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Automated Battery Backup Approach (ABBA) for Industrial Appliances using WPT

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Abstract

Objectives: The major short comings of WPT are power loss, magnetic field interference and heat emission. The proposed methodology addresses the issues encountered in the traditional wireless power transmission systems. **Methods/Statistical Analysis:** An Automated Battery Backup Approach (ABBA) is proposed here to initiate and terminate wireless charging system in auto mode. In this automated power transfer technique the battery pack device is knowledgeable of its own to take its decision based on the battery status. **Findings:** The exploration of electronic devices that ranges from handheld mobiles to unmanned vehicles and moving industrial robots, demand for wireless charging system. These nodes require to be instantly charged with dynamic energy. WPT (Wireless Power Transfer) is an effective strategy of transferring the electrical power from the source to the destination load that needs to be connected without wires. Many recent works in this area have discussed methods for improving efficiency and to prevent loss of power. The resistive heat in WPT is more than that of in direct contact charging, as continuous charging of the device happen even the battery being fully charged. Sometimes it causes short circuit damages and the battery will get easily damaged. Due to these issues of WPT the battery lifetime is also reduced. **Applications/Improvements:** The proposed ABBA methodology ensures a complete, fast, and safe charging mechanism for the battery backup process. This significant strategy is very much suitable for industrial environment to automate the process of transferring electric energy to the industrial gadgets or devices like unmanned vehicles and robots, based on the consumption of power.

Keywords: Automated Battery Backup Approach (ABBA), ADC Resolution Technique, Magnetic Resonance, Tesla Coil, Wireless Power Transmission

1. Introduction

In recent years there has been significant development in the field of consumer electronics and mobile appliances based on Wireless Power Transfer (WPT) technology. WPT is an emerging trend that revolutionizes the way of transferring power without cables and makes our life wireless. Now a days, there is a great development in the cruising range of electronic devices, the main issue in these gadgets is frequently charging the rechargeable batteries and connected to the power supply via a chord. Wireless power transfer concept addresses out most and major drawbacks for power source to the increasing number of electronic devices[1]. This wireless charging is an ingenious approach that transfers the electric power via the atmospheric medium. In general, it uses the magnetic field or a microwave instead of the traditional copper cables in order to transfer the power. WPT is a convenient, flexible and safe technology.WPT is not introduced by today's modern world of electronics, the previous two centuries had earned a lot by the use of this gross technology, such as the magnetic induction principle is used in microwave oven for food preparation, the similar concept is used for laser and X-ray transmission. Also in step up and step down transformers which is very much used in generation and distribution of electricity. At the end of 20th century, Nikola Tesla tested the WPT strategy by transmitting electric power wirelessly to glow fluorescent bulbs kept at a distance of several kilometers[2]. He is considered as the inventor of wireless power transmission. So many aspects

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of our modern life are directly influenced to be created by Nikola Tesla. The key to identify from his remarkable idea is to transfer power wirelessly by EMF (Electro Magnetic Field). His first pattern was done in the year of 1891 via generating sparks by the use of Tesla coil shown in the Figure 1[3]. The fluorescent bulbs are used to distinguish the concept of WPT. The power signals emission from the tesla coil doesn't harm humans or any living or non living things. The tesla coil generates high voltage at large frequency levels and is similar to the air-core transformer, also self generative transformer that adopts resonant principle. Several kilowatt transformers and the driver circuit are inputted with 120V power supply. The tesla coil gains a large amount electric discharge from the highly effective capacitors and sends the electric power via a few turns of primary coil and then to the secondary coil of several turns[4]. Thus the tesla coil works similar to the step up transformer and spreads the electric energy in to the air medium via toroid (the top load of the tesla coil). The transmitted energy is absorbed by the receiver coil and then the power is used to charge the battery of the node. Thus the tesla coil involves the mechanism of resonance magnetic field in transferring power wirelessly. Tesla aimed to use earth as the natural conductor of electricity and can send power around the world wirelessly. In 1943 FBI captured Tesla's papers after his death. Just after World War II the experimental notes written by tesla was last and no one saw those records thereafter. No more scientists or researchers succeed in finding the diary records of tesla. The main objective of this work is to charge the devices (such as robots or unmanned vehicles) used in the industries where the human activities are prevented inside and made dodge, like nuclear power plants, toxic gas manufactory, etc. In those places the human entry is predicted nearly 10 km away from the production environment. In these places the mobile devices such as robots and unmanned vehicles are used to activate, control and terminate the processes, also in monitoring the routine work and performance, measuring the sensor values or readings and taking decisions based on the absorption. The power source for those movable devices is battery packed; these devices are charged by plug in to the AC outlet through connecting wires. There are several drawbacks in the use of wired charging for mobile devices. Some of them are,

