# Autonomous Drone System for Emergency Charging of Electric Vehicles

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## Abstract

*This study explores the development of an emergency charging system for electric vehicles (EVs) using drones. The system is designed to address the limitations of current EV charging infrastructure, particularly in remote or inaccessible areas. The proposed solution involves a drone equipped with a battery pack, which can be dispatched to a stranded EV to provide immediate power. The system is structured to include a drone docking station, a wireless communication module, and an autonomous navigation system to ensure precise delivery and efficient energy transfer. The study outlines the material selection, system configuration, and operational procedures, supported by experimental results that demonstrate the feasibility of this innovative approach. The findings suggest that the drone-based emergency charging system can significantly enhance the reliability and accessibility of EVs, offering a practical solution to range anxiety and extending the reach of sustainable transportation. Various modifications and improvements to the system are possible within the scope of the study's technical framework, highlighting the potential for broader application and future development.*

***Keywords:*** *Drone-Based Charging, Electric Vehicle Emergency Power, Autonomous Navigation, Wireless Energy Transfer, Sustainable Transportation*

## INTRODUCTION

The rapid proliferation of electric vehicles (EVs) marks a significant shift in the automotive industry, driven largely by global environmental initiatives aimed at reducing greenhouse gas emissions and reliance on fossil fuels. To reduce air pollution and oil dependence in the transportation sector, there has been an increased overall market adoption of electric vehicles (EVs) in recent years [1]. Electric vehicles, powered by secondary batteries instead of traditional internal combustion engines, are at the forefront of this transition. Many of researchers summarized charging infrastructure of EVs [2], [3], [4], integration of EVs in smart grid [5], [6], impact of the vehicle to grid (V2G) technology [7], [8], [9], EV and smart grid interaction [10], [11]. As the demand for EVs continues to rise, so too does the need for a robust and accessible charging infrastructure. To make EVs competitive in the market, a number of challenges need to resolve, such as battery cost, efficient charging strategies, interoperability of the charging stations, and the impact of EV integration to the grid [12]. However, despite the increasing number of charging stations and chargers being installed, the current infrastructure remains insufficient to meet the growing needs of EV users. Moreover, successful growth of EVs over the next decade relies on the development of international standards and codes, universal infrastructures, associated

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peripherals and user-friendly software [13].

The inadequacy of charging infrastructure often results in significant inconvenience for EV owners. In locations where charging stations are limited, such as company parking lots or residential complexes, competition for available chargers can be intense. This scarcity forces users to wait for extended periods—sometimes ranging from several minutes to hours—before they can charge their vehicles. Even after securing a charging spot, users face further inconvenience by having to relocate their vehicles once the charging process is complete to accommodate other users. These challenges underscore the need for more flexible and responsive charging solutions, particularly in scenarios where immediate access to charging stations is not feasible.

In response to these challenges, several technological solutions have been proposed. For instance, the electric vehicle reservation charging system [14] offers a method to optimize the use of charging stations by allowing drivers to reserve charging times, thereby reducing wait times and preventing power shortages at stations. Another innovation, the electric vehicle charger reservation and roaming system [15] enhances efficiency by enabling users to reserve multiple chargers and modify or cancel reservations as needed. While these systems provide valuable improvements, they are predominantly designed for use within established charging networks and are less effective in addressing emergency situations where an EV may be stranded due to battery depletion in remote or underserved areas.

To address these limitations, this paper proposes an innovative solution: an emergency charging system for electric vehicles utilizing drones. This system is designed to provide rapid, on-demand power delivery to EVs in need of urgent charging, regardless of their location. By leveraging drone technology, the proposed system offers a flexible and scalable approach to mitigating the challenges associated with current charging infrastructure, particularly in emergency scenarios.

The primary objectives of this study are threefold: first, to enable drones to provide emergency charging services to electric vehicles; second, to protect the battery packs housed within the drone's power charger from external shocks; and third, to prevent potential electrical leakage or short circuits within the battery pack. By achieving these objectives, the proposed system seeks to enhance the reliability and convenience of electric vehicle use, thereby contributing to the broader adoption and sustainability of EV technology.

## MATERIALS & METHODS

In response to the growing need for a reliable and mobile emergency charging solution for electric vehicles (EVs), this invention introduces a novel system utilizing drones. The proposed system is designed to address situations where traditional charging infrastructure is either unavailable or insufficient. The system is composed of several key components, each contributing to an efficient and scalable method of delivering power to stranded EVs.

The central element of the system is the drone body, which serves as the primary platform for carrying and deploying the charging components. This drone is equipped with a designated mounting space specifically designed to accommodate the power charging unit. By integrating this configuration, the drone is capable of transporting and delivering the necessary power to electric vehicles in emergency situations, offering a crucial service when conventional charging options are not accessible.

At the core of the system is the power charger, responsible for storing and transferring electrical energy to the EV. This unit is securely mounted within the drone’s designated space and is comprised of several essential parts. The housing acts as a protective enclosure, safeguarding the internal components from potential external damage. The design of the housing ensures that it is both lightweight and durable, maintaining the drone's flight stability while protecting the charger during transport. Central to the power charger is a detachable and rechargeable battery pack, which stores the electrical energy needed to charge the EV. The design allows for easy removal and replacement, facilitating quick turnaround times in emergency scenarios. Additionally, the power charger includes a connection plug that directly interfaces with the EV's battery, enabling the efficient transfer of stored energy to the vehicle, crucial during critical moments.

