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Determination of forecast indicators of electricity quality in the mode of synchronised vector measurements

Abstract. New electrical technologies apply real-time synchronised vector measurement technologies to improve the reliability of power supply systems based on the use of synchrophasors to monitor and analyse the functioning of the network in real time. This was an important milestone in the implementation of the goal of developing the country's energy system through the use of sophisticated innovative control and measuring devices. The new technologies are based on the use of synchronised vector measurement devices (phasor measurement unit – PMU) to collect data from more than 344 installed devices at a frequency of 30 times per second. This significantly distinguishes new technologies from traditional ones, which allow recording measurement data every 4 seconds. This data has GPS timestamps, which allows synchronising measurements at different points and combining the results obtained for a detailed and comprehensive assessment of the state of the system over a wide geographical area. Having such data at your disposal creates more opportunities for detecting, diagnosing, and preventing network disruptions, which means it makes it smarter. The integration of these technologies into a real-time network monitoring system significantly increases our situational awareness of network functioning and contributes to its modernisation. Synchronised vector measurement technologies provide unique data that can significantly improve reliability. Due to these devices, it is possible to expand the possibilities for dynamic monitoring of the state of the power system. The purpose of the study is to summarise research on determining the forecast indicators of electricity quality in the mode of synchronised vector measurements. The authors substantiated the block diagram of the technology for diagnosing the quality of electricity. As a result of analytical approaches, a graphical interpretation of the order of receiving packets through a given communication method at a frame rate of 50 frames/s is reproduced. Conclusion – four programme codes simultaneously generate real-time indicators and are written to the MySQL database, these indicators are used to calculate voltage and frequency deviations. Scientific significance – the adequacy of modelling electricity quality data in synchronised vector measurement mode using the Google Colab service and implementation in Pytpon language is confirmed

Keywords: electricity production, quality, diagnostics, synchronised vector measurement devices, forecasting methods, dynamic database, web application

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INTRODUCTION

In the last 2 years, due to the covid-19 pandemic, there has been a need to make adjustments to the operation of various technical systems [1]. One of the most important components of providing hospitals, in particular, infectious diseases, is high-quality power supply for the uninterrupted operation of medical equipment, in particular, artificial ventilation devices [2]. There are cases when patients connected to a ventilator died due to an emergency power outage in the hospital [3]. In particular, such a case occurred in the Lviv Oblast of Ukraine [4]. According to the state emergency service of Ukraine, in the city of Enerhodar, Zaporizhzhia Oblast of Ukraine, rescuers on Sunday, June 27, 2021, in the evening provided assistance to the hospital during an

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emergency power outage [5]. Other similar cases are also known: rescuers helped doctors of the Alchevsk Hospital of the Luhansk Oblast of Ukraine by connecting generators to artificial ventilation devices.

The relevance of scientific research and development, which is devoted to this study, is conditioned by the unresolved problem of creating an automated system for diagnosing the quality of electricity of consumers using renewable energy sources [6]. Currently, some customers of energy companies use devices for generating electricity (solar panels, wind installations, etc.) [7]. And to save costs or generate revenue, they also return energy to the grid [8]. Since an electric power company is legally required to buy electricity produced by consumers [9], it wants to make sure that it does not damage the grid [10]. Now there is a need to measure and control the quality of electricity to make sure that the power supplied to the network from other sources has the same quality and standards that customer equipment expects from it [11].

Many publications are devoted to the study of the quality of electricity. Researchers from the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" studied the system of monitoring the quality of electric energy in decentralised power supply systems [12]. Researchers of the Institute of Electrodynamics of NASU have developed a recording device "Regina-H", which in its technical and functional characteristics is not inferior to the best foreign analogues [9]. The device provides recording of instantaneous values of currents and voltages [13], storage and processing of measurement results [14]; their display in the form most informative for personnel text messages, graphs, tables, waveforms [15], and transmitting information to any level of the control hierarchy with its binding to exact time signals [16]. These devices are an integral part of a transient mode monitoring system integrated into a local area network that combines measurement converters or other lower-level monitoring devices and a 100 Mbit/s TCP/IP Fast Ethernet data acquisition server [17]. A top-level remote computer is installed in the control centre of the united energy system of the National energy company Ukrenergo and the corresponding electrical system to receive information from the switching server [9].

