Implementing Wireless Power transfer using Pulse width modulation

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***Abstract*—This project presents the design and simulation of a wireless power transfer (WPT) system regulated by pulse width modulation (PWM), with a focus on FPGA-based control for efficient and flexible power delivery. A series-series two-coil topology is adopted for its cost and size advantages and the system architecture integrates rectification, high-frequency inversion and resonance-based energy transfer. Key parameters are analyzed and the circuit is modeled and simulated in Simulink, with results demonstrating optimal power transfer at the resonant frequency of 680 kHz and a maximum output power of 59.87 W. Furthermore, the project details the implementation of a digital PWM generator using FPGA, highlighting its ability to dynamically regulate power in real time. Experimental and simulation results validate the effectiveness of the proposed approach for robust, high-efficiency wireless power delivery in practical applications.**

I. Introduction

Wireless Power Transfer (WPT) facilitates the transmission of electrical energy between a source and a load without physical connectors, primarily through two methodologies: near-field electromagnetic induction and far-field electromagnetic radiation [1].

Electromagnetic induction, the foundational mechanism for short-range WPT, operates through loosely coupled magnetic fields between transmitter and receiver coils, akin to transformer principles but without a ferromagnetic core [2]. Conversely, far-field techniques like electromagnetic radiation employ directed high-frequency radio waves (exceeding 3 kHz) for energy transmission, as exemplified by satellite-based solar power systems [3]. While radiation-based methods achieve high efficiency over long distances, their complexity and cost often restrict practical deployment [4].

A critical advancement in WPT emerged in 2007 with the introduction of magnetically coupled resonance (MCR) by MIT researchers, which addresses the trade-offs between power, range, and efficiency inherent in conventional methods [5]. Unlike inductive coupling, which is optimal for low-power applications at short to medium ranges (e.g., smartphone charging), MCR enables efficient energy transfer over extended distances by leveraging resonant frequency matching between coils [6]. This technique enhances power delivery stability and minimizes losses through high-quality factor (Q) resonators, making it economically viable for industrial and consumer applications [7].

In summary, WPT technologies—spanning inductive coupling, electromagnetic radiation, and resonant methods—offer diverse solutions tailored to specific use cases. Ongoing innovations continue to refine their efficiency, scalability, and cost-effectiveness, broadening their applicability in modern power systems [8].

A. Foundations of WPT

Modern WPT systems primarily employ three fundamental approaches:

- **Inductive coupling**: Near-field magnetic resonance with typical efficiency of 70-90% at short ranges (<10cm) [9]
- **Magnetic resonance**: Mid-range operation (1-3m) using coupled LC resonators
- **Capacitive coupling**: Electric field-based transfer through dielectric barriers

The efficiency of resonant WPT systems is governed by:

$$\eta = \frac{k^2 Q_T Q_R}{(1+\sqrt{1+k^2 Q_T Q_R})^2}$$

where k is coupling coefficient, Q_T and Q_R are quality factors of transmitter/receiver coils [10].

B. Principles of PWM

Pulse Width Modulation (PWM) regulates power delivery by varying the duty cycle (D) of a square wave, where:

$$V_{avg} = D \cdot V_{max} \quad \text{and} \quad D = \frac{t_{on}}{T}$$

Here, t_{on} is the active pulse duration, and T is the signal period. FPGA implementations enable precise control of D through digital logic, achieving resolutions up to 0.39% at 248.69 MHz [11].

C. FPGA-Based PWM Architecture

The core components of FPGA PWM systems include:

- **N-bit Counter**: Generates periodic waveforms (e.g., 8-bit counters for 256 discrete duty levels)
- **Comparator**: Triggers output transitions when counter matches duty cycle values
- **RS Latch**: Maintains stable output states between counter resets [12]

D. Dynamic Power Regulation

FPGAs enable real-time adjustments using feedback loops:

$$D_{new} = D_{prev} + K_p \cdot e(t) + K_i \int e(t)dt$$

where K_p/K_i are PID coefficients and $e(t)$ is the voltage/current error.

