International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Algorithms for uninterrupted power supply to mobile communication base stations

Muradov Muhammad Murod ugli [1, 2, *]

[1] *Depotment of mobile communication technologies, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Tashkent, Uzbekistan.*

[2] *Depotment of data transmission networks and systems, Urgench State University named after Abu Rayhan Biruni, Urgench, Uzbekistan.*

International Journal of Science and Research Archive, 2025, 16(03), 617–629

Publication history: Received on 30 July 2025; revised on 11 September 2025; accepted on 13 September 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.16.3.2595

Abstract

The stable operation of mobile communication networks directly depends on the uninterrupted and reliable supply of electricity to base stations. Practice shows that the existing energy supply sources - the power grid, diesel generators and batteries - do not allow for effective operation in conditions of short-term outages. In particular, there is a delay in the start-up of the diesel generator, and renewable energy sources cannot provide continuity due to their dependence on weather conditions. Frequent charging and discharging of batteries shortens their service life and reduces system reliability. In this article, an algorithm for automatic control of energy sources was developed to improve the uninterrupted power supply of mobile communication base stations. Based on the proposed algorithm, a simulation model was created in the Proteus program and experimental tests were conducted. The results showed that the use of supercapacitors as a primary energy source reduced the delay time in load supply by 10 times, the response time in emergency situations decreased by 20–30%, and the overall efficiency of the base station increased by 1–1.5%. The results obtained show that the proposed algorithm has high scientific and practical significance in improving energy efficiency and ensuring continuity in mobile communication networks.

Keywords: Mobile Communication Base Station; Uninterruptible Power Supply; Automatic Control Algorithm; Supercapacitor; Battery; Diesel Generator; Renewable Energy Sources; Simulation Modeling; Energy Efficiency

1. Introduction

Nowadays, mobile communication systems operate as an important information and communication infrastructure in all spheres of society - economy, education, healthcare, transport and everyday life. Communication operators are striving to improve the quality of services and expand the coverage of networks by introducing modern technologies. In particular, the use of high-frequency bands allows subscribers to provide high-speed and high-quality services, but leads to a reduction in the service radius. As a result, there is a need to install additional base stations in order to ensure stable communication coverage in large areas [1-4].

Uninterrupted power supply to base stations is a key factor in ensuring the effective operation of mobile communication networks. Short or long-term power outages negatively affect the quality of communication services, the reliability of services provided to subscribers, and the economic efficiency of operators. Therefore, the issues of increasing the continuity of energy supply, effective management of energy sources, and rational use of alternative sources are considered to be urgent scientific and practical problems on a global scale.

Extensive research is being conducted in developed countries to improve the energy efficiency of mobile communications infrastructure. [2], [5], [6], [7]. These studies focus on the following areas:

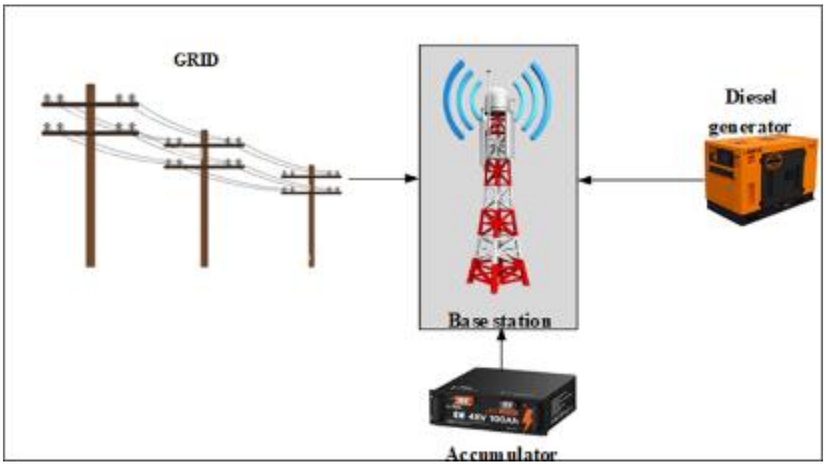
* Corresponding author: Muradov Muhammad

- Use of alternative energy sources (solar panels, wind generators, fuel cells, etc.);
- Application of energy-saving technologies;
- Development and implementation of intelligent control algorithms;
- Development of monitoring and forecasting systems.

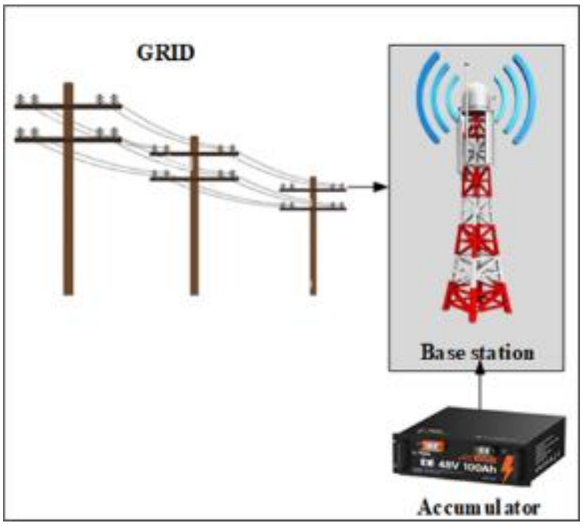
These approaches not only improve the quality of communication and ensure the continuity of network services, but also increase the overall energy efficiency of the infrastructure. From this point of view, the development of automated control algorithms designed to provide mobile communication base stations with uninterrupted power supply is one of the most important scientific and practical issues in the field of telecommunications today.

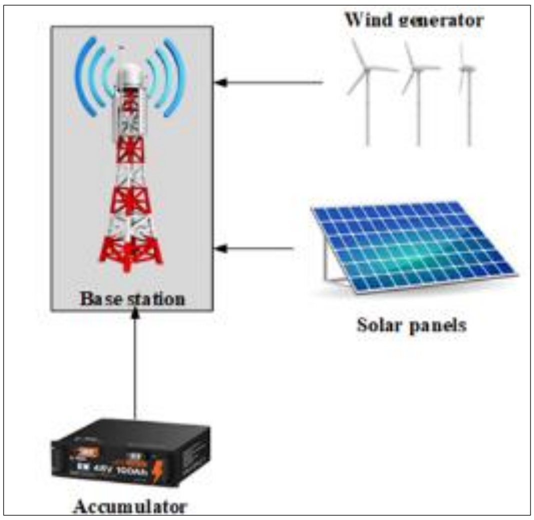
2. Literature review

Currently, the primary power source for mobile communication base stations is the local electricity grid [2], [5], [6]. All base stations are equipped with accumulators as a backup power source. Base stations that act as nodes are equipped with stationary or portable diesel generators. In addition, renewable energy sources are used to provide electricity to base stations in areas where the local electricity grid does not reach [2-4], [5-7], . Figure 1 shows the current state of the power supply structure of mobile communication system base stations.



