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Design of an Intelligent Wireless Capacitive Charging for Critical Medical and Industrial Devices

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A B S T R A C T

Automated Control of Multiple Methods for Continuous Wireless Charging Using Artificial The multi-purpose wireless charging has received considerable attention in the past five years to provide the best service for charging electrical devices easily and anywhere, using high-tech capacitors to ensure the highest performance for wireless charging. In this research, we explored two of the most important methods for wireless charging by integrating a comprehensive system for controlling charging methods according to availability without human intervention. This will enhance the performance of using available charging methods for the user, enabling them to utilize different charging methods, whether through mutual induction, solar cells, or direct connection to the electrical charging source using artificial intelligence. This will be particularly beneficial for applications that require continuous charging, such as medical applications implanted in the human body or any other industrial applications.

1. Introduction

1.1. Wireless Power Transfer

Wireless Power Transfer (WPT) is an advanced technology enabling the transmission of electrical energy from a power source to a load without the need for physical connectors or wires [1]. This method leverages various principles of electromagnetism, including inductive coupling, resonant inductive coupling, and electromagnetic radiation, to achieve efficient energy transfer across varying distances [2]. WPT has the potential to revolutionize energy distribution systems, offering applications in fields ranging from consumer electronics and electric vehicles to medical implants and industrial automation [3]. The continued development of WPT technologies promises to enhance energy efficiency [4]. reduce reliance on conventional power distribution networks, and open new avenues for innovation in diverse sectors [5].

1.2. Why we use super capacitors

Supercapacitors have emerged as a critical component in the advancement of wireless charging technologies, offering distinct advantages in energy storage and power delivery[6]. Unlike traditional batteries[7], supercapacitors can rapidly store and release large amounts of energy, which is essential for efficient and fast wireless charging applications [9]. Their high-power density, long cycle life, and ability to operate across a wide range of temperatures make them particularly suitable for powering devices that require quick bursts of energy [10], such as in wireless charging stations for electric vehicles, mobile devices, and IoT (Internet of Things) gadgets [11]. As the demand for more efficient and sustainable energy solutions grows, the role of supercapacitors in enhancing the performance and reliability of wireless charging systems becomes increasingly significant in scientific and technological innovation [13]. This table highlights the key differences between super capacitors and traditional capacitors, showcasing the unique advantages and limitations of each technology [14].

1.3. Inductive wireless power transfer

Inductive wireless power transfer (WPT) is a transformative technology that enables the transmission of electrical energy without the need for physical connections [15]. This method relies on electromagnetic induction, where an alternating current (AC) in a primary coil generates a magnetic field that induces a voltage in a secondary coil [16], thereby transferring power wirelessly [17]. Inductive WPT is widely used in applications ranging from charging small electronic devices like smartphones and wearable gadgets to powering larger systems such as electric vehicles and medical implants. Its ability to deliver power safely and efficiently over short distances has made it a cornerstone of modern wireless charging systems [19], driving innovation in various industries by eliminating the constraints of wired connections. As research continues to enhance its efficiency, range, and integration capabilities, inductive wireless power transfer is poised to play a crucial role in the future of energy delivery [20].

Table 1 Comparison between super cap and traditional cap

Feature	Supercapacitor	Traditional Capacitor
Energy Density	High (up to 10 Wh/kg)	Low (typically 0.01-0.1 Wh/kg)
Charge/Discharge Time	Seconds to minutes	Microseconds to milliseconds
Cycle Life	Extremely High (over 1 million cycles)	High (thousands to tens of thousands of cycles)
Temperature Stability	Good (wide operating temperature range)	Moderate (depends on dielectric material)
Applications	Energy storage, backup power, wireless charging	Filtering, signal processing, timing circuits

