

FINAL YEAR PROJECT REPORT

(WIRELESS POWER TRANSMISSION)



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ABSTRACT

WIRELESS POWER TRANSMISSION

The last couple decades ushered in the development of mobile devices, so the interest in wireless energy has grown very rapidly. It is important to mention that the electrical-wire grid has spread to almost every corner of the world, so now wireless transfer for distances of even several tens of centimeters could be useful. Wireless Power Transmission is the process that takes place in any system where electrical energy is transmitted from a power source to an electrical load without interconnecting wires. we want use WPT. Due to the some reasons, low efficiency of wired transmission lines, high mechanical cost of conductors and poles, high cost of insulators, high cost of grid stations, high cost of repair and maintenance, health hazardous, requires large area for poles, difficult to install in hilly areas. We use the NEAR FIELD Method in which we apply the RESONANT INDUCTION. In resonant coupling, if inductors are tuned at a mutual frequency, significant power may be transmitted over a range of many meters. There are some benefits of WPT which are, high efficiency, low installation cost, low repair and maintenance cost, no corona effect, reduce cost of protection. If the primary and secondary coils are resonant at a common frequency, it turns out that significant power may be transmitted between the coils over a range of a few times the coil diameters at reasonable efficiency. Resonant Inductive coupling is also used for wireless charging of electronic devices such as electric tooth brushes, laptops ,mobile phones and charging mats such as splash power.

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List of Abbreviations :

| | |
|-----------------------|---|
| AC | Alternating current |
| AF | Audio frequency |
| AIA | Active Integrated Antenna |
| BJT | Bipolar Junction Transistor |
| CMOS | Complementary Metal Oxide Semiconductor |
| CMRR | Common-mode rejection ratio |
| CO₂ | Carbon dioxide |
| DCR | Dynamic Cable Rating |
| DTS | Distributed Temperature Sensing |
| E | Voltage drop |
| EMF | Electromagnetic fields |
| EPDM | Ethylene propylene diene M-class |
| FET | Field Effect Transistor |
| GPS | Global Power station |
| GW | Gega Watt |
| HBT | Heterojunction Bipolar Transistor |
| HEMT | High Electron Mobility Transistor |
| HVDC | High-voltage direct current |
| ICNIRP | International Commission on Non-Ionizing Radiation Protection |
| IC | Integrated Circuit |
| IEEE | Institute of Electrical and Electronics Engineers |

| | |
|-----------------|---|
| ISIS | International Space Information Service |
| ISY-METS | International Space year – Microwave Energy Transmission Space |
| ITU | International Telecommunication Union |
| LF | Low Frequency |
| LPT | Laser Power Transmission |
| MF | Medium Frequency |
| MINIX | Microwave Ionosphere Nonlinear Interaction experiment |
| MOS | Metal Oxide Semiconductor |
| MOSFET | Metal Oxide Semiconductor & Field Effect Transistor |
| MPT | Microwave Power Transmission |
| MW | Megawatt |
| NAERC | North American Electric Reliability Council |
| NASA | National Aeronautics and Space Administration |
| NICT | National Institute of Information and Communications Technology |
| PARC | Power adaptive rectifying circuits |
| PDA | Personal digital assistants |
| PDC | Power added efficiency |
| PFD | Power flux density |
| PLC | Power-line carrier |
| RF | Radio frequency |
| RFID | Frequency identification |
| RTTR | Real Time Thermal Rating |

| | |
|---------------|--|
| SPS | Solar Power Satellite |
| SPORTS | Space Power Radio Transmitter System |
| SPRITZ | Solar Power Radio Integrated Transmitter |
| T/F | Transformer |
| UK | United Kingdom |
| VLF | Very Low Frequency |
| WPT | Wireless Power Transmission |
| XLPE | Cross Linked Polyethelene |

There are various situations in which a permanent source of electrical energy is desired but cannot be conveniently supplied. Ishiyama (2003) documented this need in mobile applications such as notebook personal computers, personal digital assistants (PDAs), and radio frequency identification (RFID) tags. Hirai (1999) conveyed it in flexible manufacturing systems; desiring that machines be wirelessly powered to allow product variation with few constraints on power supply. Additionally, it is assumed that there are numerous commercial product applications that could benefit from a wireless power transfer.

