ВЕСТНИК ТУРИНСКОГО ПОЛИТЕХНИЧЕСКОГО УНИВЕРСИТЕТА В ГОРОДЕ ТАШКЕНТЕ

ACTA OF TURIN POLYTECHNIC UNIVERSITY IN TASHKENT

ВЫПУСК
EDITION 1/2025

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ACTA TTPU

Preface

Dear readers! I am pleased to announce the publication of a new edition of ACTA TTPU, the journal of Turin Polytechnic University. It is an № 1 issue to be published in 2025 year which includes selected articles submitted to the editorial board. Since the beginning of the year, we have seen an increase in the number of articles submitted to our journal, and I believe that the growing popularity of the journal is partly due to the excellent work of the editorial board. We will continue our efforts to improve the quality as well as the submission requirements and simplify the selection procedures in order to raise the quality to a higher level.

I am very grateful to our editorial board for their contribution to the quality of our journal and to all authors for their submissions. We are always open to any criticism and suggestions to improve the readability and content of the articles published in our journal.

Editor-in-chief
DSc. O.A.Tuychiev

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EVALUATION OF THE RELIABILITY OF FIBER-OPTIC INFORMATION TRANSMISSION SYSTEMS BASED ON THE LAWS OF FAILURE DISTRIBUTION

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Abstract– The influence of various failure distribution laws on the reliability of fiber-optic data transmission systems (FODTS) components is analyzed. The article discusses the failure distribution laws applicable to hardware and software components of the system, which allow taking into account their interaction and mutual influence on the overall reliability of the system. As a methodology, reliability assessment models are used, in particular, the exponential distribution, the Weibull distribution, and the Musa- Okumoto software reliability model. Formulas for assessing the overall reliability of the system and probability density functions are given, allowing a more complete picture of the stability and reliability of the FODTS under operating conditions.

Key words– fiber-optic information transmission systems, reliability, failure, failure distribution law, software reliability model.

I INTRODUCTION

The basis of modern telecommunications are FODTS, providing high-speed and reliable data transmission over long distances. Hardware and software reliability of FODTS are among the important factors for ensuring stable and trouble-free operation of telecommunication networks. Hardware reliability of the FODTS is defined as the ability of the hardware components of the system to perform their functions for a specified time under certain operating conditions, which depends on the quality of materials, design features, operating conditions, as well as the impact of external factors such as temperature, humidity, mechanical impacts, etc.[1-3]. Software reliability is associated with the ability of the software that controls the operation of the FODTS to function correctly and process data without errors for a specified time. Software reliability includes resistance to failures, protection from software errors and viruses, as well as the ability to self -recovery after failures [4-6]. This is ensured by high-quality code, effective algorithms, thorough testing and monitoring of software operation.

The conducted analysis shows that the study of distribution laws is one of the main factors in ensuring high reliability of hardware and software components of the FODTS [5,7,8,9]. When analyzing the FODTS, it is usually assumed that the failure rate of all elements and components is the same or their reliability is the same, that is, all elements and components obey the same distribution law. However, in real conditions, the failure rate and reliability of various FODTS elements can vary significantly. The probability of failure-free operation of hardware and software is characterized by different distribution laws of a random variable. Therefore, one of the main tasks of increasing reliability is the study of complex distribution laws. In [7,8], complex distribution laws for two random variables with the same distribution laws, in particular exponential laws, are studied. This paper considers various distribution laws for hardware and software, which allow taking into account their specific features and increasing the overall reliability of the system.

II THE RESEARCH METHOD

Random discrete or continuous variables $x_1, x_2, ..., x_n$ with a joint probability distribution $f(x_1, x_2, ..., x_n)$ and a marginal distribution, $f_1(x_1), f_2(x_2), ..., f_n(x_n)$ respectively, are mutually statistically independent if and only if [5]

$$f(x_1,x_2,...,x_n) = f_1(x_1)\cdot f_2(x_2)\cdot ...\cdot f_n(x_n) \tag{1}$$

for all $x_1, x_2, ..., x_n$ within their range.

Expression (1) is valid for discrete, continuous and mixed random variables [8]

Classification	Subclass	Model	Description
Analytical models	Dynamic (continuous)	Jelinski-Moranda Model, Musa Model, Transition Probability Model, Musa-Okumoto Model	Model the growth of reliability over time, taking into account operational data.
	Dynamic (discrete)	Shooman Model, Modified Shooman Model, La Model Padula, Model Chic-Wolverton	Evaluate failure rates in real time
	Static models (by data domain)	Mills Model, Lipov Model, Simple Intuitive Model	Estimation of the distribution of errors in code and data.
	Static models (by error domain)	Corcoran Model, Nelson Model	Predicting data distribution for reliability
Empirical models	Complexity model	Analysis of software architecture and complexity of fixes	Predicting the Impact of Complexity on Software Reliability
	Model of program refinement time	Estimating time to achieve reliability	Predicting the time costs of software improvements
Software Development Life Cycle	Requirements development	Rome Laboratory Model, Musa Expectations Model	Early prediction of errors based on data collection
	Programming	Hybrid White Box Models, Hybrid Black Box Models	Testing models with or without access to code
	Testing	Jelinski-Moranda Model, Musa Model, Musa- Okumoto Model, Shooman Model	Forecasting the growth of software reliability

TABLE 1: CLASSIFICATION OF SOFTWARE RELIABILITY MODELS

In sequential systems, all components must be in a functioning state for the system to function, and its reliability is expressed as [7]:

$$P_{sys}(t) = \prod_{i=1}^{m} P_i(t) \tag{2}$$

where $P_i(t)$ is the reliability of the components.

Failure of hardware components of the FODTS, such as transceiver, amplifier, laser and software provision, for example, control systems, monitoring systems can obey different distribution laws. In order to find a generalized model of a system with independent components, a composition of distribution laws is performed [8].

In this paper, a generalized formula for the probability of failure-free operation for a FODTS consisting of a communication channel (optical fiber), an amplifier, a transceiver and software is compiled, each of which can obey different distribution laws.

The analysis showed that the transceiver failures [8,10] are most applicable to the exponential distribution for assessing the reliability of electronic parts such as semiconductor and laser diodes or photodiodes, where the "memory-free" properties simplify the calculation of failures after repair and a relatively accurate representation of the failure time of electronic components. After the initial "burnout" stage of components, failures occur randomly with a constant intensity, which is ideally modeled by an exponential law. Reliability function $P(t)$, which determines the probability of failure-free operation during time t [11]:

$$P(t)_{tr} = e^{-\lambda_{tr} t} \tag{4}$$

where λ_{tr} is the transceiver failure rate.

The uptime in this case is also distributed exponentially [12].

The fiber-optic communication channel and amplifier are subject to wear, aging and degradation, so the probability of failure may increase over time due to the influence of external factors and physical wear of the active components [11,13]. For these components, the Weibull distribution is most suitable, which allows taking into account the changing failure rate. The reliability function for the fiber-optic communication channel and amplifier is determined by the following expression [11,13]:

$$P(t)_{ch} = e^{-\left(\frac{t}{\beta_{ch}}\right)^{\alpha_{ch}}} \tag{5}$$

$$P(t)_{amp} = e^{-\left(\frac{t}{\beta_{amp}}\right)^{\alpha_{amp}}} \tag{6}$$

where α is the shape parameter, β is the scale parameter.

Software reliability is one of the important attributes that improves the quality of software. It is not easy to evaluate software reliability because there are a number of software reliability evaluation models that can be used to test and analyze failure data during software testing.

Based on the conducted analysis, a comparative table 1 of software models was compiled [14,15].

The Okumoto software model is the most applicable because it allows for the logarithmic nature of the failure rate reduction. This is especially important for software in complex systems, such as FODTS, where errors are corrected unevenly and early defects are fixed faster. The model also takes into account real failure data for reliability growth analysis, and its parameters can be easily adapted based on historical failure and defect elimination data [16].

In a state where the software is unstable, this indicates that its failure data follow a certain trend: reliability either increases or decreases, or first decreases and then increases. Using the Musa- Okumoto logarithmic Poisson runtime model and the model parameters obtained by the maximum likelihood method, an expression for the reliability function can be formulated [16]. The average value of the number of failures at time t is determined by the following formula [15]:

$$m(t) = \frac{1}{\theta}\ln(\lambda_0 \theta t + 1) \tag{7}$$

where $m(t)$ is the average value of the number of failures, λ_0 is the initial failure rate, θ is the rate of decrease in the failure rate at a given point in time.

Between the average value of the number of failures $m(t)$ and the failure rate λ_t have the following relationship [17,18]

$$m(t) = \int_0^t \lambda(t)dt. \tag{8}$$

The software reliability function can then be written:

$$P_{SW}(t) = e^{-\int_0^t \lambda(t)dt} = e^{-m(t)} = e^{-\frac{1}{\theta}\ln(\lambda_0 \theta t+1)} \tag{9}$$

III RESULTS AND DISCUSSIONS

The overall reliability of the system based on formula (2) will be as follows:

$$P_{sys}(t) = P_{tr}(t) \cdot P_{ch}(t) \cdot P_{amp}(t) \cdot P_{SW}(t). \qquad (10)$$

By substituting the reliability functions of the components and simplifying, we can obtain the following formula:

$$P_{sys}(t) = e^{-\left[\lambda_{tr} t + \left(\frac{t}{\beta_{ch}}\right)^{\alpha_{ch}} + \left(\frac{t}{\beta_{amp}}\right)^{\alpha_{amp}} + \frac{1}{\theta}\ln(\lambda_0 \theta t + 1)\right]}. \qquad (11)$$

Time to failure distribution function [2,17] :

$$F(t) = 1 - P(t). \qquad (12)$$

The probability density function of failures, which represents the probability that the system will fail at time t [2,17]:

$$f(t) = \frac{dF(t)}{dt}. \qquad (13)$$

Based on formulas (11) in (12) and keeping in mind (13), we can obtain an expression for the probability density function:

$$f(t) = -\frac{dP_{sys}(t)}{dt} = e^{-\left[\lambda_{tr} t + \left(\frac{t}{\beta_{ch}}\right)^{\alpha_{ch}} + \left(\frac{t}{\beta_{amp}}\right)^{\alpha_{amp}} + \frac{1}{\theta}\ln(\lambda_0 \theta t + 1)\right]} \cdot$$
$$\cdot \left[\lambda_{tr} + \frac{\alpha_{ch}}{\beta_{ch}}\left(\frac{t}{\beta_{ch}}\right)^{\alpha_{ch}-1} + \frac{\alpha_{amp}}{\beta_{amp}}\left(\frac{t}{\beta_{amp}}\right)^{\alpha_{amp}-1} + \frac{\lambda_0}{\lambda_0 \theta t + 1}\right] \qquad (14)$$

The correctness of the analytical models of reliability and probability density of failures is confirmed on the basis of the boundary conditions:

At $t = 0$ system reliability $P(t) = 1$, failure probability density $f(t) > 0$ i.e.

$$P(t)\big|_{t=0} = 1, \quad f(t)\big|_{t=0} > 0, \qquad (15)$$

with $t \to \infty$ system reliability

$$\lim_{t \to \infty} P(t) = 0. \qquad (16)$$

The given boundary conditions confirm the adequacy of analytical models (11), (14) to the actual operating conditions of the FODTS.

The graph, constructed based on the system reliability formula (Fig. 1) using hypothetical data, shows a decrease in system reliability over time that corresponds to real operating conditions.

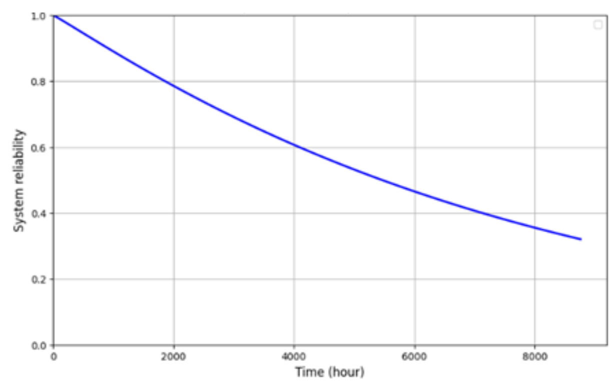

Fig. 1: System reliability depending on time

A comparative graph of the dependence of system reliability on the shape parameter and the scale parameter of the Weibull distribution, with fixed values of the exponential distribution parameters and the software reliability model, is shown in Fig. 2. It is evident from the graph (Fig. 2) that an increase in the scale parameter β in the Weibull model leads to a slowdown in the decline in system reliability. This indicates that components with a higher scale parameter have a longer service life. The shape parameter α determines the rate of change in reliability, a high value of which indicates a sharp drop in system reliability.

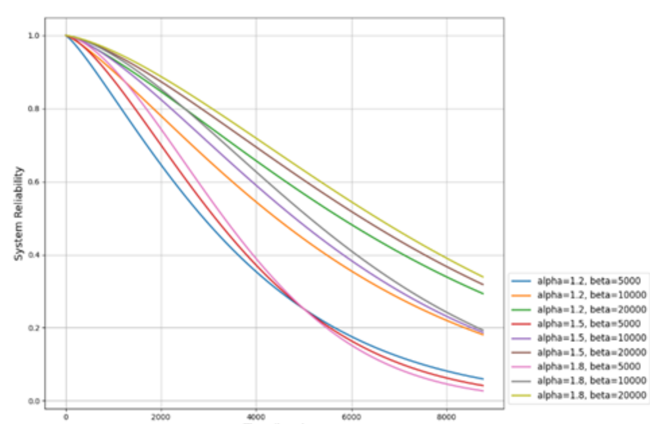

Fig. 2: Reliability of the system for different values of the Weibull distribution parameters

The dependence of the system reliability on the parameters of the software reliability model at a constant value of the parameters of the Weibull and exponential distributions are shown in Fig. 3 for the rate of decrease in the failure rate at time θ at a constant value of the failure rate and in Fig. 4 for the failure rate λ_0 at a constant value of θ.

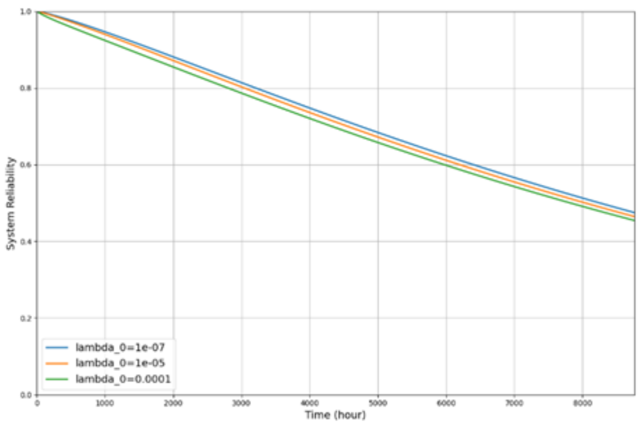

Fig. 3: Dependence of system reliability on the parameter θ in the software model

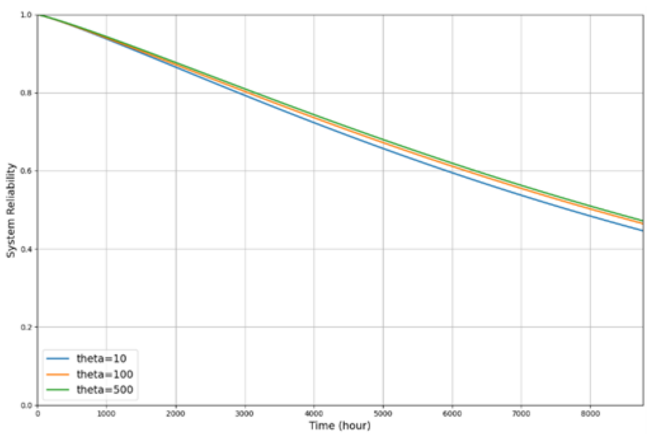

Fig. 4: Effect of initial failure rate λ_0 on system reliability

The graphs of the dependence of system reliability on the parameters θ and λ_0 (Fig. 3, Fig. 4) of the Musa-Okumoto model show that with a high value of θ, the failure rate decreases faster and leads to a slower drop in system reliability, the increase of which is achieved by improving the processes of software development and testing. The initial failure rate significantly affects the reliability of the system, its lower values λ_0 demonstrate higher resistance to failures throughout the entire period of operation.

IV CONCLUSION

The analysis showed that the choice of failure distribution models is important when assessing the reliability of the FODTS. The paper presents the most applicable distribution laws for the hardware and software components of the system. The boundary conditions and the presented graphs confirm the validity of analytical expressions in describing the behavior of the system reliability and the probability density of failures under FODTS operating conditions. To increase reliability, measures are needed to improve the quality and characteristics of each element of the system. A high value of the scale parameter depends on the durability and reliability of the components, the increase of which requires an increase in the quality of the components, improving their protection and the reliability of the design. To ensure high reliability of the system, it is important to reduce the value of the shape parameter, which is achieved through the use of high-quality materials, regular maintenance, the introduction of redundancy systems to reduce operational loads and monitoring of operating conditions also contributes to achieving the desired reliability characteristics. A decrease in the initial failure rate and an increase in the rate of decrease in the failure rate are achieved by improving the processes of software development, testing and operation. The implementation of these measures will extend the service life of the system, reduce the failure rate and increase the reliability of the FODTS.

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METHODS OF ENSURING NETWORK SECURITY

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Abstract– In the evolving digital era, network security remains a critical domain for protecting sensitive data and ensuring system integrity. This study delves into foundational strategies, including the implementation of firewalls, intrusion detection systems (IDS), and encryption techniques, to mitigate the risks posed by cyber threats. It highlights the integration of advanced technologies such as next-generation firewalls (NGFWs) and artificial intelligence for dynamic threat detection and management. Furthermore, the research emphasizes robust user authentication and access control mechanisms as pivotal defenses against unauthorized access. By exploring modern trends like zero-trust architecture and quantum-safe encryption, this paper underscores the importance of a proactive and multifaceted approach to cybersecurity. The findings advocate for continual adaptation to emerging threats, fostering a resilient digital environment that safeguards organizational assets and builds stakeholder trust.

Key words– Network Security, Firewalls, Intrusion Detection Systems (IDS), Encryption Techniques, Cyber Threats, Next-Generation Firewalls (NGFW), Artificial Intelligence in Security, User Authentication, Access Control, Zero-Trust Architecture, Quantum-Safe Encryption, Digital Resilience

I INTRODUCTION

In the contemporary digital landscape, the concept of network security has emerged as a fundamental pillar for safeguarding sensitive information and maintaining the integrity of systems. As organizations increasingly rely on interconnected networks for communication and data exchange, the threat landscape has expanded, exposing vulnerabilities that can be exploited by malicious actors. Network security encompasses a variety of measures, strategies, and technologies designed to protect these networks from breaches, unauthorized access, and data theft. This multifaceted discipline involves the implementation of firewalls, intrusion detection systems, and encryption protocols, each serving as critical defenses against potential threats. By understanding the principles of network security, organizations can cultivate a proactive approach to risk management, ensuring that their networks remain resilient against both external and internal threats. The necessity of robust network security measures underscores the imperative of protecting digital assets in an increasingly interconnected world.

II THE MAIN PART

FIREWALLS AND INTRUSION DETECTION SYSTEMS

Firewalls and Intrusion Detection Systems (IDS) serve as integral components of a comprehensive network security strategy, effectively mitigating diverse cyber threats. Firewalls function as the first line of defense, scrutinizing incoming and outgoing traffic based on predetermined security rules. Traditional firewalls, while effective, have evolved into next-generation firewalls (NGFWs) that incorporate advanced features such as deep packet inspection and real-time threat intelligence, enhancing their ability to identify and prevent sophisticated attacks. Conversely, IDS systems monitor network traffic for suspicious activity and potential breaches, allowing organizations to respond proactively. Notably, the integration of artificial intelligence within these systems has improved anomaly detection, provided a nuanced understanding of traffic patterns and reduced false positives. Together, firewalls and IDS not only fortify network perimeters but also foster a dynamic cybersecurity environment, highlighting their critical role in safeguarding sensitive information and maintaining system integrity in an increasingly complex digital landscape.

Firewalls and Intrusion Detection Systems (IDS) are crucial components of modern cybersecurity frameworks. Both technologies aim to protect computer networks, but they serve distinct roles: Firewalls: Act as gatekeepers, controlling incoming and outgoing network traffic based on predetermined security rules.

Intrusion Detection Systems (IDS): Monitor network and system activity for malicious behavior or policy violations and generate alerts.

A firewall is a network security device or software that filters and monitors traffic to enforce security policies. It operates based on predefined rules to allow or block data packets.

1. Packet-Filtering Firewalls:

- Examine data packets for source/destination IP, port, and protocol.
- Simple and fast but lack deep inspection capabilities.

2. Stateful Inspection Firewalls: o Keep track of the state of active connections. o Offer enhanced filtering by examining traffic context.

3. Proxy Firewalls:

- Act as intermediaries by inspecting and forwarding traffic.
- Provide robust filtering but can slow down network speed.

4. Next-Generation Firewalls (NGFW):

- Combine traditional firewall functions with advanced features like deep packet inspection, intrusion prevention, and application awareness.
- Traffic Filtering: Block unauthorized access and permit legitimate communication.
- Segmentation: Isolate sensitive systems or environments within a network.
- Logging and Monitoring: Record network activity for auditing and analysis.

Advantages of Firewalls

- Prevent unauthorized access.
- Protect against malware and exploits.
- Enhance compliance with regulatory standards.

Limitations

- Cannot detect threats within allowed traffic.
- Ineffective against insider threats or encrypted malicious data.

An Intrusion Detection System (IDS) identifies potential security incidents by analyzing network or host activity and alerting administrators.

Types of IDS

1. Network-based IDS (NIDS):

- Monitors network traffic to detect anomalies.
- Placed strategically within the network (e.g., near firewalls or switches).

2. Host-based IDS (HIDS):

- Monitors activities on a specific host or device.
- Tracks file integrity, logins, and system calls.

Detection Techniques

1. Signature-Based Detection:

- Compares activity against known attack signatures.
- Fast but ineffective against zero-day attacks.

2. Anomaly-Based Detection:

- Identifies deviations from established behavior baselines.
- Capable of detecting unknown threats but prone to false positives.

Key Functions of IDS

- Alerting: Notify administrators of potential intrusions.
- Incident Response: Provide information for analyzing and mitigating threats.
- Policy Enforcement: Ensure network activity complies with security policies.

Advantages of IDS

- Identifies threats missed by firewalls.
- Enhances situational awareness.
- Supports forensic analysis.

