Interoperable Wireless Charging for Electric Vehicles

A. Maideen Abdhulkader Jeylani, J. Kanakaraj and A. Mahaboob Subhani

Abstract The world is modernizing with each second passing by. World is ushering toward an era of environmental consciousness. So, green technologies and sustainable solutions vandalize previous technologies, the same is with the automobile industry. Although man learned and started to fly, roadways are the most preferred mode of transport. Usage of conventional fuel vehicles contributes a cumbersome share to the pollution caused. Obvious solution which tackles above problem is electric vehicle. Even though electric vehicles were widely commercialized in the market a decade or two ago, it was not able to reach common masses and impact their life. As rightly said, there is no 100% efficient perpetual machine in the universe, electric vehicle too have a bunch of problems associated with it. The major problem which hindered the substantial success of electric vehicle is charging. Existing vehicles are obscure in case of long-distance travel and require very frequent charging. To tackle the so arisen problem, charging stations need to be established which requires extensive changes in infrastructure and will be lucrative to respective governments. Our paper involves methods to wirelessly charge an electric vehicle. The paper emphasizes on the usage of multiple coils which develops the energy that transmits about the capability and specially designed three-phase coil which improves efficiency along with inductive power transfer mechanism. A method for measuring the energy consumed by the vehicle is also discussed.

Keywords Electric vehicle · Inductive power transfer · Charging · Coils · Energy · Efficiency

A. M. A. Jeylani (✉)
Sri Krishna College of Engineering and Technology, Coimbatore, India
e-mail: jeylania@skcet.ac.in

J. Kanakaraj · A. Mahaboob Subhani
PSG College of Technology, Coimbatore, India

© Springer Nature Singapore Pte Ltd. 2020
H. S. Saini et al. (eds.), *Innovations in Electrical and Electronics Engineering*,
Lecture Notes in Electrical Engineering 626,
https://doi.org/10.1007/978-981-15-2256-7_10

1 Introduction

Charging [1, 2] can also be called non-wired energy transmitter. This technology is the one which enables current that transfers from magnetic energy to electric energy which is loaded over different gaps, exclusive from cord connection. The technology also used in many low- to high-end applications even in hybrid E-vehicles due to user experience is good compared with other features like climatic condition or any change in public health which will reduce the damages. Our main dependencies are on fuel like petroleum which is so susceptible to provide interrupt. This also can be reduced by E-vehicles through plug-in and it reduces the fuel cost abundantly. There are various ways to charge the vehicle because it has rechargeable batteries like our gadgets which help us in many ways in our daily life. By charging often, there is no need to go to a gas station or any other fuel station. Electric vehicles also react very quickly. Moreover, they are extremely approachable, especially they also good torque. Most charging can be done in many ways; nowadays, charging a vehicle in a public place is customary; the simple way is that a plug-in charge station is enough to make the vehicle a better movable one. They raise the series of all E-vehicles which can also improve the quantity of every electric mile travelled using chargeable hybrid E-vehicle system which provides usefulness to the people who are all in need for a long trip. Mainly in hybrid vehicle, the public charger uses only the DC so the transmission to it is equipment, otherwise known as EVSE. DC fast-charge which delivers the energy more than 65 miles which reach so faster when compared to others. Public charging is located in spots where vehicles are highly concentrated, such as shopping centers, city parking lots and garages, airports, hotels, government offices and other crowded areas.

The existence of electric vehicles has overcome many disadvantages over conventional vehicles. The drawback we may face in this technology is that it consumes more time for plug-in charging. So, the concept of wireless charging of electric vehicles has been discussed in this paper.

2 Wireless Power Transfer—The Future

Though wired charging points are gaining popularity in parking lots and roadside parking bays, there will be soon more electric vehicles on the road that fixed charging point wired stations would not and can not suffice to the need. Wireless overcomes the need to stop at charging stations. Most of the major automakers are launching or planning wireless charging vehicles built on a global standard.

The market for wireless charging is increasing and holding a major chunk of global share day by day. Pike research estimates wireless products to triple by 2020 [3]. According to another research, global wireless power revenue is expected to grow from $8.5 billion in 2017 to $17.9 billion in 2024 [4]. The graph below depicts the growth of wireless market (Fig. 1).

