This study introduces a structural design and static analysis of a Mobile Battery Swap Station for electric motorcycles, powered by solar energy, to address the critical need for sustainable and off-grid charging infrastructure. As the adoption of electric motorcycles continues to grow, driven by the demand for eco-friendly transportation alternatives, the lack of widespread and accessible charging infrastructure poses a significant barrier to their widespread use. In many regions, the expansion of traditional grid-connected charging stations is hindered by high installation costs, space limitations in urban environments, and logistical challenges in remote or underserved areas. The design focuses on a robust, mobile frame made from hollow iron of AISI 1010 steel, supporting the integration of photovoltaic (PV) panels to supply renewable energy directly to the battery-swapping system. Using Finite Element Analysis (FEA), the station's structural integrity was evaluated under a uniformly distributed load of 700 kg, simulating real-world loading conditions for components essential to electric motorcycle operations, including PV mounts and battery racks. Results show a maximum displacement of 4.541 mm, a peak stress of 57.716 MPa, and a Factor of Safety (FOS) of 2.9, confirming the design's ability to securely and stably support the necessary equipment for battery swapping. This mobile, solar-powered solution advances sustainable infrastructure for electric motorcycles, enabling flexible, grid-independent battery swapping that is particularly beneficial in urban areas and remote locations. This station contributes to greener mobility solutions tailored for electric motorcycles, aligning with broader efforts to support eco-friendly transportation systems

***Keywords:** battery swap, EV infrastructure, solar-powered charging, mobile station, electric motorcycle*

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STRUCTURAL PERFORMANCE EVALUATION OF MOBILE SOLAR-POWERED BATTERY SWAP STATION FOR ELECTRIC MOTORCYCLES

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1. Introduction

The increasing demand for clean energy and sustainable mobility solutions has become a critical focus in recent years, driven by growing environmental concerns and the pressing need to reduce greenhouse gas emissions [1]. Conventional fossil-fuel-based transportation systems contribute significantly to air pollution and climate change, highlighting an urgent need to shift towards greener alternatives [2, 3]. Electric vehicles (EVs), particularly electric motorcycles, offer a promising solution by reducing emissions [4, 5] and dependency on non-renewable resources [6]. However, to fully realize the benefits of EVs, infrastructure for renewable-powered charging systems is essential [7]. This has led to a surge in interest for mobile battery swapping infrastructure powered by solar energy, providing not only a sustainable energy source but also the flexibility required for battery swap infrastructure in urban areas [8]. The aim of this study is to analyze the structural design of mobile battery swap stations for electric motorcycles, focusing on ensuring stability, durability, and adaptability in urban settings. The objective is to evaluate the performance of the station's structure under various operational and environmental conditions, thereby contributing to the development of an efficient and sustainable charging infrastructure. While mobile battery swap stations have shown potential, several unresolved issues remain. Key areas requiring further research include ensuring the structural stability of the station under diverse environmental conditions, optimizing the design for ease of deployment and mobility in urban spaces, and integrating renewable energy sources effectively into the structural design. Addressing these challenges is critical for ensuring that these stations can meet the demands of a dynamic and growing electric vehicle ecosystem.

Therefore, these studies are relevant as it addresses a critical gap in the current electric vehicle ecosystem by ensuring that the structural design of mobile swap stations is optimized for practical implementation. With the increasing reliance on renewable energy solutions, understanding and improving this infrastructure is essential for supporting the widespread adoption of electric motorcycles in urban environments.

2. Literature review and problem statement

Previous study underscores the importance of developing battery swapping infrastructure to accelerate the adoption of electric motorcycles [9]. A case study conducted in Surakarta, Indonesia, demonstrated that the strategic placement of battery charging and swapping stations could significantly improve accessibility and deliver greater benefits to local communities. This study employed a location optimization method to identify the most effective sites for constructing these stations [10]. Furthermore, while previous studies have focused on optimizing the location and operational efficiency of battery swapping stations, there is a lack of research addressing the structural design of these facilities.

