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# Intelligent Power Electronic Converter For Wired and Wireless Distributed Applications

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***Abstract* — The paper presents the method of creating an intelligent power electronic converter (iPEC) with the ability to receive information from the cloud and interact with other devices of the Internet of Robotic Things (IoRT) distributed network. Analyzed and justified the choice of a microcontroller that meets the requirements of IoT. The features of the structure, the necessary iPEC nodes and the algorithms of their interaction are discussed. A control board based on FPGA has been developed to control iPEC power modules. The present paper presents the results of the study of the infra-low voltage generator, which is the iPEC power module. An analysis of the local network configuration based on DS coding for the interaction of devices of a distributed technological system is given.**

***Keywords—power electronic converter; amplitude-modulated signal; IoT; IoRT; Field-Programmable Gate Array (FPGA)***

## I. Introduction

The equipment intellectualization task exists due to the development of modern production of electronic devices and related technologies. To improve production efficiency, the concept of Industry 4.0 (The Fourth Industrial Revolution) has been developed. The concept of Industry 4.0, proclaimed at the Hannover Fair, is based on digital and information technologies [1]. This concept is based on the process of introducing IoT (Internet of Things) [2] into production with the aim of combining technical and business processes.

Today, on the basis of IoT, a new direction is successfully developing, which integrates robots or robotic devices using network technologies. This line, called the Internet of Robotic Things (IoRT), is aimed at implementing robotic technologies, by extending the functionality of IoT devices. The work [3,4] presents the concept of IoRT, which emphasizes the tremendous flexibility in the development and implementation of new applications for network robotics while achieving the goal of providing distributed computing resources as the main utility. Robotic devices can track events, collect data from a variety of sensors from various sources, and use the intelligence of their evaluators to determine optimal actions. In IoRT, robotic systems are able to connect via wired and wireless networks, exchange information with each other through the cloud about environmental parameters and results of operations performed [5].

The development of microelectronics and information technology has allowed creating the miniature computers with low consumption and high performance, which can be embedded not only in robotic systems, but also in individual elements of these systems. This quality makes it possible to create intelligent IoRT subsystems that are capable of networking between themselves and with other systems.

In technological systems of the production of electronic devices power electronic converters (PEC) take a responsible place. PECs are used as part of control drives for positioning systems, in shapers of powerful harmonic signals for ultrasonic systems for cleaning the surface of printed circuit boards [6, 7], and in many other applications.

This article describes the creation of a prototype of an intelligent PEC (iPEC) with the possibility of remote control and networking with other devices of a distributed technological system.

The paper is organized as follows. Section 2 provides an analysis of *related work*, related to the design, modeling of processes in a PEC with remote control. Section 3 discusses the implementation and study of iPEC. The structure features, the necessary iPEC nodes and the algorithms of their interaction are discussed. The obtained results and their discussion are presented in Section 4. Finally, the conclusion is given in Section 5.

## II. Related Work

Tasks and the need to create PECs with remote control and the interaction ability are considered in many papers. In the works [8,9] the methods of balancing distributed energy systems are analyzed. The PECs structure, the possible methods of remote control, features of hardware and software for the interaction of power converters are discussed.

The use of FPGA (Field-Programmable Gate Array) technology and Verilog / VHDL high-level languages for describing hardware when creating PECs control circuits is discussed in [10-11]. The article [10] discusses an important aspect when creating PEC - real-time testing. The authors offer a stand for PEC simulation tests in real time using SoC (System-on-a-Chip) and dual-core architectures. The authors of [11] propose a methodology for verifying the controlling controller as part of the PEC in the VHDL-AMS language [12]. Using this language allows simulating a closed-loop PEC using power and analog elements. The paper [13] describes

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the advantages of using FPGA in high-performance power electronics control systems. In particular, an example of the implementation of the control of power electronics based on FPGA in a hybrid electric vehicle is considered.

Power converters for hard production conditions with remote control and the interaction ability are considered in [14]. Introduced PEC SINAMICS G120D has all the necessary characteristics for use in distributed technological systems in the manufacture of electronic tools.

