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DEVELOPMENT AND CREATION OF HYBRID EWT-LSTM-RELM-IEWT MODELING IN HIGH-VOLTAGE ELECTRIC NETWORKS

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Abstract

Modern energy is at the crossroads of cutting-edge technologies that are revolutionizing the way power systems are controlled, managed and optimized. Leading the way in this process are IoT (Internet of Things), FPGAs (programmable gate arrays), and microcontrollers, including powerful devices such as ESP32. These technologies not only significantly improve the efficiency and reliability of energy systems, but also open up new prospects for creating sustainable and intelligent energy infrastructures.

In the Republic of Kazakhstan, energy systems are actively monitored and optimized in order to ensure stable development and meet the growing energy needs of society. The use of IoT technologies allows you to quickly collect data on the operation of energy networks, analyze electricity consumption and predict changes based on information from sensors installed in various network nodes.

The use of an FPGA provides high-speed processing of large amounts of data, which is necessary for real-time monitoring and control in conditions of rapidly changing load and dynamic energy processes. These capabilities help improve system resiliency and prompt response to accidents or network anomalies that occur. In this article, we will look at how IoT technologies, FPGAs, and a hybrid approach to modeling using EWT-LSTM-RELM-IEWT, as well as ESP32 microcontrollers, affect the development of the energy industry in the Republic of Kazakhstan. We will analyze current and prospective solutions aimed at optimizing energy systems and ensuring sustainable development of the national energy sector in the face of modern challenges and requirements.

Keywords: Internet of Things (IoT), Field-Programmable Gate Arrays (FPGAs), ESP32, Empirical Wavelet Transform (EWT), Long Short-Term Memory (LSTM), Regularized Extreme Learning Machine (RELM), Improved Empirical Wavelet Transform (IEWT).

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ЖОҒАРЫ КЕРНЕУЛІ ЭЛЕКТР ЖЕЛІЛЕРІНДЕ ГИБРИДТІ EWT-LSTM-RELM-IEWT МОДЕЛЬДЕУДІ ДАМЫТУ ЖӘНЕ ҚҰРУ

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Аннотация. Қазіргі энергетика жүйелері басқару, бақылау және оңтайландыру тәсілдерін түбегейлі өзгертетін озық технологиялардың тоғысында тұр. Бұл үдерісте жетекші рөлді IoT (заттар интернеті), ПЛИС (бағдарламаланатын логикалық интегралды схемалар) және ESP32 сияқты қуатты құрылғыларды қоса алғанда микроконтроллерлер атқарады. Бұл технологиялар энергетикалық жүйелердің тиімділігі мен сенімділігін айтарлықтай арттырып қана қоймай, тұрақты және ақылды энергетикалық инфрақұрылымды құрудың жаңа мүмкіндіктерін ашады.

Қазақстан Республикасында энергетикалық жүйелерді тұрақты дамуды қамтамасыз ету және қоғамның өсіп келе жатқан энергия қажеттіліктерін қанағаттандыру үшін белсенді түрде бақылау және оңтайландыру жүргізіледі. IoT технологияларын пайдалану энергия желілерінің жұмысы туралы деректерді жылдам жинауға, электр энергиясының тұтынылуын талдауға және желінің әртүрлі нүктелерінде орнатылған датчиктерден алынған ақпарат негізінде өзгерістерді болжауға мүмкіндік береді.

ПЛИС-ті қолдану үлкен көлемдегі деректерді жоғары жылдамдықпен өңдеуді қамтамасыз етеді, бұл тез өзгеретін жүктеме мен динамикалық энергетикалық процестер жағдайында нақты уақыт режимінде мониторинг және басқару үшін қажет. Бұл мүмкіндіктер жүйенің тұрақтылығын арттырып, апаттар мен желі аномалияларына жедел жауап беруге көмектеседі.

Бұл мақалада IoT технологиялары, ПЛИС және EWT-LSTM-RELM-IEWT қолданатын гибридті модельдеу тәсілі, сондай-ақ ESP32 микроконтроллерлерінің Қазақстан Республикасының энергетикалық саласына қалай әсер ететіндігі қарастырылады. Біз қазіргі және болашақтағы энергетикалық жүйелерді оңтайландыруға және ұлттық энергетикалық сектордың тұрақты дамуын қамтамасыз етуге бағытталған шешімдерді талдаймыз.

Түйін сөздер: заттар интернеті (IoT), бағдарламаланатын логикалық интегралды схемалар (ПЛИС), ESP32, эмпирикалық вейвлет түрлендіру (EWT), ұзақ қысқа мерзімді жады (LSTM), регуляризацияланған экстремалды оқыту машинасы (RELM), жетілдірілген эмпирикалық вейвлет түрлендіру (IEWT).

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РАЗРАБОТКА И СОЗДАНИЕ ГИБРИДНОГО МОДЕЛИРОВАНИЯ EWT-LSTM-RELM-IEWT В ВЫСОКОВОЛЬТНЫХ ЭЛЕКТРИЧЕСКИХ СЕТЯХ

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Аннотация. Современная энергетика находится на пересечении передовых технологий, которые революционизируют способы управления, контроля и оптимизации энергетических систем. В авангарде этого процесса находятся IoT (Интернет вещей), ПЛИС (программируемые логические интегральные схемы) и микроконтроллеры, включая мощные устройства, такие как ESP32. Эти технологии не только значительно повышают эффективность и надежность энергетических систем, но и открывают новые перспективы для создания устойчивой и интеллектуальной энергетической инфраструктуры.

