

A SINGLE-STAGE BIDIRECTIONAL INDUCTIVE POWER TRANSFER SYSTEM WITH CLOSED-LOOP CURRENT CONTROL STRATEGY

Submitted in partial fulfillment of the requirements for the award of
**Bachelor of Engineering Degree in
Electrical and Electronics Engineering**

BY

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**INSTITUTE OF SCIENCE AND TECHNOLOGY
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Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of T.A.MUAZIM AYAS (39140705) and P.B.ARUN KUMAR (39140706) who carried out the project entitled "A SINGLE-STAGE BIDIRECTIONAL INDUCTIVE POWER TRANSFER SYSTEM WITH CLOSED-LOOP CURRENT CONTROL STRATEGY" under our supervision from November 2022 to April 2023.

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ABSTRACT

A conventional two-stage topology that consists of a dc/ac converter, a dc-link, and two ac/dc converter is being used as wireless charging of electric vehicles (EVs). However, the conventional topology contains more conversion stages with a bulky dc-link capacitor, and implementation of control strategies is not easy to transfer power from the primary coil to pickup coil or vice versa. A single-stage, inductive power transfer (IPT) system with a simple control strategy is needed to reduce the conversion stages and to increase the reliability of the system. This article proposes a control strategy for a single-stage conversion topology that is easy to implement and more importantly can achieve unity power factor (UPF) using a single controller. The experimental validation of single-stage conversion topology and steady-state analysis with series-series (SS) compensation scheme is presented in this article. A fixed angle of $\pm 90^\circ$ in between the output phase of the converters is achieved without estimating any power or current parameters. A hardware prototype working at a lower watt rating is analyzed, and the validation of the proposed system for 3.7-kVA rating as per the international standard is simulated. Furthermore, transient response is also observed to verify the closed-loop control scheme of battery current.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
BD-IPT	-	Bidirectional Inductive Power Transfer
BEV	-	Battery Electric Vehicles
CAISO	-	California Independent System Operator
CPU	-	Central Processor Unit
DC	-	Direct Current
EVs	-	Electric Vehicles
FA	-	Factory Automation
FCEV	-	Hydrogen Fuel Cell Electric Vehicles
FCV	-	Fuel Cell Vehicles
FWC	-	Fast Wireless Charging
IPT	-	Inductive Power Transfer
NWC	-	Normal Wireless Charging
PHEV	-	Plug-In Hybrids
SS	-	Series–Series
UPF	-	Unity Power Factor
V2B	-	Vehicle-To-Building
V2G	-	Vehicle-To-Grid
V2H	-	Vehicle-To-Home
VGI	-	Vehicle-Grid Interface
WPT	-	Wireless Power Transfer

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

THE technology of transferring power without using any contact, also known as wireless power transfer (WPT) is becoming popular, especially for electric vehicle (EV) applications. WPT is also widely used in other applications, such as biomedical plants and man-made satellites, while EV is becoming very popular because of the environmental and economic issues behind the fossil-fuel driven vehicle. There are still some challenges faced by EV, which need to be addressed. The limited range and long charging times are two of the main drawbacks associated with EVs. These issues are further aggravated due to the fact that the existing EVs need to be plugged-in to refuel, and it can take many hours to fully charge an EV. Fast and extreme charging systems have been developed to reduce the refueling time at the expense of battery life and user safety.

As a solution to these issues, wireless charging of stationary and in-motion EVs have been proposed to help in developing a ubiquitous charging infrastructure, where EVs are replenished regularly, thus avoiding long charging times, range anxiety, and battery degradation. Compared with conductive charging, wireless charging has got several advantages, such as isolation, prevention of shock, unaffected from dirt and moisture, flexibility, and less maintenance required. Charging vehicles wirelessly also have an advantage of a reduction in battery size when the vehicle is in motion or in the case of opportunity charging. EVs that are readily connected to the utility, especially through a bidirectional wireless charger, can also be used to provide grid services, thus helping to increase the penetration of renewable electricity.

A conventional bidirectional inductive power transfer (BD-IPT) system is shown in Figure 1.1(a). The circuit consists of two ac/dc converters and a dc/ac converter. One of the ac/dc converters is connected to the grid, which will convert the ac at line frequency to dc. A dc-link constructed using many electrolytic capacitors, which is known to have a limited life span, feeds the dc/ac converter. Moreover, the size of the capacitor is large in volume, and hence, overall physical size and cost of the converter increases and reliability of circuit decreases. The power is transferred across the air gap between the series-series (SS) compensated primary and pickup coils. The second ac/dc converter is connected to the battery and converts the high-frequency ac into dc. Because of multiple-stage conversion and the bulky dc-link used especially in a single-phase system, the efficiency and reliability of a conventional BD-IPT system can be somewhat inferior. To eliminate the bulky dc link, a single stage, ac/ac-based configuration for the application of IPT as shown in Figure 1.1(b) is being used. The ac/ac converter directly converts the line frequency to a high-frequency signal suitable to drive the primary coil. Ability to miniaturize the converter, the possibility of smaller filter size and high power density is a few other notable advantages. The comparison of conventional two-stage topology with a single-stage IPT system based on efficiency, size of system, reliability, cost, power density, and control complexity. The single-stage IPT topology reported in the literature is complex and modulation techniques limit the implementation of the converter at lower switching ($\leq 35\text{kHz}$). Moreover, the high-bandwidth sensor and sophisticated fast-acting logic gates are required to implement the control strategy.

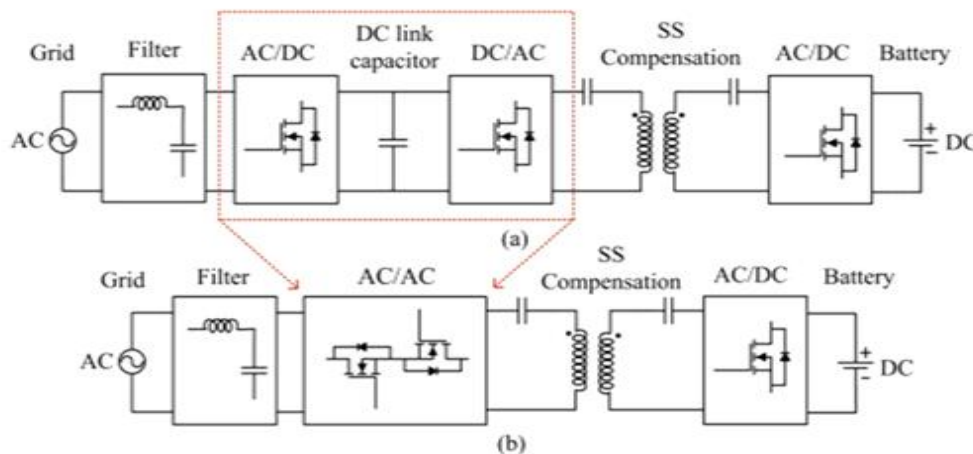


Fig. 1.1: Circuit Diagram

CHAPTER 2

LITERATURE SURVEY

2.1 MAJOR FINDINGS FROM THE LITERATURE SURVEY

Zhen Zhang et al., (2021) proposed Wireless Power Transfer, Due to limitations of low power density, high cost, heavy weight, etc., the development and application of battery-powered devices are facing with unprecedented technical challenges. As a novel pattern of energization, the wireless power transfer (WPT) offers a brand new way to the energy acquisition for electric-driven devices, thus alleviating the over-dependence on the battery. This paper presents an overview of WPT techniques with emphasis on working mechanisms, technical challenges, metamaterials, and classical applications. Focusing on WPT systems, this paper elaborates on current major research topics and discusses about future development trends. This novel energy transmission mechanism shows significant meanings on the pervasive application of renewable energies in our daily life.

Srdjan Lukic et al., (2019) proposed Cutting the Cord: Static and Dynamic Inductive Wireless Charging of Electric Vehicles, reviewed the state of the art of IPT systems and have explored the suitability of the technology to wirelessly charge battery powered vehicles. The review shows that the IPT technology has merits for stationary charging (when the vehicle is parked), opportunity charging (when the vehicle is stopped for a short period of time, for example, at a bus stop), and dynamic charging (when the vehicle is moving along a dedicated lane equipped with an IPT system). Dynamic wireless charging holds promise to partially or completely eliminate the overnight charging through a compact network of dynamic chargers installed on the roads that would keep the vehicle batteries charged at all times, consequently reducing the range anxiety and increasing the reliability of EVs. Dynamic charging can help lower the price of EVs

by reducing the size of the battery pack. Indeed, if the recharging energy is readily available, the batteries do not have to support the whole driving range but only supply power when the IPT system is not available. Depending on the power capability, the use of dynamic charging may increase driving range and reduce the size of the battery pack.