- There is a major risk for conductors in the wired energy transmission system.
- Human beings and gadgets can be suffered by tripping on wires while moving.
- Electrical insulation failures may occur.
- The Power hub and the wires can get damaged during fault current.
- Lot of maintenance is need in wired system.

These problems are overcome by using the WPT concept. Generally there are three classifications of power transferring methodologies in WPT and those classifications came under two categories namely radiated and non-radiated wireless power transfer[5]. The basic classifications of WPT are listed:

- Radiated Power Transfer
    - Magnetic Induction Coupling
    - Magnetic Resonance Coupling
- Non-radiated Power Transfer
    - Microwave Power transfer

Among the three techniques both the induction coupling and the resonant coupling transfer power wirelessly with the use of electromagnetic interference via a few turns of copper coils and the microwave power transfer use RF or microwave to achieve wireless power transmission between antennas. Induction coupling is a near-field transmission technique which includes both the concept of Faraday's Law of induction and Biot Savart's Law. Due to a large percent of misalignment the transmission process between transmitter and receiver coils lost. Resonance Coupling is similar to that on induction concept, but includes a slight difference of that the resonance power given to the transmitter coil is tuned by the capacitors. The resonance power transfer is the only WPT concept that involves multi-receiver platform. Finally the microwave transmission is a far-field transmission technique. In this approach, a microwave source is transferred via the antenna through a wave guide through line of sight and in the receiver side the power is received and converted in to DC using the rectenna (rectifier + antenna) circuit.

In WSN (Wireless Sensor Networks) nodes are to be placed in the surrounding are from where is the base station is able to communicate with, similarly in charging the batteries of those WSNs using WPT[6]. The node gets charged only if it is present inside the charging area of the transmitter coil. Employing a single base station for both the purposes of retrieving data and to transfer power wirelessly is discussed. In practice an automatic vehicle is used for collecting information from the nodes and in transferring wireless power to the battery of the nodes which have lack of energy[7]. In this OPT-t (Omni directional Power Transmission) strategy an unmanned vehicle travels in a predefined path (wherever the WSN nodes are placed) from the source to the destined location. This method of energy transmission and data acquisition in WSN works in a time based approach. Because the mobile station must enable to wait till the battery of the node get fully charged or till retrieving the entire data from the node. The performance analysis of the process is measured by using OPT-s. A Technique of transferring power at different channels at various power frequencies to charge a particular load at variable power signals is processed. The specific device which is in need of power at the time will receive the energy through the specific channel of preferable frequency. In both transmitting and receiving circuits multi non-inductive tanks are used to alter and filter the electric power at frequencies of various quantities. The band passes and band stop filters are used in the receiver devices. Based on the frequency levels of the appropriate device the receivers retrieve the transmitter wireless power from the magnetic field present in the surrounding area by the use of both band pass and band stop filters. The supporting circuits are used to set the different frequency levels based on the power requirement of the specific load. Consider that the load that requires electric energy is set to the channel of frequency at 35 kHz, that particular device which is in lack of power is only able to receive power. Other devices such as nodes or systems having power to sustain at various frequency levels such as 40 kHz or 25 kHz doesn't receive the power via wireless power transmission. By this methodology the electric current is directly sent to the appropriate device without any interference[8]. The distance separation of the load device and the transmitter coil in the wireless power transfer platform is indirectly proportional to the received power efficiency is the main drawback of the WPT system (i.e. whenever the mobile destined load moves for a large distance from the source, the power reception rapidly fall down). Due to the default in resonance power transmission, the loads which are farthest from the transmitter coil assumes low electricity and the loads which are closest to the transmitter coil receives high electricity. By using electric current division strategy and impedance matching along with the impedance inverters circuit to be embedded in the receiving circuit of the load this kind of issues are neglected. By using few arithmetic derivations defined, the concept of multi-receiver can be made possible and extending the charger surrounding area can also implemented. The similarities if the equations made them simple and understandable. By this proposal, the efficiency of the WPT is very much improved without altering the position of the destination load[9]. Magnetic induction is the well developed, costless and understandable concept of power transfer to the Electric Vehicles (EV) wirelessly. The magnetic induction produced by the transmitter coil which is embedded below the road surface is absorbed by the receiver placed at the lower end of the vehicle and then given to the battery, which in turn used as the source power to the EV's. The transmitter and receiver coils have to be kept in the same axis without misalignment in order to achieve perfect power transmission process. Implementation of this strategy the induction coupling mechanism achieves 80% of power transfer efficiency at one feet distance. In this system of approach the power supply is directly connected to the transmitter coils which are mounted underground in the vehicle parking place. The amplifier circuit is used to endow the current at the transmitter coil in the transmitter circuit. The receiver coil embedded in to the vehicle first retrieves the electric power from the air medium and then sends the received current to the load battery. Before the battery gets charged by the energy received by the receiver coil the AC power is converted in to DC using the rectifier circuit. Based on the mutual position and distance of the windings the performance and accuracy of the power transmission circuit is accumulated. The performance of the design specification is derived by using the yokogawa digital power meter[10]. A cheap prototype of charging tiny gadgets such as hearing aids, pacemakers and wearable devices. Effective reception of energy in the spatial medium is increased whenever the receiving devices are placed as near to the transmitting coil. The coils used in this method of WPT are bowl and conical shaped coils. Most preferably the coils used in the resonance wireless energy transfer are rectangular and round shaped antennas. But in this presented methodology the conical and bowl shaped antennas are used for effective transmission. These antennas are designed using the helical coils in serial manner. The induction coupling is improved here by the ferrite sheets with the receiver coil.

