National University of Science and Technology POLITEHNICA Bucharest

Doctoral School of Electronics, Telecommunications, and Information Technology

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SUMMARY OF THE DOCTORAL THESIS

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INTEGRAREA EFICIENTĂ A ENERGIEI SOLARE ȘI EOLIENE ÎN SISTEMELE DE PROPULSIE AUTO: O ABORDARE DURABILĂ A MOBILITĂȚII VIITORULUI

EFFICIENT INTEGRATION OF SOLAR AND WIND ENERGY INTO AUTOMOTIVE PROPULSION SYSTEMS: A SUSTAINABLE APPROACH TO THE MOBILITY OF THE FUTURE

COMISIA DE DOCTORAT

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Content

Chapter 1

Introduction

1.1 Research context

Global climate change and the dependence on fossil fuels represent major challenges for the transportation industry. Road transport is one of the main contributors to greenhouse gas emissions, being responsible for environmental pollution and an increased carbon footprint. In this context, electric vehicles (EVs) are considered a viable solution, significantly reducing carbon emissions and air pollution. However, to fully harness the potential of EVs, it is necessary to integrate renewable energy sources, such as wind and solar energy, both into the charging infrastructure and the vehicles themselves.

1.2 Motivation and importance of the study

The use of solar and wind energy in transportation represents an opportunity to transform the automotive industry into a sustainable and eco-friendly field. Wind energy is abundant and renewable, while solar energy is increasingly utilized efficiently in modern systems. The combination of these two sources can enhance the range of electric vehicles and reduce dependence on conventional charging infrastructure. This thesis addresses the following questions

- How can renewable energy sources be integrated into electric vehicles to maximize efficiency?
- What are the optimal technologies and methods for energy conversion and storage for use in electric vehicles?

1.3 Thesis objectives

This thesis has the following main objectives

1. Investigating the literature on the use of renewable energy in electric vehicles.
2. Analyzing methods for capturing, converting, and storing wind and solar energy.
3. Developing an integrated model for using wind and solar energy in electric vehicles.
4. Evaluating the performance of these systems in terms of energy efficiency and environmental impact.
5. Proposing strategies and practical solutions for the large-scale implementation of these systems.

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1.4 Research methodology

The methodology adopted in this thesis includes an interdisciplinary approach

- **Bibliographic analysis:** reviewing existing research in the fields of renewable energy and electric vehicles.
- **Simulations**: using digital simulation tools to evaluate the performance of the proposed systems.
- **Experiments**: practical testing of wind turbines and solar panels mounted on electric vehicles.
- **Case study**: analyzing a prototype that combines wind and solar energy, with direct applicability in road transportation.

1.5 Contents of the doctoral thesis

The thesis is organized into five chapters.

- **Chapter 1** introduces the context, motivation, objectives, and research methodology.
- **Chapter 2** explores the current trends and future of road transport without fossil fuels.
- **Chapter 3** analyzes the technologies for converting and storing renewable energy for electric vehicles.
- **Chapter 4** presents a case study and experimental results of using solar and wind energy in vehicles.
- **Chapter 5** summarizes the conclusions of the thesis, original contributions, and future development perspectives.

Chapter 2

The future of transport: vehicles that do not use fossil fuels

2.1 Electric vehicles and current trends

Electric vehicles (EVs) represent an eco-friendly and sustainable solution for both personal and commercial transportation, serving as a viable alternative to internal combustion engine vehicles. The growing popularity of EVs is supported by the following trends:

- Advancement in battery technology: lithium-ion batteries and other emerging technologies have significantly increased the range of electric vehicles. This progress has overcome limitations related to short distances.
- Expansion of charging infrastructure: public and private charging stations have rapidly increased, contributing to the adoption of electric vehicles. Additionally, fast charging and smart charging systems facilitate daily use.
- Innovations in design: the integration of aerodynamic components and lightweight materials enhances the performance of electric vehicles and improves their energy efficiency.[1]

2.1.1 The evolution of electric vehicles

From the inventions of the 19th century to the current revolution, electric vehicles have evolved considerably. The first models, created in the 1800s, were used for urban transport but were overshadowed by internal combustion engine automobiles in the first half of the 20th century. In the last two decades, government support, technological advancements, and increased ecological awareness have driven the resurgence of electric vehicles. Today, they are an essential part of the transportation decarbonization strategy.

2.1.2 The Automotive Industry in Transition

The automotive industry is undergoing a major transition, shifting from fossil fuel-based vehicles to those with low or zero emissions. This change is being accelerated by strict emission regulations, increased investments in renewable energy, and the adoption of innovative technological solutions, such as electric and hybrid vehicles. [2,3,4,5]

2.2 Integration of electric vehicles and renewable energy

The combination of electric vehicles with renewable energy sources provides efficient solutions for reducing environmental impact. Integrating wind and solar energy into the charging infrastructure and, potentially, into the vehicles themselves can contribute to carbon neutrality.