When designing a body for an electric motorcycle battery swapping system station, several key factors must be considered [11], including structural strength, material durability, ease of access, and the capacity to accommodate various battery sizes [12]. Additionally, aerodynamic design plays a critical role in enhancing performance and energy efficiency [13]. The successful implementation of battery swapping systems by companies like Tesla and Gogoro illustrates that an optimized body design is integral to supporting efficient and sustainable battery swapping operations [14].

Current EV battery swapping systems and infrastructure predominantly rely on battery swapping stations [15] and centralized battery charging facilities [16]. The strategic size and location of these stations are paramount to their effectiveness [17], particularly for electric two-wheelers, which face unique challenges in urban environments, such as high population density [18] and cost-sensitive demographics [19]. To improve accessibility and system efficiency, the placement of battery swapping stations must be carefully planned [20].

By using solar energy as the main power source, charging system for battery swap station reduce reliance on the conventional power grid, offering a more sustainable and adaptable charging solution [21]. This independence from the grid is especially beneficial in areas where charging infrastructure for electric motorcycles is limited or where power interruptions are common. Solar-powered charging system for battery swap station enable electric motorcycle users to swap the battery, even in remote locations or off-grid areas. By reducing dependency on traditional electricity sources, these stations not only support eco-friendly transportation but also help alleviate demand on urban energy systems, making electric mobility more accessible and practical in diverse settings [22].

The unresolved problem lies in the lack of research focusing on the structural design of mobile battery swap stations, how to develop and design a robust body structure for a mobile battery swab station [23] capable of integrating photovoltaic (PV) panels [24] and electrical systems for battery racks. Additionally, it seeks to analyze the structural integrity of the frame to ensure it meets the necessary strength and durability requirements.

3. The aim and objectives of the study

The aim of this study is to evaluate the structural performance of Mobile Battery Swap Station (MBSS) for electric motorcycles powered by solar energy, addressing the increasing demand for sustainable and flexible charging solutions.

To achieve this aim, the following objectives are accomplished:

– to make design formulation of Mobile Battery Swap Station (MBSS) for electric motorcycles powered by solar energy;

– to determine the load distribution on the MBSS structure during real-world operations;

– to conduct a static structural analysis using the Finite Element Analysis (FEA) method to ensure chassis safety and structural reliability under various load conditions.

4. Materials and methods

The Quality Function Deployment (QFD) method is employed in this study to systematically translate customer needs into specific technical requirements throughout each stage of product and service development. This approach is essential for ensuring that the final product or service not only meets customer expectations but often surpasses them, achieving this in a manner that is both efficient and effective [25].

A key component of the QFD method involves identifying several critical parameters for successful implementation [26]. These parameters begin with the "Voice of Customer", which highlights specific customer desires [27], such as the safety of the vehicle body and the ease of accessing the battery [28]. Understanding these requirements is crucial to aligning technical aspects with customer expectations.

Next, the QFD method addresses "Technical Requirements". For instance, a durable body material, such as AISI 1010 [29], is chosen to enhance the vehicle's resilience, and a mechanism for easy battery exchange is included to improve accessibility. Each technical requirement directly correlates with the identified customer needs [30].

The importance of each parameter is then rated to prioritize features accordingly. Safety is given the highest priority with a rating of 5 [31], durability is rated at 4 [32], and ease of access is assigned a rating of 3. This hierarchy guides design decisions, ensuring that the most critical aspects are addressed first.

Following the importance ratings, QFD outlines "Technical Priorities". These priorities focus on a strong structural design and the selection of lightweight yet robust materials, balancing safety with efficiency in material use [33]. With these well-defined parameters, QFD aids in creating a product that is not only functional but also optimized to meet customer expectations.

Once these QFD parameters are clearly established, the next step is to create a "House of Quality", a structured matrix that aids in evaluating design concepts and selecting the most suitable option. This process ensures that the final design concept aligns closely with both customer demands and technical feasibility, enhancing the overall product development outcome [34].