## III. Case Study of The Intelligent Power Electronics Converter

Consider the iPEC basic requirements used in applications that meet the IoRT concept. The power converter must have the following abilities:

- with the use of built-in sensors to perceive changes in the external environment and compensate for control actions;
- independently make decisions taking into account the security conditions and the rules of intellect of the iPEC calculators;
- interact with other IoRT system devices;
- be able to remote (system) configuration (preferably "on the fly") or perform reconfiguration at a local level;
- reliability of software and hardware.

A prototype power converter was developed to test the circuit design and layout solutions of iPEC. An analysis of the selection of individual iPEC nodes is below.

### A. IoT prototyping kits

Currently, there is a large selection of controllers on the electronic market that are designed for prototyping devices that meet IoT requirements. Review [15] presents various configurations of prototypes. IoT prototyping kits and development boards combine microcontrollers and processors with wireless chips and other components in a pre-built, ready-to-program package. Based on the requirements of IoT devices low power consumption, many prototyping kits controllers are based on ARM core.

An important argument when choosing a controller is its support by means of open source (hardware and software). In addition, the selected prototyping kit would meet the following requirements:

- have onboard LANs with a speed of ≥ 100 Mbps;
- have a wireless WiFi network with two bands: 2.4 / 5 GHz, 802.11n;
- have an additional data input / output bus for connecting peripheral devices (for example, display);
- be able to work with different operating systems.

Many IoT prototyping kits meet these requirements [15]. As a microcontroller for the iPEC prototype, Raspberry Pi 3 B + was chosen [16]. An additional argument for choosing this device was the ability to work not only under different versions of the Linux operating system, but also on Windows 10 IoT Core [17].

### B. FPGA Power Module Control Board

When developing the iPEC prototype, the task was to create a configurable platform, i.e. a powerful generator of amplitude-modulated signals with adjustable output parameters [18] or a stabilized power supply could act as a power converter. In addition, the iPEC version with several PECs of various functional purposes is possible. Managing multiple PEC processes in real time requires a quick response from the calculator. In this case, it is advisable to implement PEC's control loops on the FPGA [7, 18].

To accomplish the above tasks, a control board in the PC-104 form factor [20] was developed based on FPGA Cyclone III by ALTERA [21].

Figure 1 shows the control board. The board implements the following tasks:

- generation of control signals for iPEC power modules;
- organization of fast local communication for interaction with other IoRT devices;
- connection with the Raspberry Pi 3 B + microcontroller via the data input / output bus for setting the operation parameters of the power modules;
- diagnostics of the board and power modules operation via the USB-based technology port (if necessary).

