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-REVIEW ARTICLE-

Demands in Wireless Power Transfer of both Artificial Intelligence and Industry 4.0 for Greater Autonomy

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Abstract

There are many autonomous applications in daily life and they are limited only by our engineering. It is critical barrier for Industry 4.0 to make efficient communication between all physical objects to transfer of information and power in today's technology. This paper presents the efficient wireless energy transfer methods for different applications which is already used and will be widely used for Artificial Intelligence technology. After the review of historical background, mostly used inductive coupling and capacitive coupling methods in Artificial Intelligence and their importance related with Industry 4.0 applications are demonstrated. Energy transfer demands for radio frequency identification (RFID) application are discussed with the definition of backscatter coupling. Finally, using wireless communication and power transfer methods for greater autonomy is investigated.

Keywords: Capacitive Coupling, Energy, Inductive Coupling, Industry 4.0, Power Transfer, RFID, Wireless

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Introduction

New technology era, named as Industry 4.0 is characterized by the collaboration between computers based elements and physical entities. Researchers are developing new intelligent applications for the field which will act as the eyes and ears of IT (Katrin, 2015). There are many automatic identification methods which play key role for Artificial Intelligence communication such as barcodes, optical characters, voice, fingerprint, radio frequency and etc. Power demands

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and transfer methodologies with different coupling methods will be the key points in the near future for more intelligent developments.

Today, one of the most important controllers is the electric power to detect the quality of life. Usually, this quality factor is transferred with wires. However, the existence of wires could be constituted a problem for transmitting electric power. Some of these problems are; heavy losses of power and high costs. According to these undesirable conditions have emerged wireless power transfer methods (WPT) (Mostafa et al., 2017). The ubiquitous WPT technology is integrated inside of many variety charging systems application. Wireless power transfer method provides many advantages for embedded circuitry. For instance, the galvanic isolation prevents transferred electric energy on foil surfaces from electro shocking to human beings (Sepahvand et al., 2015). While the wireless power transmission techniques are inquired, they can be diversified according their types. These are respectively; inductive coupling, capacitive coupling, magnetic resonance, laser, microwave (Yi, 2015).

Inductive wireless power transfer is the transmission of the electrical energy from a power source in order to drive an electrical load without any physical connections (Islam, 2011). Wireless power transfer system was asserted by Nikola Tesla in the 1890's using the patented 'Tesla coil' which is acted as resonant transformers (Hassan & Elzawawi, 2015). His main objective was to supply mains power wirelessly. However, at those days, wireless power transfer methods could not became popular regarding their low efficiency which is highly dependent to distance respectively (Jiang et al., 2012). With the recent advances, WPT technology has gained importance thanks to their advantages over conventional methods (Ali & Nugroho, 2016). Especially it is considered for the cases where the connection of wires may cause hazardous and dangerous incidents.

Medical implants had started to become objective of WPT during 1960s (Poon et al., 2010). The researchers from MIT carried out a WPT system configuration in order to power a light bulb of 60W with the distance from source over 2 meters in 2007. Today, demand of WPT technology for both consumer and industrial electronics arise rapidly. In market, wide range of applications are reported such as charging devices for cell phones, laptops, toothbrushes and shavers as well as sensors for rotating components, medical implants and subsea devices with the power transfer efficiencies up to 90% (Pinuela et al., 2013).

CPT method is based on electric line that it is used electric field lines in order to transmit power and data. Electric field line do not interference of stability of imbedded. Meanwhile, the design criteria of parallel capacitive plate are very suitable for power and data transfer in systems. The electric shock is obstructed by galvanic isolation where on the capacitive plates. However, CPT is effective less than 1 mm distance between two capacitor plates. Nevertheless, the efficiency of capacitive coupling is less than IPT. Although the efficiency of CPT is lower than IPT, these lower efficiencies were reached over 90% at 1 kW (Dai & Ludois, 2015).