(A)





(B) (C)

Figure 1 a) Structure of the power grid of base stations acting as nodes b) Structure of the power grid of simple base stations c) Structure of the power grid of base stations with an independent power supply source

The main energy consumer in the mobile communication system is the base station system. Therefore, today a lot of research is being conducted to improve the energy efficiency of the base station system. As a result of the research, several areas of increasing the energy efficiency of the base station system have been identified. They are [4], [6], [7]:

- Upgrading of outdated equipment in the base station system;
- Use of dynamic energy saving systems;
- Use of radio devices and distributed antenna systems;
- Improvement of auxiliary systems.

The distribution of energy consumption of the base station system has been analyzed in many studies today. The analysis of the conducted studies shows that the electrical energy consumption of the mobile communication base station is spent on radio equipment and amplifiers, auxiliary systems, air conditioners and other devices [8], [9]. Radio equipment, amplifiers, and air conditioners at the base station are the largest energy consumers and are the main components of the mobile communication system [2], [3].

The analysis shows that the average annual energy consumption of the base station is approximately 35,500 kWh. The average daily variation of the base station electricity consumption in the study area is presented in Figure 2.

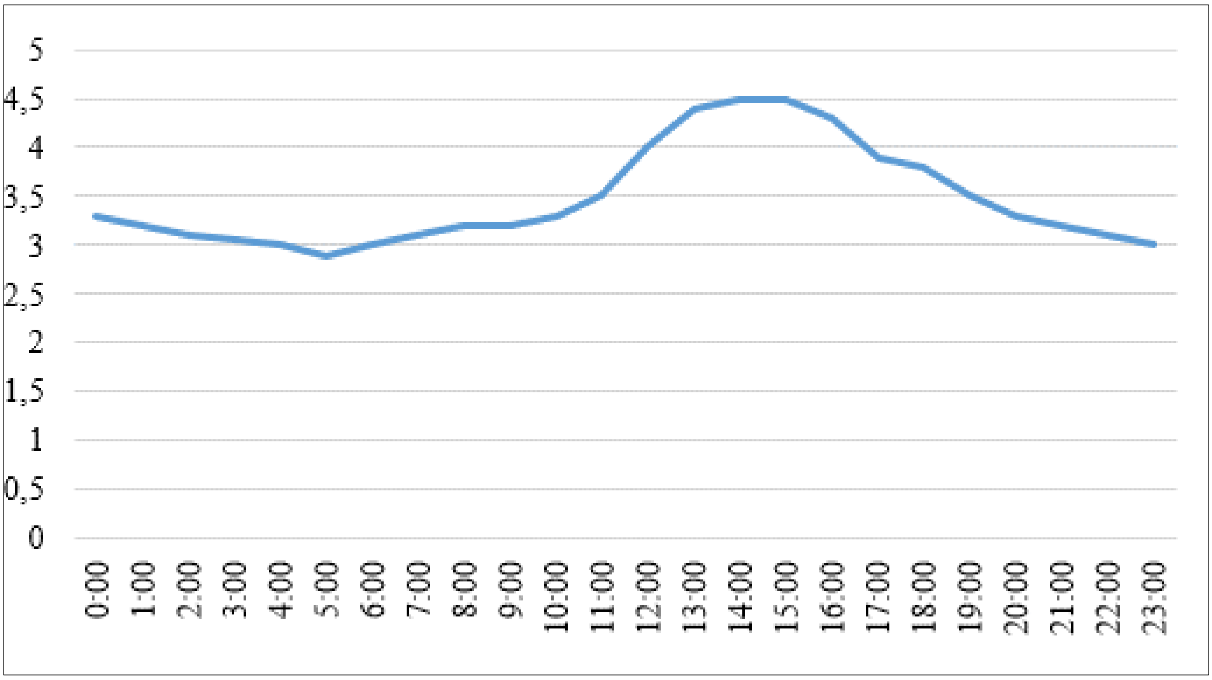


Figure 2 Daily average energy consumption changes of the base station

The daily energy consumption of the base station can be conditionally divided into two parts

- 3 kWh when the temperature is normal;
- 4.5 kWh when the temperature exceeds the set limit.

The energy consumption in the first part is due to the transmission of mobile signals, since the temperature is in a normal state. In the second part, the energy consumption of cooling systems, which are working to maintain the temperature at a normal state, is also added, since the temperature has risen above the specified limit. It should be noted that in the second part, the demands of users for mobile services and the load on the base station also increase. The analysis shows that in the second part of the energy consumption, communication quality deteriorated due to power outages [4], [8].

According to statistics, the most frequent outages at base stations last up to 1 hour (Table 1). To ensure uninterrupted operation of the base station during this outage, it is important to use an efficient power supply. Many studies have been conducted in this area today. The results of the studies show that supercapacitors are distinguished from other backup sources by their high-power charging, fast energy delivery, and unlimited charging and discharging [10-12].

Table 1 Base station power outage status

Category	Time interval (hours)	Number of power outages (number)	Power outages (%)	Network stability	Battery duty cycles
1.	0-1	4719	81,069	Stable	4719 cycles
2.	1-2	599	10,29		599 cycles
3.	2-6	416	7,147	Partially stable	416 cycles
4.	6-24	87	1,495	No connection available.	87 cycles
Total	0-24	5821	100		5821 cycles

Batteries and supercapacitors perform specific functions in the power management system and affect the stable operation of the entire system due to the variability of the energy supplied by the main power source [13-15].

Supercapacitors play an important role in compensating for short-term power outages due to their high power density and fast charge-discharge characteristics. For example, the efficiency of energy produced by solar panels can vary from a few minutes to a few hours depending on environmental factors. In such cases, supercapacitors can prevent temporary power outages by rapidly accumulating and releasing energy, thereby ensuring stable system operation [16].

