TÜRKİYE CUMHURİYETİ

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL

ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT

DESIGN AND IMPLEMENTATION OF SOLAR ASSISTED ENERGY STORAGE SYSTEM FOR REFRIGERATED TRAILER

MUHAMMET SAİT KARASOY

M.Sc.

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ÖZET

SOĞUTMALI RÖMORK İÇİN GÜNEŞ DESTEKLİ ENERJİ DEPOLAMA SİSTEMİ TASARIMI VE UYGULAMASI

Muhammet Sait KARASOY

Yüksek Lisans, Elektrik-Elektronik Mühendisliği Anabilim Dalı

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Temmuz 2023, 99 sayfa

Bu çalışma, soğutuculu römork için güneş enerjisi destekli bir enerji depolama sisteminin tasarımını ve uygulamasını tanıtmaktadır. Hareketli bir sistem olan treyler ile birlikte kullanılacak hibrit enerji depolama sistemi tasarlanarak soğutma sisteminin sürekli çalışmasının sağlanması amaçlanmaktadır. Geleneksel soğutma işlemi, kompresörün sadece sabit bir zamanda şebeke gücü ile çalıştırılmasıyla gerçekleştirilir. Soğutma işleminden sonra treyler soğuğu tutabileceği yere kadar gidebilir veya farklı bir şebekeden enerji kullanabileceği bir nokta bulup uzun süre bekleyip tekrar soğutma işlemini gerçekleştirebilir. Aksi halde taşıdığı malzemenin bozulma olasılığı vardır. Bu çalışmada, sürüş esnasında şebeke bağlantısı gerektirmeden bağımsız çalışabilen deneysel bir soğutma sistemi geliştirilmiştir. Sistem, 13 kW'lık bir kompresöre güç sağlamak için 35 kW'lık bir Li-ion pil, 5 kW'lık PV panelleri ve bir invertörü entegre eder. Römork dururken şebeke mevcutsa, hem akü şarj edilebilir hem de treyleri soğutmak için gereken enerji kompresör tarafından şebekeden çekilir. Şebeke olmadığında soğutma ihtiyacı varsa kompresörü çalıştırmak için gereken enerji PV panellerden ve bataryadan sağlanır; soğutmaya ihtiyaç yoksa, akü güneş paneli tarafından şarj edilecektir. Bu senaryolar, araç dururken veya hareket halindeyken geçerlidir ve hibrit evirici, içerdiği enerji yönetimi algoritması ile PV panelleri, bataryayı ve AC şebeke çıkışını koordine edecektir. Bu çalışma ile treylerdeki soğuk havanın daha uzun süre muhafaza edilmesi sağlanacaktır.

Anahtar Kelimeler: enerji depolama sistemi, hibrit invertör, güneş enerjisi sistemi, akü, güç yönetimi

ABSTRACT

DESIGN AND IMPLEMENTATION OF SOLAR ASSISTED ENERGY STORAGE SYSTEM FOR REFRIGERATED TRAILER

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This study introduces the design and implementation of a solar-assisted energy storage system for a refrigerated trailer. It is aimed to ensure the continuous operation of the cooling system by designing the hybrid energy storage system to be used together with the trailer, which is a mobile system. The conventional cooling process is accomplished by running the compressor on a trailer only at a fixed time with the grid power. After the cooling process, the trailer can go as far as it can keep the cold, or find a point where it can use energy from a different network, wait for a long time, and perform the cooling process again. Otherwise, there is a possibility of deterioration of the material it carries. In this study, an experimental cooling system was developed, capable of operating independently during driving without requiring a grid connection. The system integrates a 35 kW Li-ion battery, 5 kW PV panels, and an inverter to power a 13-kW compressor. If the grid is available when the trailer is at rest, both the battery can be charged, and the energy required to cool the trailer is drawn by the compressor from the grid. If there is a need for cooling in the absence of the grid, the energy required to run the compressor is supplied from the PV panels and the battery; if there is no need for cooling, the battery will be charged by the solar panel. These scenarios are valid when the vehicle is stationary or in motion, and the hybrid inverter will coordinate the PV panels, battery, and AC grid output with the energy management algorithm it contains. With this study, it will be ensured that the cold air in the trailer is preserved for a longer time.

Keywords: energy storage system, hybrid inverter, solar system, battery, power management

Dedication

Dedication to my wonderful family for their endless love, support and encouragement, and to my supervisor, Asst. Prof. Dr. Tahsin Köroğlu and Assoc. Prof. Dr. Mehmet Uğraş CUMA who always supported and motivated me during this process.

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LIST OF ABBREVIATIONS

RES	:	Renewable Energy Source
NPV	:	Net Present Value
LCOE	:	Levelized Cost of Electricity
BESS	:	Battery Energy Storage System
PV	:	Photovoltaic
LFP	:	Lithium Iron Phosphate
NMC	:	Nickel Manganese Cobalt
NCA	:	Nickel Cobalt Aluminum
VFD	:	Variable Frequency Drive
MPPT	:	Maximum Power Point Tracking
DC	:	Direct Current
AC	:	Alternating Current
BMS	:	Battery Management System
LTO	:	Lithium Titanate Battery
ESS	:	Energy Storage System
PLC	:	Programmable Logic Controller
HRES	:	Hybrid Renewable Energy Systems

LIST OF SYMBOLS

A	**:** Amper
V	**:** Voltage
W	**:** Watt
kW	**:** Kilowatt
mAh	**:** Miliampere Hour
kg	**:** Kilogram

1. INTRODUCTION

1.1. Solar energy

Solar energy is widely recognized as a renewable and sustainable source of energy, holding considerable potential to address energy demands while mitigating environmental impacts. Its utilization as a heat source has been documented throughout centuries, and advancements in technology have enabled its conversion into electrical energy through the utilization of solar systems. These systems harness the abundant and free solar radiation from the sun, offering a clean and emission-free energy source (Kannan, 2016). However, the widespread deployment of solar energy faces certain challenges, including delays in implementation, which hinder its broad-scale adoption and integration into the existing energy infrastructure (Ellabban, 2014). It becomes imperative to critically evaluate the advantages and disadvantages of solar power to gain a comprehensive understanding of its potential and limitations. A visual representation of the global solar energy distribution-is shown in Figure 1.1.

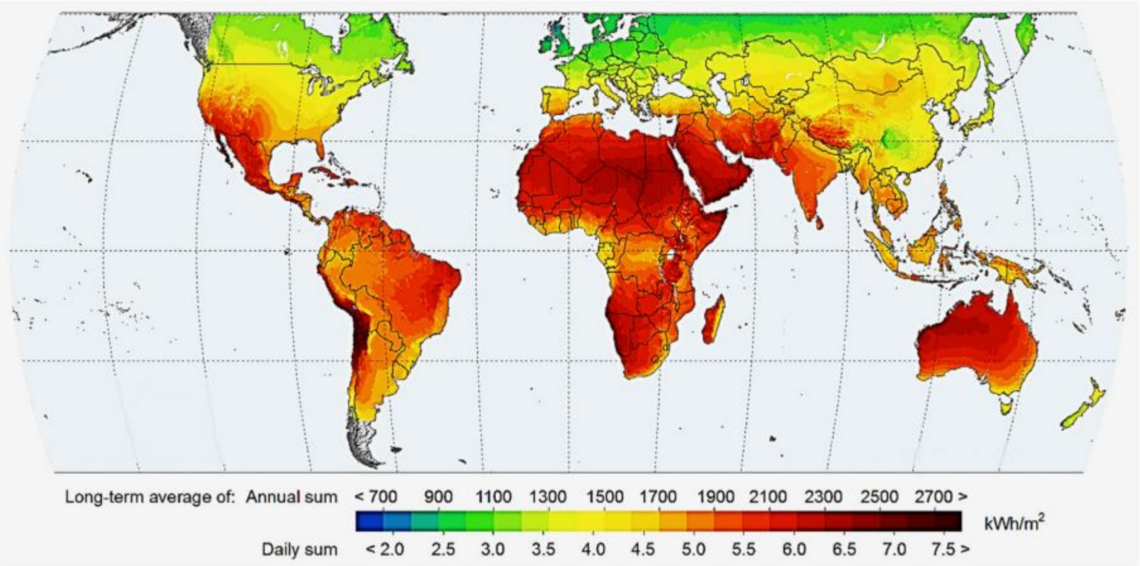

Figure 1.1. Global Solar Energy Distribution (DSI Solar, 2023).

Solar energy is a renewable energy source with uneven global distribution. Regions with the highest solar energy potential are in the tropics and subtropics, while regions with lower solar energy potential can still be good candidates for solar energy development. The global distribution of solar energy production is also uneven, with China, the United States, and India being the top three countries for solar energy production in 2023. The global distribution of solar energy resources and production is likely to change in the coming years, as more and more countries invest in solar energy.

The advantages of solar energy are as follows:

- Solar energy is emission-free, noiseless, and odorless.
- Sunlight is an endless, free resource.
- Solar energy is suitable for heating and mobility.
- Solar power systems are robust and require minimal maintenance.
- PV technologies are constantly evolving (Lakatos, 2011).

The integration of lithium-ion batteries with photovoltaic (PV) technologies has led to significant advancements in the automotive industry. The use of solar energy as a clean and renewable source of power for vehicles is not only beneficial for the environment but also helps reduce dependence on fossil fuels. The use of lithium-ion batteries in vehicles provides a reliable and efficient source of energy storage, whereas PV technologies continue to evolve, making them even more efficient and cost-effective.

By incorporating these technologies into the automotive industry, vehicles can reduce their carbon footprint while also providing consumers with a more sustainable mode of transportation. There are numerous benefits of using solar energy in the automotive industry, including reducing emissions, reducing noise pollution, and providing a cost-effective source of energy that can be used for both heating and mobility. The robust nature of solar power systems, combined with their low maintenance requirements, makes them an ideal choice for the automotive industry.

The conversion of sunlight into electrical energy does not create noise, and above all, it does not create CO_2 or other harmful exhaust gases. This is a significant advantage over fossil fuels because it does not pollute the environment. Unlike natural gas or coal, sunlight is an inexhaustible energy source. It also does not require large machines or industries for its installation. With additional equipment, such as a heat pump, heating element, or e-car charging station, most of the energy requirements can be met by solar energy. Modern solar energy systems have been designed to have a service life of at least 20 years. During this time, solar panels usually require minimal maintenance or repair. High-quality silicone surfaces are extremely durable and resistant to hail, strong winds, and snow.

Until 20 years ago, household electricity could not be provided using solar energy systems. However, both solar systems and PV storage systems are becoming more efficient. Simultaneously, e-mobility and electric heating systems are being developed that make the target of a self-sufficient energy supply attainable (Thormann, 2020). In the long run, electricity consumption will increase, and unfortunately, this also applies to energy prices. Solar energy systems on roofs, factories, and vehicles that use solar energy will become very important. Even if solar energy itself has almost no disadvantages, the economic use of energy sources is associated with difficulties.

- High investment costs for solar systems and storage
- Solar energy systems generate electricity only in daylight
- Solar energy systems are not suitable for all roofs.
- Bureaucratic effort (tax declaration, tariff guarantee, etc.)
- Solar systems and storage systems are not (yet) fully recyclable
- Solar energy can only be stored for a limited time

Despite the numerous benefits of solar energy, its practical implementation is faced with challenges. A prominent obstacle in the widespread adoption of solar energy systems and storage is the upfront investment required for installation, posing a potential deterrent for both individuals and organizations. Additionally, solar systems can only achieve maximum efficiency when the sun is shining and at the right angle, meaning they may not be suitable for areas with limited sunlight or when there is little sunlight. To ensure an uninterrupted power supply in the absence of sunlight, it is often necessary to have alternative energy sources or backup systems in place. Solar energy systems also require a suitable roof for installation and may not be an option for all buildings. The bureaucratic effort required to take advantage of solar energy, including tax declaration, and obtaining tariff guarantees, can also be a challenge.

Although solar energy systems have relatively low maintenance, their components and storage systems are not yet fully recyclable, which can pose challenges for disposal and contribute to environmental impact. In addition, solar energy can only be stored for a limited period of time, which can affect its reliability as a long-term energy source. To reduce electricity costs in the long term, it is first necessary to invest a large amount in the solar energy system (Boldyrev, 2020).

Solar energy is free, unlimited, and readily available, but it can only be used when the sun is shining. Solar energy systems do not produce electricity at night, and their efficiency drops drastically on bad weather days and in winter. However, this is only a disadvantage if solar energy cannot be stored. Technologies are constantly evolving, but both solar modules and battery storage are only partially recyclable. (Larcher, 2015).

1.2. Photovoltaic

The term photovoltaic (PV) describes the direct conversion of sunlight into electrical energy. Physicist Alexandre Edmond Becquerel discovered that conversion was possible as early as 1839 when he first demonstrated the photoelectric effect. All modern PV systems used to generate electricity in private homes, commercial enterprises, and solar parks are based on the photoelectric effect. It requires a solid compound (semiconductor layers made of silicon) and a photon source, namely sunlight. When sunlight hits a solid, photons transfer their energy to the solid. That causes electrons in the solid to move and create an electrical voltage. Solar cells are the basis of converting sunlight into electrical energy. Modern solar cells consist of two silicon semiconductor layers, separated by a transition layer (Fraas, 2014).

The upper semiconductor layer was negative (n-doped), and the lower layer was positive (p-doped). Photons from solar radiation hit the semiconductor layer, electrons are released from the semiconductor and start to move. Negatively charged electrons migrate to the top of the n-doped layer. In their place, positively charged holes are left that move to the bottom of the p-doped layer. The motion creates an electrical voltage in the transition layer between the two semiconductors, directed through the metal layers and converted into household electricity by an inverter (Sablon, 2011).

Solar modules always produce direct current (DC), but outlets in the home supply alternating current (AC) that means that all electrical appliances with plugs are powered by AC. Therefore, solar energy from the roof must be converted from DC to AC before use at home. The task is performed by an inverter installed in the house (or other applications) with a solar system. With solar modules and inverters, one has a solar system as long as the sun shines (Daut, 2013).

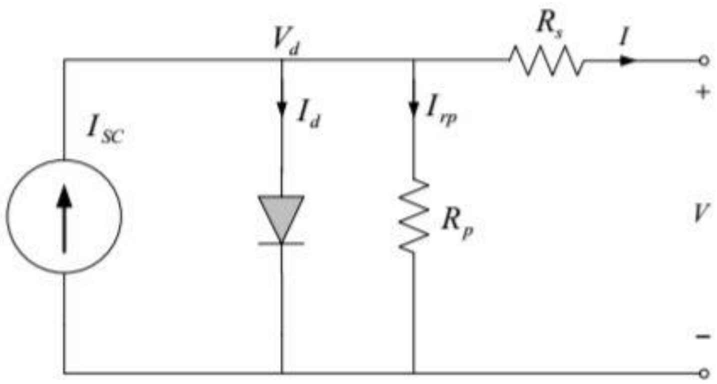

Figure 1.2. PV Electric Circuit (Işen & Koçhan,2019)

PV has evolved from an eco-trend to a fundamental part of the energy transition. Almost no other energy source is as common and easy to use as the sun. Therefore, two main goals are important for the future of PVs: increasing efficiency to maximize energy conversion and reducing manufacturing costs to make solar power more economically competitive. The number of solar power systems in the world has increased significantly over the last decade. Legislative changes, such as the solar obligations, are intended to further encourage the expansion of solar systems. Simultaneously, countries' financing programs offer financial incentives for solar energy systems, electricity storage and e-charging stations (Bajenescu, 2015).

Existing technologies are constantly being developed to use solar energy more efficiently on the one hand, and to open up new potential uses on the other. Research is carried out to increase the efficiency of solar modules and further optimize storage technologies. Many homes and businesses strive for self-sufficient sources of solar energy that was not entirely possible. It will be possible in the future thanks to technical innovations. Versatile energy solutions that align all areas of the energy supply with solar energy already exist and are currently in development. In addition to residential consumption, solar energy can charge e-cars through home stations and power heat pumps. This thesis presents a solar-assisted cooling system, similar to existing studies, but further advancements are required. Researchers continue to explore and improve these solar-based technologies. (Priessner, 2020).

After evaluating the pros and cons of solar energy, it is evident that a solar power system may not be the ideal solution for every situation. High purchasing costs and structural conditions can complicate a project. However, it is also clear that solar energy is the cleanest and easiest alternative power source. These advantages make them indispensable for the energy transition. Owing to the further development of PV systems and storage technologies, electricity generation from solar energy will become even more efficient in the future and will further evolve towards holistic energy solutions. Homeowners' dreaming of a self-contained power supply should, therefore, proactively plan their systems. In the long run, the disadvantages of solar energy can be eliminated (Ramakumar, 1993).

1.3. Battery Technologies

Batteries act as energy storage systems, converting electrical energy into electrochemical energy for subsequent retrieval as electrical energy when needed. Configurations comprising multiple interconnected batteries are referred to as battery systems, encompassing electrochemical devices such as one or more electrochemical cells or flow cells. These batteries serve various purposes including powering electronic devices like mobile phones, radios, and laptops, as well as electric vehicles. Moreover, they are essential components in satellite and space systems, communication systems, and defense systems.

A battery cell consists of a metal anode (negative electrode), a metal oxide cation (positive electrode), and an electrolyte that provides a chemical reaction between the two electrodes (Winter, 2004). While the anode is corroded during electrolysis, an electric current is generated at the cathode because of the ionic exchange reaction. The electrical energy generated by this reaction can be used in various applications. Batteries function as voltage sources, providing the necessary electric current to drive circuits. The operation of batteries relies on the conduction of electrical charges within liquids that contain different substances. This process facilitates the separation of electrical charges. The basic form of a battery is the voltaic element, developed by Alessandro Volta in 1794. Alessandro Volta chose copper and zinc metals as electrodes and diluted sulfuric acid as conductive liquids which resulted in a voltage of 0.89 V. By connecting many elements in series, he created voltage sources with relatively high voltages. These arrangements are known as voltaic columns. The basic form of a battery is the volt element, developed by Alessandro Volta in 1794 (Gill, 1976).