- **Hybrid wind-solar systems:** these systems allow electric vehicles to be powered by renewable energy, reducing dependence on the traditional electrical grid.
- **Smart lighting and charging poles:** the integration of solar panels and wind turbines into public streetlights enables vehicle charging and provides sustainable street lighting.
- **Energy generation in motion:** installing wind turbines on vehicles to generate energy while moving is an innovative direction, though technical challenges, such as the size and efficiency of these turbines, require further research.[6,7,8,9,10]

2.3 Challenges and opportunities in the use of renewable energy

- **Challenges**
  - The intermittent nature of solar and wind energy requires efficient storage solutions.
  - Initial costs for integrating renewable energy systems are high.
  - There is a need for a complex infrastructure to support electric vehicles and the use of renewable sources.
- **Opportunities**
  - Significant reduction in greenhouse gas emissions.
  - Creation of jobs in the manufacturing and research sectors for green technologies.
  - Contribution to global sustainability goals by replacing fossil fuels with renewable sources.[11,12]

2.3 Types of systems used in the integration of renewable energy

Electric vehicles can benefit from several types of hybrid systems:

- Solar panels integrated on vehicle roofs, providing additional energy for the batteries.
- Portable wind turbines to generate energy during motion.
- Smart grids that combine different energy sources for efficient charging.[13,14,15,16,17]

Chapter 3

Conversion of electric energy from wind and solar sources for vehicle powering

3.1 Renewable Energy: Potential and Usage

Wind and solar energy are essential renewable sources for the transition to sustainable transport. They are characterized by abundant availability, low environmental impact, and the ability to reduce dependence on fossil fuels.

3.1.1 Solar energy

Solar energy is captured through photovoltaic panels, which convert solar radiation into electrical energy. The panels can be mounted on vehicles, directly contributing to powering electrical systems or charging batteries. This technology offers significant advantages, such as reducing operating costs and CO_2 emissions, but it depends on weather conditions and the positioning of the panels.

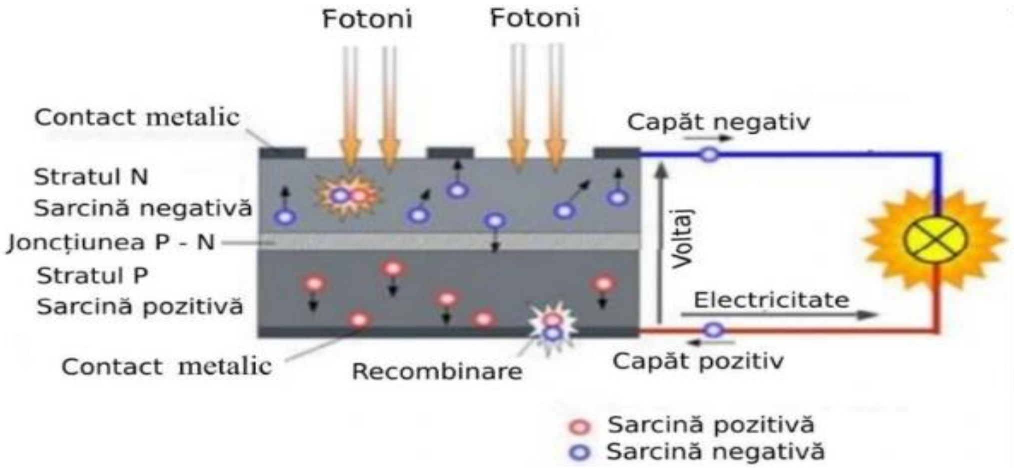

Figure 3.1 The Formation of Electric Flow in a Photovoltaic Cell[18]

3.1.2 Wind energy

Wind energy is obtained by using turbines that convert the kinetic energy of the wind into electrical energy. On vehicles, wind turbines can be integrated to generate energy during motion or while stationary. They can be used in combination with solar panels to maximize efficiency.

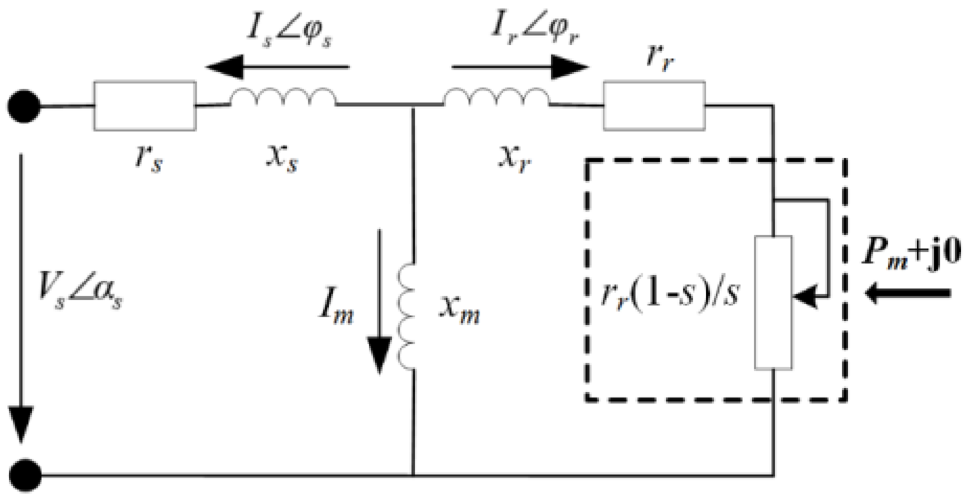

Figure 3.7 Equivalent electric circuit of a wind induction generator

3.2 Technologies for energy conversion and storage

3.2.1 Electric generators

The generators used in wind turbines can be synchronous or asynchronous, each having advantages and limitations depending on the application. The choice of generator influences the conversion efficiency and the stability of the energy flow.