Mostly used wireless identification method is RFID. It uses backscatter coupling technology for long range communication which will be discussed in chapter 4. The history RFID dates back to end of 1940s with the famous paper which was written by Harry Stockman on reflected power communication. After the development of radar and Friend of Foe (IFF) identification systems, technology became reality. With the help of theoretical developments and also laboratory experiments, RFID widely deployed and became a part of everyday life (Landt, 2005). At first glance, there are many potential hurdles for adoption like high cost values of IC chips or integration of the technology in to industrial applications (Chawla & Sam, 2007). But in reality product or application specific energy requirement is the most critical design issue for the engineers, especially for zero power consumption targets with Industry 4.0 applications.

Inductive Coupling Case

The type of WPT can be understood with help of wavelength of the antenna (1. Short range applications can be classified in the range of one antenna diameter whereas midrange applications are in the range of 10 times of antenna diameter.

$$\lambda = \frac{c}{f} \tag{1}$$

Inductive power transfer (IPT) is realized the power transfer with help of magnetic coupling between coils. Power is transferred by means of induced current on the receiver coil by the transmitter coil which is driven by source. IPT system can be short or midrange application depending on resonance configuration which can be on Table 1. Classification of IPT (Qiu et al., 2013).

Table 1. Classification of IPT

Energy-carrying medium	Technology	Power	Range	Efficiency
Electromagnetic	Traditional IPT	High	Low	High
Field	Coupled magnetic resonance	High	Medium	High

IPT system architecture can be seen in Figure 1.Fundamentals of IPT. It contains several modules. The system is powered via DC power supply which is also trigger oscillator unit. Both units come into power amplifier which is responsible to transform weak high frequency alternating signal to high frequency alternating current in order to excite transmitting coil. Power is transferred wirelessly to receiver coil that is located some distance away from transmitting coil with help of magnetic coupling. Transmitted power is rectified and regulated in order to drive load circuit.

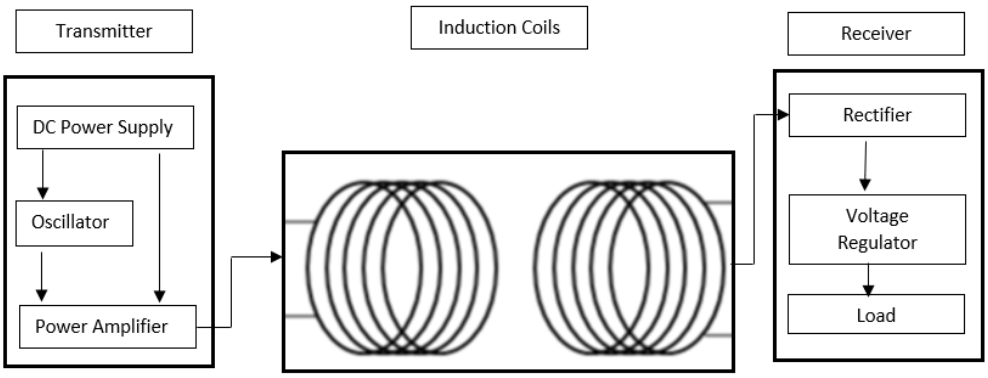


Figure 1. Fundamentals of IPT

Power transfer can be reached kilowatts range from miliwatts. Power transfer efficiency and reasonable operating range depends on the IPT configuration. One of the phenomenons is coupled magnetic resonance. In contrast to typical IPT configuration, RLC resonance circuits are integrated to both transmitter and receiver sides to enrich power transfer efficiency and transfer range. The difference between traditional IPT and coupled magnetic resonance IPT can be seen in Figure 2 (Qiu et al., 2013).

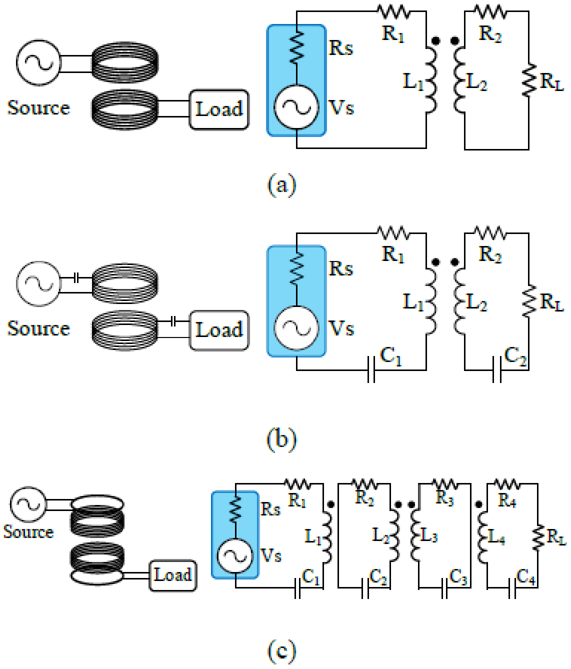


Figure 2. Topologies of (a) traditional IPT, (b) coupled magnetic resonance, (c) Strongly coupled magnetic resonance

