A DISSERTATION

ON

# "COMPARATIVE STUDY OF NEAR FIELD WIRELESS POWER TRANSMISSION TECHNIQUES (INDUCTIVE COUPLING AND RESONANT INDUCTIVE COUPLING)"

*in partial fulfillment for the award of the degree*

**Of**

**MASTER OF TECHNOLOGY**

**in**

**ELECTRICAL ENGINEERING**


***Submitted by***

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## CERTIFICATE FROM THE PROJECT SUPERVISOR

This is to certify that the project **" COMPARATIVE STUDY OF NEAR FIELD WIRELESS POWER TRANSMISSION TECHNIQUES(INDUCTIVE COUPLING AND RESONANT INDUCTIVE COUPLING)"** has been carried out and presented by **PRACHURYA CHOUDHURY , Roll No.210620064016,** student of M. Tech 4$^{th}$semester of Department of Electrical Engineering, Assam Engineering College, Guwahati, under my supervision and guidance in a manner satisfactory to warrant its acceptance as prerequisite for the award of Masters of Technology of the Assam Science and Technology University. Further the report has not been submitted /reported in any form for the award of any other degree/diploma.

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# ABSTRACT

Considering the massive development that took place in the past two decades, wireless power transfer has yet to show the applicability to be used due to several factors. This work focuses on determining the main parameters like, mutual inductance, coupling coefficient for a pair of helical coils and parameters for matching network for wireless power transfer applications. These parameters are important in designing and analysing a wireless power transfer system based on the phenomenon of inductive/ resonant inductive coupling. Here a simple approach based on fundamental laws of physics has been presented for determining the coupled coil parameters for single layered helical coils. The results are obtained by computer simulation by using MATLAB. Furthermore, this analysis is used to study the effect of change in coupling coefficient by changing the distance between coils on parameters like self and mutual inductance of coupled coils which is of great importance in Wireless Power Transfer applications. Here a comparative study is also done between inductive and resonant inductive coupling wireless power transmission technique. The research yielded promising results to show that wireless power transfer has huge possibility to solve many existing industrial problems.

# CONTENT

# List of Figure

# List of Table

## ABBREVIATIONS

| | |
|---|---|
| WPT | Wireless Power Transmission |
| IWPT | Inductive Wireless Power Transmission |
| RIWPT | Resonant Inductive Wireless Power Transmission |
| MAV | Micro Aerial Vehicle |
| Rx | Receiving Coil |
| Tx | Transmitting Coil |
| IEEE | Institute of Electrical and Electronic Engineers |
| ICNIRP | International Commission for Non-Ionizing Radiation Protection |
| WPC | Wireless Planning and Consortium |
| A4WP | Alliance for Wireless Power |
| PMA | Power Matter Alliance |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

During last few decades wireless power transfer has got attention from researchers and inventors because this technology has opportunity to improve lifestyle in this era for human being. To transfer the electrical power from one place to another place, copper cable is usually used as a medium. For example the fluorescent lamp needs copper cable to carry the current, in other words to carry the power to fluorescent lamp. So, the wireless power gives something new for the electrical appliance like fluorescent lamp which is the new concept to transfer the power without using cable but by using electromagnetic wave or other medium.

Currently researchers are trying to discover how to increase the efficiency of power transmitted wirelessly and also methods that are safe to human beings and the environment and also the methods that are cheaper and hence can be commercially viable.

Wireless power transmission (WPT) is based on the principle of electromagnetic induction. Electromagnetic induction works on the concept of a primary coil generating a magnetic field and a secondary coil being within that field, a current is induced within its coils. This effect is obtained within a relatively short range due to the amount of power required to produce an electromagnetic field.

## 1.2 Problem Statement

The project seeks to eliminate the use of wires in the transmission of power from the source to the device to be powered. Although WPT is based on electromagnetic induction, there are various methods that are used for this purpose. Some are less efficient than others and costly while others don't allow for a longer range of transmission. In this project, it is required to design two systems that will transmit power within a small range and a comparative study is carried out between them.

In this project a suitable method will be used to ensure that enough power is transmitted wirelessly to the load. The major challenge will be the design of the coupling circuit which comprises of the coils where electromagnetic induction occurs.

### 1.3 Overall Objective

To develop and compare two near field wireless power transmission Techniques.

#### 1.3.1 Objective

The main objective of the project is to develop inductive wireless power transmission system and resonant inductive wireless power transmission system and to have a comparison between the two.

### 1.4 Justification for the Study

The need for devices that can wirelessly transmit power has increased over the years. Currently a lot of research has been conducted in order to obtain suitable methods that can be used in the development of such devices. The following are reasons why it is important -

a) **Flexibility:** WPT will eliminate the use of conductors and wires. Rather than having many wires running from a power source to power devices, the power can be transmitted wirelessly hence the mess caused by cables can be avoided and also more devices can be powered without having them all placed next to the power source.

b) **Safety:** With the increase in electrification in areas, cases of electrical shocks have been rampant as people and even animals end up touching the conductors. WPT will eliminate these conductors hence preventing the electrical shocks.

c) **Convenience:** The application of WPT will enable the convenient use of devices. For example, in the medical field pacemakers which use batteries can be recharged rather than having a surgery every time the battery life is over. This will save the costs for surgery and also is a more convenient option.

d) **Reliability:** Many times people are using a device and it runs out of power yet one doesn't have a cord to charge the device or perhaps there is no source of power around. However, with WPT the devices can be charged wirelessly hence the risk of low battery power will be eliminated.

### 1.5 Scope of Work

The study has looked into the methods that are currently in use and seek to improve on the areas where the performance is low

# CHAPTER 2
# LITERATURE REVIEW

## 2 Outline of the Chapter

This chapter contains an evaluation of the current work with respect to the existing works. It is devoted to a critical review of the technical and academic literature on previous works done on wireless power transfer.

Approach adopted: The following approach is adopted for this chapter;

- History of Wireless Power Transfer
- Review of previous works
- Main concepts of wireless transmission of electric energy
- Health and safety considerations
- WPT Standards and Alliances

## 2.1 History of Wireless Power Transfer

wireless power transfer is the transmission of electrical energy from a power source to an electrical load, such as an electrical power grid or a consuming device, without the use of discrete man-made conductors.

Wireless power transmission (WPT) is one of the fields of engineering that has in the past few years received a lot of attention. A lot of companies are spending millions of dollars trying for research and develop ways of transferring power wirelessly. However the concept of WPT has been in existence for over a century.

This concept was first discussed in the late 19th century. Nikola Tesla was the brains behind this concept. He together with Heinrich Hertz theorized the possibility of power being transmitted wirelessly. Tesla's main idea was to use the planet as the conductor to transmit power to any point on the earth. In 1897, he filed his first patents dealing with Wardenclyffe tower. This tower was supposed be a pilot plant for his "World Wireless System" to broadcast energy around the globe. But he was not able to make it fully operational due to economic problems. In 1901 Tesla built the Wardenclyffe Tower.In 1899 Tesla performed experiments in the field of pulsed wireless energy transfer. Tesla's Magnifying Transmitter, an early type of Tesla Coil that measured 16 meters in diameter, was able to transmit tens of thousands of watts without wires. [10]

Figure 2.1Wardenclyffe Tower

His intentions were to use it to transmit messages and also to incorporate his WPT ideas. This however wasn't fruitful as his financer refused to invest in the project. Tesla's ideas were then dismissed as being impractical and unsafe.

Later on William C. Brown came up with the theory of microwaves. His idea focussed on beaming electric power from one point to another without wires through vacuum tubes and solar power satellites using microwaves. Around 1960, he invented the rectenna which converts microwave to dc power. This was a major breakthrough in WPT. This contributed much to the modern development of microwave power transmission which forms a major basis of the research and development of WPT currently. The next step towards WPT was development of the RFID system.

## 2.2 Review of Previous Work

- Manish Bhardwaj[1], Anil Ahlawat[2] describes all the practical methods for electricity transmission without wires that have been suggested. This research is crucial for determining how power will be transmitted in the future. These techniques are crucial in today's planet as a result of massive electricity waste. A point-to-point control transmission is a typical method of wireless power transmission. The efficacy of the power transfer was shown to be close to 100%.[6]

- A. Mahmood et al. offers a thorough examination and in-depth study of the various methods for wireless power transfer. The function of wireless power transfer in smart grid applications such as electric car charging has also been discussed. For low power and short-distance applications, feasibility, implementations, operations, results, and comparisons between various approaches have been carried out in order to find the most advantageous and cost-effective approach.[5]

- Christoph Degen provides an overview of magnetic coupling-based wireless power transfer system optimization. The goal of optimization is to increase either the transmitted power or the efficiency of power transmission. The load computation and matching techniques that resulted are reviewed. Additionally, the description of the coupling system is given, starting with its equivalent circuit and scattering parameters. Wireless communication in RFID and NFC systems, as well as its frequency characteristics and bandwidth problems, are highlighted in addition to wireless power transmission. In this study, load modulation for data transmission between a tag and reader is the main topic. Subcarrier voltages are calculated for this purpose utilising both time-domain and frequency-domain signal analysis.[3]

- Shubham1and Er. Naveen Chander provides an analysis and design for wireless power transfer using inductive coupling.Electric power can be transmitted wirelessly by passing through an air gap without the need of cables.In order to charge smart phones and other electronic devices without coming into touch with wires, this is utilised to transmit power over a short distance. Inductive power transmission has been utilised to transmit electricity over short distances. Coil construction types and variables influencing coil inductance have been provided for effective wireless power transfer. For effective wireless power transmission, calculations of a number of parameters, including output voltage, output current, self and mutual inductance, coupling coefficient, voltage and current across inductor for various turn ratios, have been provided. Additionally, the Proteus programme was used to simulate the circuit in order to verify the experimental results.[2]

- Ibrahim Alhamrouni et al. focussed on calculating key variables for a pair of helical coils used in wireless power transfer applications, such as mutual inductance and coupling coefficient. These variables play a crucial role in the design and analysis of wireless power transfer systems that rely on the inductive/resonant inductive coupling phenomena. His study outlined a straightforward method for figuring out the linked coil parameters for single-layered helical coils that is based on fundamental physics rules. The computer simulations wasperformed with MATLAB. Additionally, this research is utilised to investigate how characteristics like self and mutual inductance of linked coils—which are crucial in Wireless Power Transfer applications—are affected by changes in coil diameter, mutual inductance coefficient and distance between coils. The study's encouraging findings demonstrate the great potential of wireless power transfer to address a variety of current industrial issues.[1]

- Gregory Michael Plaizier provides the design, modeling, and experimental validation of an inductively coupled wireless power transfer (WPT) system to power a micro aerial vehicle (MAV) without an onboard power source. MAVs are limited in utility by flight times ranging from 5 to 30 minutes. Using WPT for MAVs, in general, extends flight time and can eliminate the need for batteries. In this paper, a resonant inductive power transfer system (RIPT), consisting of a transmit (Tx) coil on a fixed surface and a receive (Rx) coil attached to the MAVis presented and a circuit is described. The RIPT system design is modelled to determine a suitable geometry for the coils, and the model validated experimentally. It is found that for the MAV used in this work a suitable geometry of coils is a 19cm diameter planar spiral Tx coil made with 14 AWG copper wire, seven turns and 5cm pitch paired with an Rx coil made of 16-20AWG wire, 13cm–20cm diameter, 1mm pitch and one to two turns. A demonstration of an MAV being powered 11cm above the Tx coil with the WPT system in a laboratory setting is presented. The MAV consumes approximately 12 Watts. The overall power efficiency of the RIPT system from RF power source output to MAV motors is approximately 32%.[8]

- Marco Dionigi et al. provides a general overview of magnetic resonant wireless power transfer systems based on network models. The power transferred to a receiver load at resonance is derived and explained. The importance of using appropriate matching networks is also shown and designing of the oscillator and the load rectifier are also presented.[9]

- PuteriAthira et al. focuses on the design of a resonant inductive coupling using parallel-T topology in coupling WTR and combination of single transmitter with multiple receivers. In addition, principle of magnetic wave between the transmitter and receiver with related parameters is utilized to develop WPT. A parallel-T topology that consists of T-matching network for secondary side is proposed as it is more suitable for weak coupling wireless power transfer applications. Besides thatthree circuits are designed to show the resonant inductive coupling for WPT including the circuit with and without matching network and the circuit of single transmitter with multiple receivers. The simulation of output voltage and output current are observed to relate the effects of frequency on the circuit. The graph of output voltage and power are plotted to show the pattern on effect of the frequencies to the resonant inductive coupling circuit.[4]

- Qiaowei Yuan et al. Proposed that A practical wireless power transmission system consisting of a large rectangular wire loop and a small square wire loop with a parasitic square helical coil is proposed for use as an efficient evanescent resonant coupling wireless power transmission system in an indoor environment. In addition, a full wave-based numerical analysis on the resonant frequency of and the power transmission efficiency of wireless power transmission system are performed in this work. The effects of the following on power transmission efficiency and the resonant frequency are numerically investigated: The load of the receiving element and the presence of non-resonant objects such as a conducting box or human body. The numerical results show that a power transmission efficiency of nearly 50% can be achieved when the proposed system is used to charge only one user with the optimized load. The results also show that power transmission efficiency is reduced significantly when a human body is in very close proximity to the receiving element. This reduction in efficiency can be alleviated significantlyif the relative distance between the receiving element and the human body is greater than 0.5 m or at a resonant frequency of 19.22 MHz.[7]

- Yao Guo et al. have Proposed a novel parallel-T resonant topology consists of a traditional parallel circuit and a T-matching network for secondary side .With this method, a boosted voltage can be output to the load, since this topology has a resonant enhancement effect, and high Q value can be obtained at a low resonant frequency and low coil inductance. This feature makes it more suitable for weak coupling WPT applications. Besides, this topology shows good frequency stability and adaptability to variations of load. Experimental results show that the output voltage gain improves by 757% compared with traditional series circuit, and reaches 85% total efficiency when the coupling coefficient is 0.046.[10]
- Siqi Li et al. proposes a double-sided LCC compensation network and its tuning method for wireless power transfer (WPT). With that topology and its tuning method, the resonant frequency is irrelevant with the coupling coefficient between the two coils and is also independent of the load condition, which means that the system can work at a constant switching frequency. Analysis in frequency domain is given to show the characteristics of the proposed method. They also propose a method to tune the network to realize zero voltage switching (ZVS) for the Primary-side switches. Simulation and experimental results verified analysis and validity of the proposed compensation network and the tuning method. A wireless charging system with output power of up to 7.7 kW for electric vehicles was built, and 96% efficiency from dc power source to battery load is achieved.

### 2.3 Main concepts of wireless transmission of electric energy

As a result of the extensive research in WPT, various categories have arisen. WPT can be categorized in terms of efficiency, distance of transmission, power level and size. Classification based on distance of transmission however is more relevant.

For any electromagnetic source both electric (E-fields) and magnetic (H-fields) fields are generated around it. These fields are characterized by the radiative and non-radiative components. Depending on the distance from the source they can either be near field, transition zone or far field. The transition zone possesses characteristics of both the near and far field transfers.

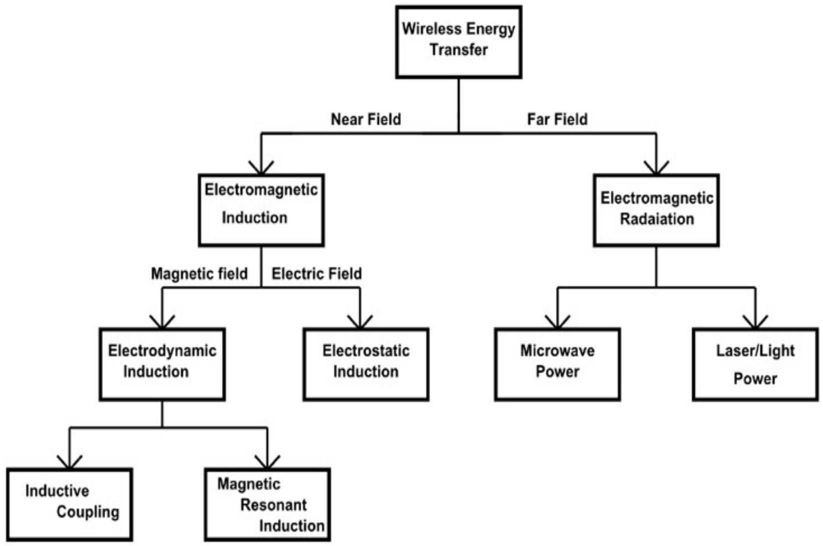


Figure 2.2 Classification of WPT

The near field region can be found within the radius of a wavelength while far field region is the area outside a radius of two wavelengths. This however is for transmitters and receivers that have diameters shorter than the wavelength being used. The near field transfers have all the polarization types i.e. vertical, horizontal, elliptical and circular while the far field transfer has only one type.

The near field transfer has been found to have a higher efficiency during transfer of power. This can be attributed to the decrease in both electric and magnetic fields proportionally to the distance from the source. In addition, the near-field region allows higher diffraction of the wave, resulting in stronger penetrability and weak directivity on a short range. In light of all these, more research is being focused on development of the near field transfers as compared to far field transfer.

Both near field transfer and far field are further categorized based on the method of operation of the transfer. Some of the methods are as follows:

**Far Field Transfer**

**a. Microwave Transmission**

Microwave transmission alludes to the innovation of transmitting data or vitality by the utilization of electromagnetic waves whose wavelengths are advantageously measured in little quantities of centimetre; they are called microwaves. The remote vitality exchange with microwaves requires a wellspring of electromagnetic radiation, and a microwave recipient with a DC rectifier to change the microwave vitality into DC electrical power. The transmitting and getting units must be in viewable pathway. Viewable pathway (LoS) is a sort of proliferation that can transmit and get information just where transmit and get stations are in perspective of each other with no kind of a hindrance between them. The electrical vitality is first changed over into microwave energy in the transmitter which is transmitted over separation to beneficiary which has rectenna that changes over these microwaves back into electrical vitality. Air conditioning can't be changed over specifically to microwave in a transmitter. To start with it must be changed over to DC utilizing oscillator. In the beneficiary, the output DC from rectenna is changed over to AC for utilize. Power radiating by microwaves has the trouble that for most space applications the required gap sizes are extensive because of diffraction constraining radio wire directionality. Remote high power transmission utilizing microwaves is well demonstrated. Investigations in the many kilowatts have been performed at Goldstone in California in 1975 and all the more as of late (1997) at Grand Bassin on Reunion Island. These strategies accomplish removes on the request of a kilometre. Under exploratory conditions, microwave transformation proficiency was measured to be around 54%.[6]

**b. Laser Transmission**

A laser is a gadget that produces light through a procedure of optical enhancement in view of the invigorated outflow of electromagnetic radiation. A laser varies from different wellsprings of light since it radiates light rationally. Spatial rationality enables a laser to be engaged to a tight spot. The instrument of creating radiation in a laser depends on invigorated discharge, where vitality is extricated from a progress in a particle or atom. Power can be transmitted by changing over power into a laser bar that is then pointed at a photovoltaic cell . This component is mostly known as "control radiating" since the power is channelled at a collector that can change over it to electrical energy. There are parcel of favourable circumstances in this framework It permits limit bar traverse huge separations; Compact size; No radiofrequency obstruction to existing radio correspondence. There are different drawbacks too. Laser radiation is unsafe. Change amongst power and light is wasteful. Photovoltaic cells accomplish just 40%—half productivity. Barometrical ingestion, and retention and dissipating by mists, mist, rain, and so on . It requires an immediate viewable pathway with the objective. This technique has been utilized as a part of military and aviation applications.[6]

## Near Field Transfer

### a. Inductive Coupling

Two conductors are eluded to as common inductively coupled when they are arranged with the end goal that adjustment in current stream through one wire initiates a voltage over the closures of the other wire through electromagnetic enlistment. In remote exchange, a segment of the attractive transition set up by one circuit interlinks with the second circuit, at that point two circuits are coupled attractively and the vitality is exchanged from one circuit to the another circuit The essentials of this procedure is that the transmitter and recipient curls are inductively coupled. Oscillators are utilized as a part of transmitters to change over DC current to AC current. The AC current go in the transmitter loop produces attractive field, which incites a voltage in beneficiary curl. Magnetic Field is packed in little volume amongst transmitter and collector. The beneficiary has a rectifier those believers Air conditioning once again into DC for utilize. The voltage controller is intended to keep up a steady voltage. The impact of inductance can be amplified or increased through winding the wire. Inductive coupling vitality exchange conveys a far lower danger of electrical stun, at the point when contrasted and conductive charging, on the grounds that there are no uncovered conductors. The principle detriment of this strategy is its lower productivity and expanded resistive warming in contrast with coordinate contact. Inductive charging additionally requires drive hardware and curls that expansion fabricating multifaceted nature and cost. Remote charging cushion, electric brush, transformer work in view of this idea.[6]

### b. Resonant Inductive Coupling

Resonant inductive coupling is transmitting power between two loops that are tuned to reverberate at a similar recurrence. Resonance happens when the self resounding recurrence of loops equivalent to the recurrence of AC control supply, when the equal circuits of loops in high recurrence have the base impedance. At that point, the most vitality will be exchanged from the thunderous way. Full exchange works by influencing a capacitive stacked essential to curl ring with a swaying current.

Resonant Frequency =Capacitance of the plate *Inductance of curl

This produces a wavering attractive field. Since the loop is exceedingly resounding, any vitality set in the curl withers away generally gradually finished a lot of cycles; however in the event that a moment curl is brought close it, the loop can get the majority of the vitality before it is lost, even in the event that it is some separation away. The fields utilized are predominately non-radiative. Attractive resounding coupling can likewise be used to convey control from an expansive source curl to one or numerous little load loops with lumped capacitors at the loop terminals giving a straightforward intends to coordinate full frequencies for the loops. In this strategy, misfortunes happen because of ohmic protection furthermore, radiation. Some of these remote resounding inductive gadgets work at low milliwatt control levels and are battery fuelled. Others work at higher kilowatt control levels. All the gadgets which are used at the certain area get power from the transmitting curl and this transmission is effective upto 75% . The power transmission between the curl is reduced after a certain distance that varies between 10 cm to 2.2 m.[6]

## 2.4 Health and safety considerations

Wireless power transmission is largely based on the radiation of electromagnetic fields. However, there are safety limits that determine the levels of human exposure to electromagnetic fields. Currently two world bodies give directives on the human exposure guidelines. These are Institute of Electrical and Electronic Engineers (IEEE) and the International Commission on Non-lonizing Radiation Protection (ICNIRP).

The main standards are: "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" (IEEE C95.1-2005) and "ICNIRP Guidelines For Limiting Exposure To Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz).

The purposes of the IEEE and ICNIRP guidelines are similar:

*"The purpose of this standard is to provide exposure limits to protect against established adverse health effects to human health induced by exposure to RF (radio frequency) electric, magnetic, and electromagnetic fields over the frequency range of 3 kHz to 300 GHz. "[IEEE]*

*"The main objective of this publication is to establish guidelines for limiting EMF (electromagnetic field) exposure that will provide protection against known adverse health effects. An adverse health effect causes a detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect on the other hand, may or may not result in an adverse health effect".* [ICNIRP]

Both the IEEE and ICNIRP groups in their recent publications claim that there is no justified evidence to show that human exposure to radio frequency (RF) electromagnetic fields causes cancer, however evidence shows that RF electromagnetic fields could actually raise the temperature of a human which causes heating up of body tissues and may stimulate nerve and muscle tissues. It is in that respect that both bodies recommend limiting human exposure to electromagnetic field strengths to levels safely below those that cause harm to human beings. In the case of tissue heating, the IEEE and ICNIRP recommend limiting the specific absorption rate or SAR, a measure of the amount of electromagnetic energy absorbed by the human body and turned into heat. In the case of electro-stimulation of nerve and muscle tissues the groups recommend limiting the internal electric field.

## 2.5 WPT Standards and Alliances

**Qi by the Wireless Power Consortium (WPC)**

The Qi standard is an inductive coupling power transfer interface standard developed by the Wireless Power Consortium (WPC). The Consortium was founded in 2008 as cooperation between European, American and Asian companies in different industries in order to develop a global standard for the inductive charging technology. The most prominent members include Motorola Mobility Inc., Microsoft Corporation, Nokia, ASUSTek Computer Inc., LG Electronics, Sony Corporation, HTC Corporation, TDK Corporation and Texas Instruments.

**Rezence by the Alliance for Wireless Power (A4WP)**

Rezence is a magnetic resonance power transfer standard developed by the Alliance for Wireless Power (A4WP). A single transmitter can power up to eight receiver devices on mid-range distances. Communication between transmitter and receiver is "out-of-band" and implemented via Bluetooth. The A4WP was founded in early 2012 in order to develop a ubiquitous WPT ecosystem. The most prominent members include Broad-com, Panasonic, Microsoft Corporation, LG Electronics, Samsung, Logitech, WiTricity, Qualcomm, Incorporated, Gill Electronics, Hewlett Packard, Integrated Device Technology, Inc., Intel and others.

**Power Matters Alliance (PMA)**

Power Matters Alliance (PMA) is a non-profit organization, which develops inductive and resonant power transfer standards. PMA was founded in 2012 in order to technically harmonize and advance multiple inductive WPT standards, promote WPT within the automobiles industry and popular public infrastructure venues. The most prominent members include Duracell Powermat, LG Innotek, Panasonic Corporation, Samsung Electronics, Toshiba Corporation, Sony Corporation, Energous Corporation, Freescale Semiconductor Inc., Integrated Device Technology (IDT) and Microsoft Corporation.

A summary of the main WPT Interface Standards and Alliances as of January 2015.

Table 2.1 Summary of main WPT Interface 1

| Organization | WPC | PMA | A4WP |
|---|---|---|---|
| Established | 2008 | 2012 | 2012 |
| Number of members | 203+ | 80+ | 140+ |
| Transfer type | Inductive Coupling | Inductive Coupling | Magnetic Resonance |
| Max. power transfer | 5w (10-15w) | 5w (10-15w) | Up to 50 w |
| Range | Short Range | Short Range | Mid Range |
| Transfer frequency | 100-205 KHz | 277-357 KHz | 6.78 MHz |
| Latest version | 1.1.2 | PMA1.1 | A4WP-S-0001 v1.2 |
| Certified Products | 684 | 24 | - |
| Authorized test labs | 10 | 3 | 2 |

# CHAPTER 3
# THEORITICAL FRAMEWORK

## 3 Theory of wireless power transmission systems

### 3.1 Wireless transfer by Inductive Coupling

This chapter elaborates on the method of wireless power transfer based on inductive coupling. The concept of transmitting power wirelessly is based on electromagnetic fields, precisely due to electromagnetic induction. Among all of the methods, this is the simplest method, this concept is very simple to understand because it uses the mutual induction concept just like electrical transformers. [9]

Considering two inductors of values L1 and L2 coupled via their mutual inductance M as shown in Figure, the power will transmit from the L1 to L2 by electromagnetic wave that was created by the first coil. This is because when the current goes through conductor (coil) the magnetic flux will be produced. So, the magnetic flux that has been produced from the first coil will move to the second coil L2 and cut the coil. From basic electromagnetic induction when the magnetic flux cut the conductor electric current will induce. After that, the current will flow to the load as an AC current. The rectifier will convert the AC current to DC current if the load requires a DC supply. In the frequency domain the two port network corresponding to coupled inductances has an impedance representation of the type:

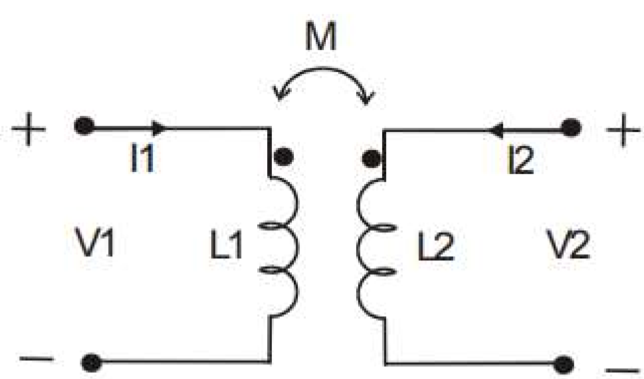


Figure 3.1 Coupled inductors may be used to represent magnetic coupling

$V_1=j\omega L_1 I_1+j\omega M I_2$

$V_2=j\omega M I_1+j\omega L_2 I_2$

The energy coupling is achieved because the receiver inductor actually intercepts a part of the magnetic field produced by the transmitter. The coupling coefficient k is typically used to represent the efficiency of energy transfer from the transmitter coil to the receiver coil.This coupling coefficient is given by the expression in terms of the mutual inductance and the self-inductances[9]:

$$k=\frac{M}{\sqrt{L1\ L2}}$$

The power coupling is seen in the transmitter as a product of the mutual inductance M and the current $I_2$ flowing in the receiver. At the receiver power coupling is due to the current $I_1$flowing in the transmitter being coupled through the mutual inductance as well. The coil inductance expressed in μH of a coil of total length Le , diameter D (expressed in meters) and N turns is given by [9]:

$$L=\frac{(ND)^2}{\sqrt{Le+0.45D}}$$

By denoting with Ri the radius of the i-th coil and by r the distance between the centers of the resonators we can compute the magnetic coupling factor as[9]:

$$K=1.4\frac{(R1R2)^2}{\sqrt{(R1^2+r^2)^3}\sqrt{R1\ R2}}$$

The mutual inductance is finally obtained from equation mentioned above. The dependence with r in the above equation is very important. In fact, as we will demonstrate later power coupling depends on $k^2$ thus going with $r^{-6}$. This fact shows why we need to be very close in order to use non-resonant magnetic coupling. On the other hand, as we will see in the next sections, by using resonance we can greatly enhance the coupling.