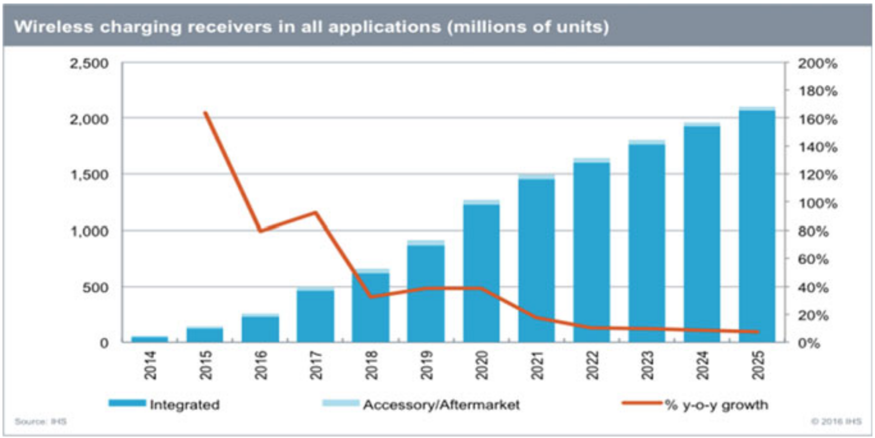


Fig. 1 Depicts the growth of wireless market

3 Challenges

Following are the challenges which hinder the phenomenal and substantial implementation of wireless charging:

1. The real, use of wireless control, even in devices that are readily available with it, has been determinedly low. Customer responsiveness remains a challenge and present wireless power technology does not provide users with a true wireless experience. Moreover, opposing hard work principles comprises of not permitted which produces the wireless power entirely. However, the greater than before dependencies on electronics and the stable need to control them will continue to drive the adoption of wireless power [5]. Battery removal brings in a great deal of parts leading to crunch in currency reserves [6] (Fig. 2).
2. When electric vehicles are commercialized in a large scale, the load on the power grid increases multiple times. As of now, there is no mechanism to measure the power consumed by wirelessly charging devices.
3. Nevertheless, normally wireless charging incurs higher implementation cost compared to plug-in charging. Moreover, as a wireless charging system creates additional high temperatures than that of hyperchargers, extra charge on crafting materials may be incurred.

Fig. 2 Electric vehicles are commercialized in a large scale

4 Literature Survey

There are many methods proposed by scientists across the globe to wirelessly charge any equipment/device. The broad classification is shown in the chart below (Fig. 3).

As illustrated, wireless incriminated technologies are classified into nonradioactive coupling-based arraign and radioactive RF-based indicting. The previous study consists of different method: Inductive coupling method [7], magnetic resonance coupling [8] and capacitive coupling [9], while the latter is supplementary of sorting the directive RF power beam into structures and non-directive RF power transfer [10]. In electrical capacitive union process, the attainable quantity of combination of the capacitance is reliant on the accessible region of the mechanism [11]. However, intended for a characteristic-volume a transferable gadget, it is tough to produce enough energy thickness for indict, which imposes a demanding the plan constraints.

As for directive RF power, ray appearance is the limitation lies in that the stallion needs to know an exact location of the Due to the obvious limitation of above two techniques, wireless charging is usually realized through other three techniques.

5 Inductive Power Transfer

This paper emphasizes the usage of inductive coupling and inductive control transmits energy to transfer the power wirelessly. The advantages of using this technique are that it is safe for humans as it is nonradioactive. It also scores over others in terms of having simple implementation. The effective charging distance using this method ranges beginning with a small millimeter to a small centimeter. The drawbacks of using this technology include short charging distance, heating effect and need tight alignment between charging devices used (Fig. 4).

The energy efficient of a coil is measured by the induction and the dependency between the different coils, based on nonradioactive substances and the two

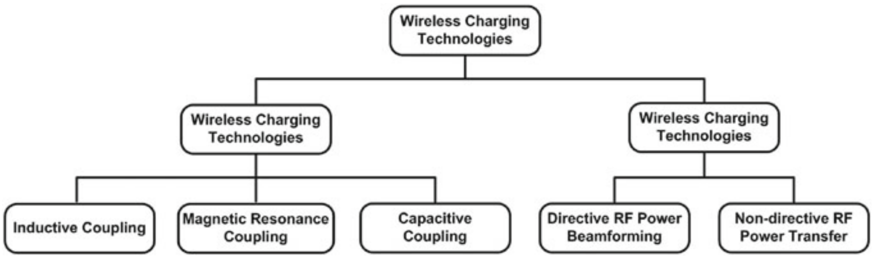


Fig. 3 Broad classification

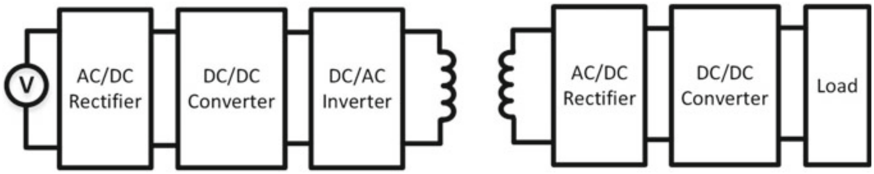


Fig. 4 A block diagram of nonradioactive wireless charging system

different factors which mainly focus on the proportionality of each coefficient is measured in which it creates the induction coil rotates propositional to another and produce coupling [12].

