ESP32 charging system prototype for EV: Design and implementation using wireless energy transmission

Amin Sallem[1*], *Zied Souissi*[2], *Mohamed Aziz* Nasri[2], *Bachir Benhala*[3], *Nouri Masmoudi*[4]

[1] LETI-ENIS, University of Sfax, Sfax, Tunisia
[2] ISGIS, University of Sfax, Sfax, Tunisia
[3] FSDM, University SMBA, Fez, Morocco
[4] LETI-ENIS, University of Sfax, Sfax, Tunisia

Abstract. Electric vehicles (EVs) are gaining popularity due to their cost-effectiveness and environmental advantages. The major objective is to design charging systems that can support extended vehicle usage. The current charging infrastructure relies on conductive ways, but technological advancements are offering wireless options. Inductive EV charging, a wireless alternative, eliminates the need for physical cables and runs on solar energy, hence removing the requirement for external power sources. This novel technology recharges EVs while they are in motion, removing the need for refueling. Batteries, transformers, solar panels, copper coils, regulator circuits, ESP32 controllers, AC / DC converters are among the prototype design components.

Index Terms. Inductive Wireless Power Transfer, Dynamic Wireless Charging System, Electric Vehicles, Solar energy, ESP32 controller.

1. INTRODUCTION

Electric vehicles are now gaining popularity, reaching a high point in 2023 with a 35% increase in global sales. The demand is concentrated in three regions: Asia, particularly China (about 60% of sales), Europe (25%), and North America (10%) [1]. By 2035, the sale of new thermal vehicles, both rechargeable and non-rechargeable hybrids, will be prohibited in the European Union in order to prevent climate change caused by fossil fuel burning [1, 2]. Nonetheless, to support this growth, the infrastructure for recharging must keep up.

The main challenges associated with the use of charging stations are: availability and accessibility (some regions, particularly rural areas, are less well served), charging time (compared to thermal vehicles, the charging time of electric vehicles can be long), infrastructure costs, standardization (different types of chargers and charging standards), maintenance and reliability (regular maintenance is required to ensure proper operation).

* Corresponding author: aminsallem@hotmail.com

To address these challenges, efforts are being made to improve charging infrastructure, particularly via public and private investments and technological advances. There are three main charging EV battery techniques: battery swapping stations [3], conductive charging [4], and wireless charging system. It is interesting to use wireless charging for lengthy drives allowing charging EV batteries remotely without the need for physical connections [5,6]. Two categories are employed for wireless charging [7]:

- Static Wireless Charging system (SWCS): the vehicle gets charged when it remains static. This system is ideally built in regions where EVs are parked for a set time interval.
- Dynamic or in-motion Wireless Charging System (DWCS): vehicle get charged while in motion. When traveling on roads and highways, the DWCS EV's battery may be continuously charged, increasing its travel range.

DWCS has various advantages. Indeed, DWCS allows EVs to greatly expand their driving range without frequent stops, removes the need to carry huge batteries, reduces the downtime associated with regular charging stations, and helps reduce dependency on fossil fuels. These features make DWCS a potential transportation technology for the future.

The origin of DWCS is using wireless power transfer (WPT) that wirelessly transmits power through the air using magnetic fields generated by inductive coupling coils. WPT may be used in various settings, including healthcare, EV, automation, and smart cities.

In this work, a prototype DWCS is proposed using an inductive wireless power transfer system, enabling charging while the vehicle is in motion without a physical connection. Using renewable energy like photovoltaic (PV) system as the primary input removes the requirement for an external power source and make the charging process more efficient especially when using IoT technology via the ESP232.

The rest of the paper is organized as follows. Section II gives details of Inductive WPT technique. Section III gives details of the proposed prototype of DWCS with results and discussion. Finally, the conclusions are presented in Section IV.