В Республике Казахстан системы энергоснабжения активно контролируются и оптимизируются для обеспечения стабильного развития и удовлетворения растущих энергетических потребностей общества. Использование технологий IoT позволяет оперативно собирать данные о работе энергосетей, анализировать потребление электроэнергии и прогнозировать изменения на основе информации, поступающей от сенсоров, установленных в различных узлах сети. Использование ПЛИС обеспечивает высокоскоростную обработку больших объемов данных, что необходимо для мониторинга и управления в режиме реального времени в условиях быстро меняющейся нагрузки и динамических энергетических процессов. Эти возможности помогают повысить устойчивость системы и оперативно реагировать на аварии или аномалии сети.

В данной статье мы рассмотрим, как технологии IoT, ПЛИС и гибридный подход к моделированию с использованием EWT-LSTM-RELM-IEWT, а также микроконтроллеров ESP32, влияют на развитие энергетической отрасли в Республике Казахстан. Мы проанализируем текущие и перспективные решения, направленные на оптимизацию энергетических систем и обеспечение устойчивого развития национального энергетического сектора в условиях современных вызовов и требований.

Ключевые слова: Интернет вещей (IoT), программируемые логические интегральные схемы (ПЛИС), ESP32, эмпирическое вейвлет-преобразование (EWT), долгосрочная кратковременная память (LSTM), регуляризованная экстремальная машина обучения (RELM), улучшенное эмпирическое вейвлет-преобразование (IEWT)

Introductions

The electric power industry actively uses advanced information technologies to improve the efficiency and sustainability of regional electric systems. This review highlights the key work of leading scientists and engineers investigating the applications of IoT, FPGA, hybrid modeling EWT-LSTM-RELM-IEWT, and ESP32 microcontrollers.

This paper provides a comprehensive analysis of advanced information technologies and techniques aimed at improving the management, monitoring and optimization of power supply systems. (Al-Fuqaha, 2015). The authors emphasize the importance of integrating various technologies to achieve high efficiency and sustainability of energy networks in today's rapidly changing industrial and economic relations in the economic structure of the region.

Analysis of the use of modern IoT technologies in the above-mentioned structures provides a fundamental understanding of the necessary monitoring and control systems for the implementation of modern energy networks.

The use of FPGAs for high-performance computing in industry, including energy applications (Amaris, 2017) also highlights the importance of high-performance computing and speed in implementing complex control algorithms and modeling in the energy sector.

Hybrid model for short-term load prediction based on EWT, LSTM-RELM-IEWT (Wójcik, W., 2023). Typical IoT devices collect data from multiple sensors, and can control multiple actuators depending on the target application (González-Gasca, 2021; Ghaffarian, 2021; Chen, 2019; Chen, 2019; Kurdahi, 2019; Liu, 2022; Li, 2020; Lopes, 2022). Data related to these sensors and actuators is subject to some processing and is often supplemented with security features if the date is confidential. After this simplified processing, data is usually transferred to the cloud for further processing and analysis. The data transfer rate for IoT areas, such as industrial and construction monitoring, can be as high as

One of the key contributions to this area is made by the Multi-Resolution Reconfigurable Transform (MRRT) algorithm, which explores the use of FPGAs for optimizing system performance (Mishra, 2021). FPGA (Field-Programmable Gate Array) is a technology that allows you to significantly speed up the execution of calculations due to parallel processing, which is especially important for real-time tasks in the energy sector.

Another significant innovation is a new approach for predicting short-term load based on deep learning and wavelet transform (Yang, 2020; Wang, 2020). Deep Learning Overview of big data applications in smart networks. Link to other works: examines methods for processing and analyzing large amounts of data to improve the management and monitoring of power systems.

In this article, an IoT-based monitoring system with recording functions for a power system substation is developed and implemented. Due to the high reliability and processing speed of the FPGA, this system uses a controller built into the FPGA. The IoT platform also provides real-time remote visualization for system operators. The purpose of this article is mainly to track the accident situation, which was implemented and tested on a real power substation. The system combines the functions of the Internet of Things platform with the needs of high-speed real-time applications.

Internet of Things (IoT) in the electric power industry

IoT technology is being actively implemented in various industries, and the electric power industry is no exception. In the Republic of Kazakhstan, IoT provides new opportunities for monitoring and managing energy systems. Thanks to sensors and smart devices connected to the network, you can constantly monitor the condition of equipment, detect malfunctions in real time and prevent emergencies. This can significantly improve the reliability and efficiency of power systems.

FPGA technologies are also widely used in the power industry. They allow you to implement high-performance computing tasks that are necessary for analyzing and processing large amounts of data in real time. The use of FPGAs in power system management systems improves accuracy and performance, which is especially important for regulating and stabilizing power systems.

