Design of Cybersecurity Smart Controller For Grid Connected Microgrid

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Abstract. The research introduces to the design and implementation of the Cybersecurity Enabled Smart Controller for the grid connected microgrid which uses the combination of the Web technologies and the authentication mechanism which enables real time monitoring with help of the Dashboards built using Chart.js which is a framework of JavaScript. Due to the role and connection of the Microgrids with the critical infrastructure they are vulnerable to the cyber threats. This project leverages the use of HTML, CSS, JavaScript and MongoDB to create a secure and responsive system ensuring the operational resilience and data integrity. By focusing on simplicity the project uses user friendly dashboard for monitoring the microgrid data , controlling the grid crafted with HTML, CSS and JavaScript allowing the users to visualize the performance metrics using Chart.js for real time data representation. This methodology focuses on creating secure communication channels which enables effective data management through MongoDB providing a responsive experience on the web application. This approach allows users to monitor grid operations continuously and the access management effectively. The findings focused on creating a user friendly interface using the HTML, CSS, JavaScript which give users the access to monitor and control microgrid operations seamlessly. Utilizing the Chart.js enabled the users to visualize real time performance metrics which enables the operators to make decisions quickly addressing operational efficiencies. This paper proposes a role-based access control system (RBAC) to protect and manage the smart controller of a grid-connected microgrid. The design integrates a login page developed with HTML, JavaScript, and MongoDB for authentication and user management, with three distinct roles: Admin, Power Operator, and User. Each role has access to specific functions in the dashboard, reflecting their respective permissions. The backend was implemented using Node.js and Express to monitor network traffic, detect potential threats, and prevent unauthorized operations. The results demonstrate that the system provides effective protection against cyber threats while ensuring that different users can access the functionalities appropriate to their roles.

Keywords. Role-Based Access Control, Microgrid, Grid Connected Microgrid, Real-Time Monitoring, MongoDB

1 INTRODUCTION

Grid-Connected Microgrids are critical to the modern energy distribution becoming increasingly vulnerable to security threats. Current Systems lack security measures leaving them prone to unauthorized access, data breaches and operational disruptions. The increasing reliance on the grid connected microgrids necessitates the development of secure and robust systems. Microgrids are localized grids which operate independently or in conjunction with the main power grid. They offer multiple benefits like energy reliance, effective usage of renewable energy resources and improved energy efficiency.

The adoption of the microgrids introduced new vulnerabilities due to the lack the security measures needed to address the threats emerging. The systems have become more interconnected and reliant on the digital communication networks leading attractive targets to cyber attackers aiming to disrupt the energy distribution and cause physical damage to the infrastructure. The consequences of the attack can lead to loss of service, financial damage and compromise national security.

Traditional Control Systems lack the security measures for the threats and do not provide real time monitoring , threat detection leaving them exposed to cyber threats such as unauthorized access and data breaches. The consequences of such vulnerabilities can lead to prolonged power outages, financial losses and threat to public safety. Traditional Systems were designed with a focus on functionality and operational efficiency often neglecting the security measures required to counter modern cyber threats. The systems are effective in managing basic microgrid operations falling short to address complex and evolving nature of cyber risks.

The proposed solution offers to provide user-friendly interface for the grid connected microgrid enables efficient real time monitoring, user management, and role based access control. The access control in the website regulates access based roles and privileges. This ensures only authorized personnel who can modify microgrid settings, interact with the system preventing unauthorized configuration changes. The integration of MongoDB with the frontend technologies stores application data which includes the data to be encrypted to maintain confidentiality.

1.1 Current Microgrids Landscape

Microgrids are localized energy systems that can operate in independently with larger electric grid. They have the capability to provide reliable power to a defined area like to a particular community or campus. Microgrids can be disconnected from the main grid during disturbances maintaining power supply to critical loads. They support the integration of renewable energy sources which enhance sustainability and reduce the reliability on fossil fuels. The initial capital investment for microgrids deployment can be very significant which may deter the potential investors in regions where the traditional energy resources are cheaper.