### 3.2 Resonant inductive coupling

Sometimes the primary coil and secondary coil are loosely connected in a WPT system. In such a case, the main and secondary sides are adjusted by a resonant circuit to transmit the rated power. However, in the current literature, resonant topology research tended to focus more on the primary side than the secondary side. Series and parallel topologies are the most fundamental for the secondary side. The load receives a boost in voltage from the parallel topology, but reactive loads are reflected back to the primary side. This issue is solved by the series topology, however because of the low open-circuit voltage the output power is only moderately high. Inductor-capacitor-inductor (LCL) and inductor-capacitor-capacitor (LCC) topologies are the most popular choices for series and parallel topologies. For these topologies, a second capacitor put in series with the pickup coil may be viewed as a current boost, compensating the reactive power at the secondary side to provide a pickup with a unity power factor. The LCL and LCC topologies are current source characteristics, and actuality, there are instances when we require a voltage-source output on the secondary side. To solve this problem, a novel parallel-T topology for WPT pickup applications with a voltage–source output is used. It features unity power factor and ultra-low no-load loss. A T-matching network in parallel connection with an inductor-capacitor (LC) parallel circuit makes it work as a voltage boost and makes it possible to transfer more power under weak coupling conditions.[10]

A schematic of the proposed parallel-T structure is shown in Fig. 3.2 a. It consists of inductor (Ls), capacitor (Cs) in parallel connection and $L_2$, $C_2$ and $C_{s2}$ are connected in the T structure, forming a matching network. Ls and L2 should meet Ls < L2. Here, we assume that the load is purely resistive. Reactance $X_{Ls} = -X_{Cs}$ , $X_{L2} = -X_{C2}$ and $X_{Cs2} = X_{C2} + X_{Ls}$ are the conditions for this structure. Resonant frequency of the system is [10]

$$\omega_0=\frac{1}{\sqrt{LsCs}}=\frac{1}{\sqrt{L2C2}}=\sqrt{\frac{Cs2-C2}{LsCs2C2}}$$

Fig. 3.2 b depicts the impedance transformation process on the secondary side. Uoc is the secondary coil's induced open-circuit voltage, whereas $r_s$ is the wire resistance. Here, we define λ as the transformation factor, and$\lambda = L_s/L_2<1$. Since it affects the transfer power and efficiency, parameter is crucial. Following is a formula for calculating capacitor $C_{s2}$.[10]

$$C_{s2}=C_2/(1-\lambda)$$

Load resistance R after transformation through matching network is named as Z″, and further divided into real part and imaginary part[10]

$$Z''=(R+X_{C2})||X_{L2}+X_{Cs2}=\frac{L2}{RC2}+j\omega_0 L_s$$

Thus, Z″ can be seen as a resistance and an inductance (Ls) in series connection and Ls, Cs constitute a new T network. Impedance after this T network is named Z′

$$Z'=\lambda^2.R$$

When the load is purely resistive, Z′ only has the real part.[10]

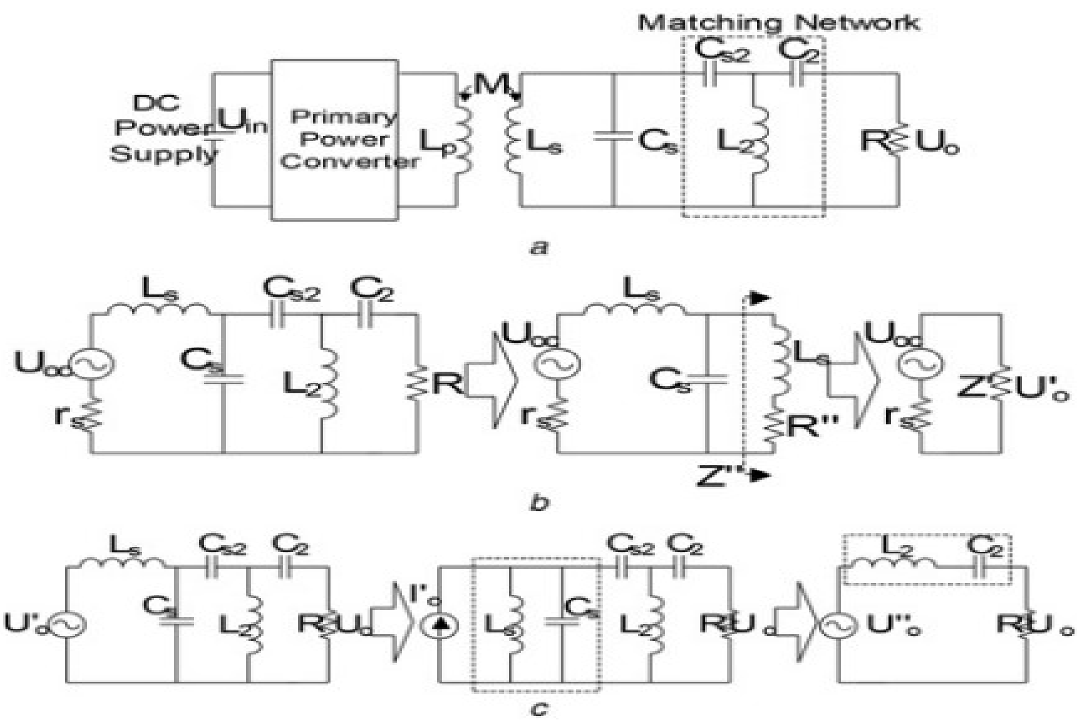


Figure**3.2** Analysis of parallel T structure

a)Schematic of the proposed WPT system

b)Analyse from impedance transformation view

c)Analyse from circuit transformation view

### 3.3 Calculation of power

The power levels for IPT systems can range from a few watts to tens or hundreds of watts. Resonant inductive coupling allows for higher power levels compared to traditional inductive methods. Depending on the implementation, power levels can range from several watts to several kilowatts. When the load is purely resistive, The power can be calculated as

$P=I^2R$

Where, R is the load resistance and I is the load current.

The amount of power transfer to receiver coil is greatly affected by changing the distance and other parameters unchanged[11]. The characteristic curves of power vs distance for IWPT and RWPT for coils of radius 2.5 cm and 2m are shown in figure 5.71 and 5.73 respectively.

### 3.4 Improvement in Efficiency($\eta_{imp}$ %)

Improvement in efficiency can be calculated using following equation,

$$\eta_{imp} = \frac{Priwpt - Pwip}{Pwipt} *100\%$$

# CHAPTER 4
# DESIGN AND SIMULATION

## 4 Methodology

For designing the Wireless Power Transfer system through inductive coupling and resonant inductive coupling, firstly the specifications of wireless power transfer system were identified. For this purpose, the materials and components used in wireless power transmission system are were identified. After identification of the specification of wireless power transfer system, the next step is to calculate the parameters of both inductive and resonant inductive power transmission system. When the parameters are calculated, the next step is to construct the wireless inductive power transmission system. When construction was completed, simulation was done for both the circuits and the system was checked for various applications. After simulating both the system, both systems were compared. So the proposed methodology for designing the wireless Power Transmission system is given by the following algorithm.

### 4.1 Algorithm

Step1: Start

Step2: Identify the specifications of systems

Step3:Calculation of Parameters of the systems

Step4:Selection of coil

Step5:Designing of Wpt system with Inductive coupling

Step6:Designing of Wpt system with resonant Inductive coupling

Step7:Compare the results of WPT with Inductive coupling and resonant Inductive coupling

Step8:Conclusion

Step8:End

## 4.2 Design specification

The values of parameters are selected according to the system requirements. Input voltage of 220V is applied to the system .For calculation, turns ratio 1:1 is considered. Number of turns in primary side and secondary side is taken as 36. For low power wireless power transmission resonant frequency of 80 kHz is selected.A wire of radius of 0.1 mm is selected for the coil.

Radius of primary and secondary coil is taken as 2.5 cm.[2]and distance between primary and secondary coil is varied from 0 cm to 5 cm.

Secondly, Radius of primary and secondary coil is taken as 2 m and distance between primary and secondary coil is varied from 0 to 3 meters.

## 4.3 Calculation of parameters for IWPT

### 4.3.1 Calculations for coil of 2.5 cm

All the calculations of parameters are done in MATLAB programming.

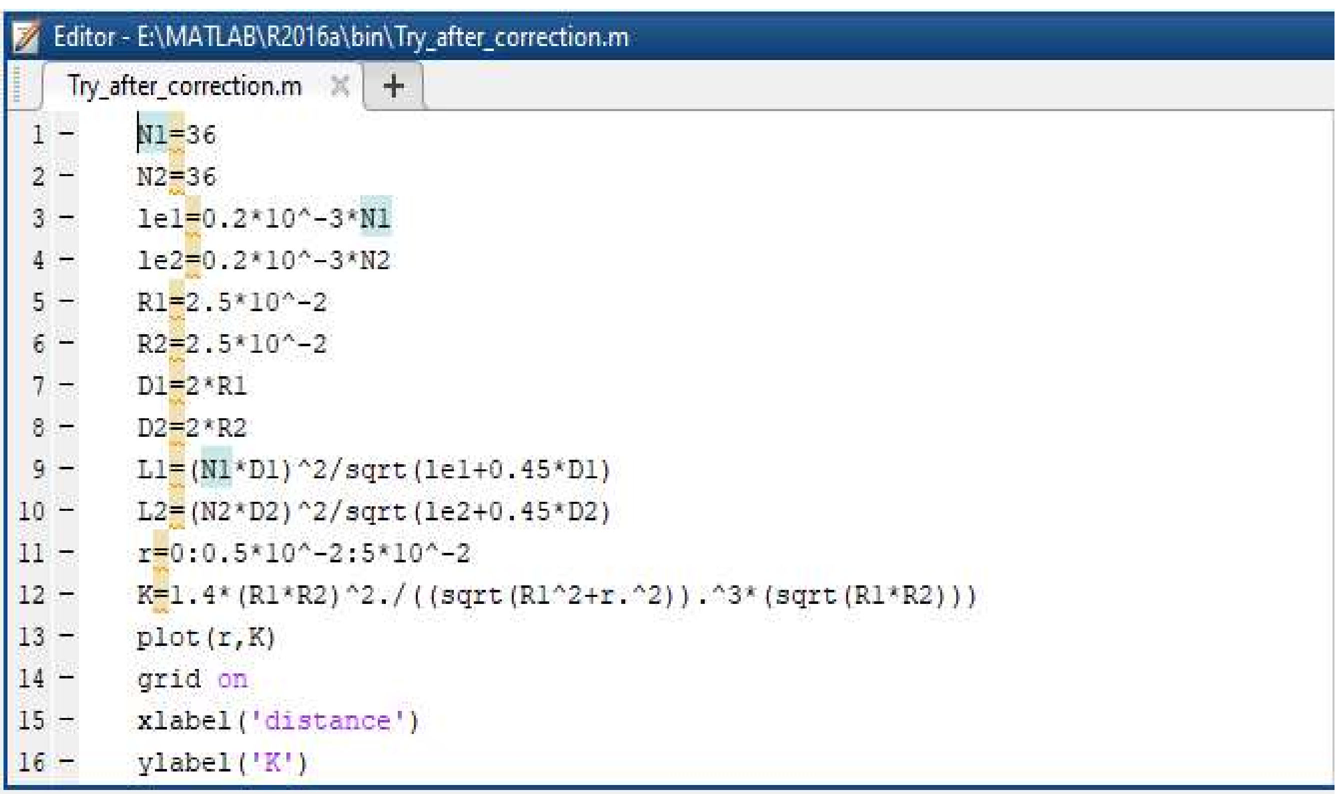


Figure 4.1 Calculations of Parameters for IWPT

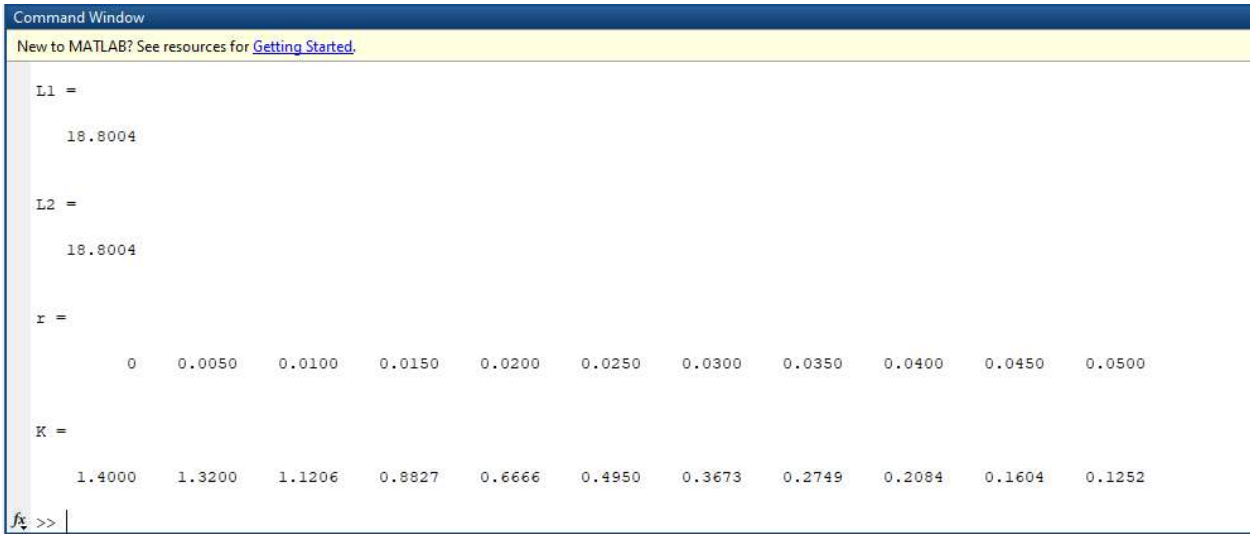


Figure 4.2 Value of Parameters for IWPT

Value of Inductance for primary and secondary coil is found 18.8004 µH. And coupling coefficients of different values.

Table 4.1 Values of K corresponding to different values of distance

| r(Distance) | K(Coupling coefficient ) |
|---|---|
| 1.5 cm | 0.8827 |
| 1.75 cm | 0.769 |
| 2.25cm | 0.5749 |
| 2.5 cm | 0.4950 |
| 3 cm | 0.3673 |
| 3.5 cm | 0.2749 |
| 4 cm | 0.2084 |
| 4.5 cm | 0.1604 |
| 5 cm | 0.1252 |

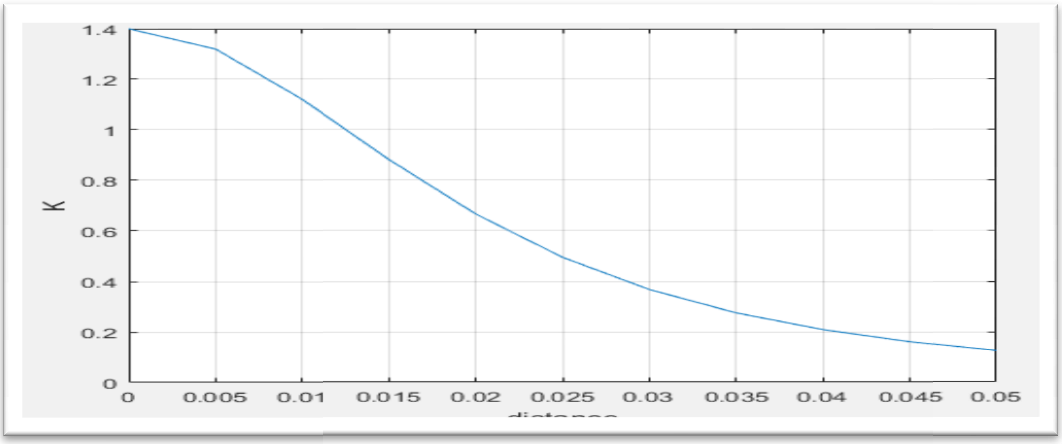


Figure 4.3 Graph of k vs r

### 4.3.2 Calculations for coil of 2m

All the calculations of parameters are done in MATLAB programming.

Editor - E:\MATLAB\R2016a\bin\Try_after_correction.m

Try_after_correction.m

```
N1=36
N2=36
le1=0.2*10^-3*N1
le2=0.2*10^-3*N2
R1=2
R2=2
D1=2*R1
D2=2*R2
L1=(N1*D1)^2/sqrt(le1+0.45*D1)
L2=(N2*D2)^2/sqrt(le2+0.45*D2)
r=0:0.250:3
K=1.4*(R1*R2)^2./((sqrt(R1^2+r.^2)).^3*(sqrt(R1*R2)))
plot(r,K)
grid on
xlabel('distance')
ylabel('K')
```

Figure 4.4 Calculations of Parameters for IWPT

```
L1 =

   1.5425e+04


L2 =

   1.5425e+04


r =

    0.5000    0.7500    1.0000    1.2500    1.5000    1.7500    2.0000    2.2500    2.5000    2.7500    3.0000


K =

    1.2783    1.1492    1.0018    0.8537    0.7168    0.5967    0.4950    0.4105    0.3413    0.2849    0.2389
```

Figure 4.5 Value of Parameters of IWPT

Value of Inductance for primary and secondary coil is found 1.543*10^4 uH and coupling coefficients of different values.

Table 4.2 Values of K corresponding to different values of distance

| r(Distance) | K(Coupling coefficient ) |
|---|---|
| 1.86 | 0.549 |
| 2.00 | 0.495 |
| 2.25 | 0.4105 |
| 2.50 | 0.3413 |
| 2.75 | 0.2849 |
| 3.00 | 0.2389 |

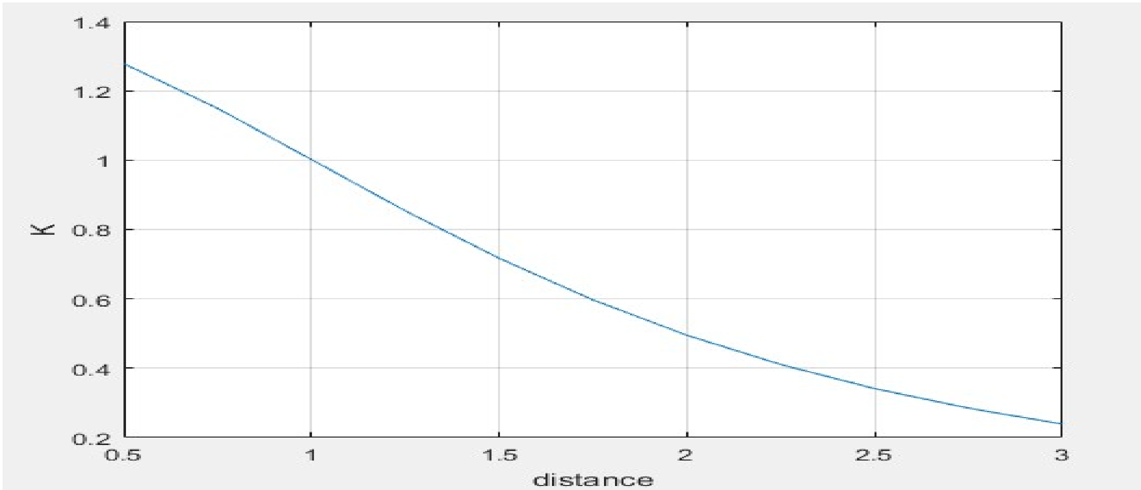


Figure 4.6 Graph of k vs r

## 4.4 Calculation of parameters for RIWPT

### 4.4.1 Calculation of parameters of matching network for RIWPT for 2.5 cm coil radius

For suitable result the transformation ratio is taken as $x = 0.12$

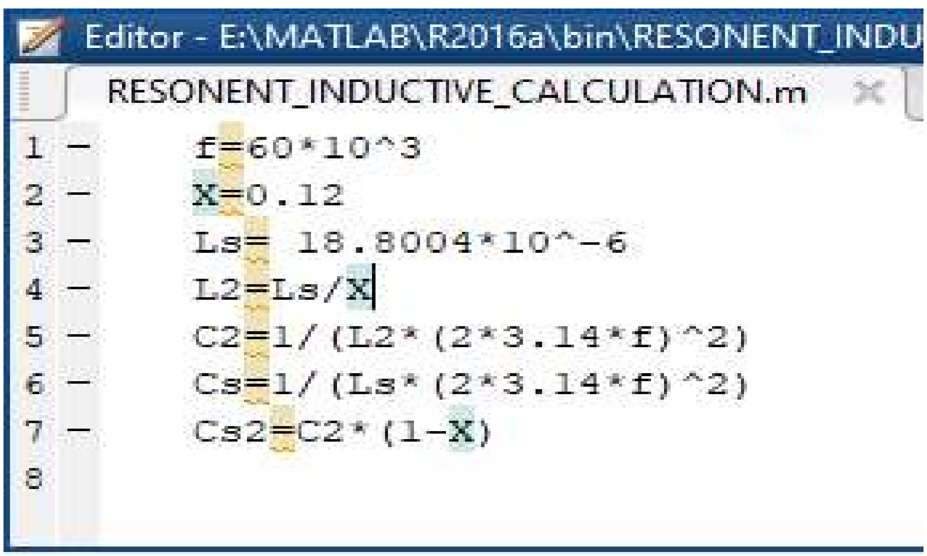


Figure 4.7 Calculation of parameters for RIWPT for 2.5cm coil radius

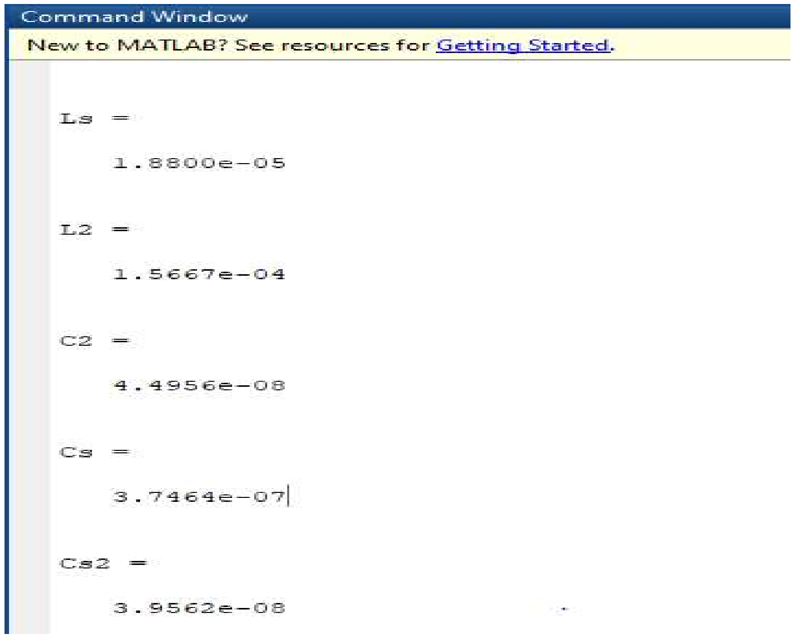


Figure 4.8 Results of parameters of matching network for RIWPT for 2.5 cm coil radius

### 4.4.2 Calculation of parameters of matching network for RIWPT for 2m coil radius

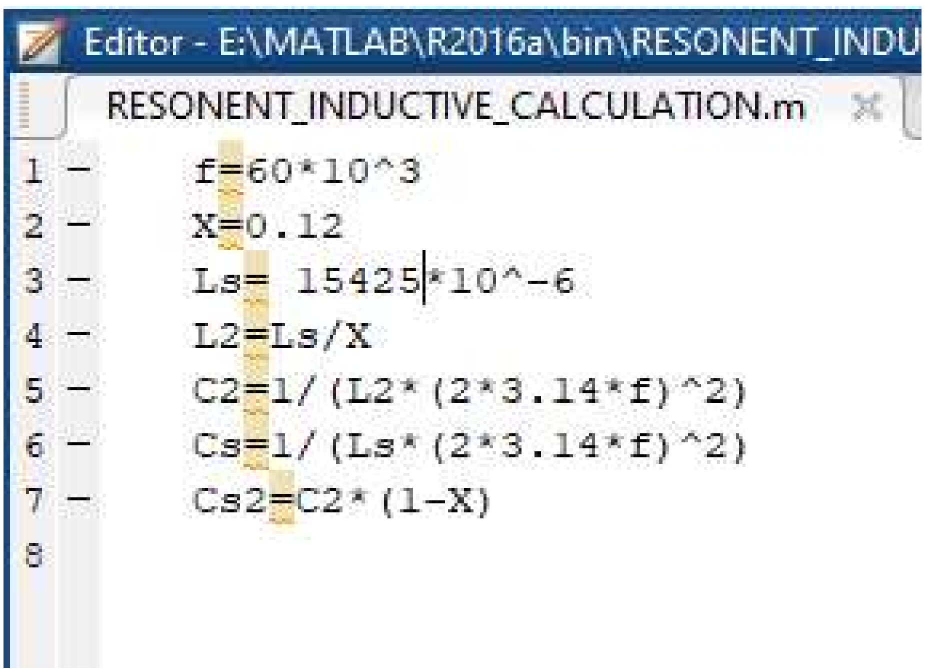


Figure 4.9 Calculation of parameters for RIWPT for 2.5cm coil radius

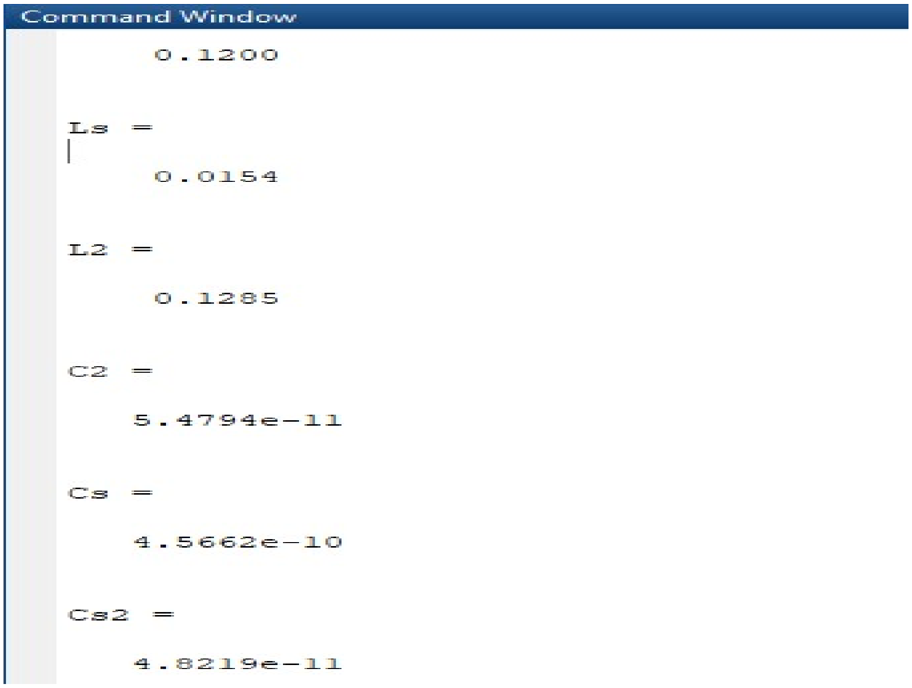


Figure 4.10 Results of parameters of matching network for RIWPT for 2.5 cm coil radius

