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APPLICATION OF THE PETRI NET AND GRAPHICAL LANGUAGE OF PROGRAMMING IN THE APPLICATION OF ARS CONTROLLER OF POWER SUPPLY SYSTEMS FOR CRITICAL APPLICATIONS

ZASTOSOWANIE SIECI PETRIEGO ORAZ GRAFICZNEGO JĘZYKA PROGRAMOWANIA W APLIKACJI STEROWNIKA UKŁADU AZR URZĄDZEŃ ZASILANIA DLA ZASTOSOWAŃ KRYTYCZNYCH

Abstract

The requirement for high reliability and safety in operating of measuring and control systems is particularly relevant in critical applications, where failure of the system can lead to large material losses and even loss of health and life of people. The above conditions require use of powerful tools and methods of modeling in formalizing of function and operation of the above system. The purpose of this publication is to present the use of Petri Net in the modeling process of the controller function of the automatic reserve switching devices of power supply system of the railway traffic control systems. The publication also shows the practical implementation of such a controller. It was implemented on the basis of the hardware platform of the CompactRIO family of controllers and the application made in the National LabView graphical programming environment.

Keywords: Petri Nets, programming of industrial automation controllers, power supply of railway traffic control systems.

Streszczenie

Wymóg zapewnienia wysokiej niezawodności i rzetelności działania systemów pomiarowo – sterujacych dotyczy zczególnie zastosowań krytycznych, w których awaria systemu może doprowadzic do dużych strat materialnych , a nawet utraty zdrowia i zycia ludzi. Powyższe uwarunkowania wymuszają stosowanie wydajnych narzędzi i metod do formalnego modelowania funkcji i działania powyższych systemuów. Celem niniejszej publikacji jest przedstawienie wykorzystania Sieci Petriego w procesie modelowania funkcji sterownika układu automatycznego załączania rezerwy urządzeń zasilania systemów steriwania ruchem kolejowym. W publikacji przedstawiono także praktyczną realizację takiego sterownika. Zrealizowano go na bazie platformiy sprzętowej rodziny sterowników CompactRIO oraz aplikacji wykonanej w graficznym środowisku programowania LabView firmy National Instruments.

Słowa kluczowe: Sieci Patrii, programowanie kontrolerów automatyki przemysłowej, zasilanie systemów sterowania ruchem kolejowym.

1. Introduction

Nowadays measurement and control digital systems (MCD systems) are commonly used in industrial processes [12]. These systems are built on the basis of hardware platforms such as PLC's, industrial computers or embedded systems. Functionality of MCD systems depends on implemented user software applications. Thus, the quality of the action of this systems is influenced not only by hardware platform, but also by its user's software. The need to ensure high reliability of the software and the reliability of the entire MCD systems is required especially in the so-called critical applications. In these applications malfunction or damage the MCD systems during theis operation can lead to abnormal functioning of the supervised process which can result in loss of life and material waste. Ensuring the required quality of MCD system in its design and prototyping process requires the use of appropriate tools and methods to formalize its functions and actions. Suitable instruments for this purpose may be Petri Nets. They are graphic and formal tools for modeling, formal analysis and design of discrete event systems. The model represented by such a net allows the analysis of the characteristics of the system´s behavior, and allows its evaluation within each phase of the system´s life cycle.

The aim of this publication is to present the possibilities of using Petri Nets in modeling MCD systems in critical application [2, 4, 5, 6, 7] which is the integrated controller of the automatic reserve switching device of the power supply ssystem of Railway Traffic Control Systems. This publication also shows the practical implementation of such the controller. It has been implemented on the hardware platform of the family of controllers CompactRIO and a software application implemented in the National Instruments LabView graphical environment [7, 8, 17].