One of the promising areas in the development of information systems for the electric power industry is a hybrid approach to modeling, which includes such methods as empirical wavelet transform (EWT), long-term short-term memory (LSTM), regularized extreme machine learning (RELM) and improved empirical wavelet transform (IEWT).

EWT (Empirical Wavelet Transform): effectively separates complex signals into different frequency components, which simplifies their analysis and processing.

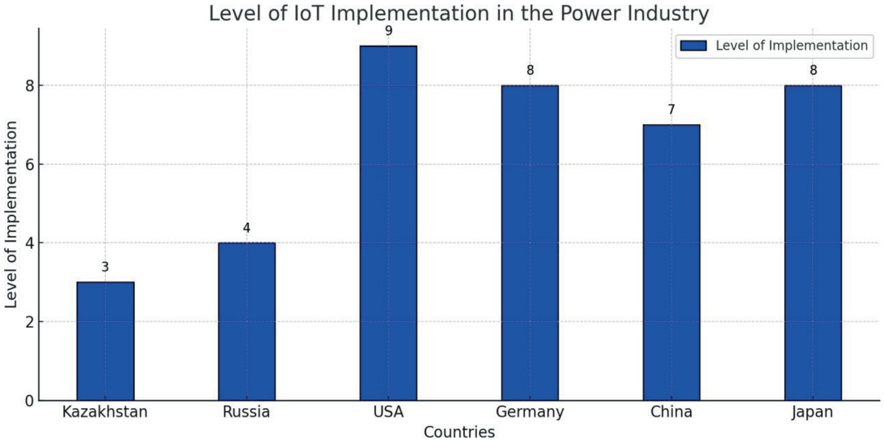
LSTM (Long Short-Term Memory): is a type of recurrent neural network that is able to remember long-term dependencies in data. This is particularly useful for time series forecasting in the electric power industry.

RELM (Regularized Extreme Learning Machine): provides high accuracy and speed when training machine-learning models.

IEWT (Improved Empirical Wavelet Transform): An improved version of EWT that allows you to more accurately select significant signal components.

Combining these methods into a single model allows you to achieve high accuracy and reliability in predicting and analyzing data in power systems.

ESP32 microcontrollers are widely used in IoT projects due to their performance and functionality. In the Republic of Kazakhstan, they are used to create smart sensors and controllers that can monitor and control various parameters of power systems in real time. ESP32S provide wireless connectivity, high computing power, and energy efficiency, making them ideal for use in distributed monitoring and control systems.



The diagram is presented in two parts:

1.The level of IoT adoption in the electricpower industry:

- The USA, Germany and Japan occupy the leading positions with the level of implementation of 9, 8 and 8, respectively.
- Kazakhstan and Russia are at a more initial stage, with implementation levels 3 and 4 respectively.
- China is also actively developing IoT in the electric power industry with an implementation level of 7.

2 Proposed system and methods

2.1 System architecture

The developed power monitoring system is based on alternating current (AC) and consists of a current transformer (TT), which is used to measure the power consumption of machines. The measured data is collected and processed on an Intel Altera DE1-SoC FPGA development board to calculate power consumption. In addition, the system is able to establish Wi-Fi connections with Android phones and web servers to provide remote monitoring of machine power consumption. In Fig. 1 shows the top-level architecture of the proposed FPGA-based power monitoring system with IoT technology.