## 4.5 Selection of coil

Three separate coil geometries are commercially available for transmission: planar spiral, circular helix (solenoid), and square helix. The circular helix coil geometry demonstrated consistent maximum power transfer efficiency (80-90%) over a range of loads. The square helix coils consistently demonstrated efficiency of approximately 80% with loads varying from the optimal load value. The planar spiral coil geometry demonstrated approximately 80% efficiency when the optimal load was considered, but fell to approximately 50% when the load was many times lower than the optimal load. Operating frequency was also varied, and it was found that the circular helix coils performed best.[9]

Another comparison between different coil geometries was performed. Two-coil inductive links were used. Four different geometries were discussed, including solenoid circular coils, flat spiral coils, printed circular coils, and printed square coils. The planar spiral coils were reported to outperform the coupled solenoid coils in both increasing separation and lateral misalignment. The coupled circular spiral coils were shown to outperform both the planar circular coils and the solenoid coils in separation distance and lateral misalignment. The square printed coils performed similarly to the planar coupled coils.[9]

The coil diameter is largely dependent on the size of the chosen MAV and the desired power transfer distance. Larger diameter coils result in greater transmission distance, in general. In ,the ratio of Tx coil size to Rx coil size is examined and shown 19 that when the Tx coil and Rx coil have similar diameters, the power transfer is more efficient for distances approximately the diameter of the Rx coil. However as the distance increases, larger Tx coils coupled with smaller Rx coils have a greater transfer efficiency than Tx and Rx coil combinations with similar diameters. [9]