Alanson P. Sample et al., (2020) proposed Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer, Wireless power technology offers the promise of cutting the last cord, allowing users to seamlessly recharge mobile devices as easily as data are transmitted through the air. Initial work on the use of magnetically coupled resonators for this purpose has shown promising results. We present new analysis that yields critical insight into the design of practical systems, including the introduction of key figures of merit that can be used to compare systems with vastly different geometries and operating conditions. A circuit model is presented along with a derivation of key system concepts, such as frequency splitting, the maximum operating distance (critical coupling), and the behavior of the system as it becomes undercoupled. This theoretical model is validated against measured data and shows an excellent average coefficient of determination (R^2) of 0.9875. An adaptive frequency tuning technique is demonstrated, which compensates for efficiency variations encountered when the transmitter-to-receiver distance and/or orientation are varied. The method demonstrated in this paper allows a fixed-load receiver to be moved to nearly any position and/or orientation within the range of the transmitter and still achieve a near-constant efficiency of over 70% for a range of 0–70 cm.

Yiming Zhang et al., (2021) proposed: Fast charging of electric vehicles (EVs) has been the trend recently. For conductive charging, normal charging can be realised by an on-board charger, while fast charging can be realised by a DC charger which is usually off-board the vehicle. However, for wireless charging, there is a need of a transmitter on the ground and a receiver on the EV side. Therefore, there will be a high-power receiver and a low-power receiver in one EV to achieve dual charging capabilities. To reduce the EV-side cost, weight, and volume, this paper proposes a wireless charging system with a shared receiver

compatible of fast wireless charging (FWC) at a small air gap and normal wireless charging (NWC) at a large air gap. The relationship between the coil size and the power level is investigated and a suitable receiver coil size is selected for FWC. The LCC-LCC topology is selected due to its characteristic of output power proportional to the coupling coefficient. Design procedures of the receiver and transmitters are investigated. The simulations and the experimental results obtained from the downscaled prototype verified the effectiveness of the compatibility design.

Grant Anthony Covic et al., (2020) proposed Inductive power transfer (IPT) has progressed to be a power distribution system offering significant benefits in modern automation systems and particularly so in stringent environments. Here, the same technology may be used in very dirty environments and in a clean room manufacture. This paper reviews the development of simple factory automation (FA) IPT systems for both today's complex applications and onward to a much more challenging application—IPT roadway. The underpinning of all IPT technology is two strongly coupled coils operating at resonance to transfer power efficiently. Over time the air-gap, efficiency, coupling factor, and power transfer capability have significantly improved. New magnetic concepts are introduced to allow misalignment, enabling IPT systems to migrate from overhead monorails to the floor. However, the demands of IPT roadway bring about significant challenges. Here, compared with the best FA practice, air-gaps need to be 100 times larger, power levels greater than ten times, system losses ten times lower to meet efficiency requirements, and systems from different manufacturers must be interoperable over the full range of operation. This paper describes how roadway challenges are being met and outlines the problems that still exist and the solutions designers are finding to them.

2.2 PROBLEM IDENTIFICATION

The isolation, prevention of shock, unaffected from dirt and moisture, flexibility, and less maintenance required. Ability to miniaturize the converter, the possibility of smaller filter size and high power density is a few other notable The advances make the WPT very attractive to the electric vehicle (EV) charging

applications in both stationary and dynamic charging scenarios. This paper reviewed the technologies in the WPT area applicable to EV wireless charging. By introducing WPT in EVs, the obstacles of charging time, range and cost can be easily mitigated. Battery technology is no longer relevant in the mass market penetration of EVs. It is hoped that researchers could be encouraged by the state-of-the-art achievements, and push forward the further development of WPT as well as the expansion of EV.

The demands of IPT roadway bring about significant challenges. Here, compared with the best FA practice, air-gaps need to be 100 times larger, power levels greater than ten times, system losses ten times lower to meet efficiency requirements, and systems from different manufacturers must be interoperable over the full range of operation. This paper describes how roadway challenges are being met and outlines the problems that still exist and the solutions designers are finding to them. This paper presents a new PWM switching technique for controlling a bidirectional isolated DC-AC-AC converter employing high-frequency link transformer. The proposed PWM technique has the ability to control the input DC current and to inject a sinusoidal three-phase current to the grid at unity power factor. The primary-side is an H-bridge converter used to convert the DC voltage to a high-frequency square-wave single-phase voltage. The secondary-side is a matrix converter used to convert the grid three-phase voltage to a high-frequency single-phase waveform. . The bidirectional power flow is controlled by the phase shift angle between the primary and secondary voltages of the high-frequency transformer. The mathematical model and the circuit operational modes are presented along with the voltage controllable limit.

2.3 SCOPE OF THE PROJECT

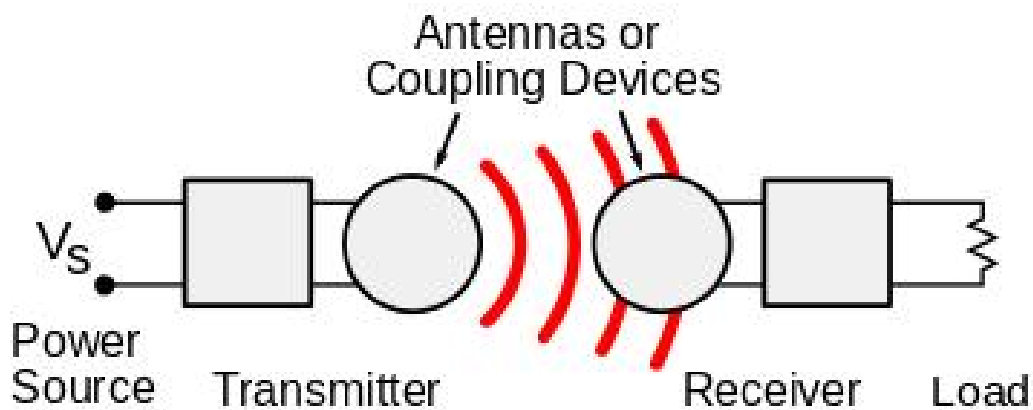
This project proposes a control strategy for a single-stage conversion topology that is easy to implement and more importantly can achieve unity power factor (UPF) using a single controller.

2.4 OBJECTIVE

The Objective is to develop project that has a conventional two-stage topology that consists of a dc/ac converter, a dc-link, and two ac/dc converter is being used as wireless charging of electric vehicles (EVs). However, the conventional topology contains more conversion stages with a bulky dc-link capacitor, and implementation of control strategies is not easy to transfer power from the primary coil to pickup coil or vice versa. A single-stage, inductive power transfer (IPT) system with a simple control strategy is needed to reduce the conversion stages and to increase the reliability of the system.

2.5 APPLICATIONS AND ADVANTAGE

The single-stage converter topology is more reliable compared with conventional topology by overcoming the drawbacks associated with dc-link capacitor, such as bulky in size, short span of life, and cost. The proposed control scheme can control bidirectional power flow with good dynamic performance and UPF is achieved in both G2V and V2G modes of converter.



"Wireless power transmission" is a collective term that refers to a number of different technologies for transmitting power by means of time-varying electromagnetic fields. The technologies, listed in the table below, differ in the distance over which they can transmit power efficiently, whether the transmitter must be aimed (directed) at the receiver, and in the type of electromagnetic energy they use: time varying electric fields, magnetic fields, radio waves, microwaves, or infrared or visible light waves.

In general a wireless power system consists of a "transmitter" device connected to a source of power such as mains power lines, which converts the power to a time-varying electromagnetic field, and one or more "receiver" devices which receive the power and convert it back to DC or AC electric power which is consumed by an electrical load. In the transmitter the input power is converted to an oscillating electromagnetic field by some type of "antenna" device. The word "antenna" is used loosely here; it may be a coil of wire which generates a magnetic field, a metal plate which generates an electric field, an antenna which radiates radio waves, or a laser which generates light. A similar antenna or coupling device in the receiver converts the oscillating fields to an electric current. An important parameter which determines the type of waves is the frequency f in hertz of the oscillations. The frequency determines the wavelength $\lambda = c/f$ of the waves which carry the energy across the gap, where c is the velocity of light.