1.4. Solar power charging

Solar charging represents a pivotal advancement in sustainable energy technology, harnessing the power of the sun to generate electricity for a wide range of applications. This process utilizes photovoltaic (PV) cells, which convert sunlight directly into electrical energy through the photovoltaic effect [21]. Solar charging systems have gained significant attention in both scientific research and practical applications due to their potential to provide a renewable, clean, and inexhaustible energy source [22]. As the efficiency of photovoltaic materials and energy storage technologies improves, solar charging has become increasingly viable for powering everything from small portable devices to large-scale energy grids [23]. This technology not only contributes to reducing carbon emissions but also offers a decentralized energy solution, making it particularly valuable in remote areas lacking access to conventional power sources [24]. The ongoing development of solar charging systems is crucial for addressing global energy challenges and fostering a transition to a more sustainable energy future [22].

2. Intelligent Mobile Medical Supply System

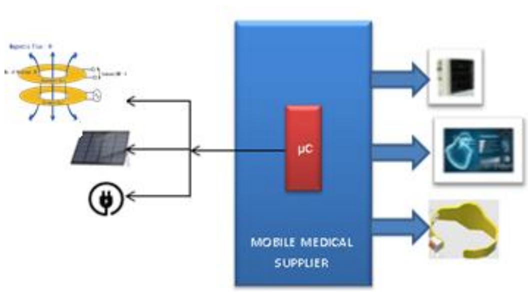

Figure 1 Block diagram of mobile medical supplier

The continuous supply of medical devices is critical in ensuring the seamless operation of healthcare services, particularly in remote or emergency settings. A mobile medical supplier, integrated with an advanced artificial intelligence (AI) system, can optimize and manage the supply chain and power usage effectively[25]. This mobile unit is designed to support continuous operation through three distinct charging methods: inductive charging, solar charging, and traditional plug-in charging. The AI system intelligently selects the most appropriate charging method based on real-time conditions, ensuring uninterrupted power supply and enhancing the reliability of the medical devices[18]. This innovative approach not only reduces downtime but also enhances the efficiency of medical operations in diverse environments.

2.1. Arduino UNO R3

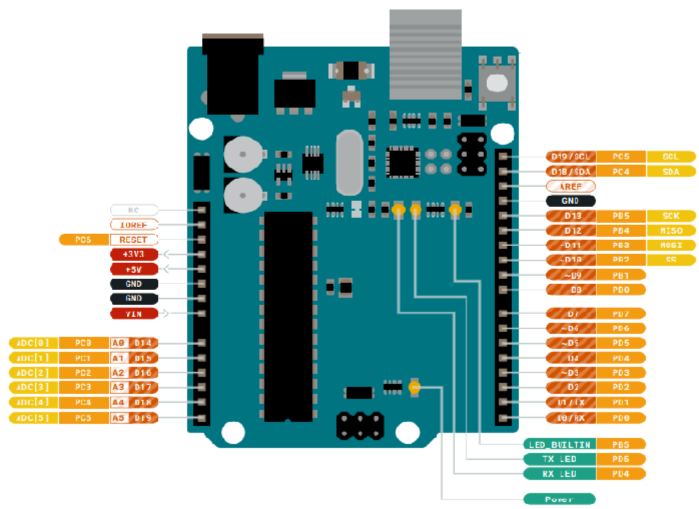

Figure 2 Arduino pin out connectors

The Arduino Uno R3 microcontroller offers a versatile platform for managing multiple charging methods, inductive wireless charging, solar charging, and plug-in charging—by intelligently sensing the voltage levels associated with each method. Through its analog-to-digital conversion (ADC) capabilities, the Arduino Uno R3 can continuously monitor the voltage across each charging input. By processing this data, the system can dynamically determine which charging source is currently available and most optimal. The Arduino then automatically selects the appropriate charging method, ensuring efficient energy management and uninterrupted power supply to the connected device [26]. This approach leverages Uno R3's flexibility in interfacing with various sensors and power sources, making it an effective solution for hybrid charging systems in low-power electronic applications.