Limitations

- Cannot prevent attacks; only detects them.
- Requires skilled personnel for effective operation.
- Prone to false alarms, leading to alert fatigue.

Firewalls vs. IDS

Modern Trends and Integration

- Unified Threat Management (UTM): Combines firewalls, IDS, and other security tools into a single platform.
- AI and Machine Learning: Enhances anomaly detection capabilities.
- Zero Trust Architecture: Complements firewalls and IDS by enforcing strict access controls.

Feature	Firewalls	Intrusion Detection Systems (IDS)
Primary Function	Block and filter traffic	Detect and alert on intrusions
Focus	Policy enforcement	Threat detection
Preventative/ Reactive	Preventative	Reactive
Placement	Perimeter or internal segments	Network or host-specific
Action	Allow/block traffic	Notify administrators

ENCRYPTION TECHNIQUES FOR DATA PROTECTION

The implementation of encryption techniques is paramount for ensuring the confidentiality and integrity of sensitive data, particularly in the context of cloud storage. As users increasingly rely on cloud services to store their information, concerns about data privacy have magnified due to potential security breaches by third-party providers. To address these concerns, technologies like Intel Software Guard Extensions (SGX) facilitate data sealing, allowing users to encrypt their files within a secure virtual file system before sharing them with storage providers. Notably, encryption not only protects data from unauthorized access but also enhances compliance with evolving government regulations regarding data security, as highlighted in current research on cloud computing security [4]. Furthermore, studies illustrate various methods, including key management and controlled disclosure of encrypted data, which are vital for securing cloud environments against emerging threats [4]. Therefore, employing robust encryption methodologies is essential for maintaining the security of data within modern network infrastructures.

Why Encryption is Critical:

- Confidentiality: Encrypting data ensures only authorized users can access the information, even if breaches occur.
- Compliance: Government regulations like GDPR and HIPAA mandate data protection, making encryption essential for legal compliance.
- Trust: Users feel secure knowing their information is protected, boosting trust in cloud services.

How Encryption Works in Cloud Environments:

Data Sealing with Intel SGX:

- Technologies like Intel Software Guard Extensions (SGX) allow users to encrypt files locally before sharing them with cloud providers.
- This creates a secure virtual file system, ensuring data remains encrypted even within the cloud.

End-to-End Encryption (E2EE):

- Data is encrypted on the user's device and remains encrypted during transfer and storage.
- Cloud providers cannot access or decrypt the data without user consent.

Controlled Disclosure:

- Encrypted data can be selectively shared by providing decryption access to authorized individuals only.

Key Management:

- Encryption is only as strong as its key management. Without proper safeguards, encryption keys can become a vulnerability.

Secure Key Management Systems: Use Hardware Security Modules (HSMs) or cloud-native key management tools to securely generate, store, and rotate keys.

Emerging Threats and Encryption Solutions:

- Cyber threats like ransomware, man-in-the-middle attacks, and insider threats target cloud environments.

Encryption mitigates these threats by ensuring:

- Stolen data is unusable without decryption keys.
- Communication channels remain secure during data transfers.

Research Insights on Cloud Encryption

Studies emphasize that robust encryption techniques, combined with proper key management and compliance measures, are essential to protect against:

1. Data Breaches: Encrypting data ensures no readable information is exposed during breaches.

2. Insider Threats: Encryption restricts access even from malicious insiders at cloud providers.

3. Evolving Cyberattacks: Advanced methods, such as quantum-safe encryption, are emerging to counter

future threats.

User Authentication and Access Control

Ensuring robust user authentication and access control is paramount in the landscape of network security, as these mechanisms serve as the first line of defense against unauthorized access. User authentication involves verifying the identity of users attempting to access a network, typically through passwords, biometric data, or two-factor authentication. Each method offers varying degrees of security, with two-factor authentication significantly reducing the risk of breaches due to compromised passwords. Furthermore, access control systems determine the level of access granted to authenticated users, thereby enforcing the principle of least privilege, which helps mitigate potential damage from internal and external threats. Effective implementation of these controls is essential, particularly in wireless networks, where vulnerabilities are heightened due to their open nature [5]. Moreover, integrating access control within the broader framework of security protocols enhances overall resilience against emerging threats [6], making it a critical focus for network administrators.

The registration process is the first step for users to join your platform. Here are the essential elements:

- Input Fields: Users should provide a unique username, a valid email, and a secure password.
- Validation: Validate inputs both on the client and server sides to ensure data integrity.
- Password Storage: Store passwords securely using hashing algorithms such as bcrypt or Argon2 to prevent plaintext password storage.
- Third-Party Authentication (Optional): Integrate OAuth for Google, GitHub, or other third-party sign-ins to simplify the process for users.

The login system should verify a user's credentials and grant access accordingly. Consider the following:

- Secure Login: Use secure protocols (e.g., HTTPS) to transmit credentials.
- Rate Limiting: Prevent brute-force attacks by limiting login attempts.
- Session Management: Use secure cookies or tokens (e.g., JWT) to maintain user sessions.
- Two-Factor Authentication (Optional): Add an extra layer of security by requiring a second verification step, such as an OTP sent to the user's email or phone.

Password Reset

A robust password reset feature enhances user experience while maintaining security:

- Token-Based Reset: Send a secure token to the user's registered email for password reset.
- The token should expire after a short duration (e.g., 15-30 minutes).
- Secure Links: Ensure password reset links are HTTPS and include a unique token.

Access Control Access control governs what users can and cannot do on your platform. Implementing proper access control prevents unauthorized actions and data exposure.

User Roles

Assign roles to categorize users and define their access rights:

- Admin: Full access to manage tasks, users, and site settings.
- Participant: Restricted to solving tasks, submitting flags, and viewing leaderboards.
- Guest (Optional): Limited access to view public information, such as competition rules or FAQs.

Role-Based Access Control (RBAC)

RBAC is a common approach for managing permissions:

- Define specific roles and associate them with sets of permissions.
- Use middleware or policy checks to restrict access to certain routes or actions based on the user's role.

Example:

- Admins can create, edit, and delete tasks.
- Participants can submit flags and view task details.

Permissions

Fine-grained permissions allow for more flexibility:

- Define permissions such as "create task," "delete task," or "solve task."
- Use libraries or frameworks to simplify permission management (e.g., Django-guardian, Cabin).

A well-designed authentication and access control system ensures the security and smooth operation of your CTF competition website. By implementing secure user registration, login, and role-based access control, you can protect sensitive data while delivering a seamless experience for users.

III CONCLUSION

In conclusion, the multifaceted approach to ensuring network security encompasses a range of strategies that collectively fortify digital environments against a myriad of threats. By integrating firewalls, intrusion detection systems, and robust encryption protocols, organizations can significantly mitigate the risks posed by cyberattacks. Moreover, the importance of regular software updates and employee training cannot be overstated, as human error often remains a critical vulnerability. As cyber threats continue to evolve in complexity, adopting a proactive stance rather than a reactive one is essential for maintaining the integrity of sensitive data. In a landscape where the ramifications of security breaches can be devastating, embracing a comprehensive and dynamic security framework is imperative. Ultimately, a commitment to continual assessment and adaptation will empower organizations to not only protect their networks but also to foster trust with stakeholders in an increasingly interconnected world.

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BIG DATA-BASED MULTIVARIATE CORRELATION AND REGRESSION FOR ENERGY PERFORMANCE ANALYSIS IN BUILDINGS

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Abstract– Accurate prediction of electricity consumption is critical for optimizing energy usage and enabling effective energy management strategies, particularly in the context of modern smart buildings. This study proposes a predictive modeling approach based on neural networks to forecast future electricity consumption in buildings. Leveraging big data and advanced machine learning techniques, we developed a data-driven model specifically tailored to the operational environment of Turin Polytechnic University in Tashkent. The model achieved a prediction accuracy of up to 96%, demonstrating the potential of neural network-based methods for efficient energy forecasting. This research contributes to the growing field of intelligent energy systems by showcasing how multivariate correlation, regression analysis, and neural network modeling can support sustainable and efficient energy use in buildings.

Key words– Neural Network, Energy Consumption Prediction, Big Data, Machine Learning, Smart Buildings, Regression Analysis, Multivariate Correlation, Electricity Forecasting, Data-Driven Model, Energy Management.

I INTRODUCTION

Energy consumption in buildings represents a substantial share of global energy demand, with significant implications for environmental sustainability and operational efficiency. According to the International Energy Agency, buildings account for nearly 30% of total global energy consumption and are responsible for approximately 28% of CO_2 emissions [1]. As urbanization intensifies and the need for smarter infrastructure grows, the ability to accurately predict electricity usage has become critical for effective energy management and sustainability. Recent advancements in data analytics and machine learning have opened new pathways for modeling complex energy systems. Artificial neural networks (ANNs) have proven highly effective for forecasting energy consumption, owing to their ability to model nonlinear and multivariate relationships within large datasets [2]. Neural networks fall under the broader umbrella of representation learning a powerful framework in which systems automatically discover the features needed for classification or prediction from raw data as described by Bengio et al. [3]. These methods are particularly well suited for building energy management systems, where traditional statistical models may fall short due to the dynamic and multifactorial nature of energy use patterns.

Prior studies have successfully applied machine learning algorithms to optimize building energy efficiency and thermal comfort. For example, Abdufattokhov et al. [4] demonstrated the use of supervisory optimal control using machine learning to regulate indoor thermal comfort levels. Similarly, the applicability of machine learning for predictive modeling in sustainable energy systems has been explored, highlighting its potential for reducing energy consumption while maintaining operational performance [5].

In this study, we present a data-driven predictive model based on a multilayer neural network to forecast electricity consumption at Turin Polytechnic University in Tashkent. By leveraging big data techniques and supervised machine learning, our model is designed to detect patterns in historical energy data and provide highly accurate consumption predictions. The goal is to support energy-efficient building operations through intelligent forecasting, with our model achieving up to 96% prediction accuracy.

II THE METHODOLOGY

This study employs a Neural Network (NN)-based predictive modeling approach to forecast electricity consumption in buildings using historical energy usage data. The method leverages the capability of artificial neural networks to learn from complex, nonlinear relationships among multiple variables in large datasets.

Neural Networks are computational models inspired by the structure and operation of the human brain. Each individual neuron in the network acts as a processing unit that receives inputs, applies a transformation function, and transmits the output to the next layer. This structure allows the network to identify patterns and correlations in the data that are not easily captured by traditional statistical methods. As illustrated in Figure 1, the sample neural network structure used in this study includes an input layer, a single hidden layer, and an output layer. The number of layers and neurons can be adjusted depending on the complexity of the prediction task. In our case, the network was optimized through experimentation to achieve high accuracy while avoiding overfitting.

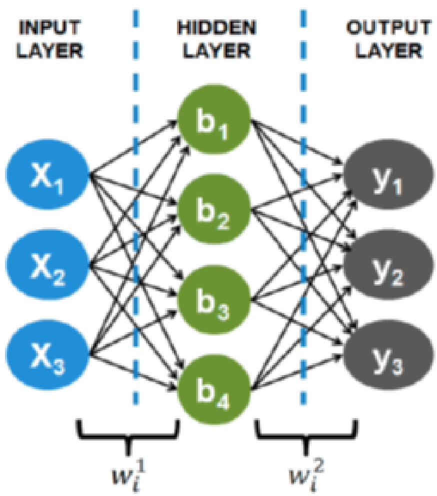

Fig. 1: Sample structure of NN with 4 hidden layers and its parameters

The modeling process began with the preparation of input data, including normalization and feature selection based on correlation and regression analysis. Key variables such as historical electricity consumption, time-based factors (hour, day, month), and environmental conditions (e.g., temperature) were considered as inputs.

The neural network was then trained using supervised learning techniques. During training, the network adjusted its internal weights to minimize the difference between predicted and actual values through a process known as backpropagation. The performance of the model was evaluated using standard metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and prediction accuracy.

Neural networks are particularly powerful in this context due to their flexibility and robustness in handling high-dimensional data and capturing nonlinear trends. However, successful applications depend on careful model design, hyperparameter tuning, and the availability of high-quality, representative data. In this study, the model demonstrated up to 96% prediction accuracy, highlighting its effectiveness for electricity consumption forecasting in building environments. To implement the predictive model, a feedforward neural network was developed with a carefully designed architecture aimed at balancing model complexity and performance.

The finalized network structure consists of:

- Number of Hidden Layers: 4
- Neurons per Hidden Layer: 100
- Activation Function: Rectified Linear Unit (ReLU), defined as ReLU(x) = max (0, x), applied to all hidden layers

The choice of the ReLU activation function is motivated by its computational efficiency and ability to alleviate the vanishing gradient problem, which can occur in deeper networks. ReLU introduces non-linearity into the network, enabling it to model complex relationships between the input features and the target variable.

The model was trained (see Figure 2.) using a supervised learning approach with backpropagation and a suitable optimizer, such as Adam, to minimize the loss function typically Mean Squared Error (MSE) for regression tasks. The learning rate, batch size, and number of epochs were empirically selected through experimentation to achieve optimal training performance and generalization on unseen data.

Fig. 2: Training Data

Training and validation were performed on historical electricity consumption data collected from the building's energy monitoring system at Turin Polytechnic University in

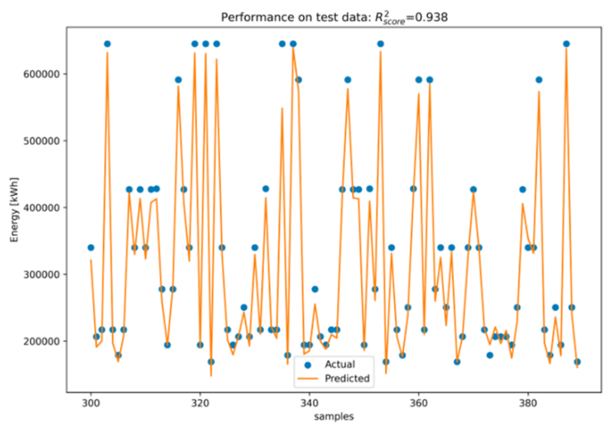

Fig. 3: Test Data

Tashkent. The dataset was split into training (80%) and testing (20%) sets to evaluate the model's accuracy and generalizability.

During training, the model's weights were iteratively updated to reduce prediction error, and early stopping was employed to prevent overfitting. The final (see Figure 3.) model demonstrated high accuracy, with a prediction performance of up to 96%, validating the effectiveness of the chosen architecture and configuration.

III CONCLUSION

This research presented a neural network-based model for predicting future energy consumption in buildings, with a case study focused on Turin Polytechnic University in Tashkent. By leveraging the capabilities of big data and advanced machine learning techniques, the model effectively captured complex patterns within historical electricity usage data. The implementation of a multilayer neural network enabled accurate forecasting, demonstrating the strength of data-driven approaches in energy management applications. The developed model achieved a high prediction accuracy of up to 96%, highlighting its potential for supporting intelligent decision-making in building energy optimization and contributing to more sustainable and efficient energy use practices.

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EVALUATING 3D SCANNING AND PRINTING FOR THE RESTORATION OF DAMAGED ARCHITECTURAL DETAILS IN TASHKENT'S MEMORIAL MONUMENTS

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Abstract– This article explores the use of 3D scanning and printing technologies in the restoration of damaged architectural elements in Tashkent's Soviet-era memorial monuments. Combining fieldwork, computational modeling, and experimental reconstruction, the research assesses the effectiveness of these technologies in preserving cultural heritage. The findings demonstrate that 3D technologies offer significant advantages in accuracy, efficiency, and material compatibility, positioning them as crucial tools for modern conservation practices.

Key words– 3D scanning, 3D printing, architectural restoration, heritage conservation, Tashkent memorials, digital reconstruction, Soviet-era monuments, cultural heritage, computational modeling, additive manufacturing.

I INTRODUCTION

Preservation of historical monuments is critical to maintaining cultural heritage, particularly in post-Soviet cities like Tashkent, where numerous memorials reflect the socio-political and aesthetic values of the Soviet era. However, environmental factors, urban development, and aging materials have led to the deterioration of many architectural details. Traditional restoration methods often fall short in replicating the intricate designs and structural integrity of the originals [1][2]. Recent advances in 3D scanning and printing have introduced new possibilities for conservation. These technologies enable precise digital documentation and physical replication of damaged elements, enhancing the fidelity and sustainability of restoration projects [3][4]. This study evaluates the application of 3D technologies in the restoration of Tashkent's memorial monuments, focusing on three case studies.

Historical Context and Cultural Significance

The memorial monuments in Tashkent are not merely architectural landmarks but also repositories of the region's complex history, embodying themes of resilience, solidarity, and artistic innovation during the Soviet era. The Courage Monument, for instance, commemorates the devastating 1966 Tashkent earthquake and serves as a powerful symbol of recovery and unity. Similarly, the Friendship of Peoples Monument reflects the ideological underpinnings of Soviet policies, emphasizing unity across diverse ethnic groups. These structures are a testament to the era's unique blend of artistry and propaganda, making their preservation a cultural imperative.

Despite their importance, these monuments face threats from environmental degradation and urban expansion. For example, pollution, temperature fluctuations, and improper maintenance have accelerated the wear on intricate architectural elements. Such challenges necessitate innovative approaches to restoration, such as 3D scanning and printing, to ensure that these cultural treasures endure for future generations.

II THE METHODOLOGY

The research employed a multi-method approach:
Site Selection and Documentation
Three prominent Soviet-era monuments were selected:

- The Friendship of Peoples Monument (Fig.1)
- The Courage Monument (commemorating the 1966 Tashkent earthquake) (Fig.2)
- The Taras Shevchenko Monument (Fig.3)

Detailed field surveys were conducted to assess the extent of damage and document architectural details using high-resolution cameras and 3D scanners [5].

Fig. 1: The Friendship of Peoples Monument

Fig. 2: Monument of Courage Earthquake Memorial, the Soviet Era Monument to the Tashkent Earthquake of 26 April 1966

3D Scanning and Digital Modeling

Structured light and laser scanning technologies were used to create accurate 3D models of damaged elements. The scans were processed using software such as Autodesk ReCap and Blender to correct distortions and fill gaps [6].

3D Printing for Restoration Prototypes

The digital models were used to fabricate physical prototypes using various 3D printing methods, including Fused Deposition Modeling (FDM) and Stereolithography (SLA). Material choices included PLA, ABS, and resin, evaluated

Fig. 3: Monument of Taras Shevchenko in Tashkent (was opened in Tashkent on December 20, 2002).

for their durability and aesthetic compatibility [7][8].

Evaluation Criteria

Restoration success was assessed based on:

- Accuracy: Alignment with original dimensions and details
- Material Performance: Durability and weather resistance
- Aesthetic Fidelity: Visual integration with surrounding structures
- Cost and Time Efficiency: Compared to traditional methods [9].

III RESULTS

3D Scanning Precision

The scanning technologies achieved sub-millimeter accuracy, enabling the capture of intricate details like floral patterns and inscriptions. Structured light scanning performed better for smaller elements, while laser scanning was more effective for larger, complex structures [10].

Prototyping and Material Evaluation

3D-printed prototypes demonstrated high fidelity to the original designs. SLA printing provided superior detail, ideal for decorative elements, while FDM was cost-effective for structural components. Resin materials showed excellent resistance to environmental factors, making them suitable for outdoor use [11].

Cost and Time Analysis

Compared to traditional methods, 3D printing reduced production time by 40% and costs by approximately 30%. The ability to reproduce multiple identical components quickly was particularly advantageous for repetitive design elements like columns and friezes [12].

Advancements in 3D Technologies

Recent years have witnessed significant progress in 3D scanning and printing technologies, which have revolutionized architectural restoration. High-resolution scanners equipped with structured light or laser-based systems capture fine details with sub-millimeter accuracy, ensuring precise digital documentation of damaged elements. These technologies are particularly effective in preserving delicate patterns, inscriptions, and sculptural details that traditional methods might overlook.

For instance, in Tashkent, the use of 3D scanning on the Friendship of Peoples Monument allowed for the exact replication of intricate floral motifs. This approach not only minimized material waste but also ensured that the reconstructed elements seamlessly integrated with the original structure. Similarly, stereolithography (SLA) printing, which uses photopolymer resins, has proven invaluable for creating durable and visually compatible prototypes of smaller decorative components.

Material Innovations in Restoration

The choice of materials is critical in restoration projects, as it determines both the aesthetic fidelity and long-term durability of the reconstructed elements. In Tashkent, various materials, including polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and resin composites, have been tested for their suitability in different environmental conditions. Resin-based prototypes demonstrated superior resistance to UV radiation and humidity, making them ideal for outdoor applications.

Comparatively, recent developments in composite materials, such as carbon-fiber-reinforced polymers, offer enhanced strength and weather resistance. While these materials are currently more expensive, their longevity could offset costs in the long term. Incorporating such advanced materials could elevate the quality and sustainability of restoration efforts.

Case Study Insights: Lessons from Other Regions

Tashkent's use of 3D technologies parallels successful restoration projects in cities like Moscow and Kyiv. In Moscow, 3D scanning and printing were employed to restore intricate facade details on historic buildings, while Kyiv leveraged similar technologies to recreate war-damaged statues. These examples underscore the adaptability and effectiveness of digital restoration methods across diverse architectural styles and historical contexts.

In Tashkent, the Courage Monument restoration project highlighted the importance of integrating traditional craftsmanship with modern technology. While 3D printing provided a scalable and precise solution, artisans contributed to the finishing touches, ensuring that the restored elements retained their original character. Such collaborative approaches exemplify how technology and human expertise can complement each other in heritage conservation.

v**Discussion**

The findings highlight the transformative potential of 3D technologies in monument restoration. By providing precise and scalable solutions, these technologies address common challenges in heritage conservation, including material degradation and the loss of original craftsmanship. However, several challenges remain, such as the high initial cost of equipment and the need for skilled operators [13].

Comparisons with other post-Soviet restoration projects, such as those in Moscow and Kyiv, underscore the universal applicability of these technologies. In these cities, 3D printing has been successfully used to restore intricate facade details and statues [14]. Tashkent can benefit from adopting similar practices, integrating traditional craftsmanship with modern technology.

IV CONCLUSION

The preservation of Tashkent's Soviet-era memorial monuments through 3D scanning and printing technologies represents a promising intersection of heritage conservation and digital innovation. By addressing challenges such as material degradation and the loss of traditional craftsmanship, these technologies offer scalable, precise, and sustainable solutions. As advancements in 3D printing materials and techniques continue to emerge, their potential to redefine restoration practices on a global scale becomes increasingly evident.

This study confirms that 3D scanning and printing are effective tools for the restoration of damaged architectural details in Tashkent's memorial monuments. They enhance accuracy, efficiency, and material compatibility, making them essential for sustainable conservation.