The factor Q is going to define the power or capacity which stores the energy in a generator [13] that provides a very small range of energy loss through energy transmission. Therefore, in a higher Q control structure is the alternation/significance refuses gradually. The inherent feature of fabricated substance is based on some issues which will lead to change in the quality of the affected effects. The feature affects most on turning point from the distances. Hence, frequency of the load matching process is having various different gaps [14], the main focus is on the matched frequency. To refrain a consignment that identical the feature which is used to continue the quality incidence identical at different expanse which can be accessible, by writing different resolutions such as combination treatment, frequency matching and resonant parameter tuning.

From some of recently developed hardware implementation of IPT systems, it is inferred that 50–80% charging effectiveness of several centimeters charging distance for IPT systems (Fig. 5).

The advantages of IPT system are listed below

1. The system is safe.
2. Reliable.

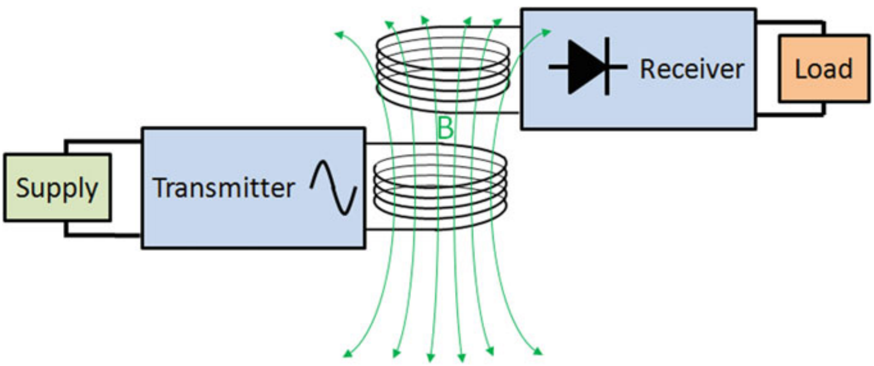


Fig. 5 Inductive power transfer illustration

3. The system has low maintenance.
4. It has long product life.
5. Energy wastage is overcome.
6. Magnetic field radiation problem is overcome.

6 Proposed Method

The figure shown represents the chunk illustration of proposed wireless power supply system for charging battery of electric vehicle.

It consists of three parts, a transmitter to generate analog signal to be transmitted by the coil is so powerful that is, both for sender and receive the energy with non-wired and receiver to convert received AC signal into DC voltage for charging the battery of electric vehicle [13]. The aim of implemented system is to design a prototype of wireless power supply system that refreshes the sequence of an electric vehicle and avoids wastage of power (Fig. 6).

Coil design is given utmost importance as it determines the quantity and quality of power transmitted and received. To keep the losses, at bay and as minimum as possible, both the transmitter and receiver end coil are tuned to have the same frequency. A specially designed three-phase coil structure is discussed in the subsequent section. The type of material used in both source plus recipient part is ferrite core.