A voltage sensor detects the electrical potential difference across two points in a circuit, allowing it to measure the voltage level. When integrated with an Arduino, the sensor continuously monitors the voltage and sends this data to the Arduino's microcontroller. Based on the detected voltage, the Arduino can be programmed to determine the appropriate charging method[26]. For example, if the voltage is below a certain threshold, the Arduino might choose a “trickle charge” mode for a battery, while a higher voltage might trigger a “fast charge” mode. The decision-making process is governed by the code running on the Arduino, which interprets the voltage readings from the sensor and adjusts the charging pathway accordingly [26].

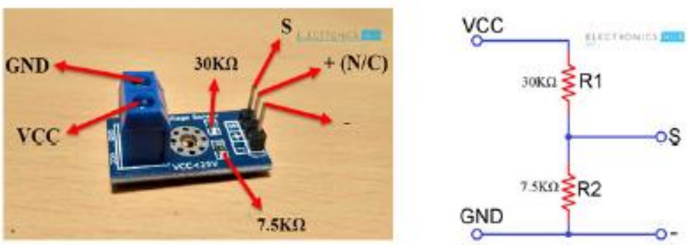

Figure 3 A voltage sensor module

2.2. Inductive wireless charging

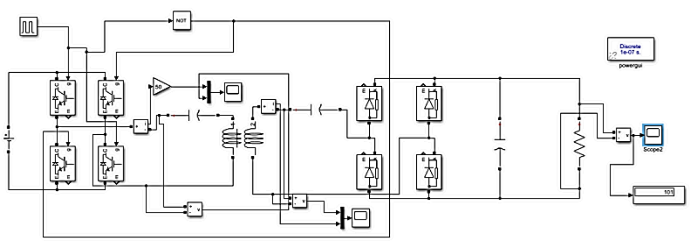

Figure 4 Simulink model of Inductive wireless charging

The circuit in the image appears to be a DC-DC converter simulation, most likely a boost converter. Below is a description of the key components and their connections:

a. Power Supply: On the left side, there is a DC voltage source connected to the circuit.
b. IGBT Modules: There are four Insulated Gate Bipolar Transistors (IGBTs) used for switching. These switches are crucial for converting the DC input voltage to a higher DC output voltage.
c. PWM Generator: The top-left part of the circuit likely contains a PWM (Pulse Width Modulation) signal generator, which controls the switching of the IGBTs. There is a “NOT” gate, which could be used to invert the signal or generate complementary signals for the IGBTs.
d. Inductor and Diode: In the middle of the circuit, there’s an inductor and a diode. The inductor stores energy when the IGBT switches are on and releases it when they are off, which is key to boosting the voltage.
e. superCapacitor: A capacitor is connected near the output side to smooth out the voltage, providing a stable DC output.
f. Load: The circuit includes a resistive load where the output voltage is applied.
g. Control System: The circuit contains some control blocks, possibly for feedback regulation to maintain the desired output voltage.
h. Scopes and Meters: There are scopes and meters in the circuit used to monitor various parameters such as voltage, current, or the PWM signal during the simulation.
i. Power GUI: There is a `power gui` block, which indicates that this is a Simulink/Matlab model for simulation in the SimPowerSystems toolbox. This simulation seems to model the behavior of a boost converter in a controlled environment.

$$fr = \frac{1}{2\pi\sqrt{L.C}} \qquad (1)$$

The resonant frequency fr of the primary and secondary coils is determined by their self-inductance L and the capacitance C of the resonant capacitors associated with the transmitter and receiver coils. Effective power transfer is achieved when the resonant frequencies of both coils are synchronized. The operating frequency of Resonant Inductive Power Transfer (RIPT) systems typically ranges from tens of kilohertz to several hundred kilohertz. Within this frequency range, the magnetic flux generated in the absence of a magnetic core significantly impacts the mutual inductance, leading to a reduction in the coupling coefficient K. The coupling coefficient in RIPT systems generally varies between 0.2 and 0.3 due to the minimum height clearance requirements for electric vehicles (EVs), which is approximately 150–300 mm. The coupling coefficient can be calculated using Eq. (2), where Lp and Ls represent the self-inductance of the transmitter and receiver coils, respectively, and Lm is the mutual inductance between the two coils. A higher mutual inductance indicates stronger coupling between the primary and secondary coils [22].