Wireless power uses the same fields and waves as wireless communication devices like radio, another familiar technology which involves power transmitted without wires by electromagnetic fields, used in cell phones, radio and television broadcasting, and Wi-Fi. In radio communication the goal is the transmission of information, so the amount of power reaching the receiver is unimportant as long as it is enough that the signal to noise ratio is high enough that the information can be received intelligibly. In wireless communication technologies generally only tiny amounts of power reach the receiver. By contrast, in wireless power, the amount of power received is the important thing, so the efficiency (fraction of transmitted power that is received) is the more significant parameter. For this reason wireless power technologies are more limited by distance than wireless communication technologies

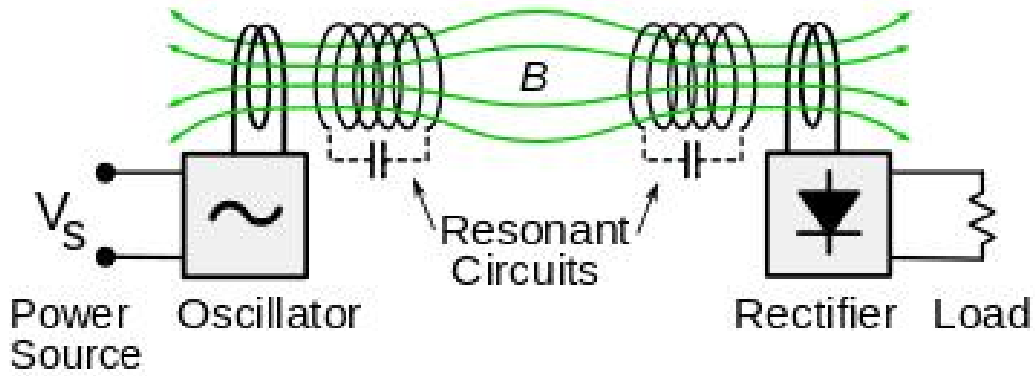


Fig. 2.1: Resonant inductive coupling

Resonant inductive coupling (*electrodynamic coupling*, *evanescent wave coupling* or *strongly coupled magnetic resonance*) is a form of inductive coupling in which power is transferred by magnetic fields (between two resonant circuits (tuned circuits), one in the transmitter and one in the receiver. Each resonant circuit consists of a coil of wire connected to a capacitor, or a self-resonant coil or other resonator with internal capacitance. The two are tuned to resonate at the same resonant frequency. The resonance between the coils can greatly increase coupling and power transfer, analogously to the way a vibrating tuning fork can induce sympathetic vibration in a distant fork tuned to the same pitch. Nikola Tesla first discovered resonant coupling during his pioneering experiments in wireless power transfer around the turn of the 20th century but the possibilities of using resonant coupling to increase transmission range has only recently been explored. In 2007 a team led by Marin Soljačić at MIT used two coupled tuned circuits each made of a 25 cm self-resonant coil of wire at 10 MHz to achieve the transmission of 60 W of power over a distance of 2 meters (6.6 ft) (8 times the coil diameter) at around 40% efficiency. The concept behind resonant inductive coupling is that high Q factor resonators exchange energy at a much higher rate than they lose energy due to internal damping. Therefore, by using resonance, the same amount of power can be transferred at greater distances, using the much weaker magnetic fields out in the peripheral regions ("tails") of the near fields (these are sometimes called evanescent fields). Resonant inductive coupling can achieve high efficiency at ranges of 4 to 10 times the coil diameter (D_{ant}). This is called "mid-range" transfer, in contrast to the "short range" of non-

resonant inductive transfer, which can achieve similar efficiencies only when the coils are adjacent. Another advantage is that resonant circuits interact with each other so much more strongly than they do with non-resonant objects that power losses due to absorption in stray nearby objects are negligible. A drawback of resonant coupling is that at close ranges when the two resonant circuits are tightly coupled, the resonant frequency of the system is no longer constant but "splits" into two resonant peaks, so the maximum power transfer no longer occurs at the original resonant frequency and the oscillator frequency must be tuned to the new resonance peak. Resonant technology is currently being widely incorporated in modern inductive wireless power systems. One of the possibilities envisioned for this technology is area wireless power coverage. A coil in the wall or ceiling of a room might be able to wirelessly power lights and mobile devices anywhere in the room, with reasonable efficiency. An environmental and economic benefit of wirelessly powering small devices such as clocks, radios, music players and remote controls is that it could drastically reduce the 6 billion batteries disposed of each year, a large source of toxic waste and groundwater contamination.

Benefits of Wireless Power

- Reduce costs associated with maintaining direct connectors
- Greater convenience for the charging of everyday electronic devices
- Safe power transfer to applications that need to remain sterile or hermetically sealed
- Electronics can be fully enclosed, reducing the risk of corrosion due to elements such as oxygen and water.
- Robust and consistent power delivery to rotating, highly mobile industrial equipment
- Delivers reliable power transfer to mission critical systems in wet, dirty and moving environments.

2.6 VOLTAGE CONVERTER

A voltage converter changes the voltage of an electrical power source and is usually combined with other components to create a power supply. The term "voltage converter" is sometimes used as a generic term for a power supply. A voltage converter or a power supply may be called a "transformer" even if it does not contain an actual transformer as the term is used in electronics. A common use of the term voltage converter is for a device that allows appliances made for the voltage of one geographical region to operate from the power outlets of another area. Most single phase alternating current electrical outlets in the world supply power at 210 to 230 volts or at 100 to 125 volts. Converters usually can only double or halve the voltage, but some can do both. Often these are sold with plug end adaptors that provide physical compatibility of normally-incompatible plugs and sockets. There are a number of methods for converting voltage. For Alternating current (AC) a transformer can be used to decrease or increase the voltage. The common power supplies for small electronics usually have a transformer that drops the voltage down to relatively small voltage ranging from 4.5 to 12 volts, a full-wave rectifier to convert the AC to a pulsed Direct Current and some additional components to flatten the wave. Some devices have only a transformer in the external power supply with any rectifier or additional power conditioning provided inside the appliance. Voltage converters sold for use in cars with 12 volt Direct Current outlets almost always have no transformer and instead use a Zener diode to drop the DC voltage with a relatively large power loss as heat. Converting a low DC voltage to a high DC voltage requires conversion to AC, the use of a transformer to increase the voltage and then a rectifier and conditioning circuit to convert it back to DC. Going through an AC step can also be used to drop voltage. For example one might use an inverter to produce 110 AC current from a car's electrical system and then use the conventional power supply that came with the device. There are two types of voltage converters, step up and step down. Step up converts from 110 volts to 230 volts and step down will convert from 230 volts to 110 volts. Most voltage converters convert both ways. DC to DC converter A DC to DC converter is a circuit which converts a source of direct current (DC) from one voltage level to another. It is a class of power converter. DC to DC converters are important in portable electronic devices such as cellular phones

and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different than that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage, and possibly even negative voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

2.7 CONVERSION METHOD

Linear regulators can output a lower, but not a higher, voltage from the input. They are very inefficient if the voltage drop is large and the current high as they dissipate as heat power equal to the product of the output current and the voltage drop; consequently they are not normally used for large-drop high-current applications. The inefficiency wastes power and requires higher-rated, and consequently more expensive and larger, components. The heat dissipated by high-power supplies is a problem in itself as it must be removed from the circuitry to prevent unacceptable temperature rises. They are practical if the current is low, the power dissipated being small, although it may still be a large fraction of the total power consumed. They are often used as part of a simple regulated power supply for higher currents: a transformer generates a voltage which, when rectified, is a little higher than that needed to bias the linear regulator. The linear regulator drops the excess voltage, reducing hum-generating ripple current and providing a constant output voltage independent of normal fluctuations of the unregulated input voltage from the transformer / bridge rectifier circuit and of the load current. Linear regulators are inexpensive, reliable if good heat sinking is used and much simpler than switching regulators. As part of a power supply they may require a transformer, which is larger for a given power level than that required by a switch-mode power supply. Linear regulators can provide a very low-noise output voltage, and are very suitable for powering noise-sensitive low-power analog and radio frequency circuits. A popular design approach is to use an LDO, Low Drop-out Regulator that provides a local "point of load" DC supply to a low power circuit.

2.7.1 *Switched Mode Conversion*

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat). This efficiency is beneficial to increasing the running time of battery operated devices. The efficiency has increased in since the late 1980's due to the use of power FETs, which are able to switch at high frequency more efficiently than power bipolar transistors, which have more switching losses and require a more complex drive circuit. Another important innovation in DC-DC converters is the use of synchronous switching which replaces the flywheel diode with a power FET with low "On" resistance, thereby reducing switching losses.

Drawbacks of switching converters include complexity, electronic noise (EMI / RFI) and to some extent cost, although this has come down with advances in chip design.

DC to DC converters are now available as integrated circuits needing minimal additional components. DC to DC converters are also available as a complete hybrid circuit component, ready for use within an electronic assembly. In these DC to DC converters, energy is periodically stored into and released from a magnetic field in an inductor or a transformer, typically in the range from 300 kHz to 500 MHz. By adjusting the duty cycle of the charging voltage, that is the ratio of on/off time, the amount of power transferred can be controlled. Usually, this is done to control the output voltage, though it could be done to control the input current, the output current, or maintaining a constant power. Transformer based converters may provide isolation between the input and the output. In general, the term "DC to DC converter" refers to one of these switching converters. These circuits are the heart of a switched-mode power supply. Many topologies exist. This table shows the most common.