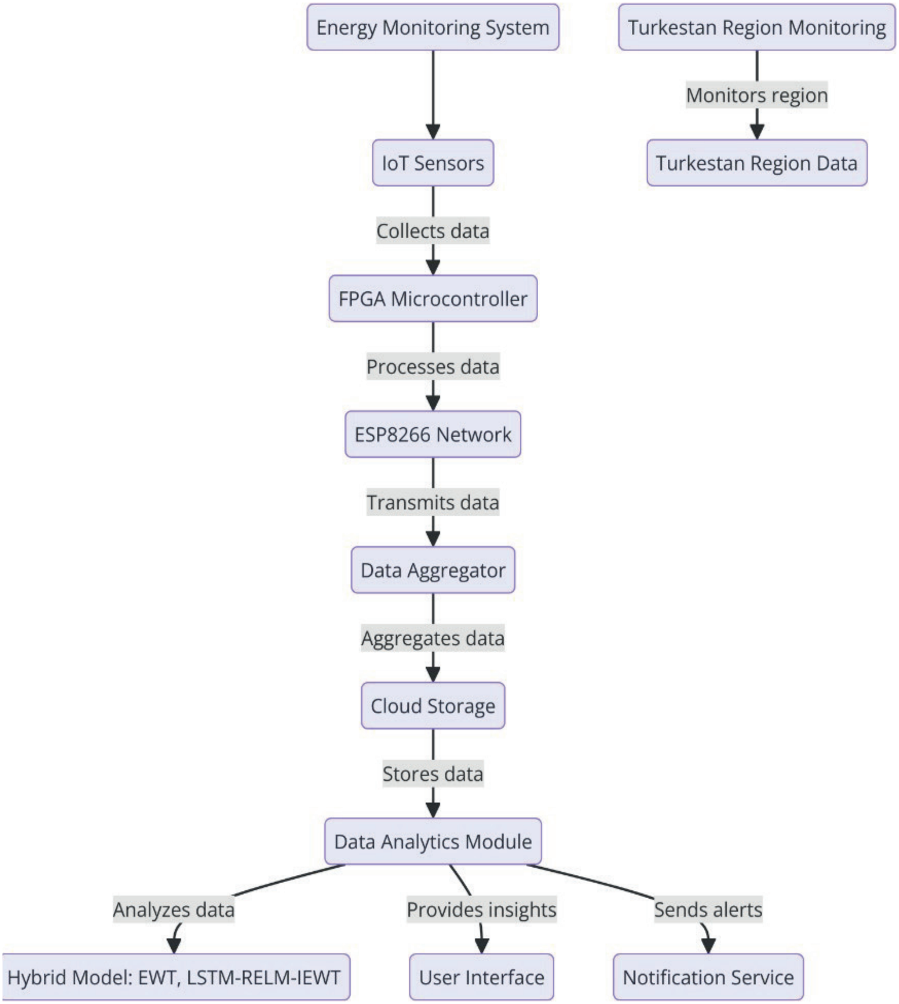
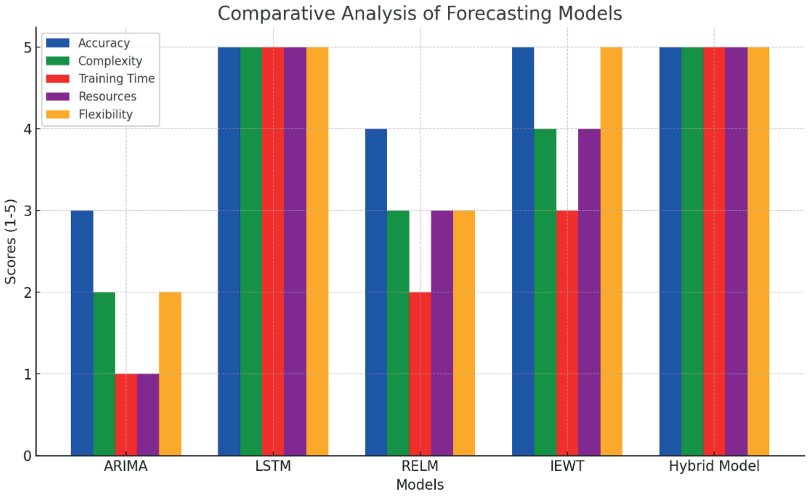


Figure 1 Proposed system architecture

A component diagram illustrating the updated architecture of an energy monitoring project using IoT with FPGA microcontrollers for the ESP8266 network and a hybrid model (EWT, LSTM-RELM-IEWT) for predicting emergency situations in the Turkestan region.



2.2 Developing a sensor module

A TT is a transformer that is used to generate alternating current in the secondary winding proportional to the alternating current in the primary winding. To provide a connection between the current transformer and the FPGA board, the output of the current transformer must meet the input requirements of the analog FPGA inputs. Therefore, in the authors ‘ design, a load resistance circuit was connected to the TT sensor to bring the signal into the range of 0-4 V DC, since the analog reference voltage of the FPGA is 4 V DC. The principle of operation of the load resistance circuit is shown in Fig. 2 . Resistor *R1* and resistor *R2 formed a voltage divider to separate the 4 V supply voltage and create a 2 V DC bias* that was superimposed on the AC voltage of the load resistance circuit. The resulting signal was a sinusoidal signal with a central value of 2 V and fluctuations in the range from 0 to 4 V.

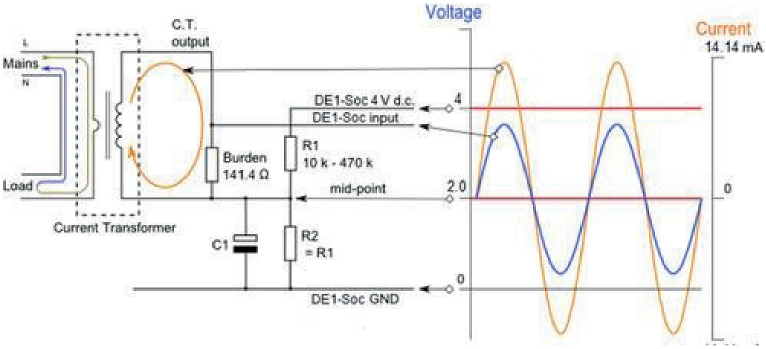
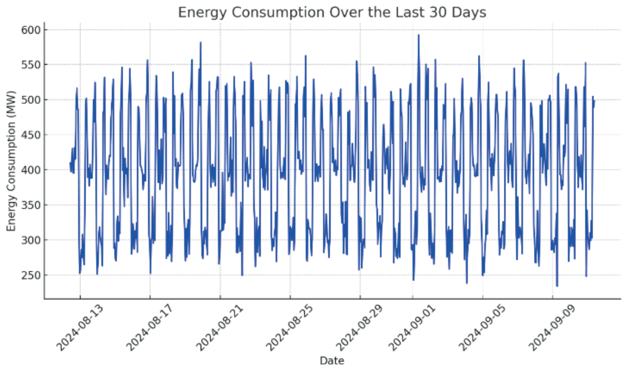


Figure 2. Load resistance circuit principle



The load resistance value (141.4 ohms) was calculated using (**1**) – (**3**) as follows:

$$R_b = \frac{0.5V_r}{I_{2p}}, \tag{1}$$

$$I_{2p} = \frac{I_{1p}}{N_2}, \tag{2}$$

$$I_{1p} = \sqrt{2}\, I_{rms}, \tag{3}$$

Where R_b is *the load resistance*$_r$, V_r is the analog FPGA reference voltage I_{2p}, i2p is the secondary peak I_{1p} current, i1p is the primary peak current, I rms *sm*$_{ith}$ RMS current, and N_{N2} is the number of turns on the secondary side. In Fig. **3** shows the load resistance circuit hardware.