As voltage sources, batteries drive the electric current in the circuits. The way batteries operate is based on electrical conduction processes in liquids into which various substances are introduced that separates the electrical charges. A battery is a source of electricity that consists of several interconnected mono cells. The most common are carbon-zinc elements as mono cells. The two electrodes are composed of carbon and zinc. Such a carbon-zinc element provides a voltage of 1.5 V. If three such carbon-zinc elements are connected in series, a flat battery with a voltage of 4.5 V is obtained. (Thounthong, 2006), (Chan, 1993), (Ahn, 2022).

Currently, several battery technologies are available on a large scale. However, not all are suitable for use in fully electric vehicles. Based on the assessments, it explains why lithium-ion technology is currently most likely to meet all requirements and offers the greatest potential for further technical development. The following battery technologies (Moeller, 2018) are currently technically available and have already been used in electric vehicles in the past:

- Lead-Acid Gel Battery
- Nickel Cadmium Battery
- Nickel Metal Hybrid Battery
- Sodium Nickel Chloride High-Temperature Battery
- Lithium Ion Battery

The battery technology types are listed in Table 1.1. (Sterjova, 2022). Although double-layer capacitors for use in electric vehicles have been increasingly discussed in recent years owing to significant advances in technical developments, they are not an option for all-electric drives because of their high self-discharge rates. Therefore, this technology has not been discussed further.

Table 1.1. Battery Technology Types.

Technology	Strengths	Weaknesses
Lead Acid	• Acceptable energy and power density • No complex cell management needed • Relatively low investment	• Limited life cycle • Ventilation needed • Recycling needed
Nickel Cadmium	• High Reliability • High Energy Density • Very low maintenance required	• Suffer from memory effect • Relatively high cost
Nickel Metal Hydride	• Environmentally friendly • 30% – 40% higher capacity from standard Ni-Cd • Recycling mercury profitable	• High intensity for self-discharge • Deteriorated performance for higher temperatures
Sodium Sulfur	• Raw material cost is low • High energy density • High cycle lifetime	• High temperature for operating • High thermal losses • Maintenance requirements
Sodium Nickel Chloride	• High cell voltage • High cycle lifetime	• Low energy and power density • High operating temperature • High thermal standby losses
Lithium Ion	• High efficiency • High energy density • Long life cycle	• High capital cost due to special packaging • Internal over-charging protection circuits

Lead-acid batteries represent a very old technology and have been widely used as starter batteries in vehicles for decades (Garche, 2017). The energy content of lead-acid batteries is very low compared with other battery systems. Gravimetric energy densities of 20-30 Wh/kg are possible. Although high gravimetric power densities of up to 430 W/kg can be achieved, they result in very low cycle stability and therefore very short service life. The service life of lead-acid batteries is very short compared to that of current technologies (Berndt & Spahrbier, 2001). The achievable calendar service life is 5-15 years, depending on the mode of operation and storage. Lead acid batteries are currently the least expensive battery systems available. With the same capacity, production costs are approximately one-fifth of lithium-ion batteries (as of 2010). However, as batteries are a mature technology with large production volumes, no significant cost reduction is expected in the future. (Ruetschi, 2004).

Owing to robust construction, the safety risks associated with lead-acid batteries are relatively low. They are thermally stable, meaning that the battery does not heat up or explode even at high temperatures. Although lead is a toxic heavy metal and sulfuric acid can harm the environment, the environmental compatibility of this technology can be classified as average. Because the electrolyte thickens into gel pastes, limiting the uncontrolled leakage of electrolyte liquid to some extent even if the battery chamber is destroyed, and there is an extremely good disposal infrastructure for lead-acid batteries. In general, it can therefore be said that this technology is basically suitable for use in electric vehicles. (Chatroux, 2016).

Nickel-cadmium batteries have been produced on a large industrial scale for decades and are used in many household and industrial areas. However, its energy density is rated as poor compared to other technologies. When subjected to a two-hour discharge, the battery exhibits gravimetric energy densities ranging from 40-55 Wh/kg, accompanied by a notably low cycle efficiency that reaches a maximum of 80%, and a significantly high self-discharge rate of approximately 20% per month at ambient temperatures. The performance availability is an average. Gravimetric power densities of up to 700 W/kg per battery are possible. The cycle stability is almost twice that of lead systems. It can be operated for up to 2000 cycles with an 80% depth of discharge, which is a significant advantage over short-lived lead-acid batteries (Sullivan, 2010).

A complete system can cost between €250 and €500/kWh, which is twice that of lead-acid batteries (Parker, 2001). In addition, due to decades of development and production, the technology is already very mature and major cost reductions are no longer expected. However, nickel-cadmium batteries contain 20% of the highly toxic and carcinogenic metal cadmium and are therefore classified as very harmful to the environment if not disposed of properly. At the European level, a ban on the use of cadmium was passed in a directive as early as 2006 and then entered into national law at the end of 2008. Therefore, this battery technology is unsuitable for future use as a traction battery (Khawaja, 2019).

With the resulting ban on nickel-cadmium batteries, replacement technologies have been increasingly developed. In recent years, nickel-metal hydride batteries have proven to be equivalent, and in some ways, even better alternatives. The theoretically possible energy content of a nickel-metal hydride battery is almost twice that of a nickel-cadmium battery. With a two-hour discharge, gravimetric energy densities of 50 to 80 Wh/kg can be achieved for a battery with a reasonable cycle efficiency of 80%. The main disadvantage of this technology is its high self-discharge rate. Thus, 30% of the stored energy is lost within a month at room temperature (Arun, 2022).

Li-ion batteries offer a notable advantage with their high-power densities of up to 1200 W/kg and can typically last through an estimated lifespan of 1000 cycles (Majeau-Bettez, 2011). The production costs of high-energy cells are very high, currently around 500 €/kWh. The technology for high-energy cells is considered mature, especially in the last few years, and no major technical improvements have been made and are not expected in the future. The potential price cuts are in the same range as for lithium-ion batteries. Nickel-metal hydride batteries are relatively thermally stable and have very low safety risks. NiMH batteries have high environmental compatibility because they do not contain harmful cadmium (Nagmani, 2022).

All the systems described so far have in common that they are operated at ambient temperature and have solid electrodes and liquid electrolytes. A sodium-nickel chloride high-temperature battery uses a different approach. It is operated at a high temperature of around 300°C and uses liquid electrode materials. Sodium-nickel chloride batteries have a very high energy density, which can even compete with lithium-ion batteries under certain conditions at present regarding the entire battery system. The energy densities of sodium-nickel chloride batteries are around 86-106 Wh/kg. In addition, 80-95 % yields can be achieved. In contrast to these positive characteristics, a high level of self-discharge is the main disadvantage of technology. To maintain high temperatures, power should be drawn from the battery when it is not in use. The energy requirement is so high that up to 10% of daily battery capacity is consumed. The limited power availability is another limitation. Power densities of only 168-181 W/kg are achieved

(Longo, 2014), (Nurohmah, 2022). The cycle stability is similar to that of the NiMH systems. Up to 1500 cycles (Sterjova, 2022) can be achieved. Also, high calendrical lifetimes are possible. Their service life is specified to be between 8 and 10 years. Since sodium is highly reactive, it should be expected that in case of mechanical destruction of the cell, leakage of liquid sodium may result in fires or personal injury in case of skin contact. A high level of thermal insulation protects the battery from external heat, for example, external fires. Therefore, the security risks can be rated as average. The environmental compatibility of sodium nickel chloride batteries is very good because of the materials used and the effective recycling process, and because of their high self-discharge rates, batteries are currently unsuitable for large-scale use in electric cars (Rajabizadeh, 2022).

Lithium-ion batteries are a relatively new technology because of lithium is the lightest metal, and very high energy per mass can be stored. For a complete system with a two-hour discharge gravimetric energy densities of 90 to 140 Wh/kg are possible (Zhang, 2022). Another advantage is that lithium batteries have the highest efficiency of all the offered technologies. Cycle efficiency ranges from 90% to 95%. Power densities can be adapted to very different requirements thanks to different material combinations and can reach very high values up to 3000 W/kg (Gupta, 2022). A typical service life is between 1000 and 1500 cycles at 80% depth of discharge. The service life can therefore be classified as quite average, nickel-cadmium batteries achieve significantly higher cycle numbers. Lithium batteries require complex and costly manufacturing; therefore, this technology is still relatively expensive (Lai, 2022). A major safety risk with lithium-ion batteries is that lithium is highly reactive. Therefore, it should not come into contact with oxygen or water, otherwise, it will react immediately with these substances and generate heat. "Thermal runaway" may occur if the cell temperature reaches approximately 100°C. Accordingly, the effort required for battery management systems (BMS) is significant. Each cell must be equipped with sensors for temperature, current, and voltage monitoring and a safety valve, and the entire battery system must be cooled efficiently (Hu, 2023).

Lithium batteries have average environmental compatibility, with potential harm to humans in large quantities and risk of skin burns due to pure metal contact, but pose no threat to humans or nature when disposed of properly. Lithium-ion batteries are suitable for use as traction batteries because of their high energy and power densities. By combining different cell materials, the lithium battery can be optimally adapted to various conditions. It achieves a very high energy density and still exhibits considerable improvement and cost-reduction potential. Therefore, lithium-ion batteries will be the dominant technology in the future (Deng, 2022).

1.4. Refrigerated Trailer

Refrigerated trucks are road vehicles used to transport goods perishable at high temperatures. These types of trucks use a variety of strategies, including the use of ice, to maintain a cool temperature in the truck's cargo area. A refrigerated truck can transport perishable goods over long distances before the cargo reaches its agreed destination. A refrigerated truck would use ice to keep the landfill cool. Often blocks of solid ice were lined up along the interior walls of the room, leaving the main area open for the storage of chilled products. Over time, the refrigerated truck began to use built-in cooling systems that worked similarly to domestic refrigerators. There are also some refrigerated truck designs that use carbon dioxide to lower and maintain the desired temperature in the trailer compartment. Refrigerated trucks are often used to transport perishable foods from production facilities to retail outlets, which in turn sell the food to the public. Generally, foods are processed foods that need to be frozen to maintain their freshness. Grocery products such as raw meat, frozen appetizers and frozen dairy products such as ice cream, sherbet, and frozen yoghurt are transported to supermarkets by refrigerated trucks (Song, 2022), (Liu, 2012), (Tso, 2002).

For short distances, the refrigerated truck can be a single unit very similar to a passenger car. Such trucks can transport smaller quantities of frozen goods from one place to another, such as from a warehouse to a nearby supermarket. One of these smaller refrigerated trucks is ideal when the total delivery is small, eliminating the need for larger semi-trailers to transport larger quantities of goods over longer distances. In addition to foodstuffs, other goods that need to be maintained at a constant temperature can be transported by refrigerated trucks. Some drugs require temperatures that cannot be transported by standard transport vehicles. Organs for transplants can also be transported to destinations via refrigerated shipping. In some cases, both temperature and humidity can be controlled by transporting valuable archaeological artifacts in such trucks. The advanced level of control enables the prevention of additional degradation of recovered artifacts during transportation to research facilities or museums.

The refrigerated truck market is witnessing significant growth, particularly due to the logistics sector's high utilization rates, driven by revenue generation from vehicle operations. In response to the current reliance on fossil fuel-based energy systems, an innovative alternative adhering to the zero-waste principle has been developed. This novel system directly contributes to sustainable logistics transportation, offering potential for the establishment of new zero-emission-focused enterprises. Although analogous systems exist in Italy, the system developed in this study demonstrates marked cost advantages. The research focuses on the design and implementation of essential components required for the first refrigerated electric truck bed in Turkey. Notably, the conventional electricity supply from diesel generators is replaced in this thesis with a 35 kW/h battery powered by solar energy, effectively meeting the electricity demands of the refrigerated truck.

2. LITERATURE REVIEW

Nowadays, human beings need energy in different forms to provide basic needs such as food, clean water, transportation, and heating/cooling. The escalation in energy consumption can be attributed to key factors, namely the rise in population size and income levels. Projections made by the United Nations show that the world population will rise to 9.2 billion in 2040 (Lu, 2015). The situation reveals the necessity of providing energy supply to 1.9 billion more people. If no change in energy policy, the international energy agency projects a 130% increase in CO_2 emissions by 2050 and an increase in the global average temperature by 6 °C (Aneke, 2016). The amount of carbon dioxide emissions resulting from the consumption of fossil-based fuels has reached the level of 33.1 Gton-CO_2 as of 2018 (Global Energy & CO_2 Status Report 2019). Increasing carbon emissions, in addition to environmental pollution, cause irreparable damages that threaten human life such as global warming and climate change. How to prevent environmental problems and seek solutions for the future are the common problems of humanity. If the increasing trend of fossil fuel emissions continues, mass human migration is predicted as a result of extraordinary climate changes and the reduction of agricultural areas and clean water resources (Bank, 2018).

The ideal scenario is to have energy readily available for use exactly when and where it is needed. Storing energy so we can use it whenever we want is called storage and can be in various forms. In the realm of natural ecology, biomass serves as an energy reservoir for animals and parasites. Similarly, in the context of energy storage, certain features are desired, including high storage capacity, efficient charge/discharge processes, minimal self-discharge and capacity losses, extended lifespan, affordability, and high energy density (measured in kWh/kg or kWh/liter). Essentially, energy storage systems should possess the ability to store a maximum amount of energy within minimal volume and weight. Various energy storage methods exist, such as biological storage, chemical storage, thermal storage, and electrical storage, as well as potential energy, gravitational potential energy, and kinetic energy. However, this discussion primarily focuses on the key energy storage methods of chemical, mechanical, thermal, and electrical storage.

Renewable energy sources (RESs) are the most effective answer to alter aforementioned problems. solar and wind energies are wide used for electricity generation. Energy storage can make the grid more responsive and reduce the need to build backup power plants by quickly responding to large fluctuations in demand and helping to recover from solar and wind power outages. The efficiency of an energy storage system is evaluated by considering constraints such as response time, energy loss rate, and energy storage density. With an increasing trend, RES are widely used to meet electrical energy demands and reduce greenhouse gas emissions. The intermittent nature of clean energy sources adversely affects electricity generation, becomes a challenge for uninterrupted and regular energy supply to the consumer, and jeopardizes the functioning of networks from different operational and technical aspects (Chong, 2016). The paramount attributes of energy storage technologies lie in their power density and energy density. Figure 2.1 illustrates and compares the power and energy density of various energy storage systems (Hajiaghasi, 2019).

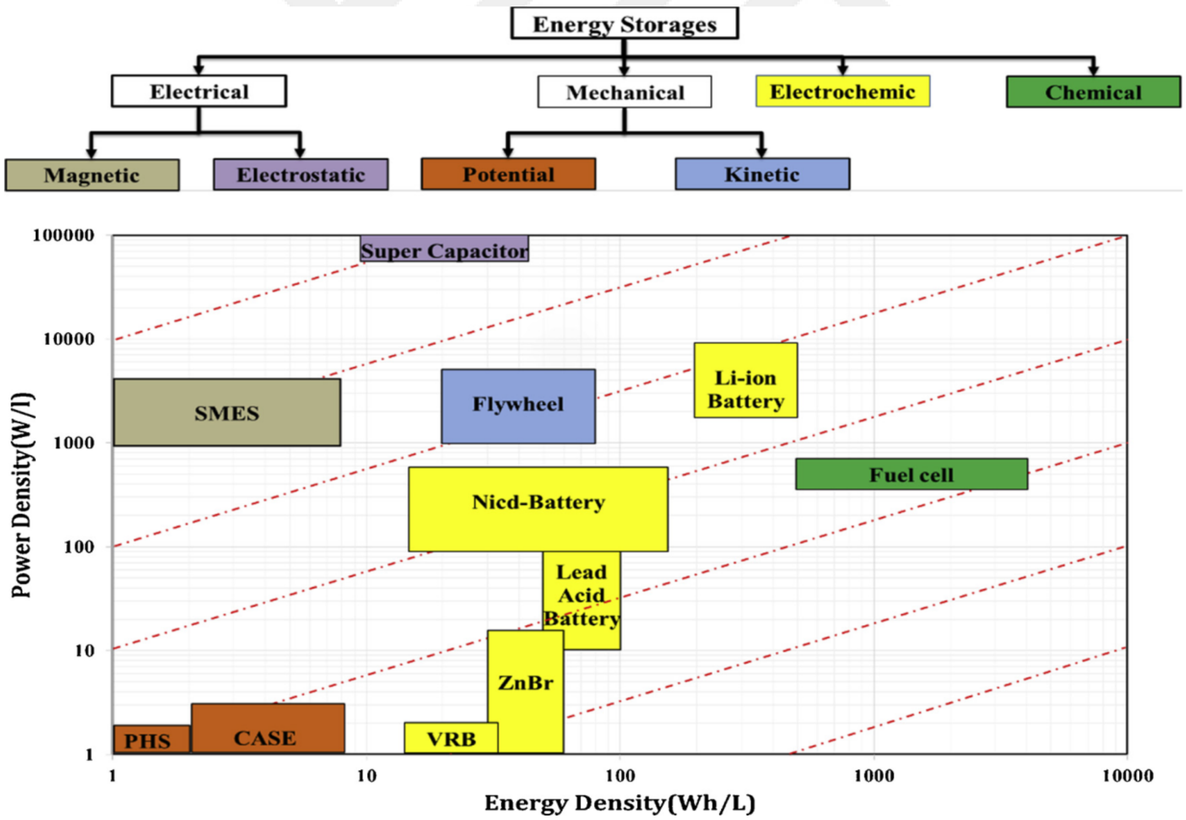

Figure 2.1. Global Solar Energy Distribution (Hajiaghasi, S., Salemnia, A., & Hamzeh, M.,2019).

Energy storage has been a well-established concept dating back to the early 1800s, with batteries serving as a prominent technology in that realm (Scrosati, 2011). On the other hand, pumped hydroelectric energy storage applications in the United States date back to the 1930s. Due to the demand for a dynamic, flexible, and clean grid, new-generation energy storage projects have gained momentum. Efforts to develop reliable, economical, efficient, and high-capacity energy storage solutions in terms of more efficient use of energy in different forms are carried out worldwide.