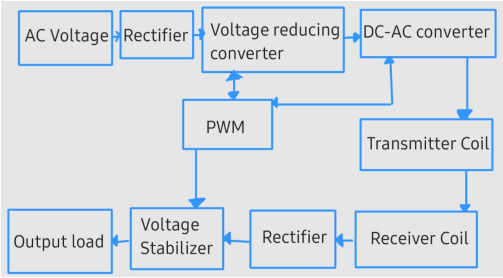

Fig. 1. Block Diagram of WPT system circuit

II. Implementation of WPT

There are a variety of WPT models available based on the application, we study a two-coil WPT with a series-series topology due to cost and size considerations. The block diagram of the WPT system is shown in Fig. 1. As shown in the figure, first an alternate voltage is converted to direct voltage by a rectifier and then the voltage level is reduced by a PWM signal-controlled reducing converter and the alternating voltage with the intended frequency is made using a DC-AC converter. The high frequency alternate voltage is transmitted through the transmitter coil to the receiver coil using resonance induction. In the receiver section, this voltage is first rectified and then transmitted to the load using a voltage stabilizer.

Maintaining resonance in WPT circuits is critical for maximizing efficiency and ensuring stable energy delivery. Resonance is achieved when the inductive L and capacitive C components of the transmitter and receiver circuits are tuned to the same frequency, typically via LC tank circuits, enabling efficient magnetic coupling.

To produce maximum power, the two coils must work at resonance frequency w according to Eq. 1.

$$w = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}} \tag{1}$$

where L_1, C_1 are inductance and capacitance of transmitter and L_2, C_2 are inductance and capacitance of receiver.

A. Rectifier

The below diagram (see Fig. 2) shows the circuit of a full wave rectifier. It is used in converting AC voltage to DC (AC input, receiver output).

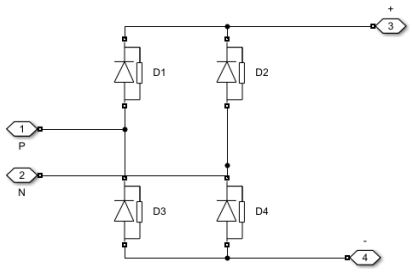

Fig. 2. Circuit diagram of a full wave rectifier

B. HF Inverter

The below diagram (see Fig. 3) shows the circuit of a high frequency inverter implemented using PWM. Insulated Gate Bipolar Transistor (IGBT) are used in this inverter due to their high switching capabilities, which is crucial for minimizing losses and improving efficiency.

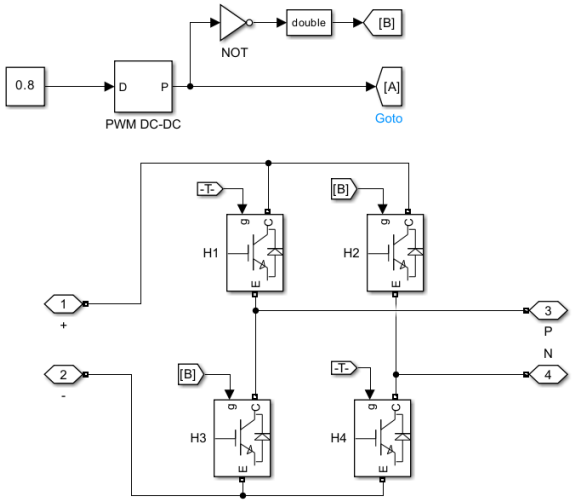

Fig. 3. Circuit diagram of a HF Inverter

C. Parameter Values

Below Table I shows the values of the circuit parameters used for experimentation. Here, k is the coupling coefficient ranging from 0 to 1, in this simulation we assume k to be 0.1. Mutual inductance (M) is calculated using Eq. 2, and is found to be 29.8μH. R_{S_1}, R_{S_2} are the total parasitic resistances of the transmitter and receiver respectively.

