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Electric Vehicle Wireless Charging

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Abstract - Electric vehicle are gaining importance day by day because of the benefits it have over conventional vehicles. One of the major problems with EV is its battery charging process which can be simplified by using Wireless Power Transfer (WPT) System It removes the need of annoying cables and provides safety to user. This paper discuss about the technique and consideration to be made while designing a system to charge vehicle wirelessly.

Keywords — Wireless power transfer, Electric vehicle (EV), Class-E Amplifier, Inductive resonance coupling, Battery.

I. INTRODUCTION

All conventional vehicles are powered by an internal combustion engine (ICE) only. These conventional vehicle produce exhaust gases during operation which are harmful for human health.

But electric vehicles (EVs) run on electricity only. They are propelled by one or more electric motors which are powered by rechargeable battery packs. Due to this electric vehicles have several advantages over conventional vehicles. No harmful gas emission. Fuel cost will be up to 70% less than conventional vehicle, maintenance cost is less, ideal for stop-start city driving as no energy is utilise when the vehicle is stationary.[6][7]

Besides the high initial cost, the long charging time of EV batteries also makes the EV not acceptable to many drivers. For a single charge, it takes about one half-hour to several hours depending on the power level of the charger, which is many times longer than the gasoline refuelling process. The EVs cannot get ready immediately when they have run out of battery. Because of this, the owner has to find any possible opportunity to plug-in and charge the battery. It really brings trouble as people may forget to plug-in and find themselves out of battery energy later on. The charging cables on the floor may lead to tripping hazards. Leakage from cracked old cable, particularly in cold zones, can bring additional hazardous conditions to the owner. Also, people may have to brave the wind, rain, ice, or snow to plug-in with the risk of getting an electric shock. The wireless power transfer (WPT) technology, which can eliminate all the charging trouble, is therefore most desirable by the EV owners. By wirelessly transferring energy to the EV, the charging becomes the easiest task. For a stationary WPT system, the drivers just have to park their car and leave. Also the battery capacity of EVs with wireless charging could be reduced to 20% or less compared to EVs with conductive charging.

II. ELECTRIC VEHICLE

Electric vehicles are one of the simplest forms of self propelled mechanical transport. In the basic design, the drive train of the car is made up of a battery array connected to an electric motor via a switch. [9] The amount of electricity that is allowed to pass through to the electric motor and gear systems is controlled such that the electric motor drives the wheels in the most efficient manner.

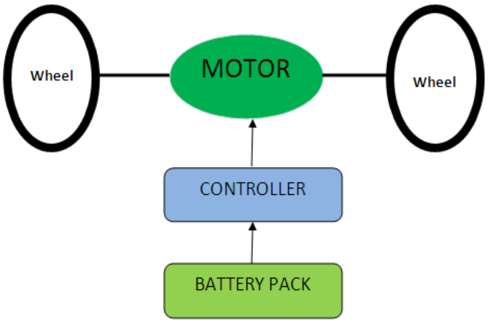

Figure 2.1 Electric Vehicle

Electric Motor

The car may run on AC or DC motors. If it uses a DC motor the car may run on any voltage between 96V and 192V of the rating around 20kW. Motors work on the principle of electromagnetic induction where change in magnetic flux causes the central shaft to rotate. In case of AC motors 3 phase motors are generally used which run at 220-240 Volts AC along with 300 Volt battery packs. AC motors have the ease of availability in various sizes, shapes and power ratings in contrast to DC motors and also have a 'regenerative braking' feature by virtue of which motor can act as a generator to charge the batteries while braking.

Motor Controller

This is the part of the system which would control the amount of current being supplied to the motor depending on amount of pressure on the accelerator pedal. The accelerator is connected to potentiometers which act as variable resistors to provide the signal on how much power to deliver. When the pressure on accelerator is zero, no power is delivered and full power is delivered when pedal has been fully pressed. In case of DC motors the controller would chop the values of DC supply voltage to obtain a current with average value that is proportional to the amount of pressure applied to the accelerator.

Batteries

Batteries are the parts that hold the energy reserve for the entire car operation. These store energy in the form of chemical energy and convert them back to electrical energy when required. Batteries are heavy, bulky and take a lot of time to charge and yet have limited capacity and life. Better replacements in the form of LiMH batteries do exist, which not only double the range of cars but also have significantly longer lives are present, but at present are too expensive to invest in. Fuel Cells offer the most attractive solution to all these problems along with being environment friendly but still need a lot of R&D before they enter the mainstream market.