An equivalent circuit is defined in order to analyze the proposed system[11]. Also the mutual inductance between the transmitter circuit and the destined load is derived and achieved. The previous works which are discussed mostly depends on the improving efficiency of wireless power and describes several algorithms to reach targeted load. But no more works have been done on the major issues in the wireless power transmission of power loss, magnetic field interference for a short distance and heat emission. The resistive heat produced in the wireless power transmission circuits is greater than that of wired systems, which is directly connected to the AC outlet. The consumer devices tend to get charging continuously even after the battery is fully charged. The lifetime of the battery is heavily reduced because of electric power overflow. Sometimes short circuit damages and the strength of battery are easily affected due to the raise of the high resistive heat and frequent charging. The fully automated strategy of WPT is focused and implemented here in order to overwhelm the predefined issues that are faced in achieving well efficient wireless power transmission for the mobile nodes in industrial environment.

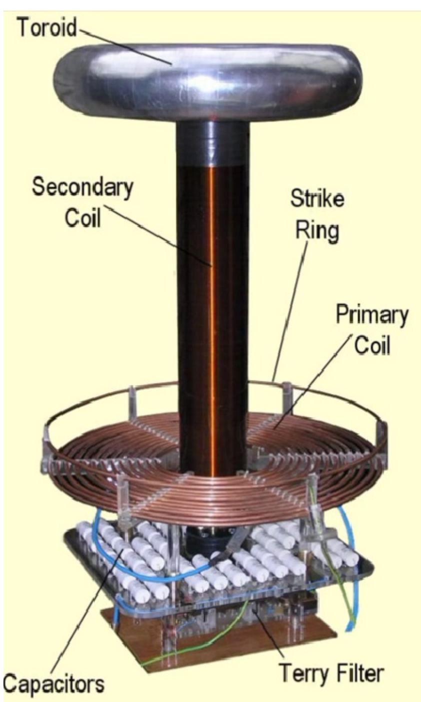

Figure 1. Tesla coil.

