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WIELOKANAŁOWY CYFROWY DYSKRYMINATOR ZAUTOMATYZOWANEGO SYSTEMU MONITOROWANIA ŚRODKÓW SYNCHRONIZACJI CZASU SIECI ELEKTRYCZNYCH SMART

Streszczenie: Rozważany jest automatyczny system monitorowania do synchronizacji czasu z wielokanałowym adaptacyjnym cyfrowym dyskryminatorem fazy. Oferujemy nowoczesną implementację sprzętową elementów automatyki z wykorzystaniem programowalnego układu logicznego ALTERA Cyclone IV EP4CE10E22C8N, który jest rozwijany w środowisku programowym Quartus Prime Lite Edition. System zapewnia wielokrotne zwiększenie wydajności procesu monitorowania sygnałów synchronizacji czasu oraz upraszcza wizualizację i analizę danych wykorzystywanych przez operatora do podejmowania decyzji w procesie zarządzania siecią elektroenergetyczną SMART-GRID.

Słowa kluczowe: monitoring, synchronizacja czasu, automatyzacja, SMART-GRID.

MULTI-CHANNEL DIGITAL DISCRIMINATOR OF AUTOMATED MONITORING SYSTEM OF SMART-GRID POWER NETWORKS TIME SYNCHRONIZATION TOOLS

Summary: An automated monitoring system for time synchronization with a multi-channel adaptive digital phase discriminator is considered. We offer modern system implementation of hardware components of the automated system using a programmable logic circuit ALTERA Cyclone IV EP4CE10E22C8N, which is developed in the software environment Quartus Prime

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Lite Edition. The system provides a multiple increase in the productivity of the process of monitoring time synchronization signals and simplifies the visualization and analysis of data used by the operator to make decisions in the process of managing the power grid SMART-GRID.

Keywords: monitoring, time synchronization, automation, SMART-GRID.

1. Introduction

Energy-efficient operation of SMART-GRID power networks requires solving problems of operation modes, stability, and organization of automation systems [1÷3]. These tasks are directly related to the level of informatization and intellectualization based on Smart-technologies, both control systems and monitoring of the electric power networks equipment parameters with reference to real time.

There is a problem of increasing the energy efficiency of integrated power supply systems due to the reliable provision of time synchronization signals for continuous equipment operation modes parameters stability monitoring. The use of synchro information from other countries (GPS, GLONASS, GALILEO, BEIDOU) as time synchronization signals poses a threat and increases the risks of losing the supply equipment monitoring results reliability. It should be noted that the main disadvantages of satellite systems are the dependence of signal quality on non-stationary characteristics of the open environment of radio signal propagation, as well as the lack of signal protection against intentional distortion [4].

It is also obvious that the increase in the share of information flows in the power grid control system SMART-GRID brings to the fore an automated system for monitoring equipment parameters as a central component that provides measurement, transmission, processing and storage of data [1, 4÷7]. It can be argued that the efficiency and reliability of operation modes directly depends on the accuracy and timeliness of the information obtained from the measurement results of the control system and transmitted to the operator to perform the actual functions of power grid management.

In view of the above, it is important to conduct research aimed at the scientific and practical development of an automated monitoring system (AMS) of time synchronization tools and its components.

2. Analysis of publications

Time synchronization tools for SMART-GRID power networks, based on the operation of which quasi-periodic signals are used to assess quality indicators, require measurements of time or phase relationships between the reference and controlled signal [6÷8]. Modern control systems and clock signals time parameters measurements include sensors as primary transducers that convert electrical quantities into electrical digital signals, presented in the form of measurement results digital data [6÷8].

Traditionally, the main measuring instruments and means of measuring time ratios are oscilloscopes, receivers of reference frequency signals, digital time interval meters.

