Research Article

Designing and Modeling a Wireless Power Transfer System

Seyed Sajjad Mirakbari Jangali [a]
Company: SETAREH YAZD Wire & Cable
[a] Master of Electrical – Power, Yazd Branch of Azad University, Yazd, Iran.

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Abstract: Wireless power transfer systems have been rapidly increasing along with electronic devices while at the same time causing problems related to their power supplies. Using magnetic resonance coupling in wireless power transfer systems has been recognized as an appropriate technique for power supply of such devices. In this research, using this technique and applying the simulation results, attempts were made to meet a suitable balance between system efficiency and transfer distance through making a laboratory sample. Various factors can affect the efficiency of a wireless power transfer system, such as the changing of the output load, the shape of the transmitter and receiver coil, the wireless transfer distance, and changing of operating frequency. The results indicated that a relatively good efficiency can be achieved at a frequency close to the resonance system frequency and by matching the load impedance on the receiver side, while increasing the distance. Moreover, several samples of different types of transmitter and receiver coils were tested and the findings suggested that the shape of the coil was somewhat effective on the transfer distance.

Keywords: Impedance Matching, Magnetic Resonance Coupling, Maximum Efficiency Point Tracking and Converter, Wireless Power Transfer

1. Introduction

Systems using this technology are becoming more and more prevalent. Wireless power transfer is increasingly becoming common today. Wireless power transfer is the process in which electrical energy is transferred from one source to a load without electrical connection. Power transfer using wires has many drawbacks, such as cost of wiring, using of electrical connections for various equipment, risk of exhausting equipment (such as wires, cables and switches) as well as adverse impacts of environmental factors. These disadvantages can reduce the system reliability and thus cause power outages for subscribers. In recent decades, with the advancement of technology and the growing use of portable electronic devices such as mobile phones, as well as electric and hybrid vehicles, it is imperative for consumers to manually connect their mobile devices to electricity, which will cause such problems as the need for recurring charging, shortened life of devices, costs, and resulting heavy and bulky batteries of these devices. Due to the limitations from the batteries of these equipment as being expensive, heavy, bulky and shortened life, Wireless Power Transfer or WPT technology can be used as a solution to these problems that can eliminate the cables and the hazards caused by them. Today, the W.P.T system has been widely used due to the shortcomings of fossil fuels and environmental pollution they cause in electric and hybrid vehicles, as well as the use of electronic devices such as mobile phones, passive sensors, portable lights, radio frequency detection, etc. In this research, various wireless power transfer techniques, including induction and resonance techniques as well as double and quad winding systems, were examined using the maximum efficiency principle. A compromise can be met between proper efficiency and good transfer distance in double-winding systems for short intervals using the principle of maximum power transfer, and in quad-winding systems by maximizing the appropriate transfer distance [1].

Therefore, wireless power transfer technology can be used as a solution to these problems that can remove cables and their ensuing hazards, thus increasing reliability and even reducing the size of equipment. This technology allows the user to charge the device while using it or walking, regardless of the charger being connected by conventional wires. For example, in electric vehicles, the driver can charge his vehicle without stopping and connecting it by wire in pre-determined stations, and also without the need to carry heavy batteries. So scientists have started their research into wireless power transfer systems.

There are two main principles in a wireless power transfer system. Meanwhile, these two principles should be distinguished; one is the maximum power transfer and the other is energy efficiency. It should be noted that low impedance power source is discarded in the system's energy efficiency. In electronic research, the power of using a power source with the lowest impedance is a basic concept for designing all switching modes of the power supply. It should be mentioned however that a power supply is characterized by its high efficiency. In radio frequency research, using impedance matching is a common technique used in designing radio frequency circuits (wireless power transfer theory) to achieve high energy efficiency in medium-range power wireless transfer; hence, it is necessary to understand the advantages and disadvantages of these two power transfer systems. It is crucial for engineers to decide which policy makes it appropriate for them.

By maximizing system efficiency, it is meant maximizing energy efficiency in the power transfer process [2]. The relationship between energy efficiency and distance has been performed in a system by two resonating loops and analyzing cross-coupling between two resonant circuits [3] as shown in reference [4].

In reference [5] the phenomenon of frequency gap is observed in four-loop systems, with this phenomenon occurring in double-winding systems when there is an impedance match. In a near-coupling range, it is possible to meet constant power transfer, as the load-receiving power can be in a given range, which is a more important feature for medical applications as implants in the body. To avoid the complexity of the frequency gap, frequency tracking-based matching methods have developed. Moreover, reference [6] has illustrated that non-parallel resonance loops can be used to eliminate the effect of frequency gap to make the resonant frequency constant.

In reference [7] a study was done on quad-winding systems based on impedance matching (maximum power transfer theory), which were effective in developing transfer distance and energy efficiency costs. Recent research also discusses new methods such as doubled transmitters and receivers. This method has a new capability to energy to low-power sensors close to the resonator transmitter. Therefore, manufacturers are cautious of using this technology in applying high power and limited energy efficiency.