In addition, each topology may be:

- Hard switched - transistors switch quickly while exposed to both full voltage and full current.
- Resonant - an LC circuit shapes the voltage across the transistor and current through it so that the transistor switches when either the voltage or the current is zero.

Magnetic DC to DC converters may be operated in two modes, according to the current in its main magnetic component (inductor or transformer):

- Continuous - the current fluctuates but never goes down to zero.
- Discontinuous - the current fluctuates during the cycle, going down to zero at or before the end of each cycle.

A converter may be designed to operate in Continuous mode at high power, and in Discontinuous mode at low power. The Half Bridge and Flyback topologies are similar in that energy stored in the magnetic core needs to be dissipated so that the core does not saturate. Power transmission in a flyback circuit is limited by the amount of energy that can be stored in the core, while forward circuits are usually limited by the I/V characteristics of the switches. Mosfet switches can tolerate simultaneous full current and voltage (although thermal stress and electromigration can shorten the MTBF), bipolar switches generally don't so require the use of a snubber (or two) Switched capacitor converters rely on alternately connecting capacitors to the input and output in differing topologies. For example, a switched-capacitor reducing converter might charge two capacitors in series and then discharge them in parallel. This would produce an output voltage of half the input voltage, but at twice the current (minus various inefficiencies). Because they operate on discrete quantities of charge, these are also sometimes referred to as charge pump converters. They are typically used in applications requiring relatively small amounts of current, as at higher current loads the increased efficiency and smaller size of switch-mode converters makes them a better choice. They are also used at extremely high voltages, as magnetics would break down at such voltages. A further means of DC to DC conversion in the kW to many MW range is presented by using redox flow batteries such as the

vanadium redox battery, although this technique has not been applied commercially to date. Step-down DC/DC converter input ripple and noise This application note discusses the proper methods for measuring input and output noise of a high frequency DC/DC converter. Without proper measurement techniques, the high frequency noise component can easily be overestimated. When necessary, simple methods are available to reduce input noise and the impact it may have on other devices. When a step-down converter shares a common input voltage with other devices, the input noise generated by the step-down converter may be sufficient to cause interference with the other devices. Simple filter methods can be used to reduce the input noise, and simple models can be developed characterise the circuit. Two circuit models—one for the fundamental switching frequency ripple component and one for the high frequency noise—simplify the analyses. In most cases, a ceramic bypass capacitor placed close to devices that share the common input voltage is sufficient. A ferrite bead placed between the converter input and other devices powered from the same source attenuates the converter input noise. The purpose of a radio frequency power amplifier is to deliver, with reasonable efficiency, a sinusoidal signal having low harmonics and other spurious components. Rf power amplifiers are classified by the operation of their output transistors. Classes A to C uses transistors in the active region, so they are generally unsuitable for use in power converters, where efficiency is far more important than signal purity. To increase efficiency, the transistors may instead be operated as switches. Class D is a two-switch topology in which the switches conduct on alternate half cycles, each with a conduction angle approaching 180°. A series resonant tank converts the square voltage waveform into a sinusoidal load current. 8+.0.0.

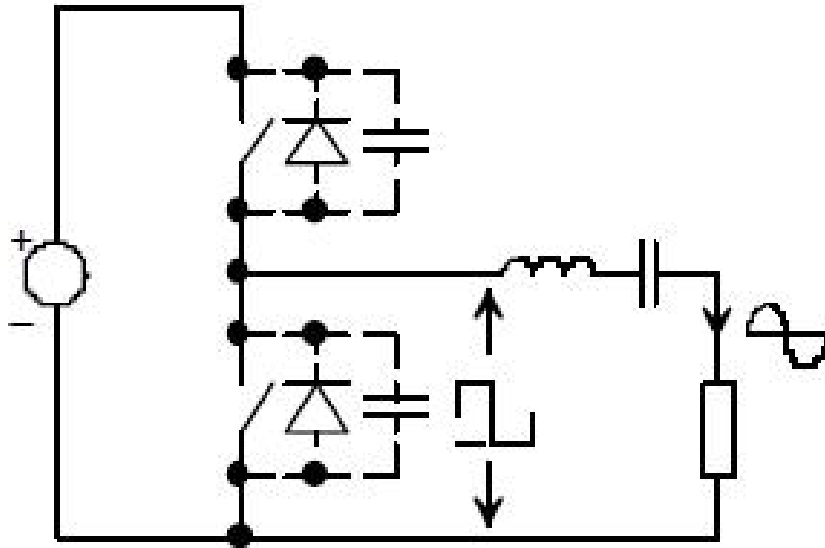


Fig. 2.2: Switched Mode Conversion

CHAPTER 3

PROJECT DESCRIPTION

A grid-tied electrical system, also called *tied to grid* or *grid tie system*, is a semi-autonomous electrical generation or grid energy storage system which links to the mains to feed excess capacity back to the local mains electrical grid. When insufficient electricity is available, electricity drawn from the mains grid can make up the shortfall. Conversely when excess electricity is available, it is sent to the mains grid. When the Utility or network operator restricts the amount of energy that goes into the grid, it is possible to prevent any input into the grid by installing Export Limiting devices.

When batteries are used for storage, the system is called battery-to-grid (B2G), which includes vehicle-to-grid (V2G).

3.1 HOW ITS WORKS



Fig. 3.1: Grid-Tied Inverter

Grid-tied Inverter

Direct Current (DC) electricity from sources such as hydro, wind or solar is passed to an inverter which is grid tied. The inverter monitors the alternating current mains supply frequency and generates electricity that is phase matched to the mains. When the grid fails to accept power during a "black out", most inverters can continue to provide courtesy power.

Battery-to-grid

A key concept of this system is the possibility of creating an electrical micro-system that is not dependent on the grid-tie to provide a high level quality of service. If the mains supply of the region is unreliable, the local generation system can be used to power important equipment.

Battery-to-grid can also spare the use of fossil fuel power plants to supply energy during peak loads on the public electric grid. Regions that charge based on time of use metering may benefit by using stored battery power during prime time.

Environmentally friendly

Local generation can be from an environmentally friendly source such as pico hydro, solar panels or a wind turbine. Individuals can choose to install their own system if an environmentally friendly mains provider is not available in their location.

Small scale start

A micro generation facility can be started with a very small system such as a home wind power generation, photovoltaic (solar cells) generation, or micro combined heat and power (Micro-CHP) system.

Sell to and buy from mains

- Excess electricity can be sold to mains.
- Electrical shortfall can be bought from mains.

Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles, such as battery electric vehicles (BEV), plug-in hybrids (PHEV) or hydrogen fuel cell electric vehicles (FCEV), communicate with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging rate. V2G storage capabilities can enable EVs to store and discharge electricity generated from renewable energy sources such as solar and wind, with output that fluctuates depending on weather and time of day.

V2G can be used with *gridable* vehicles, that is, plug-in electric vehicles (BEV and PHEV), with grid capacity. Since at any given time 95 percent of cars are parked, the batteries in electric vehicles could be used to let electricity flow from the car to the electric distribution network and back. A 2015 report on potential earnings associated with V2G found that with proper regulatory support, vehicle owners could earn \$454, \$394, and \$318 per year depending on whether their average daily drive was 32, 64, or 97 km (20, 40, or 60 miles), respectively.

Batteries have a finite number of charging cycles, as well as a shelf-life, therefore using vehicles as grid storage can impact battery longevity. Studies that cycle batteries two or more times per day have shown large decreases in capacity and greatly shortened life. However, battery capacity is a complex function of factors such as battery chemistry, charging and discharging rate, temperature, state of charge and age. Most studies with slower discharge rates show only a few percent of additional degradation while one study has suggested that using vehicles for grid storage could improve longevity.

Sometimes the modulation of charging of a fleet of electric vehicles by an aggregator to offer services to the grid but without actual electrical flow from the vehicles to the grid is called unidirectional V2G, as opposed to the bidirectional V2G that is generally discussed in this article.

Applications

Peak load leveling

The concept allows V2G vehicles to provide power to help balance loads by "valley filling" (charging at night when demand is low) and "peak shaving" (sending power back to the grid when demand is high, see duck curve). Peak load leveling can enable new ways for utilities to provide regulation services (keeping voltage and frequency stable) and provide spinning reserves (meet sudden demands for power). These services coupled with "smart-meters" would allow V2G vehicles to give power back to the grid and in return, receive monetary benefits based on how much power given back to the grid. In its current development, it has been proposed that such use of electric vehicles could buffer renewable power sources such as wind power for example, by storing excess energy produced during windy periods and providing it back to the grid during high load periods, thus effectively stabilizing the intermittency of wind power. Some see this application of vehicle-to-grid technology as an approach to help renewable energy become a base load electricity technology.

