would be realized:

$$E(\phi) \geq E(\hat{\phi}), \quad \forall E \in \Phi, \quad (4)$$

where Φ is a permitted area or an area of the possible values for the vector ф, determined by the limitations

$$a \in [a_{\min}, a_{\max}],\ \omega \in [\omega_{\min}, \omega_{\max}] \text{ and } \varphi \in [\varphi_{\min}, \varphi_{\max}]. \quad (*)$$

At this stage we have approached to the task of seeking the extreme (4) (minimum) of the energetic function (3). The function is differentiable by all the elements; however the expression (2) assumes non-linear conversion of the elements for the input vector ф. The latter circumstance challenges the possibility to apply gradient algorithms mostly recommended by themselves in the extreme systems [5,6,7].

The proposed method of tracking over the parameters of the main (and, in general, of any) harmonic of the distorted signal, makes possible to provide unique, stable and convergent solution of the non-linear dynamic system. The obtained algorithm provides the unique asymptotic trajectory, being periodical and lying in the vicinity of the approximated function – target harmonic of the signal. This method may be successfully applied in design of the multivariable systems for identification of external parameters in the water transport and in other autonomous electric power systems. A number of existing solutions with which the proposed system may be compared is rather limited. For example, such distributed methods as fast or discrete Fourier transform are beyond the comparison in connection with the fact that with the frequency shift the component of the input signal is expressed itself as so-called effect of leakage as a result of which the frequency deviation for 5 Hz causes the appearance of errors in the evaluation of amplitude more than 10%. The comparative analysis of the operation of the designed system and extended Kalman filter produces the following results of modeling. Application of extended Kalman filter with availability of the 5th and 7th harmonics besides the main harmonic with amplitudes 10% and 5% respectively, does not allow having an error less than 4%. At the same time proposed by the author system under the same conditions has an error not exceeding 0.2% by the frequency. And if to use a filter of low frequencies by the signal of the restored frequency, the error reduces to the level less than 0.04%.

3. Practical implementation

The simplicity of the proposed algorithm allows to implement multivariable approximator with minimum requirements to the computational hardware of the device. The simplest and the most effective algorithm with computational function or a FP tabular model may be implemented in the FPGA. FPGA architecture, its flexibility and possibility to implement parallel computational processes makes them the most promising platform for the practical implementation of the reviewed tracking system [7, 8].

Modeling of the scheme operation our model for realizing system by means of FPGA and generation of the firmware code were made by means of software Xilinx System Generator in Matlab 14. Spartan 6 in Xilinx was chosen as FPGA. This realization of the described algorithm is used for acquisition of the main harmonic of the circuit voltage in order to provide correct operation of automatic voltage regulators of the ship’s synchronous generators (AVR for the SG) under the conditions of high distortion of voltages and currents in the ship’s circuit.

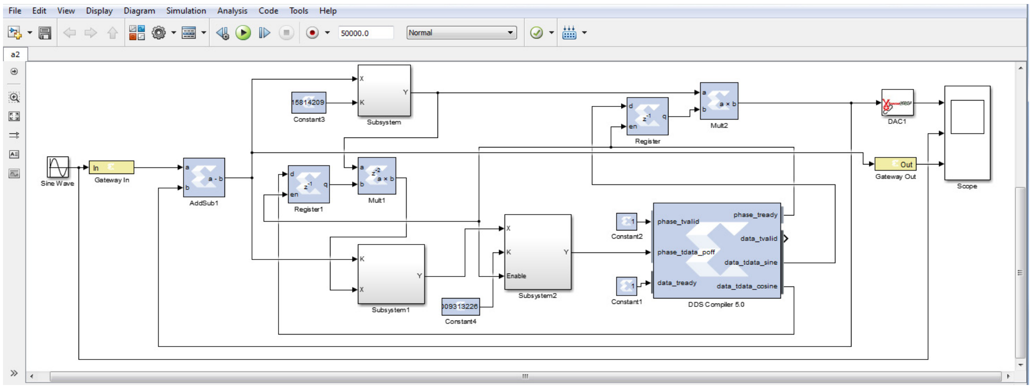

Fig. 2. Configuration of FPGA for implementation of the system.

As it is seen from a small number of the required computational resources, not exceeding even 2% of the available ones in applied FPGA, a multivariable system of parallel restoration of a number of harmonic components of the distorted signal may be developed on the basis of one microscheme.

Conclusion

For the limited power autonomous AC distribution systems, the power quality problem and the means of keeping it under control, is a growing concern. This is due to the increase in the number of non-linear power electronic equipment used in the presence of sensitive electronic equipment. For the water transport autonomous electric power systems one of the most essential tasks for their systems of the automatic controls is accurate calculation of variable harmonic components in the non-sinusoidal signals. In the systems with limited power, that operating with full semiconductor capacity the forms of line currents and voltages are greatly distorted, and generators produce voltage with inconsistent frequency, phase and amplitude. It makes calculation of harmonic composition of the distorted signals be a non-trivial task. In this paper, a task of acquisition of non-stationary harmonics of currents and voltages in the autonomous circuits of water transport craft for filter-compensating devices and AVRs was solved by simple and effective mathematical tools, which were found making possible to solve the outlined task by means of FPGA. It allows restoring simultaneously dozens of target components. For the future, it makes sense to upgrade the system so it could calculate the quantity of energy needed to compensate tracked harmonics automatically.

References

[1]. B. Singh, K, Al-Haddad and A. Chandra, "A Review of Active Filters for Power Quality Improvements," IEEE Trans. on Indusinal Electronics, Vo1.46(5), pp.960-971, Oct. 1999.

[2]. W. M. Grady, M. J. Samotyj, and A. H. Noyola, "Survey of Active Line Conditioning Methodologies," IEEE Trans. on Power Delivery, Vol. Pm-5(3), pp. 1536-1542, JUIY 1990.

[3]. R. Yacarnimi and J. C. Oliveira, " Harmonics in multiple Converter System: A Generalized Approach," IEE Proceeding, Vol. 127, No. 2, pp. 98-106, March 1980.

[4]. S. N. Govindarajan et. al., "Survey of Harmonic Levels on the Southwestern Electric power Company System," IEEE tram. on Power Delivery, Vol. 6, No. 4, pp. 1869-1873, Oct. 1991.

[5]. IEEE Working Group on Power System Harmonic, "Bibliography of Power System Harmonics, Part 1 and Ii," Papers 84WM 214-3, IEEE PES Winter Meeting, January 29-Febniary 3, 1984.

[6]. IEEE Working Group on Power System Harmonic, "Power System Harmonics: An Overview," XEEE Dans. on Power App. Syst., PAS-102 (8), pp. 2455-2460, Aug. 1983.
[7]. M. D. Cox and A. Mirbod, "A New Static Var Compensator for an Arc furnace," IEEE Trans. on Power Systems, Vol. PWRS- l(3): 110-1 19 August 1986.
[8]. G. Manchur and CC. Erven, "Development of a Mode1 for Predicting Flicker from Electric Are Fumaces," IEEE Tran. On Power Delivery, Vo1.7, No. 1, pp. 416426, January 1992.