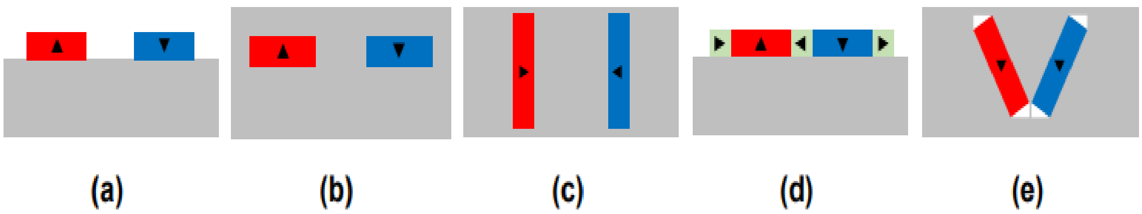

Figura 3.8 Different types of magnets [19]

3.2.2 Energy storage systems

Energy storage is a critical component in the use of renewable sources. Lithium-ion batteries are the most widely used due to their energy density and extended lifecycle. Other options, such as solid-state batteries and lithium-air batteries, are under development and may provide more efficient solutions.

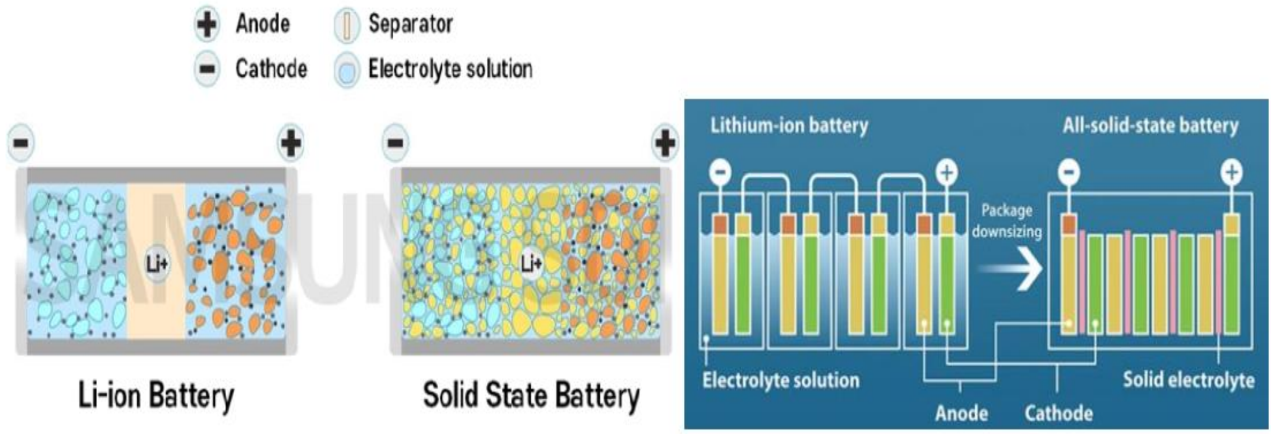

Figure 3.13 Differences between a Li-Ion battery and a solid-state battery [20]

3.2.3 Hybrid storage systems

Hybrid systems combine multiple storage technologies, such as batteries and supercapacitors, to provide both high energy density and high instantaneous power. This combination is ideal for electric vehicles that require rapid acceleration and extended range.

