Chapter 5: System Model (Software and Hardware)

This chapter deals with complete system model for wireless charging for hybrid electric vehicle. Here ANSYS Twin Builder simulation tool is used to simulate and results are compared with analytical results. Later part of this chapter is related to hardware prototype design and testing of whole circuit.

5.1 Description of system block diagram:

A prototype is prepared to check and test inductively linked power transmission for electric vehicle. The results obtained by simulation are validated practically. A single-phase prototype arrangement provides the foundation for the hardware implementation. Primary and secondary coils, a high-frequency H-bridge inverter, and compensating capacitors are present on both sides. Rectifiers and filter capacitors are also connected on both transmitting and receiving sides.

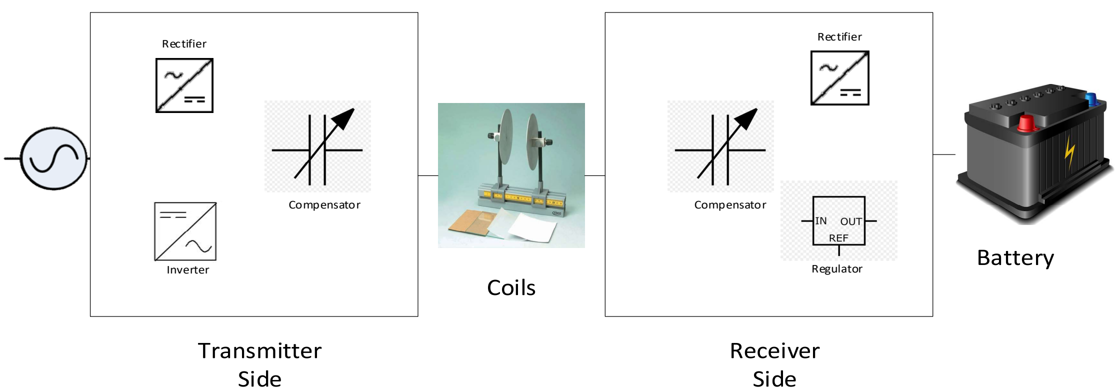

Figure 5-1 Block diagram of wireless power transmission for electric vehicle.

Figure 5-1 Block diagram of wireless power transmission for electric vehicle. shows the basic block diagram of inactive charging system for storage system of an electric vehicle. Inductive charging for the storage system of Electric Vehicles (EVs) is a wireless charging system that transmits energy from a charging point to the battery of the vehicle via electromagnetic fields. The procedure has a number of crucial parts and steps that can be shown in a block diagram.

Complete wireless power system diagram is drawn in ANSYS Twin Builder and is shown in Figure 5-2. All the components have already been discussed in previous sections. Though for the sake of simplicity and along with hardware prototype implementation point of view it is been described here.

