"IOT Based solar powered contactless EV charging system"

[1]Prof. S. K. Shinde, [2]Shreya Ravi Kamble, [3]Vaishnavi Mohan Bhokare, [4]Riya Gangadhar Devkule

[1]Professor, [234]Department of Electronics and Computer Science Engineering Padmabhooshan Vasantraodada Patil Institute of Technology, Maharashtra, India

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Abstract - *Abstract – In recent years, the fast-growing number of electric vehicles (EVs) has led to a greater need for efficient, safe, and easy-to-use charging systems. Traditional wired charging involves physical connections, which can cause damage, pose safety risks, and make the process inconvenient. At the same time, the growing interest in renewable energy has encouraged the use of solar power for sustainable EV charging. Combining wireless power transfer with solar energy and smart authentication can offer a promising solution for the future of charging infrastructure. This paper presents the design and development of a Solar-Based Wireless EV Charging Station equipped with IoT-based VI Temperature Monitoring. The system uses a solar panel to generate electricity, which is stored in a battery through a charge controller. Wireless power transfer is used to charge the EV without requiring physical connectors, while IoT monitoring ensures safety. A microcontroller controls all system operations, including IoT monitoring and power transfer. The developed prototype offers a safe, efficient, and user-friendly charging solution that can be used in smart charging stations, parking areas, and future infrastructure.*

Keywords: Internet of Things (IoT), Electric Vehicle (EV), Contactless Charging, Solar Energy, Renewable Energy, Solar-Powered EV Charging, Wireless Power Transfer (WPT), Smart Charging System.

1. INTRODUCTION:

The Demand of Electricity is increasing day by day as the population of world is increasing. so, use of electricity efficiently and in controlled manner has become the most important aspect of today's power system. most of the power system uses wired transmission of power and loss occurred due to this is enormously high. About 30% of the total loss in power is just because of wired power transmission and distribution. the main reason behind this loss is the resistance of wires during transmission. the efficiency of wired transmission can be improved composite overhead conductors and underground cables that use high temperature super conductor. but the transmission is still inefficient. India's Electricity grid has highest percentage of losses in the world. Wireless power Transfer can be effective option to curb these losses as Wireless Power Transfer uses Wireless mode of transmission. Electricity theft has also become a Crucial Factor. In India Losses due to power Theft are increasing rapidly and Wired Transmission somehow helping power theft as wired transmission is more vulnerable to power theft. In Addition to losses, Wastage of Electricity is a big Concern in Power System. as per Recent Survey of Government of India Waste of Electricity is high 8 % to be precise. electricity wastage sources include home appliances, Government offices, Street light Systems, Transport facilities. As sources like Home Appliances and Government Offices are subjected to Human Mentality we can't Control the Wastage of Electricity using technical Knowledge as they need awareness more than technical Expertise but we can control the wastage which occurs through street lights and other transportation facilities many methods have been developed over the years to curb the leakage and wastage of electricity through the transport facilities like solar power based street lights and traffic systems but still they are not able to provide an effective solution as they are irregular and subjected to environmental Conditions.

Wireless Power Transfer and its application can be extremely useful in Electricity Generation and transmission. Wireless Power transfer basically works on the principle of Transformers. We can say that transformer is a motive of Wireless Power Transfer. it is analogues to Wireless Data Transmission only power is transmitted instead of data. the concept can be used efficiently in electricity to minimize Cost, losses and maximize the Efficiency. Concluding to this we can Develop a system that could provide much higher Efficiency, low Transmission Cost and Secured to power theft. In proposed system we are Developing a Wireless Power transmission system in which vehicles Battery power is used to feed a street light system. Generally, any road has more than thousand vehicles running on it per day. If we collect energy from each vehicle without hampering its operation this energy can be used for feeding home, street lights on that road. Can be effective option to curb these losses. the IoT-Based Solar Powered Contactless EV Charging System is an innovative infrastructure project designed to provide a sustainable, efficient, and user-friendly solution for the growing Electric Vehicle (EV) market. By merging renewable energy, wireless power transfer (WPT), and the Internet of Things (IoT), the system addresses the two biggest hurdles in EV adoption: charging convenience and environmental impact.