There are four combinations for resonant circuits and the choice of configuration depends on the application. Objective is to vanish reactance part of both load and source impedances and to reduce VA rating .(Xia et al., 2012).

Resonant frequency of the system can be calculated as Eq.2.

$$\omega_0 = \frac{1}{\sqrt{L_{Tx}C_{Tx}}} = \frac{1}{\sqrt{L_{Rx}C_{Rx}}} \tag{2}$$

Class-E power amplifiers are used to achieve high switching speed in case of high operation frequencies as seen in Figure 3 (Casanova et al., 2009).

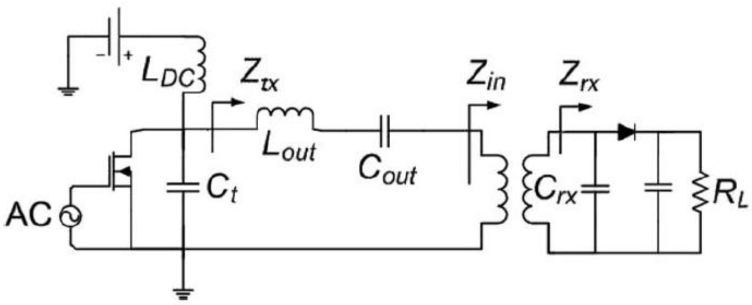


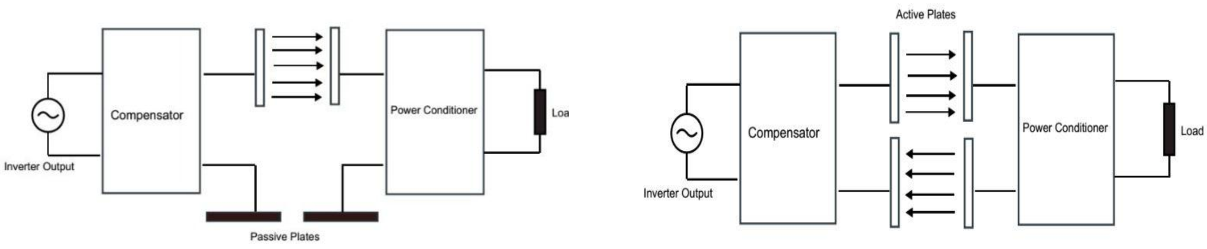
Figure 3. Class-E power amplifier circuit

Basically, class E amplifier consists of a MOSFET whose gate is driven by an oscillator. RF choke is connected serial to DC power supply in order to ensure only constant DC voltage is supplied. A shunt capacitor which is connected parallel LC resonator circuit is the components left to complete the circuitry. MOSFET acts as an on off switch and theoretically, do not appear at the same time and product of voltage and current is always zero (Sokal, 2001). Efficiency is dependent to power dissipation which is caused by switching losses and reflected signals.

Since efficiency levels rise rapidly, there is growing demand for wireless technology for Industry 4.0 applications such as wireless sensors, wireless charging, devices of measurement and monitoring for rotating components.

Capacitive Coupling Case

The basic concept of wireless power transmission (WPT) with capacitively, relies on polarized capacitors. In order to understand the operating logic of capacitors, the fundamental formulas should be investigated which have been demonstrated since past. However, this logic is provided by certain materials which are respectively, one coupling capacitor plates and dielectric materials. There are two different types capacitive power transmission method exists. The general demonstration of these designs was shown in Figure 4 (Rozario, 2016).