2. INDUCTIVE WIRELESS POWER TRANSFER SYSTEMS

The inductive wireless power transfer system (IWPT) is a reliable technology that wirelessly transmits power over the air utilizing magnetic fields created by inductive coupling coils, and it is intended to satisfy current industrial demands. They provide solutions for rail-mounted applications, surface-running vehicles, and automated battery charging for vehicles such as Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) [9].

According to the electromagnetic principle, which bases WPT employing the Inductive technique IWPT, a magnetic field and a flux connection have a major impact on the flow of charges from the transmitter unit to the reception unit, as shown in Figure 1, such that the system starts with a transmitter coil embedded in a charging station, which is connected to a power source (in our case PV system). When the system is activated, an alternating current (AC) flows through this coil, creating a magnetic field. The EV is equipped with a receiver coil, generally attached on the underside of the EV. When the vehicle is parked over the charging pad, the magnetic field generated by the transmitter coil induces an alternating current in the receiver coil. The induced AC in the receiver coil is then converted to direct current (DC) using a rectifier. This DC power is used to charge the vehicle's battery [10].

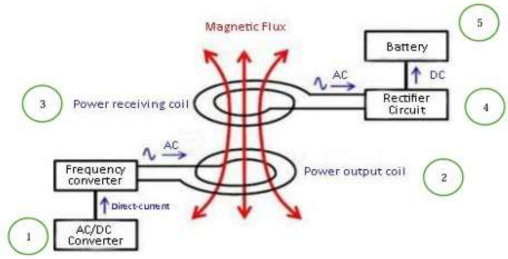

Figure 1. The principle of the inductive wireless power transfer system

IWPT is quite suitable for EV charging because to its multiple advantages, such as:

- All components are electrically isolated, making charging safer for people [8].
- Even under unfavorable environmental circumstances such as heavy rain, wind, and snow, the system is efficient and dependable.
- A self-operating system that requires no user contribution.
- The interoperability concept eliminates issues regarding plug compatibility with outlets [9].
- Capability to transport the required power (from a few kilowatts to megawatts) across huge airgaps ranging from 100 to 400 mm while supporting varying EVs' ground clearance [11].
- The absence of moving or rotating elements reduces noise and requires less maintenance.

In DWCS tracks can be stretched or segmented [9]. With stretched (single long) tracks ranging from 1 to 100 meters underground (see Figure 2a). These tracks allow multiple EVs to be charged simultaneously. The stretched transmitter consists of a long track made of litz wire, which is supplied from a primary station. This station includes a compensation network, HF DC/AC converter (inverter), and AC/DC converter (rectifier) [12]. The online electric vehicle (OLEV) charging system, developed in South Korea, uses a stretched track for general transport buses and shuttle utilities [12]. The segmented charging track consists of multiple coils laid in the ground and interconnected in parallel or series arrangement, as shown in Figure 2b,c. Each segmented coil within the track resembles the charging pad attached to the EV, resembling stationary charging [13]. In this DWCS design, only one of the transmitter track pads is excited when the EV passes over it. As the EV moves away from the excited pad, the control system turns off the excitation and switches to another pad, and so on.

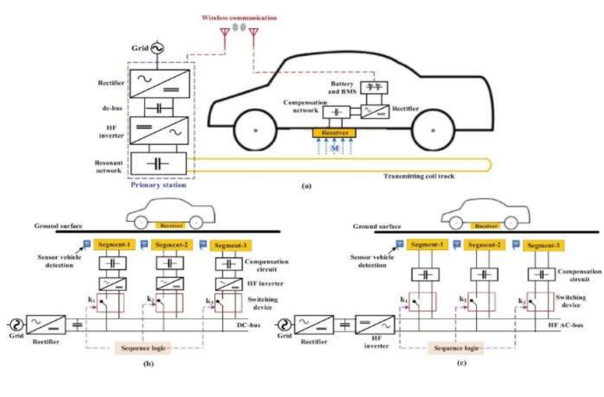

Figure 2. Design of DWCS: (a) Single long coil track design, (b) segmented transmitter design using a common DC bus, (c) segmented transmitter design using a common HF AC bus [9]

3. DEVELOPED ESP32 TROTOTYPE OF IWPT FOR EV

The primary goal of the proposed system is to develop an educational demonstration prototype that takes advantage of renewable sources, particularly solar energy, to construct a more efficient, clean, and rapid charging mechanism.