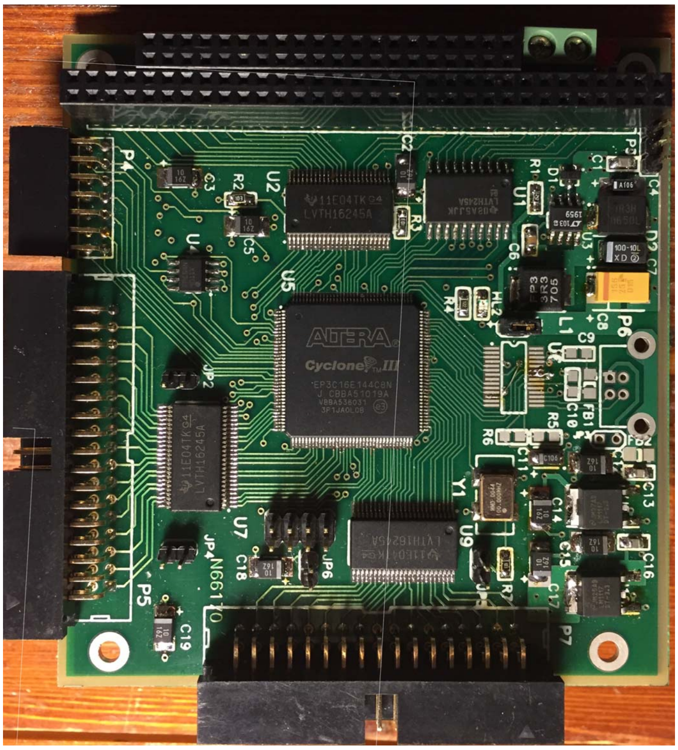

Fig. 1. iPEC Power Module Control Board

The interaction of IoRT distributed network devices is necessary for coordinating their operation, including synchronization when implementing a distributed algorithm. The use of LAN for the interaction purposes is not always justified, since LAN is usually used for system purposes: loading configurations, implementing cloud technologies, etc. In conditions of strong electromagnetic interference from process equipment and external disturbances, the use of wireless technologies to solve these problems is not always realizable. Therefore, additional fast local communication is required at the level of the control board, which would not occupy the resources of the microcontroller. In addition, for the reliability of the transmitted data and to increase the overall reliability of the systems, a special encoding at the signal level when transmitting events and messages is used.

When creating equipment based on FPGA for technological installations of the accelerator complex [22], DS-coding (Data-Strobe coding) with a signal level of LVDS [23] showed a good result. LVDS - levels have high noise immunity and energy efficiency. DS coding has been successfully applied in the aerospace industry within the SpaceWire standard, where increased requirements are applied to the reliability of transmitted data [24].

In DS coding, two lines are needed for transmission: D for transmitting data in a direct code, S for transmitting a strobe signal that changes its value each time the data remains constant in the next bit interval. Thus, in each clock cycle one of the signals changes, either D or S, which allows to realize the modeself-synchronization. As a result, DS coding allows you to transfer data at high speeds without first agreeing the speeds between the computers of the two devices. At a speed of 100 Mb / s the length of the communication line can be within 30 meters.

*Messages* between devices are transmitted in the form of telegrams, and the *message* format is determined by the number of devices in the local network and the amount of information transmitted. Messages may contain several fields, usually these are three fields: the address field, the coded *message* field, and the *event* field. If necessary, the bit depth and the number of fields can be increased without limit, but with an increase in the bit width, the exchange rate decreases.

In [25], network configuration analysis was performed using DS coding. The network configuration is largely determined by the tasks to be solved and the composition of the equipment. The study showed that the interaction of distributed technological devices requires the creation of a linear or ring network configuration. For large geographic distribution of systems, a ring network configuration with possible optical segments is preferable. The advantages of a ring serial network are as follows:

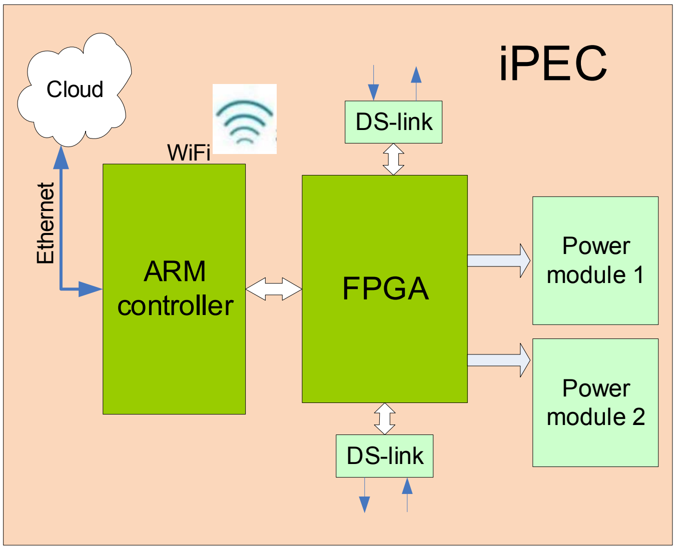


Fig. 2. iPEC structural and functional diagram

- DS-Link (D and S signals) of each device is a network repeater amplifier that allows maintaining high speed with a large number of distributed devices.
- It is possible to control the *messages* receipt in the computer of each control board.
- *Message* transmission time is strictly deterministic.

Figure 2 shows a simplified diagram of iPEC as part of an ARM controller, an FPGA-based control card, and two power modules. The iPEC control board contains two DS-Link to organize the ring highway. The number of power modules is determined by the tasks of the technological system.

## C. *iPEC Power Module*

IPEC power modules may have different functionalities. The iPEC modular structure allows selecting a configuration by defining the type and characteristics of power modules.

