A Simple Design of a Mini Tesla Coil With DC Voltage Input

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Abstract— This paper explicates the simple design of the miniature Tesla coil that have advantages compared to the typical Tesla Coil, which normally has mobility issues due to their bulky size. The proposed design has a similar functionality with the typical Tesla coil where it is able to produce medium voltage with high frequency current at the secondary circuit side. The significant part of the proposed design is that it is without alternating current voltage at the input voltage. The design only needs a low direct current voltage as an input for the primary circuit. According to the Pspice simulation, it proved that the proposed design has the capability to step up the energy and voltage at the secondary winding at least fifty times greater compared to the input voltage. The miniature Tesla coil that has been proposed in this paper is recommended to be use for advance studies particularly on wireless energy evolution.

Keywords-Miniature Tesla coil; DC voltage; medium voltage; wireless energy; high frequency current

I. Introduction

Generally, the typical Tesla Coil usually made in large-scale size and employing a medium voltage or high voltage as an input supply. The bulky size of Tesla Coil gives some barrier and difficulties for the transportation or mobility. Hence, this research is due to improve on this matter.

Basically, the objectives of this project are to develop a Tesla Coil that is small and light compared to the typical Tesla Coil. Besides that, this project tries to generate high frequency current with medium voltage, approximately 2,500V at the secondary side using a supply 24V direct current, DC as an input to the primary circuit.

In order to achieve the project's objectives, the computer simulation works is needed as a preliminary effort in order to verify the operational system design and to identify the circuit's component for the hardware development. In addition, the contribution of high voltage capacitor, primary and secondary coil, spark gap and low dc voltage input also is required to generate a high oscillating voltage at the output of secondary circuit.

II. Tesla Coil

Nikola Tesla is a person that invented the Tesla Coil, a type of resonant air core transformer, which is used to generate high voltage and high frequency electrical currents [1]. Today, many devices were developed using the concept of Tesla coil even though it is an old invention. Tesla Coil has been used to conduct innovative experiments in x-rays, electrical lighting, wireless energy transfer for electrical power transmission, industries and also for educational purposes [2, 3, 4].

TABLE I. Tesla coil Parts

Parts	Description
Toroid	• Known as top loads form the capacitor for the secondary circuit. Any lump of metal will form a capacitance. • It form a resonant circuit at the same frequency as the primary circuit.
Primary coil	• Inductive part of the primary circuit and form a resonant circuit • Usually constructed from copper tubing or heavy gauge wire. Generally, easier to vary the inductance than the primary capacitance.
Secondary coil	• Voltage multiplication is achieved. • It is a single air cored inductor wound with thousand of turns of insulated wire. • The wire size and turns dictated by the required size of the secondary. • The secondary is wound onto an insulating former, usually PVC, but many other formers are used including cardboard, glass & polypropylene.
Spark gap	• High powers switch and it is a brain to Tesla Coil. • Initiating the discharge of the tank capacitor into the primary winding. • It turns-on when sufficient voltage exists across the spark gap. The air in the gap ionizes and begins to conduct electricity like a closed switch.
Capacitor	• Tesla Coil capacitance (C_{tc}) is difficult to estimate with any accuracy. • The capacitance value used to determine the resonant frequency.

A Tesla Coil is an air-cored resonant transformer. It is similar to a standard transformer but the mode of operation is different. A standard transformer uses firm coupling between its primary and secondary windings and the voltage

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transformation ratio is dependable to the turn's ratio itself. In contrast, a Tesla Coil uses a relatively loose coupling between primary and secondary. The voltage in Tesla coil is gain due to the resonance rather than the turn's ratio. A normal transformer uses an iron core in order to operate at low frequencies, whereas the Tesla Coil uses air-cored to operate efficiently at higher frequencies [5, 6].

Tesla coil designs employed AC power source, high voltage capacitor, inductive coil and a spark gap to excite the primary side of the Tesla coil system with periodic bursts of high frequency current. The primary and secondary coil is designed precisely in order to resonate at the same frequency. Tesla coil consists of five important parts in its construction. Table I show the description for toroid, spark gap, capacitor tank and coils in Tesla coil [5, 6].

The miniature Tesla coil designed in this project has all parts as shown in Table I. However, the spark gap that's employed in the designed is using uncommon spark gap neither rotary gap nor sphere gap. It is employing the contactor of the relay as a spark gap because the ordinary spark gap is not able to work with 24V DC input voltage. However, the DC voltage applied is not enough to fires the gap between contactor of the relay because theoretically, one millimeter needs 3,000V DC. In addition, the relay's contactors have a gap approximately one millimeter, which clearly indicates that the input voltage applied will not be able to cross over the contactor gap.