Lithium-ion batteries are widely used due to their high energy storage capacity, low internal resistance, and over 90% efficiency. Technically, they should be operated by paying attention to the appropriate temperature and maximum capacity, otherwise the efficiency of lithium-ion batteries will decrease. With their high efficiencies and energy densities, lithium-ion batteries are well suited for use in distribution systems and automotive areas where energy quality is important. Lithium-ion batteries have many advantages. These; They can be listed as long-term use, high energy density, small portability, maintenance-free, and ability to work in a wide temperature range. Drawbacks associated with this technology include the elevated installation expenses and the potential risks of overcharging.

Today, there are studies conducted in many sectors with li-ion batteries and RES. The most common of these is to use the electrical energy stored in the battery thanks to solar panels in the grid. In this study, it is planned to create a hybrid system consisting of a solar panel, a li-ion battery and an inverter. The distinguishing feature of this system in comparison to other energy storage systems lies in its seamless integration into a mobile cooling trailer, offering unique advantages in terms of portability and on-the-go cooling capabilities. The utilization of RES, particularly solar and wind power, is increasingly seen as a practical and successful approach to tackling the pressing concerns of diminishing oil reserves, rising carbon emissions, and the growing demand for energy (Nehrir, 2011), (Shivarama Krishna, 2015). Simultaneously, many solar and wind power projects have been constructed or are currently being developed to achieve renewable energy goals and elevate the usage of clean energy sources.

Governments have also implemented policies and programs to encourage the growth and development of renewable energy, including incentives for renewable energy projects

(AECOM, 2015). Additionally, it is projected that by 2025, the cost of solar PV and onshore wind energy will decrease by 43% and 26% respectively. (IRENA, 2015). Despite the benefits of renewable energy for the environment and sustainability, there are still two significant challenges to integrating it into the power grid. One of these challenges is the fact that renewable energy generation is highly dependent on weather and climate conditions in a specific location which can result in intermittent and unpredictable energy production, which can cause instability in the power system. (Mahmud, 2016). Another issue is that as more renewable energy is integrated into the power grid, it becomes more difficult for traditional power systems to accommodate the increased energy generation. For example, in recent studies, there have been instances of overgeneration of solar power leading to low net demand during midday in California, while the net demand in the morning and evening remained high. As more solar power is added, this can result in a deeper "duck curve" in the net demand profile, where the net demand is low during the middle part of the day (Paul Denholm Gregory, 2017), (Operator CIS).

Therefore, the necessity to curtail the amount of solar power generated emerges from the constrained capacity to accommodate the substantial surge in energy generation. Regrettably, this results in an unfortunate decline in the economic and environmental benefits associated with the integration of renewable energy sources. One potential solution to these challenges is the use of Hybrid Renewable Energy Systems (HRES), which involve combining different types of renewable energy resources in an optimal way (Paul Denholm Gregory, 2017). In this way, times when one energy resource is not producing as much energy can be balanced by other resources that are producing more energy at that time. (Luna-Rubio, 2012). A clear illustration of this concept is the synergy between solar and wind energy, where they supplement each other. (Prasad, 2016).

By integrating various renewable energy resources, the overall efficiency and stability of the system can be enhanced (Banos, 2010), (Gupta, 2014), (Nema, 2009), (Sinha, 2015). Various detailed studies have been conducted on the optimal sizing of energy generation units, energy management and control in HRES (Arul, 2015), (Deshmukh, 2008), (Neves, 2014), (Prakash, 2016), (Siddaiah, 2016), (Olatomiwa, 2016), (Upadhyay, 2014). While HRES can help improve reliability and stability, in many cases, a conventional generator or connection to the main grid is still necessary to ensure a stable power supply. One way to overcome the issue is to incorporate Energy Storage Systems (ESS) into HRES, which can absorb and release power at different times, thus allowing for a higher penetration of renewable energy that has been an area of active research (Whittingham, 2012), (Mahlia, 2014), (IRENA, 2015).

Among the different types of ESS technology, battery energy storage system (BESS) have gained significant attention due to their quick response time, ability to be controlled and the fact that they can be placed anywhere. (IRENA, 2015). In addition to their fast response time, controllability, and geographical independence, BESS also have a diverse range of applications, such as enhancing power quality for short periods, managing energy over the long term, increasing reliability, providing the uninterrupted power supply, and deferring the need for transmission upgrades (Cho, 2015), (Nair, 2010), (Poullikkas, 2013), (Loıu, 2014). The advancements in battery storage technologies have made them more mature and reliable, however, their economic feasibility is still a major obstacle to overcome before they can be widely adopted in the energy sector. Despite expectations of cost reduction in the future, the cost of battery systems remains a major concern (Nair, 2010), (IRENA, 2015). Despite the maturity and reliability of certain battery storage technologies, the economic considerations of battery systems remain a significant barrier to their widespread adoption in the energy sector (Divya, 2008), (Lawder, 2014).

The optimal sizing of battery storage systems is crucial in achieving a balance between improving the performance of renewable energy systems and achieving profitable investments (Divya, 2008), (Lawder, 2014). However, due to the variability of renewable resources, determining the proper size of battery storage in various RES can be challenging. While there have been many studies on this topic, there is currently a lack of a comprehensive review on battery sizing issues across various RES, despite the availability of reviews on battery applications in power systems, standalone systems, storage sizing for solar and wind power plants, and HRES where the battery is included as a component (Berrada, 2016), (Zhou, 2010), (Erdinc, 2011), (Yang et al., 2018).

The size and overall design of a RES is dependent on the financial return of the system. Financial indicators, such as net present value (NPV) and levelized cost of electricity (LCOE), are commonly used to make decisions and compare different alternatives. These indicators take into account lifetime costs of the system including initial capital costs, operation and maintenance costs, and fuel costs. Optimizing these indicators, such as maximizing NPV or minimizing LCOE, can help determine the optimal size of BESS and overall design of the RES. Many studies have been conducted to evaluate the overall costs and benefits of a BESS in a RES over the operational lifetime of the system (Chen, 2011), (Shang, 2015). The size of a BESS and the overall design of a RES is often determined by the financial return of the system. Financial indicators, such as NPV or LCOE, are commonly used to compare different alternatives in a common unit, such as local currency (Nguyen, 2015), (Bahmani-Firouzi, 2014). However, determining the costs and benefits of a BESS over its operational lifetime can be complex and requires consideration of various factors such as upfront capital costs, annual operation and maintenance costs, and fuel costs. There have been numerous studies that have explored the financial aspects of BESS sizing, but the modeling of BESS costs and the inclusion of factors such as disposal and recycling costs are often overlooked (Zakeri, 2015), (Fossati, 2015). Another financial indicator approach is to optimize the market benefit of integrating a battery system into a RES. In particular, in the case of microgrids, the objective is to maximize the total benefits when connected to the main grid, while minimizing the total costs associated with operating in an isolated mode (Chen, 2012), (Khorramdel, 2015).

In microgrids, the optimal design of a BESS is often determined by maximizing the market benefits while minimizing the total costs associated with the system. This includes evaluating the levelized operating costs from the battery and other components, as well as calculating the difference between the revenue generated from selling electricity and the total operating costs to determine the overall benefits (Chen, 2012), (Khorramdel, 2015). Instead of considering the overall financial values, some studies have focused on specific financial metrics such as maximizing the profit from selling electricity to the grid and minimizing the cost of purchasing electricity from the grid in a grid-connected system (Ru, 2013). An alternative approach was to focus only on the short-term financial gain of the RES, by optimizing the system's performance to match energy output with the fluctuating electricity spot prices over a 24-hour period, disregarding the long-term operating costs (Korpaas, 2003). Another approach to determining the size of a BESS is to focus on minimizing the overall investment cost, which includes the capital cost of the battery system and other components, in order to determine the power and energy rating of the BESS.

The objective of this strategy is to alleviate the initial financial burden faced by project developers through the restriction of capital expenditure requirements. (Dragicevic, 2014). As opposed to financial indicators, which can be measured in a common unit and easily compared, technical indicators can be more difficult to compare due to their lack of a common unit. One way to integrate technical indicators is to use them as a single optimization goal or to include them as constraints during the sizing process.

Technical indicators can be quantified using binary variables, such as meeting or not meeting a requirement, or as a specific value goal, such as minimizing renewable curtailment and forecast errors. When evaluating technical indicators for battery inclusion in RES, it is important to consider how these indicators support the dynamic (i.e., time-varying) or steady-state (i.e., time-invariant) characteristics of the RES. To improve the dynamic characteristics of RES, two main technical criteria for both autonomous systems and grid-connected systems are frequency regulation and voltage stability, which can be treated as binary variables that means that the battery is dispatched to meet the frequency and voltage requirements. When it comes to technical indicators for the inclusion of a battery system in renewable energy systems, frequency regulation and voltage stability are two key considerations. These indicators are used to measure the support that the BESS provides for the dynamic or steady-state characteristics of the renewable energy system. Frequency regulation, in particular, is used to maintain the frequency of the system within a certain range by adjusting the output of the battery in response to any disturbances. For example, if the rated frequency is 50 Hz, and it starts to deviate from that level, the BESS will be activated to bring it back to 50 Hz which helps to ensure that the system remains stable and reliable (Jia, 2014). Voltage stability by BESS involves adjusting the voltage level to within a certain range. For example, when the voltage deviates from the normal level by more than 5%, the BESS is activated to bring it back within the acceptable range, as set by the American National Standard for Electric Power Systems and Equipment (Liu, 2014).

A BESS, with its ability to provide both active and reactive power, can play a crucial role in maintaining frequency and voltage stability in power systems. This aspect holds particular significance within microgrid systems, wherein the BESS serves as a consistent point of reference for frequency and voltage control, thereby contributing to system stabilization. Even in grid-connected systems, a BESS with fast dynamic response can assist in frequency and voltage regulation during disturbances such as fluctuations in renewable energy or load, or sudden failures. Studies have shown how battery systems can be used to address a range of disturbances, including generator failure, variations in solar generation, and even solar plant failure in grid-connected systems (Yue, 2014). BESS have been frequently utilized for maintaining the stability of frequency in autonomous systems, such as standalone high-renewable energy systems and power systems. Because imbalances between the power generated and the power consumed can cause frequency instability in these types of systems. However, voltage stability tends to be a more pressing concern in distribution networks that have a high penetration of RES. (Aghamohammadi, 2014), (Jia, 2014), (Johnston, 2014).

Voltage stability in a distribution network is a critical issue due to the potential for significant drops or rises in voltage as a result of heavy loads or the distance between substations and end-users. This is particularly relevant in systems with high levels of renewable energy integration, which can cause fluctuations in voltage levels (Wight, 2015), (Alam, 2014). Therefore, by using battery systems in an optimized manner, voltage stability can be effectively maintained and any potential voltage drops or increases can be prevented (Johnston, 2014), (Nazaripouya, 2014). One of the steady-state criteria for BESS sizing is reliability, which measures the ability of the system to function as intended and maintain a consistent level of performance over time. This criterion can be used to determine the necessary power and energy capacity of the battery system to ensure that it can meet the energy needs of the system even under adverse conditions (Alex, 2014), (Rodrigues, 2015).

Renewable energy curtailment is the practice of reducing the output of RES to prevent overproduction or grid instability. It can be measured as the difference between the amount of power that could be produced with available resources, and the amount actually dispatched. This difference can be expressed as a power profile or as accumulated energy in kWh, and is often used as a technical indicator for determining the appropriate size of a BESS (Bird, 2017). Another technical aspect of BESS usage is to shape the power profile by reducing peak power demand, maintaining a consistent output, and smoothing out fluctuations. One way this is achieved is through peak shaving, where the capacity of the battery system is determined by regulating the output to match the average daily wind power with the average daily load (Zhao, 2014). The sizing of BESS can also be determined by its ability to provide constant power output for a RES, such as a wind farm. This method of sizing the BESS involves using the battery to smooth out variations in the wind power generation and maintain a consistent level of power output for the farm (Wang, 2014).

The variability of renewable energy can be smoothed by using an ESS as a low-pass filter. The size of the ESS can be determined by analyzing the ESS's behavior, such as its response time and capacity. This approach can be used in conjunction with other sizing indicators such as peak shaving, constant power output, and curtailment (Watanabe, 2014), (Johnston, 2014). When designing a standalone renewable energy system or microgrid, factors related to reliability are often taken into account. This is particularly important in cases where backup options are limited or costly. One example of this is using the Loss of Load Expectation (LOLE) as a metric for evaluating the system's reliability. LOLE is defined as the expected fraction of unserved load in the microgrid during a given period. For example, a target reliability of power supply may be set at 0.1 days/year. This means that the system is expected to have no more than 0.1 days of unserved load per year (Bahramirad, 2014). One approach for determining the appropriate size of a BESS is to take into account the potential inaccuracies in forecasting the availability of RES and to ensure the BESS can compensate for any discrepancies. This can involve evaluating the expected errors in forecasting and determining the necessary battery capacity to mitigate the impact of these errors on the power system (Brekken, 2014), (Bitaraf, 2014).

Another key aspect in determining the size of a BESS is to account for the variability in RES and the potential errors in forecasting their output. This is particularly important in situations where renewable generators are participating in electricity markets and need to meet their contracted generation commitments. By using battery systems to compensate for forecasting errors, the utilization of renewable energy can be improved and potential penalties for non-delivery can be avoided. Additionally, factors such as battery cycle life, Depth of Discharge (DOD), and charge/discharge rates can also play a role in determining the optimal size of the BESS, often serving as constraints in the sizing process. Various methods can be used to evaluate the degradation of BESS. Another method for evaluating battery degradation is to consider the number of cycles over a certain time period, as proposed by Dragicevic et al. in their study. This approach can be useful for determining the overall lifespan of a BESS (Dragicevic, 2014).

Another method to assess the degradation of BESS is by evaluating the State of Health (SOH) of the battery, which takes into account both the effects of cycling and time-related aging on the battery's performance. This can provide an accurate measurement of the battery's condition and can be used to identify any degradation over time (Cervone, 2014). The second approach is to integrate both financial and technical indicators into a single optimization problem, where the goal is to find the optimal battery size that balances the trade-off between cost-effectiveness and technical performance. This approach takes into account the cost of the battery system, as well as its expected lifetime, degradation, and other technical parameters, in order to find the most cost-effective solution that meets the technical requirements of the system. This approach is becoming increasingly popular as it allows for a more holistic assessment of the battery system and its integration with the RES.

Another approach to combining financial and technical indicators is by using multi-objective optimization techniques, where the goal is to find a set of solutions that balance the trade-offs between the different objectives. This approach allows for a more comprehensive evaluation of the various options and can provide a better understanding of the trade-offs between the different indicators. For example, in the study by Bahramirad et al. (2014), the size of the ESS was determined by minimizing the investment and operating costs while also ensuring a certain level of reliability. In determining the size of a BESS, various criteria can be applied, such as technical and financial indicators. The selection of criteria will depend on the specific goals and constraints of the system. Technical indicators, such as reliability, curtailment, and smoothing of variability, can be used to improve the performance of the system. Financial indicators, such as investment and operating costs, can be used to optimize the system's cost-effectiveness. Different combinations of these criteria can be employed in various manners. For example, some studies use technical indicators as constraints within which financial indicators are optimized, while others use multi-objective optimization for a combination of technical and financial metrics. Ultimately, the critical functions of BESS are determined by the criteria used in its size determination (Korpaas, 2003). In summary, the size of a BESS can be determined through a variety of technical and financial indicators. Technical indicators, such as curtailment and peak shaving, are often used to improve the performance of a RES. Financial indicators, such as investment and operating costs, are often used to determine the most cost-effective BESS size. Additionally, some also hybrid indicators combine both financial and technical metrics, such as multi-objective optimization, used to determine BESS size. It's important to note that the critical functions of BESS change depending on the criteria used for size determination. For instance, in endeavors to enhance the dynamic attributes of a RES through the application of technical indicators, the power capacity of a BESS assumes greater significance than its total energy capacity. This consideration is particularly pertinent in studies such as Nazaripouya et al. (2014), where battery sizing was determined based on the product of per unit multiplied voltage regulation duration and for cases involving frequency regulation (Aghamohammadi, 2014). When determining the size of a BESS in a RES system, there are several factors to consider. One approach is to use technical indicators, such as the power capacity of the BESS, to improve the dynamic characteristics of the RES.

In other cases, financial indicators are used to minimize costs while still ensuring reliability. Furthermore, a multi-objective optimization strategy has been utilized in certain studies to merge technical and financial metrics together. However, it should be noted that the critical functions of the BESS can change depending on the criteria used for sizing determination. Advanced dispatch strategies can optimize the utilization of existing BESS, improving the effective use of energy and power capacity. In hybrid renewable energy systems, various components such as renewable and non-renewable energy generators can be used in combination to provide a reliable and efficient energy source. One important aspect of these systems is the integration of an ESS which can be used to optimize the performance of the system by balancing the energy generated by the renewable sources with the energy demand of the loads and the utility, particularly if the system is connected to the grid (Upadhyay, 2014).

Previous studies have classified RES into different categories, such as grid-connected or standalone (Shivarama, 2015), or further broken down into dc-coupled, ac-coupled and hybrid coupled (Nehrir, 2011). This review will classify RES applications into four categories, ranging from small to large: distributed energy systems (Prabhakar, 2012), microgrids (Fathima, 2015), (Colson, 2009), (Mahmoud, 2015), standalone HRES (Fadaee, 2014), (Johnston, 2014) and renewable energy power plants (Paska, 2009). ESS is often used to maintain reliability and stability in these hybrid renewable energy systems (Divya, 2008), (Lawder, 2014).

RES can be classified into four categories based on their size and operation: distributed energy systems, microgrids, standalone HRESs, and renewable energy power plants. This leads to different criteria for sizing the ESS or BESS. For example, a commercial-sized renewable power plant will use a BESS in a different way than a microgrid and hence the sizing criteria will also be different. The purpose of the battery also determines the sizing, such as using the battery to ride through lulls in the weather to decrease ancillary services costs or penalties (Zhao, 2016), (Katsaprakakis, 2016), (Petrakopoulou, 2016). This section will encompass studies that investigate the optimal connection point for the battery within the renewable energy system, as well as explore auxiliary technologies aimed at enhancing the storage capabilities within the system.