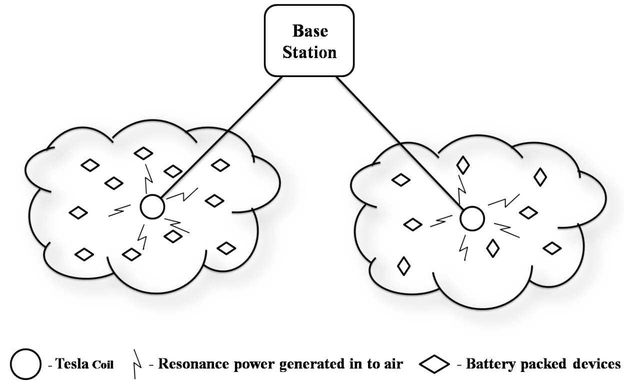

Figure 1. WPT architecture.

2. Proposed System

2.1 System Architechture

WPT is deliberated as aspiration to the power source for growing mobile electronic devices and an inspiration to the future technology. As mentioned in related works, the major problem concerns of this innovative technology of power transmission without wires are maximum level of heat emission in the circuits and power loss during transmission. As previously mentioned many past methodologies work along in increasing the efficiency and distance of the wireless charging medium and no more proposals are implemented in discussing about the heat produced and the loss of power in scattering parameters during power transmission wirelessly. In this work, an Automated Battery Backup Approach (ABBA) is proposed and implemented to automate the process of power transmission for industrial appliances in a connectionless medium. The ABBA methodology deals with the challenging aspect of this work is to switch ON/OFF the charging system based on the configuration of battery and its capacity. This ABBA system shown in Figure 2 basically include the modules to perform four functions to ensure a complete, safe, fast and connectionless power transfer. The four functions implemented in achieving the automation on the WPT are,

- Initiating the Power transmission
- Delivering charge to the battery
- Analyzing the charge rate and
- Terminating the charge

The ABBA system is designed fully automatic in transfering the electric power wireless to the devices connected in the industrial environment.The Microcontroller based system continuously monitor the battery readings and the live meter reading is transmitted from the battery powered device to the base station. This information exchange have been done by the use of RF data transmission. This system enables power transfer based on the power available in the battery of the consuming device such as an unmanned vehicle or a robot used in the industrial environment. By comparing the current battery capacity from the receiver section along with the predefined threshold value, the microcontroller in the transmitter section generates the power in to the air medium and the appropriate device that requires energy will receive it.The ABBA wireless power transfer mechanism is based on resonant coupling method of WPT. Resonant power transfer technique offers electric current without any kind of radiation. Using resonance concept of power transfer, tesla generated power up to a distance of 24 miles (nearly 42 km) distance from the transmitter or tesla coil, but no one can't able to replace his work. Till now resonant power transfer for wireless charging is achieved maximum at a distance near to 1km using gaint tesla coils[12].

2.2 Working of Tesla Coil

Basically tesla coil is the most complex device that uses the features of many components as shown in the figure and almost eradicate to physics in amplifying the input current to a massive amount and to give an idea on how volts should be increased. For example, 110 V of home purpose current is magnified up to 1,000 V by a tesla coil if a meter height and the electricity to go across a few meters. Those tesla coils should stand of almost lightening or a large quantity of electric emissions about thousands and thousands of volts flowing through the air and discharges electricity through arcs. The transformer is the very first to the tesla coil, both takes current as input and amplifies the voltage at the output end. The increase in the voltage happens because electrons create a magnetic field specially. While moving in the wire, it creates a moving magnetic field at poles and other electrons, so that the input current goes through the windings of wire shown in the Figure 3. From the transformer the amplified current goes in to the capacitor, instead of using magnetic poles it focuses more on the static electricity and also deals with magnetic field of electrons. Capacitors manage to temporally store electricity. Instead of gathering electrons on coils of windings in to two separate plates (metal and dielectric plate). When electrons become to gather in to a plate gains negative charge which forces positive charge on the other plate and almost polled together to hold a temporary charge. Because the electrons are not moving, the positive ions are moving and due to polling it temporarily holds the charge. The capacitors are strong enough to hold and push out the electricity of high voltage by magnifying itself. From the capacitor the power goes to the primary coil which is at the bottom of the tesla coil. It wraps around and those turns are separated by uniform spacing. The primary coil diameter is thicker than that of secondary coil. The secondary coil consists of several windings and releases power from the top load (toroid). In every cycle tesla coil spreads the electric current at high voltage in all directions through discharging arcs[13]. The next spark occurs after the previous spark dies. This process repeats again and again continuously in each cycle. Another important component used in the tesla coil is the active spark gap. It doesn't run frequently, but the inactive time is significant for the human eye to recognize. The gap is made at a distance of one inch. The capacitor with the spark gap is able to bypass the transformers and go straight forced to the capacitor and primary coil. By obtaining the destination load in to the charging are the device absorbs the power through the receiver coil.