In reference [8] the concept of magnetic induction wave and wireless D-R systems were examined. D-R systems are very flexible, so that resonator loops can be set as dominoes into different shapes. Unlike magnetic induction wave conductors operating at high frequencies (usually in a range of several MHz), wireless D-R systems operate in the sub-MHz range under near-field magnetic coupling conditions and the maximum energy efficiency principle. This method was successfully tested in a 500 KHz range, which is the same as the low-power converter switching. Sub-MHz operations help keep switching dissipation and AC winding resistance low, thus, allowing new analyses to optimize the resonators distance, operating system frequency and the amount of load consumed in order to meet the maximum energy efficiency.

The Qi-compliant technologies market can be divided into four groups. According to reference [9] as of 2013, 368 products were found to have complied with the Qi standard. These products included mobile phones, charging pads and accessories such as wireless charging in various forms. With the adoption of the Qi standard, an opportunity has begun for businesses in integrated circuits sectors. Companies such as TOSHIBA and Texas Instruments (TI) developed and expanded chips for wireless power transmitters and receivers. TI introduced its first Qi standard wireless power controllers under the name bq500410A in 2012. In the same year, TOSHIBA introduced the TB6865FG (for transmitters) and TB6860WBG (for receivers) chips, designed to be used in wireless charging pads.

Due to the defects of power transfer systems, attempts were made in this research to examine the magnetic resonance coupling method through designing, simulating and constructing a laboratory sample and determining the parameters affecting the efficiency and distance, in an appropriate way in terms of efficiency and transfer distance in low power ranges.

2 Materials and Methods

2.1 Examining the wireless power transfer system

Generally, a wireless power transfer system consists of an electrical energy source, a magnetic coupling (coil or antenna) to transmit power, a power receiver, a rectifier to convert DC source voltage to AC, a voltage stabilizer, and a charge management system consisting of a DC-DC converter.

When the current passes L1, the induced voltage in the 2 L winding is obtained from the following relation:

$$V_{OC} = \omega M I_i \tag{1}$$

When a short circuit occurs in the right side, the passing current is:

$$I_{SC} = \frac{V_{OC}}{\omega L_1} = L_i \frac{M}{L_t} \tag{2}$$

When a circuit is matched with a capacitor at operating frequency, the available power according to Equation 3-6 is equal to:

$$P = I_{SC}.V_{OC} \tag{3}$$

Considering the circuit resonance matching (Q) we have:

$$\rightarrow P = \omega \frac{M^2}{L_t} I_i^2 Q = \omega L_t I_i I_i \frac{M^2}{L_t L_r} = V_1 I_i K^2 Q \tag{4}$$

$$Q = \frac{\omega L}{R_L} \tag{5}$$

The amount of output power depends on the voltage and the initial current. Given that if air rather than an iron core is used for the primary and secondary windings, only a small part of the field produced by the primary winding passes through the secondary winding and the source needs to pass more current through the primary winding to produce the same amount of power, increasing the dissipation in the circuit. Adding capacitance to the primary circuit helps create a resonance; in this state, energy is traded between the magnetic field around the coil and the electric field inside the capacitor, leading large currents to be received without internal dissipation of the source. Adding capacitance to the secondary circuit such that it resonates at the appropriate frequency further increases the power transfer efficiency.

2.2 Modeling the system

In this section, a technique was suggested to model the behavior of the W.P.T system and some theoretical conditions were provided to calculate the maximum efficiency and transfer power.

In this method, only the basic components of the input voltage and the replacement of an active rectifier with a DC-DC converter were taken into account. The sine voltage V_{in} was equivalent to the effective value of the input voltage that drives the primary side of the resonance circuit.

R_p and R_s series resistances represent the total noise resistances of the primary and secondary sections of the resonant circuit. C_p and C_s series capacitors are required to equalize the primary side of resonance frequency.

The reciprocal inductance M depends on the coupling coefficient K-M $\sqrt{L_p L_s}$, which itself is affected by the geometric shape, distance and Lp and Ls. Therefore, the primary and secondary side impedance of the open circuit can be calculated according to Equations 6 and 7:

$$Z_P = R_P + jX_P = R_P + j\left(\omega L_P - \frac{1}{\omega C_P}\right) \tag{6}$$

$$Z_S = R_S + jX_S = R_S + j\left(\omega L_S - \frac{1}{\omega C_S}\right) \tag{7}$$

The load circuit impedance equivalent to the WPT system can be expressed as the model $Z_L = R_L + jX_L$, representing the total impedance seen from the secondary side of the resonant circuit; it includes the rectifier parts, DC-DC converter and battery at the system output. The impedances Z_{in} and Z_{out} are the equivalent impedances seen from the source and output side.