Such as the need to supply wireless power to household lamps. This need is considered a latent need of many homeowners because it is not widely recognized. It is estimated that in 2000, consumers spent \$759.6 million on table and floor lamps (Encyclopedia of American Industries, 2006).

In many instances, these table and floor lamps were placed in remote locations within the house that do not facilitate the use of power cords. For example, a lamp may be placed in the middle of a room making it inconvenient to power by cord. For the most part homeowners leave such lamps without power, providing only aesthetic benefits.

This thesis demonstrates the use of wireless power in a prototype for a commercial product that allows remote electronic equipment to be electrified wirelessly.

1.1 Statement of the Problem:

Wireless power transfer is a daunting task because few people have ever been able to perform it efficiently at considerable distances and then only with a very low amount of power. Even fewer people (none at the time of this thesis) have been able to implement long-distance wireless power transfer in commercial applications. Induction has been used as a form of wireless transfer for distances of less than a couple inches; however, this technology is not a feasible method of transferring power across a room, whereas in place of it resonant induction is a much better scheme. Wireless power transfer through radio frequencies has also previously been explored.

There are many applications that would benefit from the ability to transfer power wirelessly (even at low wattage) such as the charging of laptop personal computers and cell phones; the appropriate technology must be developed to satisfy these applications.

1.2. Purpose of the Study

The main emphasis in this thesis is given to the study and implementation constraints related to the wireless power transfer. This technology is a burning issue these days. In this thesis we have discussed in detail the techniques which could be used for the wireless power transfer and also the merits and demerits associated with each technique.

We have also produced a working prototype of wireless power transfer in which we have enlightened a group of led's using the technique of resonant induction with a distance of at least up to 2 inches and a power delivered at the receiver side was sufficient to charge a mobile by using some enhanced circuitry.

1.3. Historical review of Wireless Power Transmission (WPT)

We first present a brief historical review of the development of technology of the electric power transmission by radio waves. The idea of radio power Nicola Tesla first conceived transmission about a century ago. He attempted to distribute ten thousands horsepower electricity by radio waves. He said "This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horsepower. One of its chief uses will be the illumination of isolated homes". He actually built a gigantic coil, which was connected to a high mast of 200-ft height with a 3 ft diameter ball at its top. He fed 300 kW power to the Tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV. From the turning point from the 19th to the 20th century on, however, radio has been used mainly for transmitting intelligence and information, and very few attempts have been made to transmit electric power over radio following Tesla's work. The reason for a lack of interest in radio power transmission in the first half century is clear. The available radio frequency is too low to achieve small enough antenna for beamed power toward the customers' site. However at the close of World War II, engineers and scientists started to reexamine the original Tesla idea of transmitting electric power via radio to a distant place, as high-power microwave technologies became available. However, the technology of the high power microwave tube was not well developed yet for practical continuous transmission of electric power. Further, no power device was available to convert microwave power back to DC power until the 1960's.

The postwar history of research on free-space power transmission is well documented by William C. Brown [84Bro], who was a pioneer of practical microwave power transmission. Brown carried out successfully a demonstration experiment of microwave-powered helicopter in 1964, using 2.45 GHz.

The frequency 2.45 GHz is in the frequency range of 2.4 – 2.5 GHz reserved for the ISM (Industrial, Scientific and Medical) applications of radio waves. Brown also invented a new device called "rectenna" to convert a microwave power back to DC power for the microwave-powered helicopter experiment.

The highest record of 84 % microwave-to-DC conversion efficiency was achieved in the

demonstration experiment of microwave power transmission between the two fixed points on the ground carried out in 1975 at the JPL Goldstone Facility. Power was successfully transferred from a transmitting large parabolic antenna dish to a receiving site equipped with rectennas over a distance of 1.6 km. The DC output was 30 kW.