The primary focus is to create a robust and portable structure capable of supporting key components such as photovoltaic panels for energy generation and battery racks for efficient swapping operations. The design process emphasizes optimizing the structure's layout to ensure functionality, portability, and compatibility with urban deployment requirements.

The main hypothesis of this study is that the structure of the mobile solar-powered battery swap station for electric motorcycles can withstand the static loads and environmental forces it is subjected to during operational and transportation conditions. To test this hypothesis, a finite element analysis (FEA) was conducted on the structural design to evaluate its strength and stability under various loading scenarios.

Finite Element Analysis (FEA) is applied to simulate the static response of the chassis under these loads [35], with outputs including total deformation (structural deflection due to loading) and the factor of safety (the ratio between applied stress and material yield strength). These simulations are essential to determine if the chassis design can reliably support both configurations under operational conditions [36].

The study makes several assumptions to streamline the analysis. It is assumed that the materials used in the structure exhibit homogeneous and isotropic properties, ensuring uniform behavior under loading. Additionally, all joints and connections are assumed to be rigid, eliminating potential variances caused by flexibility or looseness in the connections. Environmental loads such as wind pressure and static loads from the battery modules and solar panels are assumed to represent worst-case conditions.

Simplifications were adopted to make the model computationally feasible while preserving accuracy. The structure's geometry was simplified by omitting minor details, such as bolts and small welds, which have negligible impact on the overall analysis. The loading conditions were also simplified to static loads, excluding dynamic effects like vibrations and sudden impacts, to focus on the primary structural behavior. These assumptions and simplifications ensure that the analysis provides reliable insights into the structural integrity while remaining computationally efficient.

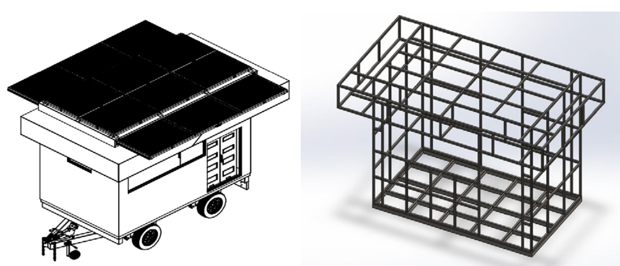
5. Research results of the study of design and structure for mobile battery swap station

5. 1. Design formulation

Mobile Battery Swap Station (MBSS) designed to provide a sustainable and flexible charging solution for electric motorcycles. The station integrates photovoltaic (PV) panels on its roof, which serve as the primary source of renewable energy by converting sunlight into electricity. This enables the station to operate independently of the power grid, promoting eco-friendly mobility. The structure includes dedicated compartments or racks for storing multiple pre-charged batteries, ensuring efficient and quick swapping of discharged batteries with fully charged ones. This feature significantly reduces downtime and supports uninterrupted operation for users.

The MBSS is mounted on a wheeled platform, making it portable and adaptable to various locations, including urban and semi-urban areas. The trailer design, complete with a tow hitch, allows for easy transportation and deployment in strategic locations to meet user demand. The station's robust structure is engineered to handle various operational loads, such as the weight of the solar panels, batteries, and environmental forces like wind, ensuring stability during both transportation and operation. The MBSS has a compact design with overall dimensions of 4000 mm in length, 2500 mm in width, and 3000 mm in height. The station is equipped with 9 solar panels, each with a capacity of 300 Wp and a weight of approximately 30 kg, ensuring sufficient energy generation while maintaining manageable load conditions. For the battery rack, the MBSS can accommodate up to 8 batteries, with each battery weighing approximately 12 kg.