Comparison methods are used, in which the measured period or frequency is compared with the reference frequency of the sample oscillations source [9]. It is obvious that their implementation requires a reference generator of higher accuracy, so ideally, the equipment for frequency-time measurements should form a single set of devices providing the ability to perform measurements with their direct "binding" to the state standard of frequency and time. In this case, all these methods can provide minimal error and even theoretically no systematic error [9]. The conditions for the occurrence of such an event for each of the methods are different, but they are based on the presence of a high-precision reference (reference) signal on the basis of which measurements are made.

Note that the measurement process is reduced to a comparison with a unit of a certain physical quantity in order to obtain quantitative information, and under control, the physical indicator is compared with its norm to determine the deviations of this indicator (qualitative characteristics of the object - "suitable" - "unsuitable"). which accordingly simplifies the decision-making process by the operator) [10].

In essence, the tasks of the control system, according to the standard [10], are to conduct two main operations: obtaining information about the actual state of the object, the characteristics and indicators of its properties (primary information); comparison of primary information with pre-established requirements, norms, criteria (secondary information) ".

Therefore, the process of object control is reduced to checking the compliance of signs and indicators of its properties to the established technical requirements [8, 10]. On the basis of the data received by means of AMS the decision-making by the operator concerning qualitative indicators of signals of synchronization of time and possibility of their use for the decision of problems of management of work of the electric power network SMART-GRID is carried out.

The aim of the work is scientific and practical development and experimental research of an automated time monitoring system using a multi-channel digital discriminator, which provides a multiple increase in the productivity of the control process and simplifies visualization and analysis of data used for decision making in SMART-GRID power grid management.

3. Presentation of the main research material

Improving the productivity and reliability of the process of monitoring time synchronization means is provided by using the method of multi-channel monitoring [1, 6÷8], based on which the AMS scheme of time synchronization means of SMART-GRID power networks is developed, which is shown in Fig. 1. The hardware structure of the AMS consists of a multi-channel digital discriminator (MCDD), which is implemented on a programmable logic circuit Cyclone IV EP4CE10E22C8N. MCDD is one of the main AMS components, which essentially performs the functions of the primary sensor, which provides the primary conversion of the time interval (controlled indicator) error into a digital signal of a given format. MCDD together with the multiplexer and the reference signal shaper are components of the primary converters block (PCB) of SMART-GRID electric networks time synchronization means AMS (Fig. 1).

PCB AMS performs measurements by converting the input physical quantity - the phase difference (time interval) in the corresponding output signal, presented in a digital code combination form. Together with the measurement process, the frequency of the clock frequency pulse sequence, amplitude and shape of the clock signals is monitored. The results of these processes, presented in digital format, are processed by a microcontroller [6] and transmitted in text format via an IP network to a centralized control system (a personal computer can be used for remote control) where they are processed using software and presented to the operator. technologist for decision making.