Distributed energy systems utilize various RES such as solar PV, which are integrated into the distribution network for both end-user and regional applications. As the usage of distributed energy increases (Nair, 2010), it can result in fluctuations in the distribution network, such as power quality issues or oscillations, which can be mitigated by using an ESS like a battery. Batteries have the ability to charge and discharge quickly, as well as store energy for longer periods, which can reduce electricity costs for consumers. For residential PV systems, the inclusion of a BESS allows end-users to control their energy usage by deciding when to release power back to the grid or store it, depending on the electricity price. In addition, at the distribution network level, the regional center can optimize the charge and discharge process of the BESS to compensate for any voltage changes caused by fluctuations in renewable energy, ensuring the reliability and stability of the distribution network.

The sizing of a BESS involves taking into account various criteria to determine the appropriate capacity and other specifications. Some different methods can be used to determine these specifications, and some of these methods are specific to certain types of renewable energy systems, while others can be applied to any system. One important consideration that applies to all systems is the ability to reduce the amount of renewable energy wasted due to overproduction during periods of low demand. This is particularly relevant for distributed renewable energy systems (Atwa, 2014), stand-alone hybrid renewable energy systems (Rodrigues, 2015), and renewable energy power plants (Etherden, 2014). Sizing a BESS involves many factors, and there are numerous methods that can be used. Some methods are specific to the size, components, and economics of a particular renewable energy system, while others can be applied to any sized system. For example, one important factor for all sized systems is the ability to reduce the amount of renewable energy that needs to be curtailed due to overproduction during periods of low demand. This is relevant to distributed renewable energy systems (Atwa, 2014), standalone hybrid renewable energy systems (Rodrigues, 2015), and renewable energy power plants (Etherden, 2014). Voltage stability is also an important factor for all systems, but it is only used for battery sizing in systems connected to the distribution network (Johnston, 2014), (Nazaripouya, 2014). The most widely used method for sizing BESS in distributed systems is analytical, and technical indicators are the main factor in determining the size of the BESS. The size of the BESS can range from approximately 10 kWh to 50 MWh, depending on the application.

BESS can be used to enhance the performance of distributed renewable energy systems by addressing the fluctuation characteristics that can arise from factors such as passing cloud cover or unpredictable weather. For example, a study shows that a small residential load with low renewable penetration can be supported by installing around 10 kWh of battery capacity (Ru, 2013). However, in other cases, a larger BESS may be needed, such as in a system with three wind turbines connected to a rural distribution network, where a battery with an energy capacity of 51.95 MWh and power capacity of 6 MW was required to accommodate spilt wind and minimize annual cost (Atwa, 2014). For residential applications, installing a BESS can significantly influence end-users' utility bills by allowing them to reduce electricity costs by using stored energy when the price is high and storing energy when the price is low (Schneider, 2014). From the standpoint of a regional distribution power system operator, BESS can serve as a valuable tool to achieve technical enhancements. These include improving the characteristics of the load profile (Wang, 2014), deferring the need for infrastructure upgrades (IRENA, 2015), and ensuring voltage quality maintenance (Johnston, 2014), (Nazaripouya, 2014).

3. MATERIALS AND METHODS

The objective of this study is to enhance the cooling performance of refrigerated trailers through the integration of a solar panel-based energy storage system. The traditional method of cooling trailers relies on an external power source and the compressor on the trailer. However, the cooling process can be time-consuming, taking several hours, depending on the size of the trailer and the extent of its usage. By implementing the proposed system, the duration of the cooling process in a sealed environment can be extended to 36 hours, thereby offering a more efficient and environmentally sustainable solution for cooling refrigerated trailers, thus enhancing their applicability across diverse domains. The reason for mentioning a closed area is because if the refrigerated trailer is exposed to direct sunlight, it will take much longer to maintain the desired temperature inside. The length of the journey that can be made with the trailer will be limited by how long the temperature inside can be sustained. The solar panel-based energy storage system and the insulated interior of the trailer work together to keep the temperature constant and prolong the duration of the cooling process, even in a closed environment by enabling longer journeys and enhancing the efficient utilization of the trailer's capabilities. The refrigerated trailer needs to be cooled regularly to maintain the desired temperature range inside, as exposure to higher temperatures can cause degradation of the materials stored inside. If the trailer is operated under direct sunlight, the cooling process takes much longer and the trailer must take breaks for longer periods to cool down using an external power source. During the journey, it is important for the refrigerated trailer to maintain a specific temperature range, as this will help prevent damage to the materials stored inside. Failure to do so can result in spoilage or deterioration of the stored goods, and negatively impact the efficiency of the transportation process.

3.1. Solar Assisted Energy Storage System Construction

With this established system, it is aimed to keep the cooling trailer in a certain temperature range with the solar panel and battery system used later by providing the first cooling process with the network. This will prevent the cooling trailer from having to take a break. It is planned to reach the point where it will go without the need for a main cooling system with a single main cooling system. Figure 3.1 shows the general system definitions.

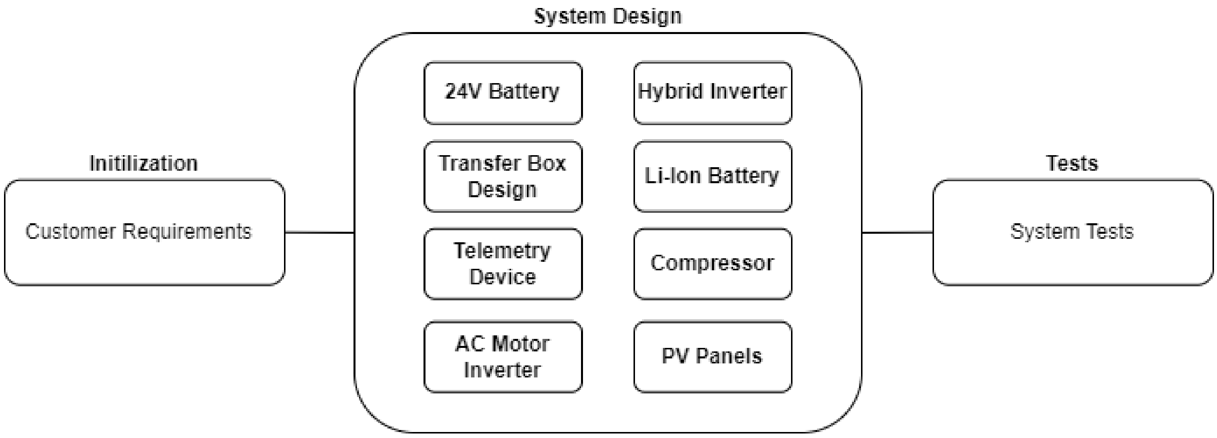

Figure 3.1. System Definitions.

The following materials were used in this system.

- 24v Battery
- Hybrid Inverter
- Transfer Box
- Li-Ion Battery
- Telemetry Device
- Compressor
- AC Motor Inverter
- PV Panels

The components employed in the implementation of this system are paramount in ensuring its effective operation. The 24V Battery serves as the repository of the energy produced by the PV panels. The Hybrid Inverter, in contrast, facilitates the conversion of the DC power generated by the PV panels into AC power that is utilized by the system. The Transfer Box facilitates the transfer of energy stored in the battery to the compressor of the refrigerated trailer, which is essential for the cooling of its interior. The Li-Ion Battery serves as a supplementary energy source in scenarios where the PV panels do not generate sufficient energy or during periods of low illumination.

The Telemetry Device plays a crucial role in monitoring and collecting data regarding the performance and energy utilization of the system. The Compressor, as previously highlighted, is utilized for cooling the interior of the trailer. The AC Motor Inverter regulates the speed of the compressor to ensure its efficient functioning. Lastly, the PV panels serve to harness the energy from the sun, which is then stored in the battery.

3.1.1. Li-Ion Battery

Lithium-ion batteries (Li-ion) are rechargeable batteries predominantly utilized in electronic devices. One of the highly regarded battery types is characterized by its exceptional energy-to-weight and energy-to-size ratios, rendering it widely employed. These batteries exhibit a lack of memory effect and demonstrate slow energy loss during periods of inactivity. In order not to lose capacity, it should be kept at standby voltage (3.6 volts). The peak voltage value is 4.2. After about 500 cycles, there is a 10% reduction in capacity. It is safer than lithium polymer batteries. The usage areas vary according to the instant and continuous power they can give, this is called the "C" value, for example, if the C value of a 2000 mAh battery is 5, the instantaneous power it can give is 10000 mAh. (On average, 2C 4/5/6 A batteries are used in laptops, 5C 10 A batteries in vehicles such as scooters, and 10C 20 A batteries are used in drills where intense power is required.) Different lithium battery designs are lithium iron phosphate (LFP) and lithium titanate battery (LTO) cells. Tools such as drills, laptops, robot vacuums and scooters have a battery called 18650.

Lithium-ion batteries are often much lighter than their counterparts made with other chemicals. This is due to the highest recharge densities of lithium-ion batteries. Lithium-ion batteries are small and portable. Lithium-ion batteries are not subject to memory effect, thus eliminating the need to discharge them fully before recharging. Similarly, interrupting the charging process does not have any detrimental impact on the battery due to the absence of memory effect. According to some research, the search for a superior energy storage solution to replace oil after the oil crisis in the 1970s was instrumental in the emergence of the lithium-ion battery, and according to others, the high energy requirement of portable electronic devices with the invention of the transistor. Although there is no definite answer as to why it emerged, it is a fact that the lithium battery is an important invention that is at the center of human life today. Lithium-ion battery; is the name given to a storage solution with high energy and power density, which uses lithium ions to store electrical energy and consists of four main elements, generally anode, cathode, electrolyte and separator. An electric vehicle is powered by a battery pack weighing hundreds of kilograms, which is formed by the combination of thousands of battery cells. Different battery cells can be used in these batteries in terms of shape, size and cathode chemistry.

In electric vehicles, there are three primary shapes of battery cells, namely cylindrical, prismatic, and pouch cells. The cylindrical cell is produced by winding the elements in the battery like a roll, placing them in a metal casing, filling the electrolyte and placing the terminal. In prismatic and sachet cells, battery elements such as anode and cathode are packed by folding or stacking on top of each other instead of rolls. Tesla, which produces the world's first lithium-ion battery electric car, uses cylindrical batteries in most of its vehicles. Cylindrical batteries are in high demand due to their widespread use in the electronics industry and their low production cost. However, in recent years, the prismatic cell type has become widespread rapidly, thanks to both its ease of production and its high energy density compared to the cylindrical design.

Prismatic batteries, which have increased their market share with the increasing interest in large cell designs in the battery industry, are especially preferred by Chinese lithium-ion battery giants such as CATL and BYD. Companies that can reduce the number of batteries used in vehicle batteries with larger cell designs, increase energy density thanks to developing thermal management systems, while not reducing thermal efficiency. When analyzed in terms of positive electrode, that is, cathode chemistry, three options stand out: LFP, nickel manganese cobalt (NMC) and nickel cobalt aluminum (NCA). Although lithium-ion batteries have been in use for a long time, their integration into electric vehicles has been possible with the development/updating of the cathodes we have mentioned and putting them into production. Because lithium cobalt, lithium manganese oxide cathode batteries used in devices such as telephones and computers, in their current form, could not provide the opportunity to store the energy needed by a car in a battery with a reasonable weight, cost-effectiveness and long life.

Developed at the Argonne National Laboratory in the USA, NMC has been one of the industry's greatest discoveries. The cathode active material, which is the result of the combination of a large amount of nickel and a relatively small amount of manganese and cobalt, is the only commercialized solution that can increase the energy density of a lithium battery to 300 Wh/kg. NMC is in the position of the most suitable battery solution for electric vehicles when evaluated in terms of both energy and power density. However, the search for alternatives continues due to the supply problems and high cost of the materials required for its production.

LFP batteries, almost all of which are produced in China, are the most serious competitor of solutions with NMC cathodes. As of March 2022, its use in the electric vehicle sector has reached 20%. The LFP cathode, in which cheap elements such as iron and phosphorus, which are abundantly available in nature, are used, makes it possible to produce batteries that are both cheap and have a longer life. Moreover, unlike NMC, it increases the safety of electric vehicles as the risk of explosion is very low in case of external intervention, impact or fragmentation.

NCA, which has a similar structure to NMC, is formed by using aluminum instead of manganese and cobalt as a nickel stabilizing material. Despite their high cost, NCA cathode cells were preferred by Tesla in the early years due to their superiority in power and energy density. Against the human problems related to the production of cobalt and the increasing cobalt prices, the company has reduced the use of cobalt in its batteries over time and turned to high nickel cathode chemistry. The world's largest manufacturer of NCA batteries is Panasonic, Tesla's manufacturing partner at the Giga Nevada factory. The production activities of NCA cathode materials are also largely under the control of Japanese companies. LFP, which costs less than $100 per kWh, although cheap, does not perform as well as NMC in terms of both energy and power density. The nominal voltage of LFP cathode batteries currently being produced is 3.0-3.2V and their energy densities at the battery pack level are in the range of 90-160 Wh/kg. In NMC batteries with a nominal voltage of 3.7V, the energy density can start from 150 and go up to 300 Wh/kg. LFP also has significant advantages over NMC. Its thermal stability is high, there is no harm in keeping it at 100% charge in electric vehicles thanks to its low voltage, its service life is much longer than NMC cathode batteries, and it can be used in larger cell designs thanks to less heat dissipation than NMC.

In this thesis, considering the usage conditions and operating temperatures that the battery pack will be exposed to, a battery pack with NMC battery chemistry has been designed. In addition, it is foreseen that a 35-kW package will be sufficient based on the route to be used and the use of other units operating in the system.

3.1.2. Battery Management System

In this study, considering the usage conditions and operating temperatures that the battery pack will be exposed to, a battery pack with NMC battery chemistry has been designed. In addition, it is foreseen that a 35-kW package will be sufficient based on the route to be used and the use of other units operating in the system. With this system, a need for a BMS system should control lithium-ion batteries. A collection of multiple cells forms a battery or battery pack, with the arrangement of cells being connected in series or parallel configurations. In battery packs, the series connections govern the voltage, while the parallel connections dictate the current and capacity that can be drawn. To facilitate coordination between these serial and parallel systems, BMSs are employed. BMSs, serving as electronic systems, play a vital role in controlling and managing rechargeable batteries. They function as protectors within battery systems by monitoring the current operational status of the batteries and ensuring that they operate within optimal value ranges. Several functions of BMSs are outlined below.

Monitoring Information: The BMS enables us to keep track on the condition of battery packs. The following is a list of the data that the BMS allows us to collect:

- Voltage: The package's overall voltage, a cell's individual voltage, and the minimum and maximum cell voltages.
- Temperature: Average temperature, cooling intake and exit temperatures, and cell-specific temperatures
- Charge state or discharge density: Charge levels of batteries
- Health state: The integrity of the package or any cell
- Current: Input and output currents of batteries during charge/discharge

Calculation: In addition, the BMS provides the necessary comparisons and value calculations as well as the calculation of the above data, for example:

- Maximum charging current
- Maximum discharge current

- The minimum/maximum voltage seen in the cells or battery pack
- Energy consumed after the last charge (kWh)
- Internal impedance of a cell
- Energy consumed from first use
- Total working time from first use
- Number of charge-discharge cycles

Protection: By monitoring the user-presented data, BMS checks to see if the optimal levels are being exceeded and takes action to protect the system. The following list includes scenarios when intervention may be essential.

- High current draw from batteries
- Formation of high voltages during charging
- Formation of low voltages throughout the discharge
- High temperature
- Low temperature
- High pressure (in NiMH batteries)
- Formation of leakage current

BMS is a critical component of the system, responsible for maintaining the safety and performance of the batteries used in the system. BMS continuously monitors various parameters such as current draw, voltage, temperature, and pressure, to ensure that the batteries are functioning within their optimal operating range. If any of these parameters exceed the prescribed values, BMS will intervene to protect the system. This could include limiting the current draw from the batteries, controlling the voltage during charging and discharging, regulating the temperature, monitoring pressure levels in NiMH batteries, and detecting the presence of leakage current. In this way, BMS helps ensure the longevity and reliability of the batteries and protects the system from potential malfunctions or damage.

To maximize battery capacity and prevent overcharging while charging, BMS makes sure that the voltage values of each cell that makes up the battery pack are balanced. Any switchgear that experiences an overvoltage or undervoltage that disturbs the voltage balances intervenes in the system and shuts it down. When necessary, it transfers energy from the cell with the highest load to the cell with the lowest load, maintaining the balance. By doing this, BMS creates a continuous control over the system and intervenes in the event of a fault, cutting off the system. This was an extremely important system for protecting high capacity and costly battery packs. TEMSA BMS system was used for the BMS system, and it was packaged as 35 kW with Li-Ion NMC batteries. The pack and its feature table are shown Figure 3.2. And technical specifications of TEMSA Battery are given in Table 3.1.

Figure 3.2. TEMSA 35 kW Battery Pack.

Table 3.1. Technical specifications of TEMSA Battery.

Li-Ion Battery Parameter	**Value**
Cell Chemistry	Lion NMC
Battery Capacity	35 kWh
Min/Max Output Voltage	280-360 Vdc
Nom Output Voltage	325 Vdc
Max Output Current	50

3.1.3. Compressor

A refrigeration compressor is a mechanical device that increases the pressure of a gas (refrigerant vapor) by reducing its volume (Sarbu, 2021). The refrigeration compressor is one of the 4 basic refrigeration elements in the refrigeration process and is called the heart of the refrigeration cycle. The other 3 basic cooling elements are condenser, expansion valve, evaporator. We can explain the working principle of the refrigeration compressor in its simplest form as follows. The refrigerant flows into the compressor, which compresses and raises the existing pressure. Subsequently, the refrigerant flows into the condenser, where it transforms from vapor form to liquid form (i.e., condenses) and gives off heat to its surroundings. The heat delivered makes the condenser "hot to the touch". In the next stage, the refrigerant passes through the expansion valve, where it experiences a pressure drop. In the last stage, the refrigerant goes to the evaporator. The refrigerant draws heat from the evaporator and this process causes the refrigerant to evaporate. The evaporator draws heat from the area to be cooled. The evaporated refrigerant returns to the compressor to restart the cycle. This cycle continues until the device is stopped.

It is possible to collect the functions of the refrigeration compressor basically under two headings.

- To remove the heat load from the condenser.
- Converting the refrigerant pressure from low pressure low temperature to high pressure high temperature.