The compact and modular layout of the MBSS, as illustrated in Fig. 1, optimizes space, making it suitable for deployment in urban environments with limited space availability. The design shown in Fig. 1 highlights the modular structure, which facilitates future upgrades, such as expanding battery storage capacity or enhancing solar panel efficiency. By utilizing renewable energy and addressing mobility challenges, this MBSS design, depicted in Fig. 1, offers an innovative solution for advancing electric motorcycle infrastructure, supporting the transition to sustainable transportation systems in areas where traditional charging infrastructure may be impractical or unavailable.



a *b*

Fig. 1. Mobile battery swap station structure: *a* – battery swap station design; *b* – main structure

Detailed structure for the mobile battery swap station as shown in Fig. 1, *a*, ensuring that it fulfills the technical and functional needs identified in the design process. Fig. 1, *b* provides an illustration of the structural layout, showing the planned arrangement of key components such as the battery rack, PV panel mounts, and other critical elements that make up the station. These figures collectively demonstrate the practical design considerations for modularity, structural integrity, and efficient component placement. By integrating these features, the design ensures the MBSS is both robust and adaptable to meet current and future requirements for electric motorcycle infrastructure.

5. 2. Load distribution

The Table 1 provides an overview of the load distribution across various components in a system, listing each component alongside its respective weight in kilograms (kg).

Table 1

Components of mobile battery swap station

No.	Part	Weight (kg)
1	PV panel mechanism	350
2	Battery rack	150
3	Other tools	200
Total		700

According to Table 1, with a total weight of 700 kg, the MBSS's structural framework must be carefully designed to support this load while maintaining stability and portability. The weight distribution across the components emphasizes the need for a robust yet efficient design to ensure the station's reliability during operation and transportation. This breakdown highlights the importance of balancing functionality, durability, and mobility in the development of sustainable infrastructure for electric motorcycles.

5. 3. Structure simulation

Fig. 2 shows the analysis of the axial and bending simulation results for the designed structure, made from hollow iron conforming to AISI 1010 steel standards, shows that it operates well within safe stress limits. The structure, with cross-sectional dimensions of 40×40×2 mm and 80×40×2 mm, experiences a maximum stress of 57.716 MPa and a minimum stress of –56.739 MPa. Given that AISI 1010 steel has a yield strength of 180 MPa, the structure's maximum stress is notably below this threshold, ensuring that it remains in the elastic range and will not experience plastic deformation under the given loads.

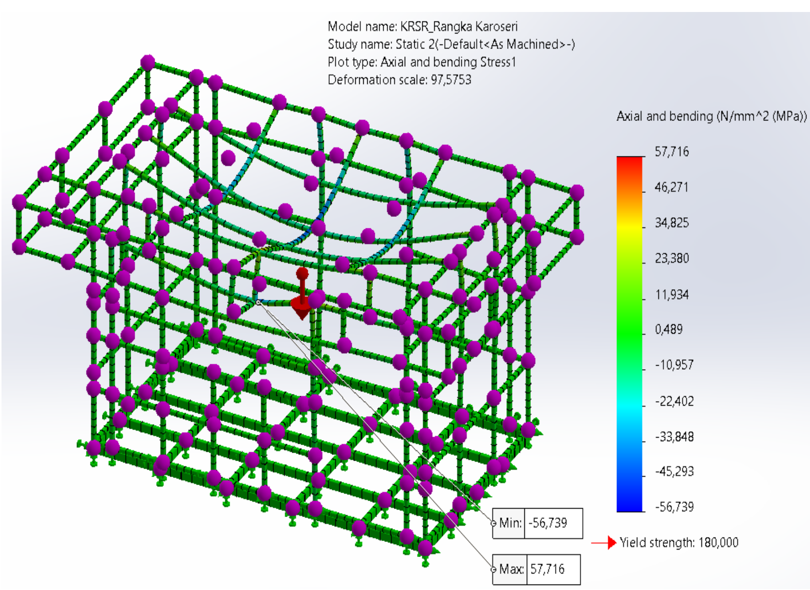


Fig. 2. Axial and bending simulation

In axial loading, the stress is distributed uniformly, indicating that the structure is well-suited for handling axial forces without risk of failure. In bending, where tensile and compressive stresses occur on opposite sides, the stress values remain balanced and within safe limits, showing that the structure will not deform under bending moments.