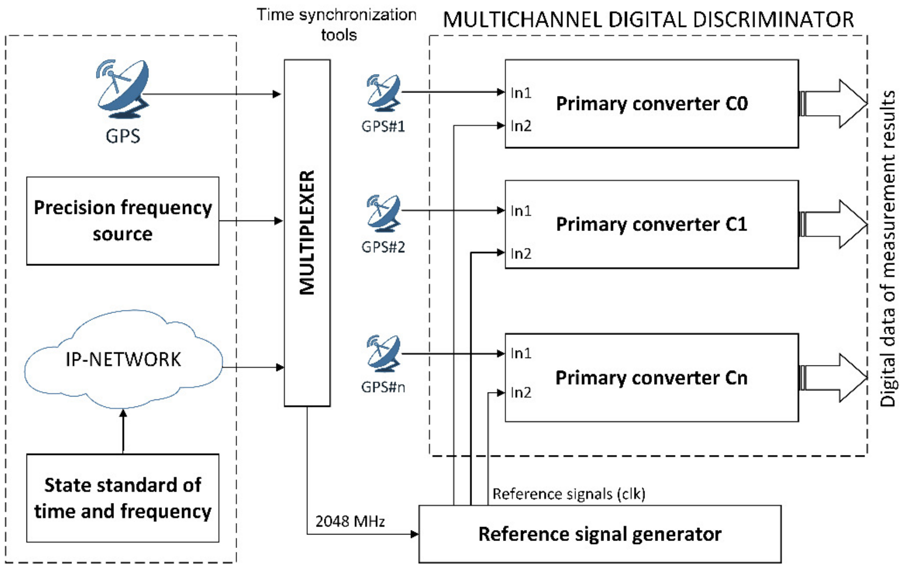

Figure 1. Scheme of the electric power networks SMART-GRID time synchronization monitoring automated system

The analysis of the realization principles which are put in creation of the PCB block gives the chance to carry it to a class of intelligent sensors. Such sensors are equipped with built-in microcontrollers that work according to rather complex algorithms and allow to provide PCB with many additional functionalities, such as signal filtering, adaptation, correction, failure detection, reconfiguration of the measuring circuit, etc. The primary conversion of the input physical quantity - phase difference into the corresponding output digital signal in the PCB can be implemented using an asynchronous digital time discriminator, which refers to information devices and can measure the time difference of the pulse sequences [1].

Asynchronous digital time discriminator allows asynchronously (at any time, without the need to synchronize the processes of obtaining digital values of the measured time difference between the pulse sequences and their reading) to obtain a code combination that determines the time difference between the first and second pulse than for half of the measurement time interval, limited only by the bit rate of the pulse counters, static registers and switch [11]. In this case, changing the bit rate of the discriminator pulse counters, you can change its range of measurements according to the established technical requirements.

The disadvantage of the asynchronous time discriminator is the lack of control over the state of the pulse counter, relative to the additional pulse counter state, at the measurement period beginning, which does not provide a reliable code combination of two mutually independent periodic pulse sequences time error.

In order to eliminate these shortcomings, an original device was developed - an adaptive digital phase discriminator (ADPD), for which a patent of Ukraine for the invention was obtained [12]. The device, the scheme of which is shown in Fig. 2, provides adaptive controlled generation of a code combination on the magnitude of the time interval error between two mutually independent quasi-periodic pulse sequences and increase the reliability of the measurement results, which are presented in digital form.

Figure 2. Scheme of adaptive digital phase discriminator

An adaptive digital phase discriminator comprising an input to which a signal of the first input pulse sequence is applied (Input 1) and an input to which a signal of the second input pulse sequence (Input 2) is applied. The digital control inputs provide the possibility of pre-setting the pulse counter, and the digital outputs of the device (n-outputs) provide the formation of a code combination that corresponds to the time mismatch between the first and second input pulse sequences.

The analysis of the considered discriminators substantiates expediency of use as the primary converter of the multichannel digital discriminator of PCB AMS of the adaptive digital phase discriminator. The ADPD scheme is shown in fig. 3 in the form of a module zh023, which was created using the software Quartus Prime Lite Edition [12]. The ADPD has a CLK input to which the signal of the first input pulse sequence (reference signal) and an input R to which a signal from the second input pulse sequence is applied, as well as inputs c1 and BNE, which provide synchronous reading from digital outputs of the device D5… D15 code a combination corresponding to a time mismatch between the first and second input pulse sequences. The controlled generation of the code combination on the magnitude of the error of the time interval between two mutually independent quasi-periodic pulse sequences is provided by the digital input W.

Fig. 4 shows a diagram of the module zh023 ADPD, which includes typical digital elements: AND2, NOT, 74163, 74374. The technical solution of the invention provides the possibility of implementing on a single programmable logic circuit Cyclone IV EP4CE10E22C8N multi-channel structure of the digital phase discriminator. MCDD forms code combinations with increased reliability of measurement results presentation in digital form and the possibility of code combination controlled formation separately for each channel.