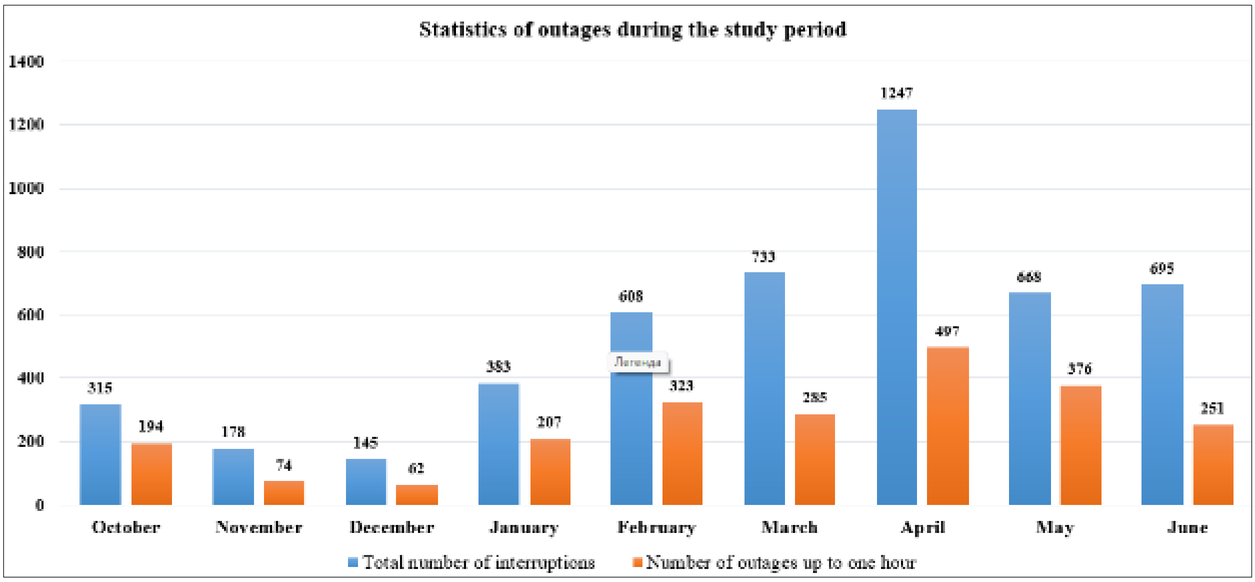


Figure 3 Statistics of power outages in the study area

Today, the control process of the base station electric power supply sources is carried out through a controller control system. The controller control system continuously receives data from each energy source on the output voltage, flowing current and other important parameters. Data on the energy consumption of the base station devices is also constantly transmitted to the controller control system. As a result, an automatic control strategy is developed, and the connection or disconnection of various energy sources is automatically carried out. A structural diagram illustrating the principle of operation of this system is presented in Figure 4.

A microcontroller control system consists of the following devices [15]

- control controller – ESP32, Rasberry PI, Arduino Uno, etc.;
- relays;
- sensors.

The energy supply management system automatically connects the next source in the event of a failure of one energy supply source. In order to implement the process of effective management of energy supply sources, it is necessary to comprehensively analyze the control system with a controller. In this case, it is important to correctly select sensors that transmit a signal corresponding to the current value to the controller in real time. These sensors must provide the system with accurate and stable information, which, as a result, increases the reliability of the control process. Also, in-depth research into the control process and the development of appropriate algorithms are required to optimize and effectively distribute energy supply.

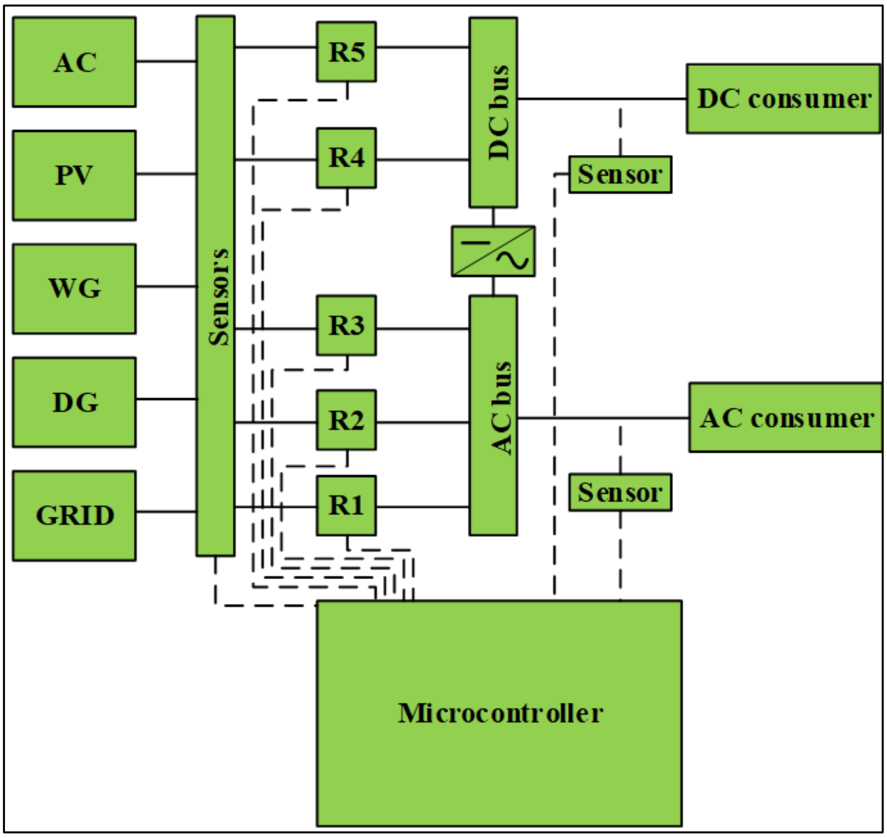


Figure 4 Generalized structure of control of power supply sources of a mobile communication base station through a microcontroller

Failures in base stations that also serve as node base stations are much more dangerous than in regular base stations, because even a small outage here can negatively affect the quality of communication with subsequent base stations [17], [18]. Taking this into account, the power supply of the base stations used as node base stations is reliably backed up. The algorithm for controlling the power supply sources of the node base station is shown in Figure 2. The algorithm for controlling the power supply sources of the node base station works as follows. Initially, the system is started and the voltage value of the local power grid is checked. If the voltage value of the local power grid is higher than 48 volts, the base station is supplied with power from this source and a message about this situation is sent to the monitoring center.

If the main power supply source is out of service or cannot provide sufficient voltage, the diesel generator is started. The diesel generator first heats up the diesel to start, which takes about 45-60 seconds, and it also takes another 45-60 seconds to warm up the generator to prepare for full load. Before the generator starts, the batteries provide power to the base station for 90-120 seconds. A message is sent to the monitoring center about the current status. After the generator is fully started, it starts supplying power to the base station [17], [18].

If all of the above energy sources are not available or cannot provide sufficient power, the base station will not be supplied with electricity and an outage will occur. In each case, after power is provided by the energy source, the device's operating status is evaluated separately. If a failure or insufficient performance is observed in the system, the algorithm is restarted from the beginning and the above processes are repeated.

Typical base stations use the local power grid and batteries as a backup power supply. The batteries provide power to the base station in the event of a power outage in the main power supply system [17].

The algorithm works as follows. First, the system is started and the voltage of the local power grid is checked. If the voltage of the local power grid is higher than 48 volts, the base station is supplied with electricity from this source and a message about this situation is sent to the monitoring center. If the local power grid cannot provide sufficient voltage or is not available, the next step is to determine the presence of an AC. If it is available, the base station is powered by the AC. During this process, information about the current status of the station is sent to the monitoring center and the device's operating status is checked. If the system is working properly, the algorithm completes its operation, otherwise the process continues.