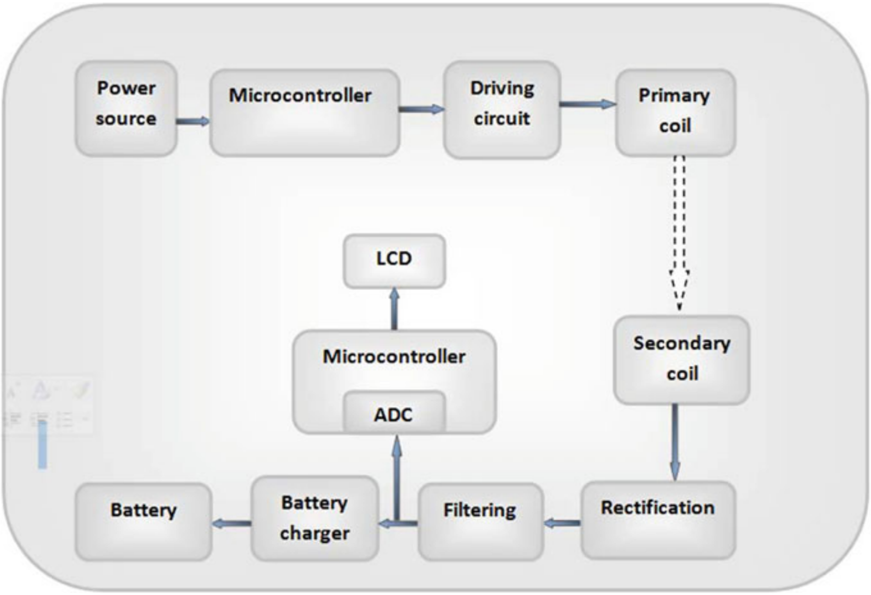


Fig. 6 Block diagram for non-wired authority transmitter

Rectifier is used to convert AC to DC, as battery used in electric vehicle charges only with constant dc supply. The components used in rectifiers are IGBT, IGCT. Using these components rather than diode or SCR reduces the conversion losses by 3%. In the filtering block, LC strain is used on the way to eliminate any harmonics if any to provide regulated ripple-free DC supply to charge the battery. Voltage regulator is also employed before charging phase on the way to decrease the magnitude of the DC supply.

As inductive power transfer is used, the distance connecting main and minor coil is kept at 6–8 cm to achieve high efficiency.

6.1 Coil Design

Coil design is of great importance since the coil determines both the power and efficiency of a wireless charging system. In this paper, a three-phase coil structure, which consists of three transmitters and receivers as shown in figure, can be used to improve the efficiency of the power transferred to a larger extent (Fig. 7).

3D FEA simulations were performed to show the purpose of the attractive ground produced through future spiral arrangement be determined in the coil structure [12].

As this coil consists of three transmitters and three receivers, its efficiency is very high because the attractive fluctuation which is produced through one transmitter passes through its two adjacent receivers and then goes back to that transmitter. The major dissimilarity is among coaxial coil and this one is in the former coil the magnetic field is more concentrated in the coil structure compared to the latter. By using ANSYS MAXWELL as the 3D FEA analysis tool, the parameters of two coils viz., three-phase coil and coaxial coil are tabulated below [12] (Tables 1 and 2).

After simulation, the following conclusions can be drawn from the magnetic field in *YZ*-plane and *ZX*-plane:

1. Both the three-phase coil structure and the coaxial coil structure give good performance in *YZ*-plane, where the attractive pasture that the three-part spiral arrangement which is stronger around receiver's coil and weaker in the center

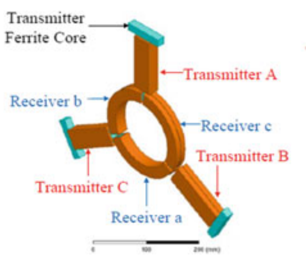


Fig. 7 Three-phase coil structure

Table 1 Simulation results

Parameters	Proposed coil	Coaxial coil
Transmitters self-inductance	131.69 uH	17.94 uH
Receivers self-inductance	33.88 uH	15 uH
Coupling coefficient between Lf and Lr	0.138	0.582
Mutual inductance between Lf and Lr	9.22 uH	9.55 uH

Table 2 Excitation in simulation

Parameters	Proposed coil	Coaxial coil
Transmitters current	3.71 A	3.58 A
Receivers self-current	5 A	15 A
Turn number of transmitters in coil	30	6
Turn number of receivers in coil	18	6

while the attractive pasture that the coaxial coil structure is weaker around the receiver's coil and stronger in the center.

2. For the magnetic fields in *ZX*-plane, the three-phase coil structure performs better as the generated magnetic fields are more concentrated in the coil structure,m thereby affecting existing electronic devices less [12].

6.1.1 Microcontroller—PIC16F877

PIC16F877 is 40 pin IC and 8-bit microcontroller.

Because of its high quality, low price and simplicity to access, the most used data is experimental and modern applications.

PIC16F877 microcontroller gives the subsequent skin texture [14]:

1. 14 K bytes of flash memory
2. 368 bytes of RAM
3. 3.256 bytes of EEPROM data memory
4. Two 8-bit and one 16-bit timer
5. Five input–output ports
6. Two serial communication ports (MSSP, USART)
7. 8-channel 10-bit ADC
8. 2 CCP modules.

