

DSP-BASED INSTRUMENT FOR POWER QUALITY MONITORING ON SHIPS

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Abstract – The paper is to present the new DSP-based device shown in the wake of hitherto development of power quality instrumentation for power quality assessment in ship systems. The basic features of the new power quality estimator-analyser are described. Further, the design of its new commercial version is shown and discussed.

Keywords: power quality, measurement instrumentation

1. INTRODUCTION

The term power quality has various meaning but usually it should be understood as supply voltage quality completed but current quality [1-2]. The proper assessment of power quality requires determining of many different parameters. Therefore, instrumentation designed for the aim is multi-parameter device and utilizes numerous methods and algorithms of signal processing [2]. The most time consuming task is waveform assessment. This requires the appropriate methods and tools if on-line measurement capabilities are desired. There are quite a few methods of waveform parameters estimation but, arguably, the most popular tools is discrete Fourier transform DFT, especially its fast algorithm called fast Fourier transform FFT. Unfortunately, FFT has commonly known downside. On the one hand, it requires the particular number of samples, usually power of two. On the other hand the input data set should contain integer number of cycles of all signal components in order to avoid consequences of spectrum leakage. This can be a problem if fundamental frequency of signal fluctuates. During last twenty years various techniques were developed for dealing with variations of input signal parameters. The most discussed solutions concern the interpolation in time or frequency domain [3] or synchronization of sampling frequency [4]. In some papers application of other tools for voltage waveform assessment has been proposed. First of all discrete wavelet transform DWT has to be mentioned. The tool is widely used for transient states detection and evaluation but some authors proposed its application in the form of wavelet packet decomposition WPD for harmonics assessment [6]. However, it seems that instruments based on other principles of waveform assessment lack simplicity and/or do not enable comparable frequency resolution. Therefore, the most of commercial power quality devices still utilizes FFT as the basic algorithm for harmonics and interharmonics assessment.

2. STANDARDS AND INSTRUMENTATION FOR POWER QUALITY ASSESSMENT

The recommended methods of measurement of power quality parameters were defined in IEC Standard 61000-4-30 [7] and IEC Standard 61000-4-7 [8]. The latter standard deals with problem of waveform assessment in the frequency range up to 9 kHz. Especially, a following structure measurement instrument was proposed [8]:

- input circuits with anti-aliasing filter,
- A/D converter with sample-and-hold unit,
- synchronisation and window-shaping unit if necessary,
- DFT-processor.

The recommended width of measurement window is 10 cycles for 50 Hz systems and 12 cycles for 60 Hz systems. Therefore synchronisation of sampling frequency is proposed [8]. The window shall be synchronized with integer number of input signal cycles in such a way that the time between the first sampling pulse in considered window and the first sampling pulse in the next window is to be equal to duration of previously specified number of cycles, with maximum permissible error of $\pm 0,03\%$ [8]. The rectangular window shall be used. Hanning window is allowed only in the case of loss of synchronisation. Further, it was assumed that normally FFT algorithm will be used [8].

The above described method of harmonics and interharmonics assessment is commonly applied in various commercial power quality analyzers, e.g. Fluke 434/435 three phase power quality analyzer [9] or PowerVisa™ power quality analyzer [10]. Unfortunately, the method lacks of versatility and should not be used in some systems, especially isolated power systems like ship systems. The proper synchronisation of sampling frequency is nearly impossible and application of Hanning window can lead to dubious results in these systems. It is caused by relatively fast fluctuations of power quality parameters. The concept of harmonics and interharmonics grouping proposed in IEC Standard 61000-4-7 [8] is no solution as well. The details can be found in [11]. Therefore, discarding FFT as basic tool of power quality analysis was suggested [12] and other methods and algorithms were developed. Especially, application of DWT, DFT and chirp z-transform CZT in complementary way was proposed [13-15]. It was behind prototype of low cost, original measurement device, developed for scientific purposes in Gdynia Maritime

University. This new solution is shortly described in the Section 3.

However, the main aim of the current paper is to describe and shortly discuss reasons for the estimator-analyser development as well as proposed hardware structure of the expanded version. This will be described in Section 4.