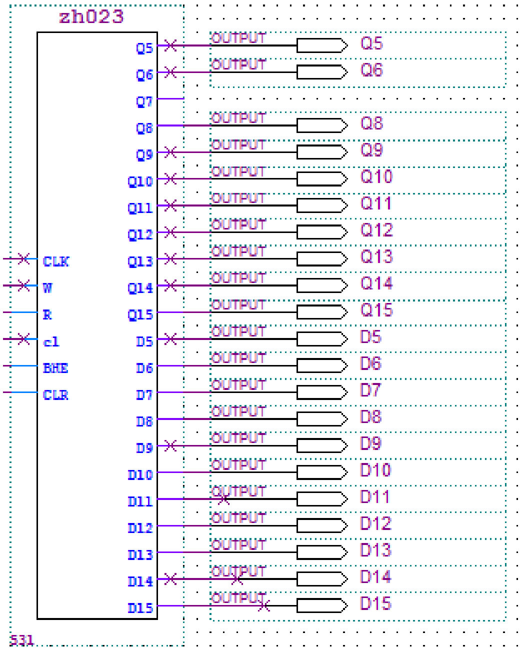

Figure 3. ADPD scheme, which is presented as a zh023 module

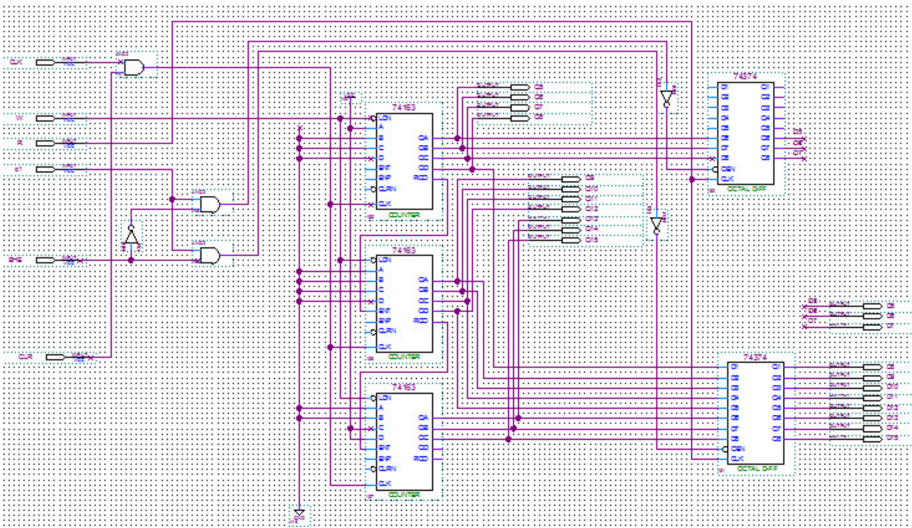

Figure 4. The scheme of the module zh023 ACFD, consisting of typical digital elements

To ensure the fulfillment of the power networks SMART-GRID time synchronization AMS formulated tasks has the following service capabilities [6 - 8]. First, it visually displays in real time the current measurement results of all channels in text format, as well as builds dynamic graphs for selected channels. Second, the AMS displays the presence / absence of alarm messages regarding the current status (presence / absence of an accident at a given time). In addition to visualization, there is a possibility of specialized processing of measurement results, as well as decentralized data storage for a fixed period of time. Third, the AMS provides direct and reliable results of measurements of controlled synchronization signals with centralized data accumulation and visual representation of the signal characteristics in real time at the control point [6] - [8]. At the same time, it is possible to access data on measurement results for previous periods, as well as the ability to "stitch" individual measurement arrays.

In order to conduct experimental studies of MCDD AMS, implemented on the ALTERA Cyclone IV chip, a laboratory stand with two GPS receivers and a reference highly stable thermostated quartz generator MXOCS, the image of which is presented in Fig. 5.