If all of the above energy sources are not available or cannot provide sufficient power, the base station will not be supplied with electricity and an outage will occur. In each case, after power is supplied through the energy source, the device's operating status is evaluated separately. If a failure or insufficient performance is observed in the system, the algorithm is restarted from the beginning and the above processes are repeated.

In areas where the local electricity grid does not reach, renewable energy sources mainly provide electricity to base stations. Stations powered by such alternative energy sources operate independently of traditional electricity grids. They are powered by solar panels, wind generators or hybrid systems. Such systems are environmentally friendly and are an effective solution for base stations in remote areas. These stations play an important role, especially in areas where electricity supply is not sufficiently developed. In order to ensure uninterrupted power supply to independent base stations outside the local electricity grid, an algorithm has been developed that controls the alternating use of solar panels, a wind generator, a wind generator and batteries.

The operation of this algorithm is as follows. First, the system is started and the voltage value of the solar panels is checked. If the voltage generated by the solar panels is higher than 48 volts, the base station is supplied with electricity from this source and a message about this situation is sent to the monitoring center. If the solar panels cannot provide sufficient voltage or are not available, the next step is to determine the presence of a wind generator. If it is available, the base station is powered by a wind generator, and if available, the batteries connected to the solar panels are also charged. During this process, information about the current state of the station is sent to the monitoring center and the operating status of the device is checked. If the system is working properly, the algorithm ends its operation, otherwise the process continues. If the wind generator is also not available, the presence of a battery pack is checked. If the battery is available and operational, then the base station is powered by this source, a status message is transmitted to the monitoring system, and the device’s performance is evaluated. If all of the above energy sources are unavailable or cannot provide sufficient power, the base station will not be powered and an outage will occur. In each case, after power is provided by the energy source, the device’s performance is evaluated separately. If a system failure or insufficient performance is detected, the algorithm is restarted from the beginning and the above processes are repeated.

The results of the analysis of the uninterrupted power supply of mobile communication base stations showed that there are a number of technical and operational problems with existing energy sources. In particular, frequent short-term outages in central power supply networks directly affect the stability of communication services. Also, diesel generators have a certain time delay in the start-up process, during which a backup energy source is required to meet consumer needs. Renewable energy sources, by their nature, are significantly dependent on weather instability, and sudden changes in sunlight intensity or wind speed do not allow ensuring continuity in energy production.

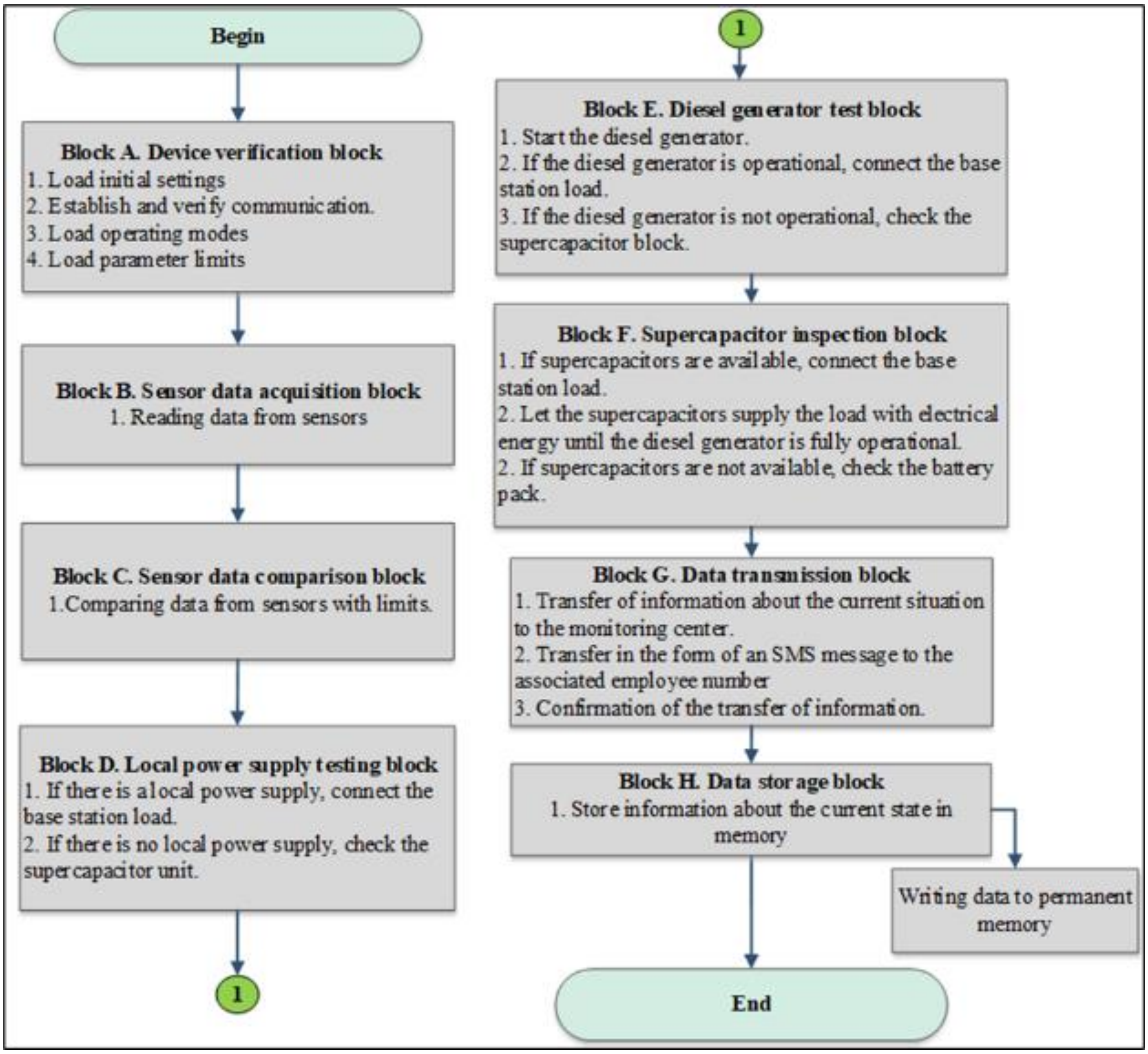
In practice, batteries are mainly used to compensate for these problems. However, the constant charging and discharging of batteries during short-term and frequently recurring outages increases their cycle count, which significantly reduces their service life. In addition, batteries have limited capabilities for quickly transferring energy and cannot immediately meet the load demand in emergency situations. Therefore, existing solutions are becoming a factor that reduces the overall reliability and efficiency of the system.

A thorough study of these problems shows the need to develop more advanced algorithms for managing energy supply sources for mobile communication base stations. It is especially important to introduce alternative energy storage technologies that are high-power, fast-response and have the ability to operate for long periods of time to compensate for short-term outages.