### 4.6 Design and simulation for IWPT

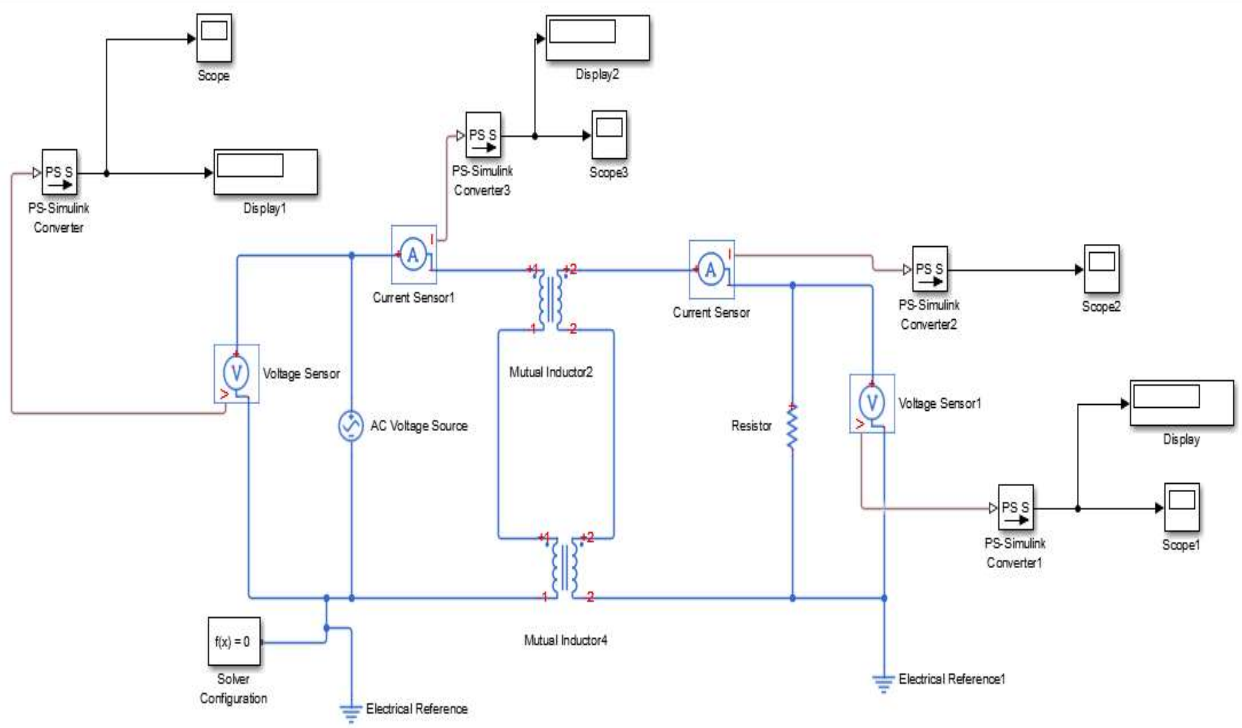


Figure 4.11 The circuit of IWPT

### 4.6.1 Designing of IWPT for coil radius of 2.5 cm

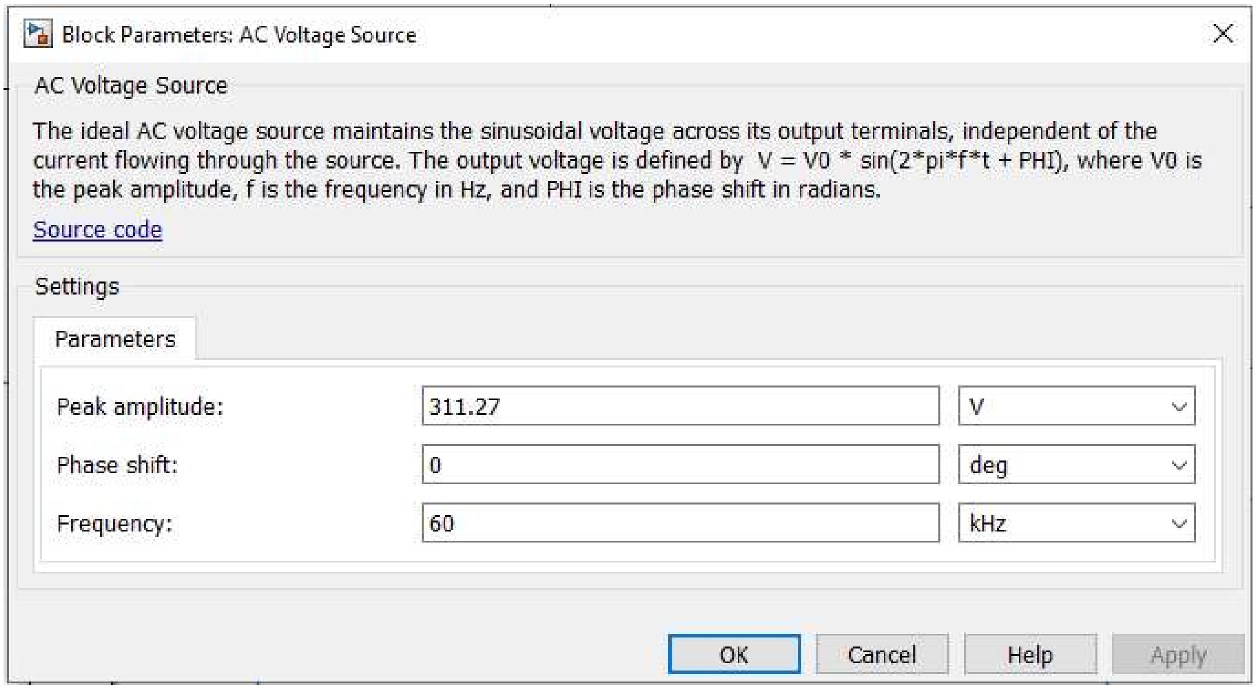


Figure 4.12 different values of source

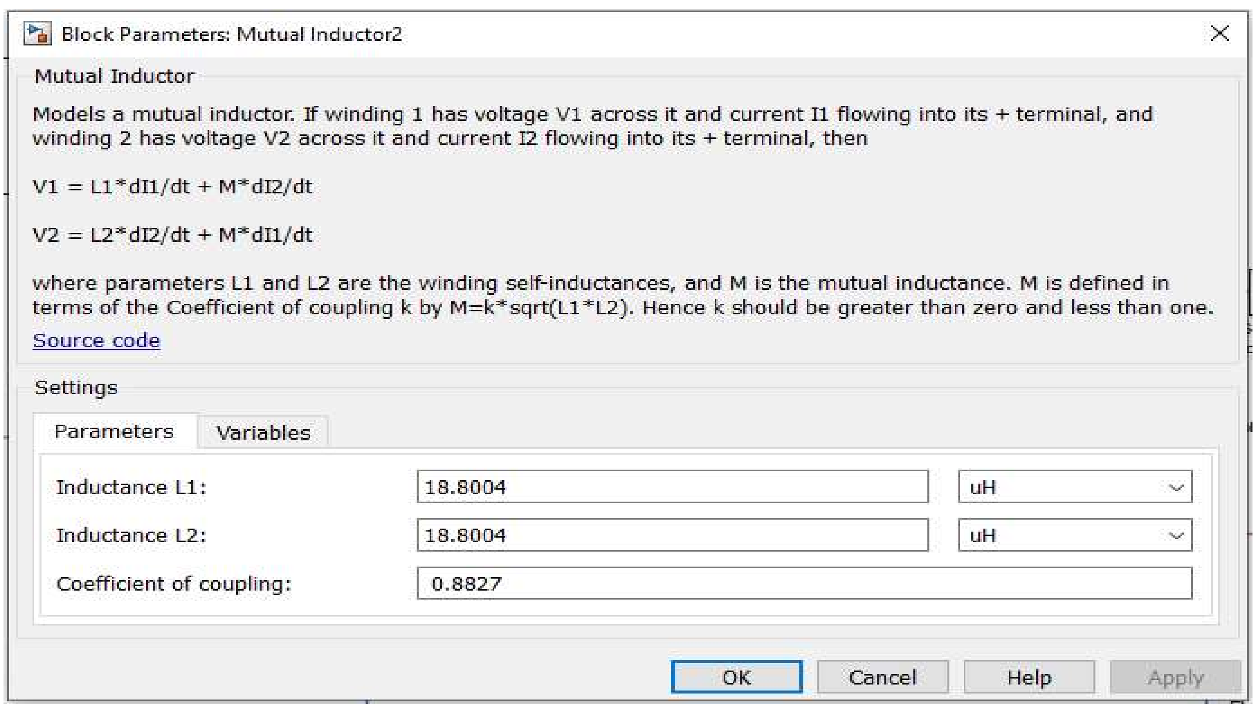


Figure 4.13 Different values of Parameters

### 4.6.2 Designing of IWPT for coil radius of 2m

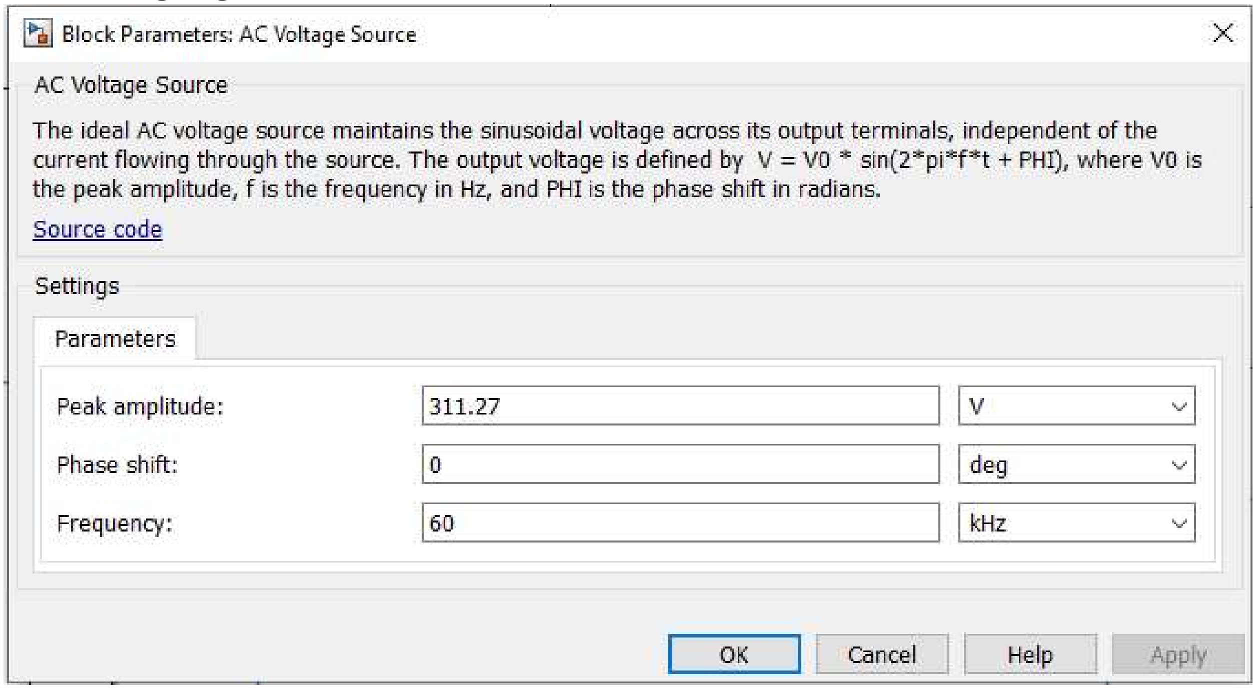


Figure 4.14 Different values of source

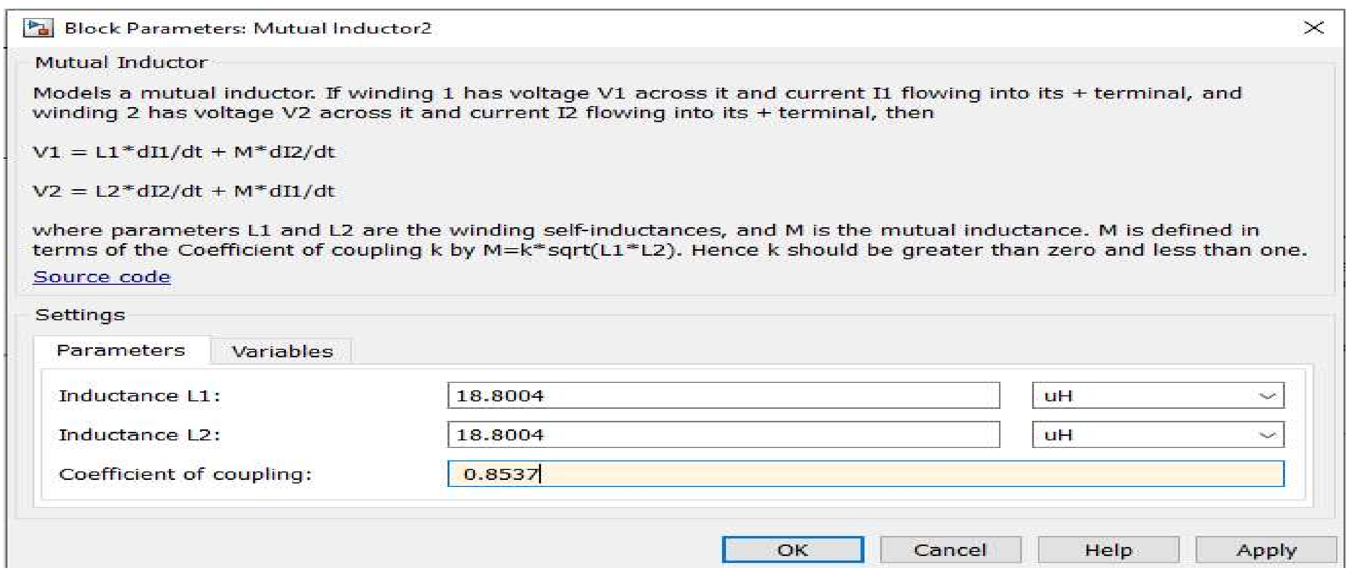


Figure 4.15 Different values of Parameters

## 4.7 Design and simulation for RIWPT

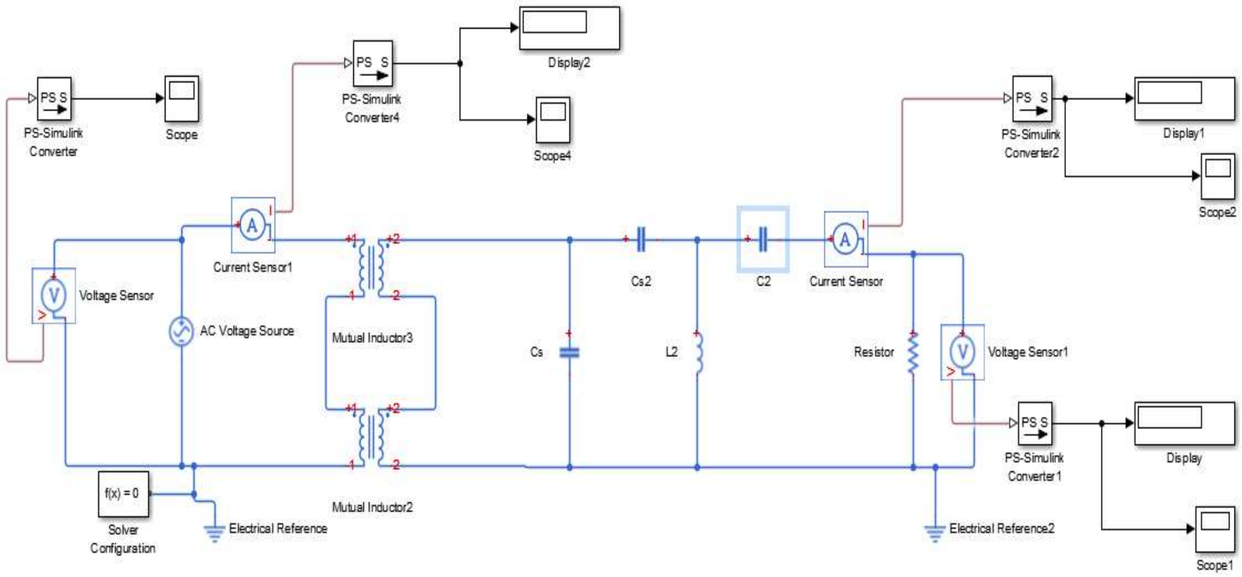


Figure 4.16 Designing Of RIWPT

### 4.7.1 Designing Of RIWPT for coil radius of 2 m

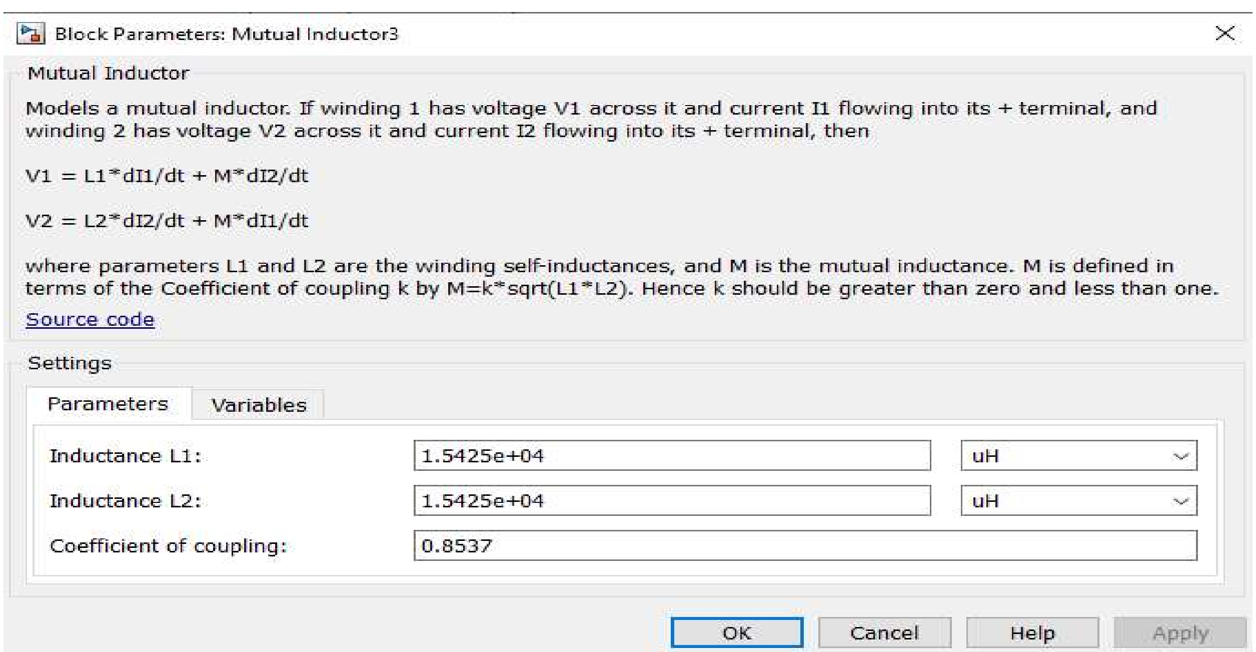


Figure 4.17 Different values of Parameters

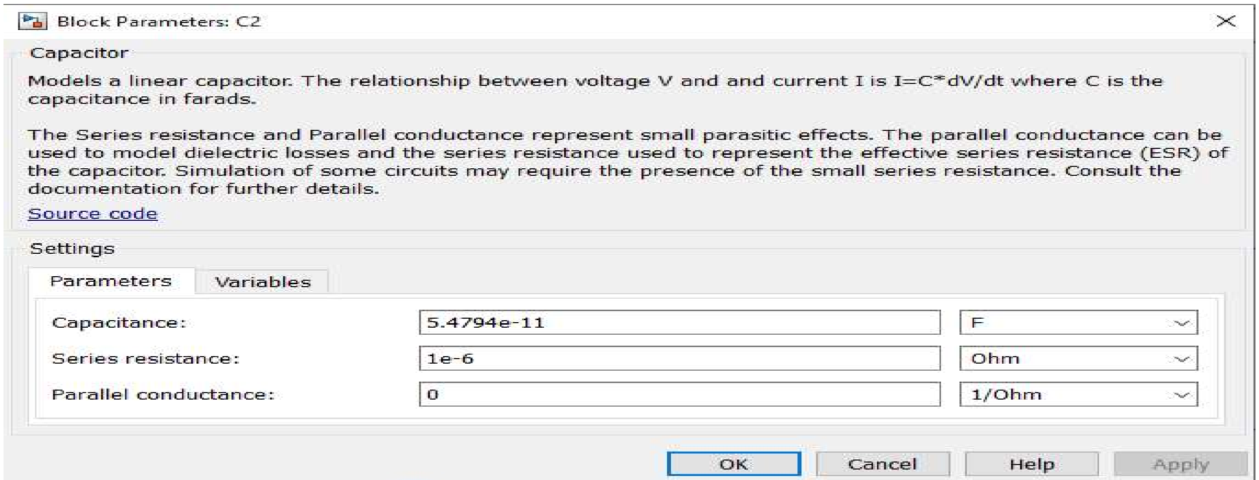


Figure 4.18 Block parameter C2

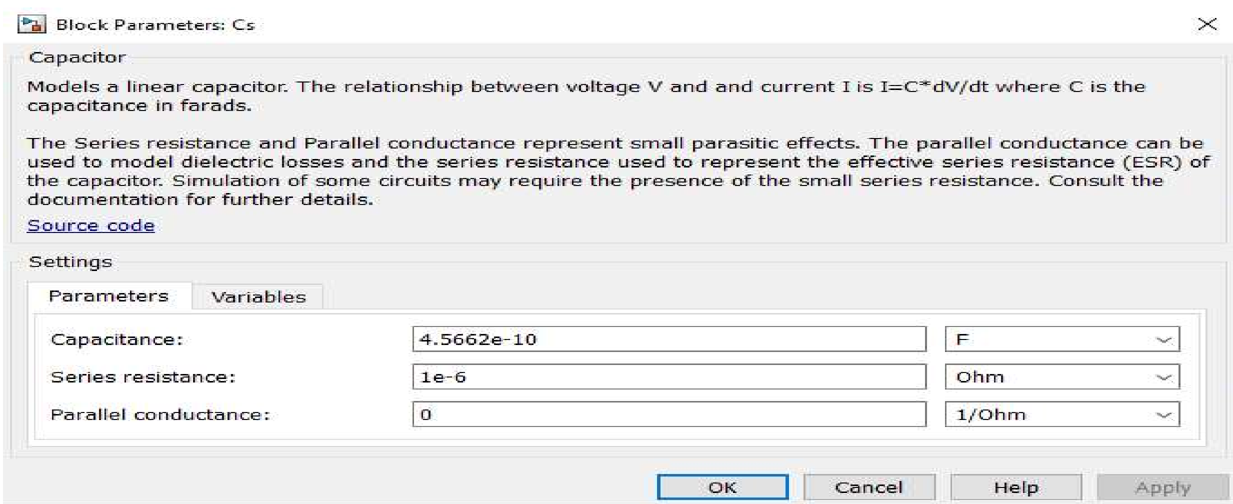


Figure 4.19 Block parameter Cs

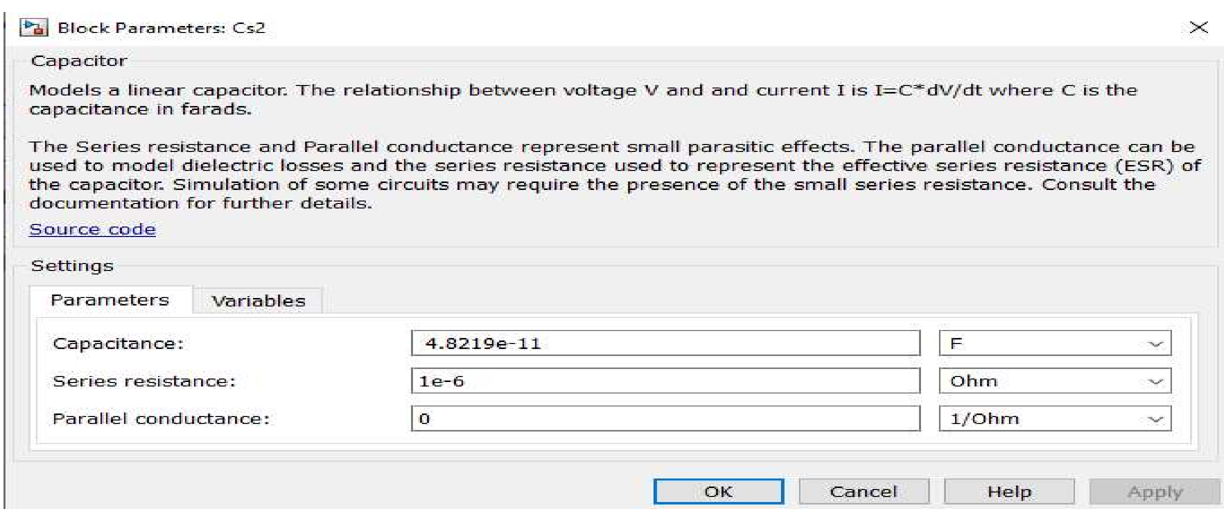


Figure 4.20 Block parameter Cs2

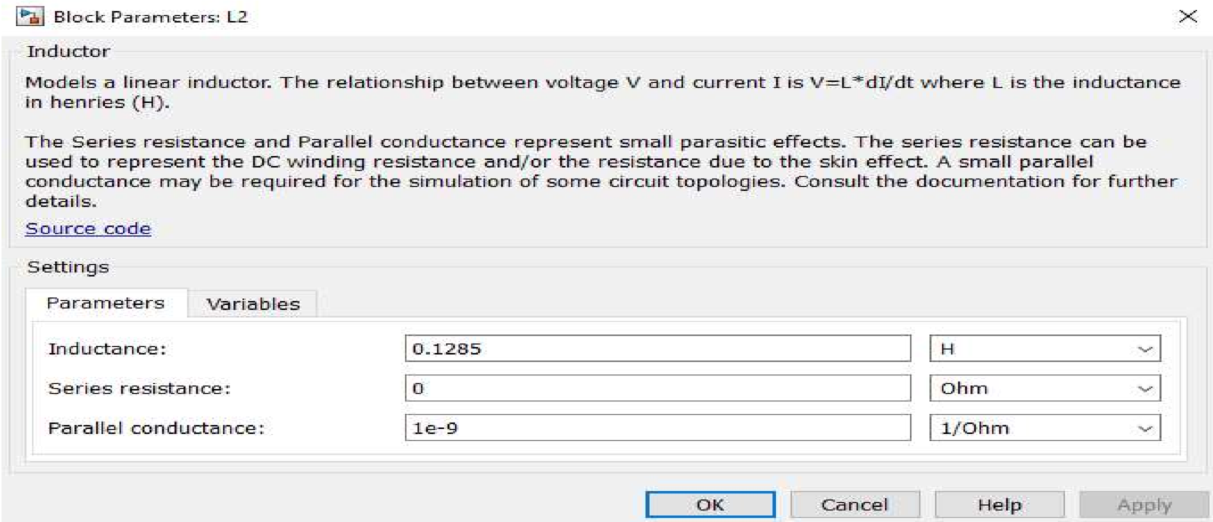


Figure 4.21 Block parameter L2

### 4.7.2 Designing Of RIWPT for coil radius of 2.5 cm

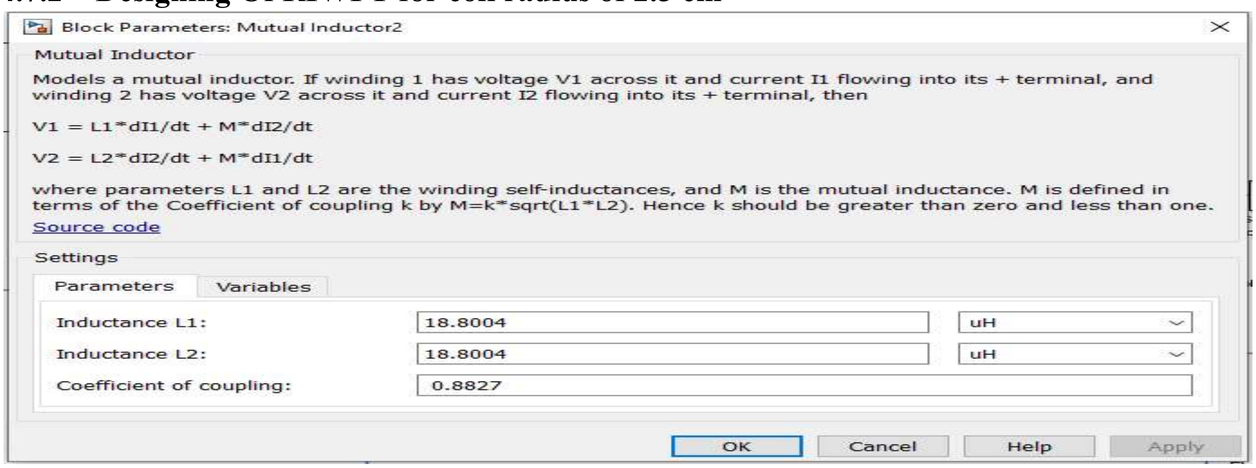


Figure 4.22 Different values of Parameters

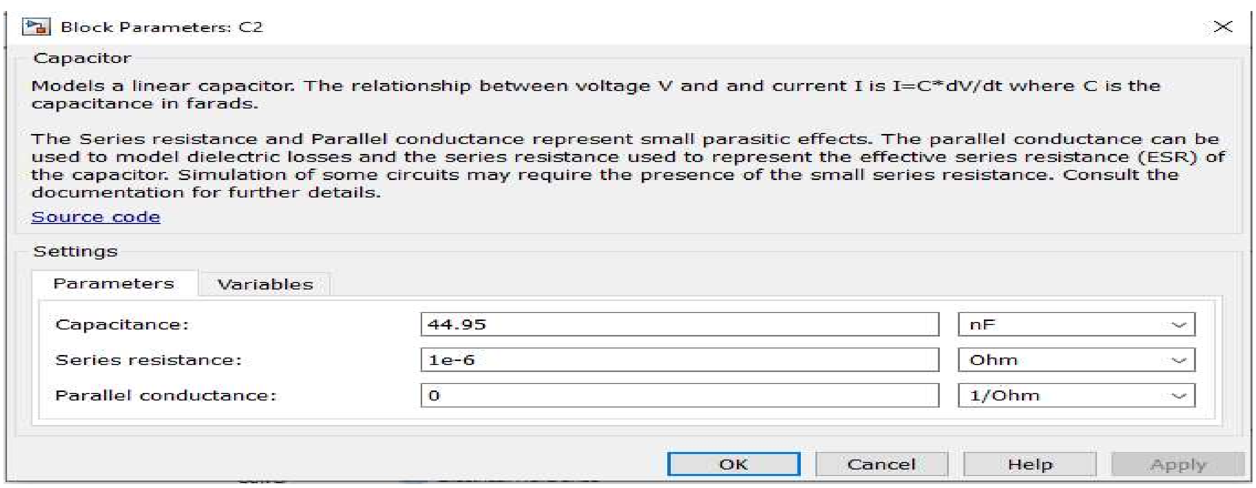


Figure 4.23 Block parameter C2

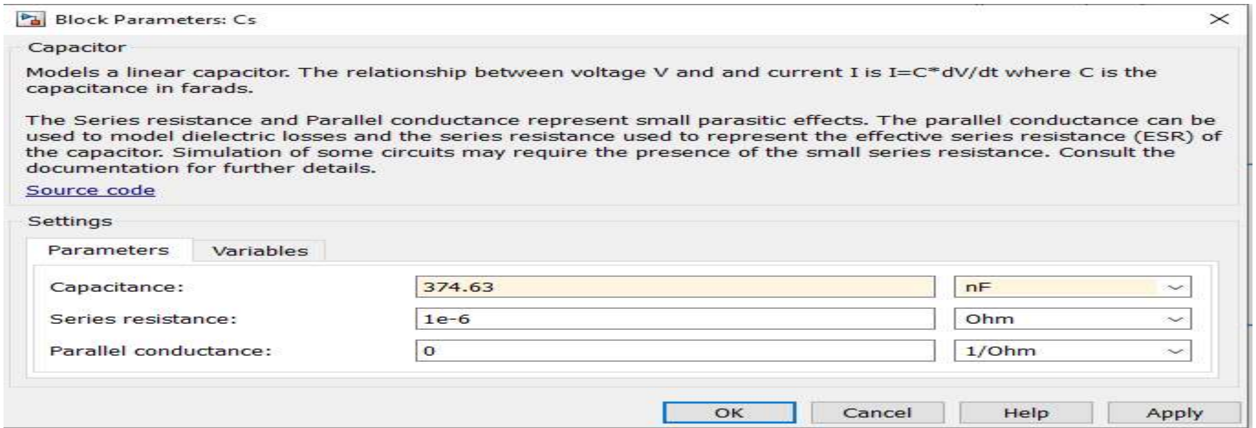


Figure 4.24 Block parameter Cs

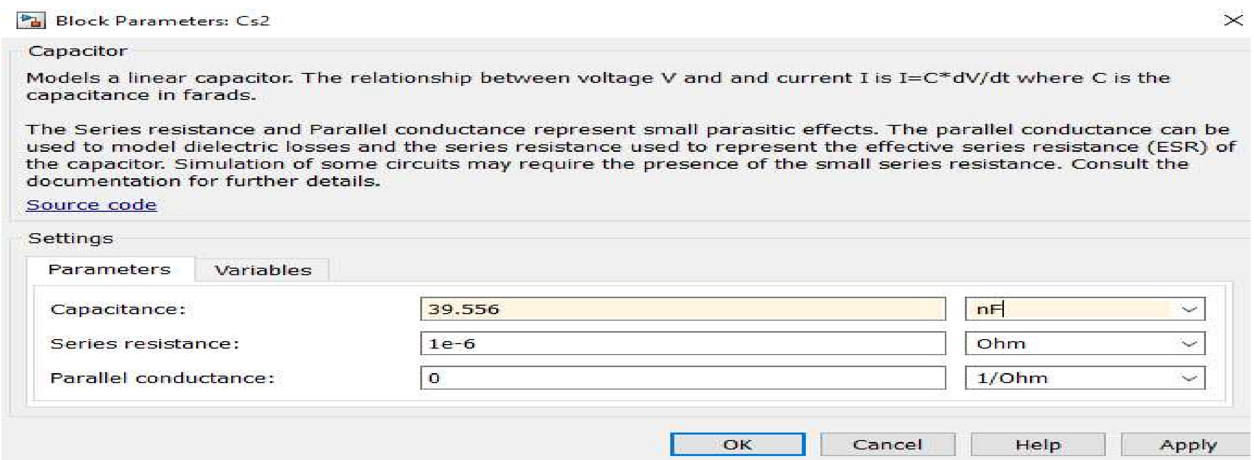


Figure 4.25 Block parameter Cs2

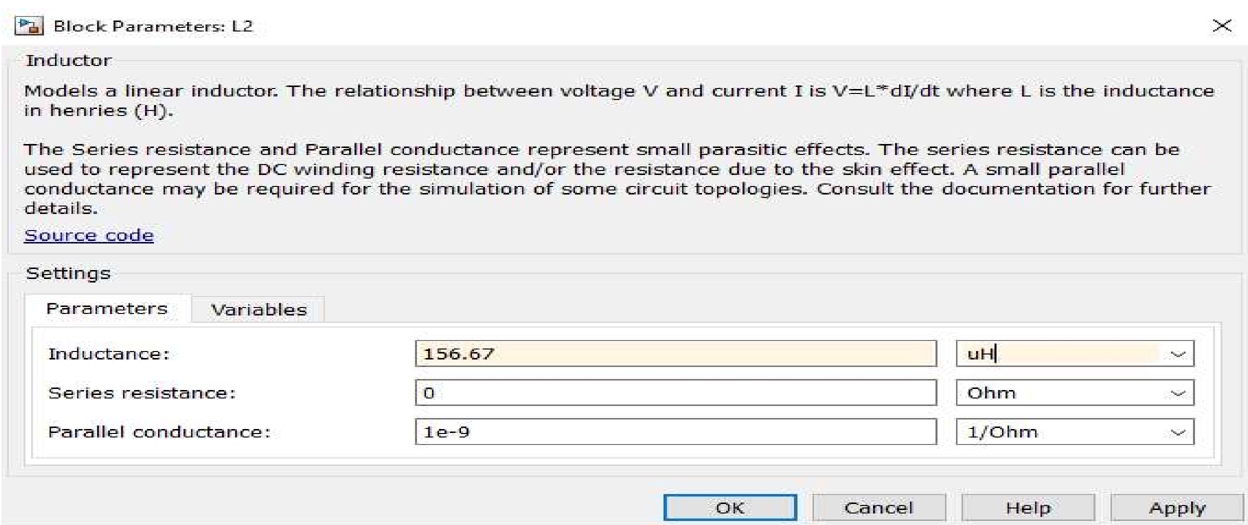


Figure 4.26 Block parameter L2

# CHAPTER 5
# RESULTS AND CONCLUSION

## 5 Simulation results

### 5.1 The results of IWPT for coil radius of 2.5 cm .

- Distance between primary and secondary coil is 1.5cm,coupling coefficient K=0.8827,resistive load R=35ohm

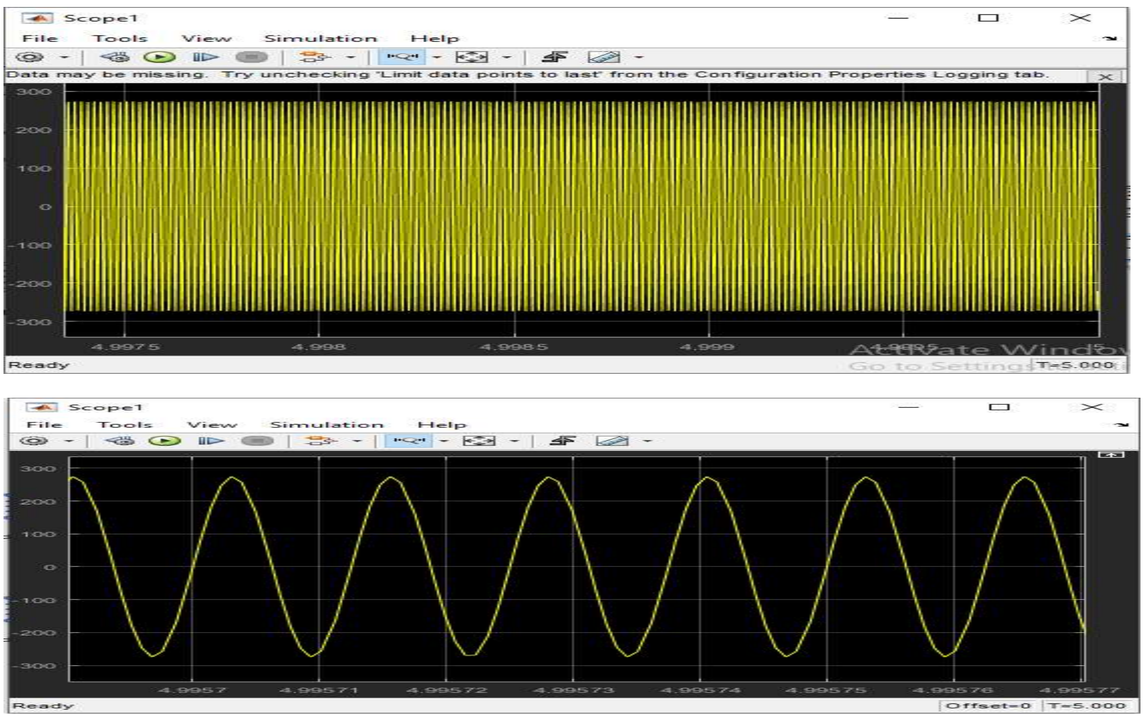


Figure 5.1 Graph of V of IWPT system with coupling coefficient(k) of 0.8827 and R=35 ohm

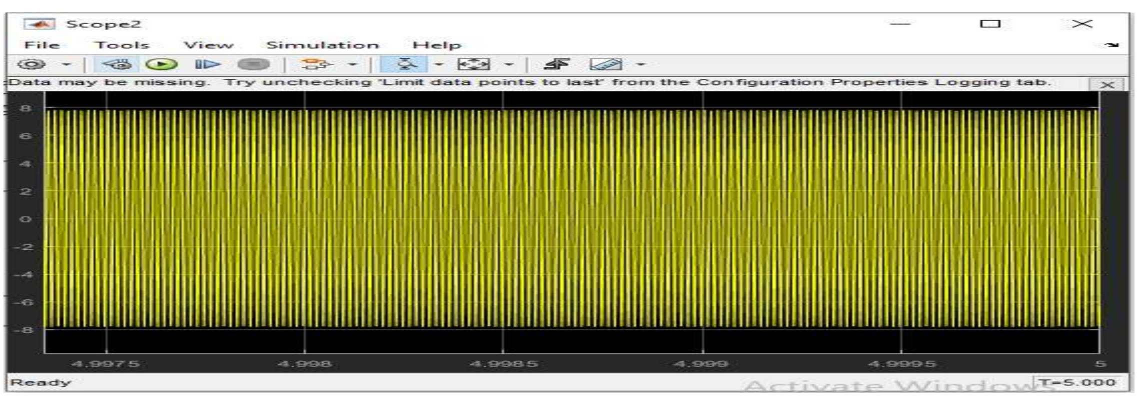


Figure 5.2 Graph of I of IWPT system with coupling coefficient(k) of 0.8827 and R=35 ohm

- Distance between primary and secondary coil is 1.75cm,coupling coefficient K=0.7697,resistive load R=11ohm

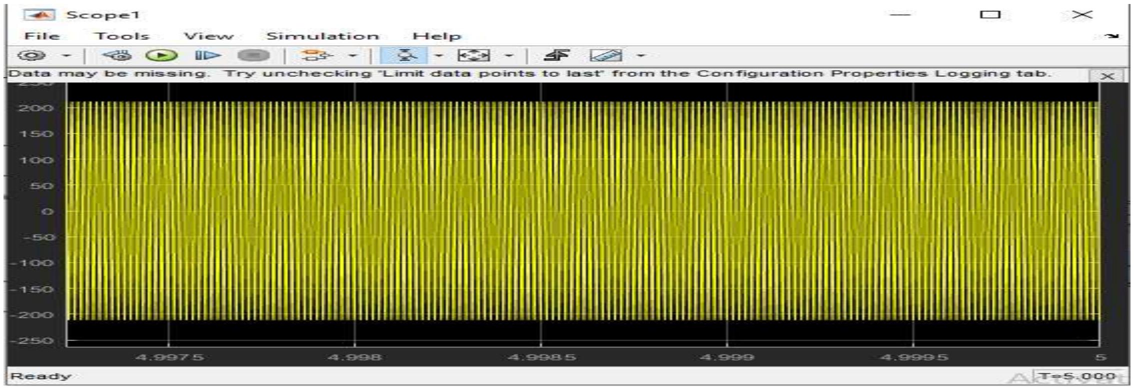


Figure 5.3 Graph of V of IWPT system with coupling coefficient(k) of 0.7697 and R=11 ohm

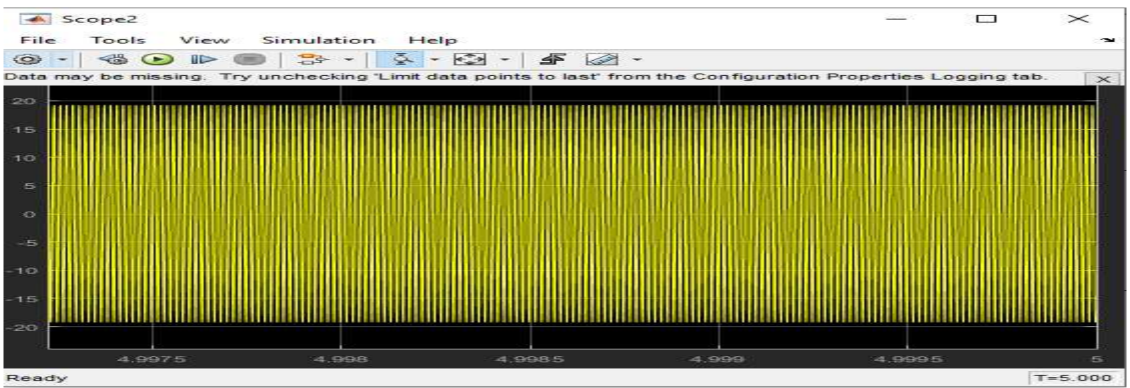


Figure 5.4 Graph of I of IWPT system with coupling coefficient(k) of 0.7697 and R=11 ohm

- Distance between primary and secondary coil is 2.25cm,coupling coefficient K=0.5749 and resistive load R=22 ohm

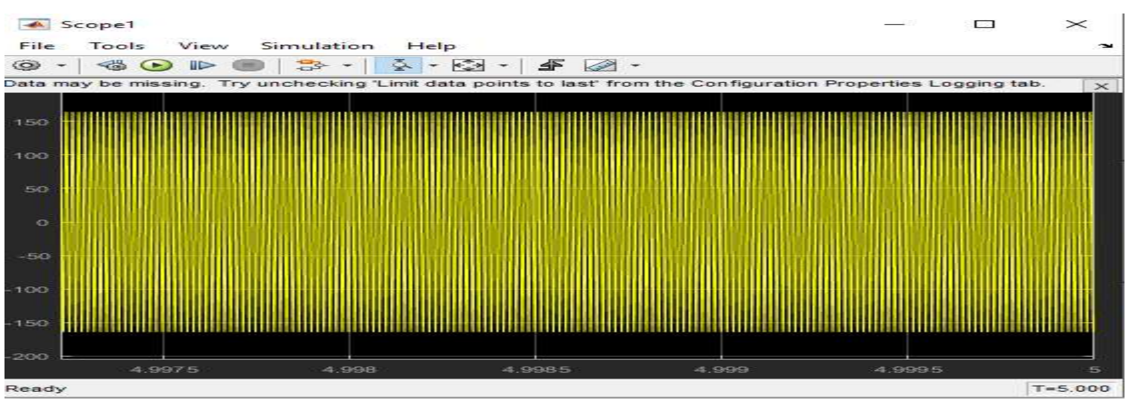


Figure 5.5 Graph of V of IWPT system with coupling coefficient(k) of 0.5749 and R=22 ohm

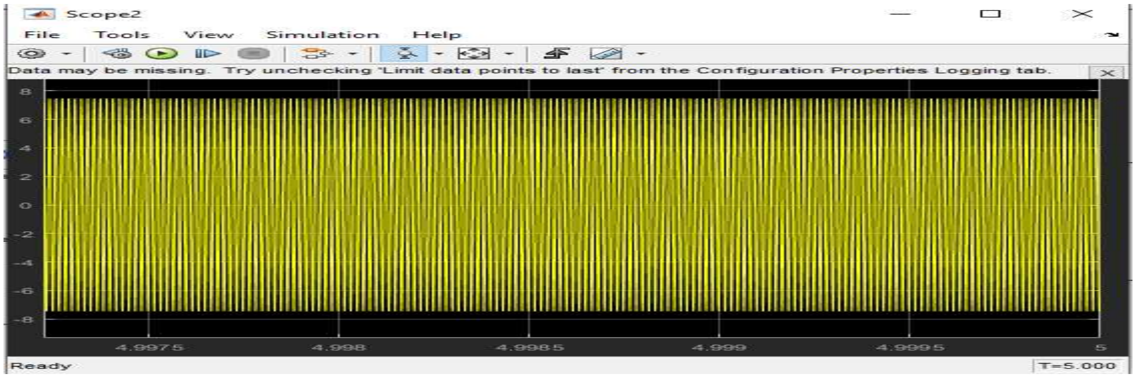


Figure 5.6 Graph of I of IWPT system with coupling coefficient(k) of 0.5749 and R=22ohm

- Distance between primary and secondary coil is 2.5cm,coupling coefficient K=0.4950 and resistive load R=35 ohm

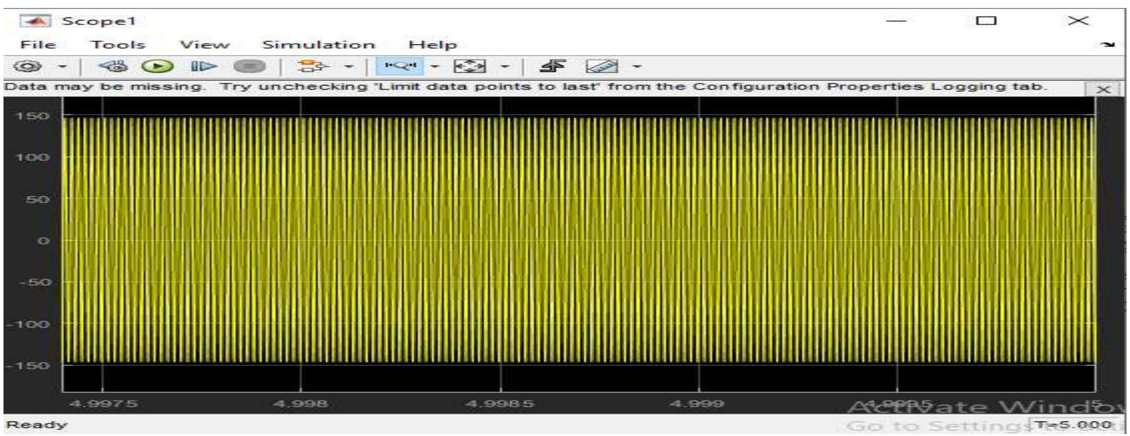


Figure 5.7 Graph of V of IWPT system with coupling coefficient(k) of 0.495 and R=35 ohm

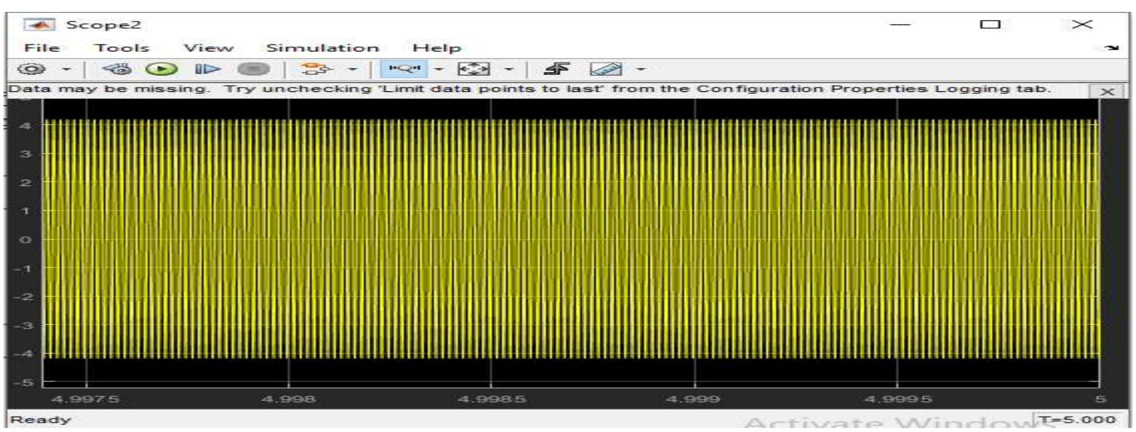


Figure 5.8 Graph of I of IWPT system with coupling coefficient(k) of 0.495 and R=35 ohm

- Distance between primary and secondary coil is 3cm,coupling coefficient K=0.3673and resistive load R=48 ohm

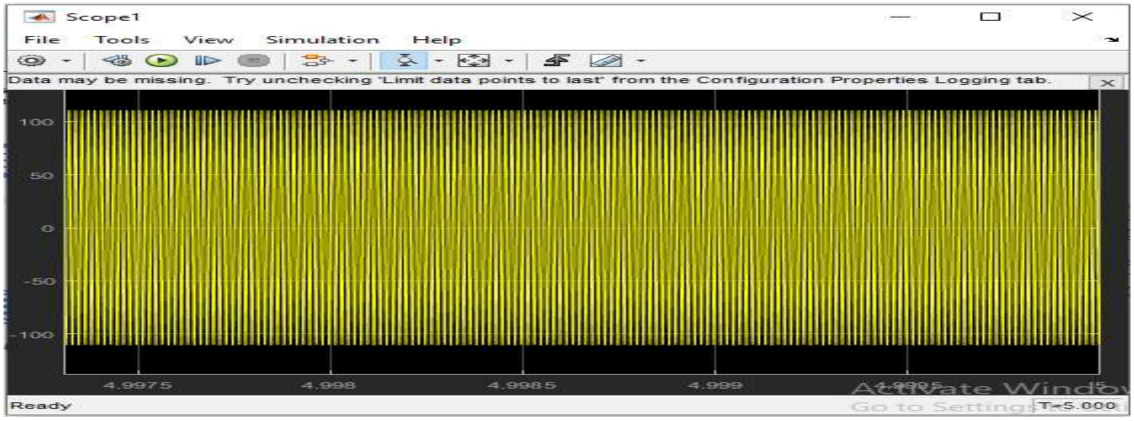


Figure 5.9 Graph of V of IWPT system with coupling coefficient(k) of 0.3637 and R=48 ohm

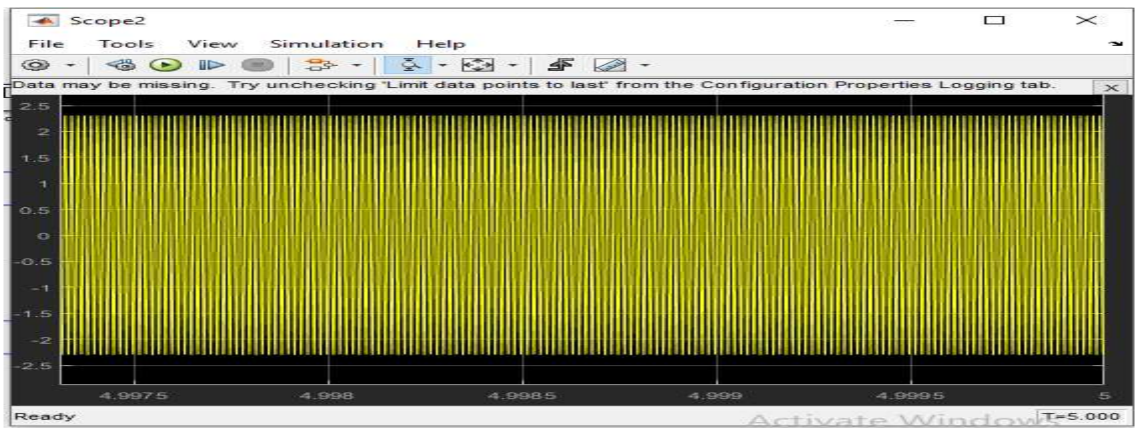


Figure 5.10 Graph of I of IWPT system with coupling coefficient(k) of 0.3637 and R=48 ohm