$$Z_{in} = Z_P + \frac{X_m^2}{Z_S + Z_L} \tag{8}$$

$$Z_O = Z_S + \frac{X_m^2}{Z_P} \tag{9}$$

2.3 Energy efficiency and extraction

The input and output power are a function of the resistance and reactive load, so according to Equations 3-24 and 3-25 we have:

$$P_{in}(R_L, X_L) = \frac{V_{in}^2 [R_P + \mathrm{Re}\{Z_r\}]}{[R_P + \mathrm{Re}\{Z_r\}a]^2 + [X_P + \mathrm{Im}\{Z_r\}]^2} \tag{10}$$

$$P_{in}(R_L, X_L) = \frac{V_{in}^2 X_m^2 R_L}{den} \tag{11}$$

Z_r is the cross-sectional impedance of the primary side, which can be represented as follows:

$$Z_r = \frac{X_m^2}{Z_S + Z_L} \tag{12}$$

As we all know, the maximum efficiency occurs when $Z_{in} = Z_L$. Therefore, the system efficiency as a function of load impedance can be expressed as Equation 3-27:

$$\eta(R_L + X_L) = \frac{X_m^2 R_L}{R_P\left[(R_S + R_L)^2 + (X_S + X_L)^2\right] + X_m(R_S + R_L)} \tag{13}$$

The maximum efficiency can be calculated by ignoring the reactive part of the load impedance through deriving and equating equation 3-27 to zero from equation 3-28:

$$R_{L,opt} = \sqrt{R_S^2 + \frac{R_S}{R_P} X_m^2} \tag{14}$$

2.4 Designing and constructing the circuit

In this section, attempts were made to design and model the W.P.T system circuit using the M.E.P.T technique described in the previous section. The block diagram of the intended system is shown in Fig. 1. First, the system circuit was simulated using MATLAB software and then designed and made using Porote software. In this design, an attempt was made to meet an energy transfer with appropriate distance and efficiency.

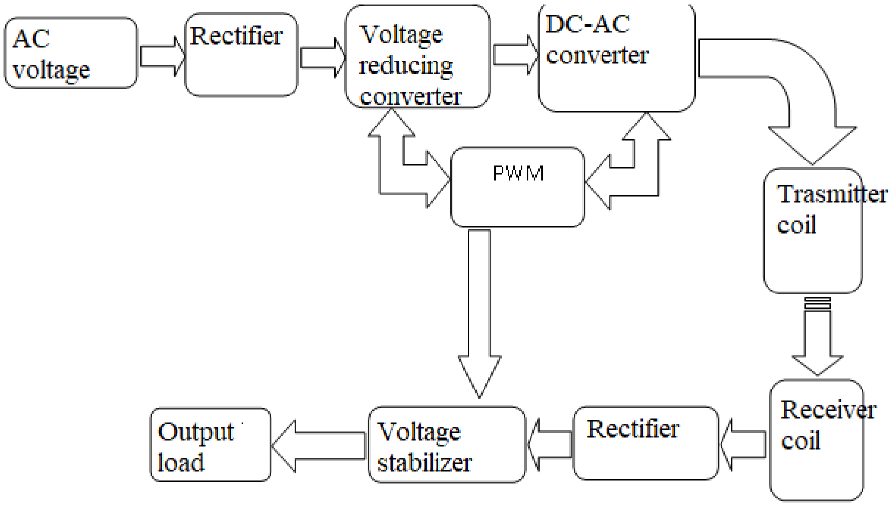


Fig. 1 Block diagram of W.P.T system circuit.

As shown in the block diagram above, 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.

2.5 Simulating the circuit

First, the block diagram in Fig. 2 is simulated using the MATLAB software simulation as follows.