An important historical milestone for WPT was a proposal of the Solar Power Satellite (SPS). Peter E. Glaser in 1968 proposed to build a gigantic power station, SPS, on a geostationary orbit (36 000km). A huge electric power is planned to be transmitted from the SPS to the ground via a microwave beam. We will describe the details of the SPS concept in the later section.

In 1980's and 1990's, a center of research of WPT technologies moved to Japan. The author examined both theoretically and experimentally a possible impact of high power microwave beam onto the ionospheric plasma environment and proposed an in-situ rocket experiment. A Japanese experimental group led by the present author carried out two rocket WPT experiments; One in 1983 and called MINIX (Microwave Ionosphere Nonlinear Interaction experiment) and the other was in 1993 and called ISY-METS (International Space year – Microwave Energy Transmission in Space). These were the first and only two space WPT experiments up to date and have brought useful knowledge concerning nonlinear interactions between intense microwave power beam and space plasmas.

1.3.1. Early History of Wireless Power Transfer:

The early history of wireless power transfer involves two main figures

- Heinrich Hertz
- Nikola Tesla.

1.3.2. Heinrich Hertz:

Heinrich Hertz was born in Hamburg, Germany on February 22, 1857. Hertz was gifted not only in school but also as a mechanic, sculptor, draftsman, linguist, and athlete (Susskind 1988). Hertz studied at numerous universities, most prominently studying at the University of Berlin under Hermann Helmholtz (Susskind, 1988). Hertz proved that electricity can be transmitted in electromagnetic waves. In 1889 Hertz received an inquiry from a German engineer, Heinrich Huber: “could not Hertzian [radio] waves be used to transmit electric power and telephone signals (Susskind, 1988)?” Hertz responded with skepticism, but ultimately created an experiment to generate high-frequency power and detect it at the receiving end (Brown, 1984). Hertz laid the foundation for wireless power and communication transfer. Hertz died January 1, 1894 at the age of 36.

1.3.3. Nikola Tesla:

Nikola Tesla was born on the stroke of midnight July 9, 1856 in what now is Yugoslavia. Tesla had a special gift of being able to imagine things so well that they seemed real. This allowed him to build mental rather than physical prototypes that led to successful finished designs. The downside to this was that Tesla took very poor notes; he only wrote down those things that he deemed absolutely necessary. Tesla was far beyond his time in his experimentations. It wasn't until 1970 that Robert Golka became the first to replicate the Tesla coil. Other experiments of Tesla have yet to be replicated.

Tesla worked briefly with Edison, but quit on a dispute over \$50,000. Edison had promised Tesla \$50,000 to solve a problem, but later reneged saying that Tesla didn't "understand our American humor." Later, Tesla met George Westinghouse, Jr. who funded Tesla's idea to develop an alternating current motor. Following this development, a feud developed between Edison's direct current and Tesla's alternating current.

1.4.1. Wireless Operations:

Wireless operations permits services, such as long range communications, that are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls, computer networks, network terminals, etc.) which use some form of energy (e.g. radio frequency (RF), infrared light, laser light, visible light, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances.

1.4.2. Wireless Communication:

Wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires". The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications). When the context is clear, the term is often shortened to "wireless". Wireless communication is generally considered to be a branch of telecommunications. It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, garage door openers and or garage doors, wireless computer mice, keyboards and headsets, satellite television and cordless telephones. The term "wireless" has become a generic and all-encompassing word used to describe communications

in which electromagnetic waves or RF (rather than some form of wire) carry a signal over part or the entire communication path.

1.4.3. Wireless Energy Transfer:

Wireless energy transfer is a process whereby electrical energy is transmitted from a power source to an electrical load that does not have a built-in power source, without the use of interconnecting wires.