- Distance between primary and secondary coil is 3.5cm, coupling coefficient K=0.2749 and resistive load R=56 ohm

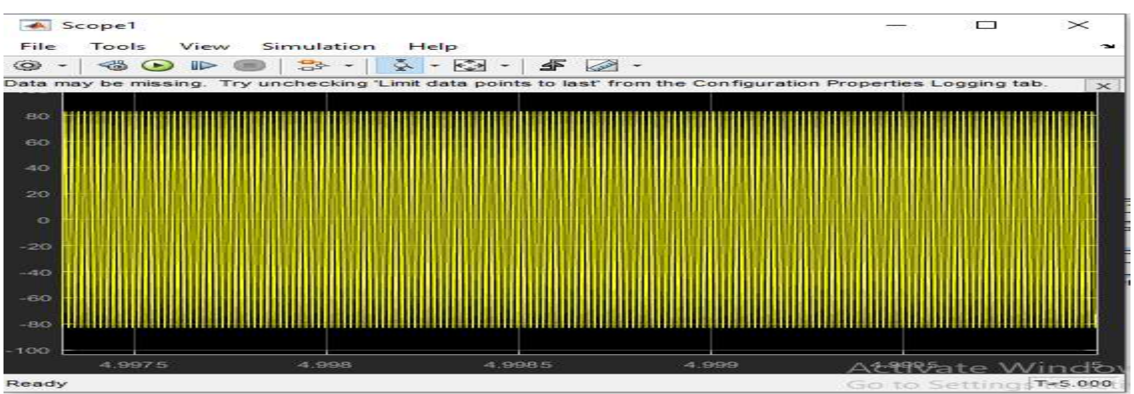


Figure 5.11 Graph of V of IWPT system with coupling coefficient(k) of 0.2749 and R=56 ohm

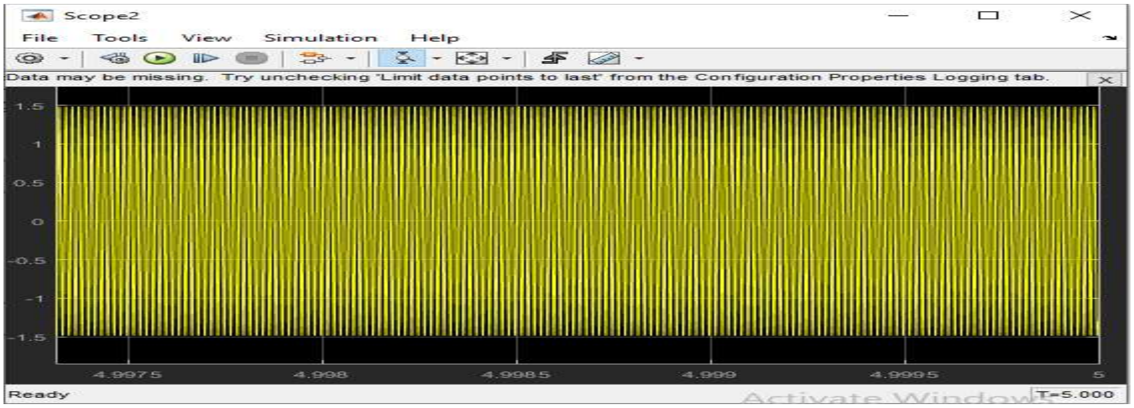


Figure 5.12 Graph of I of IWPT system with coupling coefficient(k) of 0.2749 and R=56 ohm

- Distance between primary and secondary coil is 4cm,coupling coefficient K=0.2084 and resistive load R=60 ohm

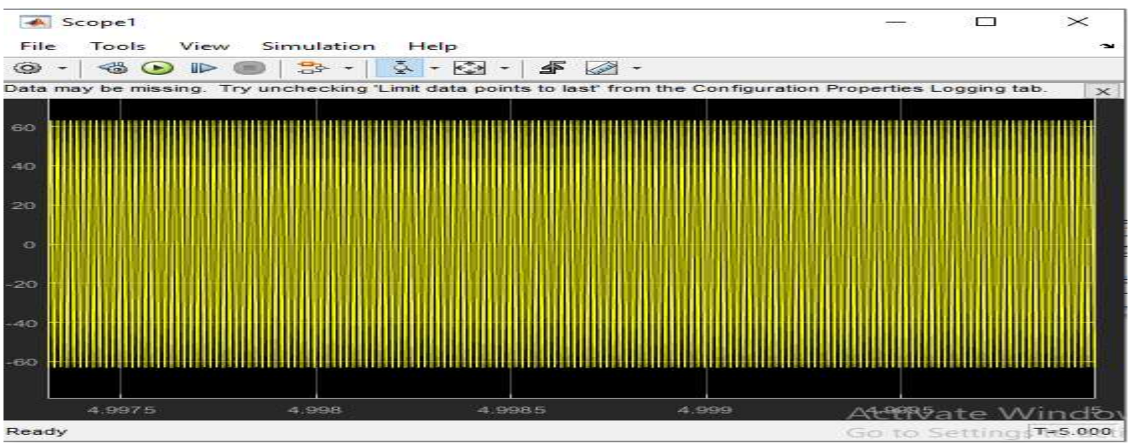


Figure 5.13 Graph of V of IWPT system with coupling coefficient(k) of 0.2084 and R=60 ohm

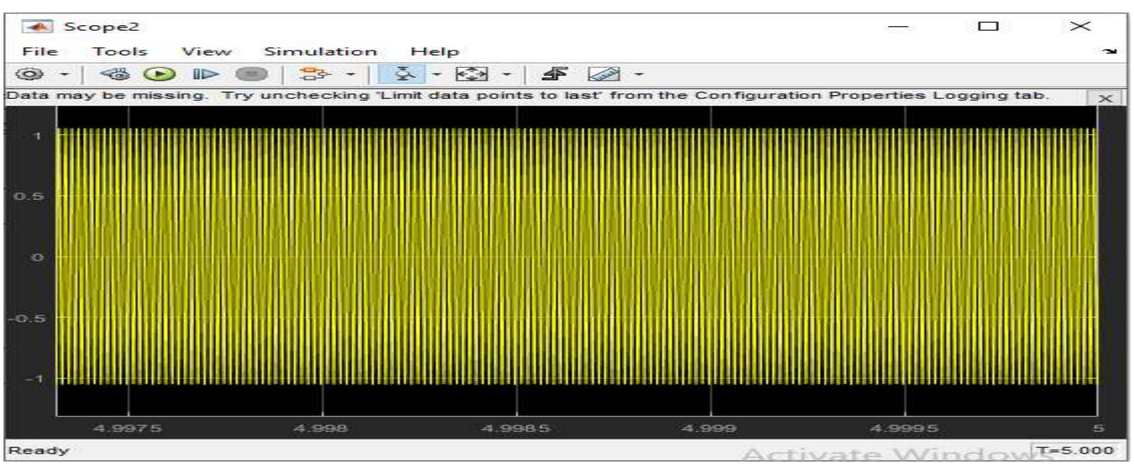


Figure 5.14 Graph of I of IWPT system with coupling coefficient(k) of 0.2084 and R=60 ohm

- Distance between primary and secondary coil is 4.5cm,coupling coefficient K=0.1604 and resistive load R=66ohm

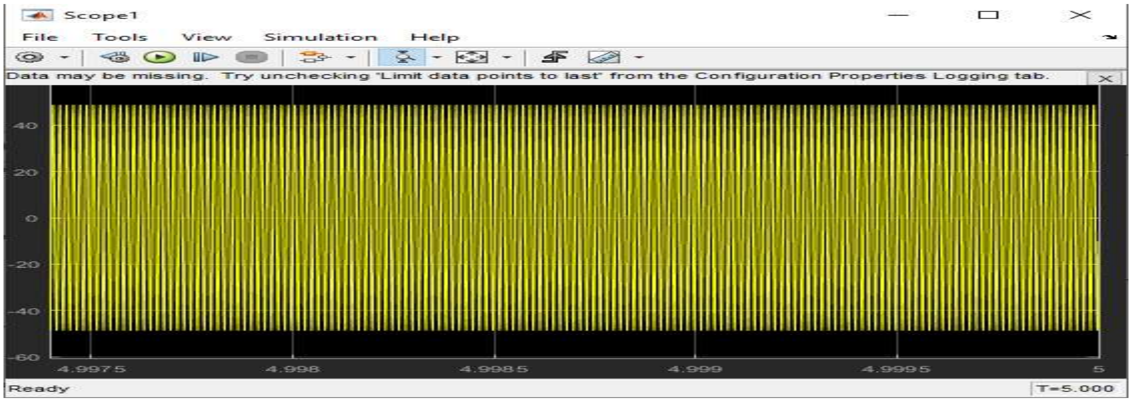


Figure 5.15 Graph of V of IWPT system with coupling coefficient(k) of 0.1604 and R=66 ohm

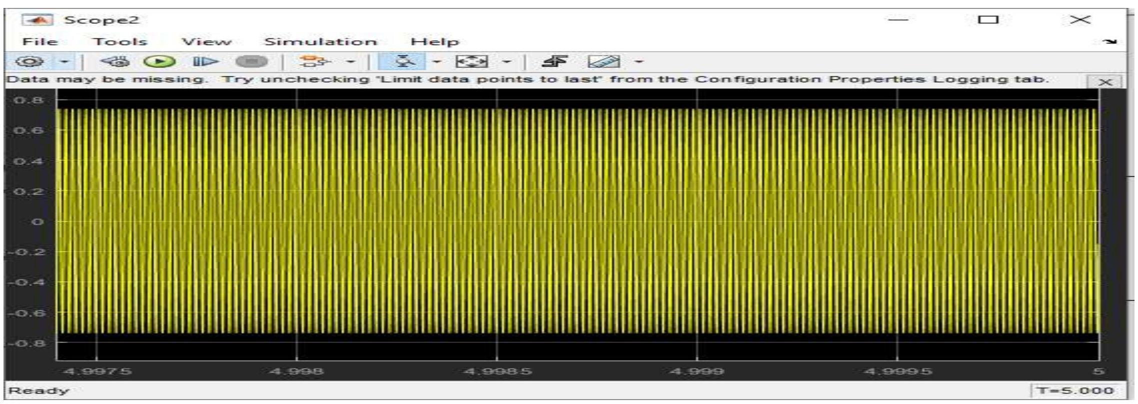


Figure 5.16 Graph of I of IWPT system with coupling coefficient(k) of 0.1604 and R=66 ohm

- Distance between primary and secondary coil is 5cm, coupling coefficient K=0.1252 and resistive load R=66 ohm

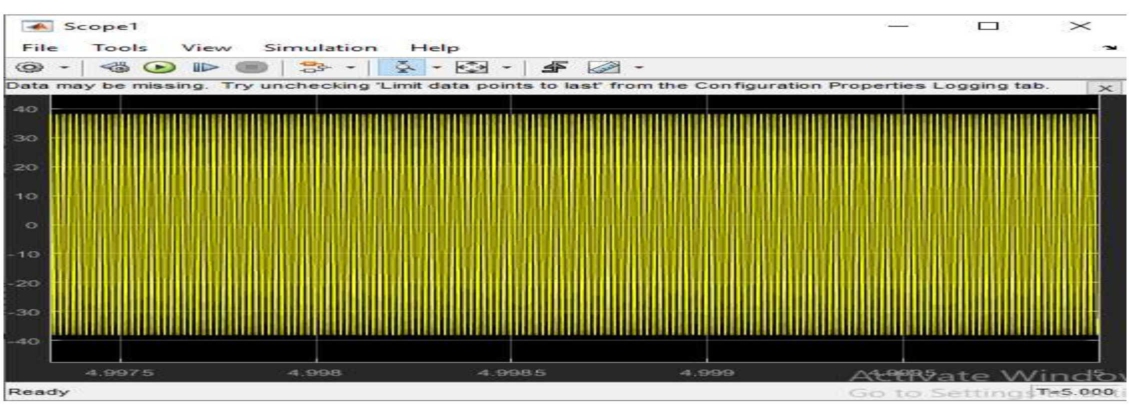


Figure 5.17 Graph of V of IWPT system with coupling coefficient(k) of 0.1252 and R=66 ohm

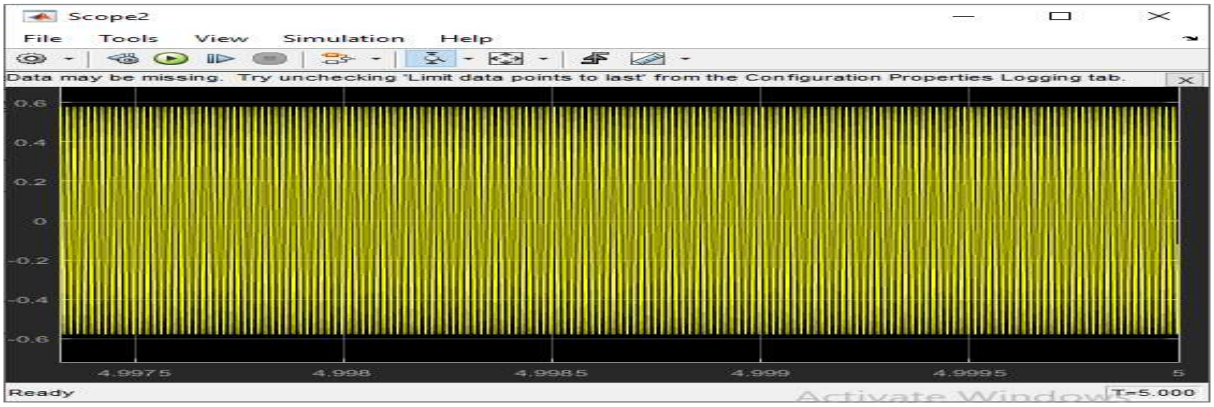


Figure 5.18 Graph of I of IWPT system with coupling coefficient(k) of 0.1252 and R=66 ohm

### 5.1.1 Output voltage,current and power of IWPT vs distance for a coil radius 2.5 cm

Table 5.1V,I and P of IWPT corresponding to different values of distance

| r(Distance) Cm | V(RMS Output volt) Volt | I(RMS Output volt) Amp | P(Output power) W |
|---|---|---|---|
| **1.50** | 193.50 | 5.53 | 1070.167 |
| **1.75** | 156.27 | 13.6 | 2034.92 |
| **2.25** | 116.31 | 5.27 | 612.16 |
| **2.50** | 103.6 | 2.93 | 299.94 |
| **3.00** | 78.3 | 1.63 | 127.73 |
| **3.50** | 58.82 | 1.05 | 61.74 |
| **4.00** | 44.73 | 0.746 | 33.39 |
| **4.50** | 34.43 | 0.523 | 18.07 |
| **5.00** | 26.95 | 0.408 | 11.00 |

## 5.2 Result of RIWPT for coil radius of 2.5 cm

- Distance between primary and secondary coil is 1.5cm,coupling coefficient K=0.8827,resistive load R=35ohm

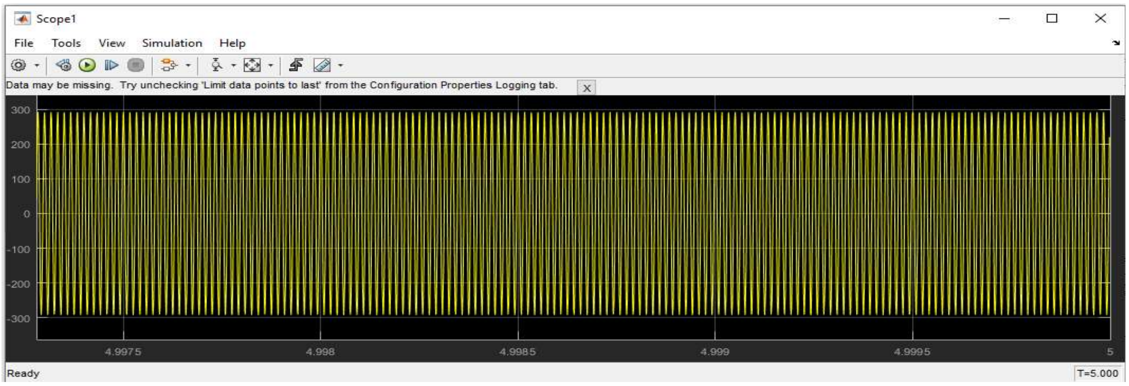


Figure 5.19 Graph of V of RIWPT system with coupling coefficient(k) of 0.8827 and R=35 ohm

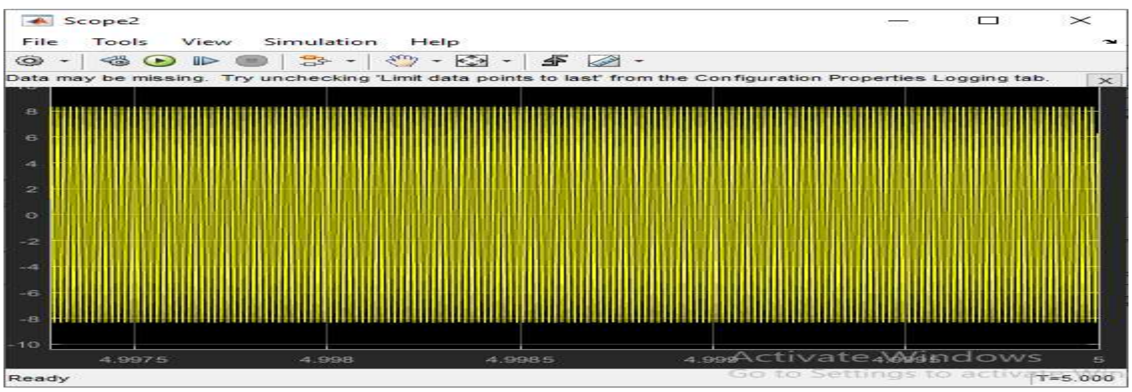


Figure 5.20 Graph of I of RIWPT system with coupling coefficient(k) of 0.8827 and R=35 ohm

- Distance between primary and secondary coil is 1.75cm,coupling coefficient K=0.7697,resistive load R=11ohm

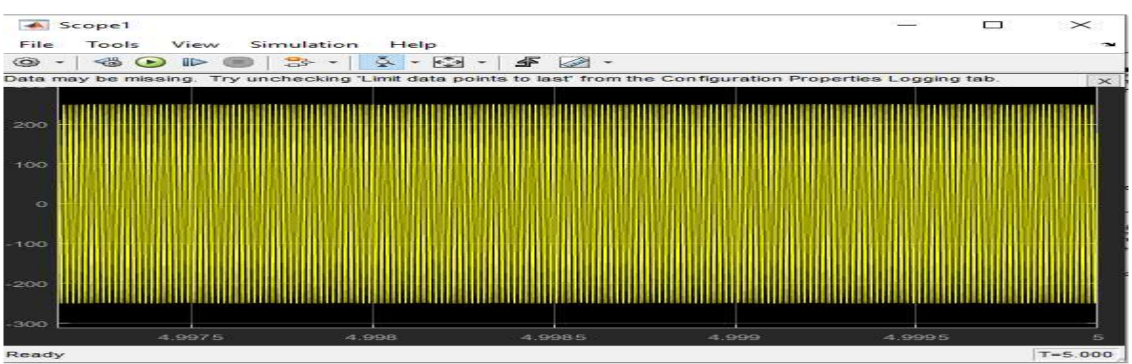


Figure 5.21 Graph of V of RIWPT system with coupling coefficient(k) of 0.7697 and R=11 ohm

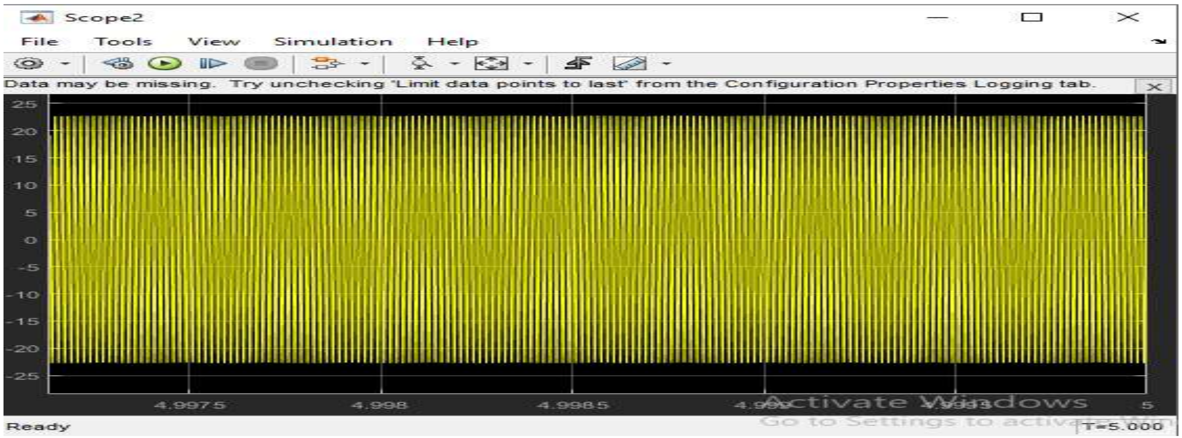


Figure 5.22 Graph of I of RIWPT system with coupling coefficient(k) of 0.7697 and R=11 ohm

- Distance between primary and secondary coil is 2.25cm,coupling coefficient K=0.5749 and resistive load R=22 ohm

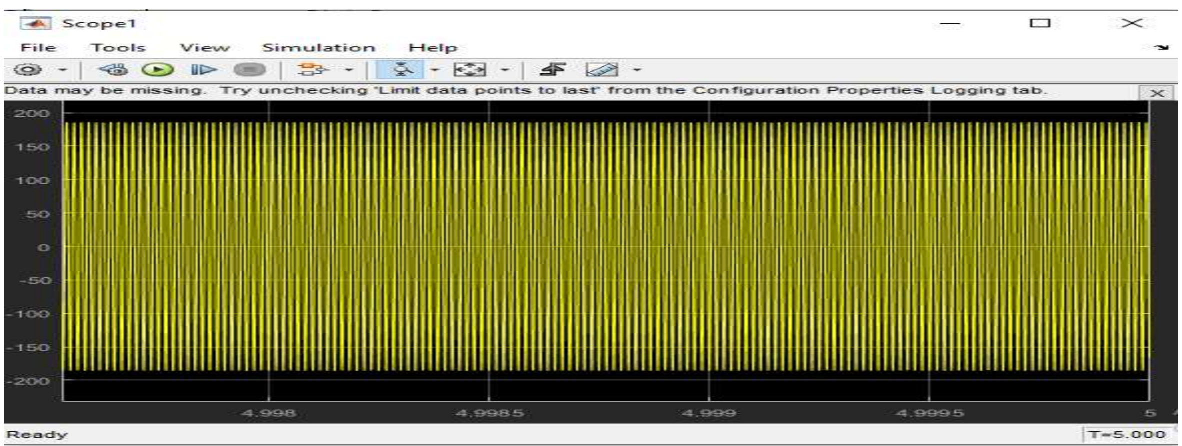


Figure 5.23 Graph of V of RIWPT system with coupling coefficient(k) of 0.5749 and R=22 ohm

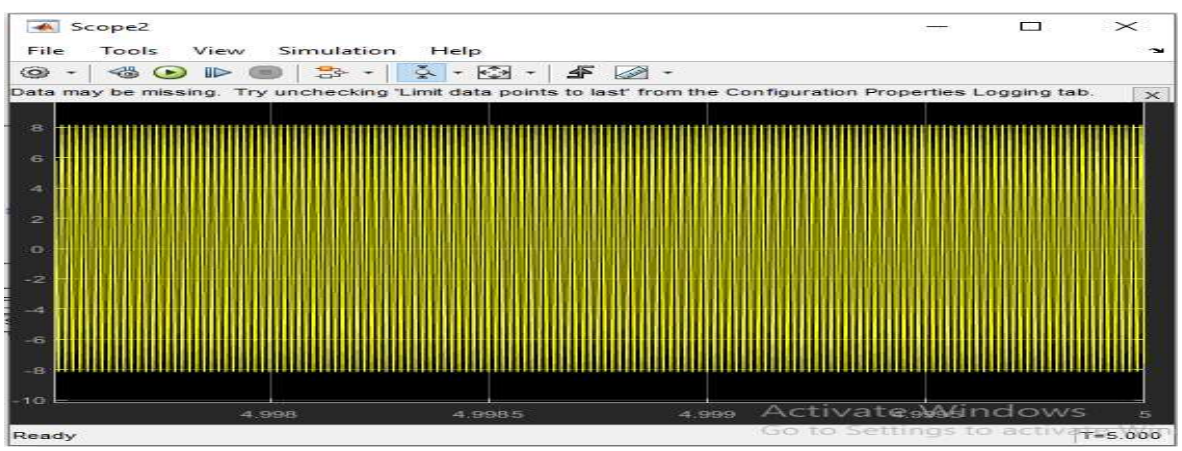


Figure 5.24 Graph of I of RIWPT system with coupling coefficient(k) of 0.5749 and R=22 ohm

- Distance between primary and secondary coil is 2.5cm,coupling coefficient K=0.4950 and resistive load R=35 ohm

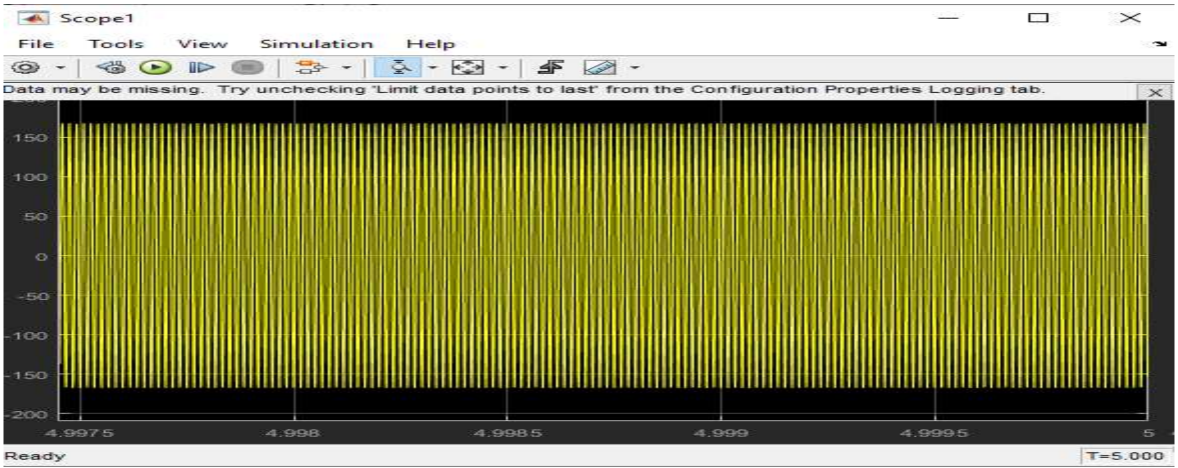


Figure 5.25 Graph of V of RIWPT system with coupling coefficient(k) of 0.495 and R=35 ohm

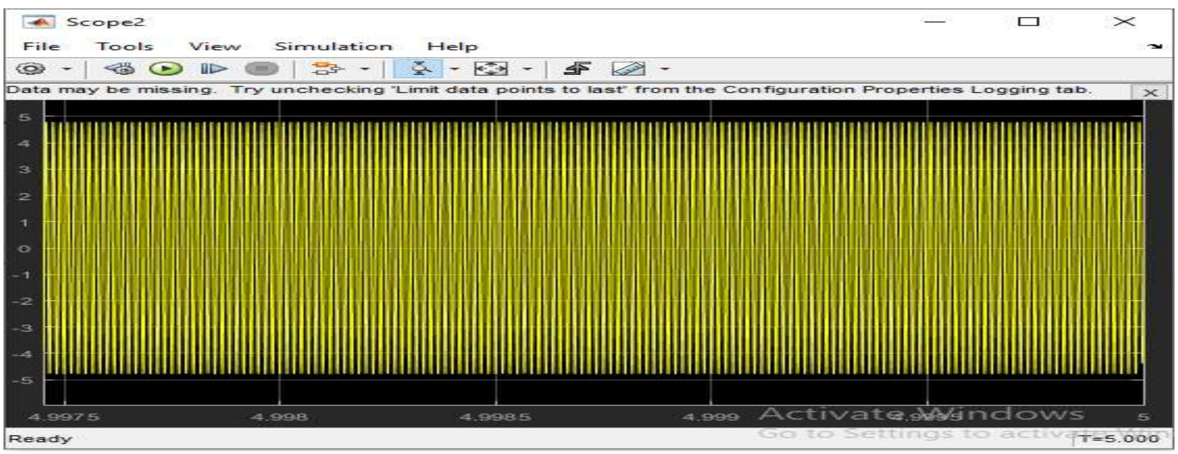


Figure 5.26 Graph of I of RIWPT system with coupling coefficient(k) of 0.495 and R=35 ohm