Recommendations for Future Research

To further advance the field of digital restoration, several areas warrant exploration. First, the development of cost-effective 3D printing materials with enhanced environmental resilience could broaden the accessibility of these technologies. Second, training programs for conservation professionals in 3D modeling and printing techniques could build local expertise, reducing reliance on external consultants. Finally, integrating machine learning algorithms into digital restoration workflows could automate tasks like damage assessment and model optimization, streamlining the restoration process.

Future research should focus on optimizing the integration of 3D technologies with traditional methods and exploring advanced materials like carbon fiber composites for improved durability. Establishing local expertise and facilities for 3D restoration could further streamline the process and reduce costs.

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ENGINEERING PROGRAMS IN UZBEKISTAN ON THE VERGE OF FIFTH INDUSTRIAL REVOLUTION

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Abstract– A researcher will cover the profound educational reforms in higher education institutions in the field of engineering programs in Uzbekistan.

Key words– Engineering Education, Industrial Revolutions

I INTRODUCTION

For the past several years Uzbekistan has introduced profound reforms in liberalizing certain economic sectors to boost the national economy and foster competition among different types of enterprises. Along with it has come a new wave of reforms in higher education as well that was reflected in establishment of dozens of private and international universities across Uzbekistan, thereby improving access to quality higher education to tap a human potential just as it was indicated in the Government's Strategy for Innovative Development of 2018 [1].

It is not a secret that technological innovation has become a key to nation's property and security in time of tough global competition [2]; and engineering schools are the backbone of that technological innovation. Now that the world has seen fruits of AI technology and the advanced nations are running toward fifth Industrial Revolution, a question arises what Uzbekistan has done and should do in order to catch that wave and become the leading nation in its neighboring countries and beyond.

1.1 Research Importance

The importance of this research to Uzbekistan is paramount as the Fifth Industrial Revolution will bring drastic changes in the manufacturing, logistics and service sectors in national scale and may create unforeseen challenges in economic and political landscape of Central Asian countries. The paper will made up of four sections, that is, literature review, research method, discussion and conclusion. The research will have a nature of descriptive research as the statement of the problem and data will be profoundly drawn from a body of literature work.

II LITERATURE REVIEW

2.1 Advanced Engineering Programs in Higher Education in Global Perspectives

It is no doubt that behind all technological innovation are advanced engineering programs. But what is generally assumed by the advanced engineering in the context of higher education. Among general characteristics of advanced engineering are its ability to (1) push the boundaries of scientific knowledge, technical skills, and innovative thinking, (2) to solve complex problems and (3) develop technologies across various sub-fields of engineering [3].

The global society has seen the exponential growth of new technological knowledge encompassing the information and communication technologies. Outsourcing and offshoring phenomena have taken the form of new premium of technological workforce. Nevertheless, for the past several years researchers and scholars conclude the urgency to better address the needs of nations in rapidly changing world [4].

Relying only on foreign specialists to solve engineering programs; that is, the outsourcing of engineering services may deteriorate the field of engineering nationwide. In fact, as many US scholars pointed out that outsourcing threaten the erosion of the engineering profession in the United States and hinder the US technological competence and capacity for technological innovation. And for a nation to prosper, it should take the leadership position in technological innovation [5].

The other side of the program is the application and research in the field of engineering, not necessarily confined in one particular nation. Some scholars raise a concern of today's engineering programs, stating that they strive to "educate 21st-century engineers with a 20th-century curriculum delivered in 19th-century institutions" [6].

So, what is the solution? Scholars and professionals in the field of engineering education conclude that the mere reformation of engineering education with old paradigms are not a solution. Rather, it should be transformed into new paradigms to meet the overwhelming challenges in technological and demographic aspects in the global context. [7] Moreover, for a country to prosper, two things must be done: build up a new scientific base through research and take a leading role in advanced technologies [8]. Moreover, for developing countries to grow their own STEM capacities, three major development activities should be implemented; that is, the development of curriculum, facilities, and faculty. And the last will be the most challenging [9].

2.2 The Emergence of Fifth Industrial Revolution and its Predecessors

Any business forums today do not stop emphasizing the paramount role of the emergence of the next industrial revolution. But what we really understand by the Fifth Industrial Revolution. The scientific community has come to believe that whatever revolutionary breakthrough we see in the artificial intelligence, in 3D printing, in nanotechnology or Internet of Things, they all will be stepping stones to the Fifth Industrial Revolution [10].

Whatever industrial revolution we have seen today, it all transformed societies. If the invention of steam power was the catalyst for the first industrial revolution, electricity, telecommunication and oil were of the second. How was it reflected on societies? What once was done in manual labor, it was replaced with automated or mechanical work. What once was produced in small workshops, it was then moved in factories. The digital revolution was the third with the boom of the Internet and personal computers. The fourth one was articulated by Klaus Schwab, CEO and founder of the World Economic Forum in 2016. It differs from all its predecessors with the fusion of a number of new technologies in physical, digital and biological dimensions and its ability to interact with a set of systems with speed, depth and breadth [11]. Self-driving cars, drones, robotics, bio-engineering products are fruits of the Fourth Industrial Revolution.

2.3 Backbones of Industry 4.0

The Industry 4.0 is all about advanced technologies. It incorporates advanced technologies such as nanotechnology, artificial intelligence (AI), Internet of Things (IOT). Nanotechnology is basically about synthesizing nano-materials and controlling their internal structure with arrangement of the atoms and molecules to develop unique products [12]. Artificial intelligence (AI) is taking over many fields of industries. Its ability to simulate human intelligence through obtaining data and using it accordingly produces fast learning machines that are capable to speak, see, understand and reach definite conclusions. Now it is applied in factories, transportation, medical area and more. The Internet of Things (IOT) is when an network of different systems (computers, mobile phones, etc) interact and exchange information between each other to deliver certain type of tasks whether opening a front door from the distance or turning off devices connected to the wifi networking.

2.4. Coming of Fifth Industrial Revolution

Experts believe we may see it on the horizon within ten years. The times span is not that long if we see how long it took its predecessors to come and go. For example, the first industrial revolution lasted about 90 years; the second one, 44; the third, 31. Yes, no doubt that the period between fourth and the fifth revolution will be shorter, but what we really know about the latter and what changes it will bring about we really do not know for sure. Nevertheless, experts believe that a playground of its revolution will be the virtual space, heavily depending data, digital gadgets and the artificial intelligence with the human involvement, merging borders between natural and virtual worlds. Experts are not sure what it will be like, but they are sure it will be far more advanced, efficient, global and intelligent.

III RESEARCH METHOD

The research has a nature of descriptive research as the statement of the problem and data have profoundly been drawn from a body of literature work.

IV DISCUSSION

4.1 More Opportunities than Challenges

Back in the mid-18th century when the first industrial revolution broke out in areas such as mining, transportation and agriculture, it was assumed it would create barriers to job opportunities, but against all odds, the reverse was witnessed. Instead, historians write that it brought drastic efficiency in workplaces. The same positive outcome happened with the second revolution.

The third industrial revolution known as the technological revolution facilitated workload with the invention of cell phones and computers. Just take typewriting grotesque machines as an example. They all were replaced with computers which drastically boosted the communications industries. Or wired phones, which were replaced with cell phones, making a huge shift to digital world.

The Internet was the driving force of the fourth industrial revolution. It changed not just how we used to communicate, but also how we came to buy more items online than from traditional stores, make payments or even exchange currencies without going to a local bank, watch media content and more. Now more data is stored, or preserved so to say, in cloud storages around the world that it is on traditional papers. Our cell phones are hundreds times more powerful than computers used during 1960s—an era of the first human step toward the space exploration.

Experts believe that all these have laid out a solid foundation for both emerging the artificial intelligence and merging realm of physical, digital and biological world into one [13].

4.2 Human-Machine Collaboration

The fifth industrial revolution is believed to create efficiency, accuracy and speed in manufacturing process through merging advanced technologies: Internet of Things, artificial intelligence and robotics. But it does not mean that we—humans—will be put aside. Rather, we will supervise the entire manufacturing operation and strive to meet the highest quality standards. Among other things, the safety measures will indeed be taken by default as dangerous, laborious and traumatic work tasks will be delegated to machines, thus reducing cost of medical bills, sick leaves and insurance claims. At the end of the day, human workers will spend more time on redesigning or refining products to the needs of market demand and focusing on innovation and excellence [14].

4.3 Educational Challenges

In the light of idyll, among foreseen challenges are training human workers to operate far-more advanced technologies that they never heard of in their university lecture halls. To help personnel catch up with fruits of industry 5.0, a significant amount of investment would be required and dramatic job displacement will be anticipated among low-skilled workers [15].

V CONCLUSION

For the past several years Uzbekistan's new wave of reforms in higher education was reflected with the establishment of dozens of private and international universities across Uzbekistan. In a sense, it drastically improved engineering programs and laid some kind of foundation to meet the Fifth Industrial Revolution. But what challenges this nation can face in the manufacturing, logistics and service sectors in national scale. One particular challenge can be seen in phenomena such outsourcing and offshoring technological workforce. In other words, you let other nations solve your national engineering problems and hence fail to upgrade or even establish your own technological and scientific bases to do the job. The paper concluded that it will not only ruin the national engineering bases, but also pose a threat to a national security. Another concern was that a country should upgrade its old engineering schools to "educate 21st-century engineers" with not of the last century's curriculum or facilities, but with something far more advanced. The solution is simple, but costly. It is of vital importance to nourish Uzbekistan's own STEM capacities, with upgrading curriculum, facilities and faculty.

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MODELING THE EFFECT OF A HYDROSTATIC REGENERATIVE BRAKING SYSTEM ON VEHICLE MOTION AND BRAKING

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Abstract– This paper presents the results of a mathematical modeling study on the influence of a hydrostatic regenerative braking system on vehicle motion and braking performance. The model accounts for resistance forces acting during vehicle movement, including wheel rotational resistance, aerodynamic drag, gravitational components, and forces generated by the hydraulic system. Using models developed in the MATLAB-Simulink environment, the vehicle's acceleration, velocity, position, and pressure variations within the hydraulic system, as well as their time dependencies, were analyzed graphically. Additionally, the movement, torque, and flow of the hydraulic pump/motor components were evaluated to assess overall system efficiency. The study demonstrates that a hydrostatic braking system enables balanced control of vehicle motion, effective energy recovery, and reduction of operational costs. This approach is significant from the perspectives of environmental sustainability and fuel consumption reduction.

Key words– Hydrostatic braking system, regeneration, MATLAB-Simulink, vehicle, modeling, resistance forces, energy efficiency.

I INTRODUCTION

In contemporary vehicle design and operation, the primary focus is on enhancing energy efficiency and minimizing negative environmental impacts. Global trends in the transportation sector encourage manufacturers to implement innovative braking systems. One such advanced solution is regenerative braking, which recovers and stores kinetic energy typically lost during braking.

Among various technological approaches to regeneration, hydrostatic-based systems are considered optimal for heavy-duty trucks. These systems offer advantages such as high torque generation, rapid energy storage and delivery, as well as reliability and durability.

This study investigates the operational principle of the hydrostatic regenerative braking system and its impact on vehicle dynamics through mathematical modeling using MATLAB-Simulink. The model incorporates mechanical, hydraulic, and dynamic forces aligned with the vehicle's real physical parameters. A detailed analysis of motion and braking phases across different operational modes was conducted.

II THE MATHEMATICAL MODEL

To develop the mathematical model, the resistance forces acting on the vehicle and the forces applied by the hydraulic system were taken into account. The vehicle acceleration can be calculated using equation (1).

$$ma = F_H - F_D \tag{1}$$

In equation (1), m represents the mass of the vehicle, a is the acceleration, F_H denotes the force applied by the hydraulic system, and FD is the sum of resistance forces acting on the vehicle. Once the vehicle's acceleration is determined through the force balance, the velocity and position changes can be obtained by integrating with respect to time. The acceleration of the vehicle, based on its mass and weight, can be visualized using MATLAB-Simulink, as shown in Figure 1.

Resistance forces acting on the vehicle

During motion, the vehicle experiences various resistance forces. Resistance forces are those that act opposite to the direction of the vehicle's movement, generated due to different factors. The main resistance forces affecting the vehicle include rolling resistance of the wheels, aerodynamic drag,

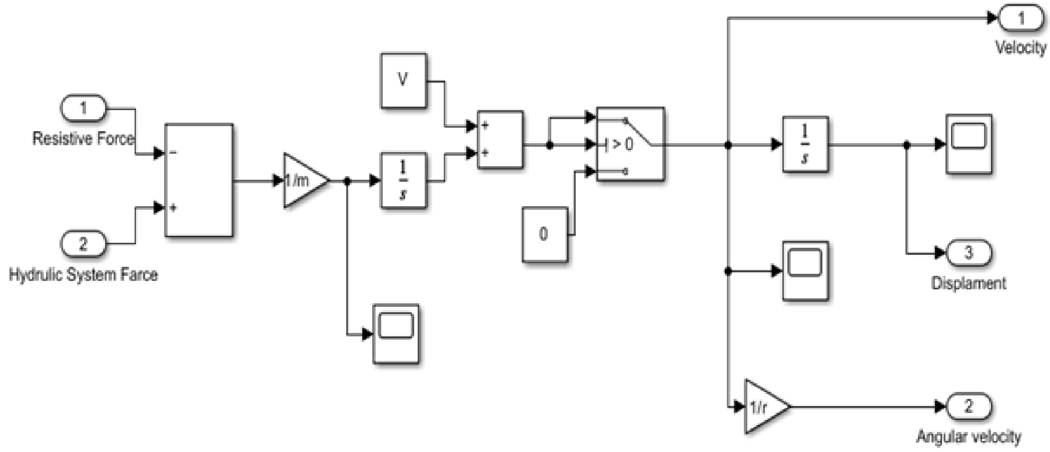

Fig. 1: Vehicle acceleration, velocity, and position in the MATLAB-Simulink model

and gravitational forces. These forces are illustrated in figure 2.

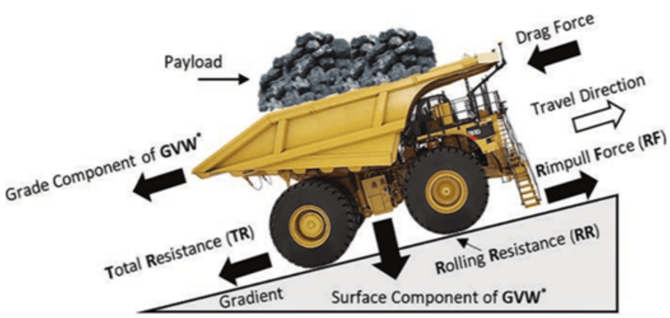

Fig. 2: Resistance forces acting on the vehicle

The total resistance force F_D acting on the vehicle is expressed by equation (2) and calculated as shown in equation (3).

$$F_D = F_r + F_a + F_y \tag{2}$$

In equation (2), F_r represents the rolling resistance corresponding to the wheel's rotational motion. The rolling resistance related to the wheel's elastic structure is a resistive force generated ahead of the contact center and acts opposite to the wheel's rotational movement. C_r is the rolling resistance coefficient that characterizes the resistance occurring between the vehicle's wheels and the road surface. It encompasses parameters related to the vehicle's mass, tire type, tire air pressure, and road conditions. Specifically, the mass of the vehicle: the greater the vehicle's weight, the higher the rolling resistance. Tire type: the materials and structures of the tires influence the resistance. Tire air pressure: underinflated tires increase resistance. Road conditions: the smoothness or slipperiness of the road also affects the resistance. The rolling resistance coefficient C_r = 0.8 is usually calculated based on experimental data and plays an important role in evaluating the energy efficiency of many vehicles. The rolling resistance corresponding to the wheel's rotational motion can be calculated using equation (3).

$$F_r = mgC_r cos\alpha \tag{3}$$

In equation (3), g represents the acceleration due to gravity, and α denotes the inclination angle of the surface on which the vehicle is moving.

During motion, the airflow encountered by the vehicle generates a force acting in the opposite direction to its movement. This force, acting against the vehicle's motion, is called aerodynamic drag [9]. F_a represents the aerodynamic drag force acting on the vehicle and is calculated as shown in equation (4).

$$F_a = C_d \frac{\rho V^2}{2} A \tag{4}$$

In equation (4), C_d = 0.8 represents the aerodynamic drag coefficient, ρ is the air density, V is the velocity of the vehicle, and A denotes the frontal area of the vehicle. Grade resistance is the force resulting from the longitudinal component of the vehicle's weight acting on an inclined surface. This resistance is directly related to the vehicle's mass and the slope angle of the incline [10]. F_y represents the grade resistance force and is calculated as shown in equation (5).

$$F_y = mgsin\alpha \tag{5}$$

The MATLAB-Simulink model is used for the calculations. The resistance forces acting on the vehicle are shown in Figure 3.

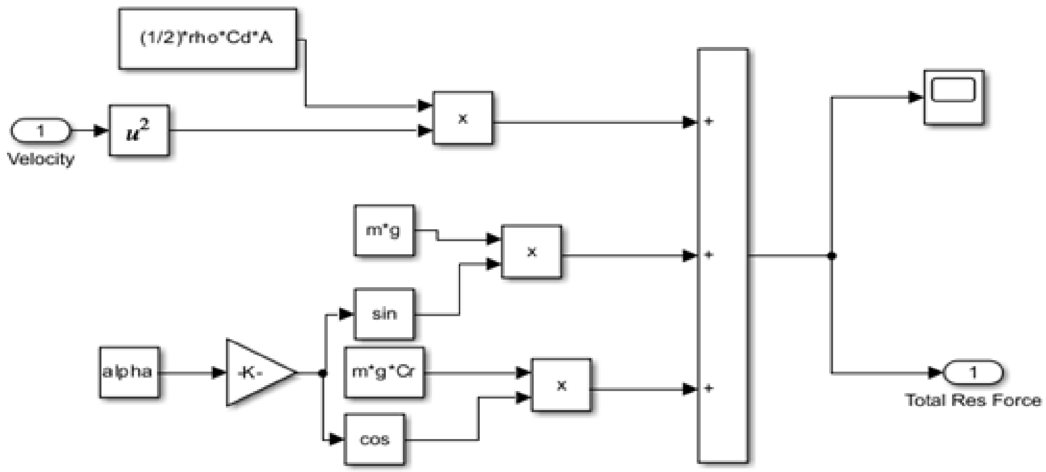

Fig. 3: MATLAB-Simulink model of resistance forces.

The connection between the hydraulic system and the vehicle.

The variables applied by the hydraulic system to the vehicle, such as force and flow, are directly related to the rotational speed of the hydraulic pump/motor shaft. A system that directly establishes the relationship between the rotational speed of the hydraulic pump/motor shaft and the vehicle speed is used to describe the connection between the wheel axle and the pump/motor shaft. A simplified representation illustrating the connection between the pump/motor element and the wheel axle is shown in Figure 4.

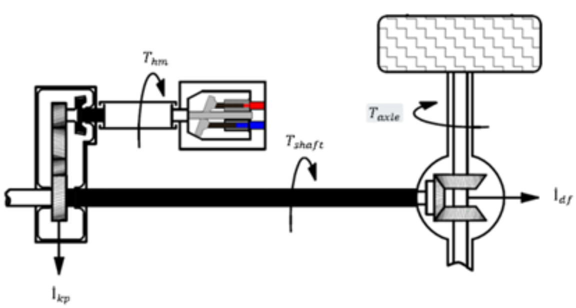

Fig. 4: Connection between the wheel axle and the pump/motor shaft

The hydraulic pump/motor element is connected to the vehicle's engine shaft via a periodic transmission. The transmission ratio of this intermediate transmission is denoted as Ikp, and its efficiency is represented by ηkp. Similarly, the wheel axle is connected to the vehicle's engine shaft through a differential. The differential transmission ratio is denoted as Idf, and its efficiency is represented by ηdf. The ratio between the torque generated by the pump-motor element and the torque on a single axle is given by equation (6).

$$T_{ask} = T_{hm} \cdot I_{kp} \cdot \eta_{kp} \cdot I_{df} \cdot \eta_{df} \tag{6}$$

In equation (1), the torque generated by the pump/motor element is denoted as T_{hm}, and the torque generated by the wheel axle is denoted as T_{ask}.

Similarly, the relationship between the rotational speed of the pump/motor component and the rotational speed of the wheel axle is shown in equation (7).

$$\omega_{ask} = \frac{\omega_{hm}}{I_{kp} I_{df}} \tag{7}$$

In equation (7), ω_{hm} represents the rotational speed of the pump/motor component, and ω_{ask} represents the rotational speed of the wheel axle.

The relationship between the rotational speed of the wheel axle and the linear velocity of the vehicle is calculated in equation (8), assuming that the wheels do not slip.

$$V = \omega_{ask} \cdot r \tag{8}$$

The MATLAB-Simulink model connecting the wheel axle with the hydraulic pump/motor component is shown in Figure 5.

Forces generated by the hydraulic system

In hydrostatic regenerative braking systems, the torque required to drive and brake the vehicle is provided by the hydraulic pump-motor component, as shown in Figure 6.

One port of this element is connected to the accumulator, while the other port is connected to the oil storage reservoir. The pressure difference between the inlet and outlet ports allows the hydraulic pump/motor to generate torque.

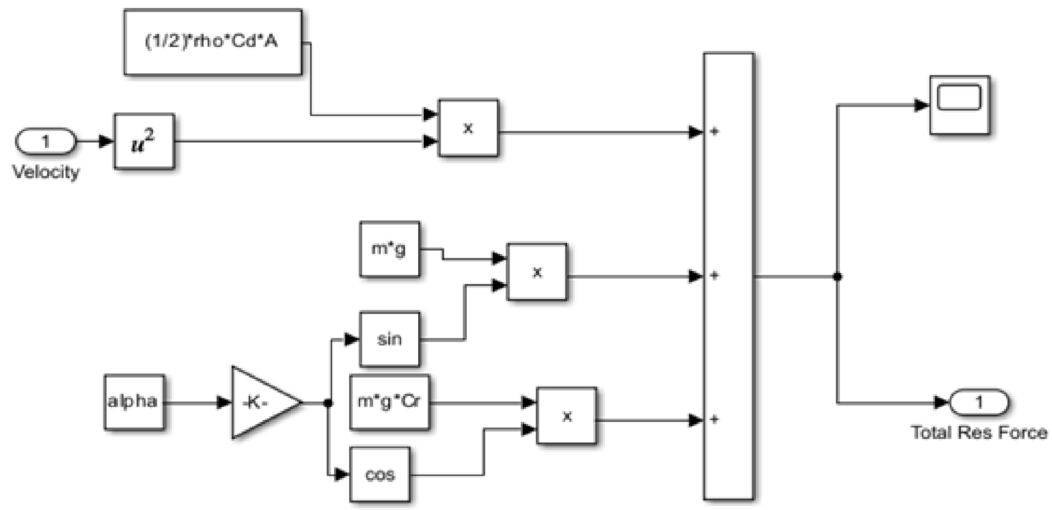

Fig. 5: MATLAB-Simulink model of the relationship between the hose pump/motor component and the wheel axle.