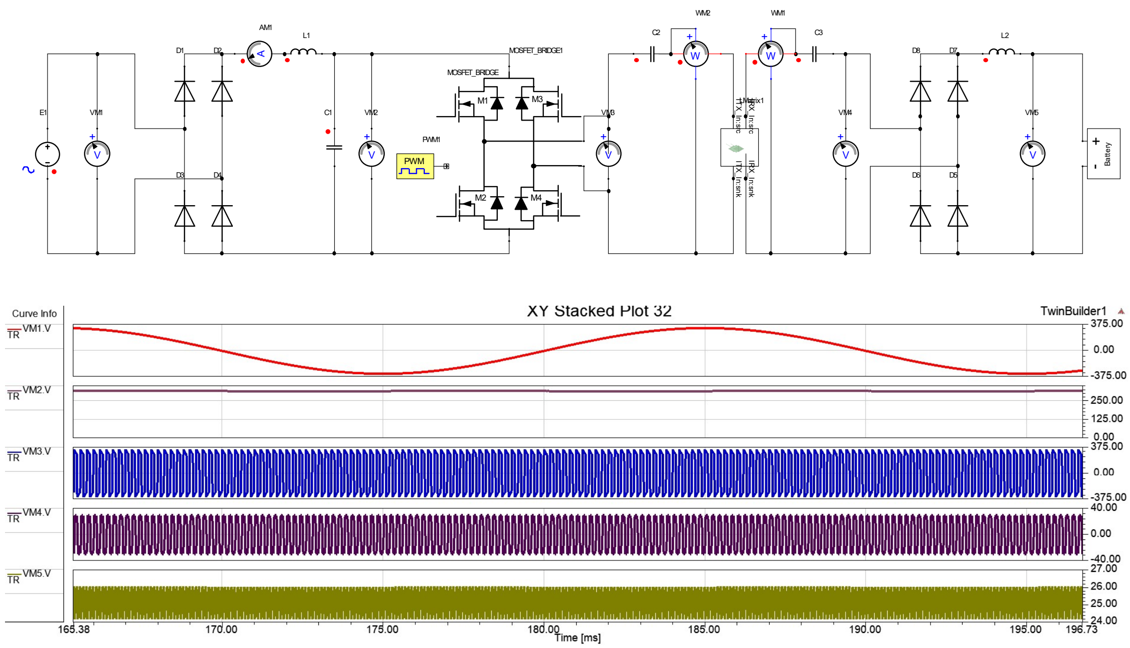

Figure 5-2 System architecture and voltage waveforms.

5.1.1 Primary Coil:

In Wireless Power Transfer (WPT) systems, a particular coil design known as a square planar coil is employed. It has a number of benefits and uses in the world of WPT, including:

- **Uniform magnetic field:** A square planar coil comprises several rounds of wire and, as its name implies, is square in shape. This arrangement results in a more uniform distribution of the magnetic field within the coils. This homogeneity guarantees that the receiver coil can successfully catch the magnetic flux, which might be helpful for efficient power transmission.
- **Better coupling efficiency:** When compared to other coil forms, such as circular or spiral coils, square planar coils can have a better coupling efficiency. It is suited for applications where high efficiency is essential because of the increased coupling efficiency, which increases the amount of power that can be passed from the transmitter coil to the reception coil.

- **Compact design:** When compared to alternative coil designs with comparable inductance values, the square form provides more compact and space-efficient design. This is especially helpful if you have a small amount of available space or need to incorporate the coil into a compact gadget.
- **Directional control:** The square design enables more control over the coil's magnetic field's direction. This might be helpful in situations where you need to focus power on a particular area or reduce interference from surrounding devices.
- **Versatility:** Wireless charging for electric vehicles (EVs), consumer electronics (like smartphone charging pads), and medical equipment are just a few applications for square planar coils. Their versatility makes them suitable for a range of WPT scenarios.
- **Reduced Electromagnetic Interference (EMI):** Due to their compact design and improved magnetic field control, square planar coils can create less EMI as compared to other coil shapes. This can be important when EMI reduction is a primary priority.

The charging facility, which has a primary coil, is the brain of the system. This coil produces alternating current (AC) at a set frequency while being linked to the power source. The coil is having 21 turns with square geometry and wound with copper conductor of 22 AWG.

5.1.2 Power Source:

The electrical energy required for the charging process is provided by the power source. Normally, it is connected to the charging station's main coil. Here in this research, we have taken 230 volts, 50 Hz single phase supply. Two different electrical components, a rectifier and a high-frequency inverter, are utilized in power electronics and electrical systems for various applications. Let's look at each of them separately:

5.1.3 Rectifier:

An electrical circuit or device that transforms alternating current (AC) into direct current (DC) is called a rectifier. The voltage is virtually rectified, allowing current to flow exclusively in one direction. Rectifiers are frequently employed in a number of different applications, such as power supplies, battery charging, and electronics.

There are various rectifier kinds, including:

- Half Wave Rectifier:

  The half of the AC cycle that this type of rectifier permits current to flow in one direction. Although it is the simplest kind of rectifier, it is not very effective.
- Full-Wave Rectifier:

  A full-wave rectifier is more effective than a half-wave rectifier because it enables current to flow in a single direction during both halves of the AC cycle.
- Bridge Rectifier:

  A bridge structure of diodes is used in the bridge rectifier, a form of full-wave rectifier, to correct AC voltage. It is frequently utilized in power supplies and other applications that need effective DC conversion.