2. PROBLEM STATEMENT:

In recent years, the rapid growth of electric vehicles (EVs) has increased the demand for efficient, safe, and convenient charging systems. Conventional wired charging methods involve physical connectors, which may lead to wear and tear, safety risks, and inconvenience during operation. At the same time, the increasing focus on renewable energy sources has encouraged the use of solar power for sustainable EV charging solutions. Wireless power transfer combined with solar energy and smart authentication offers a promising alternative for future charging infrastructure.

This paper presents the design and development of a Solar Based Wireless EV Charging Station with IOT based VI Temperature monitoring. The proposed system uses a solar panel to generate electrical energy, which is stored in a battery through a charge controller. Wireless power transfer is used to charge the EV without physical connectors, while IOT based monitoring ensures safety. A microcontroller controls the overall operation of the system, including IOT monitoring, and power transfer.

3. OBJECTIVES:

To develop an intelligent AI-based learning assistant for educational content:

The main objective of this research is to design an intelligent learning framework that helps students understand educational material more efficiently by using Retrieval-Augmented Generation (RAG). The system processes study materials such as lecture videos, audio recordings, and academic documents, enabling students to retrieve concept-specific explanations directly from their own learning resources.

To integrate Retrieval-Augmented Generation with Large Language Models:

This research aims to combine semantic retrieval techniques with large language models to generate context-aware explanations. By retrieving relevant content segments from transcripts and documents and supplying them to the language model, the system can produce accurate and grounded answers related to the student's study material.

To enhance learning efficiency and knowledge accessibility for students:

The objective is to improve how students locate and understand information within long lectures and documents by enabling semantic search across multiple learning materials. The system helps students quickly find the exact segment of a video or section of a document where a concept is explained.

To eliminate manual searching across multiple learning platforms:

Another objective is to reduce the need for students to manually navigate through different platforms, such as video players, PDF readers, and note-taking applications. The proposed system provides a unified interface where students can upload study materials and directly ask questions in natural language.

To provide context-aware explanations with source references:

The research aims to generate explanations that are grounded in the retrieved educational content while providing clear references, such as lecture timestamps or document page numbers. This approach ensures transparency and allows students to verify explanations within the original study material.

To support multimodal educational content processing:

The objective is to design a system capable of processing multiple learning formats, including MP4 lecture videos and MP3 audio recordings. By converting these materials into structured text through transcription and extraction techniques, the system builds a unified, searchable knowledge base.

To improve the effectiveness of AI-driven academic assistance:

The proposed system aims to provide an intelligent academic assistant by improving learning outcomes and reducing the time required for revision.

4. LITERATURE SURVEY:

The History of Power Transmission is found in the period Starting after World War II where Wireless power transmission is tested at microwave frequencies. Nicola Tesla who is indeed a " Father of wireless " is the one who first developed the idea of power transmission in wireless mode. In 1893, Tesla demonstrated the implementation of Vacuum Bulbs without using wires for transmission at the world Exposition in Chicago. in 1997. In 1904, an Airship motor of 0.1 Horsepower through space from a distance of least 100 feet. In 1961 Brown comes with first research paper proposing microwave waves used for power transmission and in 1964 he Demonstrated a breakthrough in wireless power transmission technology by transferring all the power needed to microwave powered helicopter through microwave beam at 2.45 GHz. from the range of 2.4 GHz -2.5 GHz frequency band. from this event the research in Wireless power transfer accelerated at high speed. during 1975-1997 time period various Experiments Demonstrated On the application of wireless power transfer. Experiments in power transmission without wires in the range often of kilowatts have been performed at Goldstone in California in 1975 and at Grand Bassin on Reunion Island in 1997.

World's first microwave power Transfer experiment in the ionosphere called the MINIX (Microwave Ionosphere Non-Linear Interaction Experiment rocket experiment is demonstrated by Japan in 1983. Similarly, the World's first fuel free airplane based on microwave energy transfer was flown in 1987 from Canada. In 2015 a South Korean Company named Samsung Launched World's. first "Wireless Charging Mobile Phones" named Samsung Galaxy note 5 and Samsung Galaxy age+ respectively.