The microgrids landscape is evolving rapidly with many Governments recognizing the roles of microgrids in sustainability and energy security. Due to the technological advancements the enhanced communication technologies facilitate real-time monitoring and control allowing microgrid operators to respond swiftly to changes in demand and supply.

2 RESEARCH METHODOLOGY

The research methodology for the development of the project revolves around creating a secure and user friendly interface system that efficiently monitors and manages the microgrids. The first phase of the research was to understand the vulnerabilities associated with the grid connected microgrids. A thorough review of the previous works on grid systems, microgrid monitoring and cybersecurity challenges was performed to understand the deficiencies in existing system particularly with respect to the security and data visualization. The study and the use of modern web technologies were used for addressing the gaps.

The next phase involved the structured approach beginning with the design and component selection. HTML, CSS and JavaScript were used to create a responsive user interface for the Admins, Power operators and Users. The dashboard allows for real time interaction with the system and displays data visualizations using Chart.js. MongoDB was used as the database for secure and scalable data storage. Node.js and Express.js were used to develop the server side application ensuring secure and efficient communication with the frontend. The role based access mechanism was implemented to ensure that only users with appropriate roles could access the sensitive parts of the application ensuring integrity.

A thorough review of existing literature on microgrid management was conducted to identify the gaps and improving the project design. By choosing the appropriate technologies the requirements and objectives of the project were fulfilled by determining the security needs with the compatibility. The different technologies helped in developing a clear architecture to separate the concerns of the application. The research methodology employed in the project provided a structured approach to develop the project. The project aimed to deliver a robust and secure solution that meets evolving needs of modern energy management.

The research methodology consists of major components: designing and implementing the Role-Based Access Control (RBAC) system to secure the microgrid control interface.

2.1 Project Design

This project adopts a design based research approach which focuses on the functional prototype for the cybersecurity smart controller. The implementation follows a client-server architecture where the frontend (Login page and the dashboards) were built using HTML, CSS, JavaScript and Chart.js, while the backend is handled by Node.js and Express.js. The MongoDB data is used to store user credentials and access logs. The operations of the microgrid is simulated through a web based interface and the roles of the users are classified based on the roles which enables to control the specific functions of the microgrid.

The dashboard incorporated Chart.js for real-time data visualization which allows users to monitor the microgrid performance metrics. It helps the users to make quick informed decisions quickly. The methodology helped in ensuring that it not only secure and efficient but also user friendly addressing the critical needs of microgrids. The findings from the research contribute to improving the microgrids management and security helping to finding new innovations in this sector. MongoDB was choosen to provide flexibility and capability to handle large datasets securely which makes it ideal for storing operational data and credentials of the user.

2.2 Role-Based Access Control (RBAC)

Users can login through the login page where they enter their credentials and depending upon the credentials the system determines the role of the user(Admin, Power Operator or the User). Based on user's role the system grants access to the specific microgrid operations through the different dashboards.

1. Admin Dashboard

Usually has full access to system settings, including user management and resource consumption data.

2. Power Operator Dashboard

Given Access to real-time microgrid power data, system logs, and operation metrics.

3. User Dashboard

General users have access to limited features like monitoring energy consumption relevant to their role and is limited only to viewing.

2.3 Vulnerability Assessment and Literature Review

In the initial phase of our project we conducted a thorough review of the vulnerabilities in existing microgrid systems. This also included reviewing the academic literature, case studies and industry related reports related to the project. The intention of the literature review was intended uncover security flaws , and know about the existing systems and how the research was used to bring improvement to the system, study about the security breaches.

We identified a few cybersecurity threats which included unauthorized access, data manipulation and denial of service attacks. These vulnerabilities highlight the need for role based access and real time monitoring.