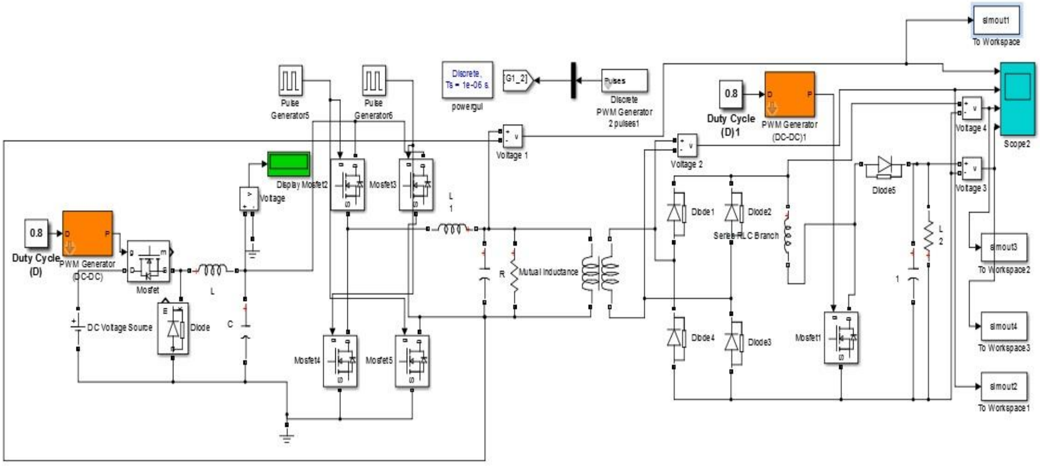
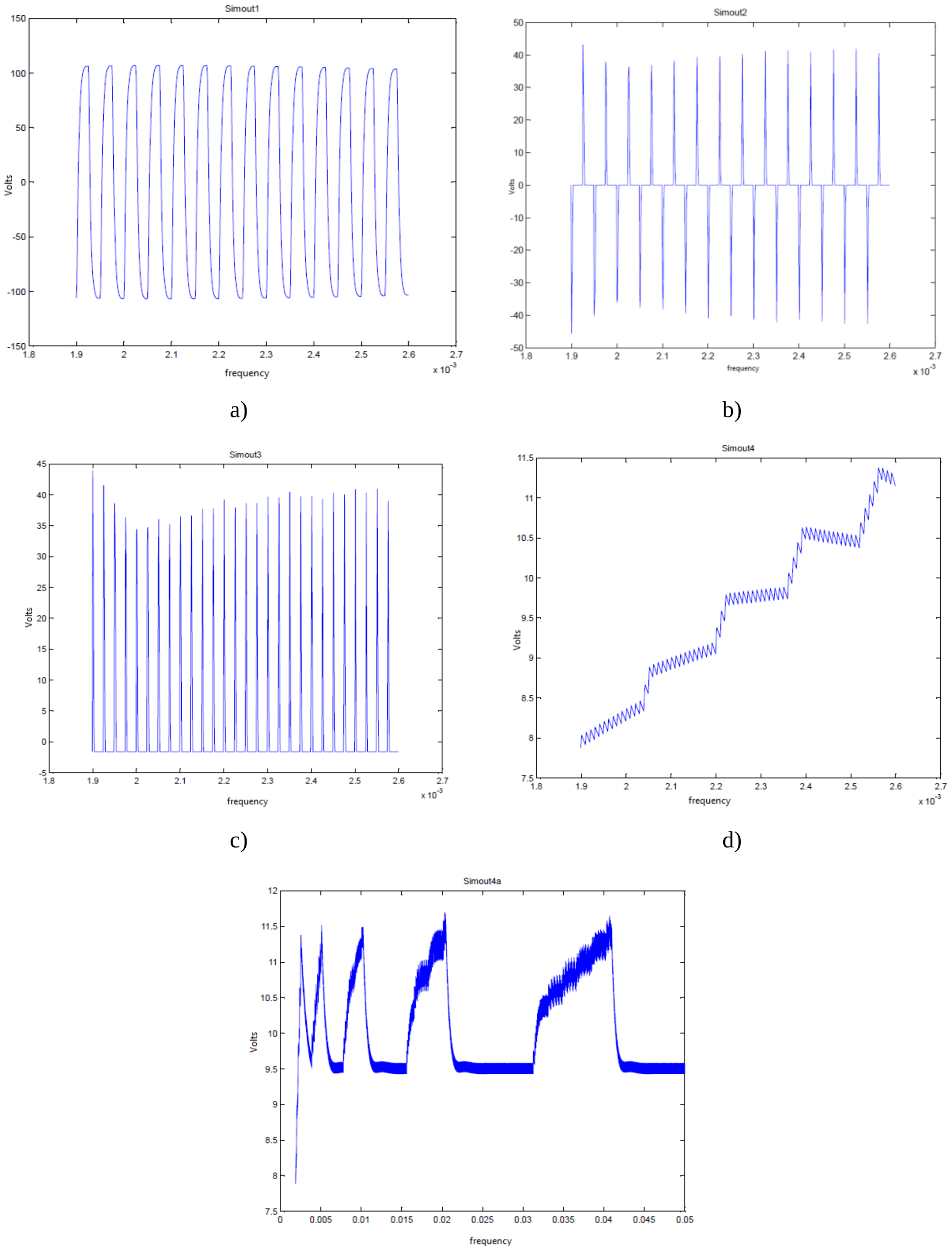


Fig. 2 Circuit simulated in the MATLAB software.

As seen, various parts of the circuit include a DC power supply whose voltage gets reduced after entering a reducing converter with the output of the reducing converter being delivered to a Full Bridge inverter to convert the DC voltage to AC at the intended frequency. The reason why a reducing converter is used is to control the output voltage using a feedback. By changing the working period of the PWM wave generating source, the input voltage can be increased and decreased to the intended and given level. The output of the full bridge circuit is delivered to a resonant tank to get the maximum power to the load at the resonant frequency of the circuit. The output voltage is then delivered to the transmitter coil at a frequency between 17 and 30 kHz. The variable voltage in the transmitter coil causes a voltage in the receiver coil according to the Faraday's law of induction. To simulate the transmitter and receiver coils, the transformer or mutual-inductance model can be used as there is no model for wireless power transfer in the software. And since the distance effect must be simulated in one way or another, the mutual inductance model is used. The coils parameters, including the inductance of the coils and the mutual-inductance coefficient, are entered in form of 2*2 matrix, with the coil resistance as1 × 2 matrix.

The amount of induced voltage depends on various parameters, including the coupling coefficient, stated earlier. The induced voltage is converted to DC voltage in the receiver coil using a diode bridge and delivered to a boost converter to adjust the output voltage. The reason why a boost converter is used is to compensate for the voltage drop from an increase in distance. This converter is also controlled in the same way as the input reducer converter using PWM pulse source. The increase in the voltage level can be reduced by increasing the operating period. After adjustment is made, the voltage is delivered to the output load. After performing the simulation and running the program, if the program has no software problems, the output waveform can be observed using the simulator oscilloscope. To better understand, voltage waveforms are seen in different parts of the circuit as shown in Figs. 3-5.