The system's operations are coordinated by a main server, which plays a pivotal role in managing the drone’s response to charging requests. The server includes two essential modules that ensure the drone’s effective deployment. The location tracking module is activated upon receiving a charging request from the vehicle owner via a user terminal. This module accurately determines the terminal’s location, ensuring the drone is dispatched to the correct location. Once the location is identified, the flight command module sets this as the drone's destination and directs the drone to navigate to the specified site, enabling timely and precise delivery of the charging service.

To ensure the functionality and safety of the power charger, the housing is equipped with several advanced features. Inside the housing, multiple storage slots are designed to securely hold the battery packs through a fitting mechanism. This prevents any movement of the battery packs during the drone's flight, which could otherwise disrupt the operation. The housing also includes connection terminals positioned on one side of each storage slot. These terminals establish an electrical connection with the inserted battery packs, facilitating the flow of energy from the battery packs to the connection plug, thus ensuring that the EV can be efficiently charged upon the drone’s arrival. To further enhance durability, the inner surfaces of the storage slots, except for the connection terminals, are lined with carbon fiber. This material provides additional structural integrity, protecting the battery packs from external shocks and ensuring the power charger remains operational under various conditions.

In conclusion, the drone-based emergency charging system for electric vehicles presented in this invention effectively addresses a significant gap in the current EV charging infrastructure. By leveraging the mobility and versatility of drones, this system offers a flexible and scalable solution for providing emergency power to EVs in remote or underserved areas. The integration of robust components such as a durable power charger, precise location tracking, and efficient energy transfer mechanisms ensures that this system can deliver reliable and timely assistance to EV owners. This innovation significantly enhances the overall user experience and contributes to the broader adoption of electric vehicles.

Figures 1 and 2 illustrate the conceptual diagrams of the system presented in this study, which focuses on an emergency charging system for electric vehicles (EVs) utilizing drones. The system primarily consists of the drone body (100), the power charger (200), and the main server (300).

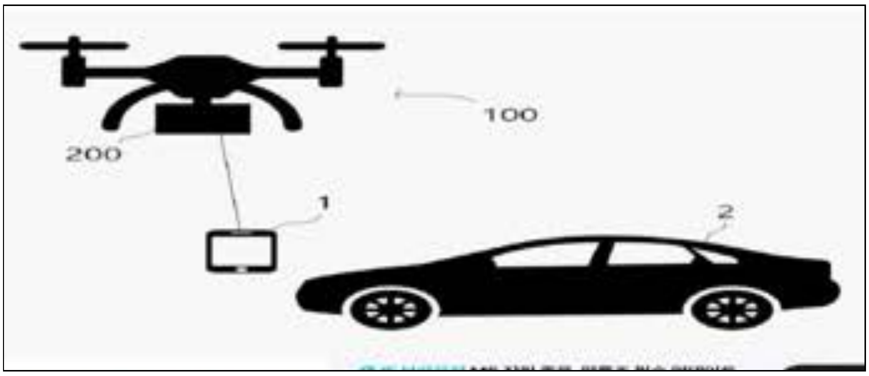


Figure 1. Conceptual diagram of the system I

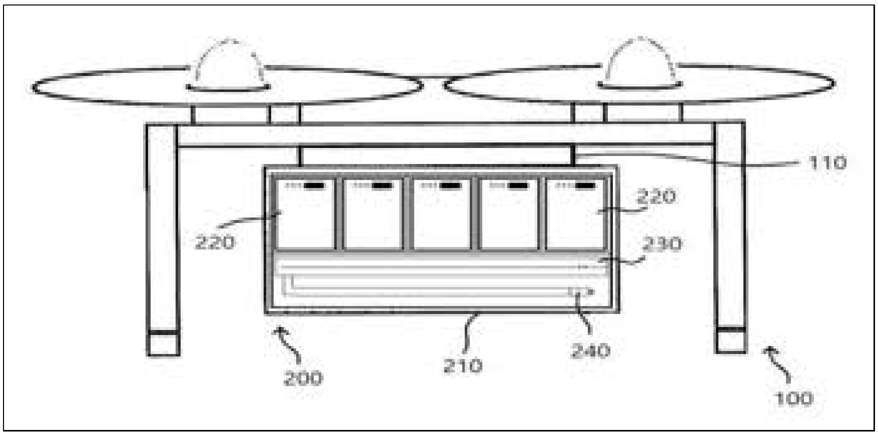


Figure 2. Conceptual diagram of the system II

The drone body (100) is generally designed with a structure that enables autonomous operation, similar to conventional drones. This means that the drone's flight status and direction can be controlled through a separate control device or it may be capable of autonomous flight. In the case of drones capable of autonomous flight, they are equipped with at least one of several components such as ultrasonic transmitters/receivers, GPS, altimeters, or cameras. The data collected by these components, such as signals detected by the ultrasonic sensors, altimeters, or cameras, can be stored in memory or transmitted to a separate control controller responsible for managing the drone body (100) via a wireless communication device.

The drone body (100) is also equipped with a designated mounting space (110) for attaching the power charger (200). Ideally, this mounting space (110) is located on the lower side of the drone body (100), allowing the power charger (200) to supply electricity to the EV (2). This mounting space (110) can be located either inside the drone body (100) or on the external lower side, where a bracket can be attached to hold the power charger (200). Thus, the mounting space (110) can be situated either inside or outside the drone body (100), with no specific restrictions on its location.