Due to that, the relay has to be use with different approach. The contactors in the relay can be a good spark gap when it is forced to be open and closed with very fast time. By energizing and reenergizing the relay coil, the contactor can be made to open and closed faster. During the intermittent time which is opening and closing of relay's contact, the supply voltage 24V DC will charge and discharge the tank capacitor. As a result, the tank capacitor transfers the energy and electrifies the primary winding. Section III gives the details explanation about the energy transfer in the Tesla coil system.

III. Basic Operation of Tesla Coil

Generally, there are two most common Tesla Coil circuit available. Figure 1 and Figure 2 are the typical and alternative circuit of Tesla coil respectively. In both circuit, it can be seen that, the circuit consisted of spark gap, capacitor tank, primary winding and secondary winding. The difference is, in typical circuit the spark gap is in parallel with the high voltage transformer meanwhile in alternative circuit the capacitor tank is in parallel with the HV transformer.

The typical circuit as shown in Figure 1 is able to prevent the transformer supply from high frequency oscillations because it has a spark gap with short circuiting action. Meanwhile, the transformer in Figure 2 is exposing to the high amplitude and high frequency oscillations emerge across the capacitor. This arrangement can induce the corona discharges between turns, finally weaken, and eventually destroy transformer's insulation [5].

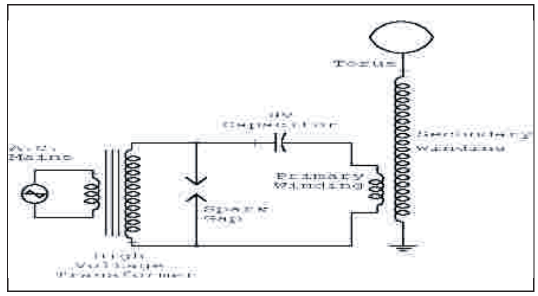

Figure 1. Typical Tesla coil circuit [9]

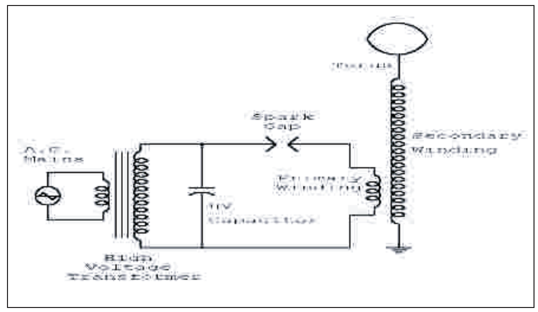

Figure 2. Alternative Tesla coil circuit [9]

By refering to the Figure 3, the spark gap is acting as an open switch. The current from the power supply entered the ballast inductor to charge the primary tank capacitor. If the voltage in the capacitor is extremely high, the air resistance between the spark gap drops quickly and now the spark gap becomes a good conductor. Hence, it creates a resonant circuit where the energy in the capacitor tank discharges in the form of high frequency oscillation into the primary winding [7].

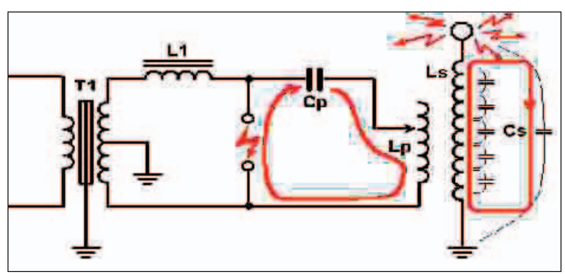

Figure 3. The working of Tesla coil circuit [8]

During the oscillation, energy is stored alternately between the capacitor and inductor. In addition, the oscillating current at the primary winding gives a similar oscillating current induced at the secondary winding. In just microseconds, numerous numbers of energy transfer occurred. As shown on Figure 3, the energy from the primary resonant circuit is transferred gradually to the secondary resonant circuit. Finally, if the secondary voltage becomes high enough, the sparks will occur and at this time, the toroid will not be able to withstand the high voltage in the secondary circuit and concurrently allowing the breakdown to happen.