One would see that the voltage of 150. V of the input DC power supply is reduced to 127. V DC after the reducing converter, according to the working period of 0.8. The range of Full Bridge output voltage in the first 1.5 milliseconds of operation is low due to the inductor's resistance against sudden voltage shocks, with the voltage on both sides of the inductor gradually increasing and finally reaching a constant value (Fig. 3d). These changes in the input are also observed in the output. However, the output is not sensitive to the rising trend of the input voltage, only taking a needle-shaped wave when the voltage rises to its maximum. The reason for this phenomenon is the low coupling coefficient between the transmitter and receiver coils. As seen, the output voltage is transmitted to the output load with an output ripple of approximately two volts.



a) b)

c) d)

e)

Fig. 3. a) Full Bridge output waveform b) Receiver loop output waveform c) Rectifier output waveform d) Full Bridge output voltage at start-up e) Load voltage waveform.

Fig. 3c illustrates the output voltage waveform of the diode bridge. As seen, the output voltage has been rectified with the negative part of the voltage converted to positive but not to a complete DC voltage. This voltage is then delivered to a boost converter; the output voltage waveform of this boost converter is converted to approximately a DC voltage and delivered to two ends of a load. The output voltage waveform reaches its final value in approximately 2.5 milliseconds at the moment the output voltage starts operating (Fig. 3e).

2.6 Design and generation

2.6.1 Circuit input

To obtain and control the circuit resonance, it is necessary to first convert the voltage of 220v into a direct voltage. The AC voltage is connected to a diode bridge by a 24 volt relay through a 100 ohm resistor. The reason is that at the moment of operation, the current passes through the divided capacitors of the output, which is called inrush current. The presence of this current causes heat and reduces the life of capacitors.

The output voltage is converted to DC using a diode bridge and then converted to half the low-ripple input voltage by means of resistive dividers and capacitors. This is because switching between a dc voltage and half of itself is used to making an AC voltage with a specific frequency to get the resonate into the circuit.

After the voltage is converted to DC voltage by means of the diode bridge, it is delivered to two IGBTs called half bridge, in a way that when the upper transistor is switched on, the output voltage is V_{cc}, and when the lower transistor is on, the output voltage is $V_{cc}/2$. Therefore, the output voltage always oscillates between two values of v_{cc} and $V_{cc}/2$.

The half-bridge circuit is used because it is both easier to control and relevant dissipation are much fewer than a full-bridge circuit, so this structure is preferred. When each IGBT is connected, a transient voltage is generated gradually reaching a maximum constant value; on the other hand, when each of them is cut, the inductive current in the resonance capacitor is discharged.

After the circuit stops operating, this circuit is used to get the voltage stored in the capacitors discharged. A snubber circuit is used to protect transient voltages in electrical systems. Types of snubber systems include the following:

1- RC snubber circuits
2- Snubber diode circuits and
3- RCD snubber.

Snubber circuits are commonly seen in electrical systems with inductive loads suddenly interrupted by the current. According to Faraday's law, this current cut in switching equipment causes high voltages. The snubber circuit creates a short-term alternating current in the circuit, thus discharging the inductive elements of the circuit safely and quickly. The snubber circuit can also be applied to avoid sparks in the relays.

Where power dissipation is not high, there is a rapid design for the RC snubber circuit; a snubber circuit capacitor equivalent to twice the sum of the switch output capacitor and the capacitor is experimentally selected. Also, the resistance value of the snubber circuit can be calculated by Equation 15.

$$R_{snub} = \frac{V_{o1}}{I_1} \tag{15}$$

$$P_{diss} = C_{snub} \times V_{o1}^2 \times f_s \tag{16}$$

When designing this simple circuit, the voltage peak will not be sufficiently limited. Accordingly, it must be modified to be usable. On the other hand, if power dissipation also matters, an optimal design should be used.

2.6.2 The way transistors are connected to HCPL316j I_{CE}

As stated, it is not possible to establish a direct connection between the TL494 IC and transistor gate, because the output pulse voltage of the I_{CE} is much lower than the direct operation voltage (direct bias) of the transistor. Hence, a connecting IC that has the necessary power to operate a transistor is used which is called HCPL316j. The DESAT base of a diode with a resistor is used. The reason for this design method is to protect the transistors as much as possible. The V_{CE} voltage is proportional to (I_{CE}), so when the I_{CE} current exceeds a value, the voltage at the diode cathode increases causing the diode to turn off. When this operation begins, in order that IGBTs do not sustain a damage, HCPL316j commands the microcontroller to turn off the control pulse, followed by a cessation of pulse production of HCPL316j. Later, upon the connection shown in the figure, another HCPL316j IC stops its pulse generation.