The stresses in the structure analyzed using the combination of axial stress:

$$\sigma\, Axial = \frac{F}{A}, \tag{1}$$

where $\sigma Axial$ is axial stress (MPa), F is axial force applied to the member (N), and A is cross-sectional area of the member (mm^2) (1) and bending stress:

$$\sigma\, Bending = \frac{M\ .\ c}{I}, \tag{2}$$

where, $\sigma Bending$ is bending stress (MPa); M is bending moment (N mm); c is distance from the neutral axis to the outermost fiber (mm); I is moment of inertia of the cross-section (mm^4) called actual stress.

In structural analysis, combining stresses is essential because most structural members experience multiple types of loads simultaneously, leading to different stress components acting on the same area. These stresses must be combined to accurately assess the overall condition of the structure and ensure its safety and functionality.

The static displacement analysis of Mobile Battery Swab Station's structure in Fig. 3 shows that it exhibits low deformation under load, with a maximum displacement of 4.541 mm in the upper central region, as indicated by the red and orange areas on the color scale. The displacement ranges from nearly zero in the blue regions to this maximum value, showing that the structure is generally stable. The highest displacement occurs at the top center, where load is applied, while minimal displacement is seen in the lower sections, which are well-supported by fixed boundary conditions (indicated by green symbols). The deformation scale is set to 97.5753, exaggerating the displacement visually, but actual deflections remain in the millimeter range, suggesting the structure has good stiffness. Although the overall displacement is small, additional reinforcement may be beneficial in the top region if lower deflection is required for functional or structural integrity. Overall, the structure demonstrates stability and resilience, with effective support at its lower sections contributing to reduced displacement.

Displacement (μ) refers to the actual movement of a point in a structure due to applied loads. It is measured in absolute terms (e. g., millimeters). Displacement is the cumulative effect of all strains in the structure, including axial and bending deformations. Strain is a localized measure, while displacement is the cumulative effect of strain over a distance. Mathematically, strain is related to the derivative of displacement as shown in:

$$\varepsilon = \frac{d\mu}{dx}, \tag{3}$$

where ε is strain, μ is displacement in the direction of deformation, and x is position along the length of the member. (3), and also related to stress through the material's elastic modulus, as described by (4):

$$\sigma = \varepsilon \cdot E, \quad (4)$$

where E is elastic modulus (MPa) of material that used for mobile battery swab station.

Fig. 4 shows a Factor of Safety (FOS) analysis for the Mobile Swab Battery Station's structure, with a color-coded scale representing the distribution of safety factors across the framework. The FOS values range from a minimum of 2.956 to a maximum of 8,808, with lower FOS values indicated by red and higher values by blue. The minimum FOS of 2.956 appears in limited regions, particularly around areas experiencing higher stress, such as near the load application point at the top center, where the red arrow is shown. Higher FOS values are observed in most of the structure, especially in the lower and side sections, suggesting these areas are under lower stress relative to their material strength and have a greater margin of safety. The use of a minimum safety factor criterion of 3 indicates that the structure is designed to be at least three times stronger than required by the applied loads. Overall, the FOS analysis suggests that the structure is robust, with most areas far exceeding the minimum safety requirements, and only a few localized regions approaching the minimum FOS, which may need closer monitoring if further loading is anticipated. This distribution reflects a well-balanced design where the structure maintains high safety margins throughout.

The Fig. 4 shows a factor of safety (FOS) of the structure, evaluated under static loading. The FOS measures the structure's safety margin, defined as the ratio between the material's yield strength and the actual stress experienced at a given point as shown in (5):

$$FOS = \frac{\sigma\, yield}{(\sigma\, Axial + \sigma\, Bending)}, \quad (5)$$

where FOS is factor of safety, $\sigma\, yield$ is material yield strength (MPa).