III. WIRELESS POWER TRANSFER SYSTEM FOR ELECTRIC VEHICLE

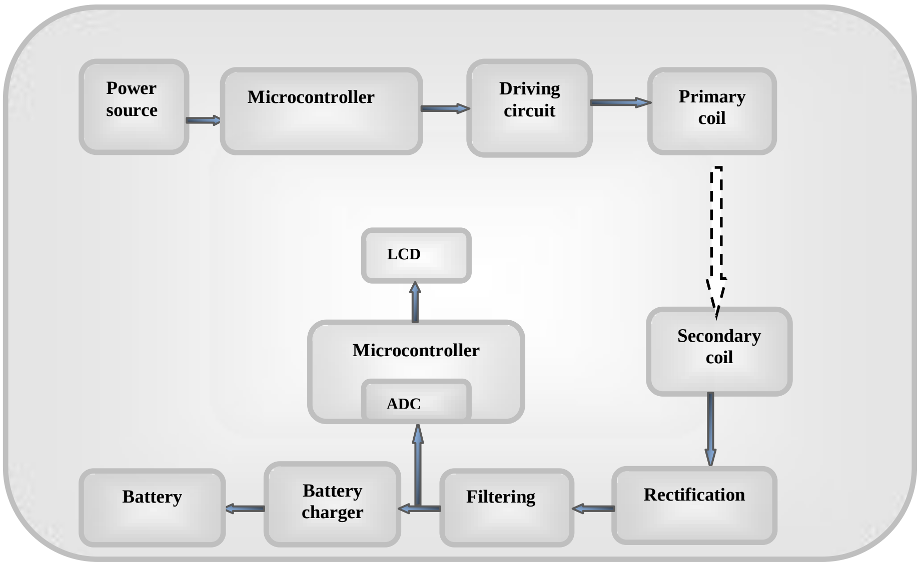

Figure 3.1 Block Diagram of WPT System for Electric Vehicle

Figure 3.1 shows block diagram of wireless power transfer system. Various components are discussed below:

Power Source

A power source is electronic device that supplies electric energy to electrical load. Its primary function is to convert one form of electrical energy to another; as a result power supplies are sometimes referred to as electric. Some power supplies are discrete stand-alone devices whereas others are built into larger devices along with their loads.

Every power supply must obtain the energy it supplies to its load as well as any energy it consumes while performing that task from an energy source. Depending on its design a power supply may obtain energy from various types of energy sources including electrical energy transmission systems, energy storage devices such as a batteries or fuel cells, electromechanical systems such as generators or alternators, solar power converters or another power supply. All power supplies have a power input which receives energy from the energy source and a power output that delivers energy to the load. In most power supplies the power input and output consist of electrical connectors or hardwired circuit connections though some power supplies employ wireless energy transfer in lieu of galvanic connections for the power input or output.

Microcontroller
A microcontroller is a small computer (SoC) on an single integrated circuit containing a processor core memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip as well as typically small amount of RAM. Microcontrollers are designed for embedded applications in contrast to the microprocessors used in personal computers or other general purpose applications. Microcontrollers are used in automatically controlled products or devices such as automobile engine control systems, implantable medical devices, remote controls, office machines, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

Driving Circuit
A typical digital logic output pin can only supply tens of MA of current. Even though they might require the same voltage levels small external devices such as high-power LEDs, motors, speakers, light bulbs, buzzers, solenoids, and relays can require hundreds of MA. Larger devices might even need several amps. To control smaller devices that use DC a transistor-based driver circuit can be used to boost the current to the levels needed for the device. When voltage and current levels are in the correct range the transistor acts like a high-current switch controlled by the lower current digital logic signal. A discrete BJT is sometimes used instead of a newer MOSFET transistor especially on older or low voltage circuits. The transistor primarily provides current gain. PNP, NPN or MOS transistors can also be used. The resistor used on the base of the transistor is typically around 1K Ohm. On inductive loads i.e. motors, relays, solenoids, a diode is often connected backwards across the load to suppress the voltage spikes that is back EMF generated when turning devices off. Sometimes the diode is also connected across the transistor instead of the load which protects the transistor. The 2N3904 is a small discrete BJT transistor that can be used for a driver circuit needing less than 200MA. In battery operated devices the load may be directly connected to the battery power and not pass through the voltage regulator. Many devices such as motors have a momentary large inrush current spike when they are first turned on and have a larger stall current so be a bit conservative on the maximum current ratings.[1]

Rectification
A rectifier is an electrical device that converts alternating current AC which periodically reverses direction to direct current DC which flows in only one direction. The process is known as rectification. Rectifiers are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for using it as a source of power. As noted detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of a flame.
Because of the alternating nature of the input AC sine wave the process of rectification alone produces a DC current that though unidirectional consists of pulses of current.