The power supply of transistors is one of the most critical parts of circuit design. In circuit design, transistors are faced with the problem of continuous burning, such that the circuit starts operating when the pulse is activated where one of the transistors or both of them gets burned after a few cycles. What we have seen is that one of the transistors turns on without a pulse being delivered by the HCPL316j to activate it. The reason why transistors are damaged is due to their inherent structure. The way semiconductor layers are connected in the transistors creates internal capacitors between transistor terminals. Capacitors between gate-drain (C_{GD}) and gate-source C_{GS} are charged and discharged each time the transistors are turned on and off. When the upper transistor is turned on by its drive command, the internal capacitor C_{GD} of the lower transistor starts charging and after being fully charged, it will have a capacity up to 10 times greater than the capacitor C_{GS}. Therefore, the voltage of this capacitor easily activates the low transistor gate and turns it on. When two transistors turn on at the same time, a large current pass through the two as the circuit is short, causing damage to the transistors. This process is called the Miller Effect. To eliminate this problem, we had to review the circuit design; hence, rather than supplying the HCPL316j driver with a voltage of +15 and 0, we make a voltage of 15+ and 5 volts as seen in Figs. 3-5. The advantage of this technique is that when the C_{GD} capacitor is charged, the negative voltage is -5 volts on the transistor gate, the voltage of the capacitor C_{GD} is discharged through the IC base, with the lower transistor remaining off and not damaged, instead of being discharged from the gate source of the lower transistor and turning it on. When choosing a transistor driver IC, the control base must have this voltage tolerance.

2.6.3 Proposed circuit

The proposed circuit of a gate drive with HCPL316j is seen in Fig. 4. Four bypass capacitors provide the current required during switching. A low current source (5mA) is sufficient to delivr transient currents of normal charge. Pf100 diodes and capacitors are necessary components for detecting external circuit errors. The gate resistor Ω10 performs a limited charge current and controls the indirect increase of the collector voltage of IGBTs at error times. The collector open circuit fault output has a passive pull-up resistor Ωk 3.3 and a pf330 filtering capacitor. A Ωk 47 pulldown resistor on the V_{OUT} base provides a predictable high output voltage (V_{OH}). In this method, the IGBT gate drive is turned off when the error is detected and switching does not start until the microcontroller delivers a reset signal.