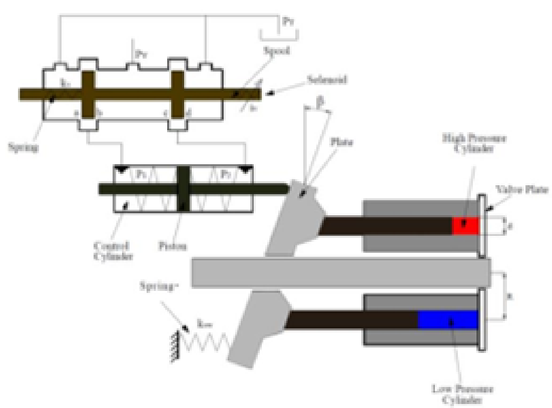

Fig. 6: Diagram of the variable displacement pump/motor component.

As shown in Figure 7, the flow and output torque of the hydraulic pump/motor component can be controlled by varying the displacement volume. The displacement volume is regulated by adjusting the angle of the swash plate inside the pump/motor element. A proportional control valve is used to control the swash plate angle. If no current is supplied to the valve solenoid, the valve remains in a neutral position due to spring force, holding the piston that moves the swash plate in its default position. The piston is controlled by applying current to the solenoid of the valve. The torque generated by the hydraulic pump/motor element can be calculated as shown in equation (9).

$$T_{hm} = \frac{\Delta p \cdot \forall \eta_{mh}}{20\pi} \tag{9}$$

In equation (1), the pressure difference between the pump/motor element ports is denoted as Δp, the volumetric displacement as $\forall$, and the mechanical output efficiencyη_{mh}. The denominator term 20π ensures the result is obtained in Newton-meters (Nm) when Δp is expressed in bars and $\forall$ is given in cubic centimeters (cm^3) per revolution. If the pressure at the inlet port is higher than at the outlet port (oil flows from the accumulator to the reservoir), the hydraulic pump/motor element operates in motor mode. In motor mode, the generated torque has a positive value, is transmitted to the wheel axle through the power transmission system, and is used to propel the vehicle, as expressed in equation (9). If the pressure at the outlet port is higher than at the inlet port (oil flows from the reservoir to the accumulator), the pump/motor element operates in pump mode. In pump mode, the generated torque has a negative value, is again transmitted to the wheel axle, and produces a braking effect on the vehicle, also expressed in equation (9).

Another important variable related to the hydraulic system is the flow rate. Calculating the flow is necessary for determining the power consumed or produced by the hydraulic pump/motor element, predicting losses in the system, and identifying the amount of oil transferred to or from the accumulator. The flow of the pump/motor component can be calculated as shown in equation (10).

$$Q = \frac{\forall \cdot \omega_{mh}}{\eta_{vol} \cdot 10^6 \cdot 2\pi} \tag{10}$$

In equation (10), η_{vol} represents the volumetric efficiency. The denominator factor $10^6 \cdot 2\pi$ ensures the result is obtained in cubic meters per second (m^3/s), assuming calculations are done with ω_{mh} in radians per second (rad/s) and $\forall$ in cubic centimeters per revolution (cm^3/rev).

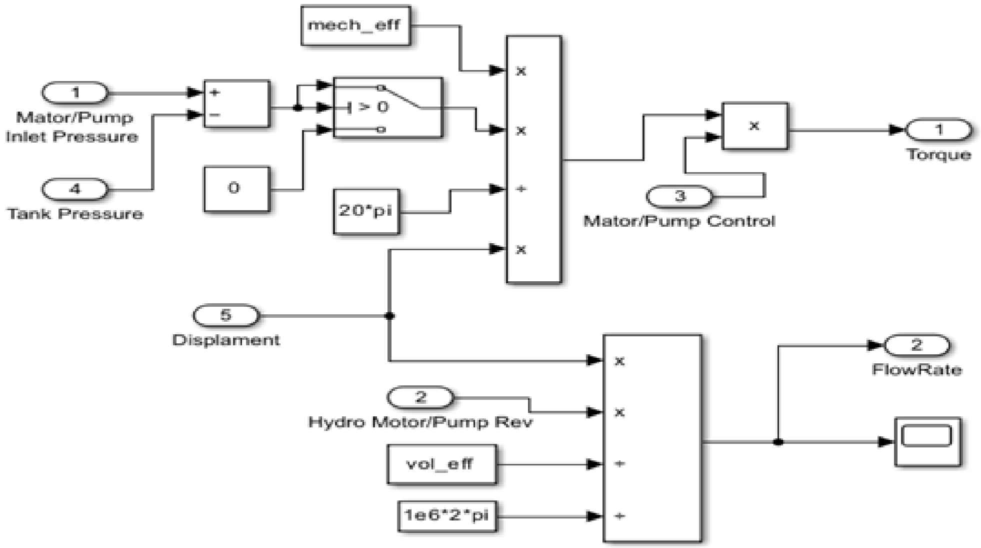

Fig. 7: Simulink model of the hydraulic pump/motor element.

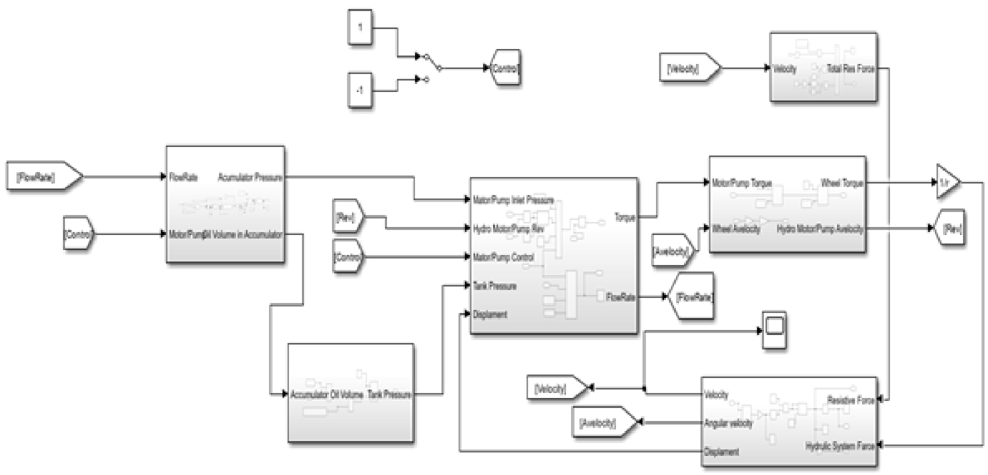

Fig. 8: MATLAB-Simulink model.

In the Simulink model shown in Figure 8, the combination of the calculated resistance forces acting on the vehicle primarily depends on the pressure difference between the hydraulic pump/motor element ports, which in turn determines the vehicle's acceleration.

III RESULTS AND THEIR ANALYSIS

Figure 9(a), (b), and (c) show the graphs of the vehicle's acceleration, velocity, and position changes, respectively. Graph (d) illustrates the time-dependent variation of the hydraulic accumulator's oil pressure.

Figure 10. Graphs of the vehicle deceleration. Graphs (a), (b), and (c) show the changes in the vehicle's acceleration, velocity, and position, respectively. Graph (d) depicts the time-dependent variation of the hydraulic accumulator oil pressure.

The graphical results obtained during the study (Figures 9 and 10) clearly demonstrate the efficiency of the hydrostatic regenerative braking system in vehicle motion and braking processes. The graphs reflect changes over time in the vehicle's acceleration, speed, state, and pressure variations within the hydraulic system.

The motion phase graphs (Figure 9) show that the vehicle's acceleration directly depends on the hydraulic system's ability to generate force through the pressure difference during the driving mode. The speed growth dynamics relate

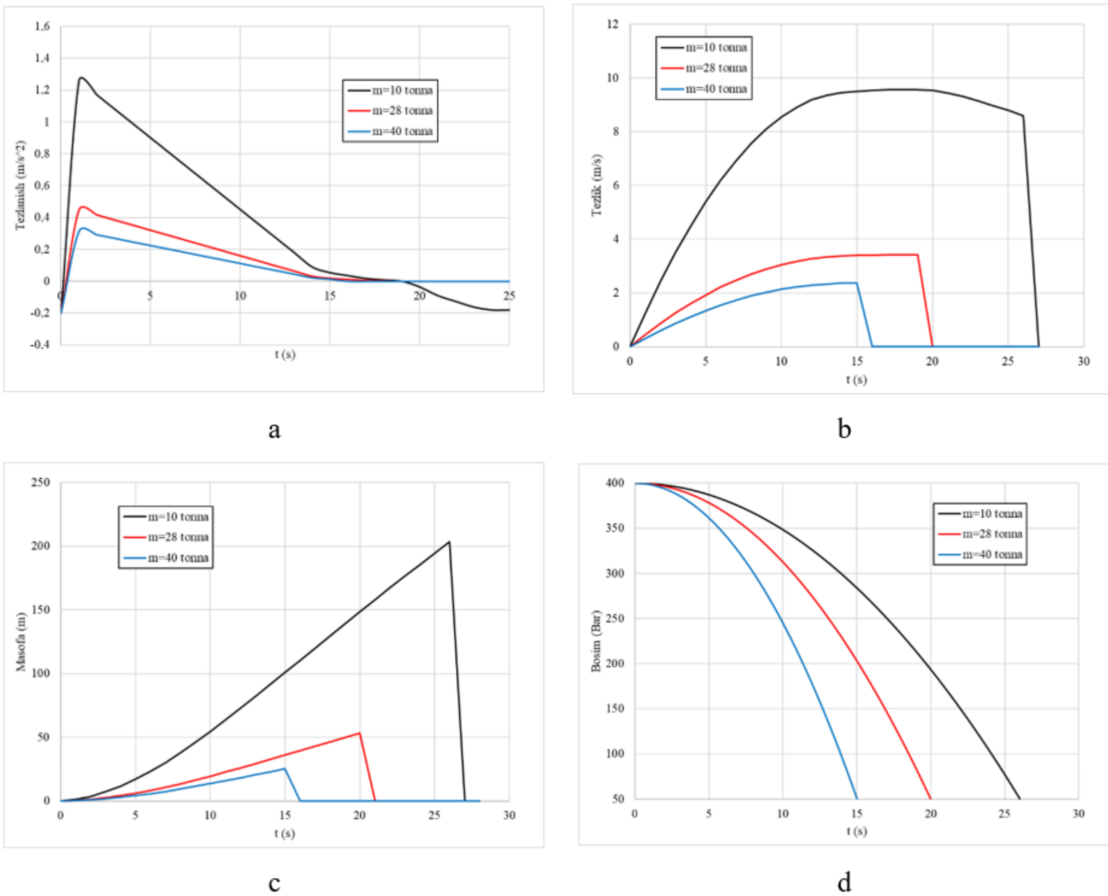

Fig. 9: Vehicle acceleration graphs.

to the vehicle's mass, the rotational speed of the hydraulic pump/motor component, and the torque produced, allowing an assessment of the system's response speed. The position graph is important for determining the actual movement trajectory of the vehicle. The braking phase graphs (Figure 10) illustrate how, during deceleration, kinetic energy is converted into pressure energy via the hydraulic system. This pressure is accumulated in the accumulator and can be reused later. The observed pressure drop and rise dynamics prove the stepwise nature of the system's activation. This condition is crucial for energy optimization and ensuring safety. Overall, the graph analyses indicate that the hydrostatic regenerative system increases the vehicle's sensitivity to speed changes, enables balanced motion control, and improves braking efficiency. This presents a relevant solution for heavy-duty trucks in terms of safety, energy saving, and environmental benefits.

IV CONCLUSION

This study deeply investigated and mathematically modeled the influence of the hydrostatic regenerative braking system on vehicle motion and braking. The main forces acting on the vehicle, including wheel rolling resistance, aerodynamic forces, gravity components, and hydraulic system forces, were modeled. Using the MATLAB-Simulink environment, realistic operational modes of the vehicle were simulated. The resulting graphical data clearly showed the efficiency of the energy recuperation process, the system's response time in various phases, and the impact of pressure changes on the energy process. According to the results, the hydrostatic braking system enables effective control of vehicle motion, energy savings during braking, reduction of operational costs, and improvement of overall ecological performance. Therefore, this system is a promising solution for heavy trucks and specialized machinery, with potential for further refinement through advanced optimization and practical testing.

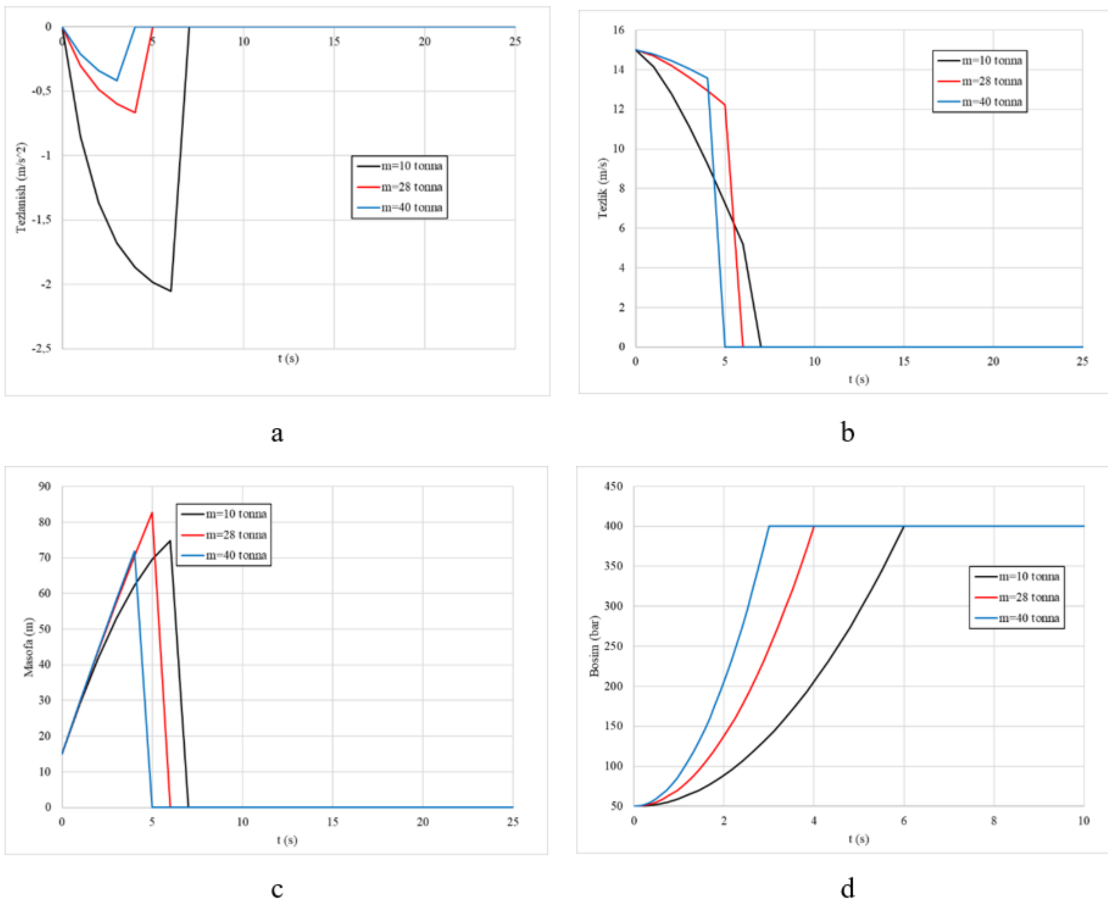

Fig. 10: Vehicle braking graphs

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COLLABORATIVE ROBOTS: TRANSFORMING THE WORKFORCE THROUGH ADVANCED COMMUNICATION AND MECHATRONICS.

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Urgench branch of Tashkent University of Information Technologies named after Muhammad al-Khwarizmi

Abstract– The article considers the issues of analyzing information security risks in smart homes, which are becoming increasingly popular due to the development of Internet of Things (IoT) technologies. The paper examines in detail the security threats associated with the use of intelligent devices, such as smart sensors, surveillance cameras, and lighting control systems. Various approaches to identifying vulnerabilities, assessing possible consequences, and risk mitigation methods are presented, and recommendations for protecting user data are offered. Particular attention is paid to the analysis of threats associated with remote access and breach of privacy. The purpose of the article is to draw attention to the importance of ensuring the security of smart homes and to offer practical solutions to improve their protection.

Key words– smart home, internet of things, security, threats, risks.

I Introduction

The Internet of Things is a system in which inanimate objects automatically collect and exchange data over wireless networks. It can also be described as the connection of various gadgets and objects, such as smart TVs. Smart sensors provide a new form of communication between objects and people [1,2]. The Internet of Things is one of the most popular terms in the modern world. The Internet of Things is the expansion and growth of Internet networks. It is a vast network formed by connecting various devices that have information to it, which allows connecting people, machines, and objects at any time and in any place. The Internet of Things is one of the most constructive forms of wireless communication in the 21st century. Today, IoT technologies play an important role in people's lives, and their use changes our lives, making it easier and more convenient [3].

II THE METHODOLOGY

Risk is the possibility that a certain unfavorable event will occur, which has its price (the amount of expected damage) and the probability of occurrence. The result of risk assessment can be presented both as a quantitative indicator (million sums) and as a qualitative indicator (acceptable or unacceptable risk).

The main information security risks are:

- risk of leakage of confidential information;
- risk of loss or inaccessibility of important data;
- the risk of using incomplete or distorted information;
- the risk of unauthorized covert exploitation of information and computing resources;

The Internet of Things is having a disruptive impact on this and is becoming a major driver of innovation and success in the industry. In recent years, with the rapid development of IoT devices, these applications have become increasingly important. In the IoT environment, all devices can be connected to the Internet, and the penetration of IoT into various sectors is fast and disruptive. In the coming decade, the depth of influence and the speed of adoption of IoT technologies will increase. The depth of influence and the speed of adoption of IoT technologies will be enormous.

• the risk of dissemination in the external environment of information that threatens the organization's reputation.

Identification and valuation of assets

Assets (resources) of the information technology system are a component or part of the overall system in which the enterprise directly invests funds and which, accordingly, require protection by the enterprise. When identifying assets,

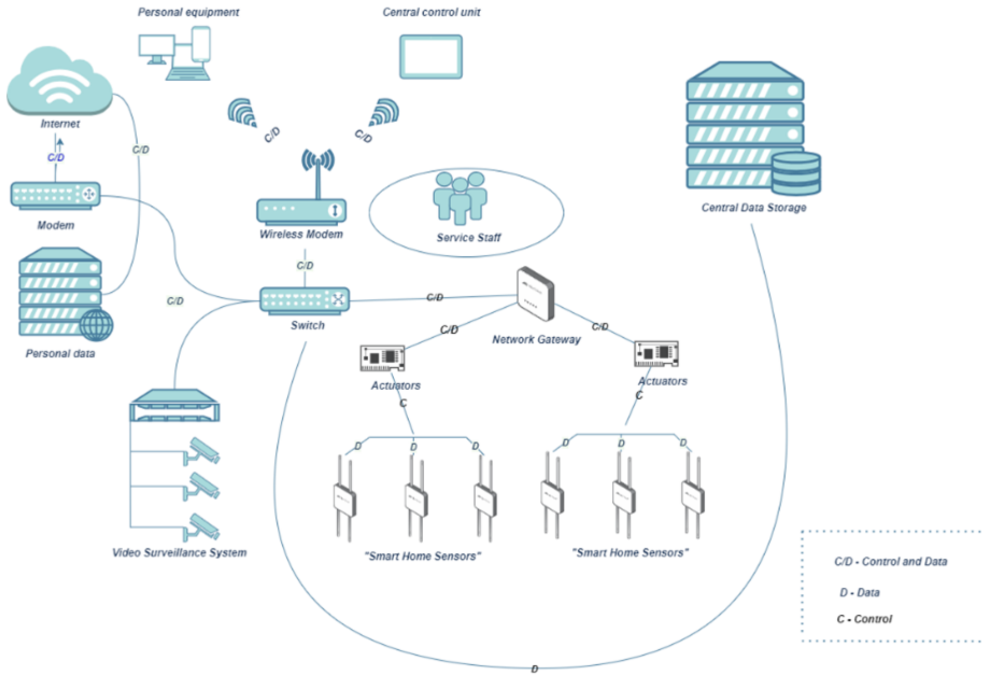

Fig. 1: Smart home system

it should be borne in mind that any information technology system includes not only hardware, but also software.

Assets include (but are not limited to):

- tangible assets (computing equipment, communication equipment, buildings);
- information (documents, databases);
- software;
- the ability to produce a product or provide a service;
- enterprise personnel;
- intangible resources (company prestige, reputation).

Valuation of enterprise assets is an important step in the overall risk analysis process. To ensure a complete accounting of assets, the following is required:

- determine the composition of the enterprise's assets;
- group them by types: information assets, software assets, physical assets and labor resources;
- determine the form of presentation of the asset: paper document, electronic medium, material object;
- identify the owners of the asset. The term "owner" refers to the person or entity assigned management-mandated responsibility for exercising control over the production, development, maintenance, use and security of the asset.

Once assets have been identified, it is necessary to determine:

- criteria for determining the value of an asset (initial value of the asset, cost of renewal, value of the organization's reputation);
- asset value. A qualitative scale is used to determine the value of an asset ("very low", "low", "medium", "high", "very high").

It is the assets that have the greatest value that should subsequently be considered as the object of protection (Table 1). The paper examines 10 assets. An example is given in table 1.

The organization of information security should be based on the analysis of possible negative consequences. The analysis of negative consequences involves the mandatory establishment of possible sources of threats, factors influencing the manifestation (vulnerabilities) and, as a consequence, the definition of current threats to information security. Based on this, it is advisable to identify possible threats based on the analysis of the logical chain shown in Figure 2.