- Distance between primary and secondary coil is 3cm,coupling coefficient K=0.3673and resistive load R=48 ohm

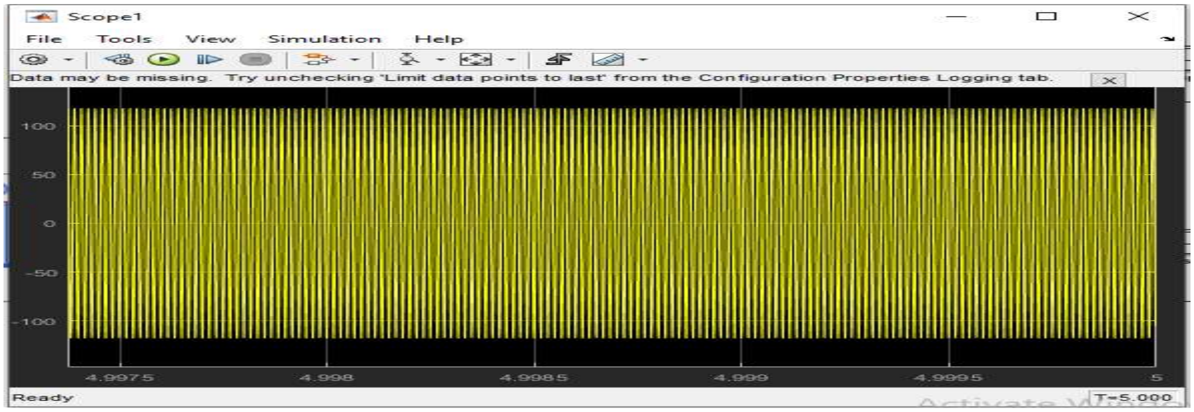


Figure 5.27Graph of V of RIWPT system with coupling coefficient(k) of 0.3637 and R=48 ohm

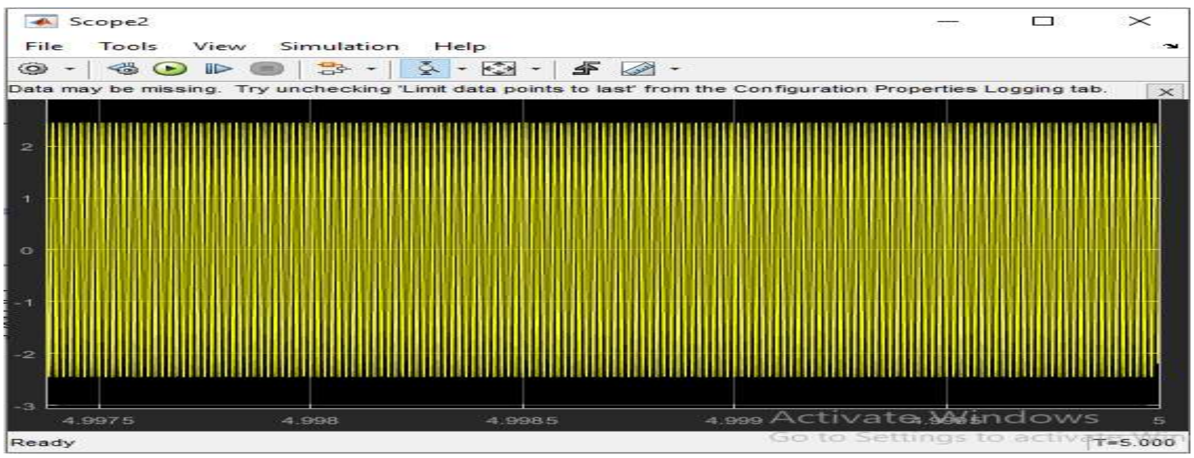


Figure 5.28 Graph of I of RIWPT system with coupling coefficient(k) of 0.3637 and R=48 ohm

- Distance between primary and secondary coil is 3.5cm, coupling coefficient K=0.2749 and resistive load R=56 ohm

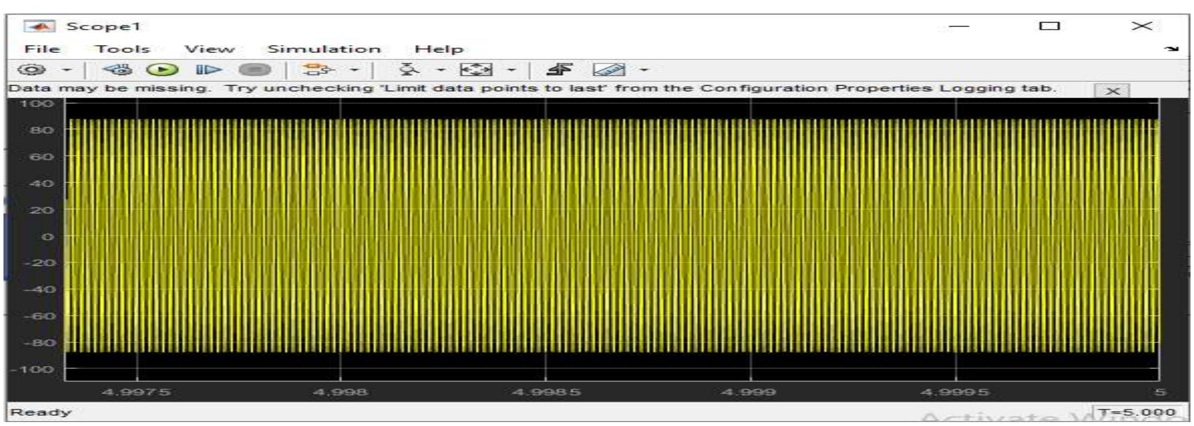


Figure 5.29 Graph of V of RIWPT system with coupling coefficient(k) of 0.2749 and R=56 ohm

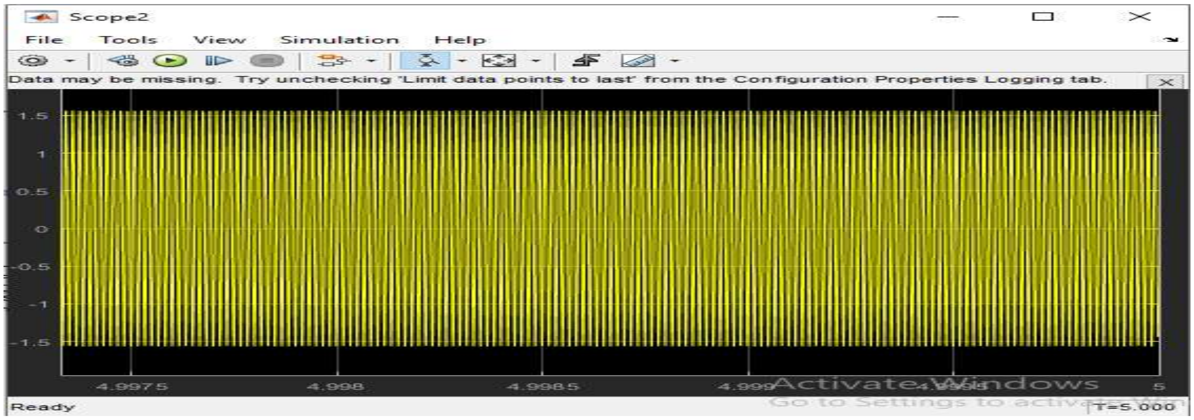


Figure 5.30 Graph of I of RIWPT system with coupling coefficient(k) of 0.2749 and R=56 ohm

- Distance between primary and secondary coil is 4cm,coupling coefficient K=0.2084 and resistive load R=60 ohm

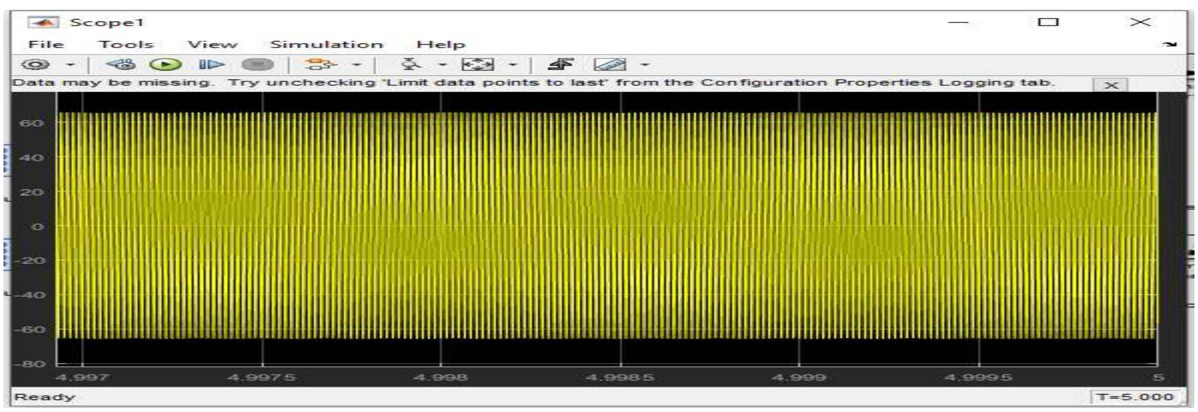


Figure 5.31 Graph of V of RIWPT system with coupling coefficient(k) of 0.2084 and R=60 ohm

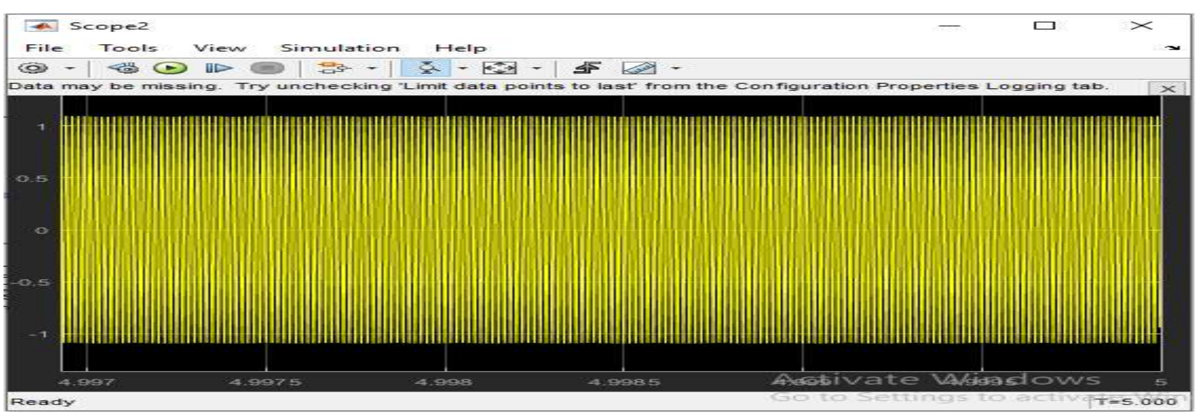


Figure 5.32 Graph of I of RIWPT system with coupling coefficient(k) of 0.2084 and R=60 ohm

- Distance between primary and secondary coil is 4.5cm,coupling coefficient K=0.1604 and resistive load R=66ohm

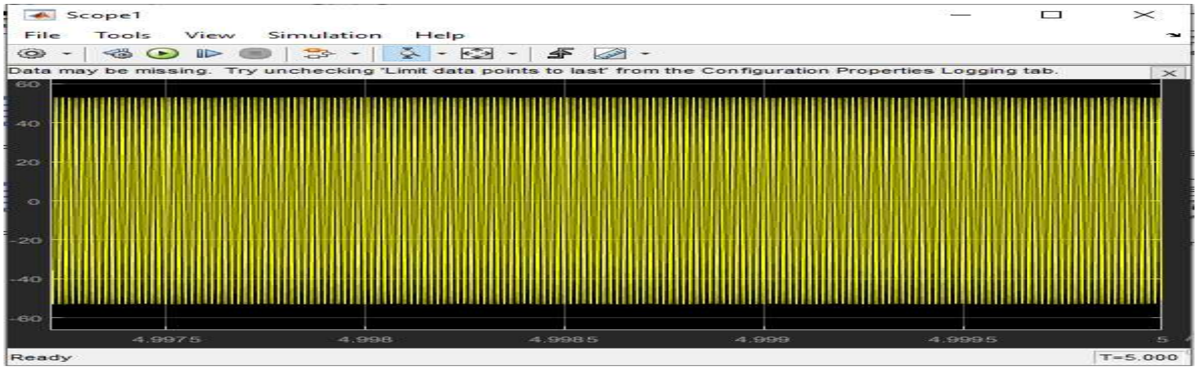


Figure 5.33 Graph of V of RIWPT system with coupling coefficient(k) of 0.1604 and R=66 ohm

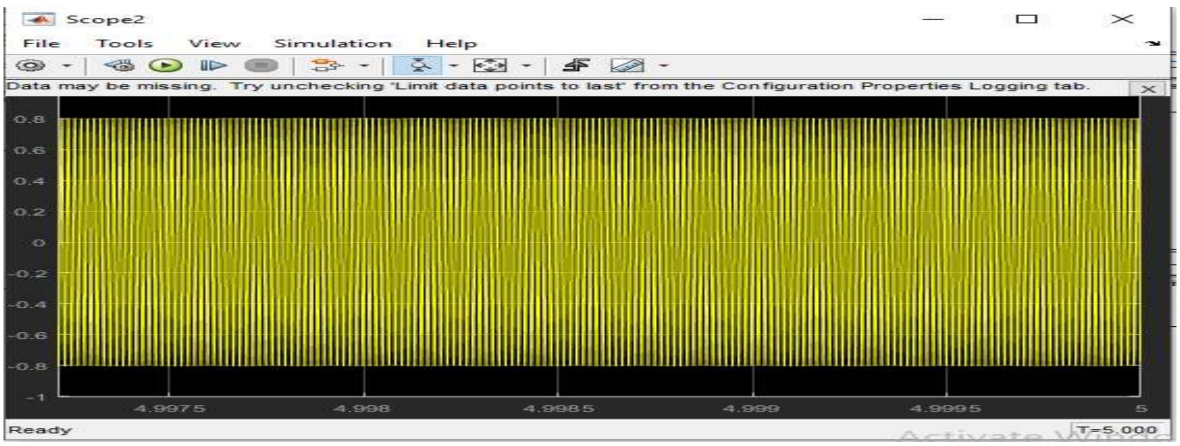


Figure 5.34 Graph of I of RIWPT system with coupling coefficient(k) of 0.1604 and R=66 ohm

- Distance between primary and secondary coil is 5cm, coupling coefficient K=0.1252 and resistive load R=66 ohm

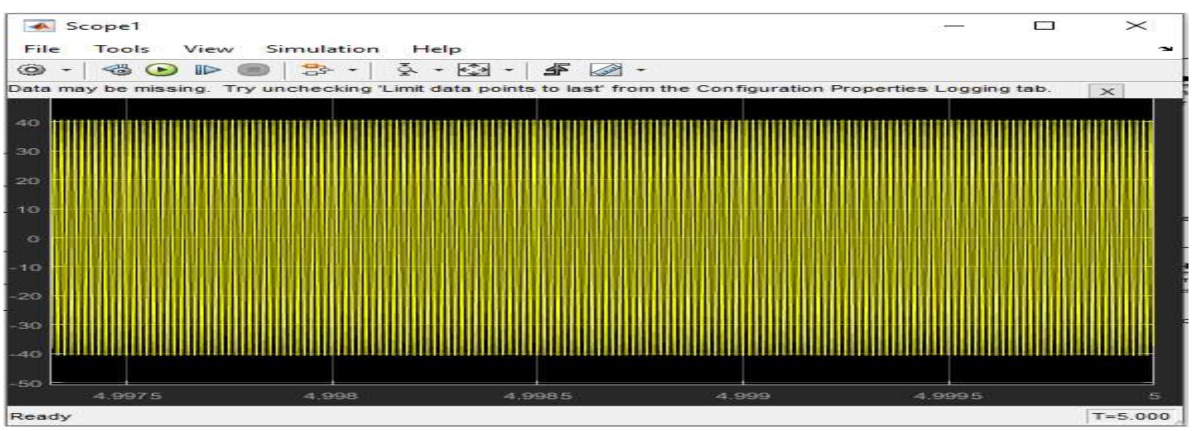


Figure 5.35 Graph of V of RIWPT system with coupling coefficient(k) of 0.1252 and R=66 ohm

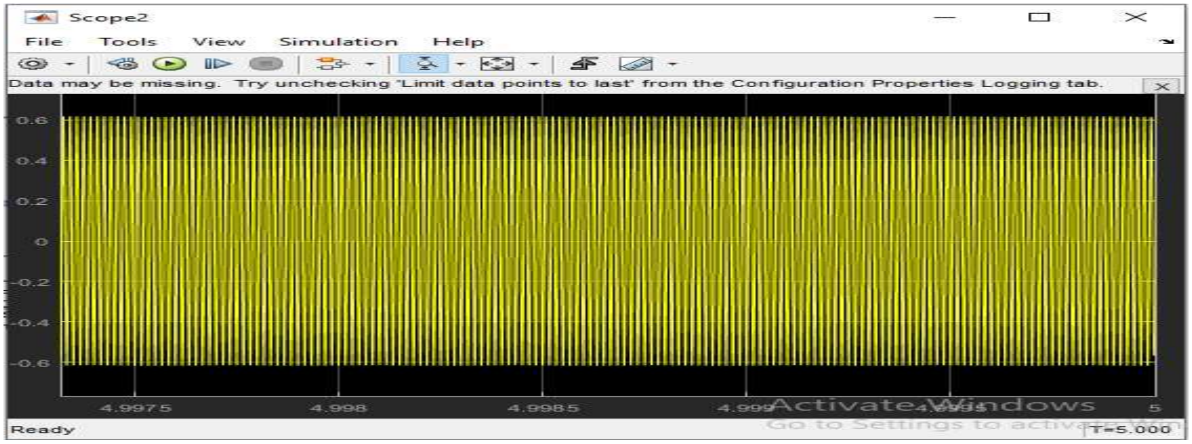


Figure 5.36 Graph of I of RIWPT system with coupling coefficient(k) of 0.1252 and R=66 ohm

### 5.2.1 Output voltage,current and power of RIWPT vs distance for a coil radius 2.5 cm

Table 5.2V,I and P of RIWPT corresponding to different values of distance

| r(Distance) Cm | V(RMS Output volt) Volt | I(RMS Output volt) Amp | P(Output power) W |
|---|---|---|---|
| **1.50** | 206.68 | 5.90 | 1220.14 |
| **1.75** | 176.98 | 16.10 | 2849.09 |
| **2.25** | 131.38 | 5.97 | 785.428 |
| **2.50** | 118.28 | 3.39 | 401.85 |
| **3.00** | 83.28 | 1.74 | 145 |
| **3.50** | 62.08 | 1.11 | 68.753 |
| **4.00** | 46.52 | 0.77 | 35.924 |
| **4.50** | 37.61 | 0.565 | 21.12 |
| **5.00** | 28.72 | 0.44 | 12.56 |

## 5.3 Result of IWPT for coil radius of 2 m

- Distance between primary and secondary coil is 1.86 m, coupling coefficient K= 0.549and resistive load R=21 Kohm

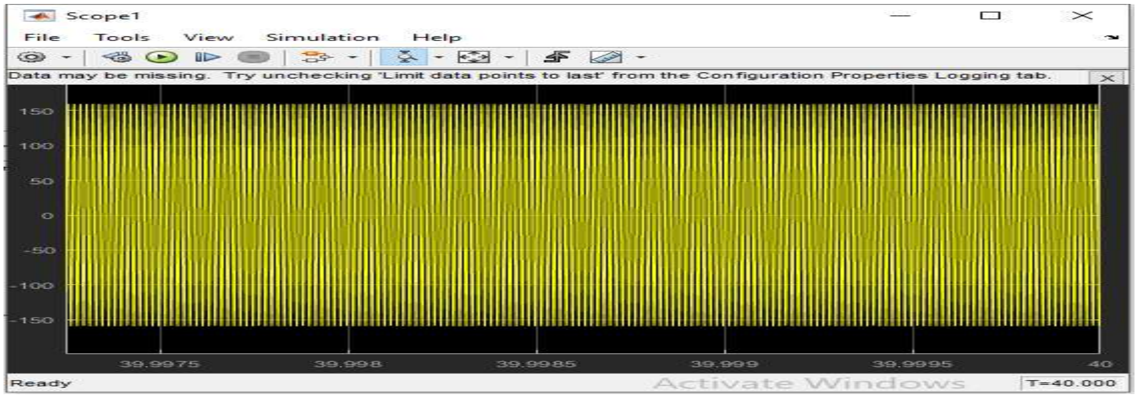


Figure 5.37 Graph of V of IWPT system with coupling coefficient(k) of 0.549 and R=21Kohm

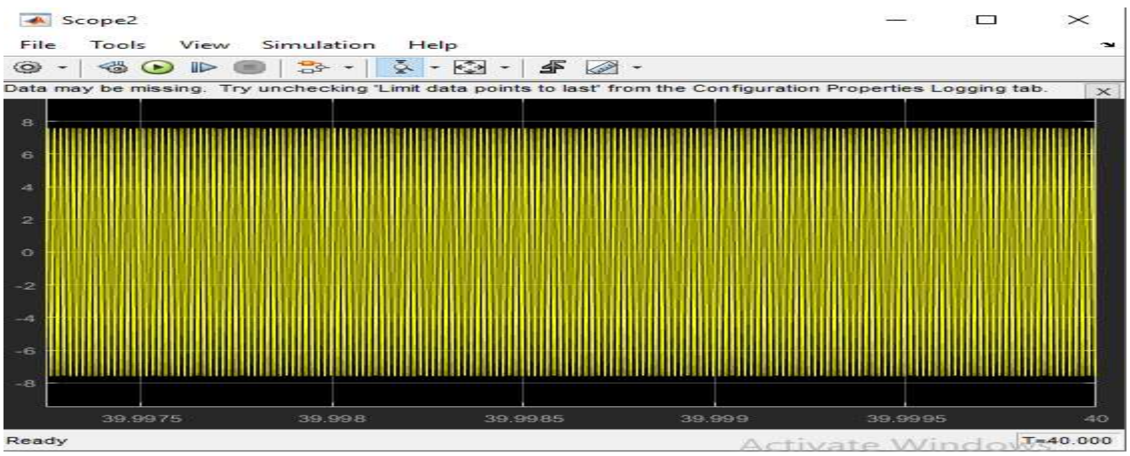


Figure 5.38 Graph of I of IWPT system with coupling coefficient(k) of 0.549 and R=21Kohm

- Distance between primary and secondary coil is 2 m and coupling coefficient K= 0.4950 and resistive load R=29 Kohm

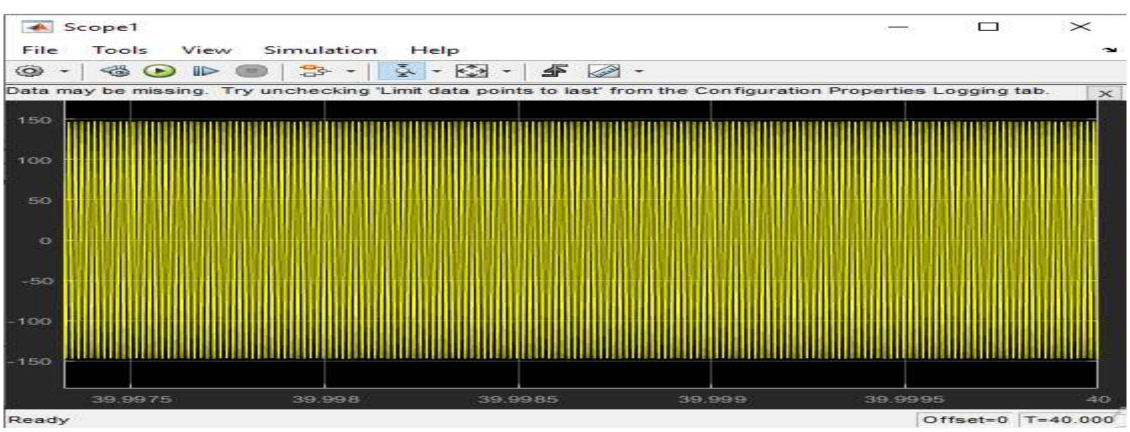


Figure 5.39 Graph of V of IWPT system with coupling coefficient(k) of 0.4950 and R=29Kohm

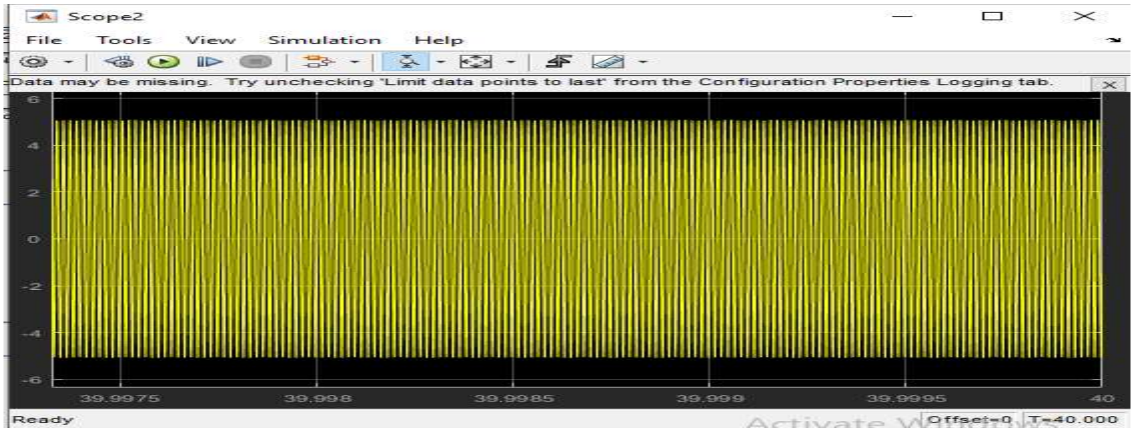


Figure 5.40 Graph of I of IWPT system with coupling coefficient(k) of 0.4950 and R=29Kohm

- Distance between primary and secondary coil is 2.25 m, coupling coefficient K= 0.415 and resistive load R=35 Kohm

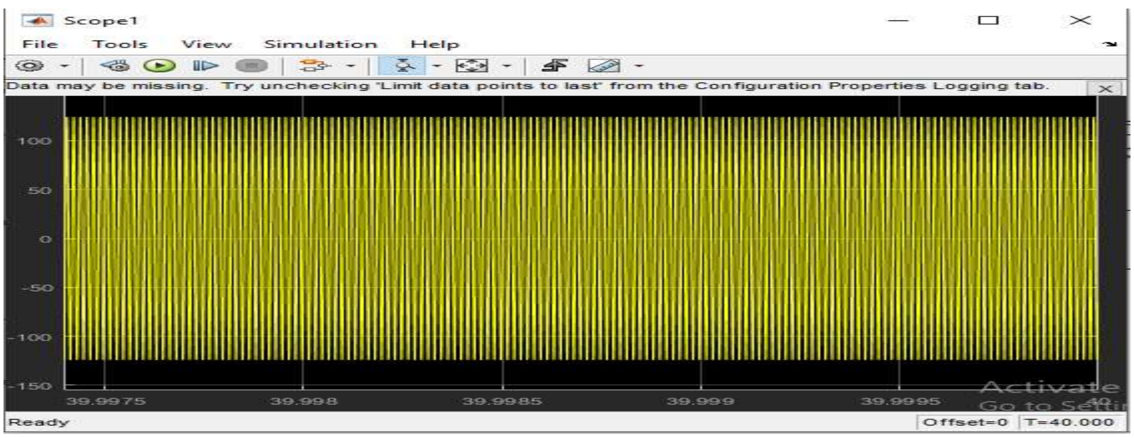


Figure 5.41 Graph of V of IWPT system with coupling coefficient(k) of 0.4150 and R=35Kohm