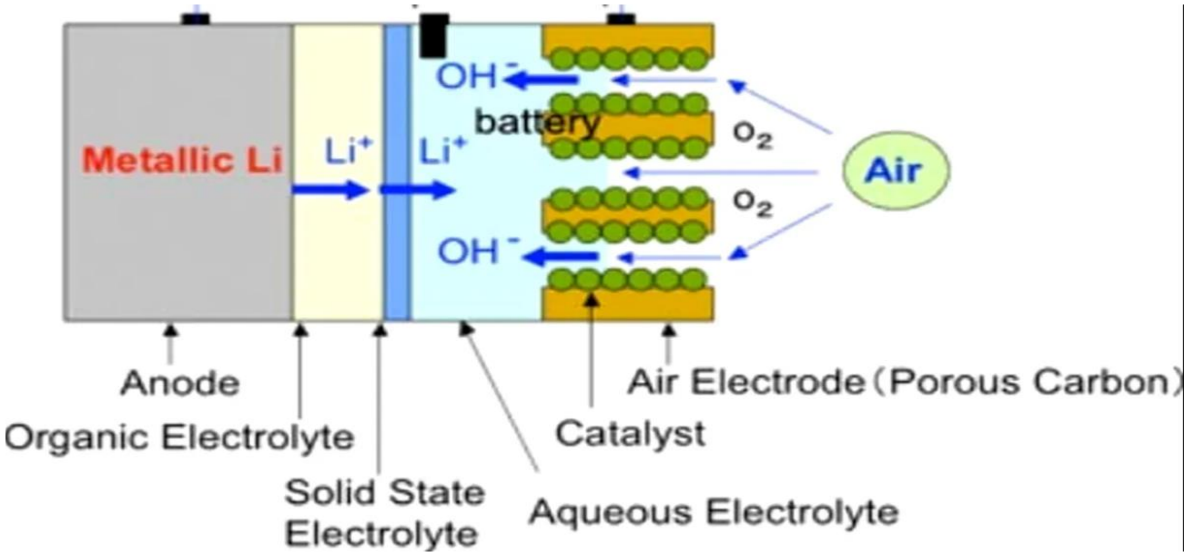

Figura 3.14 Operating principle of the lithium-air battery [21]

3.3 Inverters and energy control

3.3.1 Power inverters

Inverters convert the direct current generated by renewable sources into alternating current usable by the vehicle systems. Different types of inverters include multilevel topologies, such as neutral-point clamped inverters or capacitor-flying inverters.

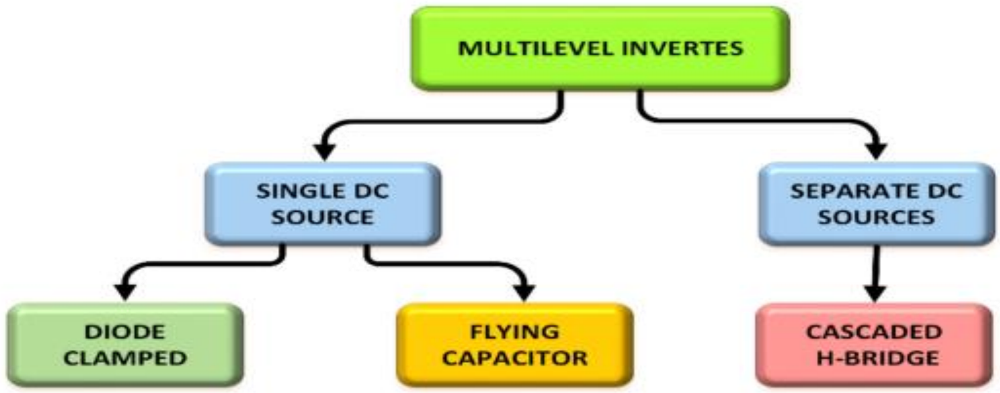

Figura 3.19 Multilevel Inverters (MLI) and Their Classification [22]

3.3.2 Maximum Power Point Tracking (MPPT)

MPPT systems optimize the use of renewable energy by adjusting the operating parameters to maximize the power obtained from solar panels or wind turbines. This is an essential component for the efficiency of the system.

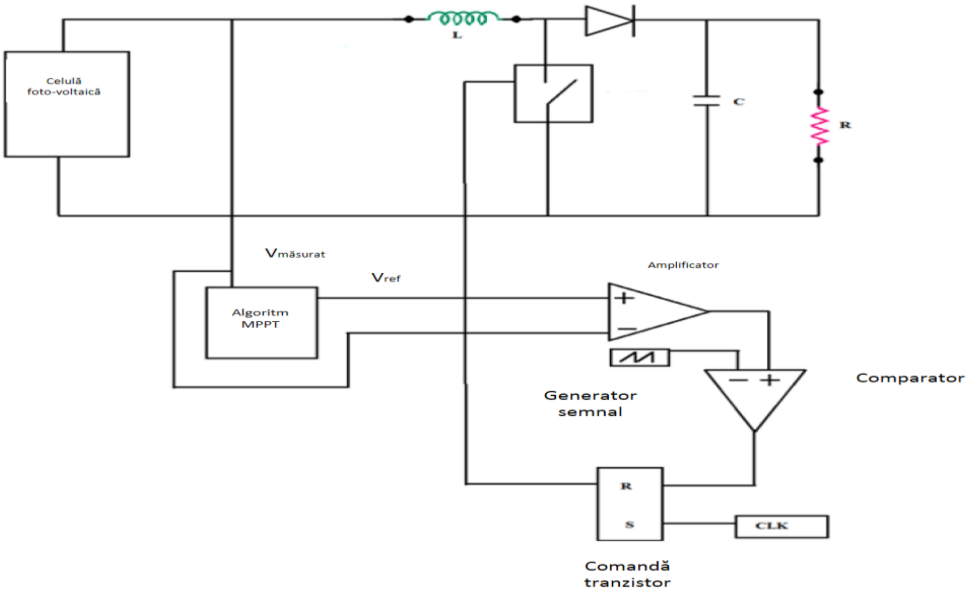

Figura 3.25 Implementation of MPPT in the Boost Converter [23]

Chapter 4

Devices that convert wind and solar energy into electrical energy mounted on vehicles

4.1 Introduction

This chapter explores the integration and practical testing of renewable energy conversion systems mounted on vehicles. The studies and experiments aim to evaluate the efficiency of wind turbines and solar panels installed on vehicles, contributing to the optimization of the use of these energy sources.