A wireless charging technology IWPT is utilized to speed charging without stopping, resulting in significantly reduced charging periods. This method not only enhances convenience but also reduces costs.

The schematic diagram presented in Figure 3 illustrates systematic procedure involved in the two IWPT systems: Transmitter and Receiver of DWCS.

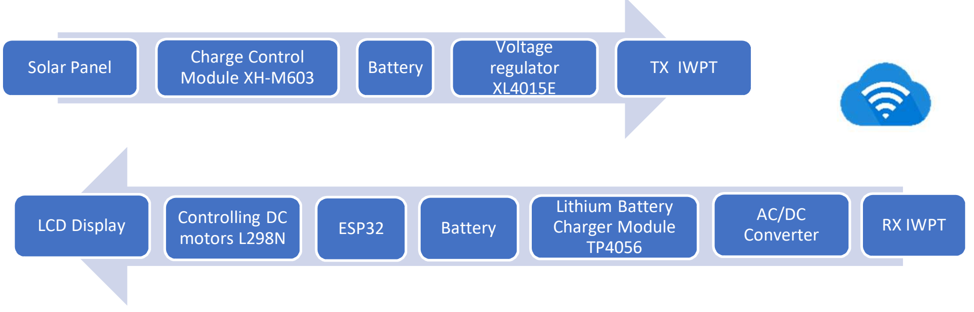

Figure 3. Diagram Bloc of the proposed prototype of the DWCS

Figure 3 shows a schematic illustration of the systematic approach for proposed DWCS using solar energy. In this system, the energy collected by the solar panels is stored in a battery unit. This stored energy is subsequently sent to an inverter, where it is converted from direct current (DC) to alternating current (AC) voltage. The converted AC voltage is step-upped by a transformer, increasing its voltage level for efficient transmission. After being wirelessly communicated, the received voltage is transformed back into direct current (DC). This converted DC voltage performs two functions: it powers the ESP32 microprocessor and charges the car's battery. The ESP32 included inside the system communicates with a 16x2 liquid crystal display (LCD) unit. This display is used to highlight and provide critical information, most notably the input voltage of the electric car battery. This availability of real-time input voltage information guarantees that the charging process is monitored and managed, allowing users to track and measure the state of their vehicle's battery charge. The block diagram depicts the progressive phases of wirelessly transmitting solar energy to an electric car.

3.1. Hardware implementation

The hardware implementation of the proposed DWCS of EV includes energy storage, conversion from DC to AC voltage, amplification, wireless communication, reconversion from AC/ DC voltage, and subsequent use for monitoring and charging the vehicle's battery via an ESP32 with an LCD display and controlling DC motors L298N. Figure 4 and 5 illustrates the Proteus ISIS simulation schematic of the TX and RX IWPT. Figure 6 present the final prototype of the proposed DWCS.