1.4.4. Historical Review of Wireless Communication:

In 1895, Guglielmo Marconi opened the way for modern wireless communications by transmitting the three-dot Morse code for the letter ‘S’ over a distance of three kilometers using electromagnetic waves. From this beginning, wireless communications has developed into a key element of modern society. From satellite transmission, radio and television broadcasting to the now ubiquitous mobile telephone, wireless communications has revolutionized the way societies function. Wireless communications and the economic goods and services that utilise it have some special characteristics that have motivated specialized studies. First, wireless communications relies on a scarce resource namely, radio spectrum the property rights for which were traditionally vested with the state. In order to foster the development of wireless communications (including telephony and broadcasting) those assets were privatized. Second, use of spectrum for wireless communications required the development of key complementary technologies; especially those that allowed higher frequencies to be utilized more efficiently. Finally, because of its special nature, the efficient use of spectrum required the coordinated development of standards. Those standards in turn played a critical role in the diffusion of technologies that relied on spectrum use.

Marconi’s pioneering work quickly led to variety of commercial and government (particularly military) developments and innovations. In the early 1900s, voice and then music was transmitted and modern radio was born. By 1920, commercial radio had been established with Detroit station WWJ and KDKA in Pittsburgh. Wireless telegraphy was first used by the British military in South Africa in 1900 during the Anglo-Boer war. The British navy used equipment supplied by Marconi to communicate between ships in Delagoa Bay. Shipping was a major early client for wireless telegraphy and wireless was standard for shipping by the time the Titanic issued its radio distress calls in 1912.

Early on, it was quickly recognized that international coordination was required for wireless communication to be effective. This coordination involved two features. First, the potential for interference in radio transmissions meant that at least local coordination was needed to avoid the transmission of conflicting signals. Secondly, with spectrum to be used for international communications and areas such as maritime safety and navigation, coordination was necessary between countries to guarantee consistency in approach to these services. This drove government intervention to ensure the coordinated allocation of radio spectrum.

1.4.5. Spectrum Allocation:

Radio transmission involves the use of part of the electromagnetic spectrum. Electromagnetic energy is transmitted in different frequencies and the properties of the energy depend on the frequency. For example, visible light has a frequency between 4×10^{14} and 7.5×10^{14} Hz. Ultra violet radiation, X-rays and gamma rays have higher frequencies (or equivalently a shorter wave length) while infrared radiation, microwaves and radio waves have lower frequencies (longer wavelengths). The radio frequency spectrum involves electromagnetic radiation with frequencies between 3000 Hz and 300 GHz.

Even within the radio spectrum, different frequencies have different properties. As Cave notes, the higher the frequency, the shorter the distance the signal will travel, but the greater the capacity of the signal to carry data. The tasks of internationally coordinating the use of radio spectrum, managing interference and setting global standards are undertaken by the International Telecommunication Union (ITU). The ITU was created by the International Telecommunications Convention in 1947 but has predecessors dating back to approximately 1865. It is a specialist agency of the United Nations with over 180 members.

The Radio communication Sector of the ITU coordinates global spectrum use through the Radio Regulations. These regulations were first put in place at the 1906 Berlin International Radiotelegraph Conference. Allocation of the radio spectrum occurs along three dimensions – the frequency, the geographic location and the priority of the user with regards to interference. The radio spectrum is broken into eight frequency bands, ranging from Very Low Frequency (3 to 30 kHz) up to Extremely High Frequency (30 to 300 GHz).

1.5.1. Electric Power Transmission

Definition:

“Power transmission is the movement of energy from its place of generation to a location where it is applied to performing useful work”.

Electricity is transmitted at high voltages (110 kV or above) to reduce the energy lost in transmission. Power is usually transmitted as alternating current through overhead power lines. Underground power transmission is used only in densely populated areas because of its higher cost of installation and maintenance when compared with overhead wires, and the difficulty of voltage control on long cables.

1.5.2. Bulk Power Transmission

Engineers design transmission networks to transport the energy as efficiently as feasible, while at the same time taking into account economic factors, network safety and redundancy. These networks use components such as power lines, cables, circuit breakers, switches and transformers. Transmission efficiency is improved by increasing the voltage using a step-up transformer, which reduces the current in the conductors, while keeping the power transmitted nearly equal to the power input.