The analysis of the axial and bending stress, displacement, and Factor of Safety (FOS) in the mobile battery swab station's structure provides a comprehensive understanding of its performance under load. The axial and bending stress results, with maximum and minimum stresses well below the yield strength of AISI 1010 steel, confirm that the structure can withstand the applied forces without entering plastic deformation, indicating structural resilience. The displacement analysis shows a maximum deflection of 4.541 mm at the top central region, while other areas experience minimal displacement due to strong fixed supports, suggesting effective stiffness across the framework. The FOS distribution complements these findings, with most of the structure exhibiting safety factors significantly above the minimum required value of 3, ensuring substantial strength reserves and effective load management. Only localized regions near the load application point approach the minimum FOS, consistent with higher stress and displacement there.

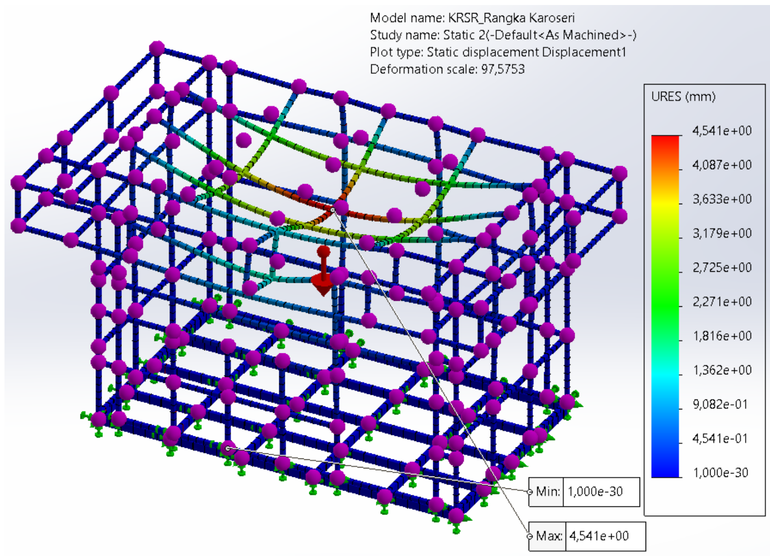


Fig. 3. Static displacement simulation

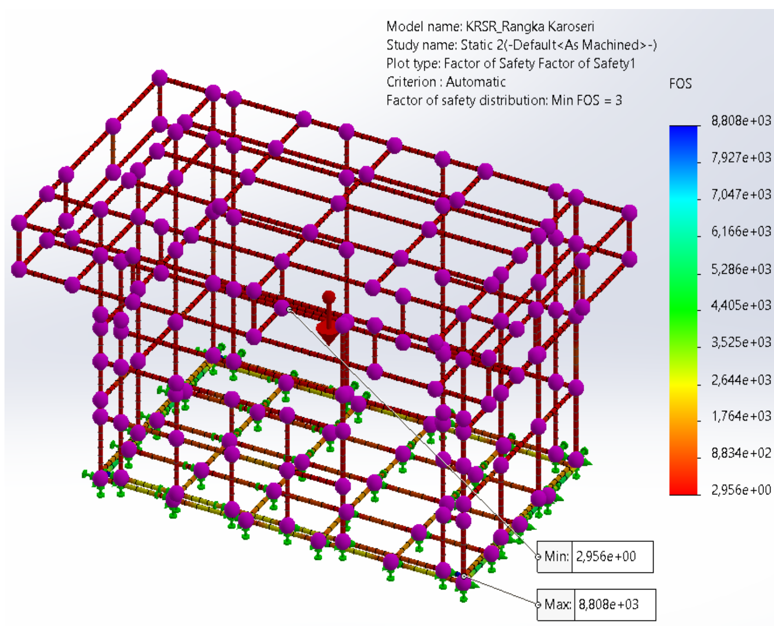


Fig. 4. Factor of safety simulation

These simulation results indicate that the mobile battery swab station's structure is both robust and reliable for mobile operations, able to withstand the stresses of movement and environmental load variations without significant deformation or risk of failure. The low displacement assures that sensitive components, such as batteries and charging mechanisms, will remain stable, minimizing wear and tear. Additionally, the high safety factors across most of the structure provide confidence in its durability, even in potentially harsh operating conditions. Overall, the structure's design ensures long-term reliability and safety, critical for a mobile station that will undergo frequent loading and unloading during use.