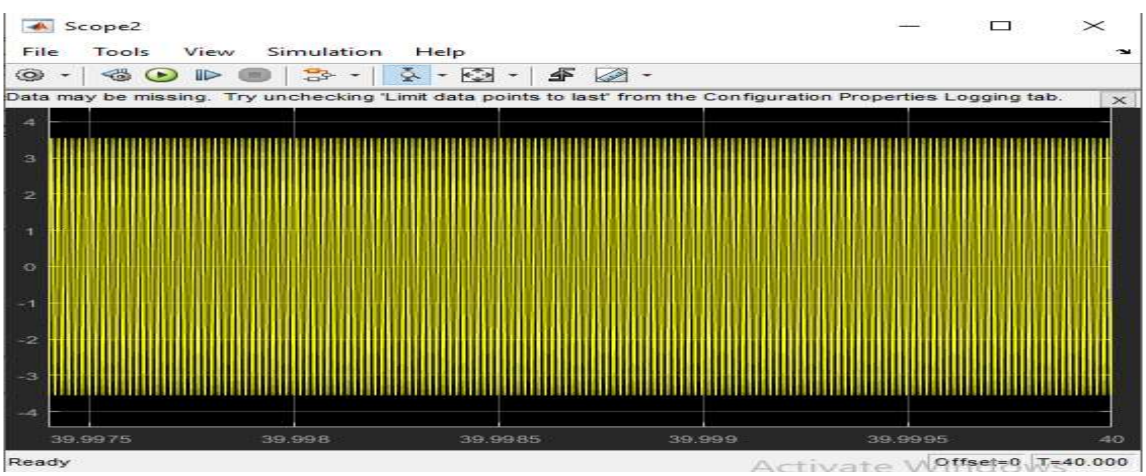


Figure 5.42 Graph of I of IWPT system with coupling coefficient(k) of 0.4150 and R=35Kohm

- Distance between primary and secondary coil is 2.5m, coupling coefficient K= 0.3413 and resistive load R=42 Kohm

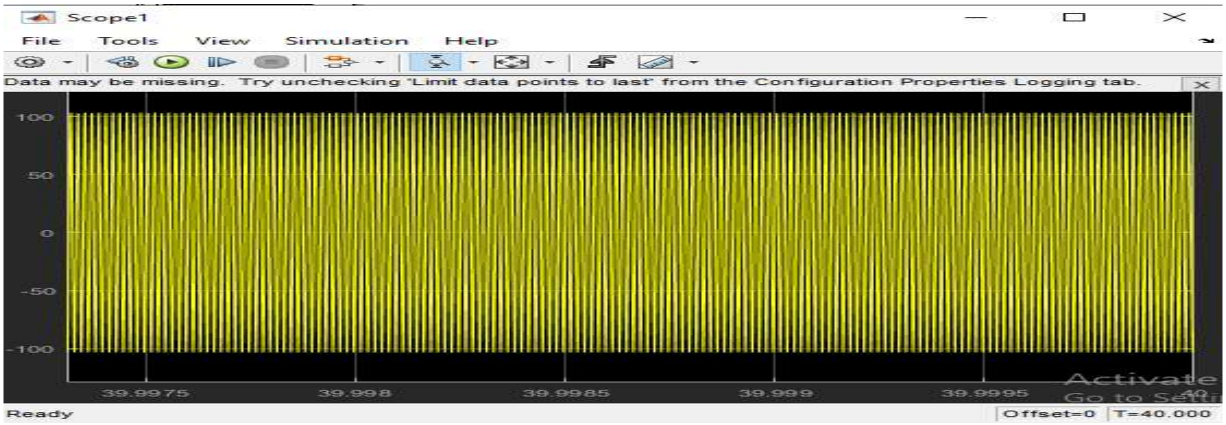


Figure 5.43 Graph of V of IWPT system with coupling coefficient(k) of 0.3413 and R=42Kohm

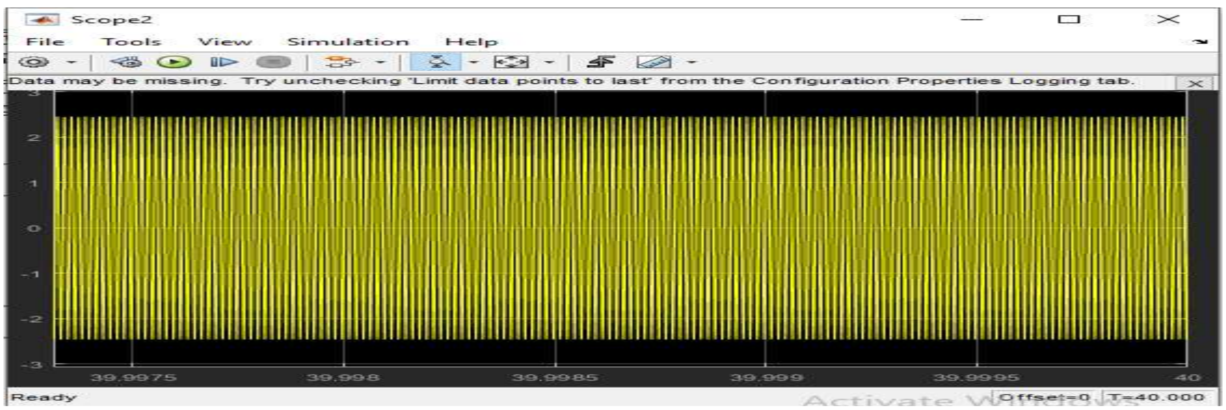


Figure 5.44 Graph of Iof IWPT system with coupling coefficient(k) of 0.3413 and R=42Kohm

- Distance between primary and secondary coil is 2.75 m and coupling coefficient K= 0.2849 and resistive load R=50 Kohm

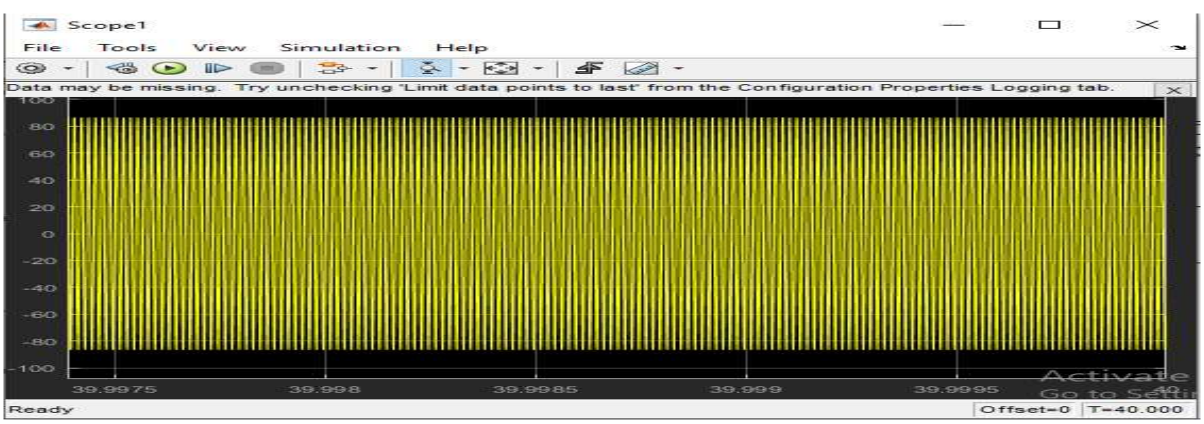


Figure 5.45 Graph of V of IWPT system with coupling coefficient(k) of 0.2849 and R=50Kohm

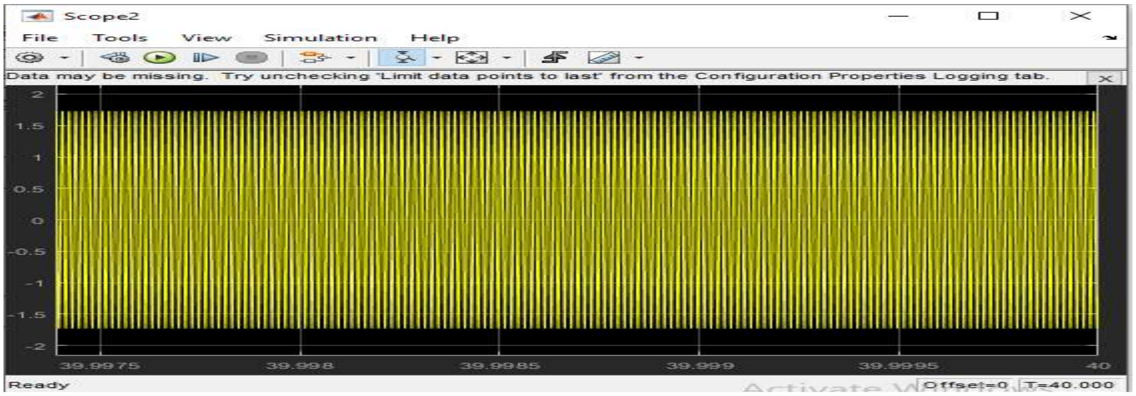


Figure 5.46 Graph of Iof IWPT system with coupling coefficient(k) of 0.2849 and R=50Kohm

- Distance between primary and secondary coil is 3 m and coupling coefficient K= 0.2389 and resistive load R=52 Kohm

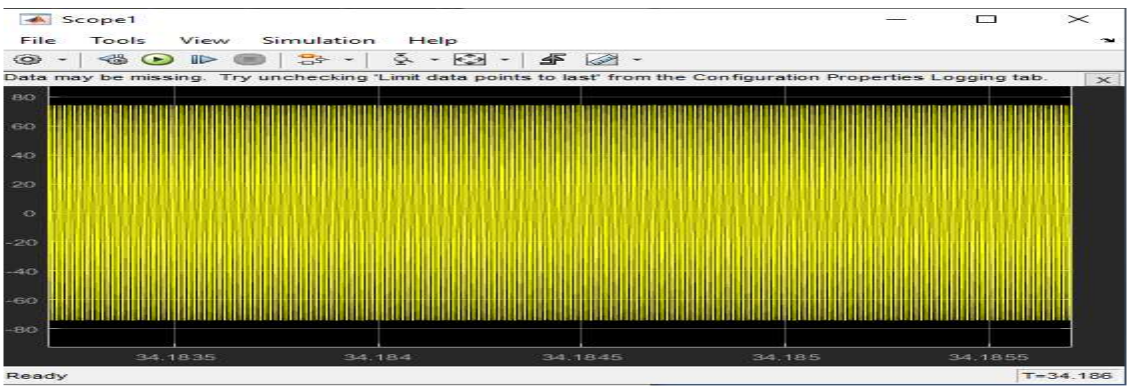


Figure 5.47 Graph of V of IWPT system with coupling coefficient(k) of 0.2389 and R=52Kohm

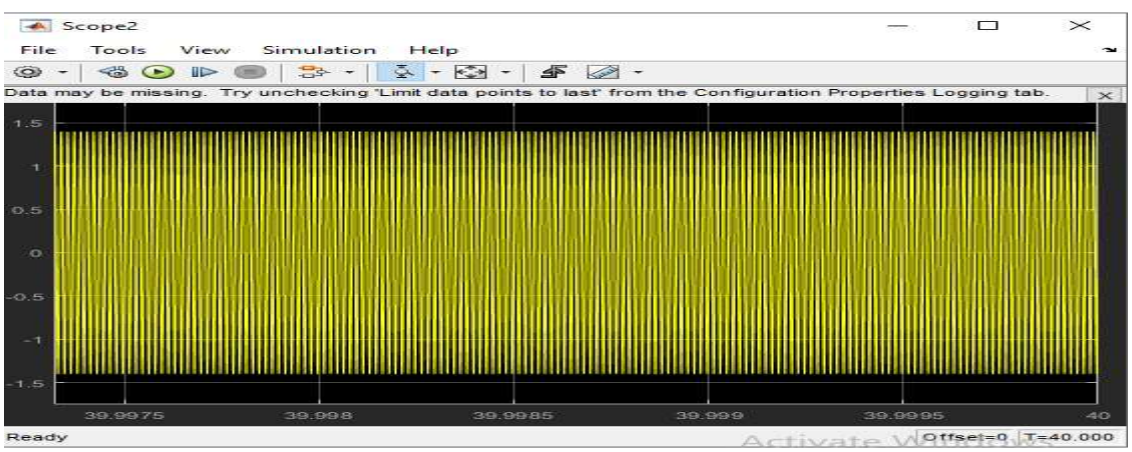


Figure 5.48 Graph of I of IWPT system with coupling coefficient(k) of 0.2389 and R=52Kohm

### 5.3.1 Output voltage,currentand power of IWPT vs Distance for acoil radius 2 m

Table 5.3V,I and P of IWPT corresponding to different values of distance

| r(Distance) Cm | V(RMS Output volt) Volt | I(RMS Output volt) Amp | P(Output power) W |
|---|---|---|---|
| 1.86 | 113.13 | 5.37 | 606480.00 |
| 2.00 | 104.24 | 3.59 | 374782.31 |
| 2.25 | 87.86 | 2.51 | 220543.75 |
| 2.50 | 72.90 | 1.74 | 126567.53 |
| 2.75 | 61.20 | 1.23 | 75082.23 |
| 3.00 | 51.44 | 1 | 50960.00 |

## 5.4 Result of RIWPT for coil radius of 2 m

- Distance between primary and secondary coil is 1.86 m, coupling coefficient K= 0.549 and resistive load R=21 Kohm

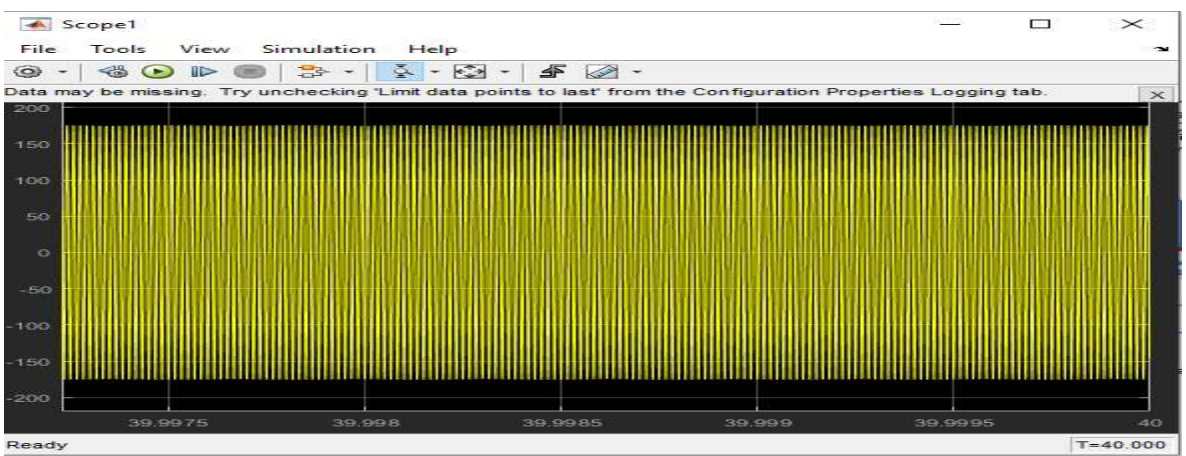


Figure 5.49 Graph of V of RIWPT system with coupling coefficient(k) of 0.549 and R=21Kohm

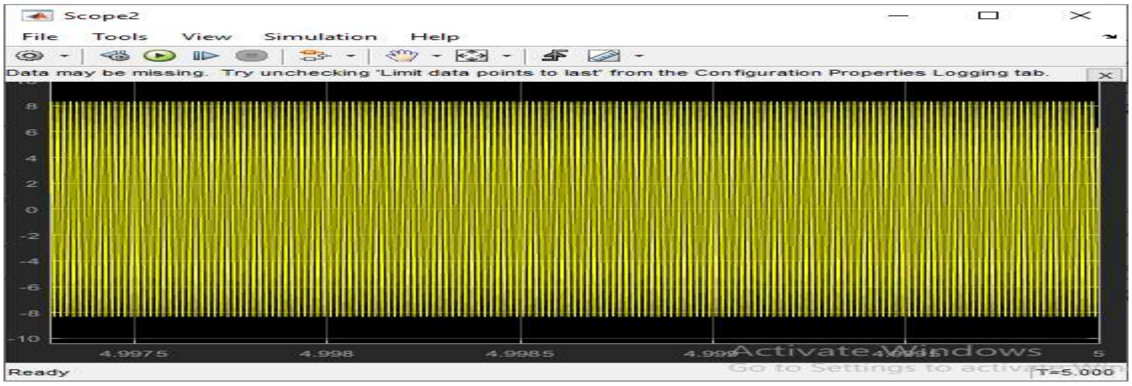


Figure 5.50 Graph of I of RIWPT system with coupling coefficient(k) of 0.549 and R=21Kohm

- Distance between primary and secondary coil is 2 m and coupling coefficient K= 0.4950 and resistive load R=29 Kohm

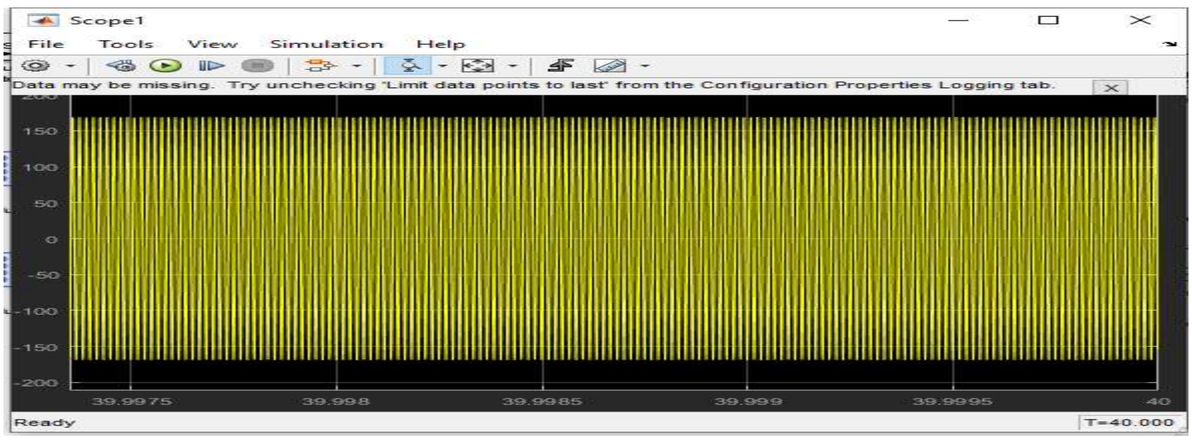


Figure 5.51 Graph of V of RIWPT system with coupling coefficient(k) of 0.4950 and R=29Kohm

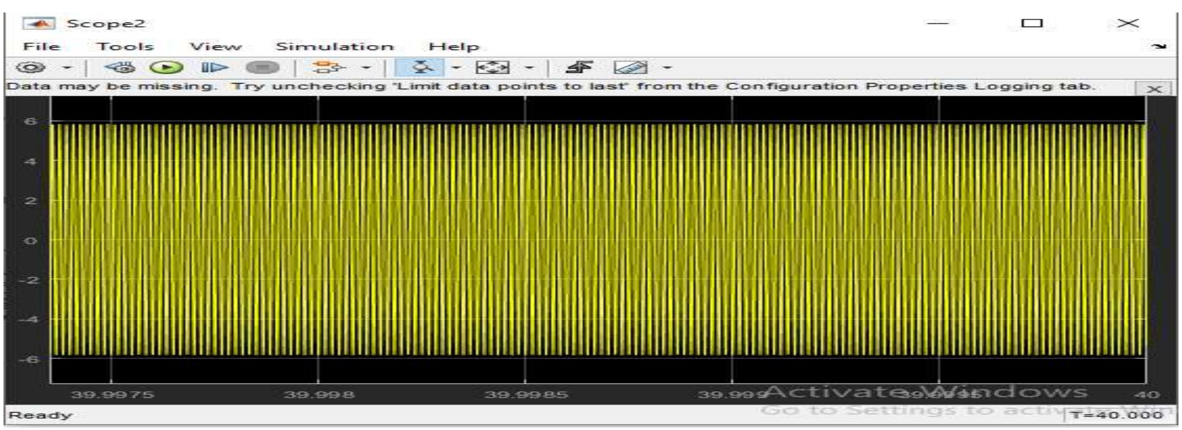


Figure 5.52 Graph of I of RIWPT system with coupling coefficient(k) of 0.4950 and R=29Kohm

- Distance between primary and secondary coil is 2.25 m, coupling coefficient K= 0.4150and resistive load R=35 Kohm

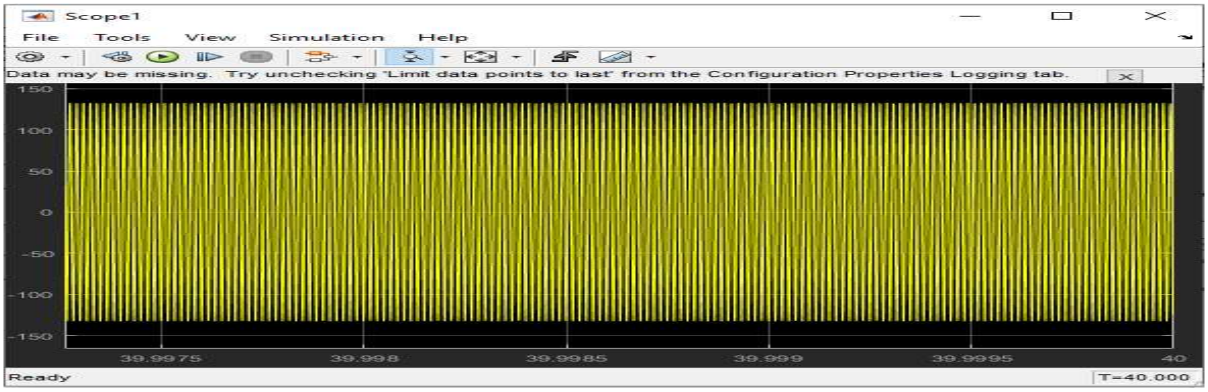


Figure 5.53 Graph of V of RIWPT system with coupling coefficient(k) of 0.4150 and R=35Kohm

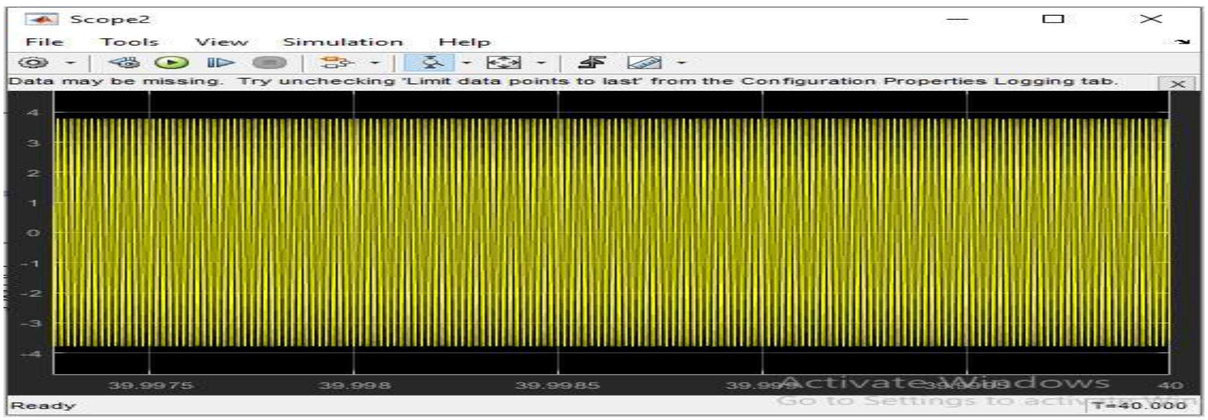


Figure 5.54 Graph of I of RIWPT system with coupling coefficient(k) of 0.4150 and R=35Kohm

- Distance between primary and secondary coil is 2.5m, coupling coefficient K= 0.3413 and resistive load R=42 Kohm

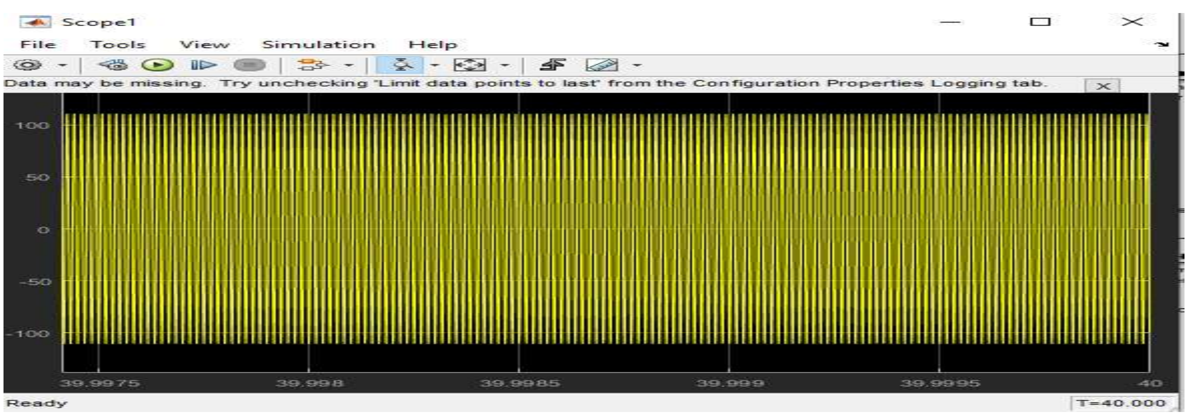


Figure 5.55 Graph of V of RIWPT system with coupling coefficient(k) of 0.3413 and R=42Kohm

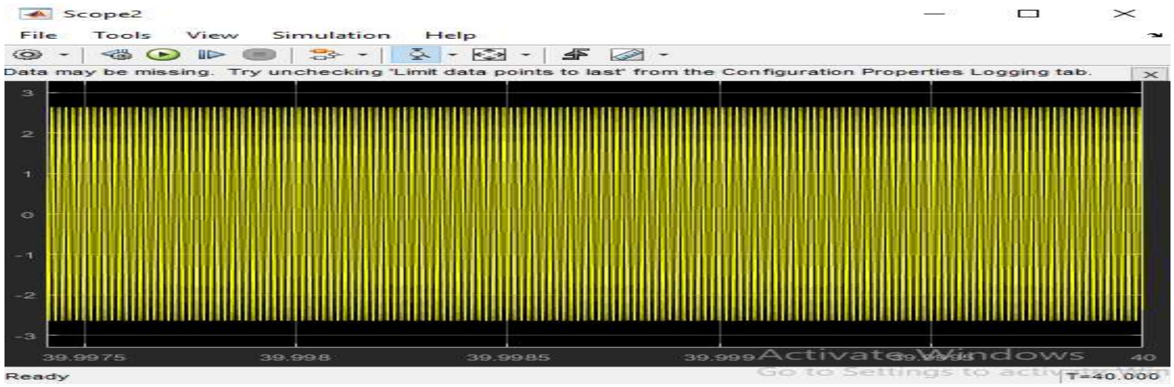


Figure 5.56 Graph of I of RIWPT system with coupling coefficient(k) of 0.3413 and R=42Kohm

- Distance between primary and secondary coil is 2.75 m and coupling coefficient K= 0.2849 and resistive load R=50 Kohm