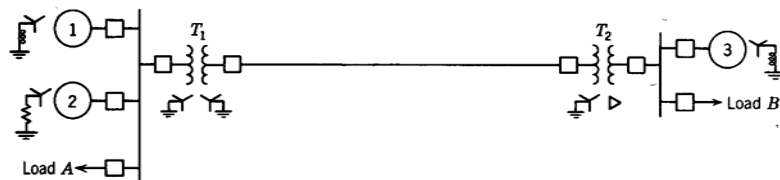


Figure 1.1 Single line diagram of an electric power system.

1.5.3. Types of Transmission:

A transmission system of electrical energy is further classified as follows.

- Overhead transmission
- Underground transmission

1.5.3.1. Overhead Transmission:

Overhead conductors are not covered by insulation. The conductor material is nearly always an aluminum alloy, made into several strands and possibly reinforced with steel strands. Copper was sometimes used for overhead transmission but aluminum is lower in weight for equivalent performance, and much lower in cost.

Overhead conductors are a commodity supplied by several companies worldwide. Improved conductor material and shapes are regularly used to allow increased capacity and modernize transmission circuits. Conductor sizes range from 12 mm² (#6 American wire gauge) to 750 mm² (1,590,000 circular mils area), with varying resistance and current-carrying capacity. Thicker wires would lead to a relatively small increase in capacity due to the skin effect, that causes most of the current to flow close to the surface of the wire. Today, transmission-level voltages are usually considered to be 110 kV and above.

Types of Over Head Transmission

The over head transmission system can be divided into the following further type. A brief description of each of these types is given below.

- Three-phase three wire system
- Two wire HVDC system

1.5.3.2. Underground Transmission:

Electric power can also be transmitted by underground power cables instead of overhead power lines. They can assist the transmission of power across:

- Densely populated urban areas
- Areas where land is unavailable or planning consent is difficult
- Rivers and other natural obstacles
- Land with outstanding natural or environmental heritage
- Areas of significant or prestigious infrastructural development
- Land whose value must be maintained for future urban expansion and rural development

1.5.3.3. Communications

Transmission lines can also be used to carry data: this is called power-line carrier, or PLC. Sometimes there are also communications cables using the transmission line structures. These are generally fiber optic cables. They are often integrated in the ground (or earth) conductor. Sometimes a standalone cable is used, which is commonly fixed to the upper crossbar. On the EnBW system in Germany, the communication cable can be suspended from the ground (earth) conductor or strung as a standalone cable. Some jurisdictions, such as Minnesota, prohibit energy On the EnBW system in

Germany, the communication cable can be suspended from the ground (earth) conductor or strung as a standalone cable. transmission companies from selling surplus communication bandwidth or acting as a telecommunications common carrier.

1.5.3.4. Health Concerns

It is argued by Some jurisdictions, such as Minnesota, prohibit energy On the EnBW system in Germany, the communication cable can be suspended from the ground (earth) conductor or strung as a standalone cable. some that living in proximity to a high voltage power line presents a danger to the animals and humans. Some have claimed that electromagnetic radiation from power lines causes elevated risk of certain types of cancer.

1.6. Alternate Transmission Methods:

1.6.1. Wireless Power Transmission:

Wireless energy transfer or wireless power transmission is the process that takes place in any system where electrical energy is transmitted from a power source to an electrical load, without interconnecting wires. Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed, but interconnecting wires are inconvenient, hazardous, or impossible. While the physics are identical, wireless energy transfer is slightly different from wireless transmission for the purpose of telecommunications (the transferring of information), such as radio, where the signal-to-noise ratio, or the percentage of power received, becomes critical if it is too low to recover the signal successfully. With wireless energy transfer efficiency is the more important parameter. The most common form of wireless power is carried out using induction, followed by electrodynamic induction. Other technologies for wireless power include those based upon microwaves and lasers. Hidetsugu Yagi attempted to devise a system for wireless power transmission. Whilst he managed to demonstrate a proof of concept, the engineering problems proved to be more onerous than conventional systems. His work however, led to the invention of the yagi antenna. Another form of wireless power transmission has been studied for transmission of power from solar power satellites to the earth. A high power array of microwave transmitters would beam power to a rectenna in an unpopulated desert area. Formidable engineering, environmental, and economic problems face any solar power satellite project. There is a potential for the use of superconducting cable transmission in order to supply electricity to consumers, given that the waste is halved using this method. Such cables are particularly suited to high load density areas such as The

business district of large cities, where purchase of a right of way for cables would be very costly.