2. Power supply system for Railway Traffic Control Systems

2.1 Railway Traffic Control Systems

Railway Traffic Control Systemes (RTCS) provide safe, reliable and efficient movement of rolling stock on the railway network [2]. Therefore, RTCS are classified as critical equipment and systems [5, 6, 7, 8]. The history of RTCS dates back to the end of the nineteenth century, when the industrial revolution introduced rolling stock for the transport of goods and then people. Initially, Railway traffic safety devices were simple, and the main role in the decision making and execution process was played by a human being. Currently mounted station RTCS are relay and computer systems or only computer systems [2, 4]. In relays and computers systems, security is ensured in the relay layer, and the setting functions are performed by a computer control panel [2]. The development of information and computer technology has led to the construction of secure computer systems. For systems of this type, PLCs or computers with "2 of 2" or "2 of 3" voting systems are used to provide the required level of security [2, 4, 8].

The use of relay and computer, computer systems requires the provision of adequate reliability and quality of power [16]. Therefore, new, more suitable power supply systems are introduced, so that they can meet the increased requirements.

2.2 Power supply systems for RTCS.

The current requirements for the design and manufacture of power supply systems for

RTCS are contained in Chapter 13 of Management Order No. 1/2014 of PKP Polish Railways. [16]. General requirements (§ 72) of this chapter are to say that the primary sources of power supply for station RTCS are power grids that meet the requirements for:

- regulations for the construction of power equipment,
- principles of protection against overvoltage,
- principles of shock protection

In § 73 of the above chapter on power supply station RTCS is required to:

- electricity was supplied from terminals from the non-traction line (LPN). This power supply should be provided by two 3x400/230V meshes power network,
- power supplies have built-in backup (emergency) power supply in the form of a combustion-power unit (chiller), inverters or UPSs,
- for switching equipment and backup power supply, bypass systems should be provided,
- voltage fluctuations in power supply and backup power supply sources shall not exceed ± 10 % of nominal value,
- circuits for powering electronic and computer systems should be protected against overvoltage protection,
- dedicated AC circuits of stations RTCS and circuits supply DC relays requiring uninterruptible power supply, should be supplied with power during the changeover from dedicated power sources such as inverters. Inverter batteries must ensure their operation for 1 hour,
- the power supply system of stations RTCS should have:.
    - equipment for the control and automatic switching of power lines, equipment for controls and automatic (or manual) switching of the power line to a backup source;
    - components for the distribution of electricity for individual circuits;
    - equipment for signaling the status of power supply equipment and the table of setting fuses (in the control room).

The general structure block diagram of power supply system intended for relays and computer, computers station RTCS is shown in Figure 1 [13, 14, 15, 16].