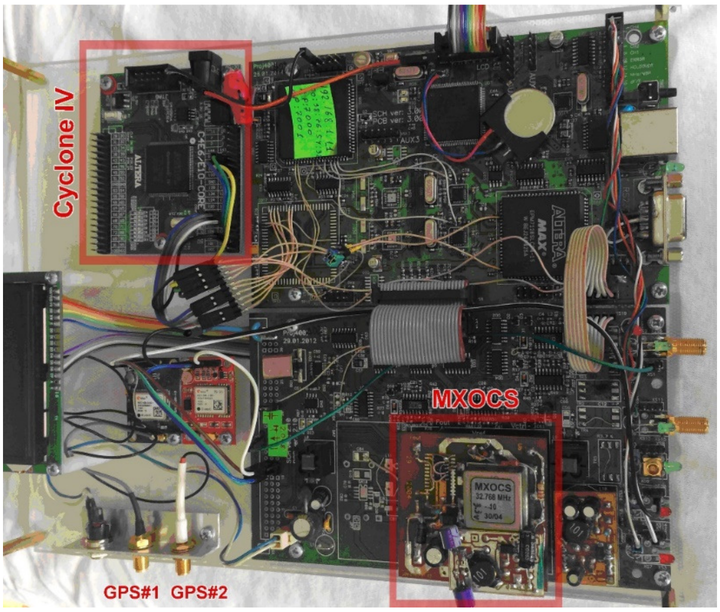

Figure 5. Laboratory stand MCDD AMS with two GPS receivers

Field experimental researches of MCDD AMS were carried out under the condition of connection of synchronous signals of type 1pps, which are formed by two sets of receivers GPS # 1 and GPS # 2 with own antenna systems. The parameter determined in the process of research is a function called the time interval error function:

$$\mathrm{TIE}_{\mathrm{t}}(\tau) = \mathrm{TI}_{\mathrm{t}}(\tau) - \mathrm{TI}_{\mathrm{O\Pi}}(\tau), \tag{1}$$

where the function of the time interval $\mathrm{TI_t}(\tau)$ is defined by the expression $\mathrm{TI_t}(\tau) = \mathrm{T}(t+\tau) - \mathrm{T}(t)$ which is a measure of the time interval τ, which begins at time t, for the studied signal (provided that there is an ideal reference signal) [9], in this case

$$\mathrm{TIE}_{\mathrm{t}}(\tau) = \mathrm{TI}_{\mathrm{t}}(\tau) - \tau. \tag{2}$$

The function of the time interval $TI_{ОП}(\tau)$ of the reference signal $T_{ОП}(t)$ has the following mathematical definition: $TI_{ОП}(\tau) = T_{ОП}(t+\tau) - T_{ОП}(t)$.

The results of the MCDD AMS research under the condition of connection for monitoring the clock signals generated by two sets of GPS receivers are shown in Fig. 6 in the form of fragments of digital measurement data (results are presented to the nearest thousandth of a microsecond, for example, for the fifth second of measurements of values on the channel C0 = 1866,376 μs, and on the channel C1 = 1866,416 μs) and graphs of TIEt τ) obtained using an Excel spreadsheet. Visual analysis of both curves for 172 seconds of monitoring, which are shown in Fig. 6, shows the absence of abrupt changes ("phase jumps") of the clock signals, and their general tendency to decrease the numerical value from 1866.465 μs to approximately 1866.2 μs indicate the "imperfection" of the clock signal of the reference generator.
In this case, we can conclude that it is necessary to use equation (1) instead of (2) to determine the error functions of the time interval $TIE_t(\tau)$.
The monitoring results can be the source data for further processing in order to support the operator's decision on the management of the SMART-GRID power grid and increase its energy efficiency.