  By stacking numerous rectifier stages in series, voltage multiplier rectifiers are utilized to produce greater DC voltages.

As a silicon rectifier diode, the BY399 is used to convert alternating current (AC) voltage to direct current (DC). The reverse voltage rating (reverse voltage peak) of the BY399 is generally 800 volts (800 V). The diode can endure this amount of reverse voltage before breaking down. The greatest continuous current that a diode can withstand is known as the forward current rating (IF), which is typically 30 amperes (30A).

5.1.4 High-Frequency Inverter:

Also known as an inverter, a high-frequency inverter is an electronic device that transforms direct current (DC) into alternating current (AC), resulting in a high-frequency output. Uninterruptible power supplies (UPS), electric vehicle drive systems, and other applications employ inverters extensively.

In applications where size, weight, and efficiency are important considerations, high-frequency inverters tend to be advantageous. For instance, they are frequently utilized in contemporary grid-connected inverters, electric car inverters, and solar inverters to effectively transform DC power from batteries or renewable sources into AC power for a range of loads.

While high-frequency inverters convert DC to AC at high switching frequencies and are frequently utilized in applications requiring compact size and great efficiency, rectifiers are used to convert AC to DC.

A power MOSFET (Metal-Oxide Semiconductor Field-Effect Transistor) is a semiconductor component that is often used in electronic circuits for switching and amplification purposes. Here are some of its main characteristics:

- IRF460 is an N-channel power MOSFET of this kind. This implies that, when utilised in the proper circuit topologies, it is made to tolerate relatively high voltages and currents.
- The greatest voltage the IRF460 can withstand in the off-state, or drain-to-source voltage rating, is generally 500 volts (V). Because of this, it may be used in high-voltage applications.
- Continuous Drain Current (ID): The IRF460 can often tolerate a continuous drain current of up to 20 amps (20A) without overheating.

5.1.5 Capacitive compensator:

In wireless power transfer (WPT) systems that employ resonant inductive coupling, a capacitor compensator, also referred to as a compensating capacitor, plays a crucial role. It is essential for adjusting the system's resonance frequency, increasing power transfer efficiency, and minimizing losses. The function of capacitor compensator in relation to wireless power transfer is described below:

- Resonant inductive coupling is frequently utilized in wireless power transfer systems to effective transfer of power between a transmitting coil (primary coil) and a receiving coil (secondary coil), despite the need for direct electrical connections.
- The primary or secondary coil (or both) and a compensation capacitor are added during capacitor compensation. This capacitor modifies the resonance frequency of coils such that it coincides with the power frequency.
- The value of the compensation capacitor can be changed to fine-tune the resonant frequency of the system. The primary and secondary coils must resonate at the same frequency in order to enhance power transfer efficiency.

A capacitor compensator is an essential part of a wireless power transfer system that is used to precisely adjust the resonant frequency of coils for whole system. This component ensures efficient power transmission by reducing energy losses while upholding resonance. This element is essential for maximizing the effectiveness of wireless charging systems employed in consumer electronics, electric automobiles, and other wireless power transfer applications. Here in this research 0.1 pF capacitor compensators are used in both transmitting and receiving end side.