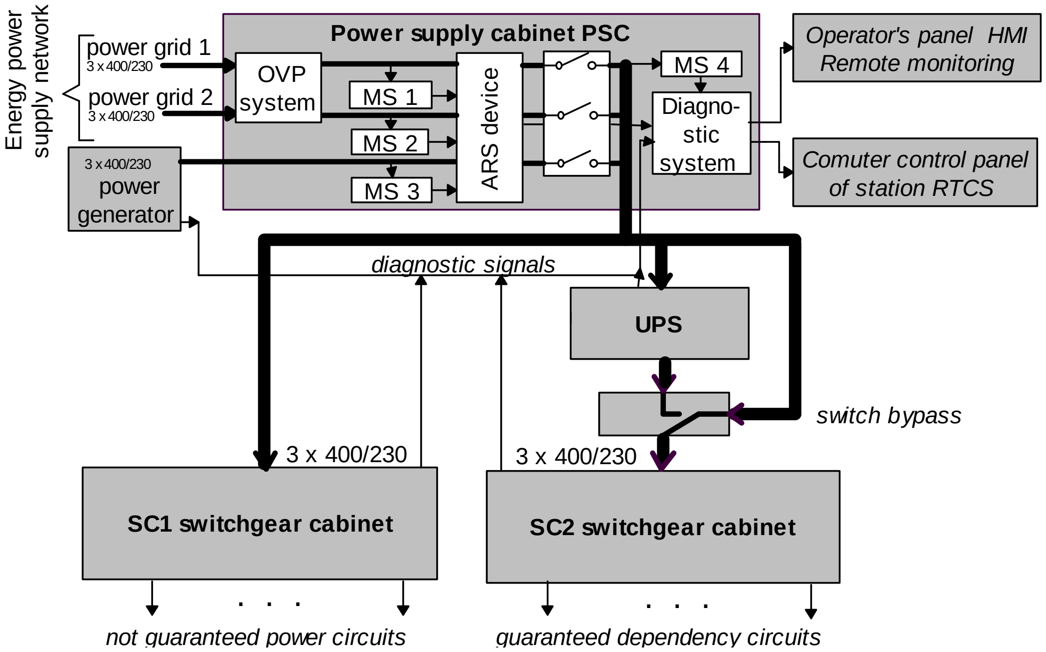

Fig.1 General structure of the station RTCS's power supply system.

As shown in the above block diagram, the power supply system are powered from 2 independent 3x400/230 V power networks. A spare power source is also included in the system - the power generator. In the power supply cabinet PSC, on the power lines are the overvoltage protection elements OVP. The parameters of the mains power supply and the backup power source (power gemerator) are measured by measuring systems MS1, MS2 and MS3. The MS4 measurement system measures the power supply parameters at the output of the automatic reserve switching device (ARS device). These systems in the current solutions are modules for measuring power supply parameters. They measure not only the correctness of the power supply voltage, but also the frequency and total harmonic distortion THD and the correct phase sequence. In the case of an incorrect value of any of the measured power parameters, the ARS devices will switch the power supply so that the power supply to the station RTCS is uninterrupted. The ARS device, in addition to its control logic, also has a contactor-mechanical coupling that provides power to the device from only one power source, even in the event of an ARS failure. The voltage of power supply from the ARS device is divided into two power distribution cabinets. The first one (DC1 switchgear cabinet) supplies components of station RTCS with power supplies not guaranteed. This means that these components, in the absence of power, will not endanger the safety of railway traffic at the station. The second distribution cabinet (DC 2 switchgear cabinet), powered by an uninterruptible power supply (UPS), supplies those station equipment of RTCS that must have a guaranteed power supply. These include: light circuits that prohibit track signalers, dependency DC relays, power supplies for dependency computers, and computer control panels. The above mentioned cabinets contain appropriate, bypass systems, which can be used to manually switch power sources. The block diagram in Figure. 1 also shows a diagnostic system that collects measurement data and status data of power components and devices. This information is saved in the recorder of this system, and the selected text or graphic information (pictogram) is displayed on the operator panel display. From the non-voltages binary output of diagnostic system, the required information is transferred to the computer control panel of station RTCS.

2.3. ARS controller

` Based on the analysis of the requirements and technical solution of the currently produced power supply systems of station RTCS (p. 2.2) development of an integrated ARS controller was proposed. This controller integrates power components such as: measuring systems MS1, MS2, MS3 and MS4, ARS logic and diagnostics system with data transfer interfaces. The location of this controller in the power supply system is shown in Figure 2.

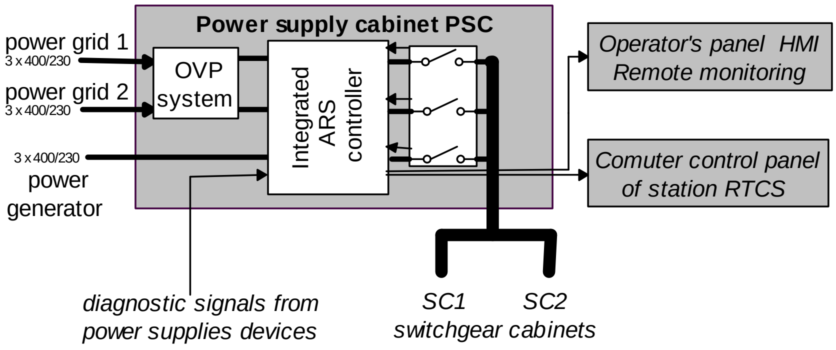

Fig.2 Structure of the station RTCS power supply system with ARS controller.