Intelligent electronic devices ENIP-2 manufactured by Energoservice Engineering Centre LLC [10] measure synchronised vectors of synchrophasors of currents and voltages by PMU Phasor Measurement Unit [18]. Synchronised measurements of the parameters of the power system mode by the current and voltage values and by the main harmonic are also performed [19]. Further, parameters are transmitted to automated technological control systems via a digitally galvanically isolated Ethernet interface [20].

These devices are intended for use in monitoring systems of transient modes WAMS and in automated technological control systems of the new generation WACS, in automated process control systems of substations and automated dispatching control systems, in automatic technological control systems of active adaptive networks, mode automation [21]. ENIP-2 devices can transmit data directly when connected to the local network of a substation or power plant, and through data collection and transmission devices for synchronised PDC measurements.

The purpose of the study was to predict quality in a distributed information and control system for diagnosing electricity quality using renewable management sources and web applications.

RESULTS AND DISCUSSION

The process of diagnosing electricity quality by synchronised vector measurements is summarised in the form of a block diagram (Fig. 1).

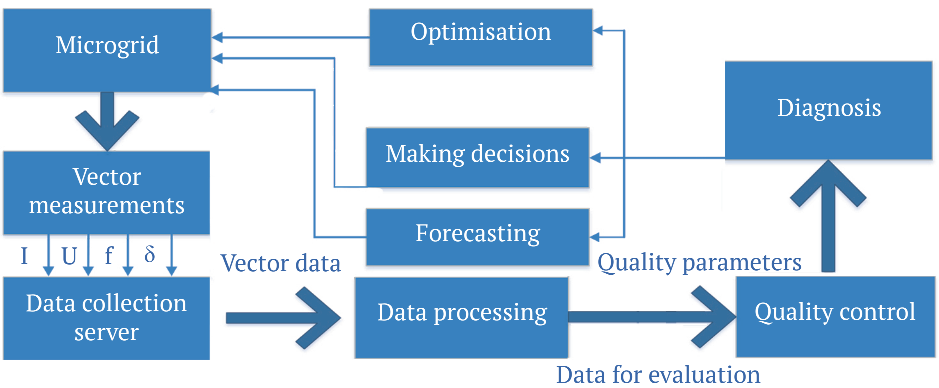

Figure 1. Block diagram of electricity quality diagnostics technology

The standards establish the following indicators of the quality of electric energy [1; 2]:

– voltage deviation δU_y;
– voltage change range δU_t;
– flicker dose P_t;
– sine wave distortion coefficient of the voltage curve K_U;
– coefficient n-th harmonic component of voltage $K_U(n)$
– reverse sequence voltage unbalance coefficient $K2_U$;
– zero-sequence voltage unbalance coefficient $K0_U$;
– frequency deviation Δf;

– voltage failure duration Δt_n;

– pulse voltage U_{imp};

– temporary overvoltage coefficient K_{perU}.

The input information will be an array of measured electrical parameters related to the measurement and values of the vector format of electrical parameters that were extracted from the online system of indicators obtained from the ENIP-2 device (Fig. 2) [22]. This electricity data were collected primarily for scientific purposes. The data relate to the measurement of electricity parameters and were extracted from the online electricity indicator system.

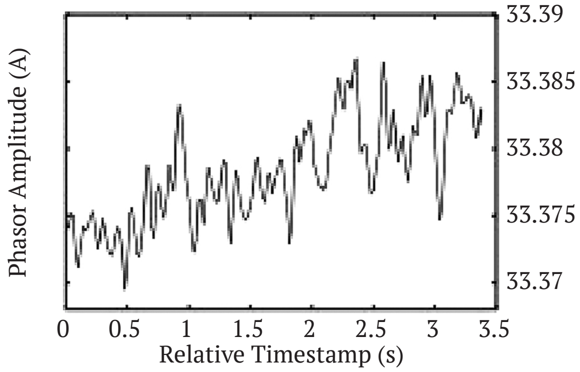

Figure 2. Procedure for receiving packages – preset communication method, frame rate 50 frames/s

1. t, s (countdown, s).
2. f, Hz (frequency per minute).
3. I, A (Current 1, A).
4. U, V (voltage, V).
5. I , A (Current 1, A).

For further statistical processing and forecasting, a dataset will be created containing 100 rows and 6 columns (Table 1).