The ideal state of the refrigeration compressor is shown below.

- Minimum torque on first start-up.
- Continuation of efficiency at a certain level at partial loads.
- Maximum security level even in different working conditions.
- Noise and vibration levels do not exceed a certain standard even at full loads and under different conditions.
- It can provide unit cooling value that will consume relatively low power.
- Product life as long as possible and malfunction-free operation.

In line with this information and considering the trailer area to be cooled, the compressor selection with the features given in Table 3.2 was made. The compressor is shown in Figure 3.3.

Table 3.2. Technical specifications of compressor.

Motor Data	**Features**
Compressor Model Version	4TES-9Y
Motor Voltage	380-420 V PW-3-50 Hz
Max Operating Current	19.9 A
Winding Ratio	50/50
Starting Current (Rotor Locked)	49.0 A Y / 81.0 A YY
Max Power Input	13.0 kW

Figure 3.3. Compressor Model 4TES-9Y.

3.1.4. Hybrid Inverter

Hybrid solar PV system has emerged because of the use of hybrid inverter solar and grid system power technologies together to provide higher advantage. The energy produced through PVs will be sufficient for consumption at home. In this case, inverter PV energy is used and provides the necessary power to the battery. Similarly, if the consumption is high enough to exceed the PV energy, then there will be an extra energy intake from the inverter grid. In the days when there is no sun, the inverter will use the energy from the battery depending on the energy consumption and will supply this energy from the grid. The integration of hybrid solar PV technology into the automotive industry has brought about significant advancements in energy efficiency and sustainability. The use of Lithium-ion batteries in combination with PV panels allows for the storage of excess energy generated from the sun, providing a reliable source of power for vehicles (Nazari-Heris et al., 2023). The hybrid solar PV system allows for a balanced approach to energy consumption, utilizing both the energy generated from PVs and grid power when necessary. This innovative solution contributes to the reduction of dependence on traditional fuel sources and the advancement towards a greener, more sustainable future in the automotive industry. These and similar situations can be multiplied. Selected hybrid inverter specifications are shown in Table 3.3. and Figure 3.4.

Table 3.3. Technical specifications of hybrid inverter.

Hybrid Inverter	**Features**
AC Nominal Output Power	10000 W
Nominal AC Output Voltage	230 V / 400 V
Nominal AC Output Frequency	50 Hz/60 Hz
AC Grid Connection Type	3W+N+PE
Battery Voltage Range	100 – 550 VDC
Max Charging and Discharging Current	25 A
Type of Battery	Lithium Battery
Battery Continues Charging and Discharging Power	10000 W
PV Max Power	13000 W
PV Voltage Range	160 – 1000 V

Figure 3.4. Hybrid inverter.

3.1.5. PV Panels

A solar panel is a form of renewable energy that harnesses the power of several sun cells. Sunlight is converted into electricity by solar panels. The energy of sunlight falling on the globe is 10,000 times greater than the energy used in the world today. Because of this, humans can efficiently meet their energy needs by using just 0.01 of the sun's rays that reach the planet. The solar panel is made up of solar cells, which take in the sunlight that strikes it. The rate at which sunlight is converted into energy by the solar cell used in a solar panel determines its efficiency.

In order to transport the electrical current produced by the solar panel, a solar panel normally consists of silicon cells, a metal frame, a glass enclosure unit, and linear cables. Because of its conductive qualities, silicon, a nonmetal, can absorb sunlight and transform it into useable electricity. A silicon cell is exposed to light, which activates the silicon cell's electrons and starts the current flow. This is referred to as the "PV effect" and it depicts how solar panel technology works as a whole. Our sun can be compared to a natural nuclear reactor. According to this model, it takes photons 8.5 minutes to travel 150+ million kilometers from the sun to the earth.

Even hypothetically, the energy bundles that travel the short distance to the earth contain enough energy to power the planet for a year in a single hour. Therefore, in order to cut carbon emissions and transition to sustainable energy production, we should all give priority to solar energy, which has enormous potential. We are able to directly generate power from sunlight using silicon-based solar cells. Solar panels are exposed to photons (sunlight particles) every day. These photons are transformed into DC electrons by the solar panel. From the solar panel, electrons go into an inverter and other electrical safety equipment. When plugged into a wall socket, appliances like toasters, computers, and televisions use AC power.

Solar energy panels enable the operation of all appliances used in homes and workplaces by converting solar heat and light into usable electrical energy. The solar energy panels' cells use the sun's beams to produce DC. The panels are connected to one another in series or parallel, depending on the area of use and the desired amount of energy, to convert the DC into electrical energy. The solar panel technology essentially uses light to separate electrons from atoms. Electricity is also produced by the process of removing electrons from their atoms. Incoming sunlight is converted into energy rather than heat by silicon-based photovoltaic cells used in solar panels. Thanks to the sun's beams, DC starts to build in these solar cells that are mounted on the panels. A serial or parallel mechanism is constructed and connected to homes or workplaces by measuring the quantity of energy obtained in accordance with the region it is located in or the season in which it is used.

The movement of solar cells for the production of energy can be summed up as follows. Each solar panel has PV cells, which allow it to absorb sunlight. Using photons, PV cells transform light into electricity. The solar panel’s PV cells begin to function when sunlight reaches it, creating DC electricity. Figure 3.5 displays PV panels.

Figure 3.5. PV Panels.

DC electricity is unable to sustain itself. It is sent to the inverters, which are home to various solar energy devices. The electrons start to travel when the silicon cell is exposed to the sun's light. The nodes intercept the transit of electrons, starting the flow of electricity through the panel's wires. Solar inverters receive DC electricity from solar wires and transform it into AC electricity. Table 3.4 displays the properties of the PV panels we chose for our energy storage system. There are 12 solar panels totaling 5 kW installed as part of the solar panel system on the body.

Table 3.4. Technical specifications of PV Panels.

Parameter	**Value**
Open Circuit Voltage	49.68 V
Maksimum Power Voltage	42.34 V
Short Circuit Current	11.24 A
Maksimum Power Current	10.39 A
Maksimum Power	440 W

3.1.6. AC Motor Inverter

AC motor speed control drivers, commonly known as inverters, regulate the motor speed by varying the frequency of the AC voltage. They are known as variable frequency drive (VFD) in the market. Ac motor drivers are used in 3-phase asynchronous motors. Because they are different in structure, they cannot be used in single-phase 220V asynchronous motors. AC motor drives have gained speed with the development of power electronics technology in recent years. Energy saving, mechanically controlling motor speeds without the use of gearboxes, has made VFD motor drivers widely used. They also control the torque, operating current of the motor and their energy efficiency. VFD motor speed control drivers communicate via programmable logic controller (PLC) with appropriate connections and allow you to intervene, stop, speed of the motor from your machine control panel. These drivers are the most critical parts of industrial automation.

The mains voltage applied to the inverter driver is first converted to DC voltage with the help of bridge diode. The obtained dc voltage is also stored in the block capacitors inside the driver.

The requirement to store the voltage is so that it does not damage the bridge diode section when the motor draws all its power from the mains during the first start. At the output of the driver, a 3-phase AC VFD frequency voltage is created with 6 mosfets connected to the dc bus voltage according to the input parameters and control type. Integrated with 6 MOSFETs is called IGBT. There are components such as current control, high voltage protection, low voltage protection and temperature control in IGBTs. In short, the ac power that first enters the VFD driver is converted to dc power, after creating a clean voltage from here, it is converted back to ac power. In this study, it was used to limit the high rated current drawn by the compressor motor at the first start and to drive it depending on the frequency. The inverter features are selected according to the features of the compressor motor. The characteristics of the AC motor inverter selected for our ESS are shown in Figure 3.6.

Figure 3.6. AC Motor Inverter.

3.1.7. Transfer Box

The transfer box is the box in which the fuses of the units in the system, the contactors and the inverter used to drive the compressor are contained. Its design was made specifically for this thesis. The diagram inside the transfer case is illustrated in Schematic Figure 3.7 that provides a visual representation of the components and their arrangements within the transfer case. It serves as a guide to understanding the various elements and their relationships to one another, which is crucial in understanding the functioning of the system.

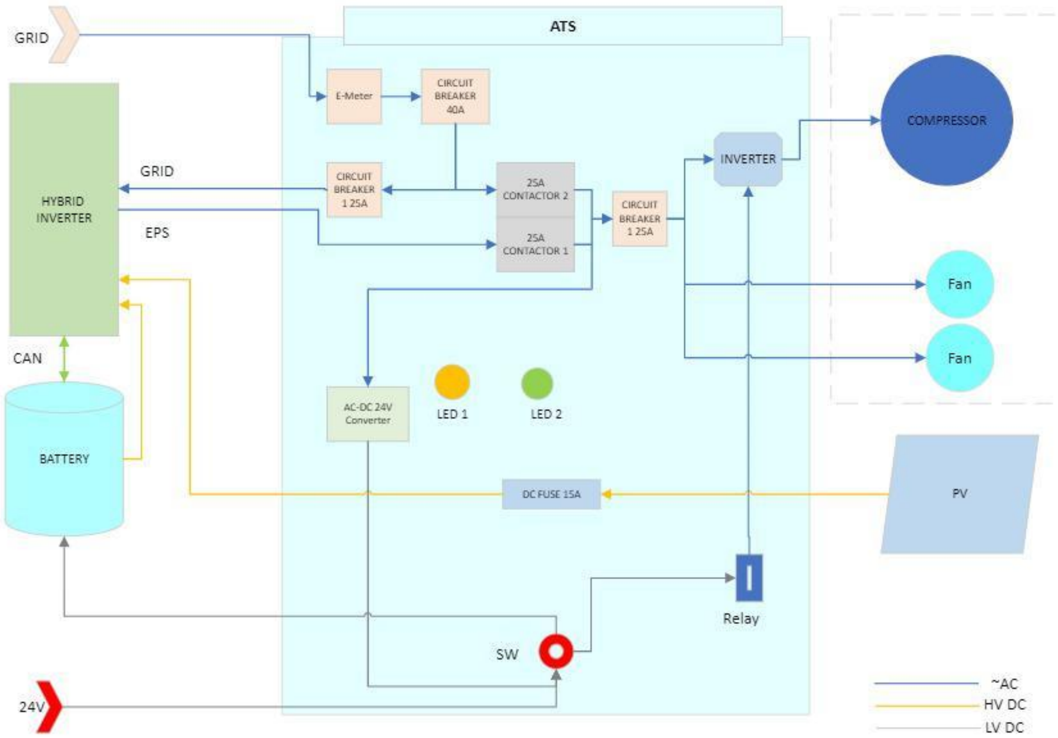

Figure 3.7. Schematic work flow.

The transfer box is a tool that connects the cables coming from other units, and also contains switching elements such as relays and contactors that control them. At the same time, motor driver and fuses also contain other units in this box. Figure 3.8 shows the production of the transfer box.

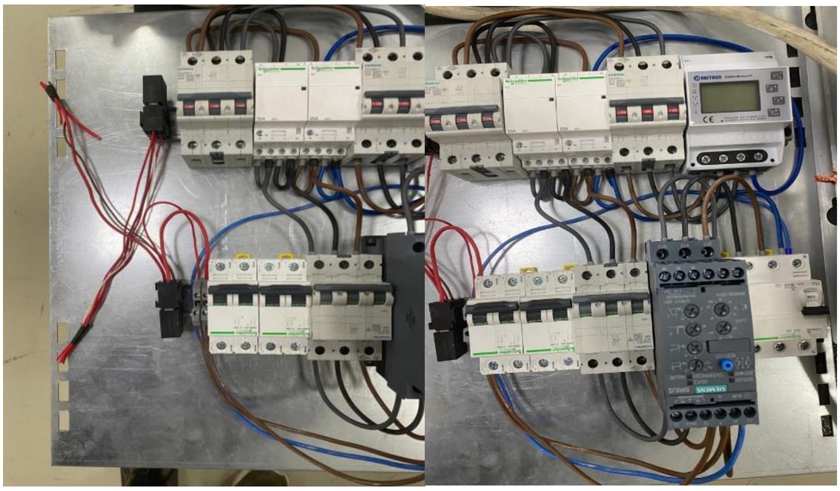

Figure 3.8. Transfer Box Part 1.

Figure 3.9 shows the implementation stages of transfer box and AC motor inverter.

Figure 3.9. Transfer Box Part 2.

The Figure 3.10 and Figure 3.11 presents a process of the transfer box and the exterior casing of the AC motor inverter, which were specifically designed and manufactured as part of this project. The diagram provides a visual representation of the components that make up the transfer box and the AC motor inverter and how they are integrated with each other. Figure 3.9 is important for understanding the physical layout of the components and observing the structural design of the transfer box and the AC motor inverter.

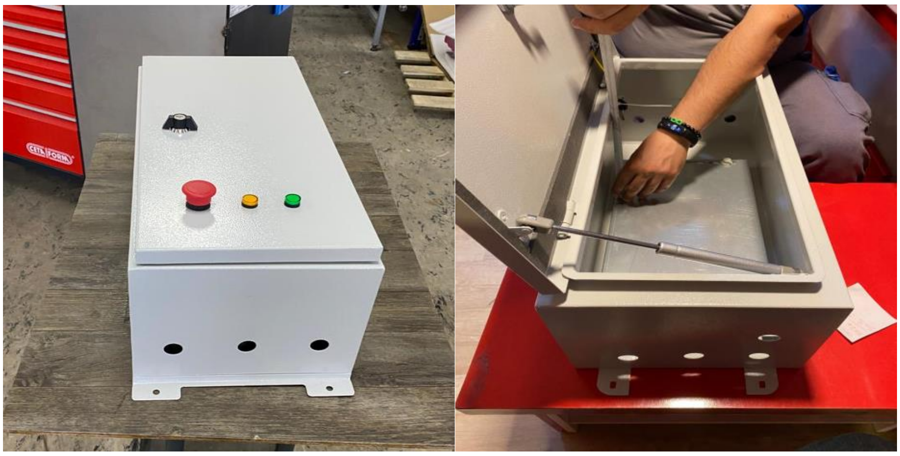

Figure 3.10. Transfer Box Part 3.

Figure 3.11. Transfer Box Part 4.

3.1.8. 24 V Battery

The trailer cooling system utilizes two 12V batteries that are interconnected in series to produce a combined supply voltage of 24V. The Battery Control Unit and other units that need 24V signal supply are supplied from these batteries in the battery pack that needs this battery to work. These batteries are only needed when the system is first activated. Afterwards, a power supply in the transfer case reduces the battery voltage (350 VDC) to 24V. After the battery wakes up and becomes active, both the 24V need of the system is met thanks to this power supply. Both these batteries are charged. We can think of this as the battery in automotive. After the diesel vehicle starts, it is charged with the help of the alternator in the vehicle. The electric vehicle batteries are actively charged using a DC-DC converter once the vehicle is started, as designed by the system. At the same time, with the button placed on the transfer box, the battery is disabled if the trailer will not be used for a long time. If the trailer will not be used, the battery will not be activated, but there will always be a low consumption in the system. In order to prevent this consumption, if it will not be used for a long time, complete consumption is cut off from the button. Figure 3.12 shows the 24V battery used within the scope of this study.

Figure 3.12. 24 V Battery.

3.1.9. Telemetry Device

Telemetry is the remote wired or wireless monitoring or control of an inaccessible part of any system. The term "telemetry" originates from the Greek words "Tele," meaning remote, and "Metron," meaning measure. This term has become a vital part of modern technology. Many modern telemetry systems use GSM networks to transmit or receive telemetry data at low cost and ubiquity using SMS. A telemetry device is used to measure any quantity remotely. A telemetry sensor consists of a transmission path, display, recording or control device.

The origin of telemetry dates to the 19th century, when the first data transmission telemetry systems were created in 1845 between the Winter Palace of a Russian Tsar and the General Staff. In 1874, French engineers developed a real-time weather and snow tracking system with the system they installed on Mont Blanc. In 1906, the Russians used a telemetry system to understand seismic movements. It is still used to monitor and adjust the water level in the Panama Canal. In 1930, the Robert bureau used the wireless telemetry system to develop the radio probe system. For the German V-2 rocket, four primitive multiple radio signals were sent under the so-called "Messina" system, tracking the rocket parameters from the ground unit. Later, America and the Russians started to use the systems they invented in the form of pulse-position modulation to use the "Messina" system quickly.

The ground for communication does not have to be flat, and any structure such as mountains or hills that will interfere with communication between antennas will only weaken the signal.

With repeating RF modems, the constant repetition of the signal eliminates this attenuation effect. There may be kilometers from the place to be communicated. Today, antenna etc. technologies play a major role in eliminating distances in communication. Rain, snow, storm etc. natural events can make it difficult to receive signals. These factors are very important especially for satellite communication. Radio Data Modems are the most powerful industrial solution. On both permitted and unlicensed bands, these devices can transmit. They allow for communication over a minimum of 100 kilometres. In short range applications, Low Power Radio Solution in the short range devices, or industrial scientific medical radio band at 0-27 dBm (up to 500 mW) broadcast power 433MHz, 868MHz, 2.4GHz and 5.8 Unlicensed radio telemetry applications in the /5.9 GHz bands are becoming more and more common. Infrared, optical cables, power lines (Power line carrier), analog telephone lines, digital telephone lines (ISDN/nDSL), infrared, sound waves (acoustic, ultrasonic), microwave communication, and their environs are some of the different communication methods used in telemetry applications.

The features and picture of the selected telemetry device are presented below. Thanks to this device, much information in the system were transferred to this unit via Modbus communication. We can give examples of this information such as state of charge (SOC), battery voltage, solar panel gain, etc. (Mokhtari et al., 2012). It is possible to monitor data remotely by inserting a sim card into this device. The data we transferred was transferred to the remote server via this device and remote system operation was followed. In addition, temperature sensors placed inside the trailer trailer are also attached to this unit. By reading the sensor data from this unit, this system decides whether the cooling compressor should work or not. The hysteresis structure system is utilized here, with an example of hysteresis presented in Figure 3.13.