Basically, the voltage grows in the Tesla Coil is coming from the process of the energy in the primary tank capacitor is transferred to the toroid of the secondary circuit. Equation 1 shows the energy stored in the primary capacitor and it is measured in Joules [8]. In addition, equation 2 is a formula in order to calculate the resonant frequencies of the primary circuit and the secondary circuit of Tesla Coil.

$$E_p \qquad (1)$$

$$f_p = \frac{1}{2}\pi\sqrt{L_p C_p} = f_s = \frac{1}{2}\pi \qquad (2)$$

In real application, the voltage at the top of the secondary is not supposed to be higher from the theoretical calculation because of several factors. First, some energy is lost due to resistance of the windings of both coils. Second, some energy is lost as light, heat, and sound in the primary spark gap. Third, the primary and secondary coils act like antennas and radiate a small amount of energy in the form of radio waves.

IV. HARDWARE DEVELOPMENTS

As mentioned before, the miniature Tesla coil proposed in this project has some modification in the circuit of typical Tesla coil. One of the modifications is the employment of relay's contactor as a spark gap. The relay's contactor that acts as a switch is utilized to initiate the tank capacitor to discharge the energy stored from input source. Then, transfer the energy to the primary winding of the Tesla Coil with the periodic time. The energy is transferred during the gap between the relay's contactor fires. The ratio between the primary and secondary coil is 1:100 and it is used to step up the 24V DC input voltage to approximately 2,500Volt in the oscillating form at the secondary side.

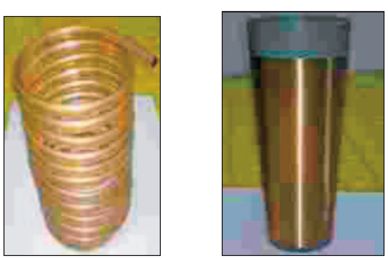

Figure 4. Primary coil and secondary coil

Figure 4 shows the primary coil and secondary coil that is constructed manually in this project. The ¾-inch copper rod tubing is used to build the primary coil. The diameter of the primary winding is 130 millimeters with the number of turns is ten. For the secondary coil, 35 SWG 0.224 mm enameled wire copper is used. The diameter for secondary coil is 50 mm and the number of turns is 1000 turns. Figure 5 shows the miniature Tesla coil that has been developed in the laboratory.

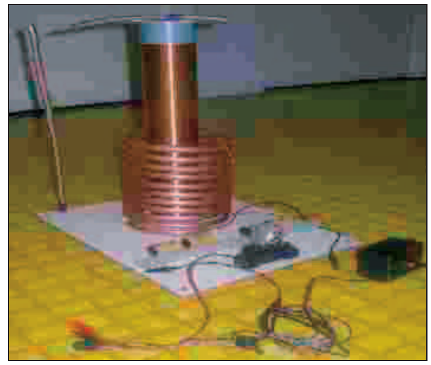

Figure 5. Miniature Tesla coil development

V. MINIATURE TESLA COIL SIMULATION WORKS

In this project, Pspice software is used for the simulation work. The computer simulation works was carried out in order to investigate the operation of the proposed circuit. In addition, the simulation result is required to verify the capability of the proposed circuit before proceeding to the components procurement and hardware developments.

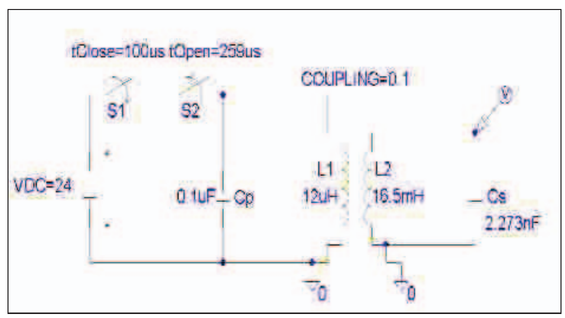

Figure 6. Simulation circuit using Pspice

Figure 6 shows the simulation circuit using Pspice software. The circuit is slightly difference with the normal Tesla coil circuit as shown previously in Figure 1 and Figure 2. Commonly, the input for typical Tesla coil is AC voltage. However, the input for the miniature Tesla coil is DC nput voltage. Due to that, the typical circuit need to be modified to obtain a circuit that can operates. As a result, it has two switches which act as spark gaps. In addition, the two switches is located in series with DC input voltage whereby in typical circuit, the spark gap is parallelly jointed with the power supply or connected in series with the primary winding.