3 THEORY AND CALCULATION

Microgrids by design are small scale grids that operate either in the island mode(independent mode) or in parallel with the central grid. They offer advantages including energy resilience, integration of different renewable energy sources and better load management. The interface developed ensures secure and efficient energy distribution ensures secure and efficient energy distribution through functionalities like User Authentication and role based access ensuring that only authorized personnel can modify microgrid settings reducing risk of unauthorized access of users.

While the system relies on theoretical concepts and practices for securing microgrids, practical calculations are necessary for effective monitoring and management of the system.

3.1 Metrics Significance

Key metrics like the average energy consumption and production are critical for the assessment of microgrid performance. These metrics helps the operators identify the inefficiencies and help in making informed decisions to optimize the operations.

3.2 Average Metrics

Average Energy Consumption

Average Consumption=Consumption(i)/n

The average energy consumption helps in understanding how much energy microgrid is used over a given period of time. This metric helps in identifying trends in energy usage which helps in enhancing future energy management strategies. By knowing the average consumption aids helps to identify excessive usage that may indicate potential threats or inefficiencies.

Average Energy Production

Average Production=Production(i)/n

Monitoring average energy production allows the operators to compare it against average consumption which ensures operation of the microgrid within its energy balance. Deviations from average production indicate issues with generation sources and need of maintenance supporting preventive measures against the operational disruptions.

3.3 Energy Efficiency Calculation

Efficiency is an important metric that determines how effectively energy is being utilized or being produced within the microgrid. The energy efficiency can be calculated as:

Efficiency(%) = (Energy Output/Energy Input) * 100

This formula helps determine the effectiveness of energy production systems such as solar panels or wind turbines or the other renewable sources of energy in generating usable energy.

3.4 Power Factor Calculation

Power factor is a crucial measure in power systems,which represents the ratio of real power (used to perform work) to apparent power (total power supplied to the circuit). A power factor close to 1 is used to indicate efficient power usage while a lower power factor suggests the inefficiency.

Power Factor= Real Power / Apparent Power

4 RESULTS AND DISCUSSION

The discussion explores the practical significance of the results and the comparison of the outcomes with the recent advancements for energy systems. The analysis addresses the emerging challenges in microgrid management. The implementation of the project utilized MongoDB, Express, Node.js, HTML, CSS, JavaScript and real-time data visualization. The user authentication system integrated with MongoDB helping to manage the user credentials. Users are assigned with roles which help to determine their access rights. This ensures improving operational security and only authorized personnel can make changes to microgrid settings.

Using Chart.js the systems visualizes real-time energy data like production metrics, turbine efficiency and production metrics. The implementation involved displaying data related to energy sources in pie charts and bar charts which the operators with immediate insights of energy distribution and efficiency. The implementation of a role-based model in this project highlights how security is maintained by limiting access to sensitive functions only to authorized users. As noted by Yang et al. (2022), RBAC has become a necessary approach for securing critical infrastructure against insider and external threats, making the current implementation a robust solution to address modern cybersecurity challenges. By real time visualization operators can quickly assess microgrid health, monitor energy sources and evaluate the efficiency metrics. The integration of Chart.js ensures data is presented in an interactive manner which plays a vital role in energy management.

5 CONCLUSIONS

The development achieved its core objective of enhancing security and operational efficiency. By implementing role-based access, and using Chart.js for real-time data visualization, the project has showed the importance of combining modern web technologies with cybersecurity principles.

The system allows the users to securely monitor and control microgrid operations through a web- based platform ensuring the data integrity and system resilience. The use of MongoDB for data management ensures scalability which enables the system to handle larger datasets as microgrid infrastructure grows.

In summary, the project is characterized by clear advantages in real-time monitoring, security, user a ccess control, scalability and user experience over traditional grid management systems. To this end, the strides forward in security and data representation are notable solutions to some of the pain points caused by grid-connected microgrids. Based on the results, we can say that the system can support grid management in both distributed and hostile environments without any security or resource problems.