C0=	1866,421	C1=	1866,465
C0=	1866,415	C1=	1866,449
C0=	1866,390	C1=	1866,434
C0=	1866,385	C1=	1866,437
C0=	1866,376	C1=	1866,416
C0=	1866,363	C1=	1866,414
C0=	1866,351	C1=	1866,412
C0=	1866,359	C1=	1866,390
C0=	1866,348	C1=	1866,386
C0=	1866,330	C1=	1866,359
C0=	1866,317	C1=	1866,355
C0=	1866,326	C1=	1866,355
C0=	1866,315	C1=	1866,335
C0=	1866,300	C1=	1866,333
C0=	1866,302	C1=	1866,329
C0=	1866,307	C1=	1866,327
C0=	1866,292	C1=	1866,323
C0=	1866,272	C1=	1866,299
C0=	1866,269	C1=	1866,291
C0=	1866,285	C1=	1866,305
C0=	1866,280	C1=	1866,301
C0=	1866,247	C1=	1866,275
C0=	1866,235	C1=	1866,268
C0=	1866,249	C1=	1866,265
C0=	1866,240	C1=	1866,261
C0=	1866,226	C1=	1866,253
C0=	1866,232	C1=	1866,241
C0=	1866,215	C1=	1866,230
C0=	1866,222	C1=	1866,222

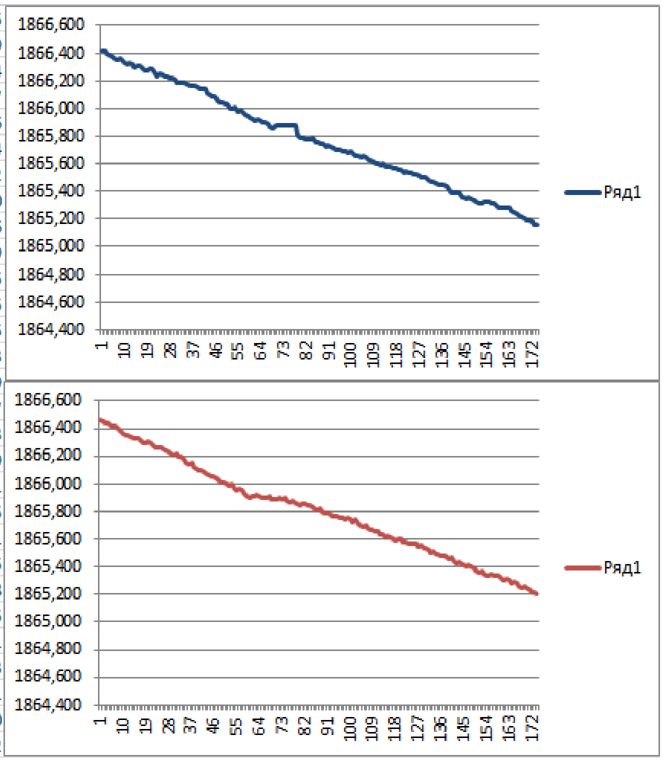

Figure 6. The results of research MCDD AMS with two GPS receivers

4. Conclusions

1. Scientific and practical development of an automated monitoring system for time synchronization using a multi-channel digital discriminator, which improves the productivity of the control process and simplifies the visualization and analysis of data used to make decisions on the management of the SMART-GRID power grid.
2. The method of converting the error of time intervals into a digital signal was further developed, using which the structure of an adaptive digital phase discriminator was developed (Ukrainian patent for invention №113473). The modern circuit implementation of the hardware components of the automated time synchronization monitoring system using a multi-channel digital discriminator, which is developed in the form of Quartus Prime Lite Edition software for the programmable logic circuit ALTERA Cyclone IV EP4CE10E22C8N
3. Experimental studies of MCDD AMS with two sets of GPS receivers were performed and quantitative values of TIEt(τ) time interval error measurements were obtained with an accuracy of thousandths of a microsecond. The results of the monitoring can serve as initial data for further processing in order to support the decision-making of the operator on the management of the SMART-GRID electricity network in order to improve its energy efficiency.

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