In the simulation circuit as shown in Figure 6, there is one unit normally open switch, S1 and one unit normally closed switch, S2. Both switches are connected in series with the supply voltage and the primary tank capacitor. Switch S1 is at closed position at 100 microseconds, meanwhile switch S2 is opened at 259 microseconds. It must be noted that the supply voltage is 24V DC with the value of primary capacitor Cp is 0.1µF and secondary capacitor Cs is 2.273nF. Besides that, the inductor L1 and L2 in the schematic diagram are representing a primary coil and secondary coil.

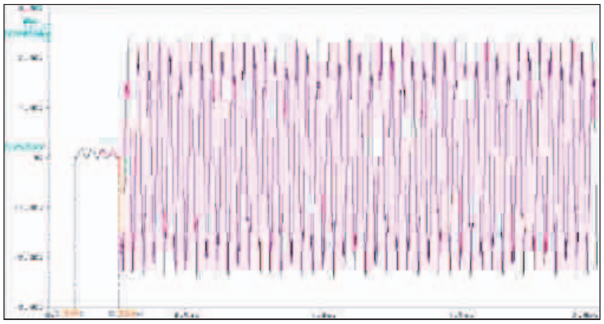

Figure 7. Voltage measured at the secondary coil of miniature Tesla coil

By referring to Figure 7, the waveform indicates the voltage generated at the secondary circuit of the simulation circuit. It can be seen that the voltage waveform only started at 0.1miliseconds because the closing time of the switch S1 is 100µs. From 100µs onwards, the current and energy from the power supply flows through a capacitor as well as primary coil and concurrently creates the high rate oscillation. At the same time, the short distance between the primary and secondary windings creates the magnetic linkage among them. Due to that, the primary winding and secondary is facing the same high amplitude fluctuate current.

According to Figure 7, the peak voltage is 175.15V and occurred between 100µs to 259µs. In this period, the input voltage 24V DC has been changed to AC form and the voltage increased about 8% at the secondary circuit. This condition continuously until the switch S2 change form close position to the open position at 259µs. And after 259µs, the voltage obtained at the secondary circuit is 14 times larger than the previous voltage.

TABLE II. ENERGY AT THE SECONDARY WINDING

Primary Circuit			Secondary Circuit			
Supply, V_{dc} (V)	**C_p (µF)**	**L_1 (µH)**	**C_s (nF)**	**L_2 (mH)**	**V_{peak} (V)**	**Energy (Joules)**
24	0.10	31.64	2.27	27.12	1,670	3,165,401.5
24	0.17	31.64	2.27	27.12	1,814	3,734,826.5
24	0.10	12.00	2.27	16.50	2,392	6,494,088.6
24	0.17	12.00	2.27	16.50	2,565	7,467,420.4
24	0.68	31.64	2.27	27.12	3,146	11,233,453.7
24	0.68	12.00	2.27	16.50	3,693	15,479,412.6

Table II shows the energy calculated in joules with varying the capacitance and inductance value and fixing the input voltage at 24V DC. The equation 1 in Section III is employed in order to calculate the energy at the secon y circuit using the value of the secondary voltage, V_{peak}. All the data indicates that the proposed circuit is capable to step up the DC input voltage approximately 50 times greater at the secondary circuit. It is good to know that the voltage at the secondary circuit is in AC form or isolation form even though the supply is only dc voltage. Lastly, the simulation results prove that the proposed circuit is capable to generate medium voltage where it was fulfilled and aligned with the theory of typical Tesla Coil. The simulation result also gives a good sign in the effort of hardware development.

VI. CONCLUSION

Generally, the race to develop the modern and rugged Tesla coil among the scientist and engineer is ongoing. Since the scientific literature about the mini Tesla coil employing the DC voltage is not easily found, therefore this paper is carried out to be a sensible part of further research studies.

Prior to this, a computer simulation using Pspice was done earlier in order to develop a reliable circuit. In addition, the simulation result gives a meaningful indicator regarding the effort to create a small scale Tesla Coil for innovation purposes. In addition, the proposed circuit is executed to generate a high voltage with high frequency oscillation currents likes the standard Tesla coil. It should be noted that the final systems of this project would provide an understanding of systems principle and give significant contribution for further research of mini Tesla Coil.

In conclusion, the next paper will describe the result of a practical lab test conducted in order to investigate the performance of the proposed miniature Tesla coil. The results will show the overall performance of miniature Tesla coil in terms of capacitor tank, primary windings, secondary winding and maximum energy transferred. Hence, the data will give a picture about the capability and the performance of the proposed design that have been tested.

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