The power charger (200) is designed to provide electricity to the EV (2) while being mounted on the drone body (100). It preferably includes a housing (210), a battery pack (220), and a connection plug (240). The housing (210) is equipped with an internal storage space to accommodate the battery pack (220), and can also house the connection plug (240). The battery pack (220), once charged, can be fitted into the storage slot (211) within the storage space, while the connection plug (240) can be stored in a designated plug storage groove within the same space. This plug storage groove includes a through-hole that allows for electrical connection between the connection plug (240) and the battery pack (220).

Furthermore, the housing (210) may feature a hinged door, which can open and close to provide access to the internal storage space. The housing (210) is ideally structured as an open-front rectangular frame, within which the battery pack (220) and connection plug (240) can be stored. The open front of the rectangular structure can be sealed with the hinged door when necessary.

Inside the housing (210), both the battery pack (220) and the connection plug (240) are installed. The battery pack (220) is mounted within the housing in a detachable manner (preferably within the storage slot (211)) and is charged with electrical power. The battery pack (220) is electrically connected to the connection plug (240), enabling the latter to deliver the stored power to the EV's (2) battery through the vehicle's charging port, thereby providing emergency charging for the EV (2). Ideally, one end of the connection plug (240) is connected to the battery pack (220) to receive power, and a power conversion unit (230) is included at the connection point to convert the battery pack's (220) power to a suitable voltage for the EV (2). The connection plug (240) then supplies the converted power to the EV through the power conversion unit (230).

The main server (300) of the present invention is designed to receive a charging request for an electric vehicle (2) from an owner terminal (1) held by the owner of the electric vehicle (2), determine the location of the requesting owner terminal (1), and then instruct the flight of the drone body (100) to that location, enabling emergency charging of the electric vehicle (2) through a power charger (200) mounted on the drone body (100). The main server (300) refers to hardware that includes a CPU and storage means, equipped with a communication unit and transmission means for transmitting communication and information. The series of modules and their specific functions, which will be described later, can be derived from the software executed by this CPU. In other words, the main server (300) is hardware equipped with a central processing unit (CPU), memory, and storage means such as a hard disk, where software that can be executed by the CPU is installed and can run. The specific configuration of this software is structured into components called 'modules', 'units', and 'interfaces'.

At this time, the main server (300) may include RAM (Random Access Memory, not shown) and ROM (Read-Only Memory, not shown) for temporarily and/or permanently storing signals (or data) processed internally, as well as a processor. Additionally, the main server (300) can be implemented in the form of a system on a chip (SoC) that includes at least one of the graphic processing unit, RAM, and ROM. The processor may include one or more cores (not shown), a graphic processing unit (not shown), and/or a communication path (e.g., a bus) for sending and receiving signals with other components. The memory may store programs (one or more instructions) for executing and controlling the modules or units. The programs stored in the memory can be divided into multiple modules based on their functions.

The steps of the methods or algorithms described in relation to the embodiments of this study can be directly implemented in hardware, implemented in software modules executed by hardware, or implemented through a combination of both. Software modules may reside on computer-readable recording media of any form known in the art, such as RAM, ROM, EPROM (Erasable Programmable ROM), EEPROM (Electrically Erasable Programmable ROM), Flash Memory, hard disks, removable disks, and CD-ROMs. In other words, the components used in this study can be implemented as programs (or applications) to be executed in combination with hardware such as computers and stored in media. The components of this study can be executed as software programming or software elements, and similarly, the embodiments may include various algorithms implemented as combinations of data structures, processes, routines, or other programming configurations, implemented in programming or scripting languages such as C, C++, Java, assembler, etc. The functional aspects can be implemented as algorithms executed on one or more processors.

The configuration of these 'modules', 'units', or 'interfaces' refers to software executed through the CPU and memory installed and stored in the storage means of the main server, or to a hardware configuration such as FPGA or ASIC. At this time, the terms 'module', 'unit', or 'interface' are not limited to hardware, and they may be configured to reside in addressable storage media or configured to cause one or more processors to execute them. For example, 'modules', 'units', or 'interfaces' may include software components, object-oriented software components, class components, and task components, as well as processes, functions, properties, procedures, subroutines, segments of program code, drivers, firmware, microcode, circuits, data, databases, data structures, tables, arrays, and variables. The functions provided by these 'modules', 'units', or 'interfaces' may be combined into a smaller number of components, units, or modules, or further divided into additional components, units, or modules. Based on this macroscopic configuration, the detailed configuration and functions will be explained below. Figure 3 is a block diagram illustrating the structure of the main server.

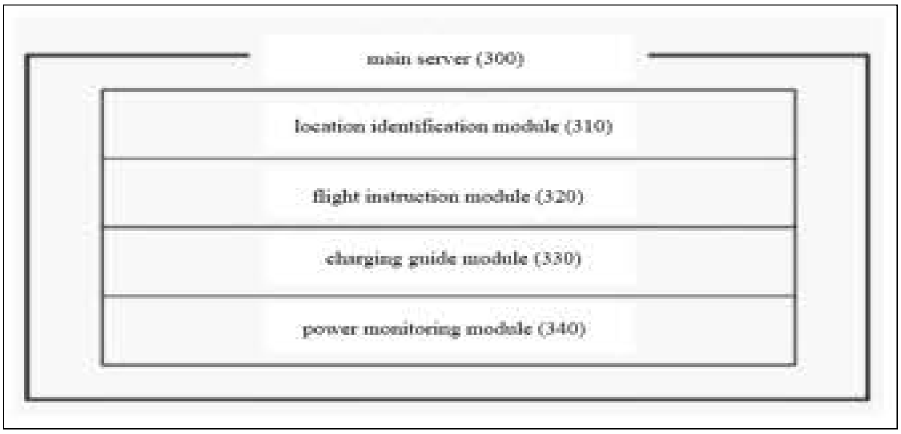


Figure3. Diagram illustrating the Structure of the Main Server

Referring to figure 3, the main server (300) of the present invention can be configured to include a location identification module (310) and a flight instruction module (320).