2.4. Application steps of ARS controller.

Controllers for automation devices are implemented on programmable hardware platforms. They can be classified as discrete real-time MCD systems class. Systems of this type are reactive systems, which implies assuming immediate (finite) response of the system to events. Designing such systems requires a behavioral approach to modeling functions and system operation. Such modeling enables effective graphing tools such as the Petri Nets or state diagrams [1, 3, 8, 10]. The important advantage of these tools is the ability to manipulate state concepts, as well as construct hierarchical structures and concurrent modeling.

Based on the analysis of current solutions [2, 13, 14, 15] and the requirements for power supply systems of station RTCS [16], a functional model of a controller with a Petri Net has been developed. Based on the developed net and the use of the National Instruments LabView graphical programming language, the software applications have been developed. In parallel with the design and implementation of the software, assumptions are made regarding the hardware platform of the controller. National CompactRIO platform has been selected. The next step of the SRS controller implementation is the integration of the software application made with the hardware platform After the integration and positive activation of the controller, functional tests were performed on the basis of a previously developed research program. This enabled verification of assumed assumptions for the ARS controller.

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3. ARS controller's Petri Net.

3.1. Petri Nets

In 1962 Carl A. Patri developed based on graph theory a tool called Petri Nets (PN) to model discrete systems [1, 3, 9, 10, 11]. As a result of long-term development of the theory of these nets a number of classes of PN emerged, for which wide applications have been found [1, 3, 5, 6, 7, 8]. As the graphical tool for modeling complex systems Petri Nets allow, during the development phase of assumptions and design requirements, good and clear communication between designers and customers. Thanks to that a comprehensive requirement specification was created, which does not contain vague rules and inconvenient for customers formal record. The resulting graphic model of the system can also be applied in computer graphics simulation environments of PN, this resulting in a virtual prototype of the system being designed [1, 3]. This allows designers fast, interactive and comprehensive testing of functionality and features at every stage of its life cycle. Petri Nets is ideal for system modeling of discrete events and analysis of their properties [1,3, 9, 10, 11], such as synchronization of processes, asynchronous events, competing tasks, conflict shared resources, jams etc. Petri Nets as formal modeling tool is described by linear algebraic equations or other mathematical formula reflecting the behavior of the designed system [9, 10, 11]. The ability of formal verification of the model is quite important in the construction of industrial MCD systems. Petri Net extended with time model can be used to model embedded systems [11], real-time systems [1], [10], and in particular real-time safety critical systems, which include railway traffic control systems [2, 4, 5, 6, 7, 8].

One of the essential characteristics of Petri Nets is their relatively simple and intuitive graphical representation. These nets, which are derived from the theory of directed bipartite graphs, allow use of terms specific to these graphs [9, 10, 11]. These graphs contain two types of vertexes called places and transitions. The vertexes represent respectively states or activity of the modeled system. They are connected with each other by arcs in such a way that the arcs connect only the vertexes of different types. The resulting graphic notation is characterized by a net structure. Graphic representation and structural properties are common features for all classes of nets [9, 11].

To be able to fully model the system, taking its dynamics into account, a definition af PN was extended by net marking. It represents the state of the modeled system. Net status is represented by tokens changes as a result of pass-time simulation of the net. Therefore *Marked Petri Net (MPN)* is an ordered four [9, 11]:

$$N = \left(P, T, A, M_0\right) \tag{1}$$

where the following conditions are met:

$N = \left(P, T, A\right)$ is the PN,

$M_0 : P \rightarrow \mathbb{Z}_+$ it is a function defined on the set of places called *initial marking* of the N net.