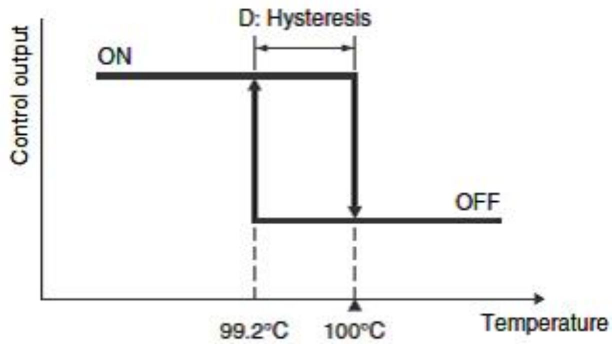

Figure 3.13. Hysteresis Example.

The technical features of the telemetry device play an important role in its performance and overall functionality. Figure 3.14 shows the Telemetry Device used within the scope of this thesis. Some of the key features of the telemetry device used in this system are:

- 2G/3G/4G data packet transmission and embedded GSM 2G/3G/4G modem
- Dual SIM technology - 2 independent GSM networks provides superior usability
- 16 binary inputs (galvanic isolation)
- 4 analog inputs 4–20 mA (galvanic isolation) and 2 analog inputs 0–10 V (no galvanic isolation)
- Ethernet port 10Base-T/100Base-TX
- RS-232/485 serial port for external devices (galvanic isolation)
- 5 V powered RS-232 port for operator panels
- OLED graphic display (128×64 pixels)
- Diagnostic LEDs
- Battery buffered power supply (SLA battery support)
- Data logger with 0.1 second resolution (micro SD card support)
- PLC
- FlexSerial – programmable management of non-standard serial protocols
- Standard communication protocols (MODBUS RTU, MODBUS TCP, M-BUS, SNMP, IEC 60870-5-104, GENIbus, GazModem, UDP Standard, Open, Open2)
- Remote configuration, programming, diagnostics, and via network.

Figure 3.14. Telemetry Device.

3.1.10. Energy Storage System Installation

A hybrid inverter is used in the system, combining a Maximum Power Point Tracking (MPPT) DC-DC Converter and a DC-AC Converter to regulate the variable voltage values coming from the solar panel and convert them into both DC and AC power. In this way, if the load requirement in the system is high, the battery and the solar panel feed the load. If it is not too much, the solar panel or if the grid is connected, the battery is charged over the grid with a hybrid inverter. At the same time, there is a motor driver inverter used to limit the starting current of the compressor in the system. The transfer box, in which units such as fuses, contactors and inverters are kept, has been designed and integrated into the system. And there is a telemetry system that collects all the information in this system, takes the measurement of the ambient temperature sensors and decides whether the cooling system will be activated or not. The system diagram is as shown Figure 3.15.

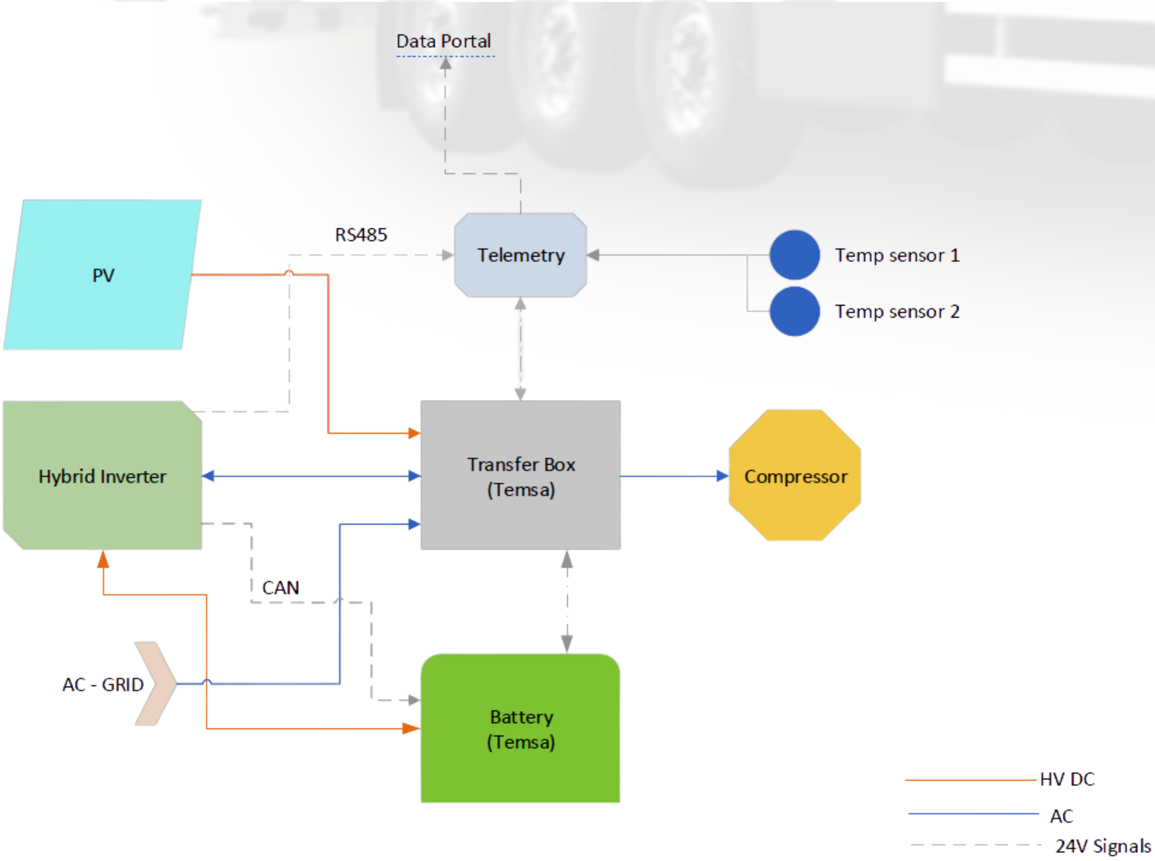

Figure 3.15. System Diagram.

The construction and assembly stages of the ESS are shown in Figure 3.16.

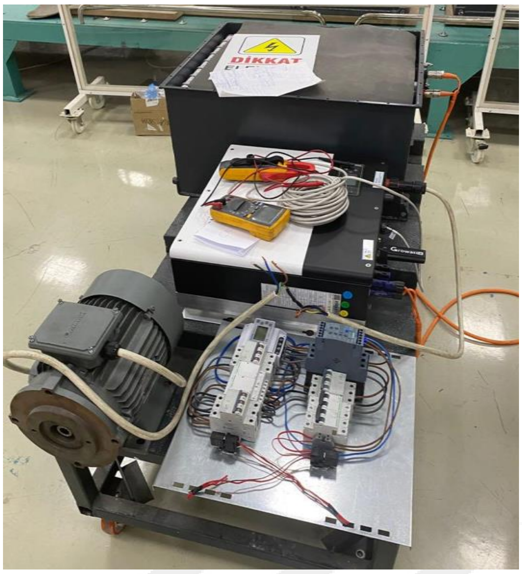

Figure 3.16. Stages of The Energy Store System - 1.

The Figure 3.17 displays the images captured during the pre-installation testing of the system. These tests are carried out to ensure that all components are working correctly, and that the system is functioning optimally before being installed. The images provide visual evidence of the testing procedures and the results obtained, which can be used to evaluate the performance of the system and identify any areas for improvement.

Figure 3.17. Stages Of The Energy Storage System-2.

The image taken while checking the assembly suitability of the transfer case and battery pack is shown in Figure 3.18.

Figure 3.18. Transfer Case And Battery Pack.

Figure 3.19 depicts an image captured during the installation of an outer protective casing, designed to safeguard the hybrid inverter vehicle from any external factors that may cause damage while in transit. The casing serves as a barrier, safeguarding the device from environmental elements such as dust, water, and other potential hazards that may affect its operation and performance. This protective layer ensures the durability and longevity of the hybrid inverter vehicle, ensuring that it operates seamlessly and effectively for an extended period. The installation of the protective casing highlights the importance of maintaining the device's longevity and performance, which is crucial in ensuring the proper functioning of the entire energy storage system.

Figure 3.19. Transfer Case And Battery Pack 2.

Figure 3.20 presents a visual representation of the telemetry screen, which is utilized for setting the temperature within the refrigerated trailer. The telemetry device, as previously discussed, plays a crucial role in monitoring and collecting data on the system's performance and energy usage. The temperature setting feature depicted in Figure 3.18 provides the means for adjusting the internal temperature of the trailer to meet specific requirements, ensuring that the contents within are stored at optimal conditions. The visual interface presents a user-friendly interface, enabling convenient temperature control and monitoring. The telemetry screen serves as an essential tool in the operation and maintenance of the system, providing real-time data on the temperature of the trailer and facilitating quick and effective resolution of any issues that may arise.

Figure 3.20. Telemetry Screen.

Figure 3.21 illustrates the battery data displayed on the hybrid inverter screen. This information provides a real-time analysis of the battery's performance and energy usage, including details such as the battery voltage, current, power, and state of charge. This information is critical for ensuring the optimal functioning of the energy storage system and making informed decisions about its operation. By monitoring this data, it is possible to identify any issues or problems with the battery, such as low voltage or high temperature, which can then be addressed promptly to prevent damage to the system. This telemetry information is essential for ensuring the safe, reliable, and efficient operation of the solar panel-based energy storage system.

Figure 3.21. Battery Data Hybrid Inverter Screen.

In addition, the desired temperature values for the cooling system to operate can be adjusted via this telemetry system. And information such as ambient temperature, battery status, pv status are monitored by being transferred to the remote server thanks to the sim card 3G support in the telemetry system. In the Figure 3.22 showing 3D Cad Data System, the communication methods and the connection of unit. And Figure 3.23 is also show the all system mounted.

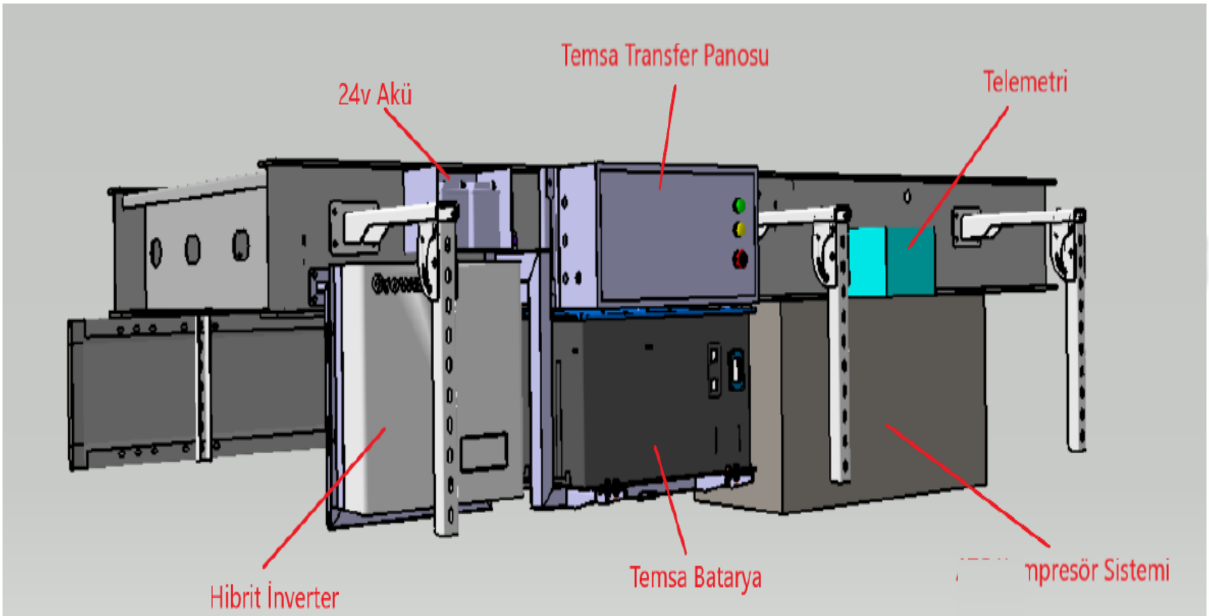

Figure 3.22. Unit Of Energy Storage System CAD Data.

Figure 3.23. Unit Of Energy Storage System.

The condition of the cooling trailer before and after the solar panels are installed is demonstrated in Figure 3.24.

Figure 3.24. Before And After The Solar Panels Installation.

3.2. Tests

Once the components of the system had been assembled, a series of tests were initiated to verify its functionality and performance. This section provides a comprehensive overview of the two tests that were carried out on the system. The purpose of these tests was to assess the efficiency and effectiveness of the system, as well as to identify any potential issues or areas for improvement. The results of these tests were used to fine-tune the system and optimize its performance, ensuring that it was fully operational and ready for use. After the assembly of the units in the whole system, the tests were started. Details of the two tests performed with this system are given in this section.

3.2.1. Refrigerated Trailer Cooling Test -1

The Refrigerated Trailer cooling test was executed in a manner that closely mimics actual use conditions. This was done to ensure that the system performs optimally in real-world scenarios and to verify its ability to effectively cool the interior of the trailer. The test was designed to closely simulate real-world use and was performed with great care to ensure the validity and accuracy of the results. The aim of the test was to evaluate the performance of the system in terms of its cooling capacity, energy efficiency, and overall functionality. The Refrigerated Trailer cooling test was performed with a scenario according to real use as follows.

- The Refrigerated Trailer cooling test was carried out with a scenario that simulates a real-world scenario as follows:
- The trailer was first filled with an appropriate quantity of empty boxes and ice cream.
- The temperature sensor alarm values were set in accordance with the Network: (-23°C) - (-24°C) range, and the battery system: (-12°C) - (-22°C) range.
- On 16th June 2022, at 17:40 in the evening, when the temperature inside the trailer was recorded to be -15°C, the cooling system was activated by connecting the trailer to the electrical mains.
- The next day, on 17th June 2022, at 7:45 in the morning, the cooling system was switched from being powered by the electrical mains to being powered by the battery and solar panels, thus disconnecting it from the electrical mains.
- On 17th June 2022, at 5 PM, the internal temperature of the trailer rose to -12°C and the cooling system was activated using energy stored in the battery.
- The system consumed battery power between 3:30 PM and 11:50 PM, bringing the internal temperature down to -18.42°C. On 18th June 2022, from 12 AM to 9:30 AM, the system was inactive due to insufficient energy. However, between 9:30 AM and 6 PM, the system was able to maintain the internal temperature at -9°C with support from the solar panels.

- On 19th June 2022, at 9:40 AM, the cooling system was unable to operate due to a lack of energy and the internal temperature increased to 1-2°C.

On 17th June 2022, after disconnecting the cooling system from the main power source, the battery was found to be fully charged. Despite this, during the evening, the internal temperature of the trailer dropped below 12°C, thus limiting the utilization of the approximately 20-30 kWh of energy that could have been generated from solar power that day. In order to observe the duration of cooling, an experiment was conducted by creating a volume inside the trailer using the boxes placed inside, as depicted in Figure 3.25.

Figure 3.25. Inside Of Trailer.

3.2.2. Refrigerated Trailer Cooling Test -2

The second refrigerated trailer cooling test was conducted with a scenario that was more representative of real-life use. The test scenario was as follows:

- The trailer was filled with the same boxes used in the previous test.
- The temperature sensor alarm values for the network were set to the range of (-23°C) to (-24°C), while for the battery system, the values were set to the range of (-14°C) to (-22°C).

- The trailer was immediately connected to the mains after the previous test had been completed.
- On 21.06.2022, at 17:45 in the evening, the trailer was disconnected from the mains and the cooling system was powered by the battery and solar energy.
- On 22.06.2022, at 4:00, when the internal temperature rose to -14°C, the battery-powered cooling system was activated.
- On 22.06.2022, the battery-powered cooling system consumed energy between 4:00 and 9:30 and cooled the trailer to approximately -20°C.
- Between 9:30 and 14:00 on 22.06.2022, the temperature was expected to rise to -14°C again, but with the help of solar energy, the temperature was maintained at around -19°C until the battery ran out.
- Finally, between 21:30 on 22.06.2022 and 10:20 on 23.06.2022, the internal temperature increased to -6°C, and the detailed status of the test can be observed from the graphs presented in the following pages.

In this test, it was determined that the use of the mains power was not included in the analysis, as the objective of the experiment was to assess the performance of the battery and solar systems in maintaining the temperature of the trailer. Specifically, the trailer was disconnected from the mains on June 21st at 17:30, and the cooling system was maintained by the battery and solar systems. It was found that the temperature of the trailer was maintained at a range of -22.33°C to -13.5°C for a total of 33 hours, until June 23rd, 02:30. This data indicates that the battery and solar systems were capable of efficiently maintaining the temperature of the trailer for a considerable amount of time without relying on the mains power source.

4. RESULTS AND- DISCUSSIONS

4.1. Refrigerated Trailer Cooling Test -1 Results

The results of the first Refrigerated Trailer Cooling Test have been analyzed and presented in this section. An evaluation of the distribution of energy consumed during the test was performed. The energy consumed was obtained from the following sources: the battery, the solar panel, and the mains. Approximately 30 kilowatt-hours of energy was obtained from the battery, 45 kilowatt-hours from the solar panel, and 43 kilowatt-hours from the mains. The total energy consumed during the test was 118 kilowatt-hours. Distribution of energy consumed during the test:

- Battery: ~30kWh
- Solar: ~45kWh
- Mains: ~43kWh
- Total: ~118kWh

Internal temperature data collected during testing is shown in Figure 4.1.