Research on wireless power transfer got pace in 20th century. as need of electricity is increasing day by day Wireless Power transfer came in picture. most of the Asian countries are Continuously making research on wireless power transfer and its applications. however the most difficult task for them is to increase the range of transmission with minimum loss and higher efficiency. until year 2000 wireless power transmission is limited to only Electricity but after 2000 wireless power transfer got Scope in many Fields which are directly or indirectly related to Electricity Such as Telecommunication, Transportation, Mobile and other Electronic Devices and Wireless Communication. Since the pioneer work done by Grover and Sahai [1], wireless information and power transfer (WIPT) has spurred considerable interest from academia and industry, especially in the area of wireless communications. Nowadays, most wireless devices are powered via power cables or battery replacements, which limit the scalability, sustainability, and mobility of wireless communications. In late 2008, the Wireless Power Consortium (WPC) has been created in order to unify the powering protocols related to inductive WPT systems. In October 2011, 100 companies have come up with innovative solutions of powering or charging consumer electronic devices using WPT.

This paper inspects the present status, latest deployment and challenging issues in the implementation of EVs infrastructural and charging systems in conjunction with several international standards and charging codes. It further analyzes EVs impacts and prospects in society. The paper highlights international standards regarding charging methods, grid integration, power quality issues, safety limitations, communication networks and equipment maintenance which are required for large-scale deployment of EVs. Furthermore, a complete assessment of charging systems including: inductive charging, conductive charging and battery swapping networks for EVs with various kinds of fast and slow battery charging techniques is explained. Moreover, the beneficial and harmful impacts of EVs are categorized and thoroughly reviewed with remedial measures for harmful impacts and prolific benefits for beneficial impacts. Bidirectional charging offers the fundamental feature of vehicle-to-grid technology. The optimal charging methodologies should be adopted to control the issues of EVs impacts.

5. METHODOLOGIES:

An IoT-based Solar-Powered Contactless (Wireless) Electric Vehicle (EV) Charging System combines renewable energy harvesting, inductive power transfer, and real-time data monitoring. Below is a detailed methodology for developing this project.

1. System Architecture

The project is divided into three primary stages: the Energy Generation Stage, the Wireless Power Transfer (WPT) Stage, and the IoT Monitoring Stage.

A. Solar Energy Harvesting

Solar PV Array: Captures sunlight and converts it into DC electricity.

Charge Controller (MPPT): A Maximum Power Point Tracking (MPPT) controller ensures the solar panels operate at peak efficiency and regulates the voltage to charge a battery bank safely.

Energy Storage: A lead-acid or Lithium-ion battery bank stores the energy to ensure charging is available even during non-sunny hours.

B. Wireless Power Transfer (WPT)

Inverter (Transmitter Side): Converts the stored DC power back into high-frequency AC. High frequency is essential for efficient inductive coupling.

Transmitter Coil (Primary): Located under the road or charging pad. It creates an oscillating magnetic field when high-frequency AC passes through it.

Receiver Coil (Secondary): Mounted on the bottom of the EV. It captures the magnetic field and converts it back into AC electricity via Faraday’s Law of Induction.

Rectifier & Filter (EV Side): Converts the received AC back into stable DC to charge the vehicle's battery.

C. IoT and Control Unit

Microcontroller: (e.g., ESP32 or ATMega with Wi-Fi) manages the sensors, real time data and data transmission.

Sensors: Voltage and current sensors (e.g., ACS712), Temperature, monitor the charging rate and battery health.