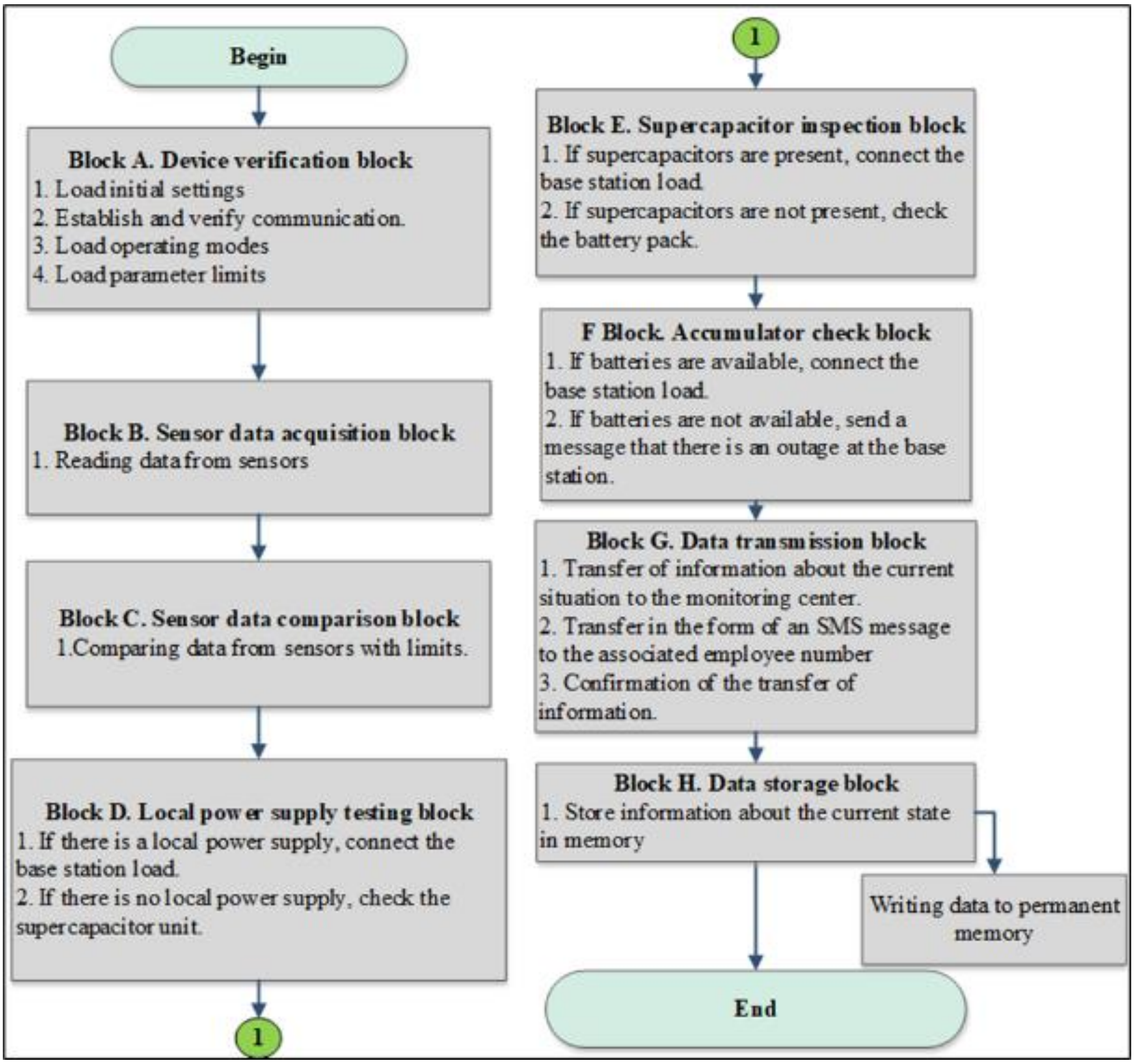
3. Methods and Materials

As an effective solution to the above shortcomings and problems, an algorithm for automatic control of mobile communication base station power supply sources has been developed to ensure the uninterrupted operation of mobile communication base stations. In this case, the algorithm automatically controls the power supply sources of the node base station (Figure 5a) and the simple base station (Figure 5b). This algorithm consists of several blocks, each block performing the following tasks:

Block A. Device Check Block - Initialization is the part where the initial settings are loaded and initialized to prepare the internal devices for operation. Communication between the monitoring center and the device is established, and the settings are loaded and configured to operate the device based on predefined parameters.



(A)



(B)

Figure 5 Algorithm of the automatic control system for power supply sources of mobile communication base stations: a) node base station, b) simple base station

Block B. Sensor data acquisition block – For data collection and analysis, current data on the indicators and status of the base station's power supply sources is obtained from sensors.

Block C. Sensor data comparison block. Based on the collected data and analysis, sensor data is compared with predefined threshold values to make management and control decisions about electricity supply sources.

D-F Blocks. Power supply control block. By analyzing the data received from the sensors, an efficient power supply is connected to the base station load. After connecting to the base station load, it is confirmed that several relay modules are connected at once so that they do not turn on at once. The voltage of the power supply is constantly monitored during the power supply of the load.

G Block. Data transmission block. Information about changes in the current status is constantly transmitted to the monitoring center. In addition, information about the status is also sent via SMS to the assigned employee number. After information about changes in the current status is transmitted via SMS, the fact that the information was sent is confirmed to prevent repeated transmission.

H Block. Data storage block. Information about current state changes is recorded in permanent memory. Data recorded in permanent memory allows for additional statistical analysis.

The automatic control system for power supply sources of mobile communication base stations allows you to monitor the status of power sources in real time, use them efficiently, and respond quickly to outages. This approach reduces maintenance costs, helps to plan preventive measures in advance, and increases the overall reliability of the system by implementing effective management among power sources. Remote monitoring provides the ability to continuously store and analyze data, ensuring uninterrupted operation of the communication system.

4. Results and Discussion

To organize effective management of the power system of mobile communication base stations, it is necessary to develop an effective and automatic control system for energy supply sources. Before developing the system, it is necessary to check the adequacy of the developed and created control method and system operation algorithms by creating a simulation model of the system and conducting experimental work on them. For the development of the system, there are schemes and microcontrollers, and for simulation based on the developed mathematical model, there are TINA-TI, Multisim, Proteus, LTspice, KiCad, Altium Designer, MATLAB/Simulink, PSCAD, PSpice, ETAP, PowerWorld Simulator and other programs [15], [19-21].