Filtering
Filter is a device or process that removes from a signal some unwanted component or feature. Filtering is a class of signal processing the defining feature of filters being the complete or partial suppression of some aspect of the signal. Most often this means removing some frequencies and not others in order to suppress interfering signals and reduce background noise. However filters do not exclusively act in the frequency domain especially in the field of image processing there exist many other targets for filtering. Correlations can be removed for certain frequency components and not for others without having to act in the frequency domain. [6]

Battery Charger
A battery charger, or recharger, is a device used to put energy into a secondary cell or rechargeable battery by forcing an electric current through it. The charging protocol depends on the size and type of the battery being charged. Some battery types have high tolerance for overcharging and can be recharged by connection to a constant voltage source or constant current source simple chargers of this type require manual disconnection at the end of the charge cycle or may have a timer to cut off charging current at a fixed time. Other battery types cannot withstand long high-rate over-charging the charger may have temperature or voltage sensing circuits and a microprocessor controller to adjust the charging current determine the state of charge and cut off at the end of charge.

Battery
An electric battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell has a positive terminal or cathode and a negative terminal or anode. The terminal marked positive is at a higher electrical potential energy than is the terminal marked negative. The terminal marked positive is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device. [6]

LED
A Light emitting diode is a two lead semiconductor light source. It is a p–n junction diode which emits light when activated. When a suitable voltage is applied to the leads the electrons are able to recombine with electron holes within the device releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

IV. RESONANT INDUCTIVE COUPLING

Resonant inductive coupling is a form of inductive coupling in which power is transferred by magnetic fields between two resonant circuits (tuned circuits) one in the transmitter and one in the receiver (see figure 4.1 below). Each resonant circuit consists of a coil of wire connected to a capacitor or a self-resonant coil or other resonator with internal capacitance. The two are tuned to resonate at the same resonant frequency. The resonance between the coils can greatly increase coupling and power transfer, analogously to the way a vibrating tuning fork can induce sympathetic vibration in a distant fork tuned to the same pitch.

The concept behind resonant inductive coupling is that high Q factor resonators exchange energy at a much higher rate than they lose energy due to internal damping. Therefore by using resonance the same amount of power can be transferred at greater distances using the much weaker magnetic fields out in the peripheral regions of the near fields. Resonant inductive coupling can achieve high efficiency at ranges of 4 to 10 times the coil diameter. This is called "mid-range" transfer in contrast to the "short range" of non resonant inductive transfer which can achieve similar efficiencies only when the coils are adjacent. Another advantage is that resonant circuits interact with each other so much more strongly than they do with non resonant objects that power losses due to absorption in stray nearby objects are negligible. A drawback of resonant coupling is that at close ranges when the two resonant circuits are tightly coupled, the resonant frequency of the system is no longer constant but splits into two resonant peaks so the maximum power transfer no longer occurs at the original resonant frequency and the oscillator frequency must be tuned to the new resonance peak.

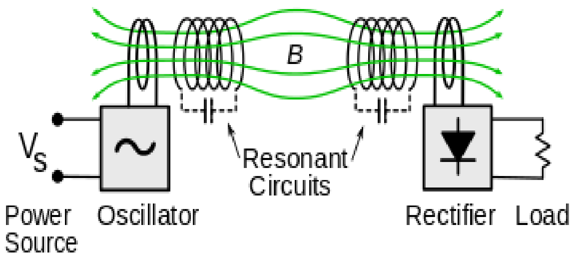

Figure 4.1 Resonant inductive wireless power systems

Resonant technology is currently incorporated in modern inductive wireless power systems. One of the possibilities envisioned for this technology is area wireless power coverage. A coil in the wall or ceiling of a room might be able to wirelessly power lights and mobile devices anywhere in the room, with reasonable efficiency. An environmental and economic benefit of wirelessly powering small devices such as clocks, radios, music players and remote controls is that it could drastically reduce the 6 billion batteries disposed of each year, a large source of toxic waste and groundwater contamination.