It has been proposed that public utilities would not have to build as many natural gas or coal-fired power plants to meet peak demand or as an insurance policy against power outages. Since demand can be measured locally by a simple frequency measurement, dynamic load leveling can be provided as needed. Carbitrage, a portmanteau of 'car' and 'arbitrage', is sometimes used to refer to the minimum price of electricity at which a vehicle would discharge its battery.

Backup power

Modern electric vehicles can generally store in their batteries more than an average home's daily energy demand. Even without a PHEV's gas generation capabilities such a vehicle could be used for emergency power for several days

(for example, lighting, home appliances, etc.). This would be an example of Vehicle-to-home transmission (V2H). As such they may be seen as a complementary technology for intermittent renewable power resources such as wind or solar electric. Hydrogen fuel cell vehicles (FCV) with tanks containing up to 5.6 kg of hydrogen can deliver more than 90 kWh of electricity.

Types of V2G

Unidirectional V2G or V1G

Many of the grid-scale benefits of V2G can be accomplished with unidirectional V2G, also known as V1G or "smart charging". The California Independent System Operator (CAISO) defines V1G as "unidirectional managed charging services" and defines the four levels of Vehicle-Grid Interface (VGI), which encompasses all of the ways that EVs can provide grid services, as follows:

- Unidirectional power flow (V1G) with one resource and unified actors
- V1G with aggregated resources
- V1G with fragmented actor objectives
- Bidirectional power flow (V2G)

V1G involves varying the time or rate at which an electric vehicle is charged in order to provide ancillary services to the grid, while V2G also includes reverse power flow. V1G includes applications such as timing vehicles to charge in the middle of the day to absorb excess solar generation, or varying the charge rate of electric vehicles to provide frequency response services or load balancing services.

V1G may be the best option to begin integrating EVs as controllable loads onto the electric grid due to technical issues that currently exist with regards to the feasibility of V2G. V2G requires specialized hardware (especially bi-directional inverters), has fairly high losses and limited round-trip efficiency, and may contribute to EV battery degradation due to increased energy throughput. Additionally, revenues from V2G in an SCE pilot project were lower than the costs

of administering the project, indicating that V2G still has a ways to go before being economically feasible.

Bidirectional local V2G (V2H, V2B, V2X)

Vehicle-to-home (V2H) or vehicle-to-building (V2B) or vehicle-to-everything (V2X) do not typically directly affect grid performance but creates a balance within the local environment. The electric vehicle is used as a residential back-up power supply during periods of power outage or for increasing self-consumption of energy produced on-site (demand charge avoidance).

Unlike more mature V1G solutions, V2X has not yet reached market deployment, apart from Japan where commercial V2H solutions have been available since 2012 as back-up a solution in case of electricity black-out.¹

Bidirectional V2G

With V2G, the electric vehicles could be equipped to actually provide electricity to the grid. The utility or transmission system operator may be willing to purchase energy from customers during periods of peak demand, or to use the EV battery capacity for providing ancillary services, such as balancing and frequency control, including primary frequency regulation and secondary reserve. Thus, V2G is in most applications deemed to have higher potential commercial value than V2B or V2H.

Efficiency

Most modern battery electric vehicles use lithium-ion cells that can achieve round-trip efficiency greater than 90%. The efficiency of the battery depends on factors like charge rate, charge state, battery state of health, and temperature.

The majority of losses, however, are in system components other than the battery. Power electronics, such as inverters, typically dominate overall

losses. A study found overall round-trip efficiency for V2G system in the range of 53% to 62%'. Another study reports an efficiency of about 70%. The overall efficiency however depends on several factors and can vary widely.

Implementation by country

A study conducted in 2012 by the Idaho National Laboratory revealed the following estimations and future plans for V2G in various countries. It is important to note that this is difficult to quantify because the technology is still in its nascent stage, and is therefore difficult to reliably predict adoption of the technology around the world. The following list is not intended to be exhaustive, but rather to give an idea of the scope of development and progress in these areas around the world.

United States PJM Interconnection has envisioned using US Postal Service trucks, school buses and garbage trucks that remain unused overnight for grid connection. This could generate millions of dollars because these companies aid in storing and stabilizing some of the national grid's energy. The United States was projected to have one million electric vehicles on the road between 2015 and 2019. Studies indicate that 160 new power plants will need to be built by 2020 to compensate for electric vehicles if integration with the grid does not move forward.

In North America, at least two major school-bus manufacturers - Blue Bird and Lion - are working on proving the benefits of electrification and vehicle-to-grid technology. As school buses in the U.S. currently use \$3.2B of diesel a year, their electrification can help stabilize the electrical grid, lessen the need for new power plants, and reduce kids' exposure to cancer-causing exhaust.

In 2017, at the University of California San Diego, V2G technology provider Nuvve launched a pilot program called INVENT, funded by the California Energy Commission, with the installation of 50 V2G bi-directional charging stations around the campus. The program expanded in 2018 to include a fleet of EVs for its free nighttime shuttle service, Triton Rides.

In 2018, Nissan launched a pilot program under the Nissan Energy Share initiative in partnership with vehicle-to-grid systems company Fermata Energy seeking to use bi-directional charging technology to partially power Nissan North America's headquarters in Franklin, Tn. In 2020 Fermata Energy's bidirectional electric vehicle charging system became the first to be certified to the North American safety standard, UL 9741, the Standard for Bidirectional Electric Vehicle (EV) Charging System Equipment.

Japan

In order to meet the 2030 target of 10 percent of Japan's energy being generated by renewable resources, a cost of \$71.1 billion will be required for the upgrades of existing grid infrastructure. The Japanese charging infrastructure market is projected to grow from \$118.6 million to \$1.2 billion between 2015 and 2020. Starting in 2012, Nissan plans to bring to market a kit compatible with the LEAF EV that will be able to provide power back into a Japanese home. Currently, there is a prototype being tested in Japan. Average Japanese homes use 10 to 12 KWh/day, and with the LEAF's 24 KWh battery capacity, this kit could potentially provide up to two days of power. Production in additional markets will follow upon Nissan's ability to properly complete adaptations.

In November 2018 in Toyota City, Aichi Prefecture, Toyota Tsusho Corporation and Chubu Electric Power Co., Inc initiated charging and discharging demonstrations with storage batteries of electric vehicles and plug-in hybrid vehicles using V2G technology. The demonstration examines how to excel the ability of V2G systems to balance demand and supply of electricity is and what impacts V2G has on the power grid. In addition to ordinary usage of EVs/PHVs such as by transportation, the group is producing new values of EVs/PHVs by providing V2G services even when EVs/PHVs are parked. Two bi-directional charging stations, connected to a V2G aggregation server managed by Nuvve Corporation, have been installed at a parking lot in Toyota City, Aichi Prefecture to conduct the demonstration test. The group aims to assess the capacity of EVs/PHVs to balance out demand and supply of electrical power by charging EVs/PHVs and supplying electrical power to the grid from EVs/PHVs.

Denmark

Denmark is one of the world's largest wind-based power generators. Initially, Denmark's goal is to replace 10% of all vehicles with PEVs, with an ultimate goal of a complete replacement to follow. The Edison Project implements a new set of goals that will allow enough turbines to be built to accommodate 50% of total power while using V2G to prevent negative impacts to the grid. Because of the unpredictability of wind, the Edison Project plans to use PEVs while they are plugged into the grid to store additional wind energy that the grid cannot handle. Then, during peak energy use hours, or when the wind is calm, the power stored in these PEVs will be fed back into the grid. To aid in the acceptance of EVs, policies have been enforced that create a tax differential between zero emission cars and traditional automobiles. The Danish PEV market value is expected to grow from \$50 to \$380 million between 2015 and 2020. PEV developmental progress and advancements pertaining to the use of renewable energy resources will make Denmark a market leader with respect to V2G innovation (ZigBee 2010).

Following the Edison project, the Nikola project was started which focused on demonstrating the V2G technology in a lab setting, located at the Risø Campus (DTU). DTU is a partner along with Nuvve and Nissan. The Nikola project completed in 2016, laying the groundwork for Parker, which uses a fleet of EVs to demonstrate the technology in a real-life setting. This project is partnered by DTU, Insero, Nuvve, Nissan and Frederiksberg Forsyning (Danish DSO in Copenhagen). Besides demonstrating the technology the project also aims to clear the path for V2G-integration with other OEMs as well as calculating the business case for several types of V2G, such as Adaptive charging, overload protection, peak shaving, emergency backup and frequency balancing. In the project the partners explored the most viable commercial opportunities by systematically testing and demonstrating V2G services across car brands. Here, economic and regulatory barriers were identified as well as the economic and technical impacts of the applications on the power system and markets. The project started in August 2016 and ended in September 2018.