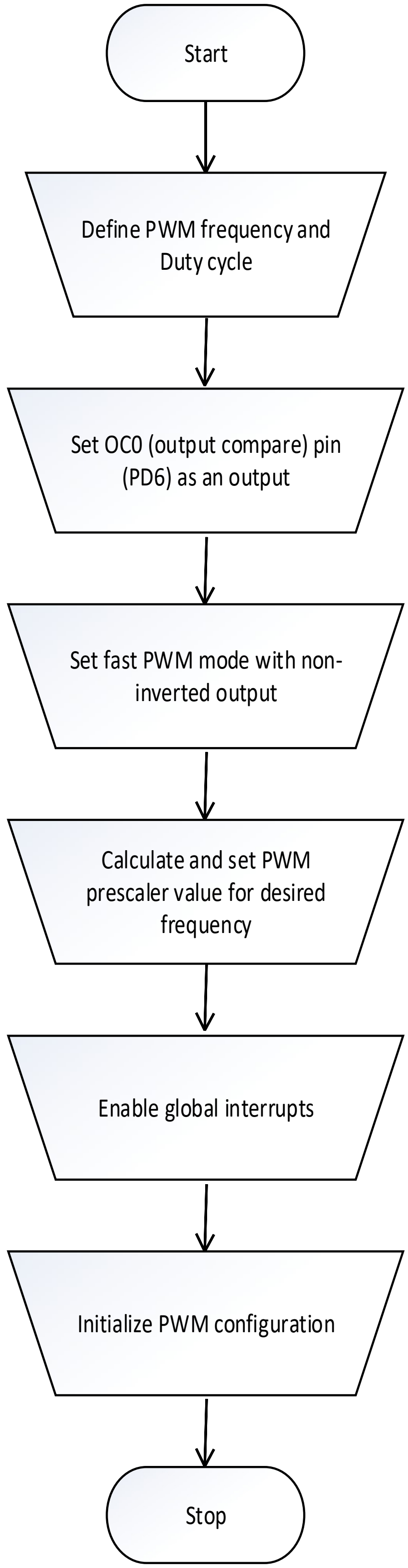

Figure 5-3 Flow chart to generate PWM

5.1.6 Microcontroller ATmega32A:

The ATmega32A is a variant of a microcontroller that belongs to the Atmel ATmega family, which is currently a division of Microchip Technology. This well-known 8-bit microcontroller is built using the AVR architecture. It's crucial to keep in mind that while the ATmega32A may be used in a variety of applications, like wireless power transfer (WPT) systems, it does not directly perform WPT operations. Instead, it might be a component of a WPT control and communication system setup. Here flow chart for PWM control is presented in Figure 5-3, while whole program for generation of PWM signal is given in Appendix-A.

To understand the code, the breakdown of the code is given here:

- We define the desired PWM frequency (**PWM_FREQUENCY**) and duty cycle (**PWM_DUTY_CYCLE**).
- In the **setup_PWM** function:
  - Set PD6 (pin associated with OC0) as an output pin.
  - Configure Timer/Counter0 for Fast PWM mode with non-inverted output.
  - Calculate the appropriate prescaler value to achieve the desired PWM frequency and set it.
  - Calculate and set the initial duty cycle based on the desired duty cycle percentage.
- In the **main** function, you can place your main application code. The PWM signal will continue to be generated in the background based on the configurations provided.
- This code configures Timer/Counter0 for PWM generation at 53.1 kHz with a 50% duty cycle. We can modify the **PWM_FREQUENCY** and **PWM_DUTY_CYCLE** constants to match according to specific requirements.

5.2 Description of hardware prototype:

Using a 230V AC supply and a series-series (SS) resonant converter architecture with a target resonance frequency of 53.1 kHz, a hardware system prototype for Wireless Power Transfer (WPT) is being developed. An overview of a hardware system prototype for this application is given below:

- **Power source:** A 230V AC power supply is used as the initial input source. This might come from a suitable AC source or the mains grid.
- **Rectifier and filter:** Use a full-wave rectifier circuit followed by a smoothing capacitor to convert the AC input to DC. This will provide a DC voltage that is comparatively steady and acts as the input power source.
- **Inverter:** To convert the DC voltage to a high-frequency AC signal, use an inverter circuit, often made up of high-power MOSFETs or IGBTs. The inverter should be configured to create a 53.1 kHz alternating current signal.
- **Tank resonant circuit:** The resonant tank circuit, which consists of an inductor (L) and a capacitor (C), is at the core of the wireless power transfer system. This tank circuit is set to 53.1 kHz, which is the appropriate resonance frequency.
- **Motor driver circuit:** Create a driver circuit to control the switching devices of the inverter. The driver circuit guarantees that the inverter creates and maintains a high-frequency alternating current signal at the desired frequency.
- **Transmission coil:** The transmitter coil should be wound around a suitable core material. This coil is situated adjacent to the reception coil and has a connection to the inverter's output.