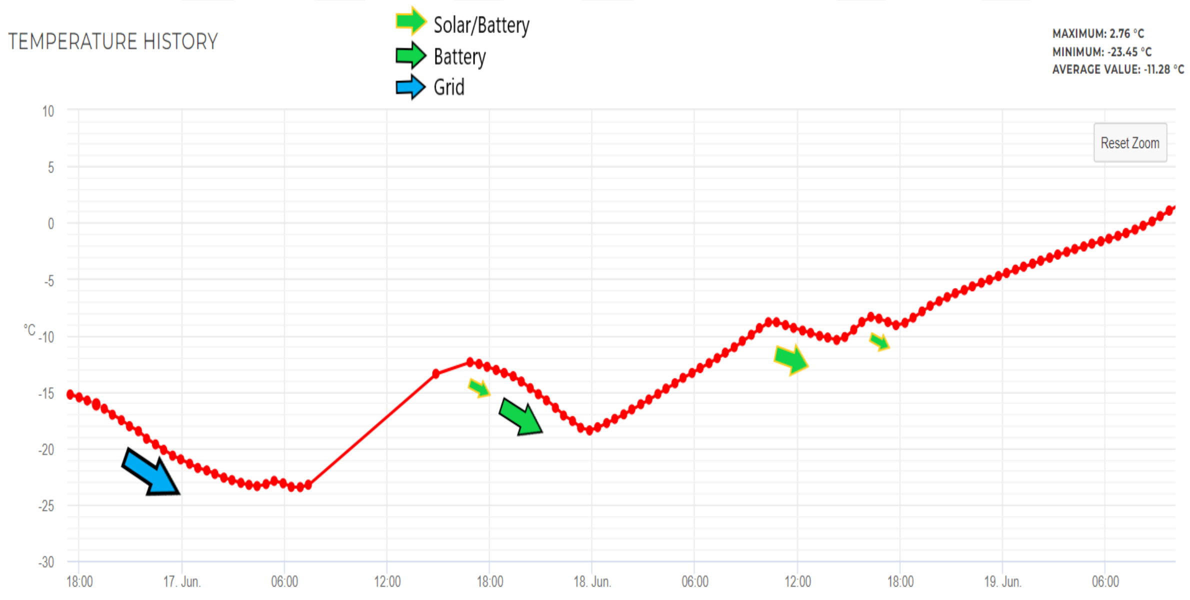

Figure 4.1. Internal temperature.

Internal humidity data collected during testing is shown in Figure 4.2.

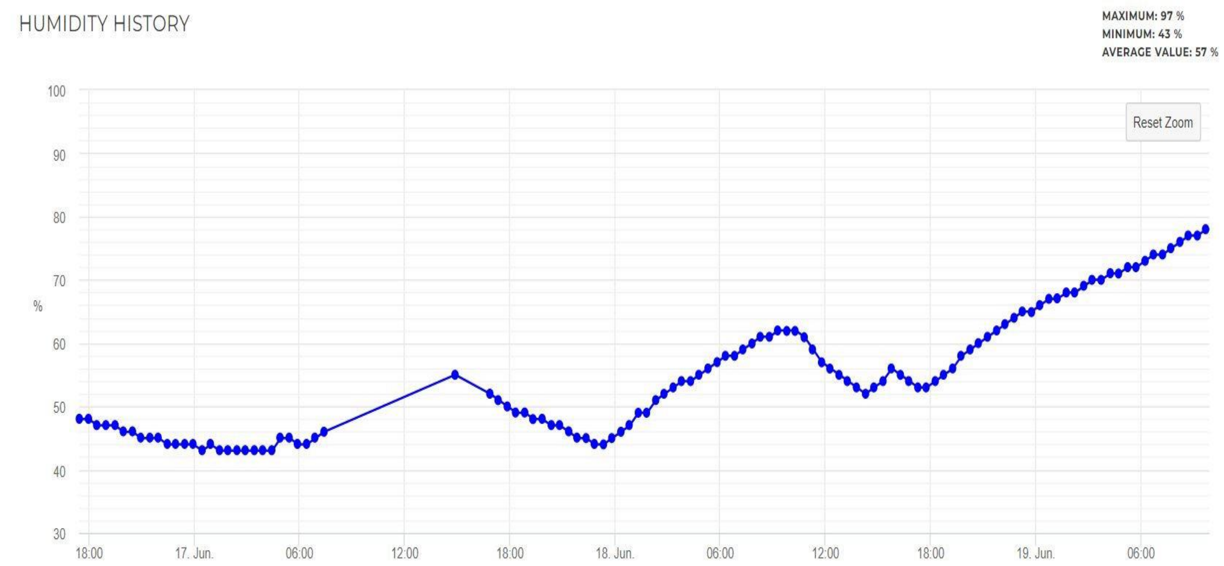

Figure 4.2. Internal humidity.

Outside temperature data collected during testing is shown in Figure 4.3.

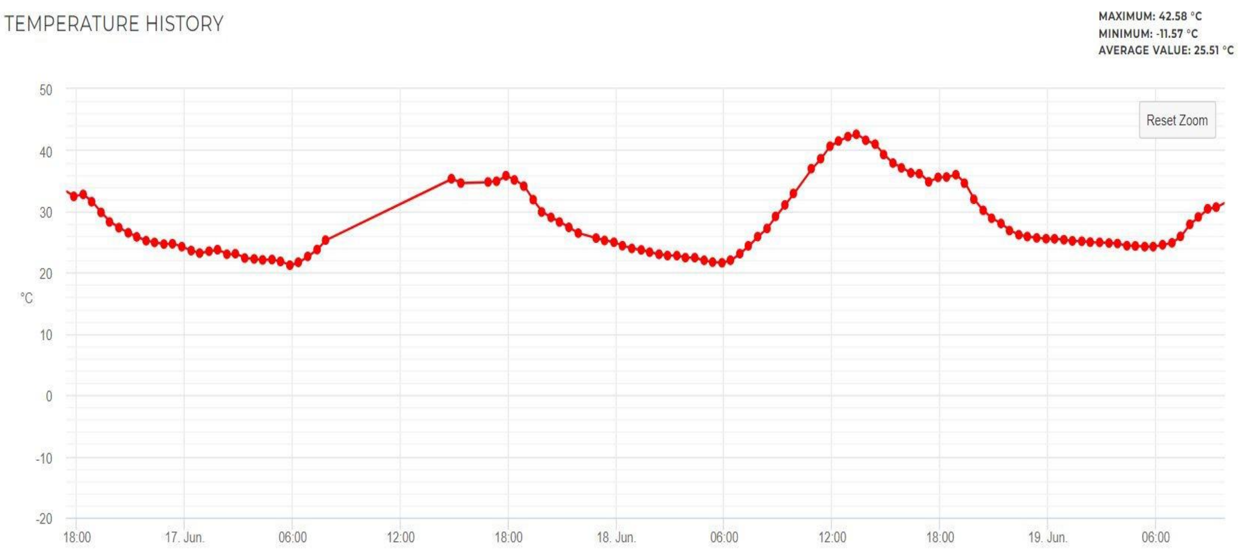

Figure 4.3. Outside temperature.

Outside humidity data collected during testing is shown in Figure 4.4.

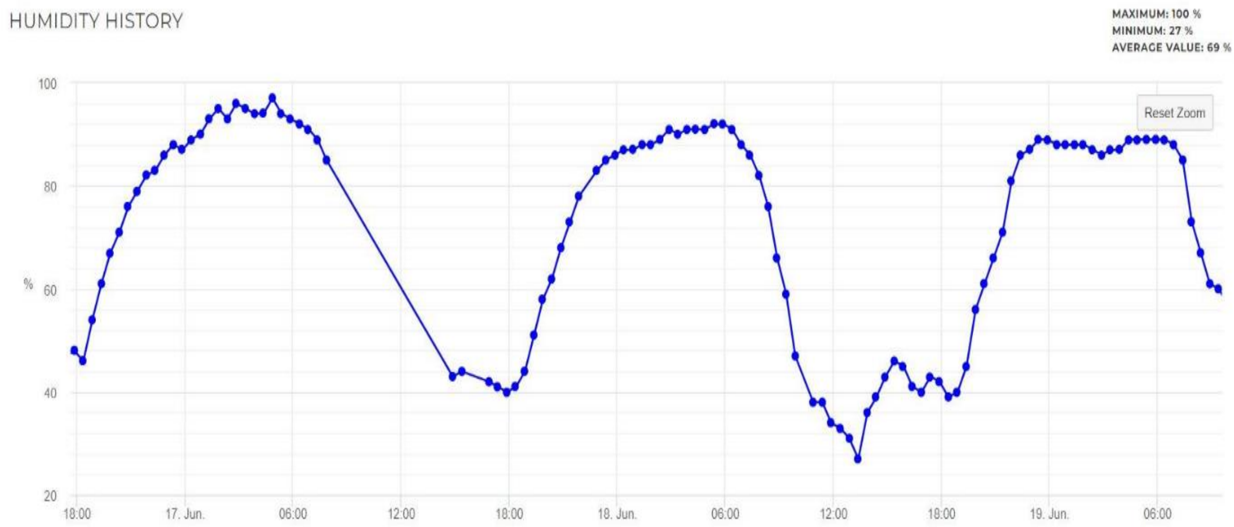

Figure 4.4. Outside humidity.

The moments when the compressor is activated are shown in Figure 4.5.

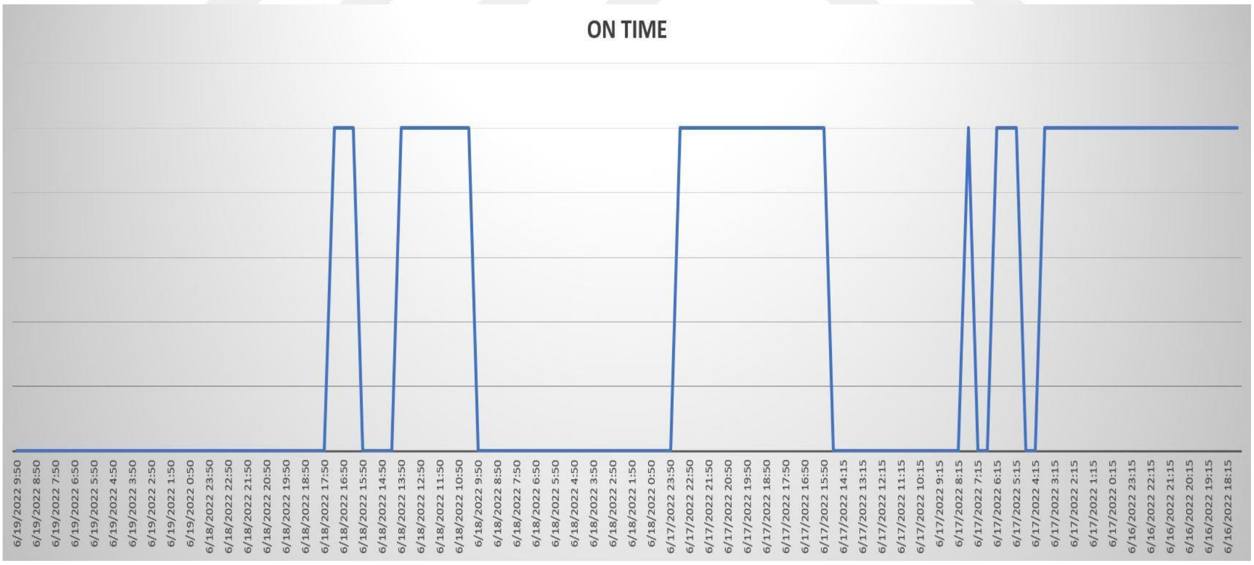

Figure 4.5. Compresor work moments.

The cumulative daily distribution of solar energy consumed during the test is given in Figure 4.6.

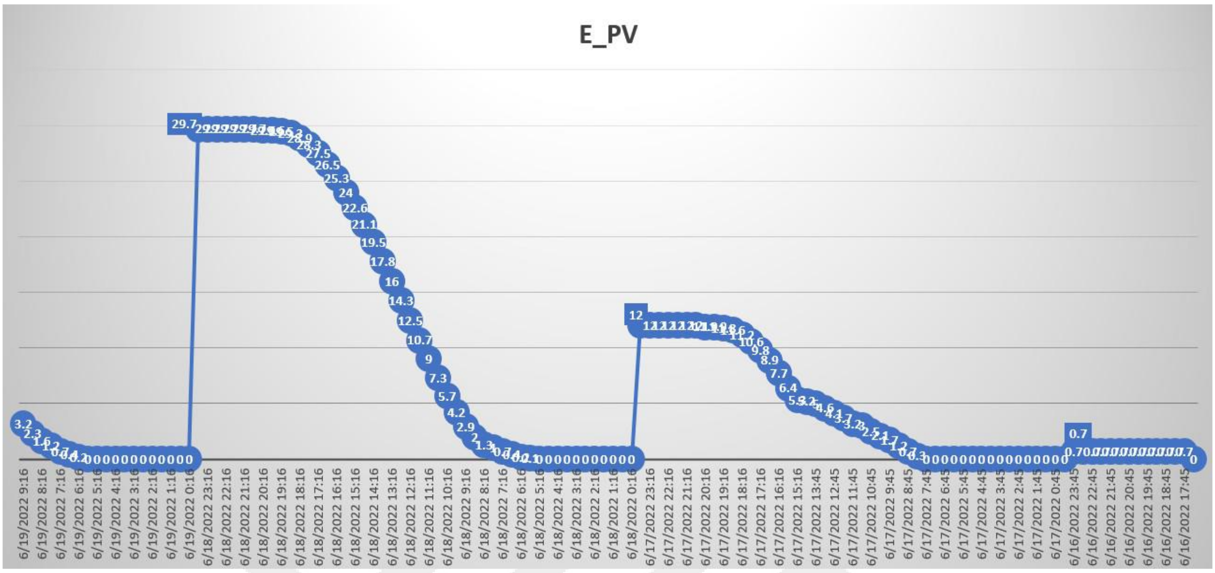

Figure 4.6. Solar energy consumption.

The cumulative daily distribution of the energy consumed from the battery during the test is shown in Figure 4.7.

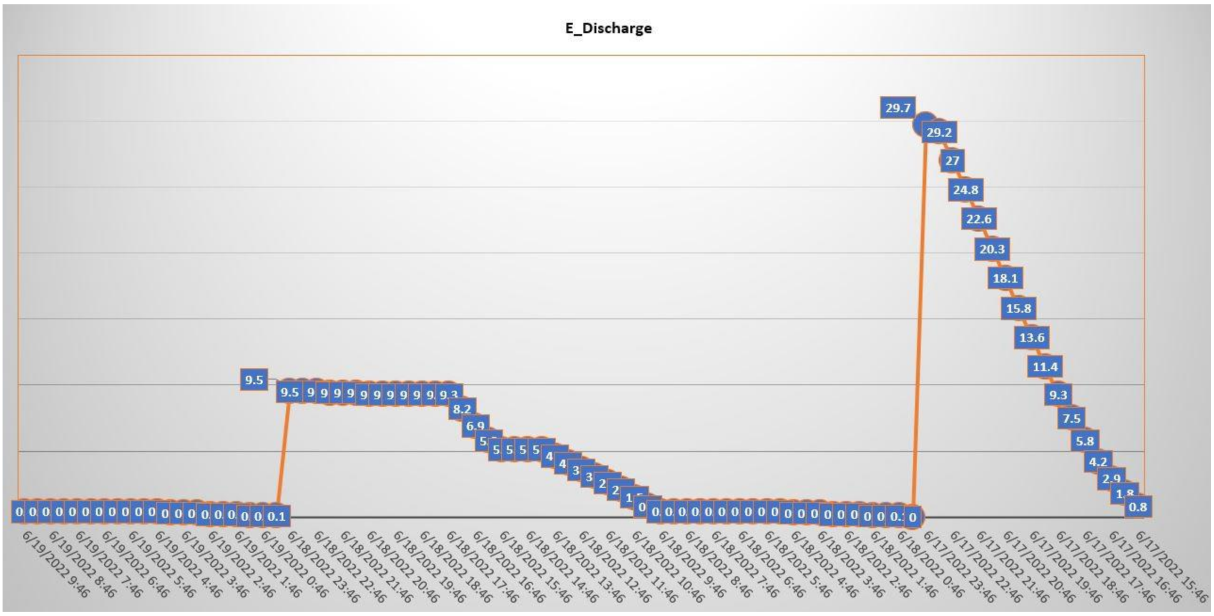

Figure 4.7. Battery energy consumption.

4.2. Refrigerated Trailer Cooling Test-2 Results

The results of the Refrigerated Trailer Cooling Test-2 are put forward in this section. The energy consumed during the test was divided into three sources, including battery, solar, and mains, with the following distributions: approximately 52 kilowatt-hours from the battery, approximately 55 kilowatt-hours from the solar, and approximately 9 kilowatt-hours from the mains. The total energy consumed during the test was estimated to be around 116 kilowatt-hours. These results demonstrate the efficiency and effectiveness of the cooling system, including the battery and solar support, in maintaining the temperature of the refrigerated trailer during this test. Distribution of energy consumed during the test:

- Battery: ~52kWh
- Solar: ~55kWh
- Mains: ~ 9kWh
- Total: ~116kWh

Internal temperature data collected during testing is shown in Figure 4.8.

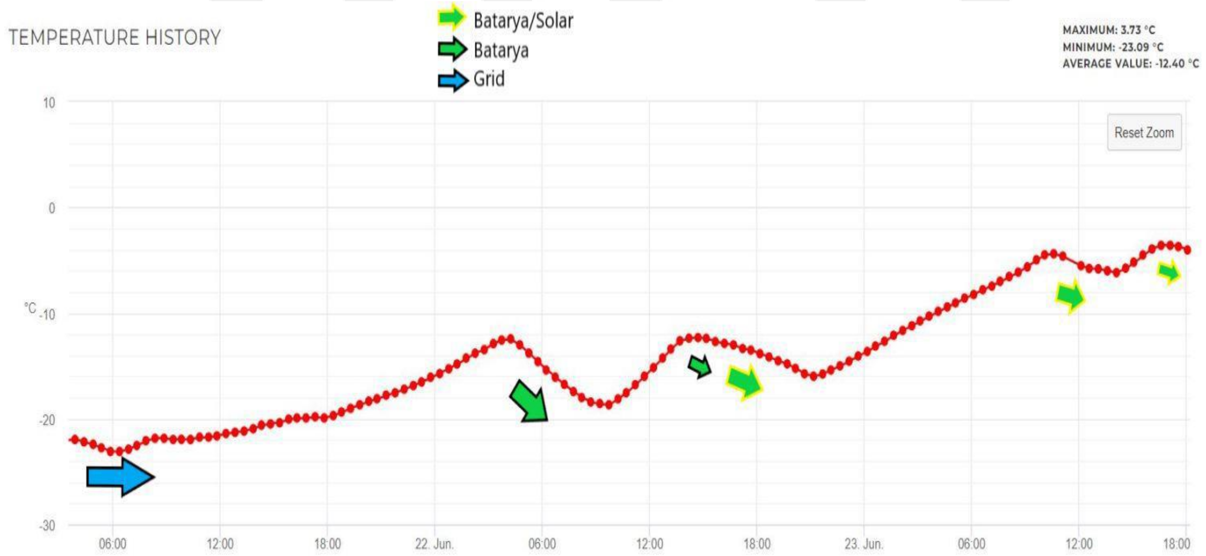

Figure 4.8. Internal temperature.