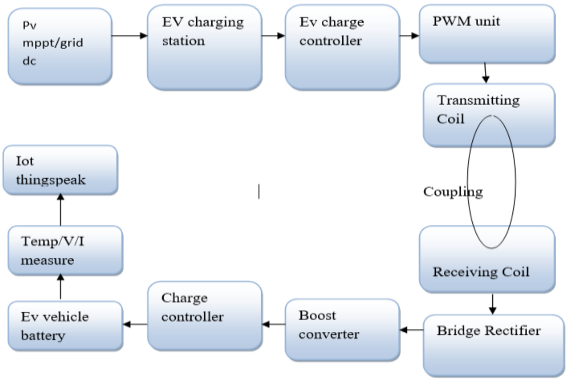

Figure No 1: System Block Diagram

The system operates in four main phases: Power Source, Wireless Transmission, Receiving & Charging, and IoT Monitoring.

1. Power Source & Input Stage

- PV MPPT / Grid DC: This is the primary power generation stage. It uses a Solar Photovoltaic (PV) system optimized by an MPPT (Maximum Power Point Tracking) controller to extract maximum solar energy. It can also integrate grid DC as a backup power supply.
- EV Charging Station: Acts as the central hub that receives the stable DC power from the solar/grid subsystem.
- EV Charge Controller: Regulates the incoming voltage and current to safe, manageable levels before passing it to the transmission circuit.

2. Wireless Power Transmission Stage (Transmitter)

- PWM Unit (Pulse Width Modulation): To transmit power wirelessly, the high-voltage DC must be converted into high-frequency Alternating Current (AC). The PWM unit switches the power at a high frequency to generate this AC signal.
- Transmitting Coil: The high-frequency AC flows through this copper coil, creating a dynamic, oscillating magnetic field around it.
- Coupling: This represents the air gap between the charging station and the vehicle. Energy is transferred wirelessly across this gap through electromagnetic inductive coupling.

3. Energy Reception & Battery Charging Stage (Receiver)

- Receiving Coil: Located on the vehicle's underside, this coil catches the magnetic field generated by the transmitting coil, inducing an AC voltage within itself.
- Bridge Rectifier: Because batteries cannot be charged with AC, the bridge rectifier converts the high-frequency AC back into smooth, stable Direct Current (DC).
- Boost Converter: Steps up the rectified DC voltage to the precise higher level required to charge the vehicle's battery pack.
- Charge Controller: A dedicated safety unit that manages the charging profile (Constant Current/Constant Voltage) to prevent overcharging, overheating, or damaging the battery cells.

- EV Vehicle Battery: The final storage element (represented by the lithium-ion batteries on your physical hardware board) that stores the received energy to power the vehicle.

4. IoT & Data Monitoring Stage

- Temp / V / I Measure: Sensors continuously read vital parameters from the EV battery in real-time, specifically Temperature (Temp), Voltage (V), and Current (I).
- IoT Thing Speak: These sensor readings are processed by a microcontroller (like an ESP8266 Wi-Fi module) and uploaded wirelessly to Thing Speak, an open-source IoT analytics platform. This allows users and station operators to remotely track charging efficiency, battery health, and system safety via online graphs and dashboards.

6. WORKING:

The hardware setup physically implements the architecture diagram. It is divided into two main sections: The Transmitter and The Receiver.

1. Power Generation and Transmission (The Base Station)

This part of the hardware mimics the ground-based wireless charging pad infrastructure.

Solar Energy Capture: The Solar PV Panel on the right captures sunlight and generates direct current (DC) electricity.

Alternative Power Input (SMPS): In the top-left corner, there is a silver SMPS (Switched-Mode Power Supply) unit with an AC mains plug. In actual project testing, this is used as a backup power source to simulate power when sunlight isn't available.

High-Frequency Inversion: The DC power from the solar panel or SMPS goes into the small custom circuit board at the top center. This board contains an H-Bridge inverter configuration (often driven by an oscillator IC like an IR2110 or NE555). It converts the steady DC power into high-frequency alternating current (AC).

Magnetic Field Generation: This high-frequency AC power is fed into the large, hand-wound Transmitter Copper Coil (the large oval coil wrapped with white zip ties). Because the current is oscillating at a high frequency, it creates a dynamic, rapidly changing electromagnetic field around itself.