Table 1. Fragment of the generated data set

No.	f. Hz	I. A.	U. V	I2. A.
1	49.9803	2.0511	230.705	33.374
2	49.9669	2.0512	230.694	33.375
3	49.9942	0.0513	230.661	33.371
4	49.9982	2.0507	230.629	33.374
5	50.0154	2.0506	230.596	33.375
6	49.961	2.0508	230.552	33.373
7	50.0107	2.051	230.535	33.375
8	49.9887	2.0509	230.508	33.3735
9	49.9905	2.0512	230.469	33.3745
10	49.9715	2.0514	230.442	33.3735
11	49.9701	2.0512	230.42	33.369
12	49.9611	2.0514	230.409	33.375
13	49.9822	2.0513	230.381	33.372
14	49.9847	2.0513	230.359	33.3745
15	49.9821	2.0511	230.337	33.379

The calculated statistical indicators for frequency, voltage, and current are shown in Table 2.

Table 2. Statistical characteristics of the measured parameters

Statistical characteristics	Frequency	Voltage	Current
Average values	49.992	33.378	228.884
Median	49.992	33.377	229.318
Maximum value	50.024	33.386	230.705

Columns (1) and (2) will predict the values of column (3) using two methods: KNN and Ridge regression.

The matrix for processing Predict data is shown in Table 3.

Table 3. Matrix for data processing

f. Hz	U. V
50.0228	228.569
49.9793	228.492
50.0041	228.404
50.0248	228.332
50.0233	228.272
49.9803	228.195
49.9734	228.113
49.9666	228.041
50.0249	227.926

Features of the software implementation include:

1. Data reading and primary processing using the Pandas library.

2. Plotting graphs using the Matplotlib and Plotly Express libraries.

3. Building a correlation table using the Seaborn library.

4. Standardisation of data, division of the training set into a training sample and validation sample, and implementation of classification models using the Scikit-Learn library.

Initially, the data was normalised for the highest calculation accuracy. An example of calculation based on normalised data is shown in Figure 3, without normalisation for Ridge regression – in Figure 4.

```
In [208]: from sklearn.linear_model import Ridge
          model = Ridge()
          model.fit(X_train_norm, Y_train)
          model.score(X_train_norm,Y_train)

Out[208]: 0.4774677178673772
```

Figure 3. Programme code snippet and calculation based on normalised data

```
In [209]: model.fit(X_train, Y_train)
          model.score(X_train,Y_train)

Out[209]: 0.45478502803711784
```

Figure 4. Programme code snippet and data calculation without normalisation

Evidently, the accuracy of the model is higher for normalised data.

Columns (1), (2) frequency and voltage, respectively. Predicted column (3) – current. The results of forecasting using the k-nearest neighbour algorithm KNN method and the accuracy of calculating the method are shown in Figure 5, and the predicted model is shown in Figure 6.

```
In [206]: model.score(X_train_norm, Y_train)

Out[206]: 0.6012872304007943
```

Figure 5. Programme code snippet and prediction results using the nearest neighbour method

```
In [207]: model.predict(X_prednorm)

Out[207]: array([33.3764, 33.3723, 33.3761, 33.3794, 33.383 , 33.38  , 33.3798,
                 33.3798, 33.3815])
```

Figure 6. Predicted model using the nearest neighbour method

The Ridge regression method and the accuracy of the calculation method are shown in Figure 7: the predicted model is shown in Figure 8.

```
In [208]: from sklearn.linear_model import Ridge
          model = Ridge()
          model.fit(X_train_norm, Y_train)
          model.score(X_train_norm,Y_train)

Out[208]: 0.4774677178673772
```

Figure 7. Code snippet of the ridge regression method and method calculation accuracy

```
In [210]: model.predict(pred)

Out[210]: array([33.38373138, 33.38404514, 33.38446656,
                 33.38480939, 33.38508349, 33.3853977 ,
                 33.38576735, 33.38608706, 33.38666182])
```

Figure 8. Predicted model using the comb regression method

Analysing the resulting forecast graph (Fig. 9), according to the normalised data, the accuracy of the Ridge regression model is higher by 10%-15%.