PIC16F877 scores over other microcontrollers in the following aspects:

1. It requires less power supply comparatively.
2. It has onboard analog to digital converter (ADC) to sense voltage and display it in digital format.
3. It is cost-effective and trustworthy in case of large applications.

The microcontroller used here is programmed in a method to give pulse width modulated output to the driving circuit. In the second case, it is programmed to display the status of charging the battery used here.

6.2 Measuring Energy—An Experimental Setup

When electrical vehicles are wirelessly charged on a large scale, it creates a lot of load on the grid. Power cannot be given free of cost to all the users of electric vehicles as it will have a negative impact on the economy of respective government. So, energy consumption monitoring is very much essential to understand the trends over a period of time and meet the demands in a smooth manner. The data acquired during monitoring will help to take necessary steps for saving the energy. This paper discusses design of the power measuring system which uses some technology from GSM mobile technique will deliver some data between the power and the consumables which calculate some data within some time period. The so designed energy meter can be placed on the receiver side of the not wired systems transmit energy, i.e., electric vehicle.

Following are the major equipments used to design the energy measuring system:

A. Energy meter
B. Arduino Uno board
C. GSM 900 module
D. Electrical load
E. Other miscellaneous equipments (12 V adapter, Cables) (Fig. 8).

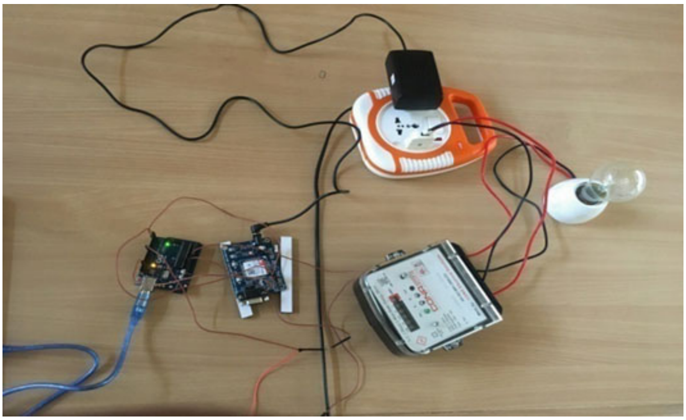


Fig. 8 Experimental setup

In this system, Arduino Uno is used as microcontroller. It serves as a communication medium/channel between GSM module and energy meter. Arduino is coded with a simple programming language with the aim of measuring the energy consumed by the electrical load connected across it by using a predefined formula. Ordinary energy meter indicates power consumption by indicator LEDs. When the LED blinks 3200 times, one kilowatt-hour (kWh) energies are extremely used by consignment.

So by basic mathematical analysis, it is safe to conclude that each blink/pulse indicates consumption of 0.0003125 kWh energy. Arduino counts/captures the number of blinks or pulses to measure the energy consumed.

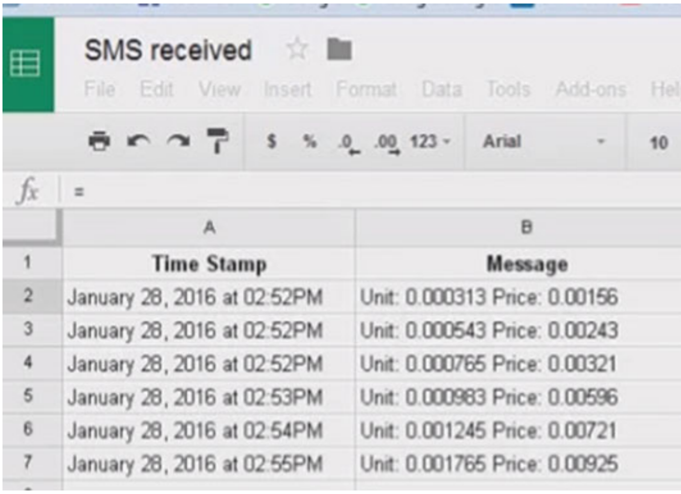
Arduino and GSM 900 module are interfaced with each other using connector wires. Arduino is programmed using open-source Arduino software. As an additional feature, the messages sent by GSM module are linked with software called **I**f **T**his **T**hen **T**hat (**IFTTT**). This a free open-source service provided with a very small uncertain announcement known as applet (Fig. 9).

In this setup, an applet is created to draft the messages received in an android phone to a Google sheet in Google drive. When the component inspired through a shipment and the cost is drafted in a Google sheet, it is easy to sort, pictorially represent the data (Fig. 10).