4.2 Digital simulations

To evaluate the performance of the proposed systems, digital simulations were conducted to model the aerodynamic behavior of vehicles equipped with wind turbines and solar panels. The results showed that the optimal positioning of the turbines and panels can reduce aerodynamic drag and increase energy efficiency.

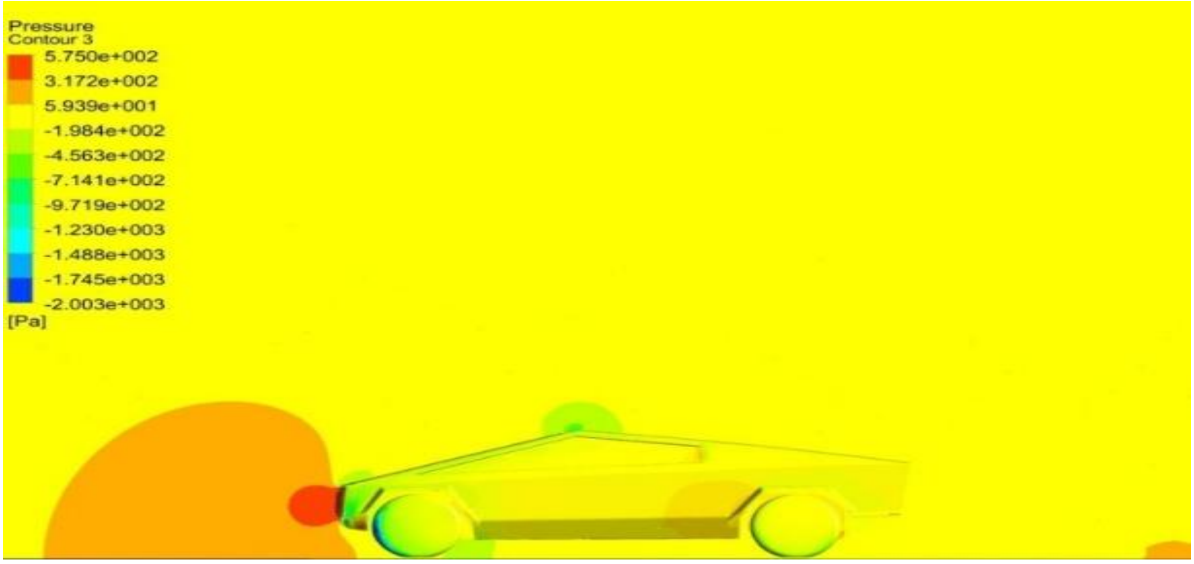

Figura 4.1 Digital simulation for pressure analysis

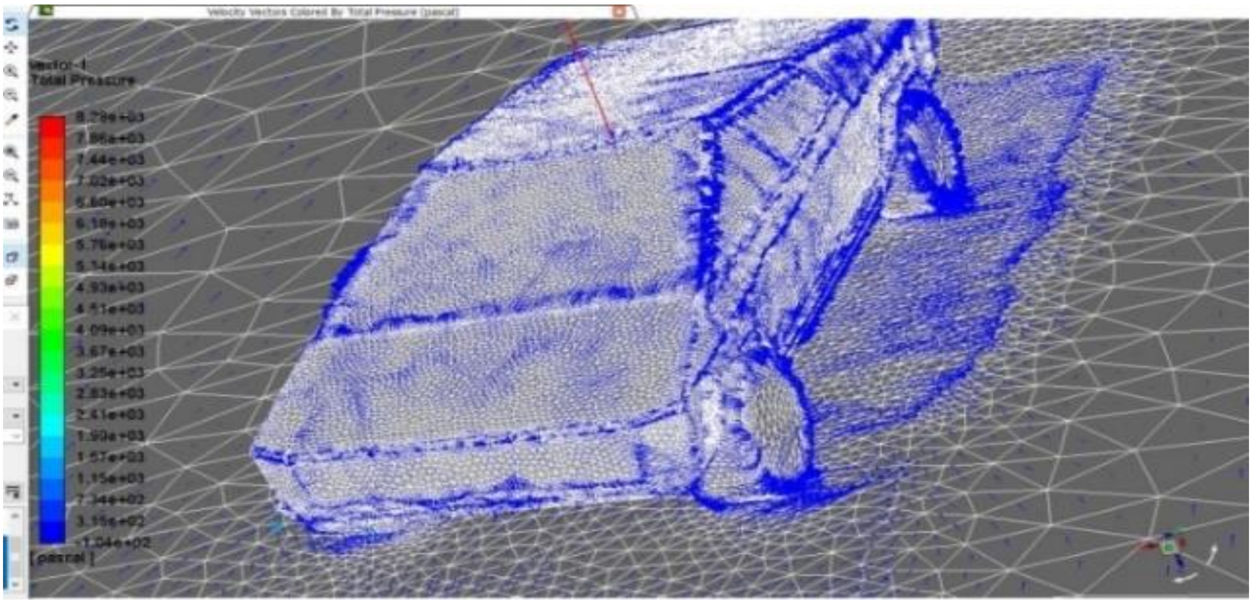

Figura 4.2 Relative wind speed and surface pressure

4.3 Wind turbine design

Several types of wind turbines, including vertical and horizontal axis models, were designed and tested to determine the optimal configuration for mounting on vehicles. The tests showed that vertical turbines are more efficient at capturing energy at low wind speeds, while horizontal turbines offer superior performance at higher speeds.