2. Wireless Power Transfer (The Air Gap)

This hardware demonstrates magnetic resonant coupling. Though this prototype setup places the boards side-by-side on a wooden platform for demonstration, in a real-world application, the transmitter coil sits on the ground, and the vehicle has a matching receiver coil mounted underneath its chassis. When the vehicle parks over the transmitter coil, the electromagnetic field passes across the air gap, inducing an electrical current in the receiver circuit without any physical contact.

3. Power Reception and Battery Charging (The Vehicle Side)

The bottom half of the board represents the onboard systems of the Electric Vehicle.

AC Rectification: The induced wireless energy is caught by a receiver mechanism and goes into the middle-bottom circuit board. This board features four prominent diodes and electrolytic capacitors, which make up a Full-Bridge Rectifier and Filter Circuit. It converts the harvested high-frequency AC power back into stable DC power.

Battery Storage: The rectified DC power is directed to the battery holder at the bottom containing three purple 18650 Lithium-Ion cells (the EV Battery Pack).

BMS & Monitoring: The bottom-left green circuit board acts as the control centre for the vehicle side. It monitors the voltage of the batteries to ensure they charge safely and do not overcharge.

4. IoT Monitoring and State Control

This is where the automation, data collection, and cloud interaction happen.

Data Acquisition: The microcontroller on the bottom-left board continually reads parameters like charging current and battery voltage.

Local Display: It updates the local LCD Screen (visible at the bottom left) to show real-time stats like "Charging..." or the current battery percentage (SOC).

Cloud Telemetry (IoT Module): Right above the LCD board, you can see a tiny separate breakout board this is an ESP8266 (Wi-Fi module) or similar IoT chip. This chip connects to the local Wi-Fi and wirelessly transmits the battery voltage and charging status up to your cloud platform (like Firebase).

Remote Control: Because the IoT module maintains a two-way connection with the cloud, when a user presses "Start" or "Stop" on their mobile dashboard app, the command travels through the cloud, hits this Wi-Fi module, and tells the microcontroller to engage or disengage the charging relays.

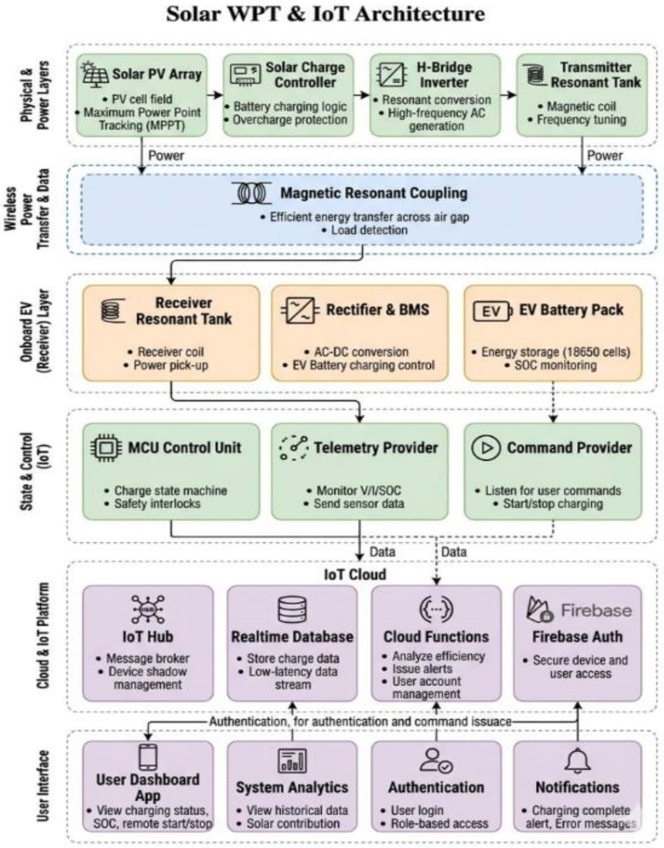
Solar WPT & IoT Architecture

Fig. 9: System Architecture

Here is a step-by-step breakdown of how each layer works and fits together.

1. Physical & Power Layers (The Transmitter Side)

This is the ground-based infrastructure (often embedded in a charging pad on the road or garage floor) that harvests solar energy and prepares it for wireless transmission.