First, the location identification module (310) performs the function of receiving charging request information from the owner terminal (1) held by the owner of the electric vehicle (2) and identifying the location information of the owner terminal (1) that transmitted the charging request information. Preferably, the owner terminal (1) that transmits the charging request information may be a communication-enabled device such as a smartphone or tablet PC that the owner carries, which can connect to the main server (300). In this case, the owner terminal (1) can transmit charging request information to the main server (300) when emergency charging of the electric vehicle (2) is required. More preferably, an application capable of communicating with the main server (300) is installed on the owner terminal (1), allowing the owner terminal (1) to transmit charging request information via the application so that the main server (300) receives the charging request information. To facilitate this, the application allows the owner terminal (1) to transmit the charging request information to the main server (300).

Once the charging request information is received, the location identification module (310) identifies the location information of the owner terminal (1) that transmitted the charging request information. To determine the location information of the owner terminal (1), the main server (300) preferably obtains access permission to the location information of the owner terminal (1) through the application, enabling the main server (300) to be provided with the location information of the owner terminal (1) as the charging request information is received. Alternatively, the owner terminal (1) can send the location information together with the charging request information.

The reason for determining the location information of the owner terminal (1) instead of the location information of the electric vehicle (2) is that, in most cases requiring emergency charging, the owner is typically in the electric vehicle (2), or even if not, the owner is usually located in close proximity to the electric vehicle (2). Therefore, by determining the location information of the owner terminal (1) carried by the owner, the location information of the electric vehicle (2), which is in need of power, can be indirectly identified.

The flight instruction module (320) functions to set the identified location information of the owner terminal (1) as the destination and instruct the flight of the drone body (100) to that destination. At this point, the flight instruction module (320) sets the location information of the owner terminal (1) as the destination, generates a route from the departure point of the drone body (100) to the location of the owner terminal (1), and provides this to the drone body (100) to instruct its flight.

Through the configuration of the main server (300) as described, when charging request information is received from the owner terminal (1), the drone body (100), equipped with the power charger (200), can be instructed to reach the location information of the owner terminal (1). This allows the owner to perform emergency charging of their electric vehicle (2) through the power charger (200) mounted on the drone body (100), thereby preparing for emergency situations such as power shortages.

Furthermore, the emergency charging system using drones in this study is aimed at emergency charging in critical situations rather than full power charging of electric vehicles. After the emergency charging is completed, the main server (300) can provide the location of nearby charging stations to the owner terminal (1) for additional charging. To achieve this, the main server (300) may further include a charging guide module (330).

The charging guide module (330) performs the function of identifying the location of electric vehicle charging stations near the location information of the owner terminal (1) and the route from the location information of the owner terminal to the charging stations, then providing this information to the owner terminal (1). The proximity criterion for nearby electric vehicle charging stations relative to the location information of the owner terminal (1) can be set by the system administrator, for example, within a radius of 10 km or 5 km. In other words, the system identifies the location of electric vehicle charging stations within a set distance range, such as a 5 km radius, from the location information of the owner terminal (1). Moreover, in addition to the location of the electric vehicle charging stations, the system generates a route from the location information of the owner terminal (1) to the identified charging station and provides it to the owner terminal (1). At this time, the location identification and route generation may be provided in conjunction with conventional navigation-based route guidance functions.

By providing the identified location of the electric vehicle charging station and the route to the charging station to the owner terminal (1), the system can maximize the owner's convenience by enabling the electric vehicle (2), which has completed emergency charging, to perform additional charging at the charging station. Furthermore, to perform emergency charging of the electric vehicle using the drone from the main server (300), it is essential to monitor the remaining power of the battery pack (220) mounted on the power charger (200) regularly.

For this purpose, the main server (300) includes a power monitoring module (340) that can determine the remaining power of the battery pack (220). Therefore, if the remaining power falls below a preset threshold, the system can stop the additional flight of the drone body (100) and direct the drone body (100) to return to the charging station for recharging the drone body (100) and the battery pack (220). Through such a power monitoring module (340), the system can monitor the remaining power of the battery pack (220) mounted on the power charger (200) in real-time, ensuring continuous emergency charging by managing the battery pack (220). Figure 4 is a cross-sectional view showing the basic structure of the battery pack housed within the casing.

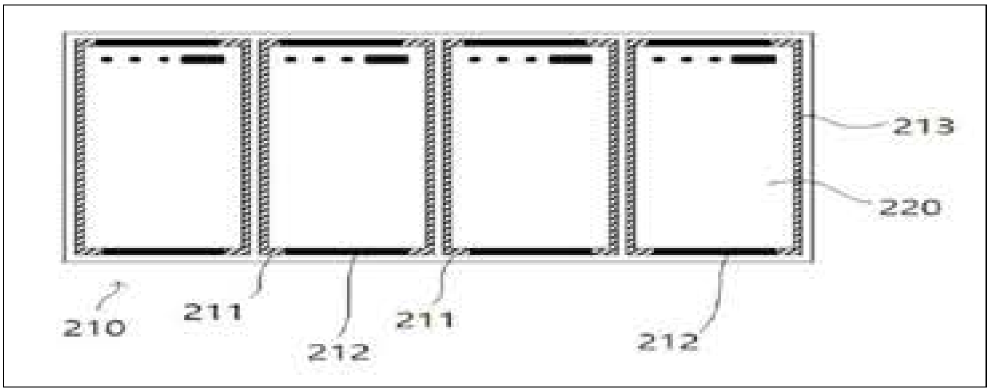


Figure 4. Cross-sectional View showing the Basic Structure of the Battery Pack

Referring to figure 4, the housing (210) of the present invention is preferably configured to allow detachable engagement of the battery pack (220) while simultaneously supplying the power from the engaged battery pack (220) to the connection plug (240). For this purpose, the housing (210) includes a storage slot (211), a connection terminal (212), and a shock-absorbing layer (213).