The Arduino board used in this experimental setup uses ATmega 328 with 16 MHz onboard crystal oscillator. When this system is used in electric vehicle, it provides real-time monitoring of the energy consumption to both the customer and producer of power.

This method can be efficiently installed in all-electric vehicles irrespective of the size of the vehicle and the magnitude of energy consumed by the vehicle. This solves single data which is most important confront of electric vehicle as discussed in the previous section titled challenges.

Fig. 9 Setup an applet



	A	B
1	Time Stamp	Message
2	January 28, 2016 at 02:52PM	Unit: 0.000313 Price: 0.00156
3	January 28, 2016 at 02:52PM	Unit: 0.000543 Price: 0.00243
4	January 28, 2016 at 02:52PM	Unit: 0.000765 Price: 0.00321
5	January 28, 2016 at 02:53PM	Unit: 0.000983 Price: 0.00596
6	January 28, 2016 at 02:54PM	Unit: 0.001245 Price: 0.00721
7	January 28, 2016 at 02:55PM	Unit: 0.001765 Price: 0.00925

Fig. 10 Messages received in Google sheets

7 Conclusion

Wireless power transfer recommends the options of eliminating frequent option which is held with the cord connection which will be mandatory for the electronic gadgets. This promising technology when implemented in electric vehicles can reduce the negative impacts of conventional fuel vehicles, thereby improving the ecological balance. This paper substantiated one such method of wireless power transfer–inductive power transfer. This paper also focused on new innovative coil design and a novel method to measure the wireless energy consumed. The methods discussed in this paper are reliable and safe to use in a macroscale.

References

1. A. Costanzo et al., Electromagnetic energy harvesting and wireless power transmission: a unified approach. Proc. IEEE **102**(11), 1692–1711 (2014)
2. J. Garnica, R.A. Chinga, J. Lin, Wireless power transmission: From far field to near field. Proc. IEEE **101**(6), 1321–1331 (2013)
3. S.L. Ho, J. Wang, W.N. Fu, M. Sun, A comparative study between novel witricity and traditional inductive magnetic coupling in wireless charging. IEEE Trans. Magn. **47**(5), 1522–1525 (2011)
4. A. Kurs, A. Karalis, R. Moffatt, J.D. Joannopoulos, P. Fisher, M. Soljacic, Wireless power transfer via strongly coupled magnetic resonances. Science **317**(5834), 83–86 (2007)
5. M. Kline, I. Izyumin, B. Boser, S. Sanders, Capacitive power transfer for contactless charging. in *Proceedings IEEE Applied Power Electronics Conference Exposition,* (Fort Worth, TX, USA, 2011), pp. 1398–1404

6. S.Y. Hui, Planar wireless charging technology for portable electronic products and Qi. Proc. IEEE **101**(6), 1290–1301 (2013)
7. J.W. Nilsson, S.A. Riedel, *Electric Circuits*, 7th edn. (Pearson/Prentice-Hall, EnglewoodCliffs, NJ, USA, 2005), pp. 243–244
8. T. Imura, Y. Hori, Wireless power transfer using electromagnetic resonant coupling. J. Inst. Elect. Eng. Japan **129**(7), 414–417 (2009)
9. T. Imura, Y. Hori, Maximizing air gap and efficiency of magnetic resonant coupling for wireless power transfer using equivalent circuit and Neumann formula. IEEE Trans. Ind. Electron. **58**(10), 4746–4752 (2011)
10. T.P. Duong, J.W. Lee, Experimental results of high-efficiency resonant coupling wireless power transfer using a variable coupling method. IEEE Microw. Wireless Compon. Lett. **21** (8), 442–444 (2011)
11. T.C. Beh, M. Kato, T. Imura, Y. Hori, Wireless power transfer system via magnetic resonant coupling at fixed resonance frequency—power transfer system based on impedance matching. in *Proceedings World Battery Hybrid Fuel Cell*, (Shenzhen, China, 2010)
12. I. Awai, T. Komori, A simple and versatile design method of resonator-coupled wireless power transfer system. in *Proceedings of the International Conference Communication Circuits System (ICCCAS)*, (Chengdu, China, 2010)
13. A three phase wireless charging system for lightweight autonomous underwater vehicles, Published in *Applied Power Electronics Conference and Exposition (APEC)*, IEEE (2017)
14. W.-T. Chen, R.A. Chinga, S. Yoshida, A 36 W wireless power transfer system with 82 percent efficiency for LED lighting application. Trans. Japan Inst. Electron. **6**(1), 32 (2013)