Internal humidity data collected during testing is shown in Figure 4.9.

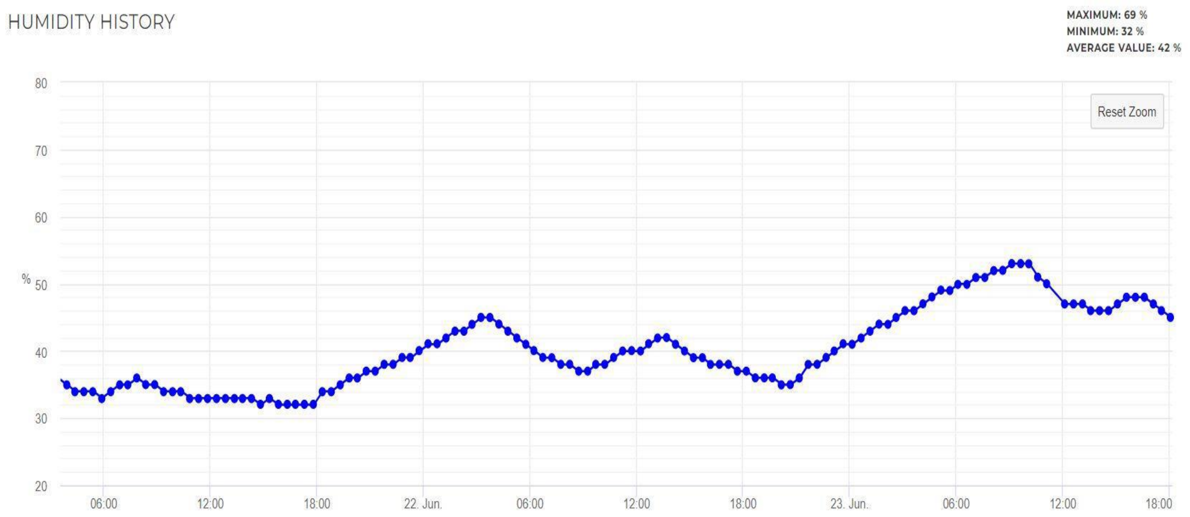

Figure 4.9. Internal humidity.

Outside temperature data collected during testing is shown in Figure 4.10.

Figure 4.10. Outside temperature.

Outside humidity data collected during testing is shown in Figure 4.11.

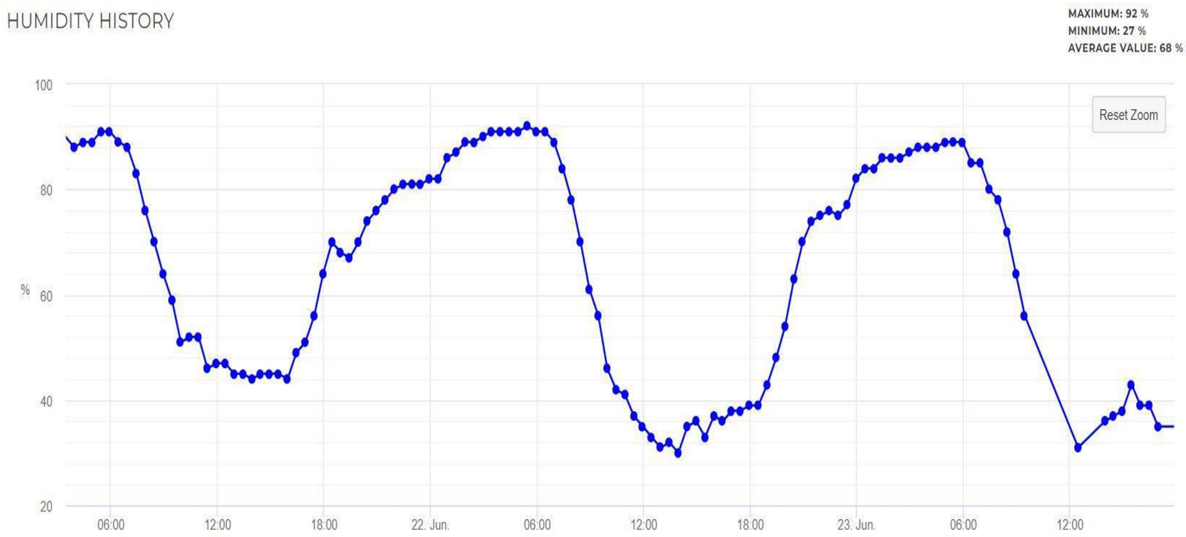

Figure 4.11. Outside humidity.

The moments when the compressor is activated are shown in Figure 4.12.

Figure 4.12. Compresor work moments.

The cumulative daily distribution of solar energy consumed during the test is given in Figure 4.13.

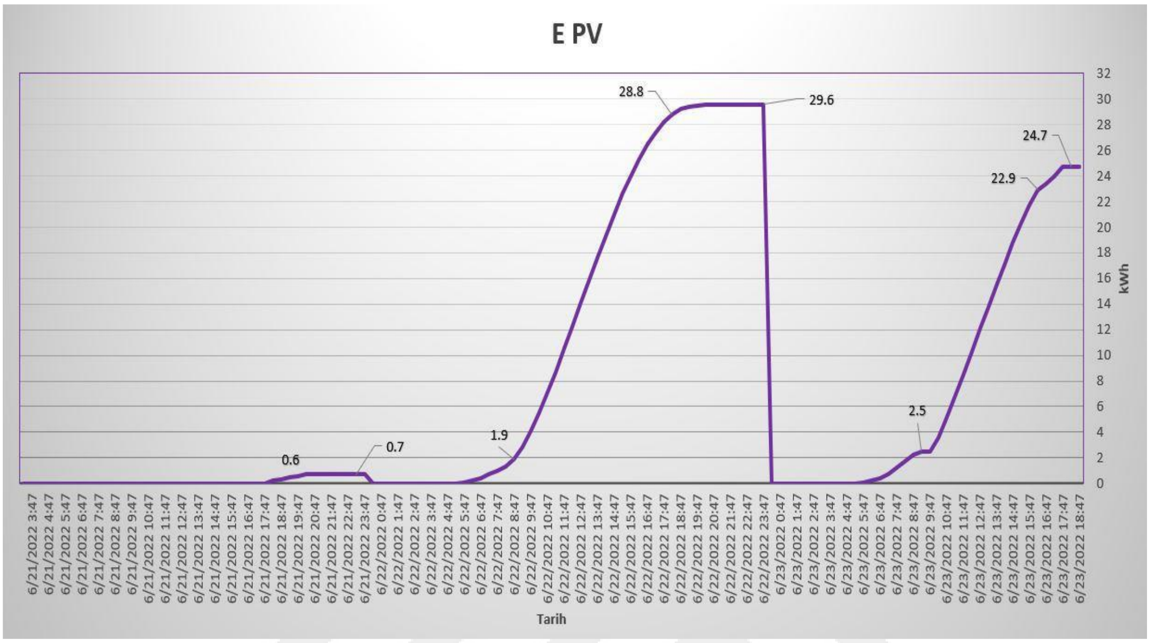

Figure 4.13. Solar energy consumption.

The cumulative daily distribution of the energy consumed from the battery during the test is shown in Figure 4.14.

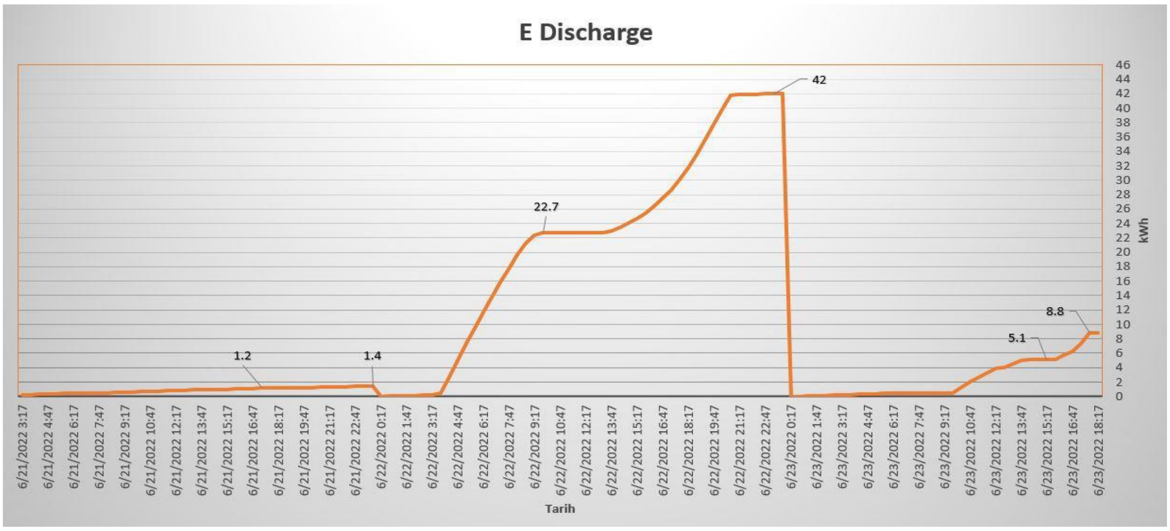

Figure 4.14. Battery energy consumption.

5. CONCLUSIONS

Battery storage technology plays a crucial role in the automotive industry as it enables vehicles to store and release energy at high frequencies, ensuring stability in both frequency and voltage that provides a solution for optimizing the energy management of electric vehicles and the ability to sustain power during periods of low energy output. The optimization process involves various performance indicators, including financial, technical, and hybrid indicators, which combine both financial and technical aspects. Financial indicators are commonly used for smaller systems, whereas hybrid indicators are more prevalent for larger renewable energy systems in the automotive industry. There are various methods for determining the optimum size of battery storage systems in electric vehicles, ranging from probabilistic, analytical, and search-based approaches to nature-inspired heuristic methods such as genetic algorithms.

In this study, by organizing the review based on the energy application type of electric vehicles, such as distributed, standalone, microgrid, and power plant systems, new insights have been gained regarding the critical design parameters and the most appropriate optimization technique for sizing the battery storage system. As the automotive industry continues to shift towards more electric vehicles, more sophisticated optimization tools will be developed, taking into consideration not just financial and technical indicators, but also environmental considerations. Lithium-ion battery technology, in particular, is expected to play a key role in the future of electric vehicles due to its high energy density and long-life cycle.

In summary, the procedures involved in the development of the Refrigerated System can be delineated as follows. Firstly, the production of the prototype for the system has been successfully accomplished. This prototype aims to ensure stability in the transportation compartment within a temperature range of -45°C to -18°C. Additionally, the system incorporates a 5 kW solar panel installed on its body, enabling the utilization of solar energy. Moreover, a 35 kW/h energy storage system is employed to facilitate uninterrupted operations. The refrigerated system is designed to operate either through solar energy or via conventional charging means. Furthermore, the integration of a remote instant data control system allows for efficient and remote monitoring and management. Lastly, the system boasts an impressive working time of 36 hours, ensuring prolonged and reliable performance.

The successful completion of the prototype of the Refrigerated System represents a significant milestone in the automotive industry. This system integrates cutting-edge technologies such as solar energy and energy storage, which not only make transportation more efficient but also align with the industry's trend towards sustainability and environmentally friendly practices. The integration of a 5 kW solar panel and a 35 kW/h energy storage system allows the system to operate even when there is no sun or the power generated by the solar panel is insufficient, making it an ideal solution for various transportation applications. In addition, the remote instant data control system allows for real-time monitoring and optimization of the system's performance, making it an effective tool for reducing energy consumption and improving the overall efficiency of the transportation process. With its capabilities of operating for 36 hours, the Refrigerated System is poised to make a significant contribution to the development of the automotive industry and the ongoing efforts to reduce its environmental impact.

6. RECOMMENDATIONS

To further advance our understanding of PV powered lithium-ion batteries as they pertain to refrigerated trucks, it is recommended that future studies incorporate the following considerations. To optimize the efficiency and performance of PV powered lithium-ion battery systems in refrigerated trucks, it is crucial to conduct a thorough analysis of the PV panels and the lithium-ion battery system. This analysis should encompass the examination of the maximum power output capability, current and voltage characteristics, and the overall efficiency of the system. Such an analysis will help to determine the strengths and limitations of the system and provide valuable insights into ways to improve its performance in real-world applications. It is important to note that the results of this analysis will be essential for the development of effective energy solutions for refrigerated trucking operations. To ensure the effective operation of PV powered lithium-ion battery systems in refrigerated trucks, it is important to integrate the system with energy management systems. Energy management systems play a crucial role in maximizing the utilization of energy produced by the PV panels and stored in the lithium-ion battery. By monitoring the energy consumption and production patterns, the energy management system can ensure that energy is utilized effectively and efficiently, reducing energy losses, and maximizing energy utilization. Furthermore, integration with energy management systems can help to optimize the overall performance of the PV powered lithium-ion battery system by ensuring that energy is being utilized at the right time, in the right way. Integration with energy management systems can also help to increase the overall reliability and stability of the PV powered lithium-ion battery system. By monitoring the performance and status of the battery, energy management systems can detect any potential problems and take appropriate action to prevent energy losses and maintain system stability. Additionally, energy management systems can be programmed to optimize the energy storage and usage efficiency, ensuring that the battery is being charged and discharged at the most optimal times to extend the life of the battery. In the context of refrigerated trucks, integration with energy management systems can also help to reduce the total cost of ownership for the PV powered lithium-ion battery system. By maximizing energy utilization and minimizing energy losses, the energy management system can help to lower the overall operating costs of the refrigerated truck, making the system more cost-effective and financially viable. Additionally, by ensuring that the battery is being used optimally, the energy management system can extend the life of the battery, reducing replacement costs and further reducing the total cost of ownership.

In conclusion, integration with energy management systems is an essential component of PV powered lithium-ion battery systems in refrigerated trucks. By maximizing energy utilization, reducing energy losses, and optimizing the overall performance of the system, energy management systems play a crucial role in ensuring the efficient and effective operation of PV powered lithium-ion battery systems in refrigerated trucks. To effectively determine the economic feasibility of PV powered lithium-ion battery systems for use in refrigerated trucks, a cost-benefit analysis should be conducted. This analysis should consider the upfront costs associated with the installation and implementation of the system, as well as the long-term operational costs such as maintenance, energy consumption, and replacement costs. Additionally, the cost-benefit analysis should consider the potential cost savings that may result from the use of PV powered lithium-ion battery systems, such as reduced dependence on fossil fuels and lower energy costs. The financial viability of the system should also be evaluated in comparison to traditional cooling solutions for refrigerated trucks, such as diesel-powered refrigeration units. Furthermore, the cost-benefit analysis should consider the potential for government incentives and subsidies, as well as the tax benefits that may be available for organizations that implement renewable energy solutions. The analysis should also consider the potential for increased revenue and profitability because of increased efficiency and reduced energy costs. Ultimately, the results of the cost-benefit analysis will provide valuable information for decision-makers, allowing them to determine the most cost-effective and financially viable energy solutions for their refrigerated trucking operations. The analysis will also inform future studies on PV powered lithium-ion battery systems, contributing to the development of more cost-effective and efficient energy solutions for the transportation industry. An environmental impact assessment is crucial in determining the sustainability of PV powered lithium-ion battery systems for refrigerated trucks. The assessment should consider various factors such as the production, use, and disposal of the materials used in the system, as well as the overall carbon footprint of the system. It should also consider the potential for reducing greenhouse gas emissions, which is a major contributor to climate change. The implementation of PV powered lithium-ion battery systems in refrigerated trucks can significantly reduce their carbon footprint, as they rely on clean and RES. Additionally, the use of these systems can also improve energy security, as they do not rely on traditional and subject energy sources to price fluctuations and availability issues. Furthermore, the environmental impact assessment should also examine the potential for waste generation and its impact on the local ecosystem. This includes waste generated during the production and disposal of the materials used in the system, as well as waste generated during the maintenance and operation of the system. The assessment should also consider the potential for the materials used in the system to be reused or recycled at the end of their lifecycle.

Finally, the assessment should also consider the potential for the PV powered lithium-ion battery system to reduce the overall environmental impact of refrigerated trucks, as they are commonly used to transport perishable goods over long distances. By reducing the carbon footprint of these trucks, the system can also contribute to the reduction of greenhouse gas emissions and the mitigation of climate change. In the context of PV powered lithium-ion battery systems for refrigerated trucks, long-term performance analysis is of utmost importance. This analysis aims to assess the degradation of the system over an extended period of time, in order to determine its longevity and efficiency. Long-term performance analysis is critical in ensuring the reliability of the system, which is of utmost importance in the demanding and often rugged conditions associated with the operation of refrigerated trucks. To perform a comprehensive long-term performance analysis, various parameters such as capacity fade, power output, and overall efficiency should be closely monitored over a prolonged period. Additionally, the effect of temperature, humidity, and other environmental factors on the performance of the system should also be evaluated. Furthermore, the impact of cyclic use, charging and discharging patterns, and other operational conditions should be taken into account in the analysis. Incorporating advanced monitoring and control systems into the design of PV powered lithium-ion battery systems can significantly enhance the accuracy and reliability of the long-term performance analysis. This may include incorporating real-time monitoring, predictive maintenance, and other advanced features to improve the overall efficiency and reliability of the system.

Consequently, long-term performance analysis plays a crucial role in ensuring the longevity and efficiency of PV powered lithium-ion battery systems for refrigerated trucks. By closely monitoring various performance parameters over an extended period of time, and incorporating advanced monitoring and control systems, it is possible to enhance the reliability and cost-effectiveness of these systems, ultimately contributing to the development of sustainable and efficient energy solutions for refrigerated truck application. By considering these factors, future studies on PV powered lithium-ion batteries for refrigerated trucks can contribute to the advancement of efficient, reliable, and cost-effective energy solutions in this specific application.

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