The storage slot (211) is provided within the internal storage space of the housing (210) to engage the battery pack (220), with multiple storage slots (211) arranged in parallel to allow the engagement of multiple battery packs in a horizontal direction. These storage slots (211) have a shape corresponding to the outer surface of the battery pack (220) to securely hold and support each battery pack (220). Furthermore, a connection terminal (212) is provided on one side of the storage slot (211), allowing the power from the battery pack (220) engaged in the storage slot (211) to be supplied to the connection plug (240) through the connection terminal (212).

The connection terminal (212) is designed to electrically connect the battery pack (220) engaged in the storage slot (211) with the connection plug (240). It not only enables the supply of power from the battery pack (220) to the connection plug (240) through the connection terminal (212) but also facilitates the mutual electrical connection between multiple battery packs (220). Therefore, electrical connections between multiple connection terminals (212) can be established via wires, and the connection terminals (212) and connection plug (240) can also be electrically connected through wires, though not shown in the diagram, to supply power from the battery pack (220) to the connection plug via the connection terminal (212).

More preferably, the interconnected connection terminals (212) are electrically connected to the aforementioned power conversion unit (230) via wires, allowing the power conversion unit (230) to receive power from the battery pack (220) and convert it into a set voltage suitable for charging the electric vehicle. The converted power is then supplied to the connection plug (240). For this, the power conversion unit (230) may be provided near the storage slot (211) within the housing (210), ensuring an electrical connection between the connection terminal (212) and the power conversion unit (230), and between the power conversion unit (230) and the connection plug (240) to supply the converted power.

Moreover, in the housing (210) configuration of the present invention, multiple battery packs (220) are fixed by engagement through the storage slots (211). In this case, the power charger (200) of the present invention, which must endure vibrations, ascents, and descents during flight, is inevitably subjected to continuous impacts from external forces, such as vibrations or shocks during ascent and descent. These impacts are transmitted to the battery pack (220) via the storage slots (211) integrated into the housing (210). Therefore, if the battery pack (220) is subjected to impacts from such external vibrations or shocks, there is a concern that the connection between the battery pack (220) and the connection terminal (212) may become unstable, and damage or defects in the battery pack (220) may occur.

To solve this problem, a shock-absorbing layer (213) is laminated on the inner surface of the storage slot (211). The shock-absorbing layer (213) is preferably laminated on the inner surface of the storage slot (211), excluding the connection terminal (212), to enhance shock resistance without hindering the electrical connection of the battery pack (220). The shock-absorbing layer (213) preferably contains carbon fiber, which is known for its high tensile strength and rigidity, excellent resistance to high temperatures and chemicals, low thermal expansion, and outstanding shock resistance due to its molecular chain structure formed by numerous carbon atoms in a crystal lattice.

More preferably, the shock-absorbing layer (213) may be composed of a polymer form that includes carbon fiber and other resins, forming a carbon fiber-reinforced polymer. Therefore, the carbon fiber may be mixed with various resins, such as epoxy resin, polyurethane, polyethylene, polypropylene, polyvinyl chloride, among others, to form a carbon fiber-reinforced polymer. As a result, when the battery pack (220) is engaged in the storage slot (211) equipped with the shock-absorbing layer (213), it prevents the transmission of vibrations or shocks caused by takeoff and landing, or other external forces, to the battery pack (220). This ensures a stable connection between the battery pack (220) and the connection terminal (212) while preventing damage or defects in the battery pack (220) due to external impacts. Figure 5 is a cross-sectional view illustrating the laminated structure of the shock-absorbing layer.

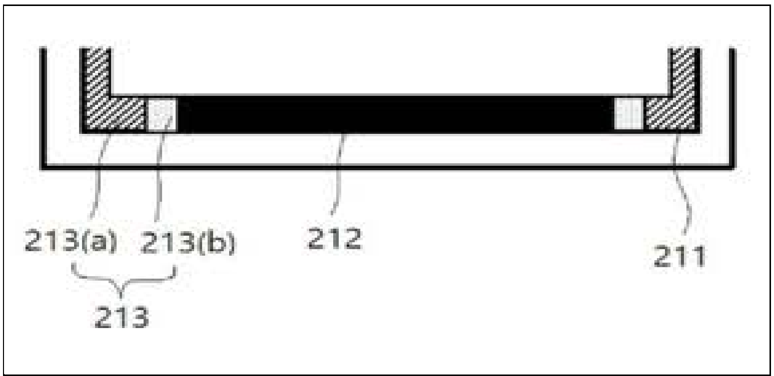


Figure 5. Cross-sectional View illustrating the Laminated Structure of the Shock-absorbing Layer

Referring to figure 5, due to the nature of drones that must perform outdoor flights, they are exposed to adverse weather conditions such as snow, rain, and thunderstorms. As a result, there is a possibility of water ingress into the housing, which can lead to short circuits, especially near the connection terminals (212) within the housing (210), due to the intrusion of water or the impact and vibrations from external forces.