The threat has the ability to cause damage to assets and, therefore, to the Smart Home as a whole. This damage may arise from an attack on information processed using information and telecommunications technologies, on the system

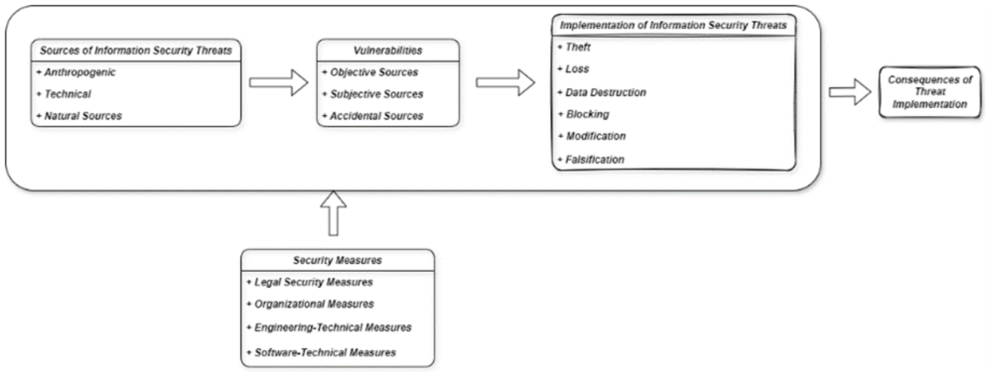

Fig. 2: Threat implementation model

Asset number	Name of assets	Asset Value
Asset №1	"SH" sensors	Average
Asset №2	Video surveillance system	Tall
Asset №3	Central data storage	Very high
Asset №4	OS "SH"	Very high
Asset №5	Service staff	Tall
Asset №6	Central control unit	Tall
Asset №7	Confidential data (subscribers)	Very high
Asset №8	Personal data	Tall
Asset №9	Personal gadgets	Average
Asset №10	Confidential data (personnel)	Very high

TABLE 1: VALUE OF SMART HOME ASSETS

itself or other resources, leading, for example, to their unauthorized destruction, disclosure, modification, damage, inaccessibility or loss. Damage to assets can only be caused if they have a vulnerability.

Threats, both accidental and intentional, must be identified and their level and probability of implementation must be assessed. A qualitative scale can be used to assess the probability of threat implementation ("very low", "low", "medium", "high", "very high"). The results of the analysis of threats and vulnerabilities of Smart Home assets are presented in Table 2.

Asset number	Threat Group	Vulnerabilities	Probability of threats being realized
"SH" sensors	Intentional damage to property	Poor organization in terms of personnel matters	Tall
		Incompetence of personnel in matters of security	Average
	Theft of property	Incompetence of personnel in matters of security	Average
		Poor perimeter protection for the Smart Home	Very high
	Sensor failure	Insufficient qualification of personnel in matters of equipment operation	Average
		Unreliable supplier of goods	Low
Video surveil lance system	Intentional damage to the video surveillance system	Poor organization of personnel	Tall
		Weak qualification of personnel in security matters	Average

	Theft of CCTV components	Lack of experience of personnel in security matters	Average
		Poor perimeter protection for the Smart Home	Very high
	Video surveillance system failure	Weak qualification of personnel in matters of equipment operation	Average
		Unreliable importer of goods	Low
	Hacking a CCTV system	Bad password policy	Tall
		Incorrect use of hardware and software	Average
Central data storage	Unauthorized access	Poor training of staff in security matters	Average
		Bad user passwords, bad password requirements	Very high
		Lack of verification by the information security service	Tall
	Malware	Insufficient knowledge of personnel regarding compliance with information security measures	Average
		Lack of experience in using hardware and software systems	Average
		Weak organization of information security measures	Tall
	Hacking DB	Poor preparation of organizational measures to protect the database	Tall
		Weak security of user tables, poor password requirements	Very high
		Insufficient level of professionalism in matters of compliance with information security measures	Average
OS "SH"	OS Hacking	Gross violation of hardware and software operation	Average
		Poor organization of OS protection measures	Tall
	Malware	Insufficient level of professionalism in matters of compliance with information security measures	Average
		Incorrect use of hardware and software systems	Average
	Technical failures in the system	Incorrect use of hardware and software	Low
		Weak organization of measures for the functioning the system	Average

Staff mainte nance	Insider threats	Poor organization of measures to protect confidential data	Very high
		Unprofessional selection and training of personnel	Tall
	Intentional damage and destruction of property	Incompetent selection of personnel	Tall
		Weak organization of measures to protect the "Smart Home"	Average
	Theft of property	Insufficient training of personnel in security matters	Average
		Weak impleme ntation of perimeter protection of the "Smart Home"	Very high
Central control unit	Malware	Poor organization in terms of compliance with information security measures	Average
		Incorrect use of hardware and software systems	Average
		Lack of access control rules	Tall
	Technical failures in the system	Unprofessional training of personnel on system operation issues	Average
		Lack of experience in using software and hardware systems	Average

	Intentional damage or theft of property	Lack of backups	Very high
		Unprofessional selection and training of personnel	Tall
Confidential subscriber data	Unauthorized access	Lack of personnel authentication systems	Tall
		Insufficiently trained personnel in information security matters	Average
	Destruction or disclosure of data	Incorrect use of hardware and software systems	Average
		Poor organization of measures to comply with information security rules	Average
Personal data	Theft or disclosure of data	Unqualified training of personnel on information security issues	Tall
		Unprofessional selection and training of personnel	Tall
	Destruction or modification of data	Weak organization of selection and training of personnel	Tall
		Poor training of personnel in information security matters	Average

Personal gadgets	Gadget theft	Insufficient level of personnel training in matters of ensuring their own safety	Average
		Insufficient professional selection and training of personnel	Tall
	Unauthorized access to the system	Lack of personnel authentication systems	Tall
		Weak organization of personnel on information security issues	Average
Confidential data (personnel)	Destruction or deletion of data	Weak information security	Average
		Lack of backups	Very high
	Blackmailing of staff	Poor awareness of the facts and methods of blackmail	Average
		Poor safety culture in the organization	Average

TABLE 2: RESULTS OF THE ANALYSIS OF THREATS AND VULNERABILITIES OF SMART HOME ASSETS

Next, it is necessary to conduct a total risk assessment of the assets. Assets that have value and are characterized by a certain degree of vulnerability are exposed to risk each time in the presence of threats. Risk is essentially a measure of the vulnerability of the system and the organization associated with it. The amount of risk depends on:

- asset values;
- ease of implementation of threats in vulnerable places with the provision of unwanted impact;
- existing or planned means of protection that reduce the degree of vulnerability, threats and unwanted impacts.

To assess the risk, we will use a qualitative scale:

- Low risk that can generally be accepted without further treatment.
- Medium level of risk that may require some treatment (acceptable risk).
- High level of risk that must be treated first (unacceptable risk). The risk level values are obtained from Figure 3.

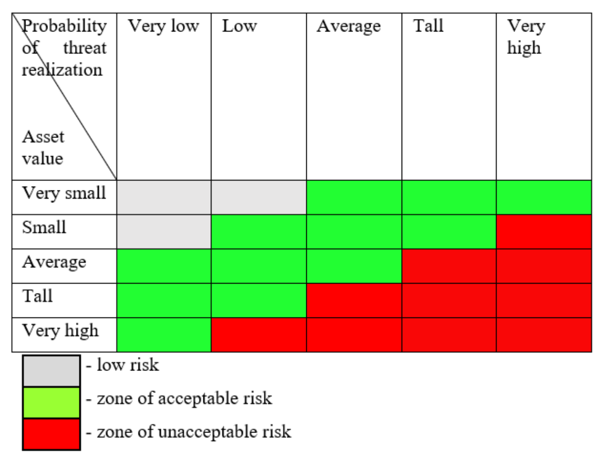

Fig. 3: Risk Level Value

The results of the risk level assessment of the Smart Home information security are presented in Figure 4.

The obtained results of risk assessment are the basis for selecting and formulating tasks for ensuring enterprise information security and choosing protective measures.

Considering the diversity of potential threats to Smart Home assets, the complexity of its structure, as well as human participation in the technological process of information processing, the goals of information protection can only be achieved by creating an information security system based on an integrated approach. In this section, we briefly described

No.	Asset name	Risk
1	"SH" sensors	Acceptable risk zone
2	Video surveillance system	Zone of unacceptable risk
3	Central data storage	Zone of unacceptable risk
4	OS "SH"	Zone of unacceptable risk
5	Service staff	Zone of unacceptable risk
6	Central control unit	Zone of unacceptable risk
7	Confidential data (subscribers)	Zone of unacceptable risk
8	Personal data	Zone of unacceptable risk
9	Personal gadgets	Acceptable risk zone
10	Confidential data (personnel)	Zone of unacceptable risk

Fig. 4: Results of the Risk Level of the Smart Home Information Security

the set of tasks to be solved further and reflected the reason for the choice made in Table 3.

Name of assets	Measures to reduce information security risks
Video surveillance system	Safeguards for Ecosystem Mapping and Ecosystem Relationships
	Security measures regarding IT security and remote access procedures
Central data storage	Security measures related to information system security risk analysis, policy, accreditation, metrics and audit, and human resource security
	Security measures related to system configuration, system management, traffic filtering and cryptography
	Security measures regarding authentication, identification and access rights
OS "SH"	Security measures related to system configuration, system management, traffic filtering and cryptography
	Security measures for detection, logging, and log correlation and analysis
	Security measures for analyzing and responding to security incidents in an information system, as well as incident reporting
Service staff	Security measures related to information system security risk analysis, policy, accreditation, metrics and audit, and human resource security
	Security measures regarding authentication, identification and access rights
Central control unit	Security measures related to information system security risk analysis, policy, accreditation, metrics and audit, and human resource security
	Security measures related to system configuration, system management, traffic filtering and cryptography
	Security measures for administrative accounts and administrative information systems
	Security measures regarding authentication, identification and access rights
	Security measures for detection, logging, and log correlation and analysis
Confidential data (subscribers)	Security measures for administrative accounts and administrative information systems
	Security measures regarding authentication, identification and access rights
	Security measures for detection, logging, and log correlation and analysis

Personal data	Security measures for administrative accounts and administrative information systems
	Security measures regarding IT security and remote access procedures
Confidential data (personnel)	Security measures related to information system security risk analysis, policy, accreditation, metrics and audit, and human resource security
	Security measures for analyzing and responding to security incidents in an information system, as well as incident reporting

TABLE 3: MEASURES TO REDUCE THE RISKS OF INFORMATION SECURITY OF SMART HOME ASSETS

III CONCLUSION

One of the key services of a smart home, which is in high consumer demand and is basic when installing any system, is security. The desire to have an integrated security and identification system, as shown by the survey conducted during the study, is fundamental for potential consumers when deciding to purchase smart home components. A threat has the ability to damage assets and, therefore, the Smart Home as a whole. This damage can occur due to an attack on information processed using information and telecommunications technologies, on the system itself or other resources, leading, for example, to their unauthorized destruction, disclosure, modification, damage, inaccessibility or loss. Damage to assets can only be caused if they are vulnerable.

Threats, both accidental and intentional, must be identified, and their level and probability of implementation must be assessed. Conducting such a study allows, in this case, the most rational distribution of investments to reduce the level of risk or eliminate threats.

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SIMULATORS FOR COMMUNICATION PROFESSIONALS: PRODUCTIVITY IMPROVEMENT, TRAINING, AND NEW MEASURES

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Abstract– This article explores the significance of simulators in enhancing the productivity of communication specialists by facilitating training and the implementation of new strategies. Simulators play a crucial role in refining professional skills and optimizing work efficiency. This study examines their effectiveness in education and professional development, highlighting their accuracy, reliability, and contribution to the adoption of innovative methods and technologies.

Key words– simulator, communication, virtual, technology, signal, analysis, electronic, module, integration, stress, resource, innovation.

I INTRODUCTION

The field of communications is an industry that occupies an important place in the development of society, is rapidly developing and in need of innovation. Today, for accurate and reliable types of communication, the introduction of new technologies and their effective application, it is important to improve the skills of specialists. Therefore, it is becoming increasingly important to use simulators to improve the skills of specialists working in the field of communications, to familiarize them with modern conditions and new technologies.

Simulators, as a rule, are educational tools that allow you to process real situations and take direct part of professionals in practical exercises. In the field of communication, simulators allow you to turn the theoretical knowledge of specialists into practical skills, or to use actions systematically. They help in system analysis, project management, signal and data transmission, use of electronic devices, coordination of structures in a virtual environment, and many other areas.

II THE MAIN PART

The advantage of simulators for communication specialists

Simulators allow professionals to correctly and safely implement work situations in a virtual environment. This allows students to follow practical work instructions with options such as correcting errors immediately and making changes to descriptions. Proximity to real conditions is one of the most important characteristics of simulators, which allows specialists to master practical skills in a virtual environment, but in conditions close to real ones. This, in turn, ensures that professionals will be prepared for any situation, and proves that they will have the necessary experience before they make a mistake. The main aspects of approaching real conditions are:

Performing practical exercises on virtual simulators. Simulators handle situations that people may encounter in real life, in a virtual environment. For example, a communications specialist may encounter situations involving signal transmission, calling, or routing Internet traffic in a virtual simulator. In each case, the simulator works with clear and realistic conditions, and also allows you to work with decisions made by specialists and the results of work. At the same time, it shows bug fixes and changes that can be made to the workflow.

Decision-making and working under stress. Real-world conditions can often cause stress and pressure. Simulators help professionals improve their decision-making skills as they learn how to act in any situation. If a specialist makes a mistake in a particular situation, the simulator, having discovered his mistake, will allow him to try to make the right decision. This process is important for creating a relationship between theoretical knowledge and practical skills in displaying events [1].

Integration of technological and human resources. Simulators allow you to integrate different technologies and human resources. For example, in communication simulators, specialists approach real conditions when using computer systems, Internet networks, mobile devices, and other means of communication together. This helps professionals gain full experience working with various devices and communication tools. To see the difference between simulation and real situations. Simulators allow professionals to test changes in various situations and situations in practice, and also show ways to eliminate or adapt the error of each workflow. In real conditions, these processes are developing rapidly, and there will be no turning back. Simulators provide professionals with a good basis for identifying and implementing these limitations.

Reaction time and activity in critical situations. Simulators help specialists learn how to react quickly and correctly. In real conditions, the consequences of any mistake can be severe, so simulators help people to analyze systematically and step by step, to be prepared for any dangerous situations. For example, a communications specialist can quickly acquire the skills to take precise and effective action in situations such as signal transmission failures or technical failures.

Save time and resources. Simulators help to avoid spending time and money on the implementation of practical and theoretical knowledge. In cases where huge amounts of money and long time can be spent on realistic communication training, simulators can reduce it several times. Another important aspect of using simulators is that they help ensure the efficient use of human resources and finances. Simulators are a tool that allows communication specialists to master real-world situations in a virtual environment, speeding up the process of their training and practical work, as well as helping to significantly reduce the time and resources spent on these processes.

The main aspects of saving time:

Effective case management. Simulators allow you to quickly and efficiently perform practical exercises and workouts. At the same time, students do not have to spend a lot of time studying one or more pieces of information in real conditions. With the help of simulators, you can repeatedly perform any task and instantly analyze the results, which helps save time and optimize the learning process.

Automation. Simulators will help you automate your work processes. For example, when checking and diagnosing communication systems, simulators quickly and automatically analyze all aspects of necessary situations. Thanks to this, a person does not waste time, consistently and efficiently conducts various examinations and tests.

Reducing exercise and learning processes. Simulators allow students to repeatedly check a particular workflow without requiring a lot of time in real conditions. Simulators also provide an advantage in using modern technologies and quickly show results, which saves time and facilitates activities.

Saving production and educational resources. Simulators are an important way to save resources. For example, communications specialists may work at high cost when using real communication devices, but simulators help process these devices in a virtual environment, which means that resources available for purchase or use are not spent on them. In addition, training with simulators in training centers or organizations can help prevent the cost of space, tools and devices.

Quick mastery of skills. Simulators allow professionals to practice their skills many times and in different conditions. This, in turn, saves time, as one-time exercises replace several repetitions, and a professional can be prepared for different situations at the same time. The main aspects of saving resources:

Saving financial resources. Simulators reduce the cost of resources for the introduction of new methods and devices. For example, communications specialists learn how to test technologies and problems using simulations, but avoid spending on real devices. This will help save financial resources and save significant funds on practical exercises.

A set of modules and processes Simulators help you properly allocate time and resources by combining several modules. For example, specialists in the field of communications can simultaneously study various communication systems using a simulator, as well as be able to automatically reproduce various processes without having to spend additional resources on each module used [2]. Rapid adaptation to technological innovations is one of the important advantages of communication professionals using simulators. Modern communication systems and methods are systematically changing. Implementing and adapting innovations is an important task for professionals, especially in fast-growing industries. Simulators are an accurate and effective tool in this process, which allows professionals to quickly adapt to the news. The main aspects of rapid adaptation to technological innovations:

Gain experience working with new technologies. Simulators provide important assistance to specialists in mastering new communication technologies. For example, innovations such as new signal transmission methods, mobile communication protocols, useful digital technologies and communication devices are very easy to learn on simulators. Knowing the practical application of these technologies can help professionals learn how they work in practice.

Rapid response to technological changes. In the face of rapidly changing technologies, simulators teach professionals how to quickly adapt to new systems. For example, by introducing a new communication protocol or device, simulators can be used to quickly explore these changes from a practical point of view without interrupting the workflow. This helps professionals avoid mistakes when implementing new technologies [3].

Lots of training and exercises. A lot of practice is a key factor in the rapid development of new technologies. With the help of simulators, you can repeatedly learn new methods and techniques at the same time. For example, the practical use of a new communication device or Internet protocol can be performed several times using simulators, which simplifies the process for professionals and allows them to quickly adapt to each new technology.

Rapid development of practical skills. As new technologies are introduced, simulators allow professionals to quickly develop practical skills. For example, learning new physical and virtual communication systems using simulators can greatly improve relevant exercises and technology skills that professionals perceive with greater efficiency.

The use of digital technologies in education and training. The study of new digital communication systems using simulators allows professionals to apply these systems in real life conditions. Simulators will also be an important tool for adapting to new innovations and technological standards, as they help professionals adapt quickly, paying particular attention to changes in a huge range of software and hardware.

Safety. In the process of adapting to technological innovations, simulators allow professionals to practice new safety standards and avoid hazards. When working with new technologies, it is very important to pay attention to safety. Simulators will become an important tool in this process of training specialists to perform technical safety measures and work in accordance with new standards.

Development of communication in teamwork. Simulators are one of the important factors that are of great importance in the process of developing knowledge and skills needed by specialists. The development of teamwork and communication in the field of communications contributes to the successful work of specialists and to improving the efficiency of the organization. Simulators are a key tool in this process, helping communication professionals develop the skills to work together, solve problems together, and communicate effectively with each other.

The main aspects:

Develop teamwork skills. Simulators help to coordinate work in a team and solve tasks together. For example, when installing communication systems or implementing large-scale projects, it is necessary that each team member clearly understands their role and mission. On simulators, these states manifest themselves through practical exercises, and effective work skills are developed through the interaction of team members with each other.

Improving the efficiency of communications. Simulators help professionals to express their thoughts clearly and clearly. Such exercises ensure that communication specialists are effective in technical and professional language, as well as in dealing with team members. Clear and fast communication is important in teamwork, and communication skills acquired through simulators increase the level of responses and decisions learned during the work process.

Simulators help to clearly define the role of each team member and understand their responsibilities. For example, in a communication system situation where one participant is checking the network, another participant can provide signal transmission. Trainings conducted on simulators allow each team member to clearly understand their task and perform it correctly, which has a positive effect on the overall result [4].

Simulators help professionals develop the ability to solve problems in a team. When responding to an error or malfunction in a real-world communication system, it is necessary for several professionals to work on fast and effective communication. Through simulations, team members learn in practice how to help each other and work together to correct mistakes.

In teamwork, situations often arise when it is necessary to make quick decisions. With the help of simulators, professionals learn to make decisions together in different situations, and this develops their abilities in a positive way. The process of work between team members allows you to refine the system of their interaction and make quick decisions.

The simulators allow each team member to express their opinions and recommendations freely and accurately. The fact that communication specialists express their opinions clearly and constructively increases the effectiveness of their team work. In the simulations, each participant makes new decisions by speaking out and discussing them together.

Simulations also promote the mutual integration of technology in teamwork. For example, it is possible to increase the effectiveness of communication between team members using new communication technologies or Internet platforms [5].

III CONCLUSION

For communication professionals, simulators are sophisticated learning tools that provide effective training and job opportunities. They are designed to improve professional skills, apply tactics and strategies, and test new technologies. Simulators, as a rule, help to increase the productivity of professionals, allowing them to develop their decision-making skills and work quickly and efficiently under stress. One of the most important advantages of education is their ability to increase the interest and confidence of professionals through animation and realistic situations. In addition, simulators can be used to test new measures and innovative programs, which makes them vital for determining their practical effectiveness and integration into education.

In short, simulators are an essential tool for communication professionals who play an important role in improving their professional skills and becoming familiar with new technologies.

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THE MAGNETIC FIELD IN THE AIR GAP IN THE PRESENCE OF ROTOR ECCENTRICITY IN ALTERNATING CURRENT TRACTION MOTORS.

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Abstract– This study focuses on analyzing the effects of eccentricity on the magnetic field characteristics of asynchronous motors. The paper investigates the air gap variations under static and dynamic eccentricity conditions and presents mathematical models to quantify these variations. Static and dynamic rotor eccentricities are analyzed, highlighting their impact on the harmonic components of air gap permeability and magnetic flux distribution. Key findings demonstrate that harmonic distortions caused by eccentricity require careful consideration during the design and diagnostics of motors to ensure efficient performance and prevent potential failures. Experimental data validate the proposed models, showing that accounting for higher-order harmonics provides more accurate estimations of air gap permeability and electromagnetic field behavior. The research contributes to improving motor diagnostics by offering advanced methods for analyzing eccentricity-induced phenomena [1].

Key words– Asynchronous motor, rotor eccentricity, static eccentricity, dynamic eccentricity, air gap permeability, magnetic flux, harmonic distortion, motor diagnostics, electromagnetic field, fault analysis.

I INTRODUCTION

The efficient operation of asynchronous motors is critical in various industrial applications. However, mechanical and electromagnetic imperfections, such as rotor eccentricity, can significantly affect motor performance and reliability. Rotor eccentricity refers to the misalignment between the rotor and stator axes, which can be categorized into static and dynamic eccentricity. These conditions cause uneven air gaps, leading to harmonic distortions in the magnetic flux and variations in air gap permeability [2].