Figura 4.3 Special design wind turbine

4.4 Practical testing of wind turbines

In the experiments, wind turbines were mounted on vehicles and tested under real conditions. The amount of energy generated and the impact on vehicle performance, such as fuel consumption and speed, were monitored.

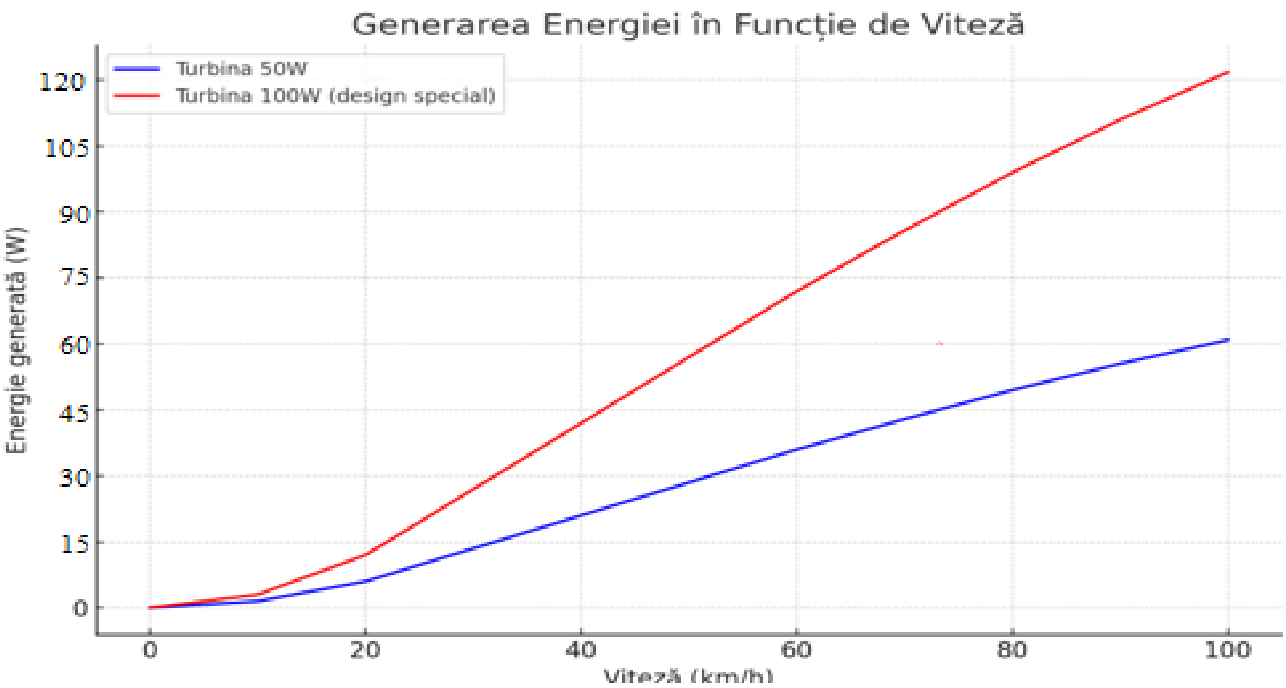

Figura 4.4 Dependency of the amount of electricity generated on the vehicle speed

4.5 Use of solar panels

Solar panels mounted on the roofs of vehicles were tested to determine their efficiency under varying sunlight conditions. The experimental results showed a constant generation of energy, which contributes to extending the vehicle's range and powering auxiliary components.