Solar PV Array: Captures sunlight and converts it into DC electricity. It uses MPPT (Maximum Power Point Tracking) to ensure the solar panels operate at maximum efficiency regardless of weather conditions.

Solar Charge Controller: Manages the power flow, ensuring the battery charging logic is stable and protecting the system from overcharging.

H-Bridge Inverter: Wireless power transfer requires high-frequency Alternating Current (AC). The inverter switches the DC power from the solar system into high-frequency AC.

Transmitter Resonant Tank: Consists of a magnetic coil and tuning capacitors. It is tuned to a specific resonant frequency to maximize electromagnetic field generation.

2. Wireless Power Transfer & Data Layer (The Air Gap)

This is the physical space between the ground and the bottom of the electric vehicle.

Magnetic Resonant Coupling: Power is transferred wirelessly across an air gap using strongly coupled magnetic fields. When the transmitter and receiver coils are tuned to the exact same resonant frequency, energy transfers efficiently without physical wires. It also handles load detection (sensing when an EV is actually parked over the pad).

3. Onboard EV (Receiver) Layer (The Vehicle Side)

This hardware is built directly into the Electric Vehicle to capture and store the transmitted energy.

Receiver Resonant Tank: An onboard coil captures the oscillating magnetic field from the ground pad and converts it back into AC electricity.

Rectifier & BMS (Battery Management System): The captured high-frequency AC power is converted back into stable DC power (via the Rectifier). The BMS then safely routes this power to charge the battery pack, monitoring cell voltage and temperature.

EV Battery Pack: The storage system, utilizing standard 18650 cells. The system constantly tracks its SOC (State of Charge) to know when the battery is full.

4. State & Control (IoT) Layer

This acts as the bridge between the physical vehicle hardware and the digital cloud, managing local operations and data collection.

MCU Control Unit: The local microcontroller (like an ESP32 or Arduino-based unit) that runs safety state machines and interlocks (e.g., shutting off power if an obstruction is detected).

Telemetry Provider: Continuously collects local sensor data specifically Voltage (V), Current (I), and State of Charge (SOC) and packages it to send to the cloud.

Command Provider: Listens for incoming signals from the cloud/user (like "Start Charging" or "Stop Charging") and triggers the local hardware accordingly.

5. CLOUD & IOT PLATFORM (THE BACKEND)

This layer processes data, handles security, and manages the logic of the system using cloud services (specifically modelled around Firebase/Google Cloud architecture).

IoT Hub: Acts as the central message broker. It handles the data traffic coming from the vehicle and uses "Device Shadows" (a virtual cloud copy of the vehicle's state) to manage offline/online states.

Realtime Database: Stores the incoming stream of charging metrics with ultra-low latency, enabling live tracking.

Cloud Functions: Serverless code snippets that run automatically to analyse system efficiency, trigger real-time safety alerts, or handle user account management.

Firebase Auth: Ensures that only authorized users can connect to the hardware and initiate charging sessions.

6. USER INTERFACE (THE FRONTEND)

The application layer where the end-user interacts with the entire ecosystem.

User Dashboard App: A mobile or web app where the EV owner can look at their current charging status, check SOC. Harvesting & Transmitting: Sunlight hits the Solar PV Array, power is converted to high-frequency AC by the Inverter, and sent into the air via the Transmitter Tank.

Receiving & Storing: The EV's Receiver Tank catches the energy, the Rectifier turns it back to DC, and the BMS stores it in the Battery Pack.

Monitoring & Controlling: The MCU reads the live charging data, sends it through the IoT Hub to the Realtime Database, allowing the user to view it live on their Dashboard App and send control commands right back down to the vehicle.

7. RESULTS AND DISCUSSION

The image shows a solar-powered electronic system setup consisting of a solar panel, battery pack, control circuitry, LCD display module, and a digital multimeter measuring the battery voltage.

It is designed to collect energy from two different renewable sources a solar panel and a wireless power receiver coil and use that energy to charge a battery pack, manage the power, and likely monitor or transmit data about the system.