In this class of net places have unlimited capacity for tokens, but arcs can carry only one token. Execution of transition involves elimination of individual tokens from the input places and adding the individual tokens to the exit places of this performed transiton. In the class of *Generalized Petri Net (GPN)* [9, 11] it is possible to eliminate or add to one place more tokens in the performance of a single transition by assigning appropriate weights arcs. By introducing function of limiting capacity of the places for tokens to the GPN, one of the most common net class in literature [9, 11], called *Places and Transitions Petri Net (PTPN)* is obtained [9], [11]. The PNPT can easily replace a GPN which has the same properties. Accordingly, the term PTPN often refersto GPN in the literature [9, 11]. It can be stated that the MPN class is a special case of GPN and PTPN, in which there is unlimited token capacity, and arcs carry only one token (the weight of the arcs is 1).

Petrii Net, as a bipartite graph, can have a hierarchical structure [1, 11], greatly facilitating modeling of complex systems. Constructing a hierarchical net can be implemented in two ways [7, 8, 11]. The first of them, from the particular to the general *(a bottom – up)*, involves extration of separate, small subsystems from the model system and then building simple nets. Then these simple nets are deposited in growing parts until a whole net of modeleted system is given. The second way, from the general to the particular *(a top down)*, is to build a net for the entire system, without a detailed analysis of the fragments and treating the individual parts of the net in a similar way etc. This procedure is called structure modeling (hierarchical modeling). The net built using one of these methods is called a *hierarchical net* and the net elements of the composite structure are called hierarchical net elements [1, 11]. These elements representing parts of the net are called makroplaces and makrotransitions. The choice of modeling depends largely on the type of system, which is being modeled. If it is completely unknown to the designer of the system, using a second method is more efficient. On the other hand, when in modeling of the system past experience can be used, the first method becomes more convenient.

3.2. ARS controller Marked Petri Net

Based on the features of the ARS integrated controller power supply system of station RTCS (p. 2.2 and p. 2.3 of this article), the ARS controller Marked Petri Net (ARS controller MPN) has been developed. This MPN, where the capacity of the places are unlimited and only one token can pass through the arc, is a special case of the GPN and PTPN class of PN. The developed ARS controller MPN can be distinguished - Figure. 3:

- producer process, that generate tokens,
- storage process (tokens buffer),
- two consumer processes that absorb tokens.

In the producer process, tokens are generated correspondingly from the placess and transitions p7 - t3, p8 - t4, p9 - t5 and p10 - t6, which represent the signal acquisition by the measurement modules MS1, MS2, MS3 and MS4. Places and transitions p11 - t7, p12 - t8, p13 - t9, p14 - t10 are responsible for the analysis of the measured signals, resulting in quality parameters of the electricity supplied. These parameters, through the storage process (buffer data), place p15 and transition t11, are passed to two consumer processes. Consumer process 1 is responsible for the control logic of the ARScontroller. In this process, besides the supplied power supply parameters (place p16), signals from the binary inputs of the ARS contactors (place p19 and transition t14) are read from the binary inputs. On this basis, the logic of the ARs controller (place p16 and transition t12) generates via binary outputs control signals for the contactor (place p17 and transitior t13). Consumer process 2 is responsible for recording the power quality parameters and the current state of the ARS controller (place p27 and transition t20). The above data is transmitted to the HMI operator terminal (place p22 and transition t17) and to the computer control panel of station RTCS (place p25 and transition t19).