To prevent such short circuits, the shock-absorbing layer (213) of the present invention may be designed with a dual-layer structure, preferably consisting of a base layer (213(a)) and an insulating layer (213(b)). The base layer (213(a)), as previously described, contains carbon fibers and forms the basic structure of the shock-absorbing layer (213). This base layer is characterized by its high tensile strength, rigidity, excellent resistance to high temperatures and chemicals, low thermal expansion, and superior shock resistance, all attributed to the carbon fiber as its active component.

Moreover, near the connection terminal (212) area of the shock-absorbing layer (213), particularly the part in contact with the connection terminal (212), an insulating layer (213(b)) is provided. This insulating layer (213(b)) is preferably located around the perimeter of the connection terminal (212), ensuring that the insulating layer (213(b)) surrounds the connection terminal (212), while the base layer (213(a)) is provided on the inner surface of the storage slot (211) where the insulating layer (213(b)) is not present. By surrounding the connection terminal (212) with the insulating layer (213(b)), insulation is enhanced.

The insulating layer (213(b)) is preferably composed of 80 to 95 parts by weight of a base made of polyethylene terephthalate (PET) and 5 to 20 parts by weight of an elastic modifier containing triphenylsulfonium triflate. The base is made of polyethylene terephthalate (PET), a resin material known for its excellent strength, ductility, rigidity, hardness, water resistance, chemical resistance, and gas barrier properties. These properties provide the basic insulating capability of the insulating layer (213(b)) while also offering a high level of physical performance.

The elastic modifier, which contains triphenylsulfonium triflate as its active ingredient, is a highly cross linkable substance that, when added to the finished base, significantly increases the molecular weight of the polymer in the composition of the insulating layer (213(b)). This promotes crosslink formation, increases the number of covalent bonds, and reduces the number of non-bonded electrons, thereby enhancing the insulation properties. As a result, it plays a crucial role in preventing and blocking potential leakage currents (short circuits) that could occur at the connection terminals.

Therefore, through this dual-material shock-absorbing layer (213), the insulating layer (213(b)) additionally wraps around the connection terminal (212), providing enhanced shock resistance while also improving insulation. This design effectively prevents and blocks any current leakage (short circuits) that could occur due to harsh weather conditions, water ingress, moisture penetration, or impacts and vibrations. Additionally, the elastic modifier included in the insulating layer (213(b)) may contain further components besides triphenylsulfonium triflate to enhance its properties. Figure 6 is a flowchart illustrating the steps involved in the production of the elastic modifier.

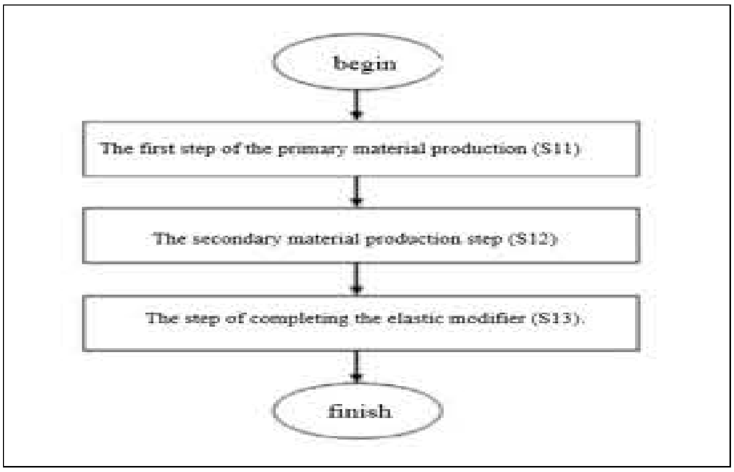


Figure 6. Flowchart of the elastic modifier

Referring to Figure 6, the elastic modifier in this study can be produced through a total of three experimental steps: the step of producing the primary material (S11), the step of producing the secondary material (S12), and the step of completing the elastic modifier (S13).

## RESULT

The first step of the primary material production (S11) involves mixing 50 to 60 parts by weight of triphenylsulfonium triflate, 30 to 40 parts by weight of trimethylolpropane triglycidyl ether, and 1 to 10 parts by weight of zinc oxide at a temperature of 50 to 60℃ for 30 to 60 minutes to produce the primary material. In this process, triphenylsulfonium triflate acts as a cross-linking agent, which, when added to the completed elastic modifier, increases the molecular weight of the polymer in the insulation layer (213(b)). Since triphenylsulfonium triflate is photodegradable, it is preferable to perform the primary material production step in the absence of light. Additionally, trimethylolpropane triglycidyl ether serves as a dispersing medium for the triphenylsulfonium triflate, while zinc oxide functions as a catalyst for the polymerization initiated by the triphenylsulfonium triflate.

The secondary material production step (S12) involves mixing 70 to 80 parts by weight of the primary material with 20 to 30 parts by weight of butyrolactone at a temperature of 90 to 110℃ for 1 to 3 hours to produce the secondary material. In this step, butyrolactone serves as a curing agent that partially polymerizes the triphenyl sulfonium triflate, thereby aiding in the curing process. It also functions to increase the viscosity of the elastic modifier, enhancing the adhesion properties of the impact-resistant layer. Like the primary material production step, this secondary material production should also be conducted in the absence of light to prevent degradation.

The final step in completing the elastic modifier (S13) involves mixing 80 to 95 parts by weight of the secondary material with 3 to 10 parts by weight of benzoyl peroxide and 1 to 10 parts by weight of an adhesion modifier containing ghatti gum at a temperature of 30 to 40℃ for 1 to 3 hours to finalize the elastic modifier.