(a) (b)

Figure 4. Unipolar demonstration coupling (a), Bipolar demonstration of capacitive coupling (b)

However in order to achieve high transferred energy the distance between two coupling capacitors should be minimized as much as possible as aforementioned by Dai & Ludois (2015). If the starting point is tried to research, the basic formulas for capacitors should be considered as given Equation 3.

$$Q = V \times C \tag{3}$$

V, C and Q are respectively represented the voltage, capacitance and charge. The capacitance of capacitor is calculated with respect to Equation 4.

$$C = \varepsilon \frac{A}{d} \tag{4}$$

In equation, d shows that the distance between two capacitor plates. A represents the cross-sectional area of capacitor plates. ε is the permittivity of free space. Generally, equation 4 is not enough in order to evaluate the equivalence capacitance of circuit. Equation 5 and Equation 6 are used for evaluating equivalent capacitance of circuit parallel and series connection respectively. Current that can be stored by capacitor is calculated with Equation 7.

$$C_{eq} = C_1 + C_2 + C_3 + \ldots + C_n \tag{5}$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n} \tag{6}$$

$$i = C \frac{dv}{dt} \tag{7}$$

In order to provide the energy and data transfer, the resonance of tank circuit should be used. The specifications of tank circuit were given on Table 2 (Nilsson & Riedel, 2011).

Table 2. General demonstration of components

Component	Resistance	Reactance	Impedance
Resistor	R	0	$Z_R = R$ $= R\angle 0^0$
Inductor	0	$2\pi fL$	$Z_R = j\omega L$ $= \omega L\angle +90^0$
Capacitor	0	$-\frac{1}{2\pi fC}$	$Z_c = \frac{1}{j\omega L}$ $= \frac{1}{\omega L}\angle -90^0$

According the last decade development, capacitive coupling method is widely used. Today, ubiquitous capacitive power transfer method was evolved beyond bio-signal, biomedical implementation, imbedded system, wireless charger circuitry, amplifiers, LED, electric vehicles, robotic application. Capacitive coupling technique was used variously applications with respect to these formulas. According to these, capacitive coupling method could be very useful for industry 4.0. For example, the power supply of fully automated systems could be provided by capacitive coupling in order to get rid of wire system which can be easily deformed. The most important advantage of capacitive coupling method is that the electric field lines are used when energy is transferred another capacitor plate. Therefore, as mentioned before, unlike magnetic field, electric field lines do not interference through the stability of fully automated imbedded system. Besides, data can be transferred while power is transferred at the same frequency. Therefore, there would not communication interruption in industry 4.0 at information transfer according to executed study from past to present. In the absence of wires, the industry 4.0 becomes quite compact. The cable connection suffers from axial rotation or movement of robotic parts. Especially, capacitive coupling method could be very useful for robotic arm sections. As mentioned before, the data and power can be transferred at the same frequency by capacitive plates. Therefore, if capacitive power transfer (CPT) technique will be applied for the data and power requirement of systems, these systems will be cost-effective, compact, and confident which has been shown in Figure 5 (Oh Eunjeon, 2018).

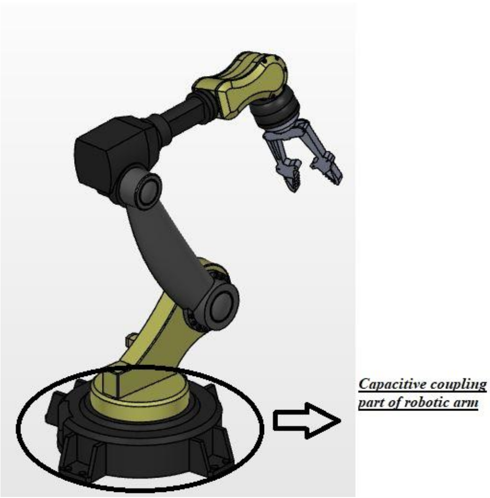


Figure 5. The capacitive coupling application with robotic arm

With the usage of capacitive coupling technique in robotic arm architecture, the business or task will not interrupted by the damaged wire connections. Additionally, electric field lines will not interference to stability of systems when data and power is transmitted.

Backscatter Coupling Case

RFID systems are classified related with the gap between the reader and the transponder. If this gap is greater than 1 meter, they are called long range systems. They are operated at the Ultra-High and microwave frequencies with far field coupling methods and require different amount of energy transfer. If the communication gap is smaller than 20cm, systems are operated with near field coupling methods and generally operated with 13, 56 MHz frequencies (Finkenzeller, 2010).