$$M = k\sqrt{L_1 L_2} \tag{2}$$

TABLE I
Parameter Values of Equivalent Circuit

Parameter	Value
L_1, L_2	298 μH
C_1, C_2	200 pF
R_{S_1}	5 ohms
R_{S_2}	2 ohms
k	0.1
M	29.8 μH
PWM frequency	~680kHz

D. Simulink circuit

We implemented the WPT circuit as shown in Fig. 4 with an input voltage of 100V and a frequency of 50Hz. Circuit parameters are measured through oscilloscopes available in Simulink.

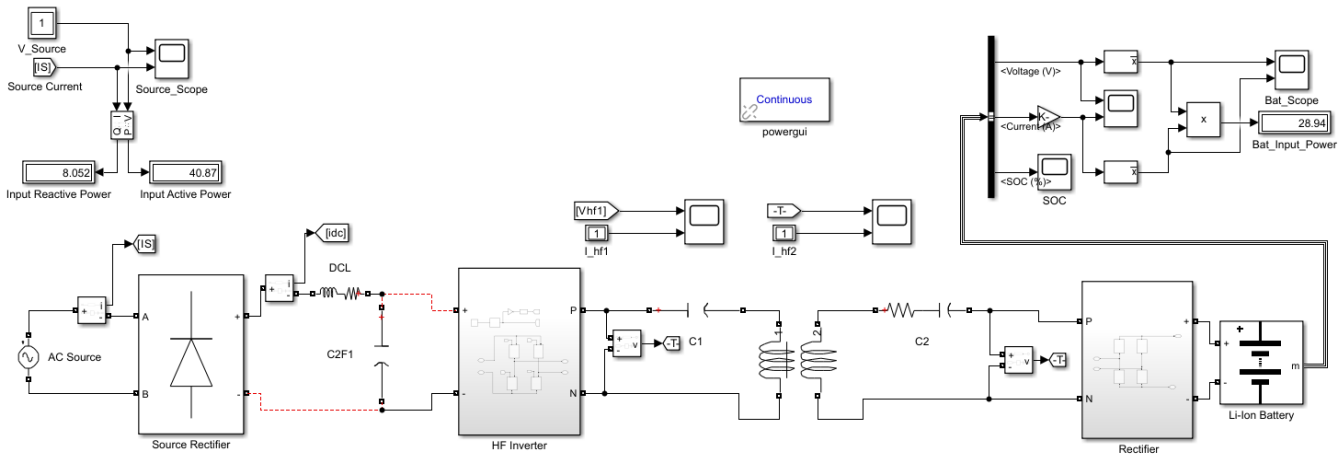

Fig. 4. WPT Circuit diagram implemented in Simulink

III. Observations

The graph depicted in Fig. 5 gives the relationship between the different frequencies and the output power for a fixed input voltage of 100V and a frequency of 50Hz. The graph shows the frequency at which power is transmitted $i.e$, 680kHz. From the graph, it is found that a maximum power of 59.87W is obtained at resonant frequency.

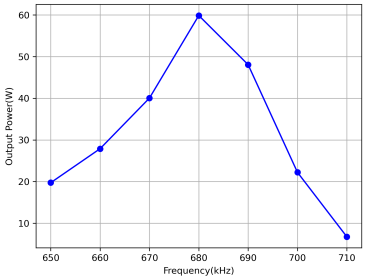

Fig. 5. Power vs transmission frequency graph

The graph depicted in Fig. 6 gives the relationship between duty cycle and the output power. The LC tank circuit has a high Q-factor, so the output power is dominated by the amplitude of the fundamental harmonic of the input PWM signal.