5.1 Research Work

By the end of the work we highlight the direction of the future research would take and how the technologies can be implemented in keeping the microgrid secure. While we have incorporated the role based access control mechanism and real-time monitoring but there is scope for the project to improve further. Adding the blockchain and machine learning technologies could help the system to learn from past incidents and prevent the potential threats early which makes the microgrids more resilient.

The microgrid continue to grow in their popularity and size finding the ways to scale the solution efficiently. The future could explore the blockchain to enhance the data security across the larger networks enabling microgrids to smoothly integrate with existing microgrids. Our solution uses standard login method but the multifactor authentication or biometric verification could add an extra layer of security. These features would be valuable for microgrids supporting critical services where unauthorized access can lead to the serious consequences.

With the use of IoT devices there is an opportunity to integrate sensors and the devices into the system seamlessly. This can enable deeper data collection and insights into the grid performance and security vulnerabilities.

5.2 Broader Impact

The provision of security to microgrids works since such essential energy services would continue to be available during disruptions. Such scenarios are critical for infrastructure such as hospitals, data centers, and emergency services hospitals. Apart from that, microgrids are very important for the integration of renewable energy sources into the electrical systems in present and future.

Energy infrastructure buildings are subject to cyber-attacks which may translate to huge losses for the companies directly or indirectly. It is noticeable that reinforcing microgrid cybersecurity aids the protection of not only the physical assets but the economies tied to them, which is paramount in regions that have invested considerably in distributed energy generation. Given that microgrids are becoming more, it is possible that strong physical security will assist people’s confidence in these systems. Proving the feasibility and safety of microgrids will provide confidence to the regulators, utility companies and customers in the adoption of the technology which serves to fast-track the deployment of such systems in the market.

6 DECLARATIONS

6.1 Study Limitations

While the research and development of the project presents significant advancements in securing the energy management systems. The limitations encountered during our study that may impact the results and the findings are:

Lack of real time data: Lack of real time data during the research was one of the primary limitations faced during the research. The evaluation of system performance in terms of response to real-world cyber threats and operational metrics relied heavily on hard coded data and simulated data. This has limited the extent to which findings can be generalized to actual microgrid environment as real-time operational conditions can vary from the controlled experimental settings.

Integration with Existing Systems: The project did not explore complexities which are involved in integrating the developed solution with existing legacy systems commonly found in operational microgrids.

Resource Constraints: The research was limited by available resources including time preventing more extensive exploration of features and capabilities which could have enhanced the system's security and efficiency.

These limitations highlight the need of further research to address the gaps allowing for a more robust evaluation and improvement in real world applications.

6.2 Acknowledgements

We would like to express our deepest gratitude to those who have supported and guided us throughout this research project. First and foremost, we extend our sincere thanks to our mentor, Mr. N Shankar Sir, Assistant Professor at Anurag University, whose expertise, patience, and encouragement have been invaluable in the development of this project. His insights and constructive feedback greatly enriched our work. We also wish to thank the Computer Science and Engineering Department at Anurag University for providing the resources and facilities necessary to carry out this research.

6.3 Funding source

This project did not require any funding as it was the part of the Academic Course. The work was part of the Department of Computer Science and Engineering, Anurag University.

6.4 Competing Interests

The authors declare that they have no competing interests related to this research. This work was conducted solely for academic purposes, and no financial or personal relationships exist that could have influenced the research outcomes or findings. Furthermore, there were no conflicts of interest with any third parties or institutions during the development and completion of this project.

6.5 Human and Animal Related Study

This study did not involve human participants and no informed consent was required. The research utilized simulated data and publicly available information to ensure ethical compliance without the need for direct human or involvement of animals.

6.6 Ethical Approval

No ethical approval was required as no humans or animals were required in the study of the project.

6.7 Informed Consent

The project did not have any human subjects and this project was done only for academic research purposes. This was done as the part of mini project as part of the college coursework.

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