There are many coupling methods for the radio communication such as backscatter coupling, close coupling, electrical coupling and etc. It is critical to choose optimized method related with the suitable application considering the communication range, energy requirements and the property of tracked targets. In our research energy requirement of backscatter coupling and the use of this method are investigated for healthy RFID communication specialized for Industry 4.0 applications.

In physical meaning, backscattering means the reflection of electro-magnetic waves, particles, or signals back to the direction they came from. Reflected weights travel not only in one direction, but also in many other directions (Shen, 2010). Passive tags and the readers have coil which can cause slight fluctuations. The RF link acts actually as a transformer; as the tag coil is momentarily shunted, the reader winding experiences a momentary voltage drop. This amplitude-modulation loading of the reader’s transmitted field provides a back scatter path to the reader. The data can be modulated in a number of methods (Sorrels, 1998).

Minimum energy requirements to track a transponder are generally no more than 5 μW levels. This situation changes related with the communication distance and also application specific properties. As an example energy requirement of the RF communication related with the communication distance is seen on Table 3 which uses Piezo inside (Fan et al., 2010).

Table 3. Required Energy with Distances

Transmission Distance L(mm)	30	40	50	60
Required min. Energy E_p (μW)	98	169	264	510

An electromagnetic field is the combination of an electric field and a magnetic field which oscillates in phase perpendicular to each other and orthogonally to the energy propagation. Electromagnetic waves will propagate an electrical current through any conductor element which it passes. This is where the passive RFID transponders scavenge their energy from. Application specific power demands are seen in Figure 6. RFID tags require about 1 to 10 μW levels for the communication.

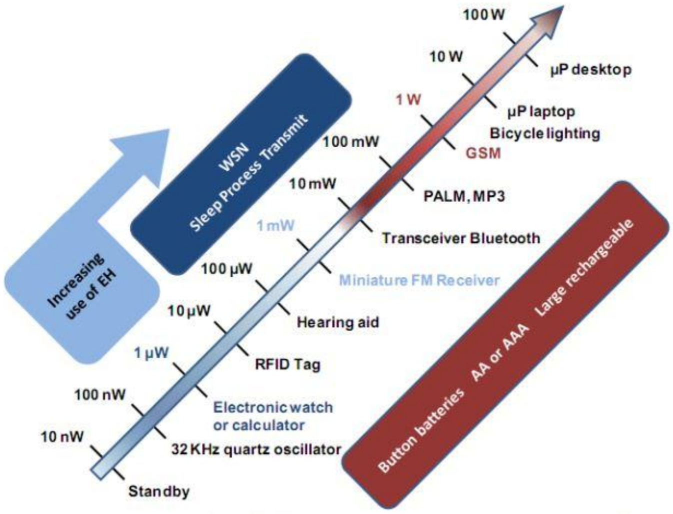


Figure 6. Power demands in micro levels (Adair, 2005)

For this coupling method, free space loss is the key parameter for the determination of power demands because it has many reflected wave directions as discussed. Free space loss is a measure of the relationship between the RF power emitted by a reader and the RF power harvested by the transponder.

As a calculation, path loss can be classified as Eq.8 with dB levels (Sayre, 2008).

$$Path\,Loss(dB) = 40 + [35\log(D)] \quad (8)$$

D = Indoor distance between transmitter and reader, m

RFID technology with backscattering communication will be widely used in condition monitoring and fault detection applications for Industry 4.0 targets with the help of sensing elements such as vibration, temperature, position, force, flow and etc. For greater autonomy in a production line, all components can be identified with a tag which has less energy consumption for Artificial Intelligence products.

Conclusion

Demands in wireless power transfer is expanding and becoming more attractive especially with Industry 4.0 applications. Power management with circuitry allows energy harvesting from multiple sources such as Piezo elements (Priya & Inman, 2009) or engine vibration (Kinergizer, 2018) for future researches.

As a result, all coupling methods will be widely used technologies to supply power for artificial intelligent systems. These wireless systems are very compact and reliable for industry 4.0 applications.

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Conflict of Interest:

The authors declare that they have no conflict of interest.

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