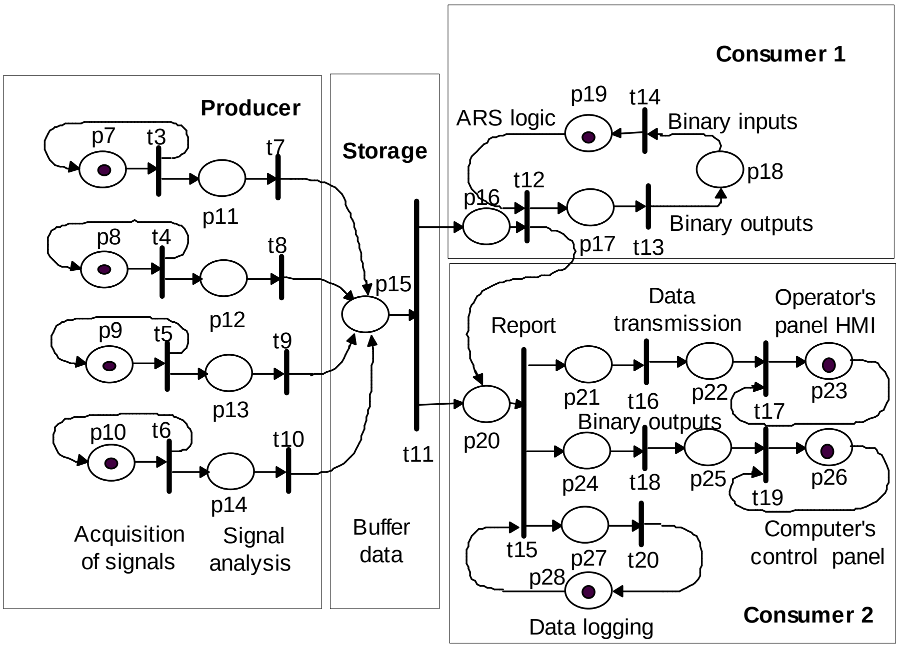


Fig. 3. The ARS controller Marked Petri Net.

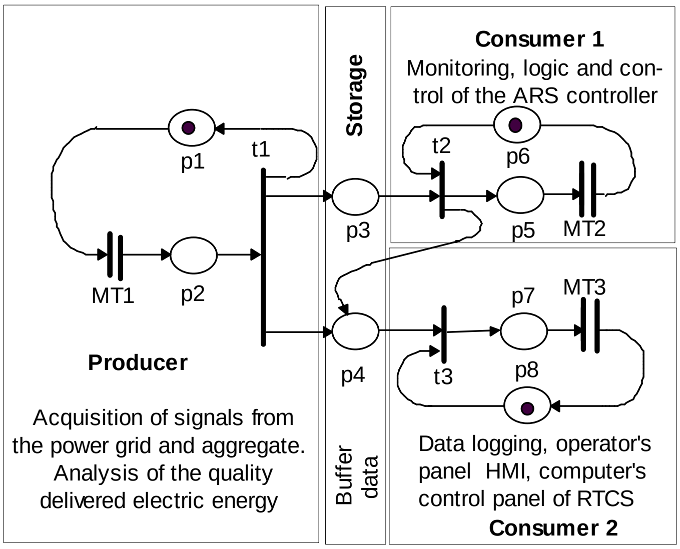


Fig. 4. The ARS controller hierarchical simplified Marked Petri Net.

Figure 4 shows the ARS controller hierarchical simplified MPN. This net was created as a result of the hierarchy of the ARS controller MPN from Figure. 3, using the bottom – up method of creating [11]. The resulting hierarchical simplified MPN is easier to analyze. This net corresponds to the producer - consumer model system. Class of this type net is well known in literature [11]. One of the important features of this net is its liveliness. This means that the net does not jammed, and every producer's token is consumed by consumer processes [11].

4. Practical implementation of the ARS controller

4.1. Hardware platform of ARS controller

The ARS controller hardware platform was configured using National Instruments CompactRIO components [17]. It is a real-time platform with modular construction. It meets the stringent requirements of environmental standards approved by the Management of the Polish Railway Lines. This platform consists of:

- NI cDAQ-9135 cassette with Processor module equipped with: Atom processor 1.33 GHz, 32 GB RAM, 8 slots, Linux RT real-time operating system, interface to HMI,
- NI PS Power Supply module: 24 VDC, 5 A, 100-120 / 200-240 VAC Input,
- 4 pieces of Analog Input modules NI 9244: 400 Vrms L-N, 24-Bit, 50 kS / s / ch, 3-Ch. These modules are designed to measure the supply voltage of the power system,
- 2 piecesof Digital Inputs/Outputs NI 9375: 16-DI, 16-DO, DI / DO. These modules are designed to control and monitor the state of the ARS contactors, and to transmit information to the computer control panel of station RTCS.