Source voltage	**230 V, single phase AC supply**
Source frequency	50 Hz
Bridge rectifier	BI399 diodes
MOSFET for inverter	IRF460
Controller	ATMega32A
Resonant frequency	53.1 kHz
Primary side capacitance C1	0.1 pF
Secondary side capacitance C2	0.1 pF
Primary side inductance L1	9 µH
Secondary side inductance L2	9 µH
Mutual inductance M	6 µH
Coupling coefficient k	0.8

Table 5-1 Hardware prototype system parameters.

- **Receiving coil:** On the receiving side, make a second coil that will serve as the receiver. For effective power transfer, this coil should also be set to the same resonance frequency (53.1 kHz).

Alignment and coupling: For effective power transfer, the transmitter and receiver coils must be properly aligned. To guarantee ideal alignment, you might require alignment devices or guides.

- **Load:** On the receiver side, connect a load to the regulated output. Any application or electronic equipment requiring wireless power may be considered to be under this load.
- **Rectification and filter action:** To rectify the incoming AC signal back to DC and regulate it to the required output voltage on the receiving side. This could comprise a voltage regulator, a smoothing capacitor, and a rectifier circuit.

The hardware prototype of WPT system has been developed with system parameters shown in **Error! Reference source not found.**.

Figure 5-4 shows the complete system hardware prototype for WPT system. This model is used to verify simulation results and is providing output voltage of 24 volts. The results obtained at various levels are taken and presented in tabular as well as pictorial forms in next chapter.

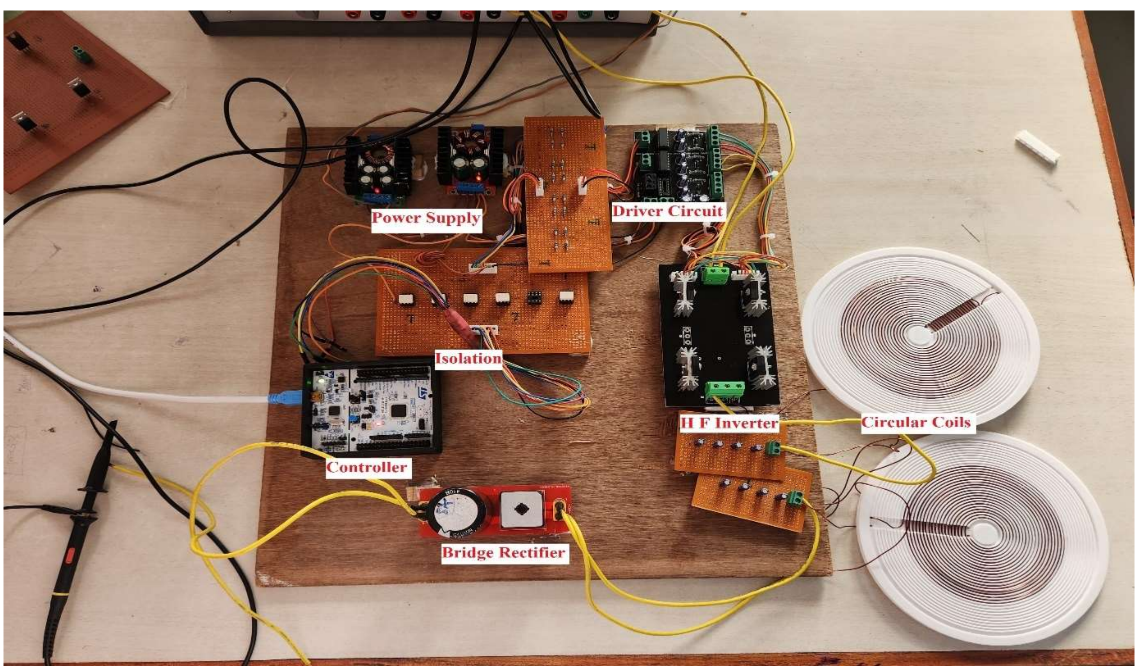

Figure 5-4 Hardware prototype

The prototypal layout of the WPTS was provided in this chapter. The coil structure is initially set up, followed by a series of experiments to determine inductive parameters and magnetic field strength, and then a power circuit is added to finish the setup. The prototype, which included both aligned and misaligned scenarios, was used to test the statistical and simulation investigations created in the earlier chapters. To validate the simulation study, a series of experiments are carried out while the entire setup is run under various load conditions.