United Kingdom

The V2G market in the UK will be stimulated by aggressive smart grid and PEV rollouts. Starting in January 2011, programs and strategies to assist in PEV have been implemented. The UK has begun devising strategies to increase the speed of adoption of EVs. This includes providing universal high-speed internet for use with smart grid meters, because most V2G-capable PEVs will not coordinate with the larger grid without it. The "Electric Delivery Plan for London" states that by 2015, there will be 500 on-road charging stations; 2,000 stations off-road in car parks; and 22,000 privately owned stations installed. Local grid substations will need to be upgraded for drivers who cannot park on their own property. By 2020 in the UK, every residential home will have been offered a smart meter, and about 1.7 million PEVs should be on the road. The UK's electric vehicle market value is projected to grow from \$0.1 to \$1.3 billion between 2015 and 2020 (ZigBee 2010).

In 2018, EDF Energy announced a partnership with a leading green technology company, Nuvve, to install up to 1,500 Vehicle to Grid (V2G) chargers in the UK. The chargers will be offered to EDF Energy's business customers and will be used at its own sites to provide up to 15 MW of additional energy storage capacity. That's the equivalent amount of energy required to power 4,000 homes. The stored electricity will be made available for sale on the energy markets or for supporting grid flexibility at times of peak energy use. EDF Energy is the largest electricity supplier to UK businesses and its partnership with Nuvve could see the largest deployment of V2G chargers so far in this country.

In fall 2019, a consortium called Vehicle to Grid Britain (V2GB) released a research report on the potential of V2G technologies.

Research

Edison

Denmark's Edison project, an abbreviation for 'Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks' was a partially state funded research project on the island of Bornholm in Eastern Denmark. The consortium of IBM, Siemens the hardware and software developer

EURISCO, Denmark's largest energy company Ørsted (formerly DONG Energy), the regional energy company Østkraft, the Technical University of Denmark and the Danish Energy Association, explored how to balance the unpredictable electricity loads generated by Denmark's many wind farms, currently generating approximately 20 percent of the country's total electricity production, by using electric vehicles (EV) and their accumulators. The aim of the project is to develop infrastructure that enables EVs to intelligently communicate with the grid to determine when charging, and ultimately discharging, can take place. At least one rebuild V2G capable Toyota Scion will be used in the project. The project is key in Denmark's ambitions to expand its wind-power generation to 50% by 2020. According to a source of British newspaper The Guardian 'It's never been tried at this scale' previously. The project concluded in 2013.

Southwest Research Institute

In 2014, Southwest Research Institute (SwRI) developed the first vehicle-to-grid aggregation system qualified by the Electric Reliability Council of Texas (ERCOT). The system allows for owners of electric delivery truck fleets to make money by assisting in managing the grid frequency. When the electric grid frequency drops below 60 Hertz, the system suspends vehicle charging which removes the load on the grid thus allowing the frequency to rise to a normal level. The system is the first of its kind because it operates autonomously.

The system was originally developed as part of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Phase II program, led by Burns and McDonnell Engineering Company, Inc. The goals of the SPIDERS program are to increase energy security in the event of power loss from a physical or cyber disruption, provide emergency power, and manage the grid more efficiently. In November 2012, SwRI was awarded a \$7 million contract from the U.S. Army Corps of Engineers to demonstrate the integration of vehicle-to-grid technologies as a source for emergency power at Fort Carson, Colorado. In 2013, SwRI researchers tested five DC fast-charge stations at the army post. The system passed integration and acceptance testing in August 2013.

Delft University of Technology

Prof. Dr. Ad van Wijk, Vincent Oldenbroek and Dr. Carla Robledo, researchers at Delft University of Technology, in 2016 conducted research on V2G technology with hydrogen FCEVs. Both experimental work with V2G FCEVs and techno-economic scenario studies for 100% renewable integrated energy and transport systems are done, using only hydrogen and electricity as energy carriers. They modified a Hyundai ix35 FCEV together with Hyundai R&D so it can deliver up to 10 kW DC Power while maintaining road access permit. They developed together with the company Accenda b.v. a V2G unit converting the DC power of the FCEV into 3-phase AC power and injecting it into the Dutch national electricity grid. The Future Energy Systems Group also recently did tests with their V2G FCEVs whether it could offer frequency reserves. Based on the positive outcome of the tests an MSc thesis was published looking into the technical and economic feasibility assessment of a hydrogen and FCEV based Car Park as Power Plant offering frequency reserves.

University of Delaware

Willett Kempton, Suresh Advani, and Ajay Prasad are the researchers at the University of Delaware who are currently conducting research on the V2G technology, with Dr. Kempton being the lead on the project. Dr. Kempton has published a number of articles on the technology and the concept, many of which can be found on the V2G project page. The group is involved in researching the technology itself, as well as its performance when used on the grid. In addition to the technical research, the team has worked with Dr. Meryl Gardner, a marketing professor in the Alfred Lerner College of Business and Economic at the University of Delaware, to develop marketing strategies for both consumer and corporate fleet adoption. A 2006 Toyota Scion xB car was modified for testing in 2007.

In 2010, Kempton and Gregory Poilasne co-founded Nuvve, a V2G solutions company. The company has formed a number of industry partnerships and implemented V2G pilot projects on five continents worldwide.

Lawrence Berkeley National Laboratory

At Lawrence Berkeley National Laboratory, Dr. Samveg Saxena currently serves as the project lead for Vehicle-to-Grid Simulator (V2G-Sim). V2G-Sim is a simulation platform tool used to model spatial and temporal driving and charging behavior of individual plug-in electric vehicles on the electric grid. Its models are used to investigate the challenges and opportunities of V2G services, such as modulation of charging time and charging rate for peak demand response and utility frequency regulation. V2G-Sim has also been used to research the potential of plug-in electric vehicles for renewable energy integration. Preliminary findings using V2G-Sim have shown controlled V2G service can provide peak-shaving and valley-filling services to balance daily electric load and mitigate the duck curve. On the contrary, uncontrolled vehicle charging was shown to exacerbate the duck curve. The study also found that even at 20 percent fade in capacity, EV batteries still met the needs of 85 percent of drivers.

In another research initiative at Lawrence Berkeley Lab using V2G-Sim, V2G services were shown to have minor battery degradation impacts on electric vehicles as compared to cycling losses and calendar aging. In this study, three electric vehicles with different daily driving itineraries were modelled over a ten-year time horizon, with and without V2G services. Assuming daily V2G service from 7PM to 9PM at a charging rate of 1.440 kW, the capacity losses of the electric vehicles due to V2G over ten years were 2.68%, 2.66%, and 2.62%.

Nissan and Enel

In May 2016, Nissan and Enel power company announced a collaborative V2G trial project in the United Kingdom, the first of its kind in the country. The trial comprises 100 V2G charging units to be used by Nissan Leaf and e-NV200 electric van users. The project claims electric vehicle owners will be able to sell stored energy back to the grid at a profit.

One notable V2G project in the United States is at the University of Delaware, where a V2G team headed by Dr. Willett Kempton has been conducting on-going research. An early operational implementation in Europe was conducted via the German government-funded MeRegioMobil project at the "KIT Smart Energy Home" of Karlsruhe Institute of Technology in cooperation with Opel as

vehicle partner and utility EnBW providing grid expertise. Their goals are to educate the public about the environmental and economic benefits of V2G and enhance the product market. Other investigators are the Pacific Gas and Electric Company, Xcel Energy, the National Renewable Energy Laboratory, and, in the United Kingdom, the University of Warwick.

University of Warwick

WMG and Jaguar Land Rover collaborated with the Energy and Electrical Systems group of the university. Dr Kotub Uddin analysed lithium ion batteries from commercially available EVs over a two year period. He created a model of battery degradation and discovered that some patterns of vehicle-to-grid storage were able to significantly increase the longevity of the vehicle's battery over conventional charging strategies, while permitting them to be driven in normal ways.

Skepticism

There is some skepticism among experts about the feasibility of V2G and several studies have questioned the concept's economic rationale. For example, a 2015 study found that economic analyses favorable to V2G fail to include many of the less obvious costs associated with its implementation. When these less obvious costs are included, the study finds that V2G represents an economically inefficient solution.

The more a battery is used the sooner it needs replacing. Replacement cost is approximately 1/3 the cost of the electric car. Over their lifespan, batteries degrade progressively with reduced capacity, cycle life, and safety due to chemical changes to the electrodes. Capacity loss/fade is expressed as a percentage of initial capacity after a number of cycles (e.g., 30% loss after 1,000 cycles). Cycling loss is due to usage and depends on both the maximum state of charge and the depth of discharge. JB Straubel, CTO of Tesla Inc., discounts V2G because battery wear outweighs economic benefit. He also prefers recycling over re-use for grid once batteries have reached the end of their useful car life. A 2017 study found decreasing capacity, and a 2012 hybrid-EV study found minor benefit.