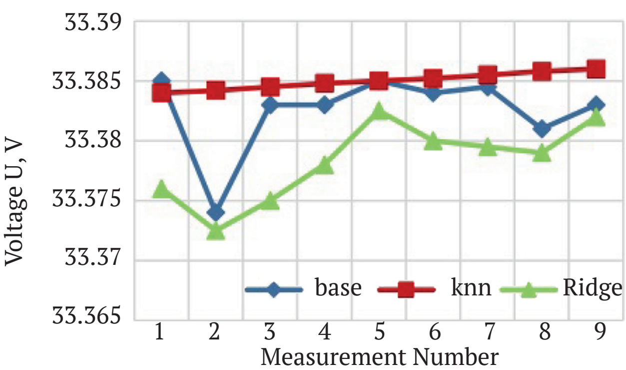

Figure 9. Graphical representation of output and predicted data using KNN and Ridge regression methods

A web-based software application for displaying synchronised vector measurements in the analysed system is described in [13]. Input information is represented by the readings of 4 electricity indicator recorders (PMU devices), which are located in 4 different locations in Ukraine:
- Central PMU, Kyiv Oblast;
- West PMU, Lviv Oblast;
- East PMU, Slovyansk city;
- South PMU, Kherson city.

Data modelling is performed using the Google Colab service and implemented in the Pytpon language. Four programme codes generate real-time metrics in parallel and are written to a MySQL database. These indicators are used to calculate the voltage and frequency deviation. This web interface should provide the ability to view readings from measuring devices connected to the power grid in different locations. These indicators should be presented both in tabular form and in a more user-friendly form – graphically.

The system uses the following tables: Locations, PMUS, Indicators, Quality. Next, an analytical system was constructed for determining the quality of electricity using a mathematical apparatus, which is implemented using the Google Colab service in Python. A fragment of the program results with dynamic data in the Indicators table is shown in Figure 10. The main page of the web interface is shown in Figure 11.

indicator_id	pmu_id	datatime	frequency	voltage	amperage
10 000	1	2020-12-06 13:03:43	50,646	212	18
30 000	3	2020-12-06 13:03:45	49,015	228	22
20 000	2	2020-12-06 13:03:45	51,399	211	21
10 001	1	2020-12-06 13:03:46	49,485	241	21
40 000	4	2020-12-06 13:03:46	51,161	200	24
30 001	3	2020-12-06 13:03:47	48,926	229	22
20 001	2	2020-12-06 13:03:48	49,211	214	17
40 001	4	2020-12-06 13:03:49	49,114	203	16
10 002	1	2020-12-06 13:03:49	50,711	234	25
30 002	3	2020-12-06 13:03:49	51,051	236	19
20 002	2	2020-12-06 13:03:51	50,107	241	18
40 002	4	2020-12-06 13:03:51	50,523	241	18
10 003	1	2020-12-06 13:03:52	51,301	231	22
30 003	3	2020-12-06 13:03:52	48,969	239	19
40 003	4	2020-12-06 13:03:53	50,062	205	24
20 003	2	2020-12-06 13:03:53	48,798	202	15
30 004	3	2020-12-06 13:03:54	50,159	203	22
10 004	1	2020-12-06 13:03:54	50,366	240	11
40 004	4	2020-12-06 13:03:56	50,707	203	10
20 004	2	2020-12-06 13:03:56	50,283	218	26

Figure 10. Dynamic data in the Indicators table

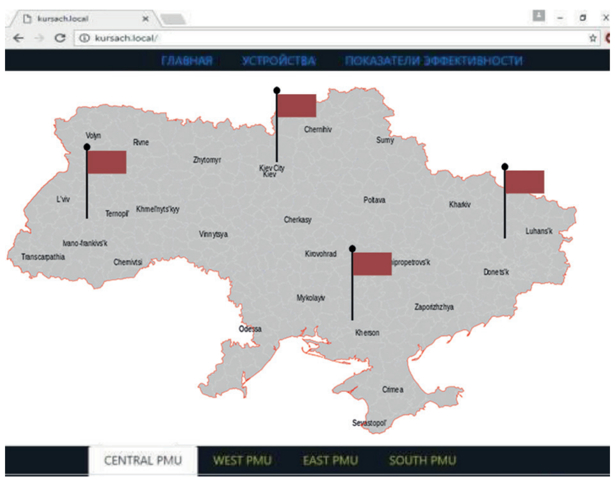

Figure 11. Home page of the web interface

In the future, it is planned to develop this project as follows:

– connecting multiple types of PMU devices, integrating them into the system, and collecting information at various facilities;

– application of optimisation and decision-making methods for managing the quality of electricity at the connection points of renewable generation sources;

– conducting tests in various objects of electricity consumption, in particular, the electrical complex of an industrial greenhouse, described in [23];

– investigation of information security methods and tools for transmitting data from the measurement source to the server.