In the developed iPEC prototype, the power module implements the function of the infra-low voltage generator. When automating technological processes in various industries, it is often necessary to form infra-low signals of high power (for example, powering equipment for ultrasonic processing of parts, solving geophysical tasks, etc.). For these purposes, powerful transistor generators are used, with the ability to change output parameters. One of the adjustment methods is the amplitude modulation method.

The most responsible and expensive unit of geophysical equipment is a submersible projectile, on which acoustic receiving and transmitting devices are mounted [26]. As a rule, these are piezoceramic transducers (PCT), which use direct and inverse piezoelectric effects. To excite the transmitting PCT, a sufficiently powerful generator (0.5 - 1.0 kW) of high-frequency harmonic oscillations with a frequency from 10 to 40 kHz is required. But for some geophysical studies, frequencies of the order of hundreds or even tens of hertz are needed. Piezoceramic and even magnetostrictive transducers are unable to operate at such low frequencies. In such cases, the PCT excitation method is applied with amplitude modulated voltage. In this case, the low-frequency sinusoid envelope "carries" complete information, and the high-frequency sinusoid serves to transmit this signal along the entire path, from the control system to the executive body (in this case, the PCT).

In [18], a generator circuit with a resonant oscillating circuit was investigated. Figure 3 shows the substitution pattern. The device works as follows. A constant stable voltage is applied to one diagonal of the bridge of four transistors $M_1$-$M_4$. The gates of these transistors are supplied with control signals $U_1$-$U_4$ (square-wave pulses) from the control board, the duration of which is always guaranteed to be less than half the oscillation period in order to avoid the appearance of through-currents in the transistor arms of the bridge. When pairwise cross-switching transistors $M_1$, $M_4$ and $M_2$, $M_3$ on the other diagonal of the bridge, an alternating voltage of a rectangular shape occurs with an amplitude equal to the voltage of the power source $E$, which is fed to the input of the filter $C_1$, $L$, $C_2$. This filter is formed by two interconnected resonant circuits, so that the rectangular voltage is converted into a harmonic signal.

In the study of the circuit operation modes, filter construction features were considered, namely, the presence of a serial resonant circuit $C_1$, $L$, $R_L$ (circuit $K_1$) and parallel - $L$, $C_2$, $R_L$ (circuit $K_2$). Initially, these circuits are tuned to the resonant frequency, which is necessary for the execution of the technological process, and which is set when designing the generator along with its other parameters.

Thus, the signal of a slowly varying modulating voltage is superimposed on the pulses of the control signals of the carrier frequency. When this voltage increases, the duration of current flow in transistors $M_1$ and $M_3$ decreases, which leads to a decrease in the sinusoidal voltage in the load. This ensures non-simultaneous unlocking of the transistors $M_1$ and $M_3$ in relation to the transistors $M_2$ and $M_4$. This process is described in more detail in [18-19].