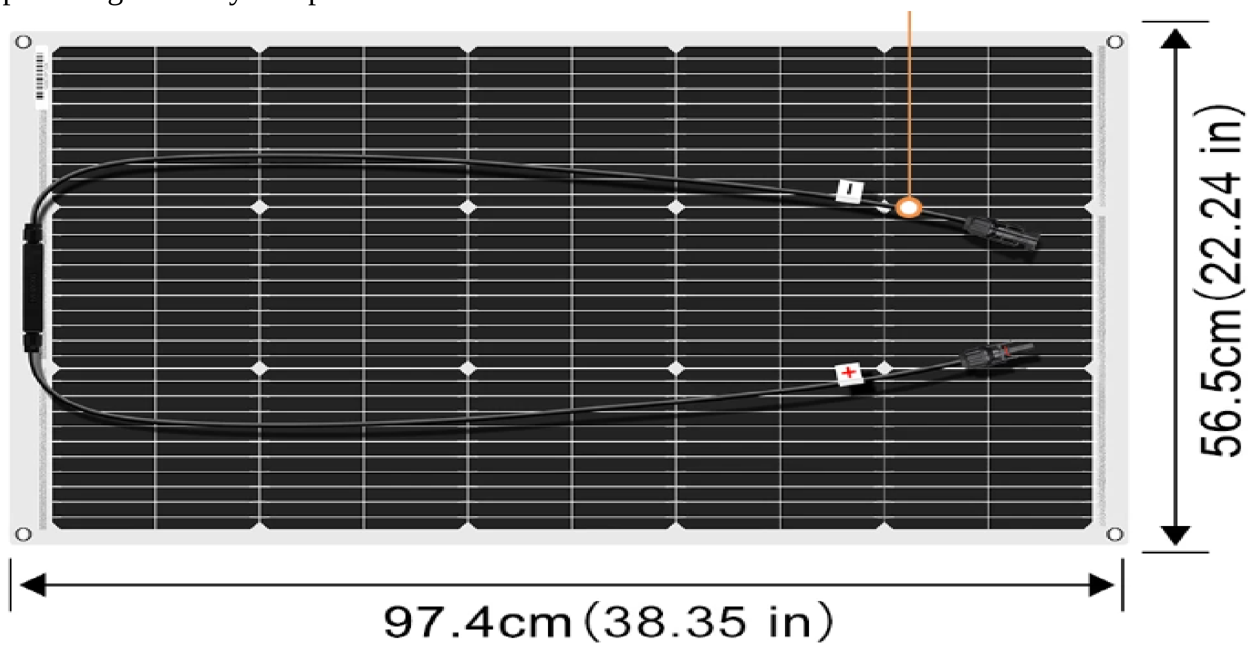

Figura 4.15 Solar panel used

4.6 Integration of wind-solar hybrid systems

The tests also included the integration of wind turbines with solar panels to create a hybrid power system. The systems were connected to an inverter that optimizes the use of the generated energy, either for charging the battery or directly powering the vehicle's motor.

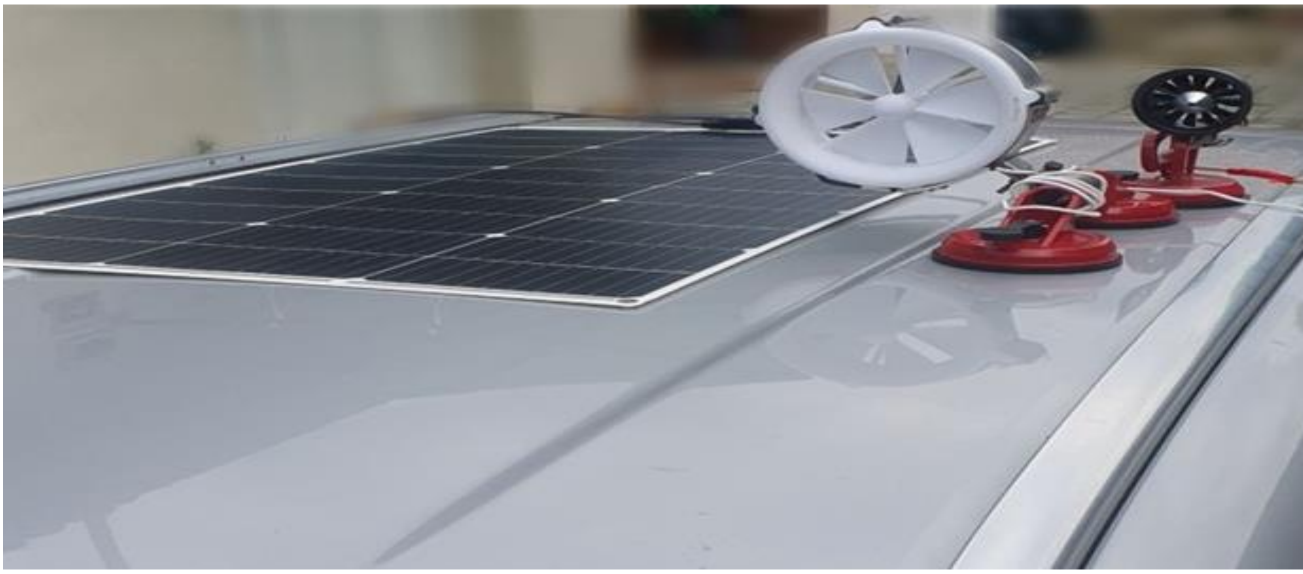

Figure 4.25 Hybrid system mounted on the car

Figure 4.26 Hybrid system mounted on the car, rear view

4.7 Experimental results

Main conclusions of the experiments

- Wind turbines can generate significant energy at medium and high vehicle speeds, helping to reduce the energy demand from the battery.
- Solar panels provide a stable energy source in sunny conditions, complementing wind turbines.
- Wind-solar hybrid systems can improve vehicle range by up to 20% under optimal conditions.