CONCLUSIONS

1. To determine the quality of electricity, the following parameters are presented: frequency, voltage, and current strength, which are used to diagnose the quality of electricity.

2. A web interface for interactive interaction and visualisation of indicators with tables and graphs was designed and developed. This information is used for further analysis, graphical representation, and output of power quality results.

3. The developed software application allows quickly analysing the quality of electrical energy, and detecting power outages at an early stage.

REFERENCES

[1] Shing, C.K., Yiu, C.Y., & Xiong, C. (2021). Housing market in the time of pandemic: A price gradient analysis from the COVID-19 epicentre in China. *Journal of Risk and Financial Management*, 14, article number 108.

[2] Borghetti, A., Nucci, C.A., & Paolone, M. (2011). Synchronized phasors monitoring during the islanding maneuver of an active distribution network. *IEEE Transactions on Smart Grid*, 2(1), 1-8.

[3] Lixia, M., Benigni, A., Flammini, A., Muscas, C., Ponci, F., Monti, A. (2012). A software-only PTP synchronization for power system state estimation with PMUs. *IEEE Transactions on Instrumentation and Measurement*, 61(5), 1476-1485.

[4] Dileep, G. (2020). A survey on smart grid technologies and applications. *Renewable Energy*, 146, 2589-2625.

[5] Singh, A., & Surjan, B.S. (2014). Microgrid: A review. *International Journal of Research in Engineering and Technology*, 6, 185-198.

[6] Agapova, O., Popovych, N., Shulika, B., & Fylenko, V. (2018). Research of the spatial aspects of using renewable energy sources for sustainable development of the territory. *Technology Audit and Production Reserves*, 6(1(44)), 50-58.

[7] Oliveira, R., Camanho, A., & Zanella, A. (2017). Expanded eco-efficiency assessment of large mining firms. *Journal of Cleaner Production*, 12, 2364-2373.

[8] Volodarskyi, Y.T., & Voloshko, A.V. (2014). System monitoring electrical quality energy in decentralized systems power supply. *Eastern-European Journal of Enterprise Technologies*, 3(8-69), 10-17.

[9] Díaz-Villavicencio, G., Didonet, S., & Dodd, A. (2017). Influencing factors of eco-efficient urban waste management: Evidence from Spanish municipalities. *Journal of Cleaner Production*, 164, 1486-1496.

[10] Huang, X., Wang, X., Chen, L., Ye, C. (2020). Optimal portfolio strategies of purchasing electricity for electricity company based on distributional robust CVaR. *IOP Conference Series Earth and Environmental Science*, 467(1), article number 012200.

[11] Skok, S., Frlan, K., & Ugarković, K. (2017). Detection and protection of distributed generation from island operation by using PMUs. *Energy Procedia*, 141, 438-442.

[12] Hudson, J., Hudson, D., Morini, P., Clarke, H., & Stewart, M.C. (2020). Not one, but many "publics": Public engagement with global development in France, Germany, Great Britain and the United States. *Development in Practice*, 30(6), 795-808.

[13] Kiktev, N., Osypenko, V., Shkurpela, N., & Balaniuk, A. (2020). Input data clustering for the efficient operation of renewable energy sources in a distributed information system. In *2020 IEEE 15th international conference on computer sciences and information technologies (CSIT)* (pp. 9-12). Tokyo: The University of Tokyo.

[14] Lu, W., Jiang, W., Zhang N., & Xue, F. (2021). A deep learning-based text classification of adverse nursing events. *Journal of Healthcare Engineering*, 2, article number 110.

[15] Rogovskii, I.L., Titova, L.L., Gumenyuk, Yu.O., & Nadtochiy, O.V. (2021). Technological effectiveness of formation of planting furrow by working body of passive type of orchard planting machine. *Earth and Environmental Science*, 839, article number 052055.