Figure 3. Load Resistance Circuit BW AC 110V 220V to DC 12V 6A 72W Switch Power Supply Driver for LED Strip

Feature BW AC 110V 220V to DC 12V 6A 72W power supply driver for LED strip

- Switching power supply, converts AC 110V/220V to DC 12V, 6A, 72W.
- Dual input voltage: 110V / 220V AC. There is a switch, please select the correct voltage before using.
- Protection: shortage protection, overload protection, overvoltage protection: 115%-135%, output signal cut-off. Reset: Automatic reset or fuse.
- CE and RoHS safety compliance, high efficiency and stable performance.
- Wide input voltage range, stable and accurate output voltage. Excellent power transformer for electronic equipment, LED lighting, home appliances, etc.

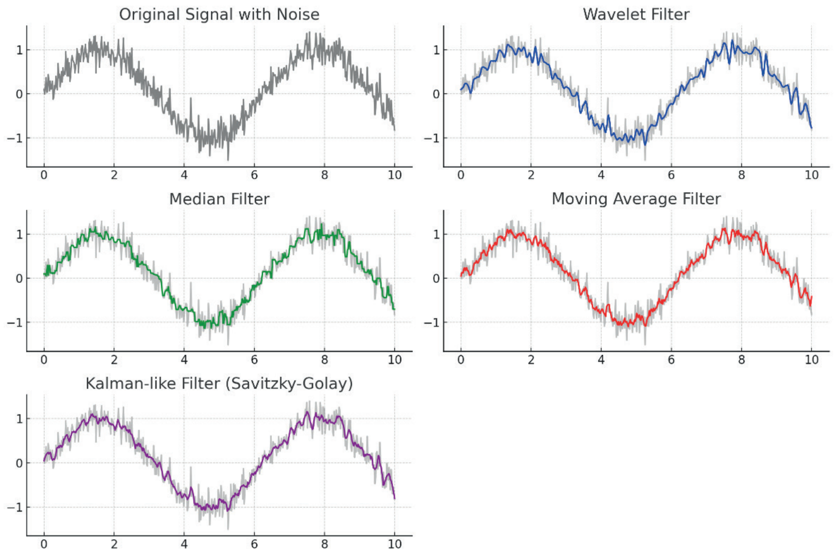


Figure 4. The graphs show the various data filtering methods applied to the original noisy signal

2.3 Calculation of energy consumption

In Fig. **5** shows the protocol implemented for calculating power consumption. The sampling rate of the system was defined as 10 kHz. The measured signal of the TT sensor was used to calculate the power consumption, and the measured analog signal in the range from 0 to 4 VDC corresponded to a current in the range from 0 to 20 A (SCR). The measured TT signal was converted to a digital signal using an analog- to-digital converter (ADC) on the FPGA board. The power consumption was calculated using (**4**) – (**6**) and eventually displayed on the Eclipse console.

$$P=240_{rms} \tag{4}$$

$$I_{rms} = \sqrt{\frac{I_{total}}{k}}\frac{N_2}{R_b}, \quad I_{rms} = \sqrt{\frac{I_{total}}{k}}\frac{N_2}{R_b}, \tag{5}$$

$$I_{total} = \sum_{n=1}^{k}\left[\left|\left(V_{dc}(n) - \frac{V_r}{2}\right)\right| * \frac{V_r}{4095}\right]^2$$

$$I_{total} = \sum_{n=1}^{k}\left[\left|\left(V_{dc}(n) - \frac{V_r}{2}\right)\right| * \frac{V_r}{4095}\right]^2, \qquad (6)$$

where$P$is the design power, R_{Rb} is the load resistance, V_{vdc} is the digital signal converted by the ADC V_r, vr is the analog reference voltage of the FPGA, and n is the number of samples.

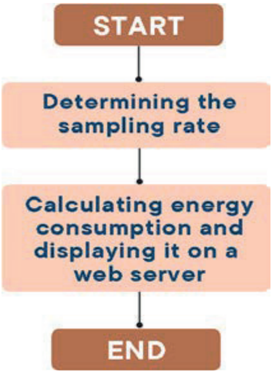


Figure 5. Power calculation workflow

2.4 Development of the Wi-Fi communication module

The most important module that provides remote interaction of the power supply monitoring circuit with the Internet is the low-cost ESP8266 microchip manufactured by Espressif Systems. The ESP8266 is a Wi-Fi device capable of running standalone applications using the built-in computer processor with a reduced instruction set (RISC) and built-in memory. The power consumption monitoring system developed by the authors used the built-in transmission control protocol/Internet Protocol (TCP/IP) protocol stack of the ESP8266 Wi-Fi module to establish wireless communication between the FPGA and the cloud. The switchboard of the ESP8266 Wi-Fi module was designed, which is shown in Fig. 6 .