$$K = \frac{Lm}{\sqrt{Lp.Ls}} \qquad (2)$$

Magnetic ferrite cores with various configurations are employed to enhance the coupling coefficient in wireless transformer designs. Further details will be provided in subsequent sections. At high frequencies, the skin and proximity effects become significant, potentially impacting power transfer efficiency. To mitigate these issues, litz wire, which consists of individually insulated thin twisted strands, is commonly used in the design. This approach also helps reduce parasitic resistance and improves the quality factor Q of the coil. The quality factor Q can be calculated using Eq. (3), which considers the operating frequency f, self-inductance L of the primary or secondary coil, and the resistance R of the coils [22].

$$Q = \frac{\omega Lp,s}{Rp,s} = \frac{2\pi f\ .Lp,s}{Rp,s} \qquad (3)$$

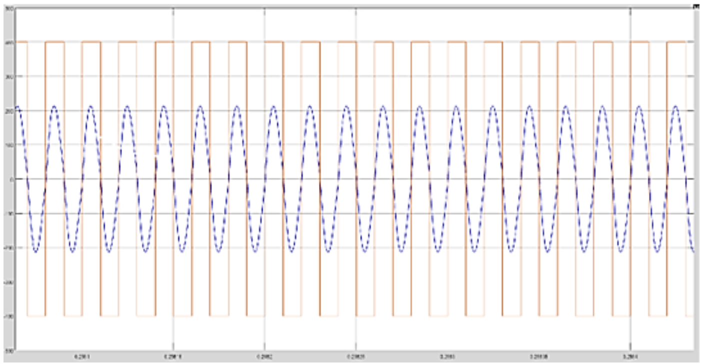

Figure 5 Simulation output of TX

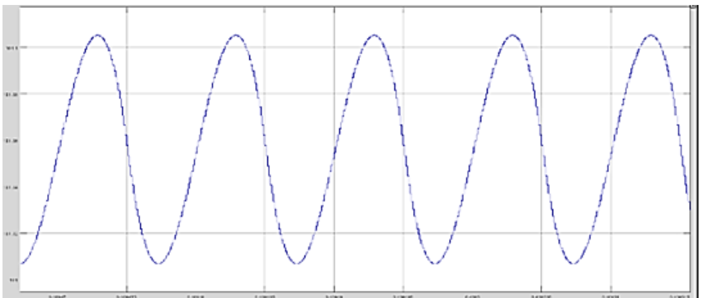

Figure 6 The output power transfer

2.3. Solar Charging

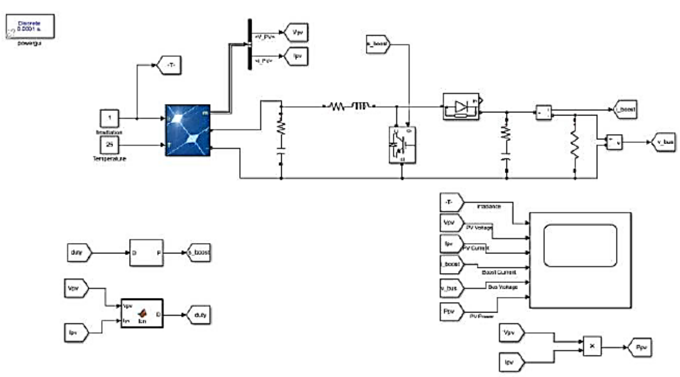

Figure 7 Simulink model of solar charging

The proposed work incorporates a solar power charge controller. To complete this work, two distinct software tools are utilized: MATLAB and Proteus. A foundational model of the solar power charge controller has been developed in MATLAB/Simulink. The basic design of the solar power charge controller is presented below.