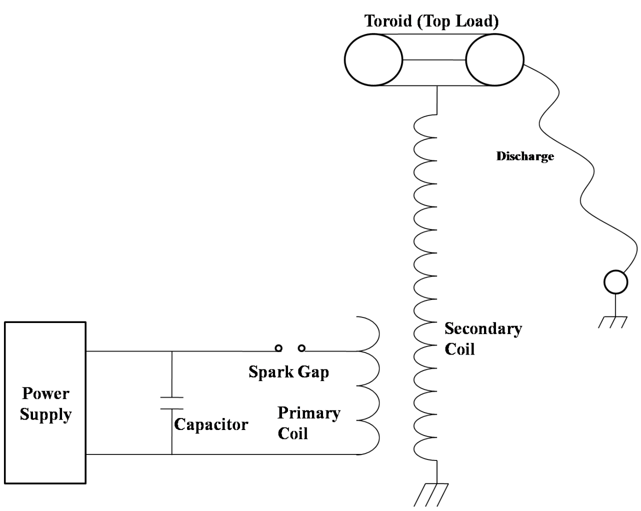

Figure 3. Block diagram of Tesla coil.

2.3 Automated Battery Backup Approach (ABBA)

The ABBA system is a safe technology and achieves mobility. In this approach copper coils or antennas are used to transmit and receive the electrical power wirelessly. Both the transmitter and receiver sections individually include a relay shown in the Figure 4 to initiate and terminate the power supply and an individual microcontroller to take control over the relay and also used to provide communication. A tool is used to monitor the status and parameters of the batteries used as the power source to the industrial gadgets. By comparing the current battery capacity from the receiver section along with the predefined threshold value, the microcontroller in the transmitter section generates the power in to the air medium and the appropriate device that requires energy will receive it. All the electronic gadgets that are energized through ABBA are sensitive to energy variations and will all comply with battery specific requirements. The experimental setup of ABBA is shown in the Figure 5. This strategy resolves short circuit damages, tripping issues and also enhances the lifetime of the battery. In the transmitter section, first of all the three phase industrial power supply is given to the transformer in the tesla coil. All the battery powered movable devices used in the industrial environment which needs to be wirelessly charged are embedded with the receiver section of ABBA. The transmitter section is common for a particular surrounding area and its stable in that place. The transformer and the tesla coil are separated by a relay, which in turn initiates and terminates the power transmission. The battery status of each and every mobile device which requires WPT is monitored and displayed by the LPC2148 microcontroller in the receiver section. There are two threshold values (namely Upper U_t and Lower L_t threshold) are defined in means to represent the draining and overflow of the battery. If the charge level of the battery fall behind L_t or else exceed U_t then the microcontroller sends a signal to the transmitter circuit using RF transmitter in order to enable or disable the power transmission process. The LPC2148 microcontroller on the transmitter section controls the operation of the relay circuit based on the appropriate signal obtained from the receiver section of battery backup device. If the battery level becomes low the controller sends the signal to initiate power transmission and if it becomes high, sends a signal to terminate the power supply in the air medium. RF receiver circuit is used for communication purpose in retrieving the data transferred from the appropriate device to the tesla coil. The particular device's battery pack becomes drain or below the threshold level of 20%, the specific device only gets charged by the wireless power transmission in the ABBA platform. Also if the battery pack gets fully charged or exceeds the threshold level of 80%, the particular node gets disconnected from the power transmission network. The performance of the power transmission is inversely proportional to the distance separation shown in the Figure 6 between transmitter and the node that requires energy. A rectifier circuit is used in the receiver section to convert the received AC power in to DC power and then the DC power is delivered to the battery of the node. The efficiency of received power is analyzed and visualized using the LCD display connected to the microcontroller.