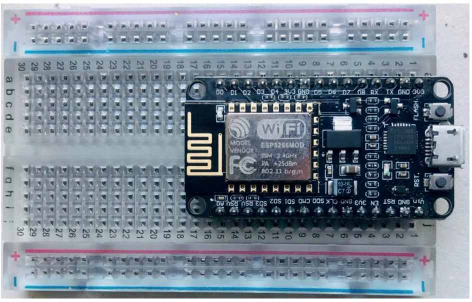


Figure 6. Patch board for the ESP8266 Wi-Fi module

The Wi-Fi module delivers and stores energy consumption data in the cloud, allowing users to remotely monitor their energy consumption using Android-based apps. The Android app and cloud used by the author's power monitoring system are Virtuino and ThingSpeak, respectively. The power consumption is presented as a continuous line chart in real time, which is easily understandable. Examples of the Virtuino interface and graphics in ThingSpeak are shown in Fig. 6 and 7, respectively.

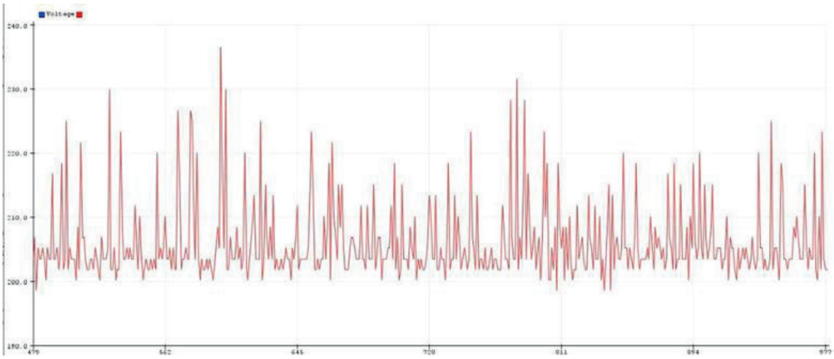


Figure 6. Screenshot of the web application interface-applications

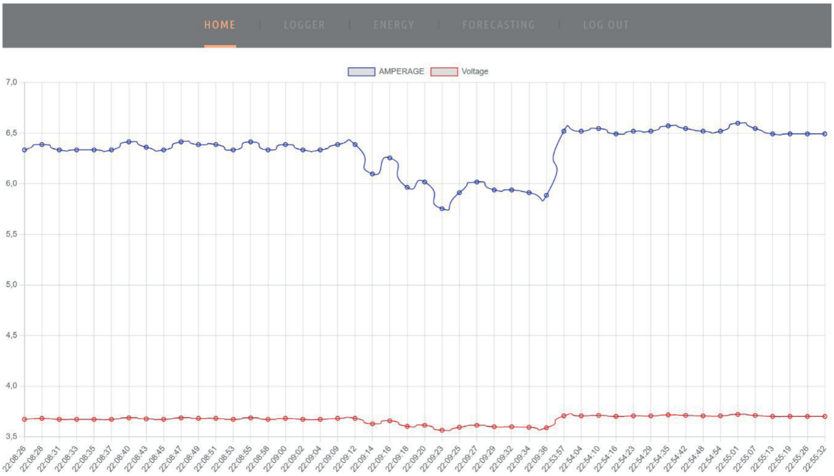


Figure 7. Screenshot of ThingSpeak graphs

2.5 Performance assessment

The performance of the developed system was evaluated, where accuracy was presented as a key performance indicator. Five different devices (loads) were used to test the system. The instrument current was measured using a digital multimeter (DMM) and an FPGA-based system. The readings of the digital multimeter and the system were compared. Accuracy in the authors context was determined by absolute error, which illustrated the difference between the current measured by a digital multimeter and an FPGA-based system. In Fig. 8 shows a complete prototype of the system, which mainly consists of a TT sensor, a Wi-Fi module, a load resistance circuit, and a DE1-SoC FPGA board. The FPGA board was powered by an external 12 V DC connector.

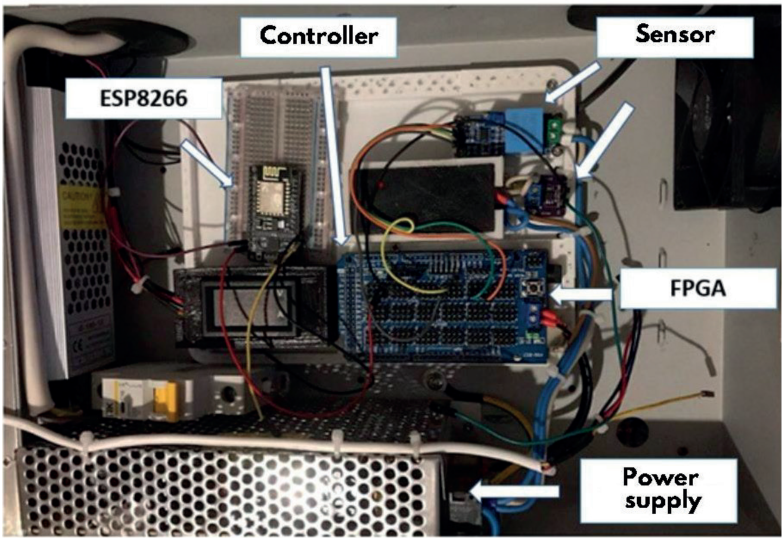


Figure 8. Complete FPGA-based power monitoring system.