In this step, benzoyl peroxide acts as a photoinitiator, which initiates the polymerization of the elastic modifier upon exposure to light. Therefore, it is recommended that this stage is conducted in a light-blocked environment to suppress the activation of benzoyl peroxide. After mixing the base with the elastic modifier, exposure to light should be provided to induce polymerization.

Ghatti gum serves to increase the viscosity, enhance emulsification stability, and improve the texture and physical properties of the mixture. It is highly soluble, effectively increases viscosity, and, when added to the elastic modifier, improves the flexibility and texture, providing a more flexible coating.

The elastic modifier produced through this process, when mixed with a base containing carbon fibers and activated by light, forms a polymer with high insulating properties, effectively preventing current leakage or short circuits around the connection terminals. Additionally, the modifier's flexibility allows it to absorb external shocks, and it offers excellent adhesion to the surface of the base layer.

To evaluate the effectiveness of this elastic modifier, experiments were conducted. The results were compared with a control group using a known resin. The experiment consists of two preferred embodiments (trials) of the elastic modifier composition developed in this study, referred to as Trial 1 and Trial 2. The control group for comparison purposes is a known resin composition.

In Trial 1, 55g of triphenylsulfonium triflate, 35g of trimethylolpropane triglycidyl ether, and 10g of zinc oxide were mixed at 55℃ for 45 minutes to produce 100g of the first material. Next, 75g of the first material and 25g of butyrolactone were mixed at 100℃ for 2 hours to produce 100g of the second material. Then, 90g of the second material, 5g of benzoyl peroxide, and 5g of ghatti gum were mixed at 35℃ for 2 hours to complete 100g of the elastic modifier. Finally, 15g of the produced elastic modifier was mixed with 85g of polyethylene terephthalate to produce 100g of the resin composition.

In Trial 2, 15g of triphenylsulfonium triflate was mixed with 85g of polyethylene terephthalate to produce 100g of the resin composition. For the control group, the resin composition was processed using an injection molding machine (Goldstar Cable Co., IDE90EN, screw diameter: 36mm, injection volume: 119g) to create specimens for tensile strength, heat distortion, cold resistance, and flame retardancy tests. Additionally, specimens for the tracking resistance test were molded using a compression molding machine (Wabash). The physical properties of the compression- and injection-molded specimens were then measured according to the following 5 experimental methods:

| Test | Experimental Methods |
|---|---|
| Tensile | Assessed the material's ability to withstand tensile forces |
| Heat Distortion | Measured the temperature at which the material deformed under a specific load |
| Cold Resistance | Evaluated the material's ability to maintain its properties at low temperatures |
| Flame Resistance | Determined the material's resistance to ignition and burning |
| Tracking Resistance | Measured the material's ability to resist electrical tracking, which can lead to electrical failures |

Table 1. Experimental Methods

These tests aimed to compare the physical properties of the newly developed resin composition (including the elastic modifier) against the conventional resin used in the control group.

The first experiment involved testing tensile strength and elongation in accordance with Section 4 of KS M 6518 (Test Specimen: Dumbbell Type No. 3, Tensile Speed: 200mm/min). as the second experiment, the heat distortion test was conducted by placing a test specimen (10 x 30mm, thickness: 3mm) in a thermostatic chamber at 75±3℃ for 1 hour. After heating, the specimen was placed between parallel plates, subjected to a force of 1kg for 1 hour, and the thickness was measured. The reduction rate was calculated using the following formula:

*Reduction Rate (%) = ((Thickness before heating - Thickness after heating) / Thickness before heating) × 100.*

For the third, the cold resistance test involved placing the specimen in a thermostatic chamber at -20±2℃ for 2 hours, then removing it and allowing it to stand at room temperature for about 30 minutes, during which it was visually inspected for any cracks, deformation, or other abnormalities (Specimen: 100 x 100mm, thickness: 1.5mm). Forth, the flame resistance test was conducted according to ASTM D-645 (Testing Temperatures: Low Temperature (-30℃), Room Temperature (23℃)). Last, the tracking resistance test was performed according to Section 15 of KSC 3004 (Specimen: 150 x 25mm, thickness: 3mm). Table 2 presents the results of these experiments.

| | Tensile Strength | Elongation | Heat Distortion | Cold Resistance | Flame Resistance | Moldability | Tracking Resistance | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 23°C | -30°C |
| | kg/cm² | % | % | - | # | - | kg/cm | |
| Trial 1 | 98 | 430 | 4 | N | >200 | N | 40 | 15 |
| Trial 2 | 87 | 415 | 5 | N | 198 | N | 39 | 14 |
| Control Group | 43 | 210 | 20 | Y | 100 | Y | 21 | 8 |

Table 2. Results of Experiments

The physical properties results indicated that tensile strength and elongation are related to the toughness of the composition, and it is desirable for these properties to be well-balanced. Impact strength measures the extent to which molded products can withstand impact energy at both room and low temperatures. Tracking resistance is a measure of how much the composition can resist carbonization and retain its insulating properties under a constant voltage (4,000V), with higher values indicating better electrical properties.

Heat distortion and cold resistance tests show the ability of the composition to maintain its shape under certain temperature conditions. Additionally, the moldability was assessed by using an injection molding machine to produce a specimen (100 x 100mm, thickness: 1.5mm) and visually inspecting it for flow marks and gas generation. As can be seen from the results in table 2, both Trial 1 and Trial 2 from this study demonstrate superior performance across all five evaluated areas compared to the control group.