4.8 Challenges and limitations

During testing, several challenges were identified:

- The efficiency of wind turbines decreases at low vehicle speeds or under weak wind conditions.
- Solar panels are sensitive to shading and orientation, which limits energy generation.
- The integration of hybrid systems requires advanced solutions to reduce weight and optimize vehicle design.

Conclusions

This thesis demonstrates the potential of renewable energy in transforming electric vehicles into a truly sustainable solution for transportation. The theoretical study and practical experiments highlight the importance of integrating solar and wind energy sources to increase vehicle efficiency and range, while reducing environmental impact.

n.1 Results

The experimental results and simulations led to the following conclusions:

- **Wind turbines** installed on vehicles can generate additional energy, helping to reduce dependence on traditional charging infrastructure..

- **Solar panels** mounted on vehicles provide a consistent energy source under favorable light conditions.

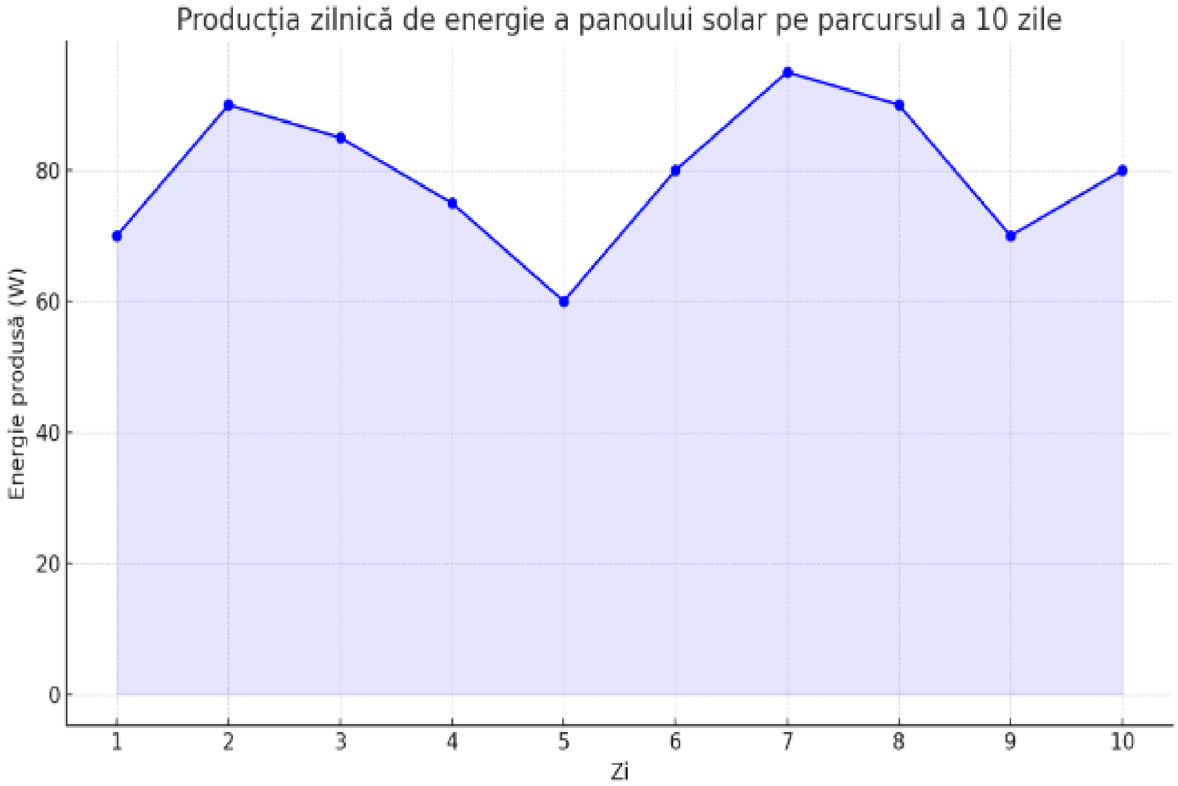

Figura 4.18 Graph for the solar panel over 10 days

- **Wind-solar hybrid** systems enhance overall performance, increasing vehicle range by up to 20%.

Figura 4.25 Hybrid system mounted on the car

n.2 Original contributions

The main original contributions of this thesis

1. Design of a simplified system for integrating a wind turbine. [1]
2. Experimental testing of a wind turbine prototype under real-world conditions. [2]
3. Simultaneous integration of solar and wind energy for hybrid cars. [3]
4. Optimization of photovoltaic panel efficiency for use on hybrid cars. [4]
5. Optimization of the hybrid system, including evaluation of the interaction between solar panels and wind turbines. [5]

n.3 List of original articles

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n.4 Future development perspectives

The research opens new directions for the implementation of hybrid solutions in road transport and beyond:

1. Optimization of wind systems for commercial and utility vehicles.
2. Advanced integration of high-efficiency solar panels.
3. Development of intelligent hybrid systems capable of adapting the use of renewable sources based on weather conditions and vehicle needs.
4. Expansion of applications to other types of vehicles, such as maritime or rail transport.
5. Assessment of the ecological and economic impact of large-scale implementation of renewable hybrid systems..

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