8. CONCLUSION:

The IoT-based solar-powered contactless EV charging system provides an innovative and sustainable solution for modern electric vehicle charging needs. By integrating solar energy, wireless power transfer technology, and IoT-based monitoring, the system enhances charging convenience, improves safety, and reduces dependence on conventional electricity sources. the proposed system demonstrates the potential of combining renewable energy and smart technologies to create an efficient, eco-friendly, and intelligent EV charging infrastructure. This project can play a significant role in supporting the future growth of electric mobility and sustainable energy management

9. REFERENCES:

[1] Sigi Li and Chanting Chris Mi" Wireless Power Transfer for Electric vehicle applications" IEEE journal of Emerging and Selected Topics in Power Electronics, Vol. 3, No.1, March 2015

[2] A. K. A. Kurs, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljacic, "Wireless power transfer via strongly coupled magnetic resonances," Science, vol. 317, no. 5834. pp. 83-86. 2007.

[3] A. P. Sample, D. A. Meyer, and J. R. Smith, "Analysis, experimental results, and range adaptation of magnetically coupled resonators for wireless power transfer," IEEE Trans. Ind. Electron., vol. 58, no. 2, pp. 544-554, Feb. 2011.

[4] B. L. Cannon, J. F. Hoburg, D. D. Stancil, and S. C. Goldstein, "Magnetic resonant. coupling as a potential means for wireless power transfer to multiple small receivers," IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1819-1825, Jul. 2009.

[5] Askin Erdem Glindogdu and Dr. Erkan Afacan " Some Experiments Related to Wireless Power Transmission " Cross Strait Quad-Regional Radio Science and Wireless Technology Conference 2011

[6] Yoon Do Chung, Chang Young Lee, Hyoung Ku Kang and Young Gun Park " Design Consideration and Efficiency Comparison of Wireless power Transfer with HTS and Cooled Copper Antennas. " IEEE Transactions On Applied Superconductivity, Vol. 25, No. 3, June 2015

[7] S. J. Gerssen-Gondelach and A. P. C. Faaij, "Performance of batteries for electric vehicles on short and longer term," J. Power Sour., vol. 212, pp. 111-129, Aug. 2012.

[8] A. Kurs, R. Moffatt, and M. Soljacic, "Simultaneous mid-range power transfer to multiple devices," Appl. Phys. Lett., vol. 96, no. 4, pp. 044102-1-044102-3, 2010.

[9] C. Sanghoon, K. Yong-Hae, S.-Y. Kang, L. Myung-Lae, L. Jong-Moo, and T. Zyung, "Circuit-model-based analysis of a wireless energy transfer system via coupled magnetic resonances," IEEE Trans. Ind. Electron., vol. 58, no. 7, pp. 2906-2914, Jul. 2011.

[10] L. C. Kwan, W. X. Zhong, and S. Y. R. Hui, "Effects of magnetic coupling of nonadjacent resonators on wireless power domino-resonator systems," /EEE Trans. Power Electron., vol. 27, no. 4, pp. 1905-1916, Apr. 2012.

[11] Y. Nagatsuka, N. Ehara, Y. Kaneko, S. Abe, and T. Yasuda, "Compact contactless power transfer system for electric vehicles," in Proc. /PEC, Jun. 2010, pp. 807-813.

[12] C. J. Chen, T. H. Chu, C. L. Lin, and Z. C. Jou, "A study of loosely coupled coils for wireless power transfer," IEEE Trans. Circuits Syst., vol. 57, no. 71, pp. 536-540, Jul. 2010.

[13] M. Budhia, G. A. Covic, and J. T. Boys, "Design and optimization of circular magnetic structures for lumped inductive power transfer systems," /EEE Trans. Power Electron., vol. 26, no. 11, pp. 3096-3108, Nov. 2011.

[14] C. Wang, O. H. Stielau, and G. A. Covic, "Design considerations for a contactless electric vehicle battery charger," IEEE Trans. Ind. Electron., vol. 52, no. 5, pp. 1308-1314, Oct. 2005.

[15] M. L. G. Kissin, G. A. Covic, and J. T. Boys, "Steady-state flat-pickup loading.