Based on the obtained results, the factor of safety for the structure can be calculated using FOS (5). This calculation utilizes the yield strength of AISI 1010 steel, which is 180 MPa, as shown below:

$$FOS = \frac{180\,\text{MPa}}{57.716\,\text{MPa}} = 3.118. \quad (6)$$

The difference between the factor of safety (FOS) obtained from simulation and manual calculation arises from several factors related to the methods used to determine the values. The simulation provides a more detailed and realistic representation of the structure by accounting for various complexities, while the manual calculation relies on simplified assumptions.

One major reason for the discrepancy is the stress distribution. The manual calculation uses a single maximum stress value for the entire structure, assuming a uniform stress state. In contrast, the simulation captures the actual stress distribution throughout the structure, including localized stress concentrations and secondary effects. These localized factors can significantly influence the FOS but are not reflected in the manual approach.

Additionally, geometric effects and load distribution play a critical role. The simulation takes into account the exact geometry of the structure, including member dimensions, connections, and constraints, which affects how stresses are distributed. Manual calculations often simplify these complexities, potentially underestimating or overestimating stresses. Similarly, the simulation applies loads more realistically across multiple members and nodes, leading to stress redistribution that is difficult to replicate in manual calculations.

Boundary conditions and constraints are another contributing factor. The simulation incorporates detailed boundary conditions, such as fixed supports and joint behavior, which affect the overall stress state of the structure. Simplifications in manual calculations might ignore these effects, leading to less accurate results. Furthermore, the mesh refinement used in the simulation helps detect localized stress variations, while manual calculations assume a uniform stress distribution, missing these subtleties.

Lastly, numerical precision and rounding differences also play a role. The simulation uses advanced numerical methods to solve complex equations, introducing slight approximations that can affect the final FOS value [37]. Manual calculations, while straightforward, rely on idealized equations that omit these subtle numerical effects.

6. Discussion of the result of the study of design and structure for mobile battery swap station analysis result

From Fig. 1, it can be observed that a well-formulated design for the Mobile Battery Swap Station (MBSS) has been successfully developed. The design ensures that all essential components required for the battery swap process, such as the battery rack, PV panel mounts, and other critical elements, are appropriately positioned. This careful arrangement not only optimizes the functionality of the MBSS but also enhances its overall efficiency and usability. The design reflects a comprehensive approach to meeting the technical and operational requirements of a mobile energy solution, providing a solid foundation for its practical implementation.

The load distribution as shown in Table 1, for the Mobile Battery Swap Station (MBSS) has been successfully determined by taking into account the essential elements required for its operation. Proper load distribution is critical in ensuring that the selected materials can adequately support the structural and operational demands of the MBSS. By analyzing the weight and placement of key components such as the battery rack, PV panel mounts, and other critical elements, the study ensures that the design is both safe and efficient. This analysis plays a vital role in material selection, ensuring durability and structural integrity under various loading conditions.

The results from the structural analysis of the Mobile Battery Swap Station as shown in Fig. 2, confirm the robustness of the design under applied loads. The axial and bending stress simulation reveals that the maximum stress experienced by the structure is 57.716 MPa. These values are significantly below the yield strength of AISI 1010 steel (180 MPa), indicating that the structure remains in the elastic region (4) and is safe from plastic deformation. This also shows that the strain (3) experienced by the structure is within the elastic limit, ensuring that it returns to its original shape upon unloading. From Fig. 3, it can be observed the maximum displacement obtained is approximately 4.541 mm. The stress is distributed uniformly under axial loading (1), while bending stresses (2) are balanced, ensuring that the structure can effectively resist deformation caused by bending moments. The Factor of Safety (FOS) maximum value is 2.956 as shown in Fig. 4, ensuring a high safety margin across most of the structure.