3. THE PROTOTYPE OF ESTIMATOR-ANALYSER OF POWER QUALITY

The prototype of the new device for power quality assessment called estimator-analyser was developed in Gdynia Maritime University in co-operation with Institute of Power Engineering, Gdansk Division. The most important feature of the unit is its ability to correct operation under condition of great changeability of input signal parameters and it does not require synchronisation of sampling frequency. The estimator-analyser is two-processor device, including digital signal processor ADSP 21364, and it is capable of working in stand alone condition or in co-operation with external device, e.g. PC computer. The instrument can operate in two basic modes: estimator and analyser. In the former mode only parameters which current values exceed user defined limits are determined, whereas in the latter mode all defined parameters are calculated. In the estimator mode less computational power is required, so it enables increase in sampling frequency (currently sampling frequency equal to 148917.8 Hz is utilized). The feature was achieved due to implementation of original distortion band factors DBF for rough waveform assessment in the estimator mode [14]. Finally, estimator-analyser is capable of determining the following voltage quality parameters [12]:

- r.m.s. value,
- frequency,
- unbalance,
- newly introduced distortion band factors DBF,
- voltage dip estimation (value and duration),
- harmonic subgroups measurement up to 50th harmonic,
- interharmonic centered subgroups measurement in the range up to 50th harmonic,
- sub-harmonic,
- dc component,
- groups of high frequency components with bandwidths approximately 200 Hz in the range from 50th harmonic up to 9 kHz,
- transient and notching detection and assessment,
- power quality temperature factor for assessment of additional temperature rise of windings of induction motors [16].

The picture of the estimator-analyser is shown in Fig. 1 [12].



Fig. 1. Front panel of the estimator-analyser of power quality.

The prototype of estimator-analyser uses several screen types in order to present various measurement results in both operation modes as well as setting of basic parameters of the device. The exemplary photograph of the device display is shown in Fig. 2.

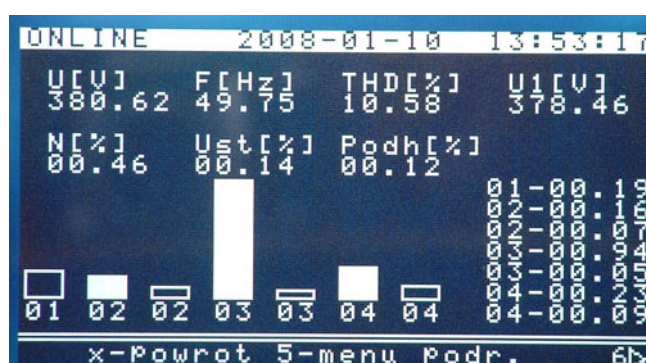


Fig. 2. An example of screen of estimator-analyser prototype; analyser mode and display of harmonic and interharmonic subgroups up to 4th harmonic.

The estimator-analyser was tested under laboratory conditions for several various testing signals as well as in ship environment [17]. The positive results of the experimental verification were premises for manufacturing of the second piece of estimator-analyser. The total cost of the manufacturing did not exceed 2000 EUR, including taxation.

The details of methods and algorithm applied in the prototype of this new device for power quality assessment will be published in separate papers together with results of its experimental verification. This paper is focused on the planned device further development and motivation for the undertaken work.

4. DESIGN OF THE EXPANDED VERSION OF ESTIMATOR-ANALYSER OF POWER QUALITY

The complete assessment of power quality in ship systems requires an estimation of more parameters than current estimator-analyser is capable of. Therefore, new version of the estimator-analyser was designed and it is now under construction. First of all, it is capable of current and power parameters monitoring. Especially, the later should be underlined since system for power quality estimation on ships is to control power distribution between generating sets working in parallel. The improper power and current

distribution increases a risk of overloading of generating set (generator and prime mover) and, as consequence, increases a risk of black-out in whole ship's system. The consequences are easy to predict.