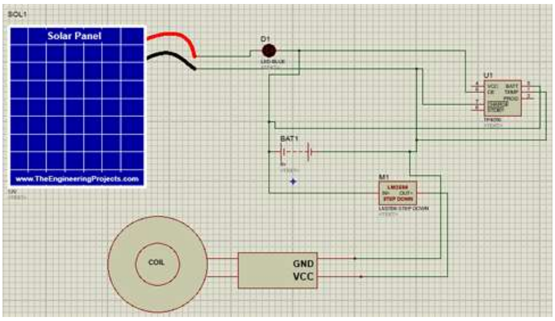

Figure 4. Proteus ISIS of the TX IWPT

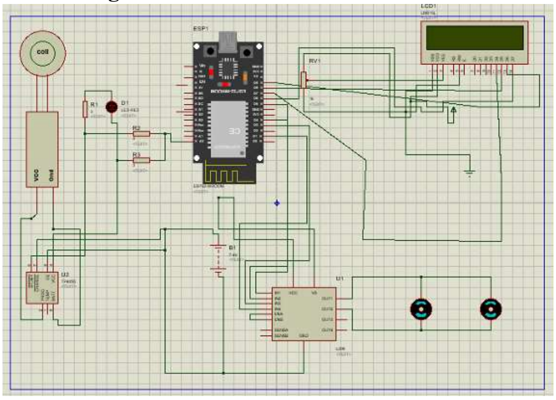

Figure 5. Proteus ISIS of the RX IWPT

Figure 6. Results and implementation of the proposed DWCS of EV

3.2. Software Implementation

The DWCS utilizes ESP32 as its principal microcontroller. The ESP32 manages the essential operations of the system. Programming the ESP32 with the Arduino IDE enables quick creation and behavior customization of the system. Figure 6 present a part of the pseudocode of the wireless charging procedure by guarantying optimal power transmission and battery well-being for EV. Indeed, when the car is given a 12V (from solar panels), the battery is able to charge to its maximum efficiency. To obtain a significant charge while the EV is in-moving, it takes between thirty and sixty minutes. The car can leave the charging lane when it has finished charging. The battery's energy capacity (Ah) divided by the provided current (A) determines how long it will take to charge the battery.

https://doi.org/10.1051/e3sconf/202560100112

$$\text{Time to charge} = \frac{\text{Energy } (Ah)}{\text{Current } (A)} \tag{1}$$

While charging times vary, a moving car in the charging lane can reach a significant charge in 30 to 1 hour, making it easier for the car to leave once completely charged.

4. CONCLUSION

Wireless charging appears as the most straightforward and rapid way to charge electric vehicles as EVs and solar power become more widespread, while dynamic charging enables on-the-go charging while driving. Dynamic charging allows for flexibility in EV charging power, which makes it possible to synchronize with solar energy generation. The expansion of charging infrastructure, integration of renewable energy sources like solar power, and advancements in autonomous driving and V2G systems are crucial for widespread adoption of electric vehicles (EVs). Integrating Internet of Things (IoT) and Artificial Intelligent (AI) into DWCS . This will lead to a cleaner, more sustainable transportation ecosystem, with EVs dominating the market.

```
#include <LiquidCrystal.h>
#include <SoftwareSerial.h>
SoftwareSerial bth(6, 5);
LiquidCrystal lcd(12, 11, 10, 9, 8, 7);
#define pwm 3
#define IN1 4
#define IN2 2
void setup() {
Serial.begin(9600);
bth.begin(9600);
lcd.begin(16, 2);
pinMode(pwm, OUTPUT);
pinMode(IN1, OUTPUT);
pinMode(IN2, OUTPUT);
lcd.print("WL Charging Sys.");
delay(1000);
lcd.clear();
}
void loop() {
float voltage = analogRead(16) * (5.0 / 1023.0);
lcd.setCursor(0, 0);
lcd.print("CHG ON AT ");
lcd.print(voltage, 2); // Affichage de la tension
avec 2 décimales
lcd.print(" V");
lcd.setCursor(0, 1);
lcd.print("Command: ");
if (bth.available() > 0) {
char msg = bth.read();
Serial.println(msg);
executeCommand(msg);
}
delay(100);
}
}
void Stop() {
analogWrite(pwm, 0);
digitalWrite(IN1, LOW);
digitalWrite(IN2, LOW);
}
void Forward() {
analogWrite(pwm, 80); //max 70-255
digitalWrite(IN1, HIGH);
digitalWrite(IN2, LOW);
}
void Back() {
analogWrite(pwm, 80); //max 70-255
digitalWrite(IN1, LOW);
digitalWrite(IN2, HIGH);
}
void Left() {
// Action à effectuer pour tourner à gauche
}
void Right() {
// Action à effectuer pour tourner à droite
}
void executeCommand(char cmd) {
switch (cmd) {
case 'F':
Forward();
lcd.setCursor(9, 1);
lcd.print("Forward   ");
break;
case 'B':
Back();
lcd.setCursor(9, 1);
lcd.print("Back
");
break;
case 'L':
Left();
lcd.setCursor(9, 1);
lcd.print("Left
");
break;
case 'R':
Right();
lcd.setCursor(9, 1);
lcd.print("Right
");
break;
case 'S':
Stop();
lcd.setCursor(9, 1);
lcd.print("Stop
");
break;
default:
lcd.setCursor(9, 1);
lcd.print("Invalid   ");
}
```