Static eccentricity occurs when the rotor axis is offset but remains parallel to the stator axis, while dynamic eccentricity involves a shifting rotor axis that varies during rotation. Both forms of eccentricity contribute to disturbances in motor operation, increased losses, and potential damage if left undetected.

This study focuses on mathematical modeling and analysis of the effects of rotor eccentricity on air gap characteristics, harmonic behavior, and electromagnetic field distortions. By understanding these phenomena, engineers and researchers can develop more effective diagnostic techniques to improve motor design and operational efficiency, ensuring reliable motor performance in practical applications.[3]

II THE METHODOLOGY

This study investigates the impact of rotor eccentricity on the air gap permeability and electromagnetic behavior of asynchronous motors in the context of diagnostics for traction motors used in Uzbekistan Railways. The research methodology encompasses analytical modeling and experimental validation tailored to the specific challenges faced in the railway sector. Maintenance issues in traction motors of Uzbekistan Railways have revealed frequent occurrences of rotor eccentricity faults, which lead to reduced operational efficiency, overheating, and eventual motor failures. Static and dynamic eccentricities, caused by wear, manufacturing defects, or prolonged usage, were identified as key factors contributing to operational disruptions [4]. Mathematical models were developed to describe the air gap variations caused by eccentricity faults in traction motors. The models focused on quantifying air gap permeability and electromagnetic distortions by incorporating harmonic components using Fourier series analysis Experiments were carried out on traction motor prototypes under controlled conditions. Measurements included rotor displacement, air gap flux density, and harmonic distortion analysis to validate the accuracy of the diagnostic models. The harmonic components of air gap permeability were analyzed for both healthy and faulty motors. This analysis provides railway maintenance personnel with a robust tool for detecting early signs of rotor eccentricity. Air gap in the presence of static and dynamic eccentricity of the rotor. Figure 1 shows a diagram of the rotor surface axis displacement in the presence of static and dynamic eccentricity. The vectors $\bar{\varepsilon}$ and $\bar{\varepsilon}'$ correspond to the vectors of the rotor axis in relative units, and the vector $\bar{\varepsilon}_{\sum}$ is the instantaneous total eccentricity of the rotor. Sum of instantaneous eccentricity and rotor displacement direction [5]

$$\bar{\varepsilon_{\Sigma}} = \sqrt{(\varepsilon\, cos\varphi_{\varepsilon} + \varepsilon'\, cos\varphi_{\varepsilon}')^2 + (\varepsilon\, sin\varphi_{\varepsilon} + \varepsilon'\, sin\varphi_{\varepsilon}')^2}, \quad (1)$$

$$\varphi_{\varepsilon\Sigma} = acrtg\frac{\varepsilon\, sin\varphi_{\varepsilon} + \varepsilon'\, sin\varphi_{\varepsilon'}}{\varepsilon\, cos\varphi_{\varepsilon} + \varepsilon'\, cos\varphi_{\varepsilon'}} \quad (2)$$

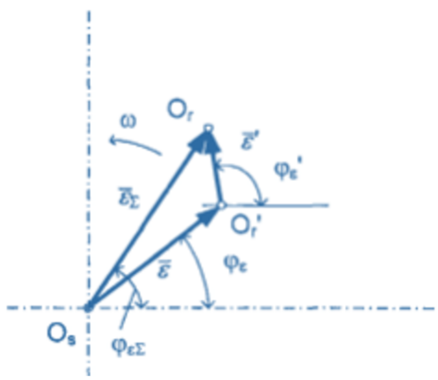

Fig. 1: Scheme of axial displacement of the rotor surface under eccentricity. O_s – stator axis, O_r' – rotor rotation axis, O_r – outer axis of the rotor surface.

The air gap value is determined by the distance between the rotor and the stator surface, measured in R' along the axis O_s of the stator axis. The air gap value is determined by the following formula.

$$\delta(\varphi) = R_s - \delta_0\varepsilon_{\Sigma}cos(\varphi - \varphi_{\varepsilon\Sigma}) -$$

$$-\sqrt{R^2 - \delta_0^2\, \varepsilon_{\Sigma}^2\, sin^2(\varphi - \varphi_{\varepsilon\Sigma})} \quad (3)$$

For small air gap values in asynchronous motors, R' is almost perpendicular to the rotor surface, so formula (3) can be considered accurate. More in small intervals is $\sqrt{R^2 - \delta_0^2\varepsilon_{\sum}^2 sin^2(\varphi - \varphi_{\varepsilon\sum})} << \delta_0\varepsilon_{\sum}cos(\varphi - \varphi_{\varepsilon\sum})$ and after simplifying (3) it can be formed below formula.

$$\delta(\varphi) = \delta_0(1 - \varepsilon_{\Sigma}\, cos(\varphi - \varphi_{\varepsilon\Sigma}) \quad (4)$$

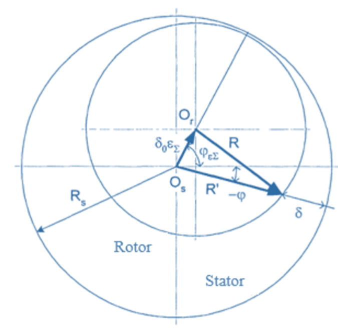

Fig. 2: Determining the magnitude of the air gap in the presence of eccentricity

The error of the $\delta(\phi)$-value in formula (4) is not more than 1.1% compared to formula 3 and is equal to $\delta_0/R_s = 0,02$ and $\varepsilon_{\sum} = 0,9$ while in the experimental asynchronous motor, for an increased air gap, it should be no more than 0.8%.

Practically, calculating the air gap using formulas (1), (2), (3) is difficult, as it is impossible to distinguish between dynamic and static eccentricity. Similar to (4), we write the following formula to sufficiently determine the size of the air gap [6].

$$\delta(\varphi) = \delta_0[1 - \varepsilon cos(\varphi - \varphi_{\varepsilon}) - \varepsilon' cos(\varphi - \varphi_{\varepsilon}')] \quad (5)$$

Since there is an additional additive, the error of (5) increases by 1.4% for the same engine compared to (3). Then formula (5) can be used to determine the size of the air gap, moreover, it can express the deviation of the rotor surface relative to the concentric cylinder in the air gap by comparison. For example, an elliptical rotor can be written as follows.

$$\delta(\varphi) = \delta_0[1 - \varepsilon cos(\varphi - \varphi_{\varepsilon}) - \varepsilon' cos2(\varphi - \varphi_{\varepsilon}')]$$

Air gap conductivity in the presence of static eccentricity. In the presence of static eccentricity, instead of the constant component Λ_0 in the air gap permeability formula of the known formula [8], an air gap permeability harmonic spectrum arises.

$$\sum \widetilde{\Lambda}_0 = \Lambda_{e0} + \sum_{k_{\lambda}=1}^{\infty} \Lambda_{ek_{\lambda}} cosk_{\lambda}(\varphi - \varphi_{\varepsilon}) \quad (6)$$

where φ_ε is the angle of location of the minimum air gap, which is the determinant of the direction of rotor displacement and, accordingly, is the static eccentricity.[9-10].

In the presence of eccentricity $\Lambda_{[ek]_\lambda}$, the harmonic amplitude of the air gap has a significant value compared to the constant component Λ_0. Figure 3 shows the harmonic amplitude of the air gap conductivity for different types of eccentricity values of the experimental asynchronous motor. As can be seen from this figure, it is necessary to take into account the permeability harmonics of the air gap with a large eccentricity of no less than ε>0.8, while for small values of ε, it is sufficient to take into account 3 permeability harmonics of the air gap.

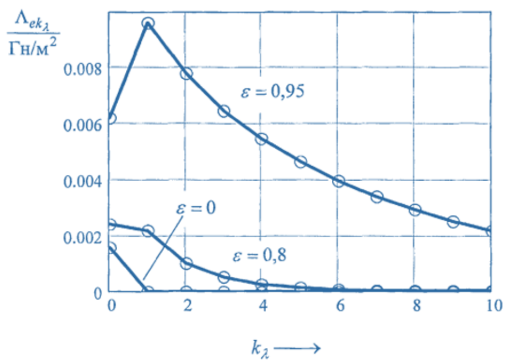

Fig. 3: The harmonic spectrum of the conductivity of the air gap in the presence of eccentricity

Let's consider the influence of eccentricity on the harmonics of the conductivity of the air gap from the density of the magnetic conductor. Due to the unevenness of the air gap caused by eccentricity, the amplitude of the tensile harmonic of the air gap conductivity along the stator circumference changes [5], [4]. Expanding the conductivity curve of the dental harmonic of the air gap into Fourier series, we obtain the harmonic spectrum:

$$\sum \tilde{\Lambda}^*_{zk_z} = \sum_{n=-\infty}^{\infty} \Lambda^*_{zk_zn} \cos\left[(k_z Z + n)(\varphi - \varphi_0) + k_z Z \frac{\omega(1-s)}{p} t\right] \qquad (7)$$

Here: k_z = 1,2,3... tooth harmonic order Z- the number of corresponding grooves of the magnetic core $\Lambda^*_{zk_zn}$- relative amplitude of the air gap conductivity tooth harmonic n – whole number From this, instead of the conductivity of the air gap according to the order k_z, there exists a spectral harmonic in (7), which, in the presence of rotor eccentricity, has a side harmonic order $kz\, Z+n$ and a "primary" harmonic k_z. We call the conventionally defined harmonic "the spectrum of harmonics of n-density at eccentricity."[8] Figure 4 shows the spectrum of the first tensile harmonics of the air gap permeability of the rotor of the experimental asynchronous motor 2 $(Z_2 = 26)$ with an eccentricity of the rotor ε=0.8. This spectrum contains the main dental harmonic $k_z = Z_2$, as well as the lateral harmonic of the air gap conductivity in the presence of rotor eccentricity.

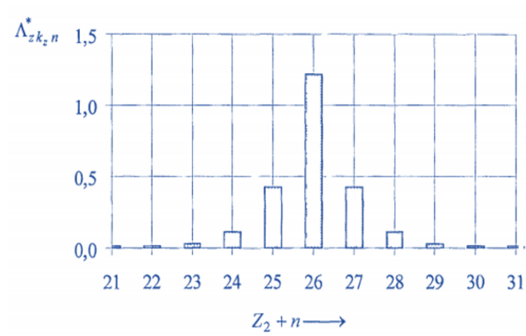

Fig. 4: The spectrum of the first harmonic of the air gap conductivity of the rotor of the experimental asynchronous motor (Z_2 = 26) with a rotor eccentricity of ε=0.8. The permeability of the air gap is assumed to be equal to the amplitude of the first tooth harmonic ε=0.

The most expressed harmonic was obtained at n = 0 (main tensile harmonic). Then, given the presence of a static eccentricity of the rotor according to [5], the total conductivity of the air gap is determined by the following formula:

$$\sum \tilde{\lambda}_\delta = \left[\Lambda_{e0} + \sum_{k_\lambda=1}^{\infty} \Lambda_{ek_\lambda} \cos k_\lambda (\varphi - \varphi_\varepsilon)\right] \cdot$$
$$\cdot \left[1 + \sum_{k_{z1}=1}^{\infty} \sum_{n_{z1}=-\infty}^{\infty} \Lambda^*_{z1k_{z1}n_{z1}} \cos(k_{z1}Z_1 + n_{z1})(\varphi - \varphi_\varepsilon)\right] \cdot$$
$$\cdot \left[1 + \sum_{k_{z2}=1}^{\infty} \sum_{n_{z2}=-\infty}^{\infty} \Lambda^*_{z2k_{z2}n_{z2}} \cos(k_{z2}Z_2 + n_{z2})(\varphi - \varphi_\varepsilon) + \frac{k_{z2}Z_2\omega t}{p}\right] \qquad (8)$$

The first factor in formula (8) determines the absolute specific conductivity δk_δ, which is equivalent to the air gap in the presence of eccentricity. The second and third factors represent the relative values of the tensile harmonics of the air gap conductivity (stator and rotor tensile strength, respectively) [7].

Air gap conductivity in the presence of dynamic eccentricity.

In the simplest case, the dynamic eccentricity occurs when the axis of the outer surface of the rotor moves parallel to its axis of rotation, making the rotor surface cylindrical.

In the future, we will consider the dynamic eccentricity of a cylindrical rotor as the axis of the rotor surface shifts parallel to the axis of rotation of the rotor. Taking this into account, the shape of the air gap remains the same as the static eccentricity, but the location of the minimum air gap changes and is determined by the rotational speed of the rotor. Dynamic eccentricity ε' with static eccentricity ε can exist in parallel.

In the presence of only a dynamic eccentricity of the conductivity of the air gap, it is determined in the same way as the formula for determining the static eccentricity of the conductivity of the air gap, but the harmonic of the conductivity of the air gap, caused by the eccentricity of the rotor, rotates with a frequency equal to the rotation frequency of the rotor [3]

$$\sum \tilde{\lambda}_{\delta} = \left[\Lambda_{e0} + \sum_{k_{\lambda}=1}^{\infty} \Lambda_{ek_{\lambda}} cos k_{\lambda}(\varphi - \varphi_{\varepsilon}) \right] \cdot$$
$$\cdot \left[1 + \sum_{k_{z1}=1}^{\infty} \sum_{n_{z1}=-\infty}^{\infty} \Lambda^{*}_{z1k_{z1}n_{z1}} cos(k_{z1}Z_1 + n_{z1})(\varphi - \varphi_{\varepsilon}) \right] \cdot$$

III CONCLUSION

This study investigated the influence of rotor eccentricity on the magnetic field in the air gap in alternating current traction motors (AC traction motors). The main results showed that the eccentricity of the rotor leads to an uneven distribution of the magnetic field, which can reduce the efficiency of the motor and cause additional vibrations and noise. The research results showed that:

As the eccentricity of the rotor increases, the unevenness of the magnetic field in the air gap increases.

Uneven distribution of the magnetic field can increase the heat losses of the motor and reduce its reliability.

A high degree of consistency was found between the experimental and simulation results, confirming the reliability of the methodology used.

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PROSPECTS OF APPLICATION OF SONO (CHEMICAL AND ELECTROCHEMICAL) METHODS IN THE SYNTHESIS OF METAL NANOPARTICLES

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Abstract– Chemical sonochemical and sonoelectrochemical methods for producing copper nanoparticles are generalized and analyzed. The sonochemical method for the synthesis of CuO nanoparticles is a simple and effective method for obtaining nanoparticles in high yield. The size of nanoparticles varies from 45 to 80 nm depending on the ultrasonic treatment time and calcination temperature. CuO nanoparticles produced by ultrasound in less than 20 minutes produce particles with a size of about 80 nm, while if the reaction is extended to 30 minutes, the resulting particle size is 45 nm. The results will be inversely proportional in the sense that the size will increase after increasing the sonication time to 40 minutes. The morphology of nanoparticles also depends on the pH of the medium. When the pH is set to 8, the morphology appears like leaves, and after increasing the pH to 11, the morphology changes to a clumpy flower. The sonoelectrochemical method makes it possible to synthesize chemically pure copper powders with unique and stable properties, controlled by the parameters of electrolytic deposition. Cu2O nanoparticles were obtained by pulsed sonoelectrochemistry in a potentiostatic mode. When applying a current density range of 55 to 100 mA cm2, monodisperse spherical copper nanoparticles with a diameter of 25–60 nm were observed. The work is based on a voltametric study which showed that by applying potentials ranging from -0.65 (for sample A), -0.85 (for sample B) and -1 V/SSE (for sample C) the formation of a mixture can be avoided Cu2O and Cu

Key words– nanoparticles, copper, synthesis, morphology, sonochemistry, sonoelectrochemistry

I Introduction

Physicochemical properties of ultrasound in the synthesis of nanoparticles The effect of ultrasonic (US) radiation is primarily associated with the development of such an effect as acoustic cavitation, which occurs in the medium during the propagation of ultrasound and is an effective means of converting the energy of a low-density sound wave into high-density energy associated with pulsations and the collapse of cavitation bubbles [1]. At an ultrasonic wave intensity of more than 2 W/cm2 in a liquid medium with a large accumulation of cavitation bubbles, sonoluminescence occurs. This is due to the fact that at the moment of collapse of cavitation bubbles, the pressure and temperature of the gas reach significant values - according to some data, up to 100 MPa and 5000-25000K [2]. After the collapse of the cavity, a spherical shock wave propagates in the surrounding liquid, quickly attenuating. Since the explosion occurs in less than a nanosecond [3], it creates very high adiabatic heating rates, exceeding 1011 K/s. Bubble explosions also lead to the appearance of microjets in the liquid, the speed of which reaches 150 m/s. Ultrasonic field energy is used for chemical synthesis of nanostructured materials. This direction, known as sonochemistry, is based on the occurrence and development of the cavitation process and accompanying sonochemical reactions in liquid media. In intense cavitation fields, high temperature and pressure gradients result in the decomposition of water molecules and the formation of active radicals and oxidants: H2O2, O3, etc. [4]. Sonochemical methods are used to obtain nanostructured amorphous materials.

For cavitation to occur, a certain value of ultrasound intensity [threshold value] must be achieved. The threshold value depends on the ultrasound frequency and the adhesion forces in the liquid. In the synthesis of metal nanoparticles, the ultrasound frequency varies from 20 kHz to 40 kHz. With an increase in the density of the acoustic energy flux to

$1Wcm^{-2}$ [and higher], a number of nonlinear phenomena occur in the liquid, the most important of which is cavitation.[5, 6]. In any case, nanomaterials have been obtained in almost all sonochemical reactions leading to inorganic products, although there are differences in the size, shape, structure and nature of the solid product, such as amorphous or crystalline [4]. The electrochemical method is usually used to obtain metal nanoparticles and nanocomposites based on them immobilized on a conducting substrate (electrode). However, for a wider use of metal nanoparticles, they must be converted into powder form. In the presence of stabilizers, the proportion of deposited metal decreases, but remains high. One of the methods to prevent the deposition of nanoparticles on the electrode is the use of sonoelectrochemistry. In this method, an ultrasonic probe serves as a cathode and an ultrasound emitter, thereby cleaning the cathode surface from deposited nanoparticles. This method makes it possible to obtain nanoparticles in the form of powder.

II THE MAIN PART

1. Sonochemical method of synthesis of nanoparticles Sonochemistry is a method of synthesizing materials using sound energy to induce physical and chemical changes in a liquid medium. The chemical action of ultrasound causes acoustic cavitation, which is the formation and growth of foam in a liquid. The frequency used in sonochemistry is in the range of 20 kHz – 2 MHz. The basic principle of sonochemistry is the displacement of sound waves that form and collapse bubbles, which leads to a local increase in temperature and pressure, causing physical and chemical changes in the material [7]. When these bubbles collapse, they create extreme conditions in a small volume for a short period of time, including very high temperatures and pressures, as well as liquid jets and shock waves. These conditions can trigger chemical reactions and facilitate the formation of nanoparticles. The scheme of the equipment used in the sonochemical method is shown in Figure 1. The materials used in the synthesis of CuO nanoparticles by sonochemical methods are copper nitrate trihydrate (CuN2O6.3H2O) and sodium hydroxide (NaOH) with polyvinyl as the initial precursor [8]. The synthesis of CuO nanoparticles begins with the dissolution of NaOH in deionized water. The resulting solution is then slowly added dropwise to CuN2O6.3H2O over 30 minutes.

Sonication was performed using a VCX 750 model. Several other researchers used different sonication models such as the Branson 102C [7] and the UC-20A ultrasonic chemical reduction model [9]. Sonication was performed until the desired product was completely precipitated. The precipitated product was then calcined at different temperatures in the range of 400-700°C for 2 hours. The thermal behavior of the product was investigated by powder thermogravimetry (TG) in open air at a heating rate of 10 deg/min [8]. Thermogravimetric and thermal differential analysis of CuO nanoparticles were performed using ultrasound for 30 minutes. In this ultrasonic treatment, it is seen that 2 weight losses occur at 180-250 C and at 500-700 C, as shown in Figure 2. The first decrease is due to the evaporation of polyvinyl alcohol and deionization in the mixed solution, while the second decrease is due to the oxidation of metallic copper in air, leading to the crystallization of CuO [8].

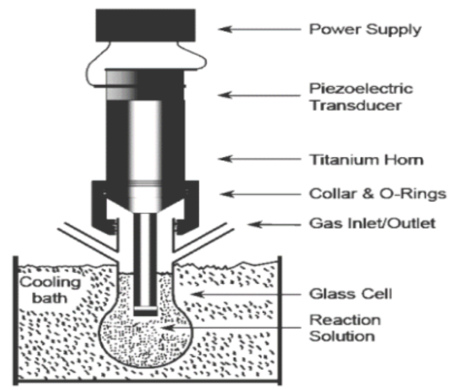


Fig. 1: Scheme of equipment for sonochemical synthesis.[46] Copyright 1999 Annual Reviews

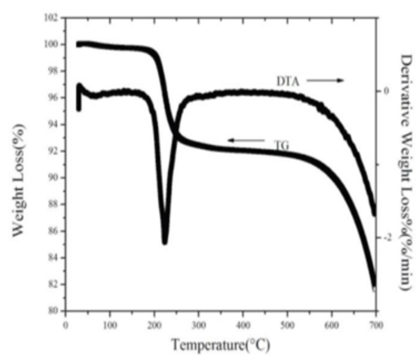


Fig. 2: TG and DTA curves of freshly precipitated product treated with ultrasound for 30 min. [8].

The diameter of CuO nanoparticles obtained by sonochemical methods is 50 nm [10]. These results were confirmed by TEM (transmission electron microscope) and SEM (scanning electron microscope). A similar method can also obtain CuO nanoparticles of 80 nm before calcination and 70 nm after calcination at 500 °C for 2 hours [11]. The results of calcination of the sample at a temperature of 400-500 °C and the X-ray diffraction pattern of the sample showed that good CuO particle powder is obtained only by the sonochemical process [8]. The XRD (X-ray diffraction) results of

CuO nanoparticles calcined and sonicated at different temperatures and times are shown in Figures 3 and 4.