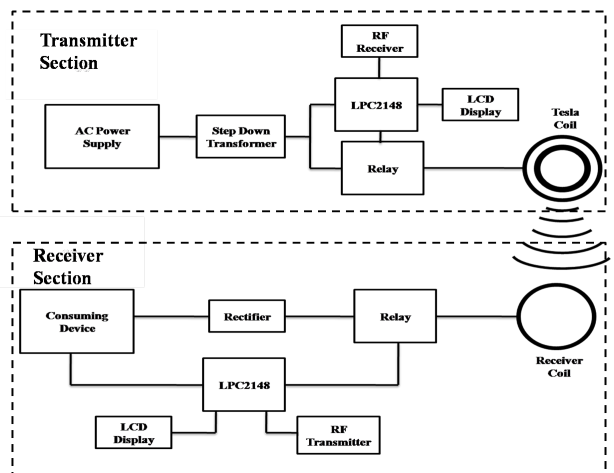

Figure 4. WPT using ABBA.

Figure 5. ABBA resonant power transmission using Tesla coil.

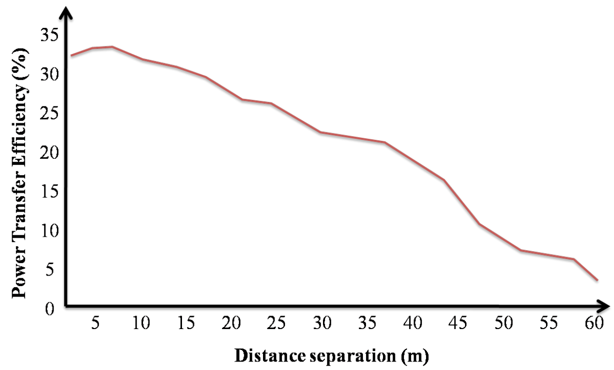

Figure 6. Flow graph of power transfer efficiency.

2.4 Performance Analysis

The performance of power transmission analysis in the ABBA system is measured by the 10-bit ADC resolution technique using ARM LPC2148 microcontroller. The ABBA system doesn't include any reading meter to measure the performance of power transmission and the power loss during transmission. The performance analysis is calculated using the ADC resolution technique. The theoretical analysis of the power transmission measurement using ABBA system is estimated here. The analyzing formula to calculate the power transmission and reception by the destined load along with the battery status are derived using the ADC. These measurements are determined by directly connecting the power line to the ADC. In order to derive the efficiency of power in terms of voltage, few calculations based on the resolution of ADC are considered for reference. The output power (O_p) in milli Volt is proportional to the input power (I_p) in Volts. For a 10 bit ADC we have 1023 steps. The efficiency of input and output power is derived using the formula,

$$O_p\left(inmilliVolts\right) = \frac{I_p\left(inVolts\right)}{1023}$$

$$I_p\left(inVolts\right) = 1023 \cdot O_p\left(inmilliVolts\right)$$

Also the ADC resolution steps (1023) are obtained using its 10 bit configuration as,

$$Steps = 2^{no.of\ bits} - 1$$

$$= 1024 - 1$$

$$= 1023$$

By use of the above equations the efficiency of the input and output power are measured and the performance of the WPT in ABBA platform is derived. The electric current at the transmitter and receiver coils along with the battery status obtained are made visualized by the LPC2148 using LCD display as shown in the Figure 7 and Figure 8.

Figure 7. Transmitter power efficiency.

Figure 8. Received power and battery status.

3. Conclusion

The ABBA system is very important for the wireless charging of nodes in the industrial environment to automate the process of transferring energy based on the consumption of power. Several methodologies, algorithms and techniques have been taken in to considerations and achieved in improving the received power efficiency of the node, on deriving the power transfer efficiency and in increasing the charging area of the power transferring network. The major problems of resistive heat and power loss which are encountered in traditional approaches are addressed by implementing automation to the wireless charging device. In this automated power transfer technique the battery pack device is knowledgeable of its own to take its decision based on the battery status. This ensures a complete, fast and safe charging for gadgets in industrial environment.

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