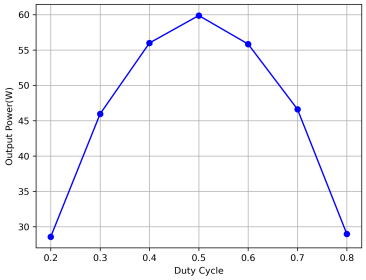

Fig. 6. Power vs duty cycle graph

IV. FPGA-based PWM

Figure 7 illustrates the block diagram of a typical Pulse Width Modulation (PWM) generation system implemented in digital hardware, such as an FPGA. The system begins with an Analog-to-Digital Converter (ADC) that receives both data and load inputs. The ADC digitizes the analog input signals, which are then fed into a comparator. The comparator also receives input from a digital counter, which increments at a fixed clock rate and produces an overflow signal.

The comparator continuously compares the digitized input from the ADC with the current value of the counter. When the counter value matches the ADC output, the comparator triggers the R/S (Reset/Set) latch. The latch generates the PWM output signal, where the pulse width is modulated according to the input data and load conditions. The overflow from the counter resets the cycle, ensuring periodic PWM signal generation. This closed-loop configuration allows dynamic adjustment of the PWM duty cycle in response to varying load conditions, providing precise and real-time power regulation in wireless power transfer or motor control applications.

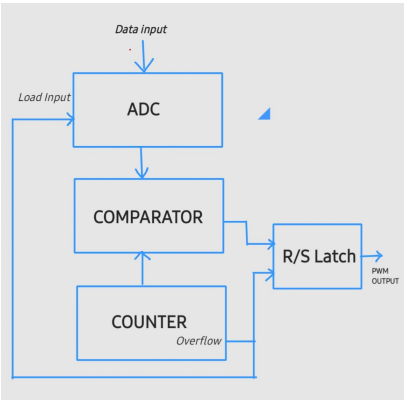

Fig. 7. Block diagram of FGPA-based PWM

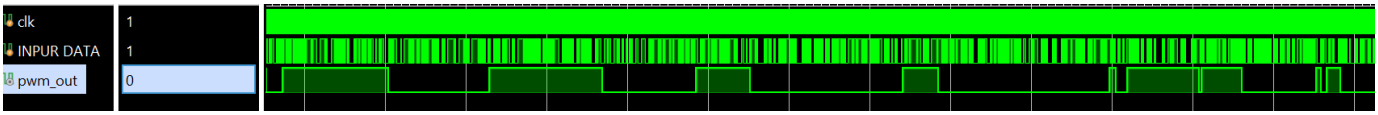

Fig. 8. Vivado simulation of FPGA-based PWM

V. Conclusion

In this work, we have designed, simulated, and implemented a wireless power transfer (WPT) system regulated by pulse width modulation (PWM), leveraging FPGA-based control for dynamic and efficient power delivery. Through the adoption of a series-series two-coil topology and the integration of resonance-based energy transfer, the system demonstrated optimal performance at a resonant frequency of 680 kHz, achieving a maximum output power of 59.87 W. The implementation of a digital PWM generator on FPGA enabled real-time adjustment of the duty cycle, ensuring stable power regulation under varying load conditions. Experimental and simulation results validated the effectiveness of this approach, highlighting the advantages of combining resonance techniques with digital control for robust, high-efficiency wireless energy delivery.

Future extensions of this work could focus on several promising directions. First, implementing adaptive resonance tracking and automatic impedance matching would enable the system to maintain peak efficiency in the presence of coil misalignment or changing environmental conditions. Second, exploring multi-coil or multi-receiver architectures could expand the applicability of WPT to more complex systems, such as simultaneous charging of multiple devices. Third, integrating advanced control algorithms—potentially leveraging machine learning—on the FPGA could further optimize power transfer efficiency and system responsiveness. Finally, miniaturization of the hardware and exploration of higher frequency operation may open new opportunities for biomedical implants, IoT devices, and other emerging applications requiring compact and reliable wireless power solutions.

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