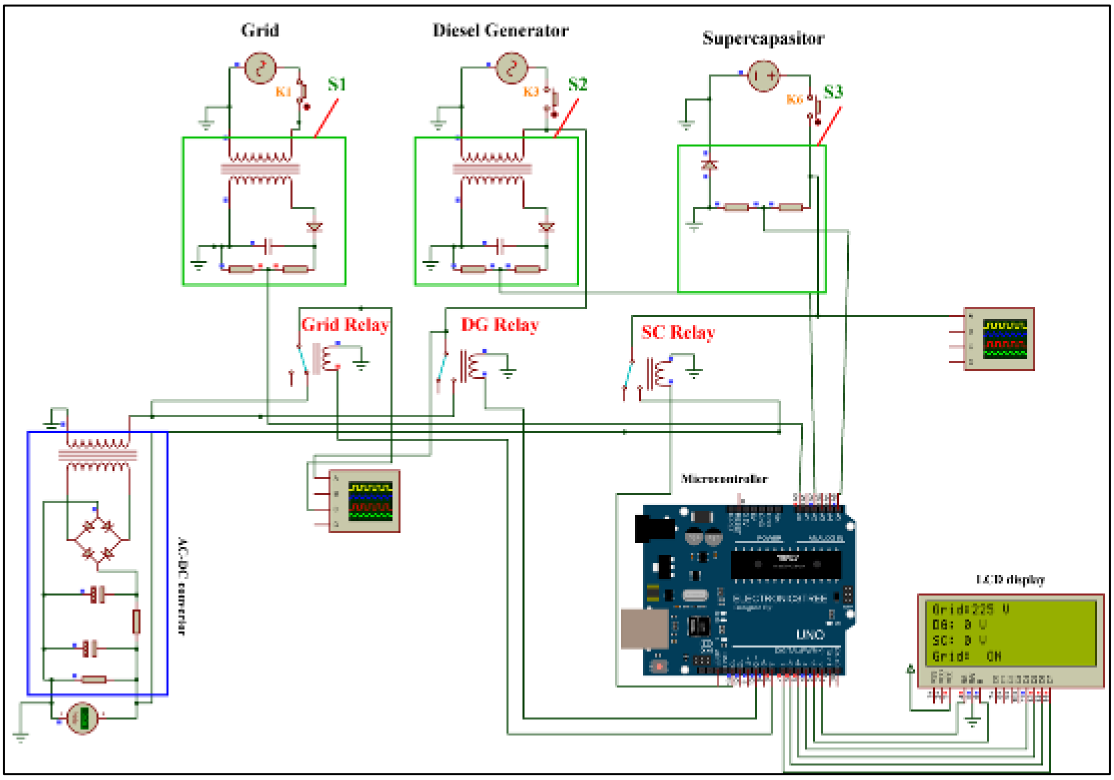


Figure 6 The main power supply source parameter is within the specified limits

Among the above programs, the Proteus program provides the ability to select network elements, write program codes, and build a simulation model of the system during the modeling process. With the help of this program, you can create a model of the system, check the operation process, design electronic circuits, and diagnose them. Proteus is a program belonging to the VSM (Virtual Simulation Modeling) category, which allows not only to develop electronic systems schematically, but also to analyze their operating principle in real time. Therefore, this program is widely used in modeling microprocessor-based devices, power supply systems, and automation systems [15], [21-24].

Based on the conditions of the proposed algorithm, the power supply management system of mobile communication base stations and its operation process were modeled in the Proteus program. This algorithm analyzes the real-time state of various power sources and provides their automatic control. Based on the algorithm, software was developed in the C++ programming language and Arduino environment and placed in the device's microcontroller. As a result, automated control is implemented in the power supply process. In this case, the main power supply source is local power grids (Figures 6-9).

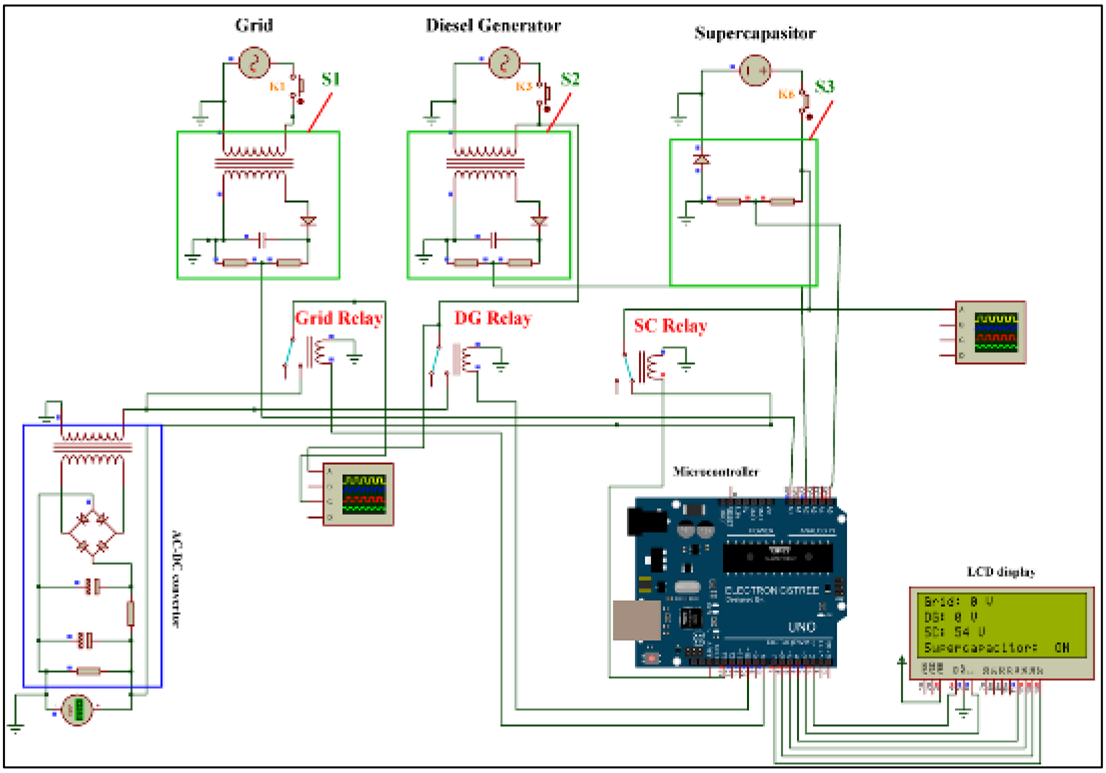


Figure 7A situation where there is an interruption in the main source of electricity supply and the supercapacitor parameter is within the specified limits