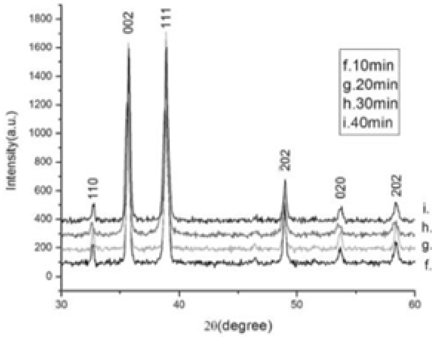


Fig. 3: X-ray diffraction pattern of calcined CuO nanoparticles at different temperatures [8]

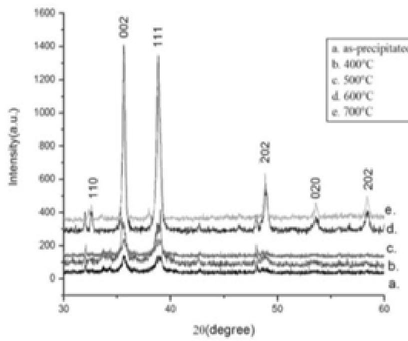


Fig. 4: XRD diagram of ultrasound exposure at different times [8]

The size of the CuO nanoparticles obtained can be affected by the sonication time as well as the Kalisani temperature. Longer sonication time will result in smaller particle size as compared to shorter sonication time. CuO nanoparticles obtained from the reaction for less than 20 minutes will form particles of about 80 nm in size, whereas if the reaction is extended to 30 minutes, the resulting particles will be 45 nm in size. This result is believed to be due to the sufficient amount of energy supplied to the system by ultrasound after a certain time and can cause the nucleation to break down. The results will be inversely proportional in that the size will increase after the sonication time is increased to 40 minutes. This is believed to be due to the changes in the crystal structure caused by the abundant ultrasound energy after the critical time has passed [8]. The effect of temperature also causes a change in the size of the particles formed. As the calcination temperature increases, the particle size will increase. This is because the crystallization of CuO nanoparticles is complete, well-defined and uniform with a particle size of 50-70 nm. SEM analyses (Figure 5) were conducted on the morphology of CuO nanoparticles at different calcination temperatures, namely 400, 500, 600 and 700 C. The morphology of the nanoparticles can be affected by the pH of the surfactant. When the pH is set to 8, the morphology looks like leaves, and after increasing the pH to 11, the morphology changes to a clumpy flower.

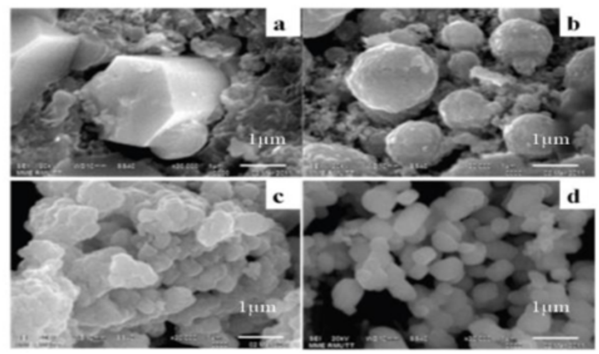


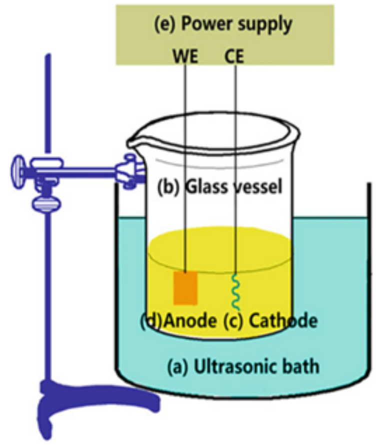
Fig. 5: SEM morphology of CuO nanoparticles by sonochemical method, calcined at different temperatures: 400, 500, 600 and 700 C [8].

The sonochemical method has a number of advantages, namely, ease of preparation at low temperatures [12], allows obtaining products with small nanometer-sized particles [13], a more uniform particle size distribution and higher phase purity [7], reproducibility [9], and the product can be used for the wide removal of environmental pollutants. The disadvantage of the sonochemical method is the uneven distribution of particles [8].

2. Sonoelectrochemical method

The electrolytic method allows obtaining chemically pure copper powders that have unique, stable properties (dendritic shape, dense particle texture). The main advantage of this method is the ability to regulate the structure and properties of the powder by varying the parameters of electrolytic deposition and electrolyte compositions. This allows influencing the structure, size, shape and chemical composition of the powders. But the electrochemical method is usually used to obtain metal nanoparticles (M- NP)and nanocomposites based on them, immobilized on a conductive substrate (electrode). However, for a larger-scale use of M- NP, it is necessary that they be in the form of powder or they are in the volume of the solution in other states: in a shell in a stabilizer, on non-conductive solid carriers, in matrices, in nanocapsules, etc. In particular, the introduction of chemically active compounds (complexing agents, stabilizers and surfactants) into the electrolyte allows obtaining more stable powders with improved technological properties and the required particle size [14-15]. In the presence of stabilizers, metal nanoparticles, the proportion of deposited metal decreases, but still remains high. Thus, when obtaining nanoparticles in an aqueous solution by electrochemical reduction of metal ions in the presence of poly(N-vinylpyrrolidone), up to 80% of the metal is deposited on the cathode, and in the presence of tetraalkylammonium salts and sodium dodecylbenzenesulfonate, almost all of the generated metal is deposited on the electrode [16-17]. One of the best methods for preventing the deposition of nanoparticles is the use of sonoelectrochemistry. Recently, there has been growing interest in the application of sonoelectrochemistry for environmental remediation [18,19] and the production of nanopowders [20]. A number of different equipment configurations have been used to introduce ultrasound into electrochemical systems. The first and simplest setup was to immerse a conventional electrochemical cell in a fixed position in an ultrasonic bath (Figure 6) [21]. Some studies have been conducted using this configuration [22], but the power transmitted within the electrochemical cell is low and the results are highly dependent on its location, since the ultrasonic field distribution is nonuniform [23]. Another option is to implement an ultrasonic horn system (often referred to as an ultrasonic probe) directly into the electrochemical cell. This allows the ultrasound waves to be directed onto the electrode surface and provides much more efficient power control (Figure 7). Various types of sonoelectrochemical cells using ultrasonic probes have been reported. In the most commonly used configuration, the electrodes and ultrasonic horn are immersed in the solution, with the emitter of the ultrasonic horn placed face to face at a known distance from the electrode surface [21] (Figure 8, B). Another scheme is to convert the ultrasonic horn itself into a working electrode [24]. Such an electrode is called a sonotrode [21] or sonoelectrode [24]. This new type of sonoreactor was first introduced by Reisse et al. [24] to study copper electrodeposition and the electroreduction of benzaldehydes [25,26] and benzoquinone [26] were also reported using this device. Subsequently, a sonotrode system incorporating successive pulses of electrolysis (for precipitation) and ultrasound (for precipitate release) was used in the preparation of nanopowders. There are two types of sonoelectrochemical setups for the production of nanomaterials, based on ultrasound irradiation, ultrasonic bath, and ultrasonic horn immersion. Ultrasonic bath is commonly used due to its ability to clean the electrode surfaces and support dissolution (Figure 6). However, the transmitted power inside the electrochemical cell is small, and the results mainly depend on how it is positioned, since the propagation of ultrasonic waves is not uniform [23, 27].

On the other hand, the probe-type ultrasonic apparatus is the most widely studied setup, since the ultrasonic probe used in this process is inserted directly into the electrochemical cell (Figure 7).



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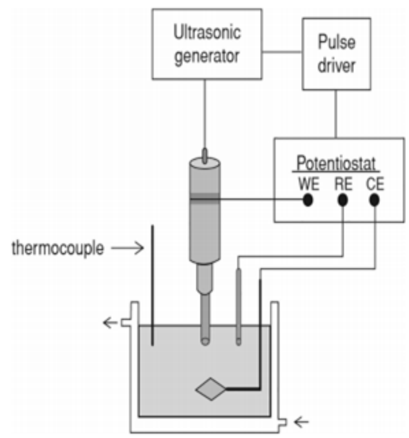

Fig. 7: Copyright (2019) John Wiley and Sons[48].

Experiments can be performed using alternative geometries of the ultrasonic probe relative to the working electrode to gain a more detailed understanding of the processes that drive the sonovoltammetric responses. Three alternative geometries that have been studied are shown in Figure 8.

- The conventional or face-to-face geometry discussed above (Figure 8, A).

- The "side-on" electrode geometry, in which the electrode is positioned perpendicular to the tip of the ultrasound emitter, with the center of the electrode at the same distance from the tip as the electrode surface in the "face-to-face" geometry described above [21] (Figure 8, B).

- The tip of the ultrasound emitter can be used directly as the working electrode [29] or after insertion of an insulated metal disk [30]. Such electrodes are called "sonotrodes" (Figure 8, C).

Sonoelectrochemistry mainly uses an ultrasound probe.

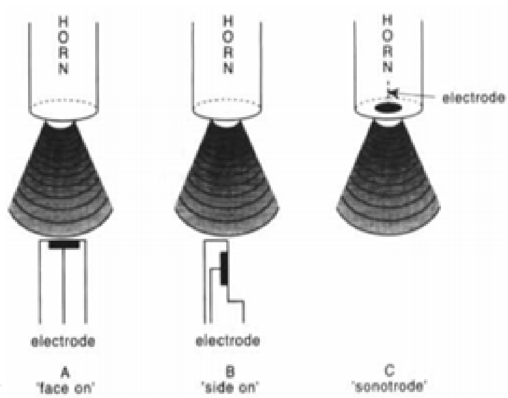

Fig. 8: Three types of electrode geometries used in sonovoltammetric experiments [21].

Reisse et al.[24] described a device for producing metal powders by pulsed sonoelectrochemical reduction [31,32]. Figure 7 shows the experimental setup used. In these experiments, a titanium probe [20 kHz] acts as a cathode and ultrasound emitter. The electroactive part of the sonoelectrode is a flat round surface at the bottom of the horn, and the cylindrical part immersed in the electrolyte is covered with an insulating plastic shell. The ultrasonic sensor is connected to the generator and potentiostat using a pulse driver (Figure 7). In the first system, the simplest configuration of a two-electrode cell was used, since the process is carried out under galvanostatic conditions. The disadvantage of this configuration is the presence of undesirable secondary reactions under galvanostatic control, to overcome which an adaptation was made. The replacement of the two-electrode configuration (cathode and anode) by a three-electrode (working, reference and auxiliary electrodes) in the sonoelectrochemistry system was carried out in order to apply a controlled potential to the sonoelectrode in order to obtain better control over the process. In most cases, the processes were carried out under galvanostatic conditions, since the use of such a configuration is simpler and it can be used for large-scale production of nanoparticles. In the work [33], the process was carried out under galvanostatic conditions without using a reference electrode and two pulse drivers were used. One pulse driver (General Valve) was used to control the potentiostat, and the second (Wavetek 164 function generator) to control the ultrasonic processor adapted to operate in pulse mode. The fundamental basis of the pulsed sonoelectrochemical method for producing nanopowders is massive nucleation [33]. At the cathode, a current (or potential) pulse reduces the number of cations, depositing a high density of metal nuclei on the sonoelectrode surface, while the titanium probe functions only as an electrode (TON). This short electrochemical pulse is immediately followed by a short pulse of high-intensity ultrasound (TUS), which removes metal particles from the cathode surface and replenishes the double layer with metal cations by stirring the solution. Sometimes the two previous pulses are followed by a rest time (TOFF) without current or ultrasonic vibrations, and it is useful to restore the initial conditions near the sonoelectrode surface. Figure 9 shows the pulse distribution in time. The duration of the electrochemical and ultrasonic pulses is typically between 100 and 500 ms, and the rest time lasts no more than 1 s.

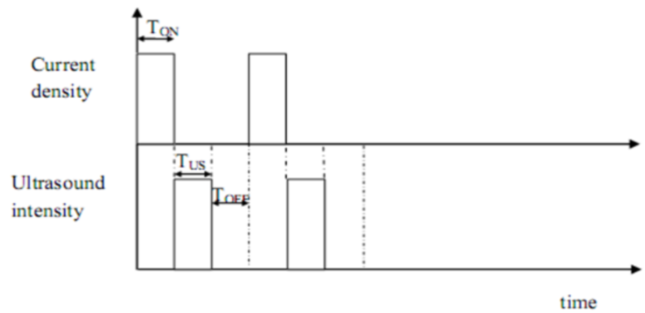

Fig. 9: Duration of electrochemical and ultrasonic pulses[33]

Copper electrodeposition is a well-known industrial process in which all electrodeposition parameters and electrolytes are well known [34], so copper was one of the first metals synthesized by pulse sonoelectrochemical methods. The synthesis of a number of metallic copper nanostructures by pulse sonoelectrochemistry has been reported [31,32,35,36]. Hass et al. [35] synthesized copper nanoparticles from aqueous acidic CuSO4 solution using polyvinylpyrrolidone (PVP) as a stabilizer. When the current density range from 55 to 100 mA cm-2 was applied, monodisperse spherical copper nanoparticles with a diameter of 25-60 nm were observed. A reaction mechanism between copper ions and PVP was proposed. The first step was the formation of a coordination bond between PVP and copper ions, forming a Cu2+-PVP complex. The resulting complex was present in the solution and upon application of a current pulse, Cu2+ was reduced to Cu0 on the polymer, preventing agglomeration of the metal nanoparticles. IR studies showed that PVP coordinates with Cu via C-N and C=O bonds. Using PVP as a stabilizer [36], copper with a dendritic morphology was obtained. Cu2O nanopowders were obtained in the potentiostatic mode [37]. The experimental setup used (Fig. 10) is similar to that of Reisse et al. [38]. The power varies from 7 to 100 watts, and the frequency of the ultrasonic probe is 23 kHz. The production of nanopowders was controlled using a three-electrode electrochemical setup in which a sonotrode was used as the working electrode. The reference electrode is a saturated mercury sulfate electrode (SSE). Heat shrink tubing surrounds the side walls of the horn tip [diameter = 10 mm], leaving only a flat active surface for electrodeposition equal to 0.785 cm2 to the tip of the ultrasonic instrument. The counter electrode is a copper wire (3.7 x 2.4 cm2) acting as a soluble anode. All particles were lifted using 80 W ultrasound (110 W cm-2). This power density is largely sufficient to remove the electrodeposition from the working electrode and insufficient to extract the metal atoms of the sonotrode.

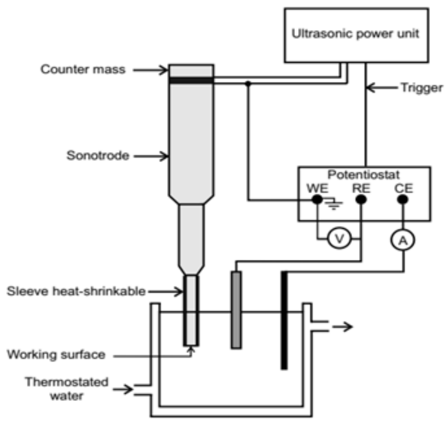

Fig. 10: Experimental setup[37]

The applied potential is in the range of - 0.65 to - 1.2 V/SSE for a variable time TON (100, 200 and 300 ms). During this time TON, electrolysis occurs without ultrasound. Then the potentiostat starts the ultrasound pulse for a variable time TUS (from 100 to 400 ms). At the end of the ultrasound examination time, a rest period without ultrasound and the possibility of application is introduced to reduce the acoustic flow formation. Its duration, corresponding to (TOFF TUS), is always 100 ms longer than TUS. The work was based on a previous voltametric study which showed that at applied potentials in the range of -0.65 (for sample A), -0.85 (for sample B) and -1 V/SSE (for sample C) the formation of a mixture of Cu2O and Cu could be avoided. The resulting powders were analyzed by XRD and only Cu2O peaks were detected, indicating that neither metallic copper nor CuO were formed at these potentials (Figure 11a,b).

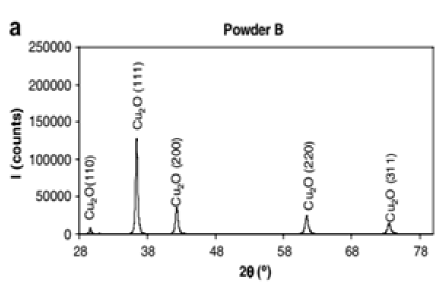

Fig. 11: a[37]

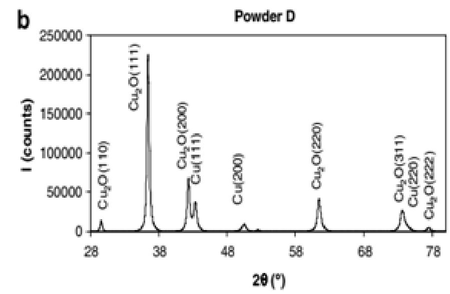

Fig. 12: b[37]

However, the powder was synthesized at -1.2 V/SSE (sample D) to verify that the mixture of Cu2O and Cu was obtained as expected. TEM micrographs showed numerous agglomerates of nanoparticles of various sizes, but individual particles with diameters ranging from 7 to 20 nm were also detected. Crystal growth slows down at low temperatures, resulting in a smaller crystal size at these temperatures [39]. On the other hand, at higher temperatures, the amount of powder obtained is very small. The latter can be explained by the increase in the rate of re-dissolution of nanoparticles with increasing temperature. Therefore, in general, it is necessary to maintain low temperatures in the system to obtain higher efficiency and small particle size. Current density can influence crystal size in at least two opposite directions [40]. At lower currents, smaller sizes can be expected due to less deposited material, however, lower currents allow more time for atomic diffusion processes to occur and this can lead to larger crystal sizes. In the synthesis of CdSe [41], current density was found to be an important factor: lower current density resulted in larger crystal sizes: 10 nm at 100 mA cm-2 compared to 5 nm at 250 mA cm-2. In contrast to this result, the synthesis of copper nanoparticles [42] showed a change in particle size from 29 to 10 nm with an increase in the applied current density from 55 to 100 mA cm-2. With the exception of a few reports [43,41] where increasing the current resulted in an increase in crystal size or even particle aggregation, most authors concluded that increasing the current density resulted in a decrease in the size of nuclei and faster nucleation [44,45,42].

III CONCLUSION

CuO nanopowders were obtained by sonochemistry. The size of the nanoparticles varies from 45 to 80 nm depending on the sonication time and calcination temperature. Two weight losses were observed: at 180-250 °C and at 500-700 °C. The first weight loss is due to the evaporation of polyvinyl alcohol and deionization of the solution, the second is due to the oxidation of metallic copper in air, which leads to the crystallization of CuO. CuO nanoparticles obtained as a result of the reaction for less than 20 minutes form particles of about 80 nm in size, whereas if the reaction is extended to 30 minutes, the size of the obtained particles will be 45 nm. The results will be inversely proportional in the sense that the size will increase after increasing the sonication time to 40 minutes. This is believed to be due to changes in the crystal structure caused by abundant ultrasound energy after the critical time has elapsed. The effect of temperature also causes a change in the size of the formed particles. As the calcination temperature increases, the particle size will increase. This is because the crystallization of CuO nanoparticles is complete, well-defined and uniform with a particle size of 50-70 nm. The morphology of the nanoparticles also depends on the pH of the environment. When the pH is set to 8, the morphology looks like leaves, and after increasing the pH to 11, the morphology changes to a lumpy flower. Cu2O nanoparticles were obtained by pulsed sonoelectrochemistry in potentiostatic mode. Copper nanoparticles were synthesized from an aqueous acidic solution of CuSO4 using polyvinylpyrrolidone (PVP) as a stabilizer. When the current density range from 55 to 100 mA cm-2 was applied, monodisperse spherical copper nanoparticles with a diameter of 25-60 nm were observed. The work is based on a voltametric study which showed that at applied potentials in the range of -0.65 (for sample A), -0.85 (for sample B) and -1 V/SSE (for sample C) the formation of a mixture of Cu2O and Cu can be avoided. The resulting powders were analyzed by XRD and only peaks of Cu2O were detected, indicating that neither metallic copper nor CuO were formed at these potentials. It is proven that in the synthesis of CdSe, the current density was found to be an important factor: lower current density resulted in a larger crystal size: 10 nm at 100 mA cm-2 compared to 5 nm at 250 mA cm-2. In contrast to this result, the synthesis of copper nanoparticles showed a change in particle size from 29 to 10 nm with an increase in the applied current density from 55 to 100 mA cm-2.

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RELIABILITY ANALYSIS OF ASYNCHRONOUS TRACTION ELECTRIC MOTORS OF O‘Z-EL SERIES LOCOMOTIVES AND WAYS TO IMPROVE THEIR OPERATIONAL RELIABILITY.

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Abstract– This article examines the main methods for diagnosing and monitoring the technical condition of asynchronous traction motors, analyzing the impact of operational factors on their reliability and durability. Voltage asymmetry, instability of the power current, and dynamic loads lead to the deterioration of the technical condition of asynchronous traction motors of electric locomotives. The reliable operation of these motors is crucial for ensuring the efficient and uninterrupted operation of rolling stock. Analyzing their technical condition allows for the timely detection of faults and improvement of operational performance.

Key words– Asynchronous motors (ATEM), O‘Z-El locomotives, reliability, overheating, short circuit, cooling system, bearing wear, mechanical damage, electrical overloads, winding damage.

I INTRODUCTION

The transition of the Uzbekistan-Kyrgyzstan-China railway construction project into the practical stage is one of the most important events of strategic significance for our country. This project will create the foundation for expanding the transport and logistics capabilities of Central Asia, diversifying international trade routes, and more efficiently organizing the freight transportation system in the region [1]. The construction of new railway lines will contribute not only to the development of transport infrastructure but also to strengthening economic ties. In the process of implementing such a large-scale project, there is a need to form additional traction rolling stock for movement on the new railway tracks. This requires a thorough analysis of the current technical capabilities of the locomotive fleet, as well as the implementation of systemic measures to maintain the existing traction rolling stock in a constantly technically sound condition [2]. One of the main tasks for the effective implementation of these functions is the ability to perform preliminary fault assessment through the analysis of the technical condition of the asynchronous traction electric motors of locomotives.

The analysis of the reliability of asynchronous traction electric motors (ATEM) in the O‘Z-EL series electric locomotives (Fig.1.1) involves studying the degree of reliability and durability of the electric motors used in locomotives from this series, which are likely to be in operation in Uzbekistan.

Fig. 1: High-speed electric locomotive of the O‘Z-EL series.

II RESULTS AND ANALYSIS OF RESULTS

Such an analysis may include assessing reliability under different operating conditions, identifying the most common faults and their causes, and detecting vulnerable components. On the O‘Z-EL electric locomotives (Figure 1.2), the ATEM 1TB2624 with a squirrel-cage rotor is used with a three-phase current converter [3-5].

Fig. 2: ATEM 1TB2624-0GA02 with damaged gears.