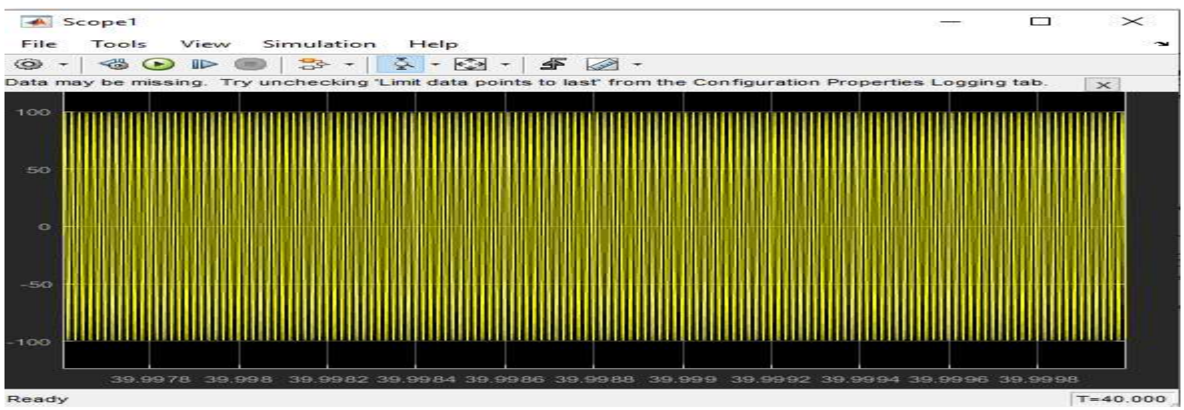


Figure 5.57Graph of V of RIWPT system with coupling coefficient(k) of 0.2849 and R=50Kohm

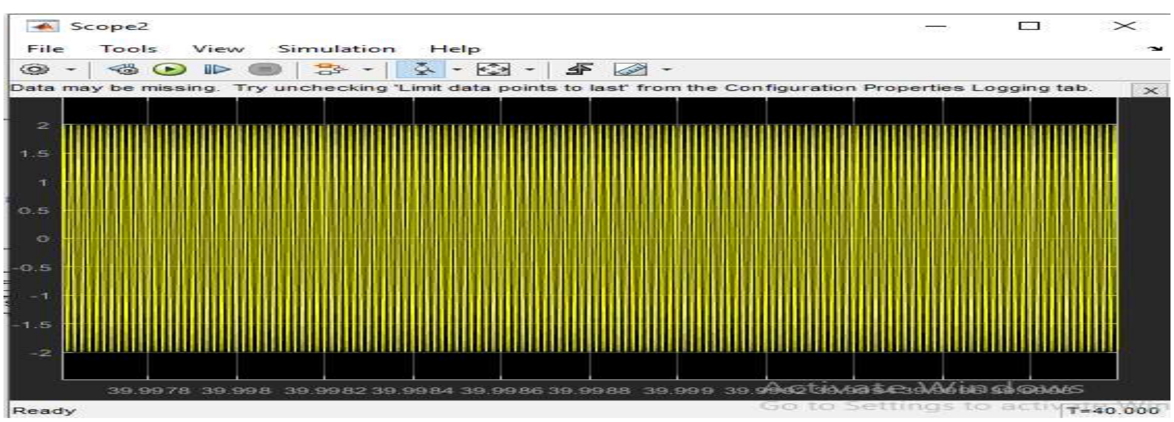


Figure 5.58 Graph of I of RIWPT system with coupling coefficient(k) of 0.2849 and R=50Kohm

- Distance between primary and secondary coil is 3 m and coupling coefficient K= 0.2389 and resistive load R=52 Kohm

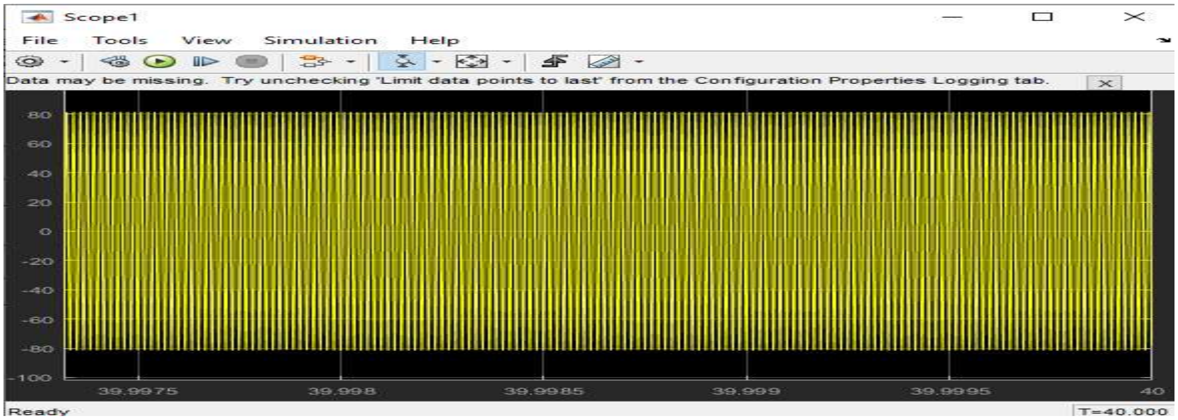


Figure 5.59 Graph of V of RIWPT system with coupling coefficient(k) of 0.2389 and R=52Kohm

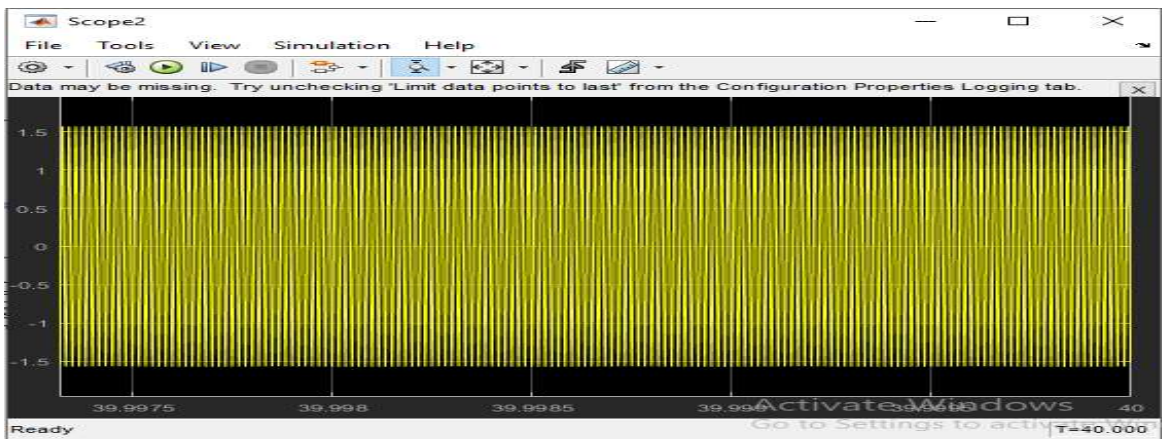


Figure 5.60 Graph of I of RIWPT system with coupling coefficient(k) of 0.2389 and R=52Kohm

### 5.4.1 Output voltage, current and power of RIWPT vs Distance for a coil radius 2 m

Table 5.4V,I and P of RIWPT corresponding to different values of distance

| r(Distance) Cm | V(RMS Output volt) Volt | I(RMS Output volt) Amp | P(Output power) W |
|---|---|---|---|
| 1.86 | 123.74 | 5.89 | 730333.80 |
| 2.00 | 119.5 | 4.122 | 492839.05 |
| 2.25 | 93.69 | 2.687 | 252700.00 |
| 2.50 | 78.43 | 1.86 | 146472.50 |
| 2.75 | 70.36 | 1.414 | 100000.00 |
| 3.00 | 57.72 | 1.11 | 64087.40 |

## 5.5 Comparative representation of IWPT and RIWPT for radius of 2.5 cm coil

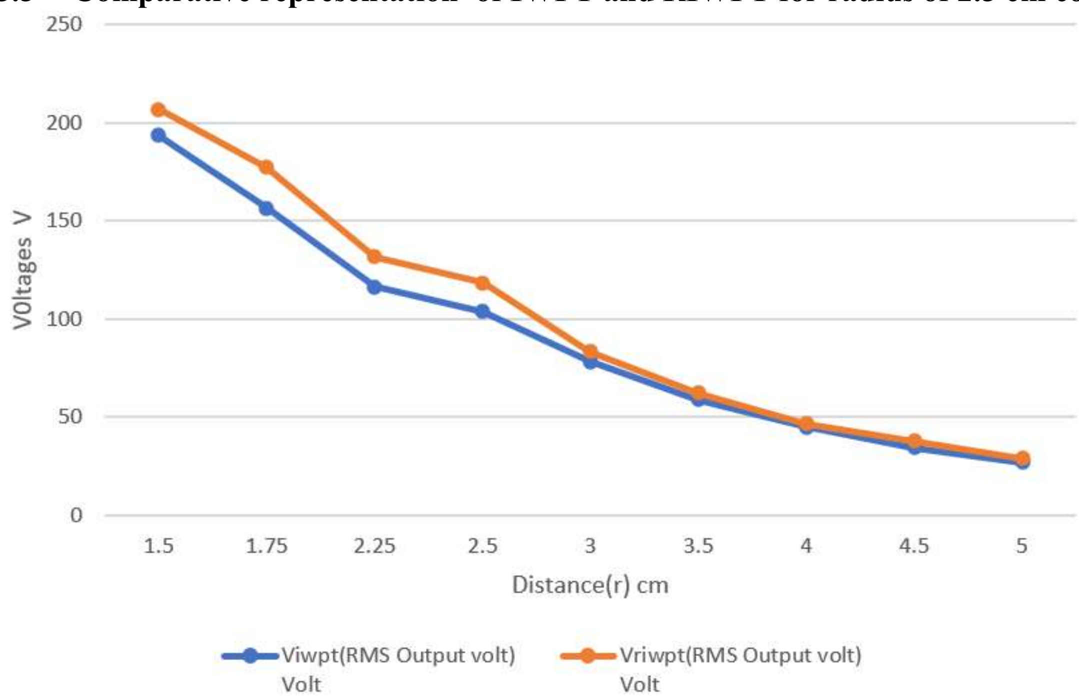


Figure 5.61 Graph of voltages for IWPT and RIWPT corresponding to distance between the coils

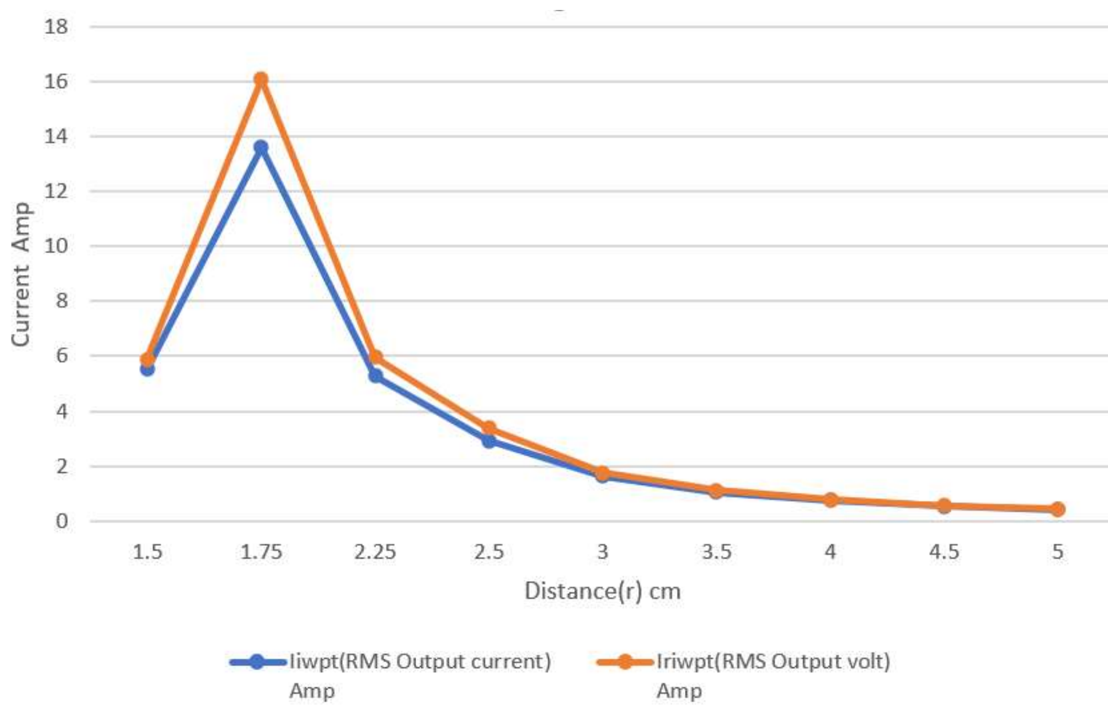


Figure 5.62 Graph of currents for IWPT and RIWPT corresponding to distance between the coils

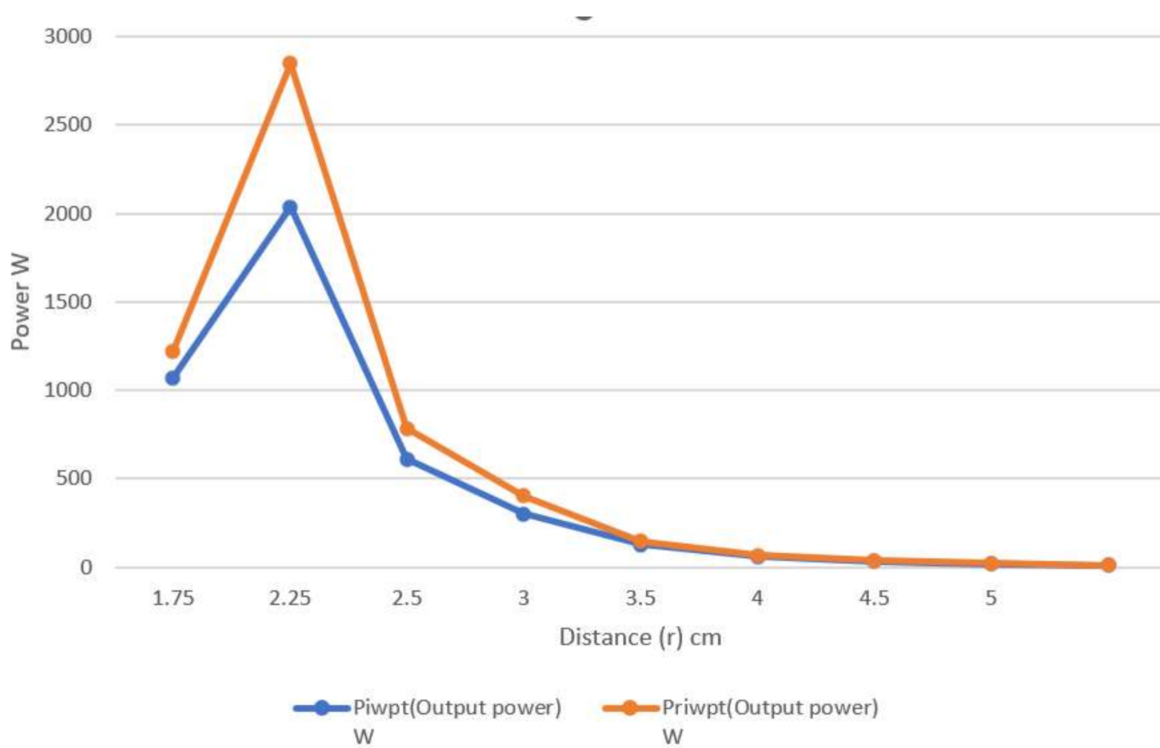


Figure 5.63 Graph of power for IWPT and RIWPT corresponding to distance between the coils

## 5.6 Comparative representation of IWPT and RIWPT for radius of 2m coil

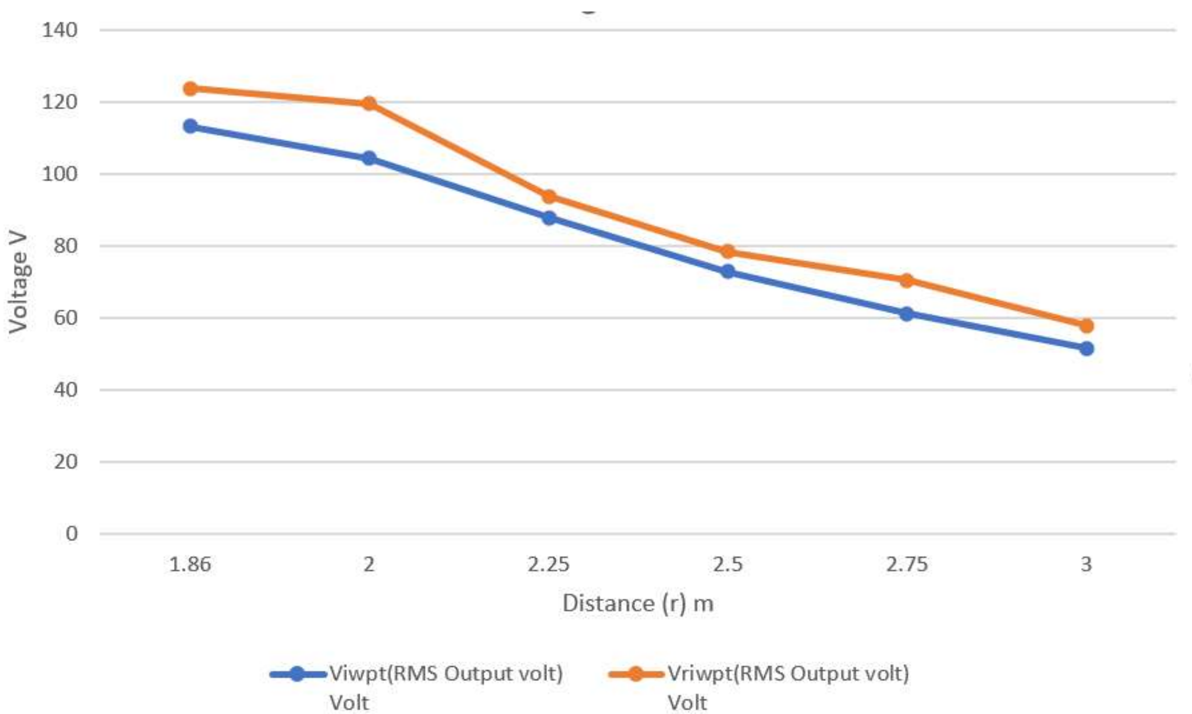


Figure 5.64 Graph of voltages for IWPT and RIWPT corresponding to distance between the coils

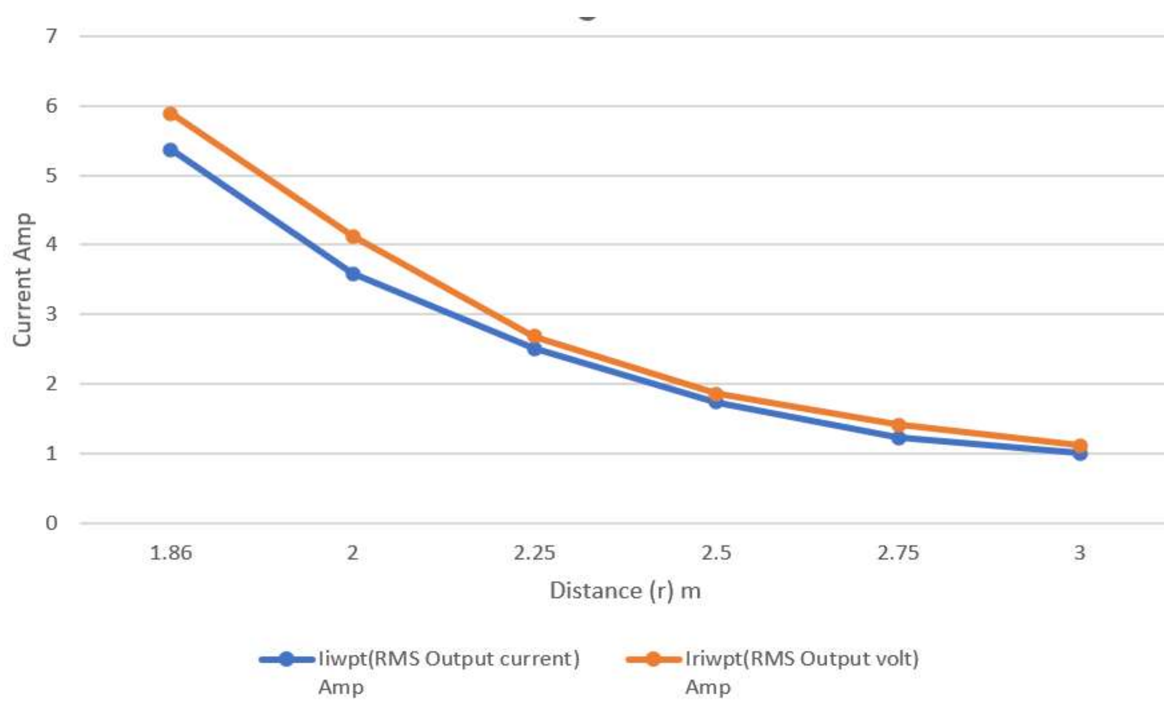


Figure 5.65 Graph of currents for IWPT and RIWPT corresponding to distance between the coils

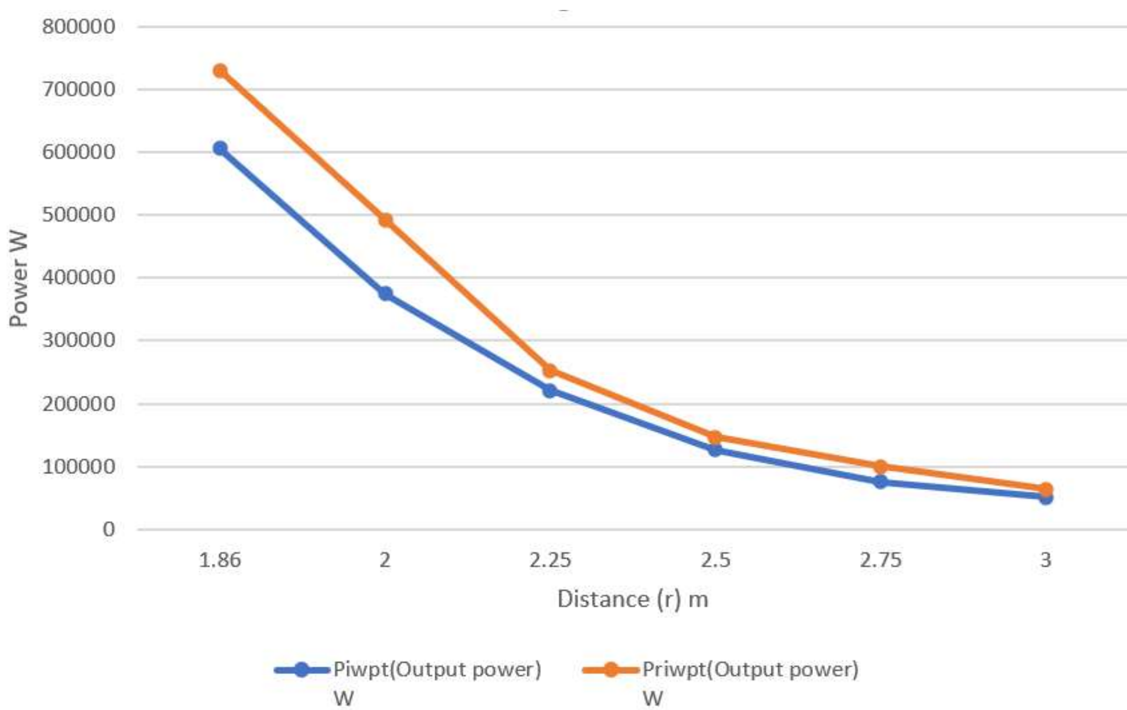


Figure 5.66 Graph of power for IWPT and RIWPT corresponding to distance between the coils

## 5.7 Improvement in efficiency

### 5.7.1 Improvement in efficiency for the system with 2.5 cm coil

Table 5.5 Improvement in efficiency for the system with 2.5 cm coil

| Distance, r cm | Improvement in Efficiency(%), $\eta_{imp}$ |
|---|---|
| 1.50 | 14 |
| 1.75 | 40 |
| 2.25 | 28.30 |
| 2.50 | 34 |
| 3.00 | 13.52 |
| 3.50 | 11.35 |
| 4.00 | 7.5 |
| 4.50 | 14.34 |
| 5.00 | 16.87 |

### 5.7.2 Improvement in efficiency for the system with 2 m coil

Table 5.6 Improvement in efficiency for the system with 2 m coil

| Distance, r<br>m | Improvement in<br>Efficiency(%),$\eta_{imp}$ |
|---|---|
| 1.86 | 20.42 |
| 2.00 | 31.50 |
| 2.25 | 14.58 |
| 2.50 | 15.73 |
| 2.75 | 33.18 |
| 3.00 | 25.76 |

## 5.8 Results and discussion

Our whole study is based on inductive wireless power transmission (IWPT) and resonant coupling inductive wireless power transmission system. For that two cases have been considered. One is when power is transmitted in a short distance where transmitter coil and receiver coil radii are of 2.5 cm each. Another case is when the power is transmitted in medium distance and transmitter coil and receiver coil radii are of 2m each.

For the first case the resistive loads are varied in the range from 11 Ω to 66 Ω for different distances. When distance between the coils is changed from 1.5cm to 5 cm the voltage is about 193.50V for a distance of 1.5 cm and coupling coefficient(k) of 0.8827. As the distance is increased the voltage is decreasing and it is about 27V for the distance of 5cm and k of 0.1252. Similar to voltage, the current also decreases from 5.53 Amp to 0.408 Amp for the same condition but an increase in current has been seen for distance ranging 1.5cm to 1.75 cm. Then it decreases with distance. Similar to current the Power also decreases from 1070.17 W to 11 W with distance and an increase in power is seen for the distance ranging 1.5cm to 1.75 cm.

When the matching network is introduce to the system i.e. for the RIWPT, the voltage for the distance 1.5 cm has become 206.68 v and starts decreasing as the distance between the coils is increased. But it is seen that all the voltages are improved and it can be seen in the figure 5.69. Similar to voltage, the currents also improved which ranges from 5.9 Amp to 0.44 Amp for the same condition as shown in the figure 5.70. The output power is also improved which ranges from 1220.14W to 12.56 W as shown in figure 5.71 and the improvement in efficiency can be seen in the table 5.5.

For the second case i.e. for the medium range, the load resistances are varied in the range of 15KΩ – 52KΩ for different distances. When the distance is changed from 1.86 m to 3m it is seen that the voltage is about 113.13 V for a distance of 1.86 m between the coils and it is decreasing with increase in distance. Similar to voltage, the current also decreases from 5.37Amp to 1Amp for the same condition. The output power also decreases from 606.480KW to 50.96KW with increase in distance.

When same study is done for RIWPT, the voltage is increased to 123.74 V for a distance of 1.86m and decreasing with increase in distance. But all the voltages are improved as seen in figure 5.72. Similar to voltage, the current is also improved which ranges from 5.89Amp to 1.11 Amp for the same condition which is shown in figure 5.73. The output power is also improved that ranges from 730.33 KW to 60.087 KW and it is shown in figure 5.74. The improvement in efficiency can be seen in the table 5.6.

## 5.9 Conclusion

Recently, wireless power transfer has got more attention from researchers and inventors because this technology has opportunity to change many things in the daily lifestyle as well as the industrial sector. In this report, wireless power transfer by using inductive coupling and also by Resonant Inductive Coupling has been successfully simulated by using MATLAB Simulink. Parameters like self-inductance, mutual inductance and coupling coefficient are analytically determined for a pair of helical coils. Promising results have been obtained, the results indicated that, wireless power transfer can be considered as a solution for many situations where the power has to be transmitted wirelessly. In this project report comparison of inductive coupling and Resonant Inductive Coupling has been carried out both analytically and graphically. It has been observed that delivery of electric power wirelessly to device using resonant inductive coupling provides better level of convenience over the inductive coupling to users of portable devices and eliminates the environmental threat posed by bad cord and cable. Tremendous research is still going on in the field of WPT specially for long distance power transmission. As future scope of the present work we can mention that the work may be extended in the fields of

1. **Charging of electric vehicle wirelessly**

a charging pad sits on the ground, connected to a wall-mounted power adapter. All the cars park over it. On the backside of the car there is a receiver when charger detects the receiver within range, it automatically starts charging.

2. **Wirelessly powered home appliances**

In future ,All the home appliances such as Television, Laptop, Lamp, Iron, Sound Box, Fridge, Mobile etc. can be powered wirelessly through a single transmitting device inside a room.

### 3. Universal power source in emergency

In an emergency or disaster situation where all the communication medium and power system has broken down. In this situation an emergency power source may help to provide necessary power source to power their communication devices so that they can easily connect with their family and rescue services. An universal power source consists of an airship built in power trasmitter which act as power source and drones ;which consists of power receiving and trasmitting device which provide basic communication as well basic wireless power to the affected people

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