The purposes of power quality assessment in ship's system are to be taken into account as well. Basically there are two aims of the monitoring of power quality in these systems: evaluation of conformity with respective standards and trouble-shooting applications. The first task is carried out mainly by surveyors of ship classification societies, whereas the second one is carried out by ship's crew. The surveys carried out by ship classification societies are carried out during ship classing and portable devices would be appreciated. The monitoring carried out by ship crew is carried out on continuous everyday basis and device built in main switchboard can be used.

Further, the device structure and applied algorithms should be as versatile as possible in order to increase scope of possible applications. Simply put, designing a device dedicated only to ship's application would be economically unjustified. Therefore, the software and hardware of the expanded version of estimator-analyser should enable its application in various power systems, isolated or not. First of all, the estimator-analyser is to monitor power quality in three-phases three-wires and four-wires networks. Moreover, it should be capable of measurement currents as well as active and reactive powers in these both networks. But in the case of ship systems the load distribution between generating sets working in parallel. It was assumed that at least three generating sets are to be monitored concurrently.

Taking into account the above described reasons and minimal requirements as well as the results of the prototype investigation, the structure of the expanded version of estimator-analyser was determined. The simplified hardware structure of the new instrument is depicted in Fig. 3.

The signal conditioning unit will consist of programmable antialiasing filters LTC1564. The cut-off frequency of the former estimator analyser was 60 kHz but it will be significantly increased, due to increase in sampling frequency in the new version. The increase of considered frequency band is planned up to 100 kHz (planned sampling frequency 250 kS/s). As a result, an enhancement of transient monitoring capabilities will be achieved. It should be added that the sampling frequency is sufficient for determining parameters of quite a number of transients and notching observed in real ship power systems [18].

In the case of voltage channels a voltage divider and isolation amplifiers AD215 will be used. The estimator-analyser will be supplied with six external current probes.

The expanded version of estimator-analyser will be two-processor device. Such a solution was positively tested in above mentioned prototype of estimator-analyser. DSP is to carry out all signal processing tasks and control of ADC converters, whereas GPP is to control remaining peripherals and communicate with external devices. Due to such a solution the resources of DSP are reserved for the most time-consuming procedures of signal processing, without unnecessary interruptions (user or external devices). Therefore, it is easy to design software for real-time gapless

power quality monitoring. But it should be mentioned that more powerful processors (especially DSP) will be used.

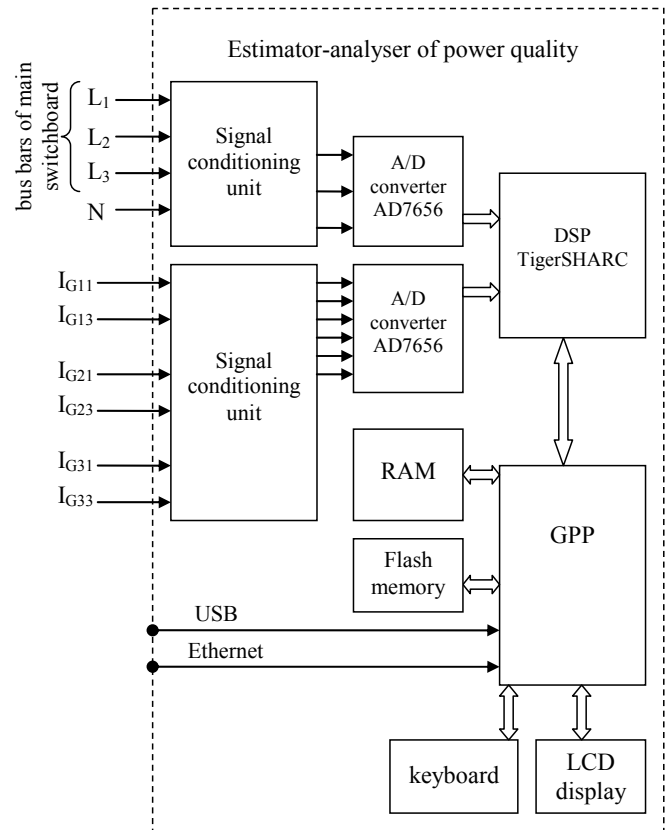


Fig. 3. Simplified hardware structure of the new version of estimator-analyser of power quality; DSP – digital signal processor, GPP – general purpose processor.