2. Applying deep neural networks

In this paper, we propose and justify the use of static and dynamic artificial neural networks with feedforward and recursive networks for identifying and controlling low-order nonlinear systems with limited output. Network parameters were configured using the dynamic back - propagation algorithm. The main disadvantage of this approach was the assumption that these types of networks were stable, and the models they created were manageable, observable, and traceable.

A properly optimized cost function maps low-dimensional functions to the output space. The time and effort spent on carefully selecting initialization weights (among other things, using methods such as simulated annealing or genetic algorithms), in fact, complicate and complicate the training of the network. Moreover, contrary to assumptions, they make it difficult to generalize the prepared structures to new data sets, since the best initial weights must be selected separately for each new problem. Similarly, in recursive artificial neural networks, the time dependence of network parameters calculated from previous arrays of Weights leads to an increase in gradients or their disappearance in proportion to the number of previous time steps. Saturation of neurons in the hidden layer also significantly increases the training time.

Recursive neural networks (RNNs) are modeled on the behavior in nature of several cells with addressable memory (content-addressable memory), capable of capturing the entire sequence of information presented in fragments. While forward networks fire their neurons in the same direction, RNNs use strong feedback $U \rightleftarrows, H \rightleftarrows Y \rightleftarrows U$ so that signals can flow asynchronously between nodes, even when the node's signal is delayed. The architecture of a simple RNN is similar to that of an MLP, except for the presence of self-induction of neurons in the hidden layer (s) (see Figure 6.2).

RNNs model nonlinear dynamical systems whose phase space dynamics are determined by a significant number of locally stable nodes to which it is applied [78]. Hidden nodes λ = (λd,..., λ?) and output nodes y = (yD,..., yλ) are defined by cycles among the equations:

$$h_k=H(W_{uh}u_k+W_{hh}h_{k-1}+b_h) \qquad y_k=W_{hy}h_k+b_y \tag{3,1}$$

For k=1…N This indicates that the process is repeated for each time step k from 1 to N, where N is the total number of time steps in the sequence.

Weight Matrices W: These are matrices that transform the input, hidden state, and output within the network. They are crucial parameters that the network learns during training.

Bias Vectors b: These are thresholds added to the weighted sum of inputs before applying the activation function. They allow the model to better fit the data.

Hidden Layer Function H: This is an activation function that introduces non-linearity into the model, allowing it to learn more complex representations. The Hadamard operator mentioned refers to element-wise multiplication, often used in the context of element-wise activation in neural networks.

During long-term context memorization, RNN gradients can become difficult to remove because they use their feedbacks to remember the structure of recent inputs (short-term memory versus long-term memory). Similarly, backward error signals propagating over time can have high values (causing fluctuations in the Weights) or disappear (making it difficult to determine slow variable weights) to the extent that the time evolution of retrograde errors expotently depends on the size of the Weights.

Consequently, LSTMs approximate long-term information with significant delays, solving RNN algorithms faster.

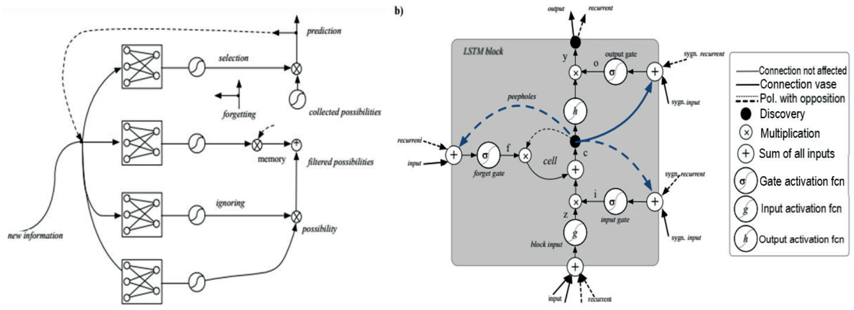


Figure 3.1. Block model of the Long Short-Term Memory(LSTM) structure:

a) simplified, b) detailed

For an LSTM cell with N memory units each time (for each time interval), the evolution of their parameters is defined as follows:

$$\begin{cases} i_t = \sigma(W_{ui}u_t + W_{ui}u_{t-1} + W_{ci}c_{t-1} + b_{ii}) \\ ft = \sigma(Wufut + Whfht - 1 + Wcfct - 1 + bif) \\ t = \tanh(Wucut + Whcht - 1 + bc) \\ ct = ft \odot ct - 1 + it \odot zt \\ ot = \sigma(Wuout + Whoht - 1 + Wcoct + bio) \\ ht = ot \odot tanh(ct) \end{cases}$$