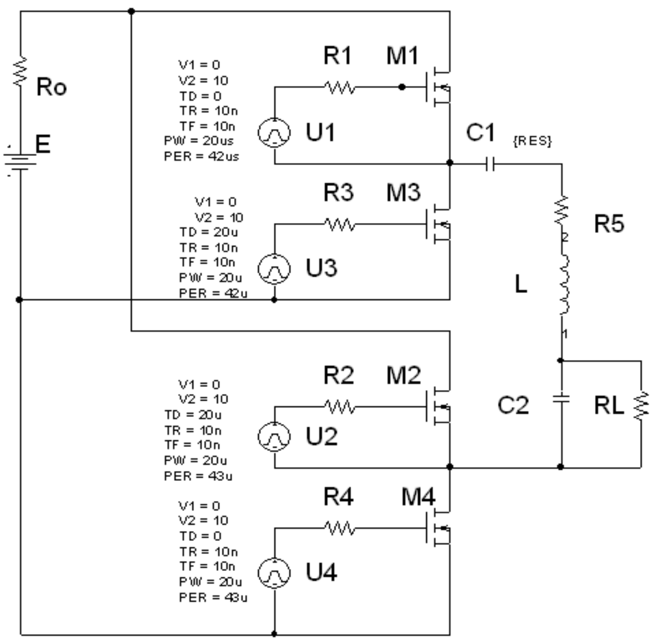


Fig. 3. Generator replacement circuit

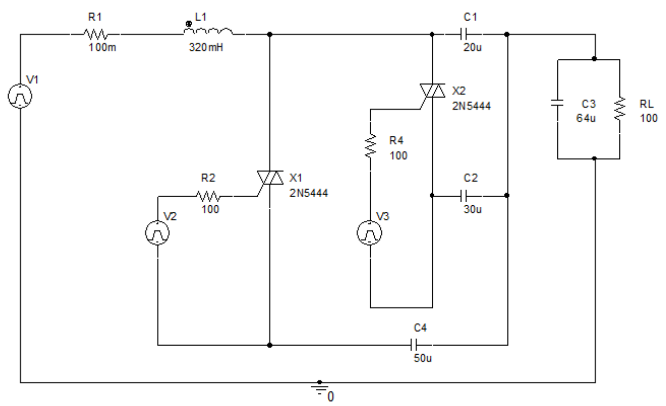


Fig. 4. The equivalent circuit to adjust the output voltage

To adjust the generator output voltage, it is necessary to change the capacitance of capacitor $C_1$ (Figure 3) [18]. Figure 4 presents a discrete method for changing the capacitance by connecting (or disconnecting) additional capacitors $C_2$ and $C_4$ to the main capacitor $C_1$ using the triacs. The time diagram of Figure 5 shows transients on the load $R_L$ as the capacitor changes. The diagram shows three amplitudes of the output voltage:

- In the range from 0 ms to 120 ms the amplitude of the voltage on the load $R_L \leq 40$ V ($C_1$ = ON, $C_2$ = OFF, $C_4$ = OFF).
- In the range from 120 ms to 460 ms the amplitude of the voltage on the load $R_L \leq 140$ V ($C_1$ = ON, $C_2$ = ON, $C_4$ = ON).
- B In the range from 460 ms to 700 ms the amplitude of the voltage on the load $R_L \leq 80$ V ($C_1$ = ON, $C_2$ = OFF, $C_4$ = ON).

## IV. Discussion

The developed iPEC prototype showed stable operation as an infra-low voltage generator. The microcontroller is based on a 64-bit four-core ARM Cortex-A53 processor with a frequency of 1.4 GHz. The microcontroller is equipped with 1 GB of RAM, which allows you to successfully use various Linux clones as an operating system. The program of interaction between the microcontroller and the FPGA via the I / O bus is written in Python 3.0.

The control board is implemented on FPGA Cyclone III EP3C16E144C8N company ALTERA (INTEL). The project for FPGA is designed and verified in the Quartus II 13.1.0.162 Web Edition package.

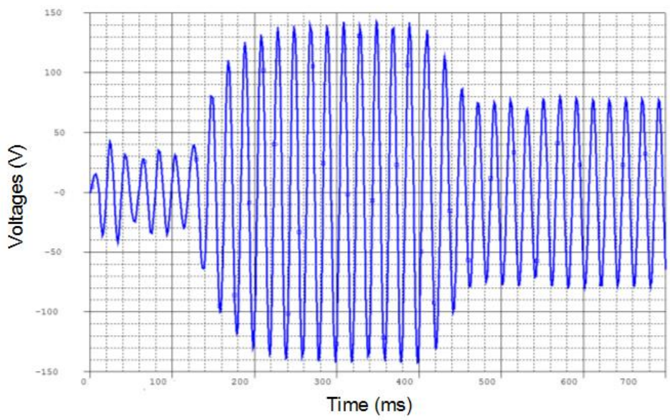


Fig. 5. Diagram of transient processes on the load as the capacity of the additional capacitor changes

## V. Conclusion

The development of a prototype of an intelligent power converter showed the possibility of using executive devices of technological systems as participants in a distributed IoRT network. As a basis for intellectualization, opportunities are used to obtain information from the outside world (from the cloud) through a microcontroller via LAN, receive messages from other devices through a computer implemented on the FPGA, and a fast local network.

iPEC's modular design allows implementing the various tasks by replacing individual nodes.

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