Figure 7. Arduino code of the DWSC system

REFERENCES

[1] IEA (2024), Global EV Outlook 2024 report, The International Energy Agency, Paris, Licence: CC BY 4.0, April 2024. https://www.iea.org/reports/global-ev-outlook-2024

[2] Jaume Duch Guillot (2023), Nouveaux objectifs de réduction des émissions de CO2 pour les voitures et les camionnettes, Direction générale de la communication du Parlement européen du 17-07-2023.

[3] Zheng, Y., Dong, Z.Y., Xu, Y., Meng, K., Zhao, J.H., Qiu, J., Electric vehicle battery charging/swap stations in distribution systems: Comparison study and optimal planning. IEEE Trans. Power Syst. 29(1), 221–229 (2013)

[4] Mohamed, A.A.S., Shaier, A.A., Metwally, H., Selem, S.I., A comprehensive overview of inductive pad in electric vehicles stationary charging. Appl. Energy 262, 114584 (2020) https://doi.org/10.1016/j.apenergy.2020.114584

[5] Ahmad, A., Alam, M.S., Chabaan, R., A comprehensive review of wireless charging technologies for electric vehicles. IEEE Trans. Transp. Electrification 4(1), 38–63 (2017)

[6] X. Zhang, Z. Yuan, Q. Yang, Y. Li, J. Zhu, and Y. Li, "Coil Design and Efficiency Analysis for Dynamic Wireless Charging System for Electric Vehicles", IEEE Transactions on Magnetics, 2016.

[7] K. Kumar, S. Gupta, and S. Nema, A Review of Dynamic Charging of Electric Vehicles", 7th International Conference on Electrical Energy Systems (ICEES), 2021.

[8] Budhia, M., Covic, G.A., Boys, J.T., Design and optimization of circular magnetic structures for lumped inductive power transfer systems. IEEE Trans. Power Electron. 26(11), 3096–3108 (2011)

[9] Mohamed, A.A.S., Shaier, A.A., Metwally, H., Selem, S.I., Wireless charging technologies for electric vehicles: Inductive, capacitive, and magnetic gear. IET Power Electron. 00, 1–27 (2023). https://doi.org/10.1049/pel2.12624

[10] Okasili, I.; Elkhateb, A.; Littler, T., A Review of Wireless Power Transfer Systems for Electric Vehicle Battery Charging with a Focus on Inductive Coupling. Electronics 2022, 11, 1355. https://doi.org/10.3390/electronics11091355

[11] Mohamed, A.A.S., Mohammed, O., Physics-based Co-simulation platform with analytical and experimental verification for bidirectional IPT system in EV applications. IEEE Trans. Veh. Technol. 67(1), 275–284 (2018). https://doi.org/10.1109/TVT.2017.2763422

[12] Lu, F., Zhang, H., Hofmann, H., Mi, C.C., A dynamic charging system with reduced output power pulsation for electric vehicles. IEEE Trans. Ind. Electron. 63(10), 6580–6590 (2016). https://doi.org/10.1109/TIE.2016.2563380

[13] Miller, J.M., Jones, P.T., Li, J.-M., Onar, O.C., ORNL experience and challenges facing dynamic wireless power charging of EV's. IEEE Circuits Syst. Mag. 15(2), 40–53 (2015). https://doi.org/10.1109/MCAS.2015.2419012