[16] Usman, M.U., Faruque, M.O. (2019). Applications of synchro phasor technologies in power systems. *Journal of Modern Power Systems and Clean Energy*, 7, 211-226.

[17] Al Hadi, A., & Sinha, U. (2019). Internet of things (IOT) – enabled solar micro inverter using blockchain technology. In *IEEE industry applications society annual meeting* (pp. 128-138). Baltimore: IEEE.

[18] Rogoskii, I., Mushtruk, M., Titova, L., Snezhko, O., Rogach, S., Blesnyuk, O., Rosamaha, Yu., Zubok, T., Yeremenko, O., & Nadtochiy, O. (2020). Engineering management of starter cultures in study of temperature of fermantation of sour-milk drink with apiproducts. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 1047-1054.

[19] Soetens, N., Famaey, J., Verstappen, M., & Latr'e, S. (2015). SDN-based management of heterogeneous home networks. In *11th international conference on network and service management* (CNSM) (pp. 402-405). Barcelona: IEEE Computer Society.
[20] Anisha, N.P., Prasanna, V., & Suyampulingam, A. (2015). Soft phasor measurement unit. *Procedia Technology*, 21, 533-539.
[21] Venkatesh, T., & Trapti, J. (2017). Placement of synchronized measurements for power system observability during cascaded outages. *International Journal of Emerging Electric Power Systems*, 18(6), article number 1021.
[22] Leibovich, P., Issouribehere, F., & Barbero, J. (2019). Synchrophasor communication over internet: Performance analysis of different methods based on real experiences. In *IEEE power & energy society general meeting* (PESGM), (pp. 78-89). Atlanta: Georgia State University.
[23] Lysenko, V., Bolbot, I., Lendel, T. (2019). Energy efficient system of electrotechnological complex control in industrial greenhouse. *Technical Electrodynamics*, 2, 78-81.

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Визначення прогнозних показників якості електроенергії у режимі синхронізованих векторних вимірювань

Анотація. Нові електротехнології застосовують технології синхронізованих векторних вимірювань у режимі реального часу для підвищення надійності енергосистем, засновану на використанні синхрофазорів, для моніторингу та аналізу функціонування мережі в режимі реального часу. Це стало важливою віхою на шляху реалізації мети щодо розвитку енергосистеми країни за допомогою застосування складних інноваційних контрольно-вимірювальних пристроїв. Нові технології базуються на використанні пристроїв синхронізованих векторних вимірювань (phasor measurement unit — PMU) для збору даних від більш ніж 344 встановлених пристроїв із частотою 30 разів на секунду. Це значно відрізняє нові технології від традиційних, що дозволяють реєструвати дані вимірювань кожні 4 секунди. Ці дані мають тимчасові мітки GPS, що дозволяє синхронізувати вимірювання на різних точках та комбінувати отримані результати для детальної та всебічної оцінки стану системи на широкій географічній території. Маючи в своєму розпорядженні такі дані, виникає більше можливостей для виявлення, діагностики та запобігання порушенням у функціонуванні мережі, а значить, робить її розумнішою. Інтеграція цих технологій у систему моніторингу мережі в режимі реального часу значно підвищує нашу ситуаційну поінформованість про функціонування мережі та сприяє її модернізації. Технології синхронізованих векторних вимірювань надають унікальні дані, що дозволяють суттєво покращити надійність. Завдяки цим пристроям існує можливість розширили можливості щодо динамічного моніторингу стану енергосистеми. Мета статті – узагальнити дослідження з визначення прогнозних показників якості електроенергії у режимі синхронізованих векторних вимірювань. В статті автори обґрунтували структурну схему технології діагностики якості електроенергії. В результаті аналітичних підходів відтворено графічну інтерпретацію порядку прийому пакетів через заданий метод зв'язку в частоті кадрів 50 кадрів/с. Висновок – чотири програмні коди паралельно генерують показники в реальному часі і записуються в базу даних MySQL, за цими показниками розраховується відхилення напруги та частоти. Наукова значимість – підтверджена адекватність моделювання даних якості електроенергії у режимі синхронізованих векторних вимірювань за допомогою сервісу Google Colab та реалізацією мовою Phyton

Ключові слова: електроенергії, якість, діагностика, пристрої синхронізованих векторних вимірювань, методи прогнозу, динамічна база даних, веб-додаток