This study offers significant advantages over previous research on solar-powered battery swap stations with fixed locations [24]. Unlike fixed stations, the mobile battery swap station (MBSS) proposed in this study provides greater flexibility and accessibility, especially in areas where fixed infrastructure may be impractical or economically unviable. The mobility of the MBSS enables it to serve diverse locations, including remote or underserved areas, by bringing the infrastructure directly to the users. This capability reduces the dependency on users traveling to specific locations for battery swaps, thereby enhancing convenience and user experience. Additionally, the mobile design optimizes the utilization of renewable energy by allowing the station to be deployed strategically based on solar energy availability or user demand patterns.

This study successfully addresses the structural strength challenges of the Mobile Battery Swap Station (MBSS). The analysis revealed a Factor of Safety (FOS) value (5) of 2.956, which indicates that the structure is not only robust but also meets the necessary safety requirements for its intended application. This result confirms that the designed structure is suitable and capable of supporting the operational demands of an MBSS, including the loads from batteries, solar panels, and mobility-related stresses. The high FOS value underscores the reliability and durability of the structure, ensuring its effectiveness and safety in real-world applications. This achievement demonstrates the feasibility of the proposed design for advancing mobile energy solutions in sustainable transportation.

The current study has inherent limitations, including the assumptions of static loading conditions, which do not account for dynamic loads or environmental factors such as wind and vibration. These limitations might affect the real-world performance of the design. Additionally, the analysis is based on AISI 1010 steel, and alternative materials or composite structures with different properties have not been considered. The findings also depend heavily on the mesh refinement and boundary conditions used in the FEA, which may vary between simulations. Moreover, the results are valid within the applied load range and may not be extrapolated to extreme conditions without further validation. Nevertheless, a comparison between the FEA results and manual calculations (6) shows good agreement, validating the accuracy of the simulation. FEA offers significant advantages, including the ability to model complex geometries, apply various boundary conditions, and analyze multiple load cases with high precision, making it an indispensable tool for optimizing designs and predicting performance under realistic conditions that would be challenging to evaluate manually.

The study also highlights a few disadvantages as shown in Fig. 4. Certain regions near the load application point exhibit a lower FOS (minimum 2.956), suggesting a need for reinforcement to further enhance safety margins. The static loading assumption limits the generalization of the results, and incorporating dynamic and environmental loading conditions in future studies is necessary. Furthermore, the heavy reliance on simulation tools might introduce variability based on the software and modeling parameters. A combination of experimental validation and simulation is recommended to achieve a more robust analysis.

Future research could explore dynamic loading scenarios to validate the design under real-world conditions, as well as investigate alternative materials such as lightweight alloys or composites to enhance performance while reducing weight. Experimental validation of the simulation results is crucial to refine the model further. Additionally, employing advanced optimization algorithms could help improve the structural design for increased efficiency and cost-effectiveness. However, potential challenges include the complexity of modeling dynamic scenarios, the cost of experimental validation, and the computational demands of high-fidelity simulations. Despite these challenges, the proposed design demonstrates a strong foundation for future improvements, ensuring safety, reliability, and operational efficiency.

7. Conclusions

1. The design formulation for the Mobile Battery Swap Station (MBSS) ensures functionality through well-positioned components, practicality with its modular and user-friendly layout, and safety and reliability through a robust structure. These factors confirm that the MBSS design is functional, practical, and dependable, supporting sustainable energy solutions for electric motorcycles.

2. With a total component load of 700 kg, the study ensures that the design supports functional requirements, maintains practicality through balanced weight allocation, and prioritizes safety and reliability by selecting materials capable of withstanding operational stresses.

3. The study demonstrates that the structural design of the mobile battery swap station (MBSS) effectively meets safety and performance requirements. The combined axial and bending stress of 57.716 MPa remains within the material's allowable limits, while the maximum displacement of 4.541 mm ensures structural stability under operational loads. With a Factor of Safety (FOS) of 2.956, the structure is proven to be robust and reliable, providing a durable and secure solution for mobile energy infrastructure. These results confirm the design's suitability for its intended application.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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