1.7. Contemporary Mediums for Wireless Power Transfer

There are five types of mediums for power transfer that are explored in this thesis:

- Radio Wave/Microwave Wireless Power Transfer
- Inductive Power Transfer
- Laser Wireless Power Transfer
- Ultrasonic Wireless Power Transfer
- Resonant Induction:

1.8. The importance of a Wireless System of Energy Transmission:

A great concern has been voiced in recent years over the extensive use of energy, the limited supply of resources, and the pollution of the environment from the use of present energy conversion systems. Electrical power accounts for much of the energy consumed. Much of this power is wasted during transmission from power plant generators to the consumer. The resistance of the wire used in the electrical grid distribution system causes a loss of 26-30% of the energy generated. This loss implies that our present system of electrical distribution is only 70-74% efficient. A system of power distribution with little or no loss would conserve energy. It would reduce pollution and expenses resulting from the need to generate power to overcome and compensate for losses in the present grid system.

The proposed technique would demonstrate a method of energy distribution calculated to be 90-94% efficient. An electrical distribution system, based on this method would eliminate the need for an inefficient, costly, and capital intensive grid of cables, towers, and substations. The system would reduce the cost of electrical energy used by the consumer and rid the landscape of wires, cables, and transmission towers. There are areas of the world where the need for electrical power exists, yet there is no method for delivering power. Africa is in need of power to run pumps to tap into the vast resources of water under the Sahara Desert. Rural areas, such as those in China, require the electrical power necessary to bring them into the 20th century and to equal standing with western nations.

As first proposed by Buckminster Fuller, wireless transmission of power would enable world wide distribution of off peak demand capacity. This concept is based on the fact that some nations, especially the United States, have the capacity to generate much more power than is needed. This situation is accentuated at night. The greatest amount of power used, the peak demand, is during the day. The extra power available during the night could be sold to the side of the planet where it is day time. Considering the huge capacity of power plants in

the United States, this system would provide a saleable product which could do much to aid our balance of payments.

1.9. Comparison of Wireless and Wired Power Transmission:

A crude economic comparison is made using past studies and contemporary estimates of wireless vs. wired power transmission systems in the range of 1 MW to 10 GW, for transmitting electric power between continents. The installed transmission system costs in terms of $\$/\text{km}^W$, excluding prime generating means and the ultimate load, but including DC-RF and AC-DC converters as appropriate, are plotted as a function of the transmitted power level. Wired power systems considered are AC and DC open wire lines, undersea or buried cables, and buried TEOI mode microwave circular waveguides.

Wireless power transmission systems consisting of fixed phased or retro directive phased array transmitters and rectennas are costed for point- to-point paths on the Earth's surface for short ranges, and via orbiting reflectors for long range systems.

Transmission system losses are compared and discussed. Both the wired and wireless systems have right-of-way and electromagnetic field safety concerns, but only the wired, closed waveguide and shielded cables have in theory no radio interference problems. Earth curvature must be considered for relay, TEOI waveguides and the line-of-sight RF paths. The well developed open wire lines are the lowest cost electric power transmission systems. However, to be truly intercontinental, transmission across a body of water is required. In the conventional case, undersea cables are typically utilized, and the cost is at least an order of magnitude over land based open wire lines.

Costs generally decrease with increasing power level for both wired and wireless systems, due to economies of scale. The quantity of data points is small, but the wireless power transmission system cost as estimated appear to be comparable to the undersea cables cost for the short range (e.g. Strait of Gibraltar, 15 km) but lower in cost for the longer range (e.g. Brazil to Martha's Vineyard floating Rectenna, - 6500 km) relay system.