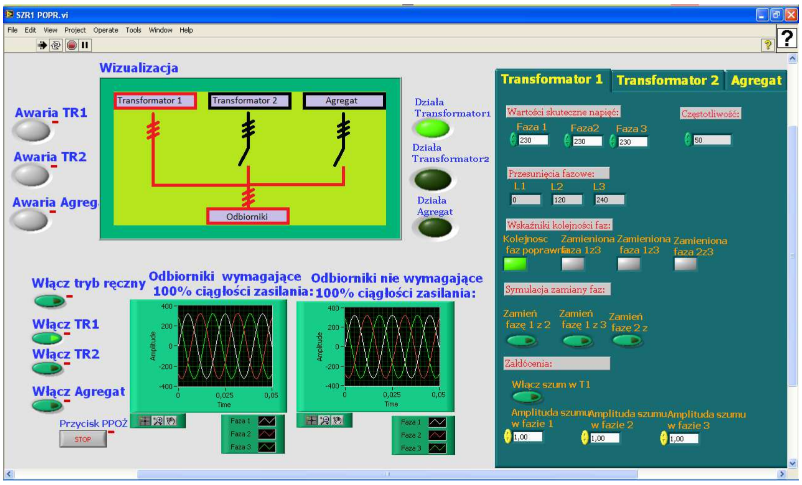
The front view of the ARS controller is shown in Figure 5..

Fig. 5. The front view of the ARS controller [17].

4.2. Software application of ARS controller

The National Instruments LabView graphical software environment [17] was used to implement the ARS controller software application. This environment has many tools for fast software development. The main advantage of this environment is that the execution of the program is based on the data flow between the nodes of the program. These include simple functions, complex functions, VI Express function and SubVI functions made by the user. Executing the node function will only occur if the node inputs will have data. This requirement is similar to the mechanism of triggering transitions in the Petri Net. This environment also includes programing structure patterns. One of them is the producer-consumer pattern. It transmits data from the producer to the consumer through the data buffer so that no data is lost. The pattern of this structure was used in the software application of the ARS controller. In the application also used the previously mentioned mechanism of building own subprograms (SubVI). For analysis of the measurement signals was used Electric Power tool, in which functional blocks are used to analyze the quality of electricity. DAQmx functions driver have also been used for acquisition of measuring signals. Software in the LabView environment is created in two windows. The first, the Front Panel, is responsible for the communication between the operator and the system. In the second window, the Block Diagram, the program code of application is placed.

Figure 6 shows the view of the Remote Monitoring Panel of the ARS controller. The visualization of displaying application enables the user to monitoring the state of the power supply system continuously.



Wartości skuteczne napięć:
Faza 1 230
Faza2 230
Faza 3 230

Częstotliwość: 50

Przesunięcia fazowe:
L1 0
L2 120
L3 240

Amplitude szumu w fazie 1 1,00
Amplituda szumu w fazie 2 1,00
Amplituda szumu w fazie 3 1,00

Fig. 6. The view of remote control Front Panel of ARS controller.

5. Conclusions

After the integration of the hardware platform and application software and the launch of the ARS controller, laboratory functional tests of the controller were performed. These studies were made on the basis of a previously prepared research program. After minor modifications to the controller's application software, it has been said that the ARS controller is working properly. This tested controler and documentation was provided to the manufacturer of the power supply system of the station RTCS. The controller is currently undergoing field testing. Once done, it will be possible to issue an admission for the use of the integrated ARS controller in station RTCS on the Polish Railway Lines.

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