Furthermore, a comparison between Trial 1 and Trial 2 reveals that Trial 1, which includes a composite formulation, exhibits overall superior properties compared to Trial 2.

Additionally, the adhesive modifier included in the elastic modifier, which features gatti gum, can incorporate additional components. The steps involved in manufacturing this adhesive modifier are explained as follows. Fig. 7 illustrates the process for manufacturing the adhesive modifier.

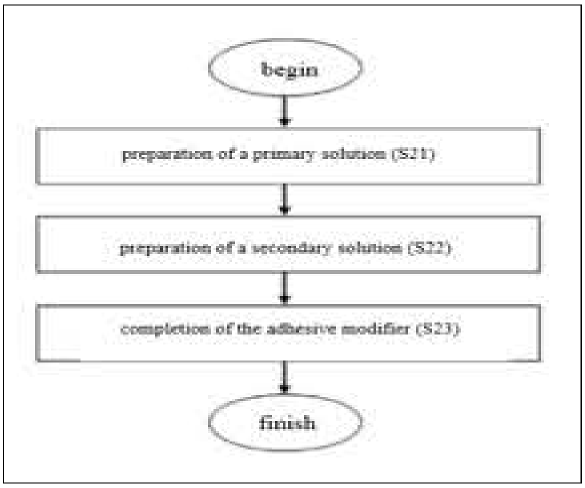


Figure 7. Process for manufacturing the adhesive modifier

Referring to Fig. 7, the adhesive modifier of this invention can be produced through the following three steps: the preparation of a primary solution (S21), the preparation of a secondary solution (S22), and the completion of the adhesive modifier (S23).

The first step in the preparation of the adhesive modifier (S21) involves mixing 50 to 70 parts by weight of polyisobutylene with 30 to 50 parts by weight of xylene to create the primary solution. Polyisobutylene is a synthetic rubber composed of a polymer of 2-methyl-1-propene. It is a colorless or pale yellow, sticky, and elastic semi-solid material known for being eco-friendly and safe for human contact, even suitable for food additives. When added to the adhesive modifier, polyisobutylene increases the viscosity of the insulating layer, enhancing its adhesion. It also adjusts the hardness to an appropriate level and imparts flexibility, allowing the insulating layer to absorb external impacts with resilience instead of breaking easily. In this step, polyisobutylene is dissolved in xylene, which acts as an organic solvent capable of easily dissolving organic materials, resulting in a uniform mixture.

The second step (S22) involves preparing the secondary solution by mixing 90 to 96 parts by weight of the primary solution with 3 to 5 parts by weight of lecithin and 1 to 5 parts by weight of potassium cocoyl glutamate. Lecithin functions as a natural defoamer, which makes it environmentally friendly while preventing bubble formation on the surface of the insulating layer. This layer is formed by curing the elastic modifier, to which the adhesive modifier is added, and lecithin improves the miscibility of various materials within the adhesive modifier while also contributing to the flexibility of the insulating layer. Potassium cocoyl glutamate, a coconut-based natural surfactant, complements the function of lecithin by enhancing the miscibility of the components and preventing the separation of organic and inorganic substances within the adhesive and elastic modifiers.

Finally, the adhesive modifier is completed in step (S23) by mixing 92 to 98 parts by weight of the secondary solution with 1 to 5 parts by weight of butyl carbitol acetate and 1 to 4 parts by weight of ghatti gum. Butyl carbitol acetate is added to increase the viscosity of the adhesive and elastic modifiers, as well as the final insulating layer, thereby enhancing adhesion. It also serves as a solvent for resin components within the adhesive and elastic modifiers, improving the overall miscibility of the ingredients. Ghatti gum, as previously mentioned, increases viscosity during mixing, enhances emulsion stability, and improves the physical properties and texture. Its excellent solubility and viscosity-boosting effects contribute to a high level of adhesion and flexibility in the insulating layer.

With the inclusion of this adhesive modifier, the hardness of the insulating layer can be adjusted, allowing it to absorb external shocks rather than breaking easily. Furthermore, it enhances the adhesion between the insulating layer and the base layer while also improving the overall insulation properties.

## DISCUSSION

The development and implementation of a drone-assisted electric vehicle (EV) charging system present a significant leap forward in addressing the limitations of current EV infrastructure. This innovative approach leverages drones equipped with advanced charging technology to provide on-demand power to electric vehicles, particularly in areas where charging stations are scarce or inaccessible. The system's design emphasizes efficiency, flexibility, and environmental sustainability, ensuring that it not only supports the growing adoption of EVs but also contributes to a reduction in carbon emissions.

Through the integration of intelligent control systems, real-time monitoring, and autonomous navigation, the drone charging system can efficiently locate and service EVs in need, minimizing downtime and enhancing user convenience. Furthermore, the use of lightweight, high-capacity batteries within the drones ensures that they can deliver a meaningful charge quickly and safely.

The successful implementation of this system could revolutionize the way electric vehicles are charged, making the technology more accessible and reliable. As the world continues to shift towards sustainable energy solutions, the drone-assisted EV charging system stands as a promising innovation that bridges the gap between current capabilities and future needs. It offers a practical and scalable solution to one of the most pressing challenges facing the EV industry today, paving the way for a more connected and sustainable transportation ecosystem.

Lastly, the structure and operation of the emergency charging system for electric vehicles using drones, as discussed in this study and depicted in the accompanying diagrams, are limited to the experimental context provided. However, the scope of this research is not confined to the explanations and illustrations presented. It is understood that various modifications and alterations can be made within the spirit and scope of the underlying technical concept of this study.

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