V. CLASS-E AMPLIFIER FOR RECTIFICATION

Class-E power amplifiers are very important part of designing a WPT system. This helps in transmitting power wirelessly at high frequency with less loss or 100% efficiency theoretically.[2] Figure 5.1 shows the schematic diagram of the Class-E power amplifier which is used to convert DC power to AC power. The output power capability of a WPT system is related to the maximum output power of the DC-AC inverter. In order to obtain a higher output power the value of load resistor R of the Class-E power amplifier should be smaller. That is because the Class-E power amplifier will be driven by a higher current and the output power will dramatically increase when the biasing voltage is at the same condition. However the Class-E power amplifier needs a smaller C1 to operate normally when a smaller R is chosen.

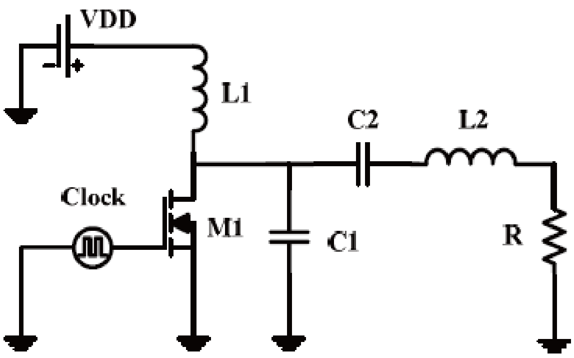

Figure 5.1 Schematic diagram of the Class-E power amplifier

In the design IRF 640 transistor is used to replace C1 simplifying the circuit structure while keeping the same performance. [4]

VI. COUPLING COILS

In electrical engineering two conductors are referred to as mutual-inductively coupled or magnetically coupled when they are configured such that a change in current through one wire induces a voltage across the ends of the other wire through electromagnetic induction. The amount of inductive coupling between two conductors is measured by their mutual inductance.

The coupling between two wires can be increased by winding them into coils and placing them close together on a common axis so the magnetic field of one coil passes through the other coil. Coupling can also be increased by a magnetic core of a ferromagnetic material like iron or ferrite in the coils which increases the magnetic flux. The two coils may be physically contained in a single unit, as in the primary and secondary windings of a transformer or may be separated. Coupling may be intentional or unintentional. Unintentional inductive coupling can cause signals from one circuit to be induced into a nearby circuit, this is called cross-talk and is a form of electromagnetic interference.

An inductively coupled transponder consists of a solid state transceiver chip connected to a large coil that functions as an antenna. When brought within the oscillating magnetic field of a reader unit the transceiver is powered up by energy inductively coupled into its antenna and transfers data back to the reader unit inductively.

Figure 6.1 Picture of coupling coil

Magnetic coupling between two magnets can also be used to mechanically transfer power without contact, as in the magnetic gear.

An air core copper coil is mostly used to for making inductive coupling coil circuit. The inductance of an air core inductor is calculated by below formula [11]

$$L = (d^2 * n^2) / (18d + 40l) \quad \text{……….} (1)$$

Where: L is inductance in micro Henrys
d is coil diameter in inches
l is coil length in inches
n is number of turns

Both the coils are similar in construction as shown in above figure 6.1. Both the coil that is transmitting and receiving coils should similar mutual inductance between them which will be

$$M = \sqrt{L1L2} = L \quad \text{………..} (2)$$

And coupling coefficient should be

$$k = M / \sqrt{L1L2} \quad \text{……….} (3)$$

VII. MODEL DEVELOPED

A wireless charging system is developed for charging electric vehicle. The electric vehicle is battery powered electric vehicle having 8V battery for its operation. The motor used for vehicle driving are two 60 rpm motors connected to the rare wheels shaft. Wireless power transfer system is developed by using copper wire of inductance value 57 µH of both transmitting and receiving coil.

Fig. 7.1 shows picture of actual hardware model. Picture clearly shows transmitting and receiving coil having 10 turns each and the distance between the two coils is 6 to 7cm. An IR sensor is used for sensing the presence of vehicle so that power supply is given to transmitting only when vehicle is present. It reduces the wastage of electricity.

PIC controller is used to control the power transfer and amount of power transfer.

Figure 7.1 Picture of actual hardware model

A class E amplifier is used for converting DC to AC signal for supplying to transmitting. Principle of strong inductive coupling is used for efficient transfer of power. Bridge rectifier and capacitor are used to filter rectify and purify received power. An LCD is used to display charging and not charging condition of vehicle. Press button is used operation of vehicle.

CONCLUSION

Thus a wireless power transfer system for charging battery i.e. 8 V of an electric vehicle is developed. This eliminates the need of plug in wires or cables for charging. Also the tripping hazards brought by them like leakage from cracked old cable in particular in cold zones which can bring hazardous conditions to the owner. It minimizes the dependence of vehicle operation on fossil fuels.

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