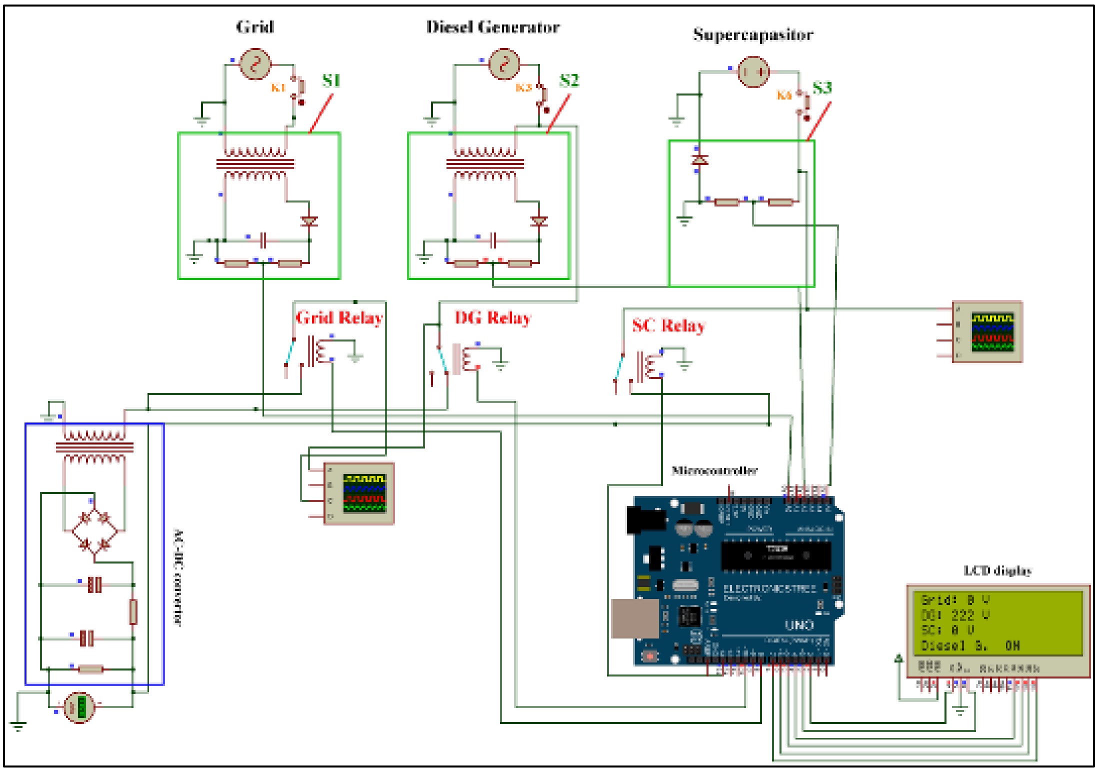


Figure 8 A condition in which the supercapacitor experienced a disruption, and the diesel generator operated within the specified parameter limits

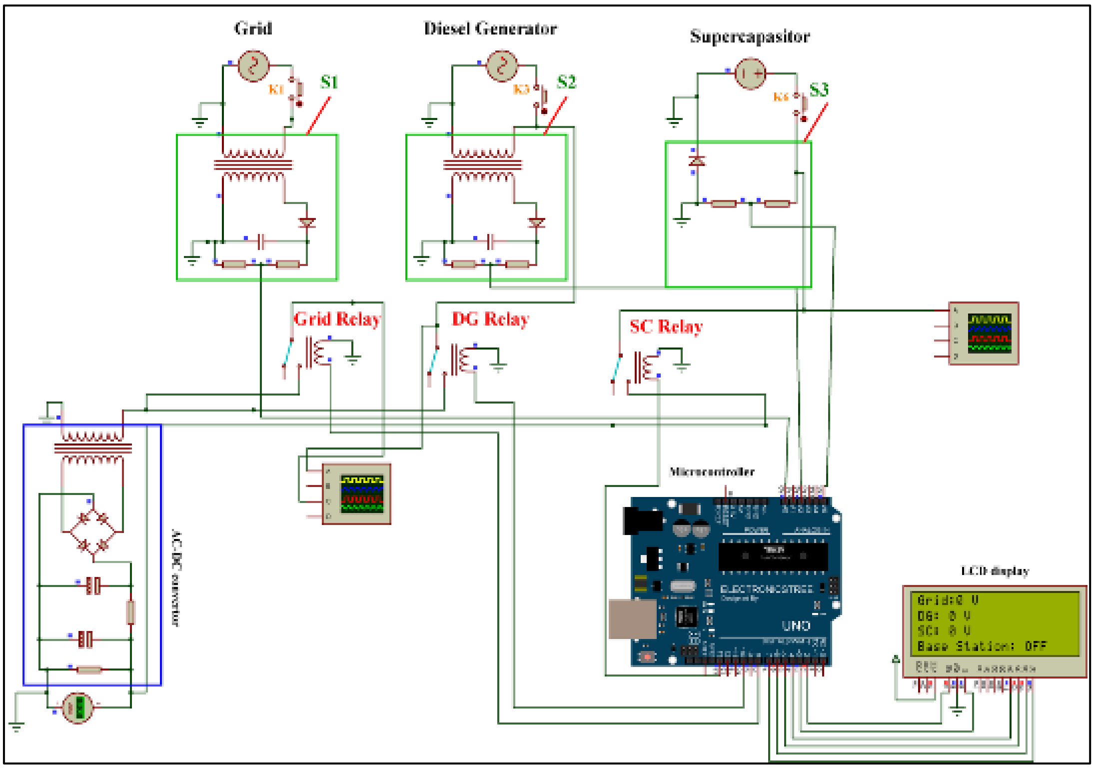


Figure 9 A situation where all electricity supply sources are out of order

Using the Proteus program, a simulation model of the uninterrupted power supply system for mobile communication base stations was created. Experimental tests were carried out based on the created model. The results of the experimental tests showed that this model was able to respond quickly to power supply sources during outages at the base station, and as a result, it was determined that the base station could be provided with uninterrupted power supply. During outages at the base station, the response time during outages was reduced by 10 times due to the use of supercapacitors as the primary source of power supply to the load. Using the algorithms of the automatic control system for power supply sources of mobile communication base stations, the response time to emergencies in the power supply system was reduced by 20-30 percent, and the efficiency of uninterrupted operation of the base station was increased by 1-1.5 percent by detecting and preventing outages in advance by recording and analyzing the system's operating parameters.

5. Conclusion

In order to study the uninterrupted power supply of mobile communication base stations, a simulation model was created using the Proteus program. This model integrated the main energy sources (electrical grid, battery, diesel generator and supercapacitor) and their automatic control algorithms. Experimental tests conducted on the basis of the model showed the following scientific results

Rapid response to outages

- The use of supercapacitors as a primary backup source significantly reduced the delay time in providing power to the load.
- While the response time in traditional battery solutions was on average 2–3 seconds, when supercapacitors were used, this indicator decreased to 0.2–0.3 seconds, that is, a reduction of about 10 times was observed.

Efficiency in emergency situations:

- When automatic control algorithms for electrical power supply sources were implemented in the system, the response time to emergency outages was reduced by an average of 20–30%.
- This helped reduce the frequency of outages in communication services and increase the reliability of the system.

Monitoring and analysis capabilities:

- It became possible to detect outages in advance and take preventive measures by recording and analyzing system parameters in real time.
- As a result of this approach, the overall efficiency of base stations increased by 1–1.5%.