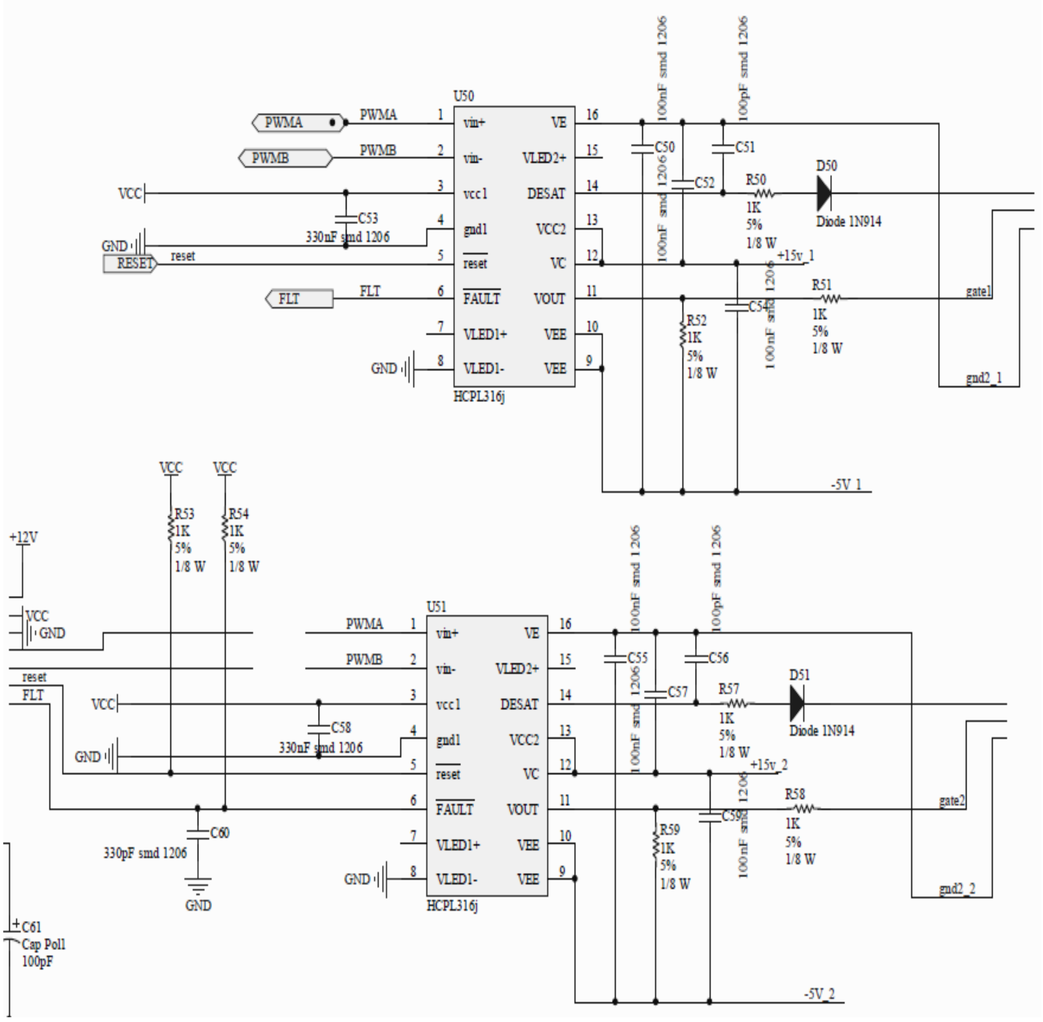


Fig. 4 Proposed circuit for hcpl316j

3 Results and Discussion

In this project, attempts were made to design a wireless charging system using resonant power transfer and an LC resonance tank. The overall circuit made is in accordance with Fig. 5, which includes the power supply of the frequency control circuit and the transmitter and receiver coupling. As stated in the previous section, the city power voltage is first converted to DC voltage using a diode bridge and is then converted into an AC voltage through a DC-AC converter and applying the switching mechanism via PWM signal. On the other hand, the AC voltage is amplified by a boost transformer and delivered to an LC circuit in order to reduce dissipation and increase the transfer distance. Then, by adjusting the pulse width of the PWM wave and changing the frequency of the DC-AC converter's output voltage, the circuit is resonated to deliver the maximum amount of power to the transmitter. Then, using the magnetic field produced and using a receiver coil, the transmitter voltage is received at a certain distance.

The results from this simulation were represented using different couplings of circular, square and hexagonal shapes with the same inductance at experimental distances of 5, 10, 15 cm as shown in Table 1. The results from this simulation indicated that at a fixed distance, the coupling of a circular coupling will have a higher transfer voltage value than the other two forms at the resonant frequency and the power transferred in this case is also at the highest as shown in Fig 5. As seen, at all distances, the output voltage at the resonant frequency reaches its maximum value.

In Fig. 6, different types of coils are made using flexible wire with a cross-sectional area of 2.5 mm. As stated earlier, using a multi-core wire reduces the skin effect and this in turn reduces dissipation in the system. The inductance of the windings is the same and is seen to be about 30 microns.

(a) (b) (c)

Fig. 5 Different types of coils a: octagonal b: square c: circular.

Table 1. Output voltage results.

	Frequency (kHz)																		
Core shape	Output voltage results from changing the frequency with different shapes at a distance of five centimeters																		
	17.17	17.77	18.44	18.84	19.2	20.2	21.4	22.5	23.1	24.2	24.6	25.2	26.7	27.3	28.9	29.2	30	32.9	
Circle(v)	1.02	1.09	1.23	1.26	1.87	2.01	2.63	3.23	6.14	7.27	11.87	15.13	23.12	15.67	5.74	4.63	3.27	2.74	Voltage (volt)
Squre	0.67	0.68	1.11	1.44	1.51	2.82	2.9	3.12	6.22	6.41	8.74	10.26	12.01	10.67	3.32	3.03	2.92	2.015	
PolyGon	0.73	0.76	1.13	1.29	1.77	3.16	3.5	5.61	6.93	6.62	9.06	11.19	12.84	11.37	4.07	3.48	3.12	2.66	
Core shape	Output voltage results from changing the frequency with different shapes at a distance of ten centimeters																		
	17.17	17.77	18.44	18.84	19.2	20.2	21.4	22.5	23.1	24.2	24.6	25.2	26.7	27.3	28.9	29.2	30	32.9	
Circle	1.036	1.04	1.101	1.174	1.216	1.314	1.485	1.612	1.82	2.31	3.1	5.27	12.21	5.81	2.2	1.7	1.6	1.112	Voltage (volt)
Squre	0.61	0.67	0.95	0.97	1.01	1.11	1.31	1.512	1.75	2.18	2.98	4.26	7.113	4.97	1.97	1.56	1.46	1.015	
PolyGon	0.55	0.59	0.93	1.16	1.65	1.93	2.12	2.45	2.76	2.9	3.41	5.37	7.853	5.89	2.65	2.15	1.86	1.77	
Core shape	Output voltage results from changing the frequency with different shapes at a distance of fifteen centimeters																		
	17.17	17.77	18.44	18.84	19.2	20.2	21.4	22.5	23.1	24.2	24.6	25.2	26.7	27.3	28.9	29.2	30	32.9	
Circle	0.06	0.19	0.69	0.75	0.92	1.03	1.39	1.67	1.72	1.89	2.37	3.21	5.812	3.27	1.78	1.23	0.84	0.08	Voltage (volt)
Squre	0.01	0.12	0.54	0.66	0.73	0.91	1.19	1.41	1.57	1.61	1.79	2.89	2.883	2.74	1.53	0.98	0.68	0.01	
PolyGon	0.06	0.18	0.6	0.71	0.84	0.96	1.24	1.59	1.66	1.76	2.22	3.11	3.769	3.17	1.67	1.03	0.76	0.03	
	Output from changing distance for square core													Voltage					
Squre	17.17	17.77	18.44	18.84	19.2	20.2	21.4	22.5	23.1	24.2	24.6	25.2	26.7	27.3	28.9	29.2	30	32.9	
5cm	0.67	0.68	1.11	1.44	1.51	2.82	2.9	3.12	6.22	6.41	8.74	10.26	12.01	10.67	3.32	3.03	2.92	2.015	