Figure 7 shows a Simulink model of a Solar Power Charge Controller. The model simulates the operation of a charge controller in a photovoltaic (PV) system. Here is a breakdown of the key components:

a. Solar Panel (PV Array): The solar panel block (with the image of a sun and solar cells) generates power based on the input parameters of irradiation and temperature. These inputs control the amount of power generated by the PV array. The outputs from the PV array are the PV voltage (Vpv) and PV current (Ipv).
b. Boost Converter: The output from the PV array is fed into a boost converter. The boost converter increases the DC voltage from the PV array to a higher level suitable for charging the battery or powering the load. The boost converter is controlled by a pulse-width modulation (PWM) signal, which is generated based on the voltage and current conditions.
c. Load and Battery: The output of the boost converter is connected to a load and possibly a battery for storage. The load is represented by a resistor in the model, and there might be another block indicating the battery. The current flowing through the load and the bus voltage (v_bus) are measured.
d. Control System: The lower portion of the circuit shows the control system that regulates the boost converter. The control system likely uses inputs such as Vpv, Ipv, and other parameters to adjust the duty cycle of the PWM signal, ensuring that the maximum power is extracted from the solar panel (Maximum Power Point Tracking or MPPT).The control system also includes a display or scope to monitor various parameters such as irradiation, PV voltage, PV current, bus current, bus voltage, and PV power.
e. Power GUI:A `power gui` block is present, indicating that this is a simulation within the Simulink environment, specifically designed for power electronics and renewable energy system simulations.
f. Outputs: The model provides various outputs such as PV power, PV voltage, and current, which can be observed in the connected display or scope blocks for analysis. This Simulink model is designed to simulate the performance of a solar power system with a charge controller, allowing for the analysis of different operating conditions and the efficiency of the power conversion and storage system.

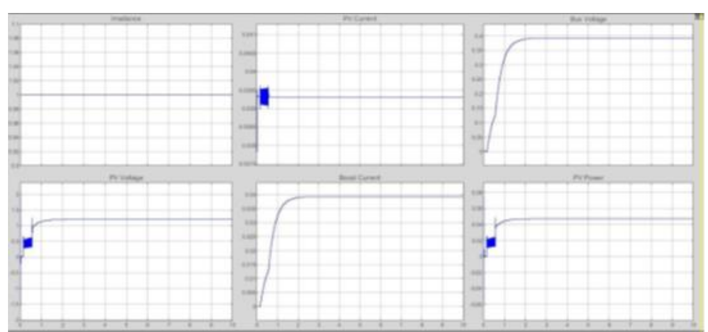

Figure 8 Simulink model plots

The results obtained through the scope of the Simulink model, after compiling and running the MATLAB and Simulink files, provide valuable insights into the solar charging controller's performance. The simulation was conducted with an irradiance value of 1 as the input to the photovoltaic (PV) array and a temperature setting of 25°C.

3. Conclusions

In this paper, I discuss controlling various methods of mobile charging, focusing on their integration and optimization for reliable power supply. The first method explored is inductive wireless charging, which utilizes electromagnetic induction to transfer power wirelessly between a primary and secondary coil. This method is particularly suitable for short-distance applications and ensures safe and efficient energy transfer. By incorporating advanced control algorithms, the system intelligently manages this charging method based on availability and real-time conditions, ensuring seamless operation.The second method discussed in this paper involves charging using photovoltaic (PV) technology, which harnesses solar energy to generate electrical power. This approach employs a solar power charge controller to optimize energy capture from PV panels. By leveraging the photovoltaic effect, sunlight is converted into electricity, making this method highly sustainable and ideal for remote or outdoor environments. The system dynamically monitors solar irradiance and temperature to maximize power output through real-time adjustments, ensuring efficient and reliable charging under varying environmental conditions.

Conflict of Interest

The authors declare no conflict of interest.

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