Thus, the modeling and experimental tests conducted scientifically substantiated that the proposed control algorithm and the use of supercapacitors effectively organize uninterrupted power supply at mobile communication base stations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Oʻ.K.Matyokubov, M. M. Muradov and O.B.Djumaniyozov “Analysis of sustainable energy sources for mobile communication base stations using the example of the Khorezm region,” (in Uzbek), “Axborot texnologiyalari, tarmoqlar va telekommunikatsiyalar” xalqaro ilmiy-amaliy anjumani, Urganch-2022, pp. 107-111.

[2] M. M. Muradov “Off-load power supply of mobile communication base stations from renewable energy sources”, (in Uzbek) Al-Farghani descendants magazine № 4 1(8) 2024, pp. 245-250.

[3] U. K. Matyokubov, M. M. Muradov and O. B. Djumaniyozov, "Analysis of Sustainable Energy Sources of Mobile Communication Base Stations in the Case of Khorazm Region," 2022 International Conference on Information Science and Communications Technologies (ICISCT), Tashkent, Uzbekistan, 2022, pp. 1-4, doi: 10.1109/ICISCT55600.2022.10146885.

[4] Davronbekov, D., and Muradov, M. (2025). Assessment of the state of disruptions in the power supply system of a mobile communication base station. Scientific Journal of Astana IT University, 21, 125–136. https://doi.org/10.37943/21JFNX5577.

[5] Zheng, F.; Chen, K.; Liu, M. Optimization of Communication Base Station Battery Configuration Considering Demand Transfer and Sleep Mechanism under Uncertain Interruption Duration. Sustainability 2023, 15, 16645. https://doi.org/10.3390/su152416645

[6] Marsan, M.A.; Bucalo, G.; Di Caro, A.; Meo, M.; Zhang, Y. Towards zero grid electricity networking: Powering BSs with renewable energy sources. In Proceedings of the 2013 IEEE International Conference on Communications Workshops (ICC), Budapest, Hungary, 9–13 June 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 596–601.

[7] Wang, H.; Zhao, Z.; Cheng, X.; Ying, J.; Qu, J.; Xu, G. Base station sleeping strategy for on-grid energy saving in cellular networks with hybrid energy supplies in IoT environment. IEEE Access 2018, 6, 45578–45589.

[8] M. M. Muradov “Analysis of power outages at mobile communication base stations”, Наука и образование: теория и практика. г. Нефтекамск, Республика Башкортостан, 2024 17-22.

[9] Murod oʻgʻli, Muradov Muhammad. "Enhancing the energy efficiency of wireless sensor networks." International scientific conferences with higher educational institutions. Vol. 1. No. 05.05. 2023.

[10] Matyokubov, U. K., and D. A. Davronbekov. "The impact of mobile communication power supply systems on communication reliability and viability and their solutions." International Journal of Advanced Science and Technology 29.5 (2020): 3374-3385.

[11] Davronbekov, Dilmurod Abdujalilovich and Matyokubov, Utkir Karimovich (2021) "The use of supercapacitors to stabilize the power supply system of the base station of mobile communication" Scientific-technical journal: Vol. 25: Iss.1, Article 1.

[12] Dilmurod Davronbekov, Muhammad Muradov, and Dilshod Mirzaev. 2025. Application Features of Supercapacitors in Energy Supply Systems. In Proceedings of the 8th International Conference on Future Networks and Distributed Systems (ICFNDS '24). Association for Computing Machinery, New York, NY, USA, 314–318. https://doi.org/10.1145/3726122.3726168.

[13] Matyokubov, U. K., and D. A. Davronbekov. "Increasing energy efficiency of base stations in mobile communication systems." Acta of Turin Polytechnic University in Tashkent 10 (2020): 1.

[14] Davronbekov Dilmurod, Matyokubov Utkir, Muradov Muhammad. (2025). A Device that Controls the Power Supply Sources of a Mobile Communication Base Station, International Journal of Innovative Research in Engineering and Management (IJIREM), 12(2). 22-29, doi:10.55524/ijirem.2025.12.2.4.

[15] Dilmurod Davronbekov, Muradov Mukhammad. Analysis of monitoring and management methods for energy supply sources. (2025). Digital transformation and Artificial Intelligence, 3(1), 221-228. https://dtai.tsue.uz/index.php/dtai/article/view/v3i133.

[16] Qutliyev, U. O., et al. "Integration Of Fuzzy Set Approach For Comprehensive Study Of Sustainable Functioning Of The Telecommunication System Of Uzbekistan." The American Journal of Engineering and Technology 3.06 (2021): 35-46.

[17] U. K. Matyokubov, M. M. Muradov and J. F. Yuldoshev, "Development of the Method and Algorithm of Supplying the Mobile Communication Base Station with Uninterrupted Electrical Energy," 2024 IEEE 25th International Conference of Young Professionals in Electron Devices and Materials (EDM), Altai, Russian Federation, 2024, pp. 2400-2406, doi: 10.1109/EDM61683.2024.10615043.

[18] Matyokubov, O‘tkir, and Muhammad Muradov. "Mobil aloqa tayanch stansiyasi elektr ta’minot tizimlaridagi dolzarb muammolar." International Journal of scientific and Applied Research 1.3 (2024): 79-83.

[19] U. K. Matyokubov and M. M. Muradov, "Comparison of Routing Methods in Wireless Sensor Networks," 2023 IEEE XVI International Scientific and Technical Conference Actual Problems of Electronic Instrument Engineering (APEIE), Novosibirsk, Russian Federation, 2023, pp. 1780-1784, doi: 10.1109/APEIE59731.2023.10347799.

[20] Nayeem, M.K.; Alam, S.T. A scenario-based stochastic programming model for multi-commodity distribution considering disruption in distribution network. Results Control Optim. 2022, 8, 100167.

[21] Dr. Dilmurod Davronbekov, Muradov Muhammad, and Alisher Khayrullaev , Trans., “Mathematical Modelling of the Power Supply System of a Mobile Communication Base Station”, IJIES, vol. 12, no. 8, pp. 21–29, Aug. 2025, doi: 10.35940/ijies.H1118.12080825.

[22] Wang, F.; Fan, X.; Wang, F.; Liu, J. Backup battery analysis and allocation against power outage for cellular base stations. IEEE Trans. Mob. Comput. 2018, 18, 520–533.

[23] Davronbekov, D. A., and U. K. Matyokubov. "Influence of communication lines on reliability in mobile communication systems." 2021 International Conference on Information Science and Communications Technologies (ICISCT). IEEE, 2021.

[24] Davronbekov, D. A., and U. K. Matyokubov. "Algorithms for calculating the structural reliability of a mobile communication system." 2021 International Conference on Information Science and Communications Technologies (ICISCT). IEEE, 2021.