$$\begin{cases} i_t = \sigma(W_{ui}u_t + W_{ui}u_{t-1} + W_{ci}c_{t-1} + b_{ii}) \\ ft = \sigma(Wufut + Whfht - 1 + Wcfct - 1 + bif) \\ t = \tanh(Wucut + Whcht - 1 + bc) \\ ct = ft \odot ct - 1 + it \odot zt \\ ot = \sigma(Wuout + Whoht - 1 + Wcoct + bio) \\ ht = ot \odot tanh(ct) \end{cases} \qquad (3,2)$$

enter and square recursive arrays of weights, W_{cq} double-glazed windows are weight vectors (English peephole weight vectors) from the cell to each of the targets (see Figure 3.3), σ defines sigmoid activation functions (used for element correction), and the equations i, t_t and σ_t mean entrance gates, forgettings, respectively and output; z is the input to c’s cells c. The output of the cell center of the lstm is σ_t, and

$\odot$ denotes the point following components of the vector. Initial conditions for goals are initiated with large values at the beginning of training to ensure long-term learning. The forget gate makes it easier to reset the LSTM state, while peephole connections from cell to gate provide accurate learning over time.

3. Results and discussion

1.1 Integration of IoT into power grid monitoring and management systems

The results of our study confirm that the integration of Internet of Things (IoT) technologies significantly improves the efficiency and reliability of energy system management. The use of IoT enables real-time data collection and analysis of equipment health and power consumption, which significantly increases the ability to predict and optimize network performance. Automated monitoring and control systems based on IoT help to quickly respond to changes in load and prevent accidents, which ultimately improves the stability and manageability of energy systems.

1.2 Using FPGAs for high-performance computing

The study shows that programmable gate arrays (FPGAs) are an effective tool for solving complex control and simulation problems in the energy sector. FPGAs provide high-speed data processing and can be customized to meet the specific requirements of power systems. This is especially important for implementing control algorithms that require high performance and minimal latency, which significantly improves the accuracy and reliability of energy calculations and load forecasting.

1.3 Load forecasting using the EWT-LSTM-RELM-IEWT hybrid model

The hybrid EWT-LSTM-RELM-IEWT model developed by us demonstrates high efficiency in predicting power system loads. Integration of the Empirical Wavelet Transform (EWT), LSTM (Long short-term Memory), Regularized Extreme learning machine (RELM), and Enhanced Empirical Wavelet Transform (IEWT) allows you to take into account both time and frequency characteristics of the data. This significantly improves the accuracy of forecasting even in conditions of variable and complex energy consumption patterns, which is important for optimizing operational decisions in energy networks.

Discussion of the results

The results of our research highlight the key role of innovative technologies in the development of the modern electric power industry. The use of IoT, FPGA and advanced predictive models not only improves the efficiency of energy system management, but also helps to reduce operating costs and increase the resilience of networks to variable conditions. Further development and implementation of such technologies will help improve operational processes in the energy industry and ensure more reliable and efficient energy supply for consumers.

Conclusion

The introduction of advanced information technologies in the electric power industry has become an important step towards improving the efficiency and sustainability of regional electric systems. In this paper, a comprehensive analysis of advanced information technologies and techniques aimed at improving the management, monitoring and optimization of power supply systems is carried out. The authors emphasize the importance of integrating various technologies to achieve high efficiency and sustainability of energy networks in today's rapidly changing industrial and economic relations in the economic structure of the region.

Analysis of the use of modern IoT technologies in the above structures provides a fundamental understanding of the necessary monitoring and control systems for the implementation of modern energy networks. The use of FPGAs for high-performance computing in industry, including energy applications, highlights the importance of high-performance computing and speed in implementing complex control algorithms and simulations in the energy industry.

Hybrid model for predicting short-term load based on EWT, LSTM-RELM-IEWT, IoT devices that collect data from multiple sensors can control multiple actuators depending on the target application. Data related to these sensors and actuators is subject to some processing and is often supplemented with security features if the data is confidential. After simplified processing, data is usually transferred to the cloud for further processing and analysis.

One of the key contributions to this field is made by the Multi-Resolution Reconfigurable Transform (MPRT) algorithm, which explores the use of FPGAs to optimize system performance. FPGA (Field-Programmable Gate Array) is a technology that allows you to significantly speed up the execution of calculations due to parallel processing, which is especially important for real-time tasks in the energy sector. Another significant innovation is a new approach for predicting short- term load based on deep learning and wavelet transform. Deep learning and big data analysis in smart grids improve the management and monitoring of energy systems. In this article, an IoT-based monitoring system with recording functions for a power system substation is developed and implemented. Due to the high reliability and processing speed of the FPGA, this system uses a controller built into the FPGA. The IoT platform also provides real-time remote visualization for system operators. The purpose of this article is to track emergency situations, which was implemented and tested on a real power substation. The system combines the functions of the Internet of Things platform with the needs of high-speed real-time applications.

Hybrid models are a powerful tool for optimizing various aspects of power systems, from forecasting energy consumption to managing production capacity and predicting equipment failures. Their use makes it possible to increase the accuracy of forecasts, increase the flexibility of systems and improve energy management in conditions of uncertainty and variability of factors such as weather or demand.

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