The depicted in Fig. 3 hardware configuration enables an evaluation of power distribution between three generating sets working in parallel in three-phase and three-wire systems. It should be mentioned that it is typical configuration of ship networks. The exemplary connection of one generating set with instrument under construction is shown in Fig. 4.

The calculation of active power can be carried out by following formula [19]:

$$P = \frac{1}{N} \cdot \left(\sum_{k=0}^{N-1} u12_k \cdot i1_k + \sum_{k=0}^{N-1} u32_k \cdot i3_k \right) \quad (1)$$

The reactive power can be calculated on the basis of the very same algorithm (it means that the same sub-routine can be used) but it requires shifting starting address of voltage samples by $N_{T/4}$, where T is a period of input signal. In fact it means shifting the voltage signal by 90° . The solution can lead to flawed results in the case of distorted signals [20]. Fortunately, it seems that in the case of ship systems chiefly reactive power of fundamental components is to be considered (diagnostics of voltage controller operation). Therefore, the simple solution is taking into account only fundamental component of currents. It requires low-pass

filtration. Finally, the reactive power of fundamental components can be calculated as follow:

$$Q_1 = \frac{1}{N} \cdot \left(\sum_{k=0}^{N-1} u12_{k-N_T/4} \cdot ifund1_k + \sum_{k=0}^{N-1} u32_{k-N_T/4} \cdot ifund3_k \right) \quad (2)$$

The proposed solution simplifies hardware structure and software for active and reactive power calculation as much as possible.

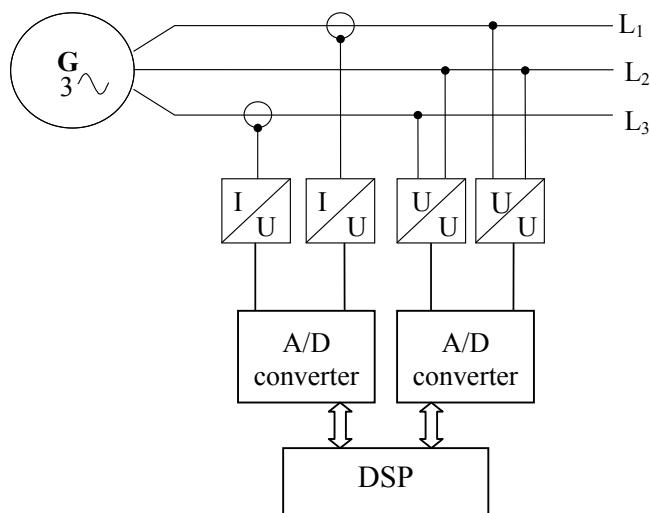


Fig. 4. The scheme for determining the power parameters for one generating set in the three-phase and three-wire system.

5. FINAL REMARKS

Nowadays used analysers for power quality assessment display some disadvantages in relation to application in isolated electrical power networks. It concerns used methods of measurement of power quality parameters as well as their hardware. Typically, these analysers are equipped with four current input channels. It is insufficient for assessment of power distribution in ship systems. Their hardware structure enables a calculation of respective parameters only for two generating sets working in parallel, whereas in many cases three generators are connected together in ship systems. Obviously, the software of commercial analysers is inappropriate as well.

Finally, the new solution for power quality assessment in ship systems was proposed. Comparing with current solutions, it utilizes the new methods of waveform assessment and it has increased number of current input channels. Due to the latter feature, the device will be capable of determining active and reactive power distribution between up to three generating sets working in parallel.

Although it was designed for marine applications, the applied methods and algorithms can be utilized for other systems as well. Simply put, the ship power system can be treated as the hardest case from power quality assessment point of view. The additional input for neutral line N will be provided in order to increase instrument versatility.

Obviously, device's software has to be designed accordingly.

Finally, the device will be capable of power quality assessment in one-phase two-wire systems, three-phase tree-wire systems and three-phase four-wire systems.

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