10cm	0.61	0.67	0.95	0.97	1.01	1.11	1.31	1.512	1.75	2.18	2.98	4.26	7.113	4.97	1.97	1.56	1.46	1.015
15cm	0.01	0.12	0.54	0.66	0.73	0.91	1.19	1.41	1.57	1.61	1.79	2.89	2.883	2.74	1.53	0.98	0.68	0.01
	Output from changing distance for octagonal core													Voltag				
PolyGon	17.17	17.77	18.44	18.84	19.2	20.2	21.4	22.5	23.1	24.2	24.6	25.2	26.7	27.3	28.9	29.2	30	32.9
5cm	0.73	0.76	1.13	1.29	1.77	3.16	3.5	5.61	6.93	6.62	9.06	11.19	12.84	11.37	4.07	3.48	3.12	2.66
10cm	0.55	0.59	0.93	1.16	1.65	1.93	2.12	2.45	2.76	2.9	3.41	5.37	7.853	5.89	2.65	2.15	1.86	1.77
15cm	0.06	0.18	0.6	0.71	0.84	0.96	1.24	1.59	1.66	1.76	2.22	3.11	3.769	3.17	1.67	1.03	0.76	0.03

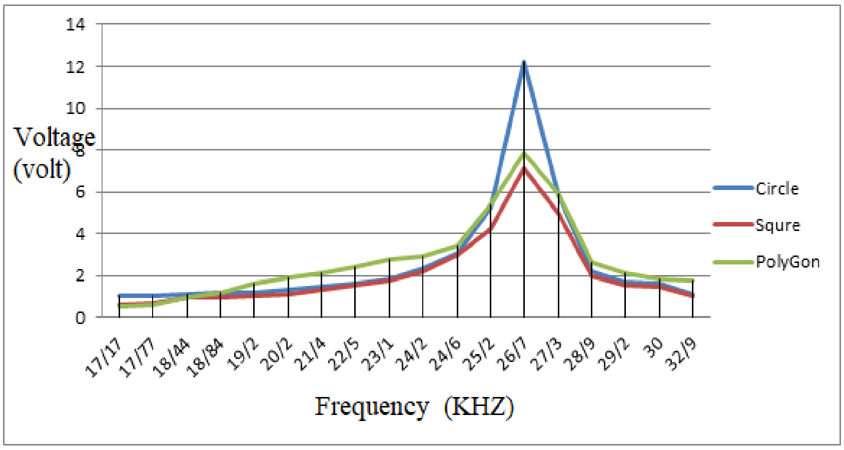


Fig. 6 Comparison of output voltage with frequency changes with different windings.

4 Conclusion

Wireless power transfer system can be used as an appropriate way to power mobile devices such as mobile phones and electric vehicles. Wireless power transfer is performed using various methods, including resonant power transfer. Resonant power transfer method can be seen as a suitable method for wireless power transfer system because other methods have some drawbacks such as efficiency and transfer distance. In this method, the transmitter and receiver frequency is the same, causing the highest amount of power to be delivered to the receiver. By using external or internal inductors and capacitors and their different placement conditions, the circuit can be used in resonance mode.

Power transfer in this method depends on various parameters, including the coupling coefficient between the transmitter and the receiver coils. The coupling coefficient sharply decrease by distance, as an appropriate solution can be made to increase efficiency by designing different types of transmitter and receiver coils with high Q coefficient and using safe switching sources and changing the frequency. Studies have demonstrated that at a resonant frequency with a circular coil, a relatively good distance can be achieved with good efficiency at the resonant frequency.

Another key issue in a wireless power transfer system is the stabilization of the output voltage, which is affected by the output load. This effect can be reduced by using boost and buck converters and sampling the circuit output and controlling it while applying appropriate changes to the circuit input. Because the operating frequency of the system is in the range of kHz and megahertz, using switching techniques can help reduce dissipation and increase system efficiency. Using the Maximum Efficiency Point Tracking (M.E.P.T) method to maximize system efficiency under different output load conditions via applying continuous changes to the circuit input and output is another method.

Frequency classification using impedance matching can deliver maximum power to the load. Using frequency classification can be used when maximum power transfer at the resonant frequency is not possible. Using quad-wiring and domino resonator systems, it is considered as a mechanism to increase the transfer distance. The placement of the coils in these systems causes the power to be transmitted in a directional manner. The use of these systems on the other hand increases the dissipation, which limits their use.

According to the obtained results, the following ideas can be considered for further work in this field:

1- The shape of the transmitter and receiver coils has some effect on the system efficiency, so it is possible to manufacture a type of coil having a higher coupling coefficient at a longer distance with lower dissipation rates via examining different types of coils, including coils with inflexible, flexible wires, in form of tubes coated with semiconductor layers, shaped coils and with high-conductivity coils.

2- As new controllers such as FPGA have emerged, these processors were used to control the circuit.

3- It is worth noting that this project can be used in industrial applications, i.e., in the system of electric vehicles charging.

4- Using interface circuits to increase the distance is not recommended due to the high dissipation of such circuits.

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