The O'Z-EL series electric locomotives are equipped with six traction electric motors. To ensure their stable and efficient operation, a forced cooling system is used. This system utilizes a special fan to deliver cooling air to the motors. The fan ensures a constant flow of air directed at the motors to prevent overheating and maintain the optimal operating temperature [6]. Thus, the fan plays a key role in maintaining the reliability and durability of the traction electric motors, which is especially important during their intensive operation. The main faults of asynchronous traction electric motors type 1TB 2KF2624 are:

1. Overheating: Overheating is one of the most common problems. It can be caused by improper operation, insufficient ventilation, wear, or malfunction in the cooling system. Overheating can lead to damage to the insulation, windings, and other motor components. During operation, you may notice that the locomotive's motor periodically becomes too hot, indicating possible overheating issues. The causes of this overheating may vary:

- incorrect operation: Operators may improperly manage the electric locomotive, for example, by running the engine at maximum revolutions for extended periods or frequently overloading the locomotive. This can lead to excessive heating of the motor;
- inadequate ventilation: poor ventilation in the engine compartment of an electric locomotive can lead to inadequate cooling of the engine. For example, if the ventilation system is clogged with dust or debris, air cannot circulate freely, resulting in overheating;
- wear or malfunction of the cooling system: Cooling system components such as fans, radiators, or thermostats may be worn or malfunctioning, resulting in an inability to cool the engine properly.

The following problems can occur as a result of overheating:

- insulation damage (Fig. 1.3.): High temperatures can damage the insulation of wires and cables inside the motor, which in turn can lead to short circuits or other malfunctions;
- winding damage (Fig. 1.3.): Overheating of an electric motor poses a serious threat to its performance and durability. When a motor overheats, the temperature of its internal components, particularly the windings, rises significantly. Motor windings consist of insulated wires that are wound around a core. These insulating materials have a certain temperature limit above which they begin to deteriorate. If the temperature exceeds this limit, the winding insulation may deform or break down. If overheating continues, the motor may fail completely;
- damage to other motor components: At elevated temperatures caused by motor overheating, damage can affect not only the windings, but also other key motor components such as bearings and seals. Bearings play an important role in ensuring smooth and stable rotation of the motor shaft. They are subjected to significant mechanical stress and friction under operating conditions, so their lubrication properties can deteriorate at elevated temperatures, leading to premature wear and damage. Damage to bearings and seals can lead to premature wear and failure of the engine as a whole. In addition to potential failure, replacing or repairing these elements can also incur significant maintenance and parts costs.

Fig. 3: Damage of stator windings of ATEM type 1TB 2KF2624

Therefore, it is important to regularly check the condition of the cooling system, ensure that the electric locomotive is operated correctly and address any signs of overheating in a timely manner to avoid serious damage and ensure the normal operation of railway transport [7-8].

2. Short circuit: This occurs when the stator or rotor windings are suddenly connected, causing high current and insulation damage. The causes of short circuit can be mechanical damage, insulation wear or improper assembly. Consider an example of a short circuit on a locomotive electric motor. An electric motor installed in a locomotive. It consists of a fixed part stator and rotor (rotating part Fig. 1.4).

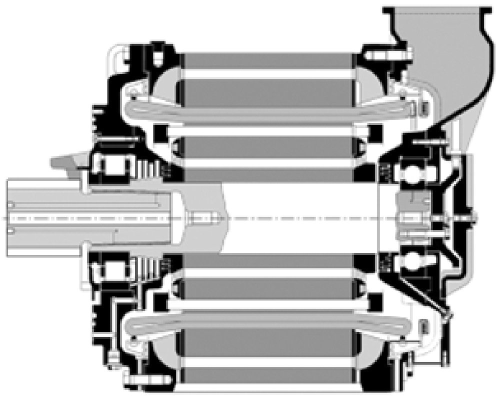

Fig. 4: Rotors of ATEM type 1TB 2KF2624

During locomotive operation, due to mechanical damage such as impact or vibration, the insulation of the stator wires may be damaged [9]. For example, a metal wheel rim may accidentally come into contact with the stator wires. Also, during long term operation, the wire insulation may wear out due to thermal expansion and contraction or vibration. Improper assembly or installation of the motor may cause the stator wires to accidentally contact each other or the housing, causing a short circuit.

The following can occur as a result of such a short circuit:

- high current flows through the stator or rotor windings;
- the conductors start to heat up due to the high resistance at the short-circuit point;
- wire insulation may start to melt or burn due to the high temperature and high current;
- If the short circuit is not repaired in time, it may cause serious damage to the windings, as well as damage to the motor as a whole.

As a result, the locomotive may become incapacitated, leading to downtime and delays in railway traffic. It is therefore important to regularly check the condition of the electric motors and carry out the necessary maintenance to avoid the possibility of short circuits and related problems.

3. Insufficient bearing lubrication: If the bearings are not sufficiently lubricated or the lubricant is of poor quality, it may cause bearing wear and reduce the efficiency of the motor. Improper lubrication can also cause damage to other moving parts. Let's imagine a situation on a railway where an electric locomotive uses bearings to support and rotate the wheel axle. These bearings are subjected to high loads and frequent use while travelling on railway tracks [10]. During the operation of an electric locomotive, the bearing lubrication system does not function properly, resulting in insufficient lubrication of the bearings. Bearings play a critical role in ensuring smooth and efficient motor shaft rotation. They support certain radial and axial loads, allowing the motor to function without overload and excessive friction. However, if the radial clearance between the bearing rings and rollers becomes too large, it can cause the bearing to seize. Bearing seizure means that the bearings become stuck and cannot rotate freely around the shaft. This results in significant friction and increased heat load on the bearings and adjacent parts of the machine [11]. This can result in the inner ring of the bearing turning, especially on the drive side where the loads are highest. Complete destruction of the bearings on both sides will render the motor unsupported and can lead to serious damage. Such bearing damage can be caused by various reasons, including wear or damage to the bearing itself, improper lubrication, excessive loads or impact during operation. It is therefore important to regularly check the condition of the bearings and ensure that they are properly maintained to prevent such incidents and ensure reliable operation of the machine:

- wheel bearings appear dry and unlubricated;
- wear marks can be seen on the inside of the bearings, indicating friction and excessive wear;
- the locomotive wheels make strange noises when travelling, which may be the result of friction in insufficiently lubricated bearings.

The consequences of insufficient bearing lubrication can be serious:

- increased wear of the bearings, which can cause them to break down and bring the locomotive to a standstill;
- damage to other moving parts such as wheel axles or gears due to increased friction and wear;
- increased loads on the locomotive engine due to increased resistance from friction, which can lead to overheating and engine damage.

To avoid such problems, regular maintenance of the bearing lubrication system should be carried out, including checking the lubricant level, changing the lubricant on time and checking for any leaks or faults in the lubrication system.

№	Title	Number of failures on O'Z-EL electric locomotives in the period 2020-2024.					Total
		2020	2021	2022	2023	2024	
1	Asynchronous traction electric motors (ATEM)	9	7	11	10	12	49

TABLE 1: FAILURES OF TRACTION EQUIPMENT ON O'Z-EL ELECTRIC LOCOMOTIVES.

4. Damage to rotor, stator and pinion: Mechanical damage such as cracks, dents or fractures can lead to serious malfunctions and failure of the electric motor.

Electric locomotive on which an asynchronous traction motor is installed. During operation, mechanical damage occurs which may lead to serious malfunctions of the rotor, stator and pinion.

During inspection of the electric locomotive, you notice the following: Cracks or fractures are seen on the motor rotor, possibly due to overloads or mechanical shocks during operation. The stator shows dents or damage, possibly caused by external influences or improper assembly. The gear that connects to the rotor also shows signs of wear or damage, possibly due to improper lubrication or stresses.

The consequences of such damage can be serious: The motor rotor may stop working due to mechanical integrity failure, resulting in a complete motor stoppage and loss of tractive power. Damage on the stator can lead to deterioration of electrical insulation and possible short circuits, which can also cause motor malfunctions. Damage to the pinion (Fig.1.5) can lead to impaired torque transmission from the rotor to other mechanisms of the electric locomotive, which can lead to loss of efficiency and performance.

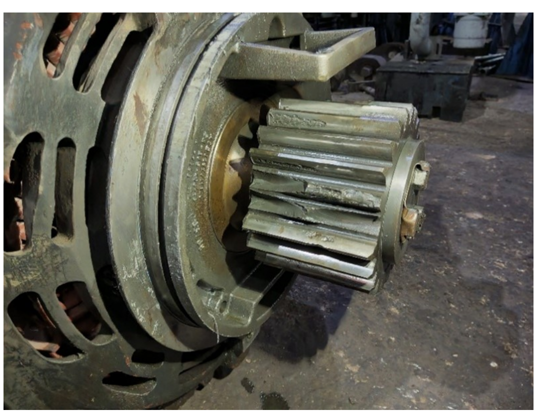

Fig. 5: Mechanical damage ATEM

5. Electrical overloads: Overloading can occur due to improper use or operation, for example, by attempting to exceed the rated power of the motor. This can cause damage to the windings and other components of the motor. Electrical overloads occur during operation and can cause serious damage to the windings and other components of the electric motor. While operating an electric locomotive, the driver attempted to switch on the maximum power of the motor to overcome a steep climb. This resulted in a significant increase in current which exceeded the rated values for the motor. The following events have occurred as a result of such action:

- current in excess of the rated value flowed through the motor windings;
- the windings began to overheat due to the excessive load, resulting in insulation damage and possible short circuits;
- the overload may also have caused damage to other motor components, such as bearings or shafts, due to increased loads and torques.

The consequences of electrical overloads can be severe and include:

- damage to motor windings, which can result in reduced efficiency and reliability;
- the need to replace or repair damaged components, which can lead to costly repairs and temporary downtime of the locomotive.

In order to avoid electrical overloads, it is important to follow the recommendations for the use and operation of the electric locomotive, and not to exceed the permissible motor loads and capacities. In addition, regular maintenance and monitoring of the electric motor should be ensured in order to identify and eliminate any potential problems in a timely manner. The number of modern electric locomotives of O'Z-EL type in the locomotive fleet of "O'zbekistan temir yo'llari" JSC is currently 10 units. At the same time, in the period from 2020 to 2024 during the operation of electric locomotives of this series, various faults of traction electric motors were identified. Table 1.1 below presents the cases of failure of the main ATEM units, which were recorded both in the course of travelling and during maintenance.

The number of traction equipment failures on O‘Z-EL series electric locomotives is the total number of times that various elements, components or systems related to the traction equipment have stopped working or functioning correctly over a period of time. This includes failures of electric motors, control systems, current converters, and other components responsible for transmitting and regulating power to keep an electric locomotive moving. Understanding the failure rate of traction equipment is key to ensuring the safety, reliability and efficiency of electric locomotives. The higher the failure rate, the greater the likelihood of downtime, schedule delays and additional maintenance and repair costs. Therefore, monitoring and analyzing this indicator makes it possible to identify problem areas, develop plans to prevent failures and improve equipment reliability.

III CONCLUSION

IV References

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FORMALLY VERIFIED IOT ARCHITECTURE FOR EARTHQUAKE DETECTION AND AUTOMATED SAFETY MEASURES

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Abstract– This paper presents a novel IoT-based architecture designed for earthquake detection and automated safety response in smart homes. The system integrates a network of low-cost, high-precision seismic sensors and edge computing devices to enable real-time earthquake detection and rapid response. At its core, the architecture employs Node-RED for rule-based automation, ensuring seamless integration of IoT devices and enabling customizable safety protocols. To enhance reliability, formal verification techniques are applied to verify the correctness and consistency of the rules, ensuring robust and error-free operation during critical events. The proposed architecture has broad applications in smart home environments, particularly in earthquake-prone regions. By automating safety responses, the system reduces human intervention, mitigates risks, and enhances disaster resilience.

Key words– verification, IoT, formalmethods, earthquake

I INTRODUCTION

Earthquake early warning (EEW) systems and IoT-enabled smart home automation have emerged as critical research domains in disaster resilience, yet their integration remains underexplored. Prior studies[1][2], demonstrated IoT networks for seismic monitoring in smart cities, focusing on centralized cloud-based analytics. Similarly, Brian et al. [3] proposed edge-computing frameworks for earthquake detection but limited their scope to structural health monitoring rather than occupant safety. Meanwhile, formal verification of IoT rule-based systems has gained traction, with Yan et al. [4] emphasizing its role in ensuring reliability for industrial automation. However, these works lack a unified approach that integrates localized seismic sensing, multi-source data fusion, and verified automation for smart homes—a gap this paper addresses.

Our architecture bridges IoT-driven earthquake analysis and formal verification, introducing three key innovations. First, unlike existing systems that rely on single data sources (e.g., Lin et al.[5], which uses standalone seismic sensors), we combine local seismic data from Raspberry Shake devices—a low-cost, high-sensitivity seismometer validated in community-driven studies (Anthony et al.[6], 2023 in Seismological Research Letters)—with global data from APIs like USGS and EMSC. This hybrid approach enables preemptive action by detecting earthquakes in neighbouring regions before tremors reach the home's location. Second, we formalize safety rules in Node-RED [10], a platform widely adopted for IoT workflows (as noted in Gupta et al.[7],), using model checking and theorem proving to eliminate ambiguities and conflicts in automation logic. This contrasts with prior IoT safety systems [8] that lack rigorous verification, risking failure during critical events. Third, our safety response framework targets residential risks uniquely: in addition to standard alerts, it automatically shuts off gas valves via smart relays, unlocks egress routes, activates emergency lighting, and opens windows to reduce structural stress from air pressure changes—a measure absent in commercial systems like Japan's UrEDAS.

The proposed system's applications extend beyond immediate damage mitigation. By integrating with existing smart home ecosystems (e.g., Zigbee or Matter-based devices), it provides a scalable, cost-effective solution for households in seismically active region such as Uzbekistan. This work advances disaster-resilient automation by demonstrating how formal methods and multi-source IoT data fusion can create reliable, life-saving interventions, addressing limitations in both academic literature and real-world deployments.

II THE METHODOLOGY

This section outlines the practical setup and methodology employed for device integration, rule creation, and the verification process within the proposed IoT-based earthquake detection and automated safety response system. The methodology is divided into three key components:

device attachment and hardware configuration, rule creation environment, and formal verification of rules.

2.1 System Architecture and Setup.
The proposed IoT architecture for earthquake detection and automated safety response is illustrated in Figure 1, which outlines the topology of the smart home environment. The system is designed as a hybrid edge-cloud framework, prioritizing low-latency local decision-making while retaining optional cloud integration for auxiliary services.

2.1.1 Hardware Configuration.
The smart home is equipped with a heterogeneous network of IoT devices, categorized into three layers: sensing, actuation, and control. Sensor layer comprises:

- Raspberry Shake 4D seismometer: Deployed as the primary earthquake detection node, this low-cost device (validated by Anthony et al. [6] for community seismic monitoring) captures local ground motion data (P and S waves) with a sampling rate of 100 Hz.
- Global Seismic APIs: Integrated with the USGS (United States Geological Survey) and EMSC (European-Mediterranean Seismological Centre) APIs to receive real-time earthquake alerts from neighboring regions, enabling preemptive action before tremors reach the residence.

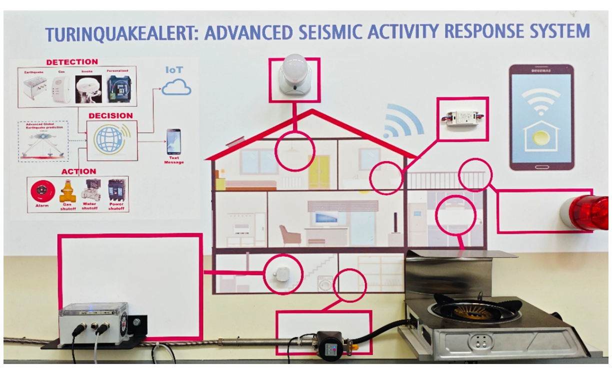

Fig. 1: TURINQUAKEALERT – An IoT-based seismic response system for detecting hazards and automating safety actions.

In our topology, the actuation layer includes retrofitted non-smart appliances equipped with Bluetooth-enabled smart buttons (SwitchBot), which are attached to conventional appliances (e.g., HVAC systems, ovens) to enable remote shutdown via simulated button presses. Another category of the actuation layer consists of safety-critical actuators:

- Zigbee-controlled smart lamps (Philips Hue) in all rooms, programmed to switch to white light (5000K, 800 lumens) during emergencies to illuminate egress paths.
- WiFi-connected red LED strips (WS2812B) mounted on ceilings, activated to visually signal danger.
- 110 dB piezoelectric sound alarms (Adafruit) for auditory alerts.
- Smart gas valve (Zigbee-based Sonoff SV01) to shut off the main gas supply.

The final layer consists of a local server, featuring a Raspberry Pi 4 (4 GB RAM) running Home Assistant OS (version 2023.7), an open-source platform for IoT device management. This server serves as the central hub, aggregating sensor data and coordinating actuator responses without relying on the cloud. Additionally, a Node-RED instance is deployed within Home Assistant OS to implement rule-based automation workflows. These workflows follow a state-machine model, with triggers based on seismic intensity thresholds (derived from Raspberry Shake data) and API alerts. The system ensures reliable and interoperable communication using Zigbee 3.0 for low-power device control, WiFi for high-priority alerts, and Bluetooth Low Energy (BLE 5.2) for retrofitting legacy appliances.

2.1.2 Edge Computing Framework.
To minimize latency, seismic data processing occurs locally on the Raspberry Shake device, which runs a lightweight ML model (pre-trained on the STEAD dataset [9]) to discriminate earthquake signals from ambient noise. Detected events are classified using the Modified Mercalli Intensity (MMI) scale, with thresholds set as follows:

- MMI $\geq$ IV: Trigger visual/auditory alerts and appliance shutdowns.
- MMI $\geq$ V: Activate gas valve closure and emergency lighting.

Global API alerts are cross-validated with local sensor data to reduce false positives. The system's response time—from detection to actuator activation—is benchmarked at <1.5 seconds, meeting EEW (Earthquake Early Warning) requirements.

2.1.3 Formal Verification of Node-RED Rules.
To ensure the logical consistency of automation workflows, Node-RED[10] rules are formally verified using the UPPAAL model checker. Safety properties (e.g., "Gas valve

Earthquake Intensity (MMI)	Detection Time (s)	Actuation Time (s)	Total Response Time (s)
IV (Light)	0.8	0.6	1.4
V (Moderate)	0.7	0.7	1.4
VI (Strong)	0.6	0.5	1.1
VII (Very Strong)	0.5	0.4	0.9

TABLE 1: SYSTEM'S ABILITY TO DETECT AND RESPOND TO EARTHQUAKES OF VARYING INTENSITIES WITHIN SECONDS, MEETING EEW REQUIREMENTS.

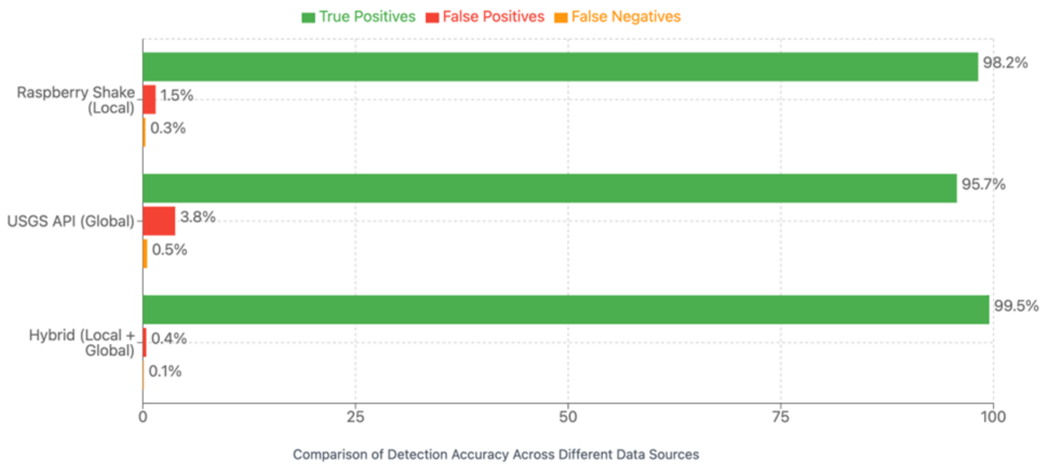

Fig. 2: Seismic Detection Accuracy Comparison.

must close within 2 seconds of MMI $\geq$ V detection") are expressed in timed computation tree logic (TCTL), while liveness properties (e.g., "Alarms must activate persistently until manual override") are validated via reachability analysis. This approach addresses the reliability gaps identified in unverified IoT systems[8]. The safety property such as "Gas valve must close within 2 seconds of MMI $\geq$ V detection." is formally expressed

$$A[]\ (\text{MMI} \geq V \Rightarrow \text{valveClosed} \leq 2s)$$

This ensures that in all possible executions, whenever the condition MMI >= V occurs, the valveClosed action must happen within 2 seconds. By applying these rigorous verification techniques, we transform Node-RED from a visual programming tool to a mathematically validated automation platform with provable safety guarantees. When the formally specified Node-RED workflow is input into the UPPAAL model checker, the verification process yields a mathematically validated automation platform with provable safety guarantees.

III RESULTS

The proposed IoT-based earthquake detection and automated safety response system was evaluated through extensive testing in a simulated smart home environment. In Table 1, we can observe an interesting pattern as earthquake intensity increases, both detection and actuation times decrease, resulting in faster total response times for stronger earthquakes. For instance, Very Strong earthquakes (VII) have the quickest total response time at 0.9 seconds.

On the other hand, the chart in Figure 2 clearly illustrates that the hybrid approach, which combines local and global seismic data sources, outperforms both individual systems. The most significant improvement is seen in the reduction of both false positives and false negatives, making the hybrid system more reliable for earthquake detection and early warning applications.

IV CONCLUSION

This paper presented TURINQUAKEALERT, a novel IoT-based architecture for earthquake detection and automated safety response in smart homes. By integrating low-cost, high-precision seismic sensors with global seismic APIs, the system achieves a hybrid detection approach that enables pre-emptive action before tremors reach the residence. The architecture leverages edge computing to minimize latency, ensuring a total response time of <1.5 seconds, which meets stringent Earthquake Early Warning (EEW) requirements.

The proposed architecture has broad applications in earthquake-prone regions of Uzbekistan, particularly in smart home ecosystems. By automating safety responses, the system reduces human intervention, mitigates risks, and enhances disaster resilience. Future work will focus on scaling the system for multi-residential buildings and integrating advanced machine learning models for improved seismic signal discrimination.

In conclusion, TURINQUAKEALERT represents a significant advancement in disaster-resilient automation, demonstrating how IoT, edge computing, and formal verification can be combined to create reliable, life-saving solutions for earthquake-prone communities.

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