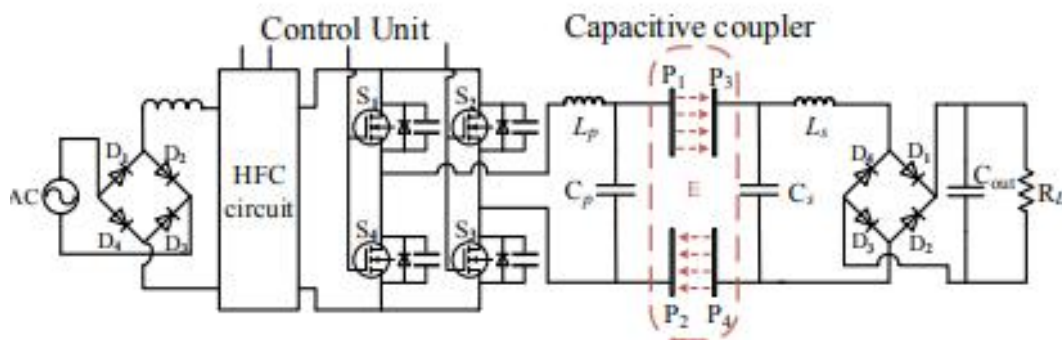
Another common criticism is related to the overall efficiency of the process. Charging a battery system and returning that energy from the battery to the grid, which includes "inverting" the DC power back to AC inevitably incurs some losses. This needs to be factored against potential cost savings, along with increased emissions if the original source of power is fossil based. This cycle of energy efficiency may be compared with the 70–80% efficiency of large-scale pumped-storage hydroelectricity, which is however limited by geography, water resources and environment.

Additionally, in order for V2G to work, it must be on a large scale basis. Power companies must be willing to adopt the technology in order to allow vehicles to give power back to the power grid. With vehicles giving power back to the grid, the aforementioned "smart-meters" would have to be in place in order to measure the amount of power being transferred to the grid.

Vehicles

There are several electric vehicles that have been specially modified or are designed to be compatible with V2G. Hyundai ix35 FCEV from Delft University of Technology is modified with a 10 kW DC V2G output. Two vehicles that have a theoretical V2G capability include the Nissan Leaf and Nissan e-NV200.

3.2 EXISTING DIAGRAM



The creation and use of battery-powered devices is confronted with previously unheard-of technical difficulties as a result of restrictions such as poor power density, high cost, and heavy weight, etc. The wireless power transfer (WPT)

gives a brand-new method for acquiring energy for electric-driven gadgets, reducing the over-dependence on the battery. WPT is a fresh pattern of energization. This study provides a review of WPT approaches with a focus on technical difficulties, metamaterials, and traditional applications. This article examines future development patterns and elaborates on significant current research areas with a focus on WPT systems. This innovative energy transmission system illustrates important implications for the widespread use of renewable energies in our daily lives.

3.3 METHODOLOGY

The methodology of a single-stage bidirectional inductive power transfer (IPT) system with closed-loop current control strategy typically involves the following steps:

- **System design:** The system is designed based on the power requirements of the devices and the operating frequency of the IPT circuit. The design includes the selection of components such as the power source, power converter, and IPT circuit.
- **Closed-loop current control:** A closed-loop current control strategy is implemented to maintain a constant level of power transfer between the two devices. This involves measuring the current flowing through the IPT circuit and adjusting the power converter to maintain the desired current level.
- **Power transfer:** Power transfer can occur in both directions, depending on the requirements of the devices. The IPT circuit is used to transfer power wirelessly between the two devices.
- **Efficiency optimization:** The efficiency of the system is optimized by adjusting the operating frequency of the IPT circuit and the design of the components.

- Safety considerations: Safety considerations such as isolation between the two devices and protection against overvoltage, overcurrent, and overheating are taken into account in the system design.
- Performance testing: The performance of the system is tested under various operating conditions to ensure that it meets the power requirements of the devices and operates safely and efficiently.

Overall, the methodology of a single-stage bidirectional IPT system with closed-loop current control strategy involves designing, implementing, and testing a system that can transfer power wirelessly between two devices while maintaining a constant level of power transfer through a closed-loop current control strategy.

3.4 IEEE Standard

1. IEEE 2030.1.1-2017: This standard specifies the requirements for a single-stage bidirectional inductive power transfer system with closed-loop current control strategy for electric vehicles and grid integration.
2. IEEE 802.3bu-2016: This standard specifies the physical layer specifications and management parameters for Ethernet over a single-stage bidirectional inductive power transfer system with closed-loop current control strategy.
3. IEEE 1701-2017: This standard provides guidelines for the design and testing of a single-stage bidirectional inductive power transfer system with closed-loop current control strategy for electric vehicle charging.
4. IEEE 2700-2014: This standard specifies the technical requirements for a single-stage bidirectional inductive power transfer system with closed-loop current control strategy for wireless charging of portable and mobile devices.

5. IEEE 1184-1994: This standard provides test procedures for evaluating the performance of a single-stage bidirectional inductive power transfer system with closed-loop current control strategy used in electric vehicles.

CHAPTER 4

RESULT OF EXPERIMENTS

4.1 MATLAB/SIMULINK

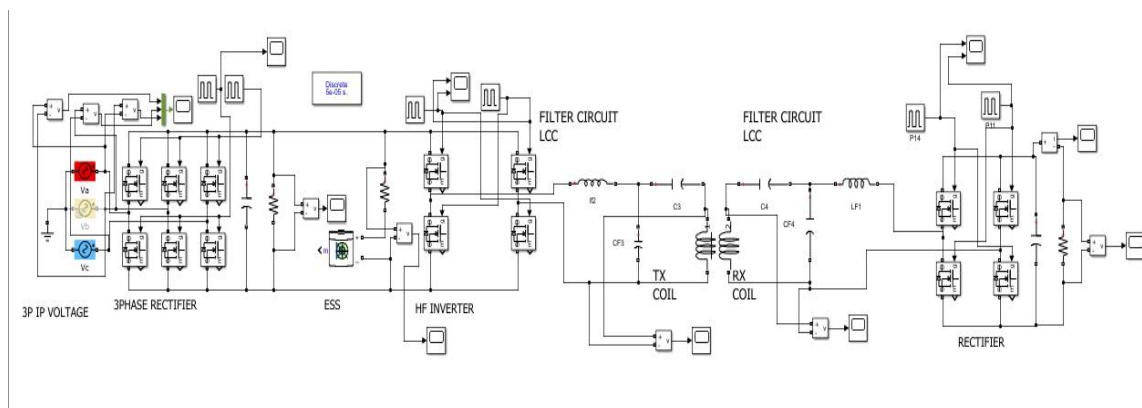


Fig. 4.1 Matlab/Simulink

4.2 FULL CIRCUIT

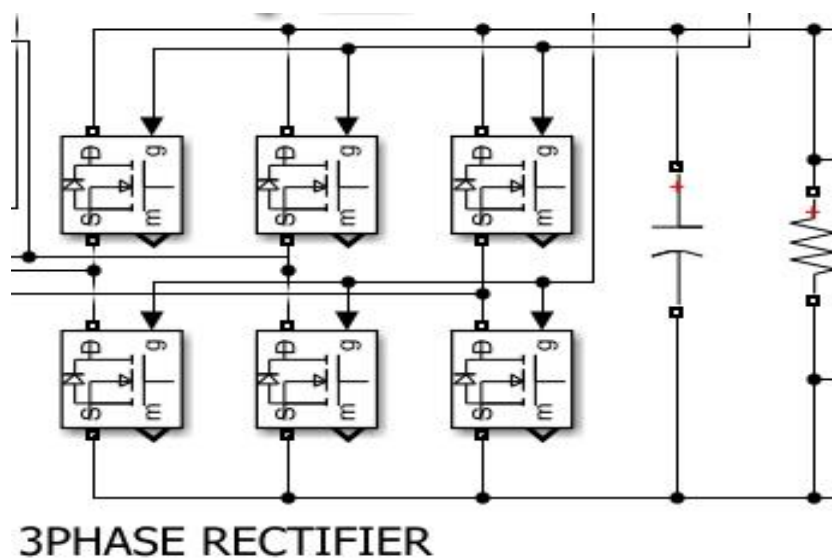


Fig. 4.2: 3 Phase Rectifier

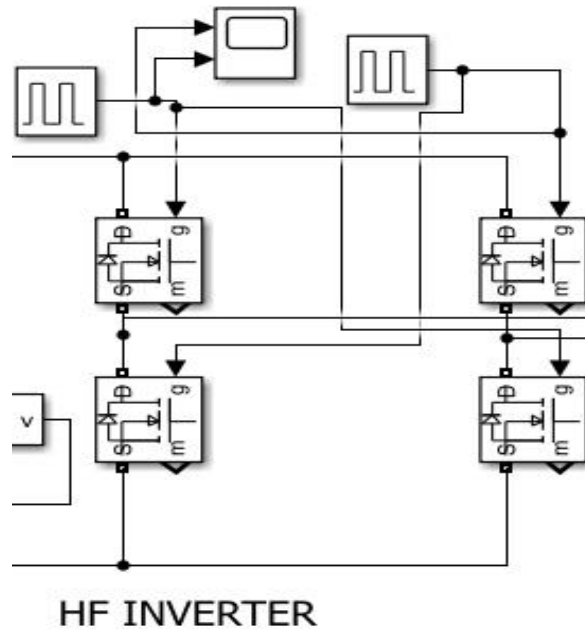


Fig. 4.3: HF Inverter

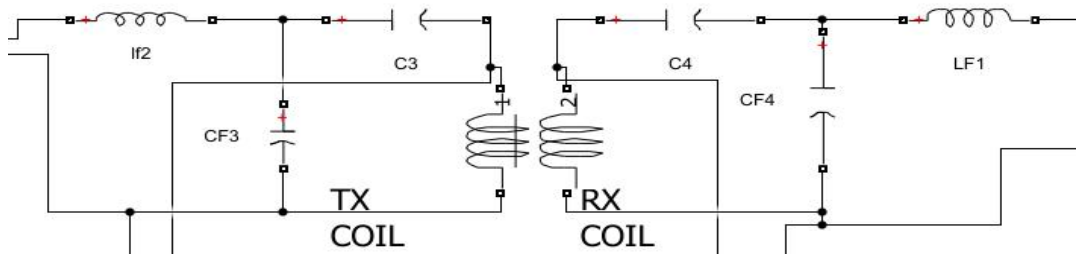


Fig. 4.4: LCC Filter with Mutual Induction Coil

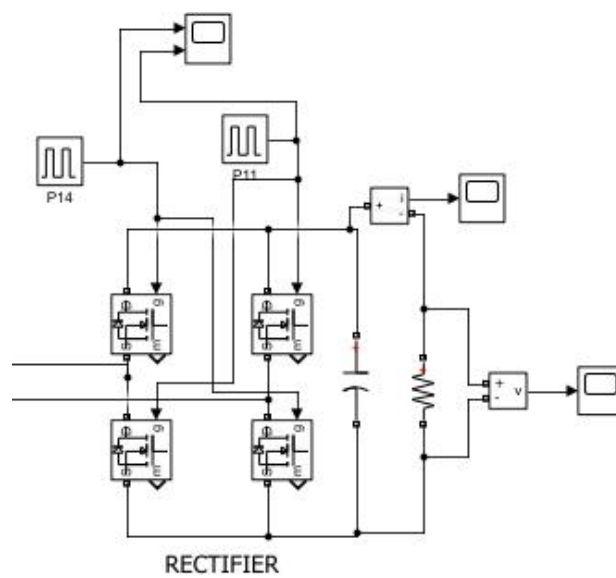


Fig. 4.5: Receiver Side Rectifier

4.3 SOFTWARE REQUIRED ELEMENTS

- AC VOLTAGE SOURCE
- GROUND
- VOLTAGE MEASUREMENT
- BATTERY
- MUX
- MUTUAL INDUCTANCE
- POWERGUI
- PULSE GENERATOR
- SERIES RLC BRANCH

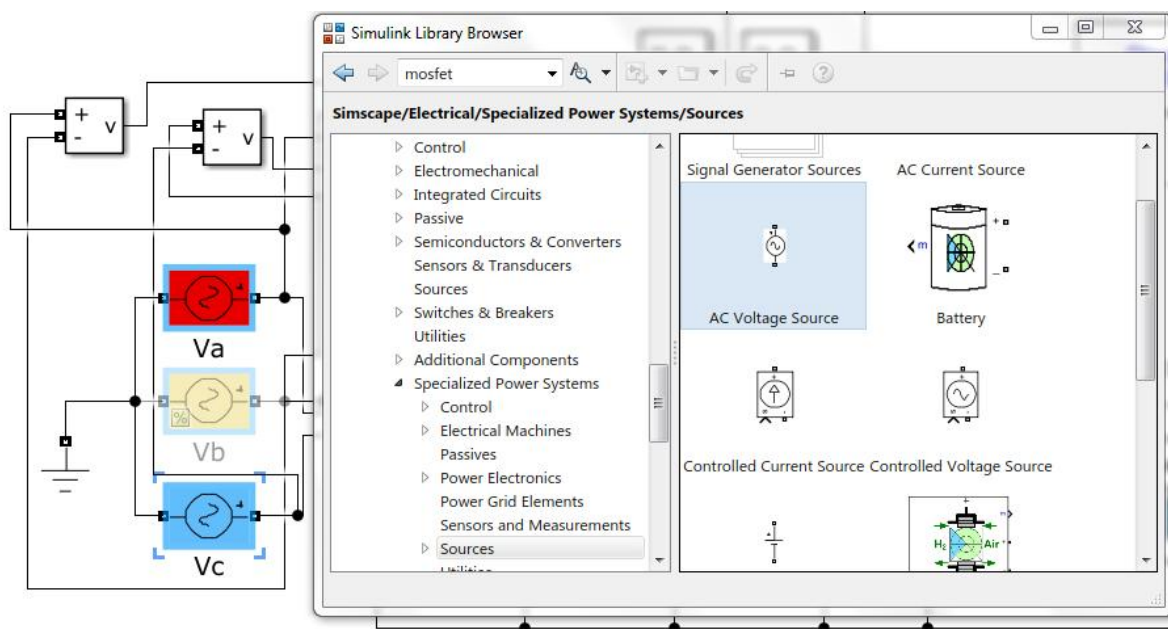


Fig. 4.6: AC Voltage Source

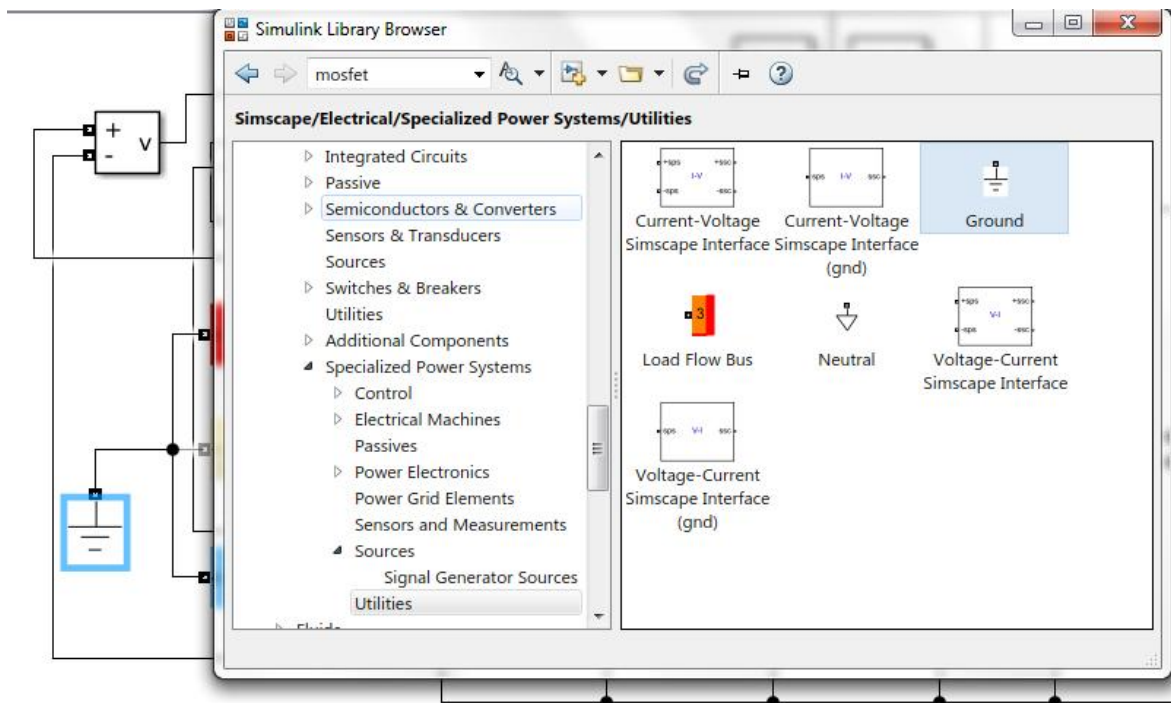


Fig. 4.7: Ground

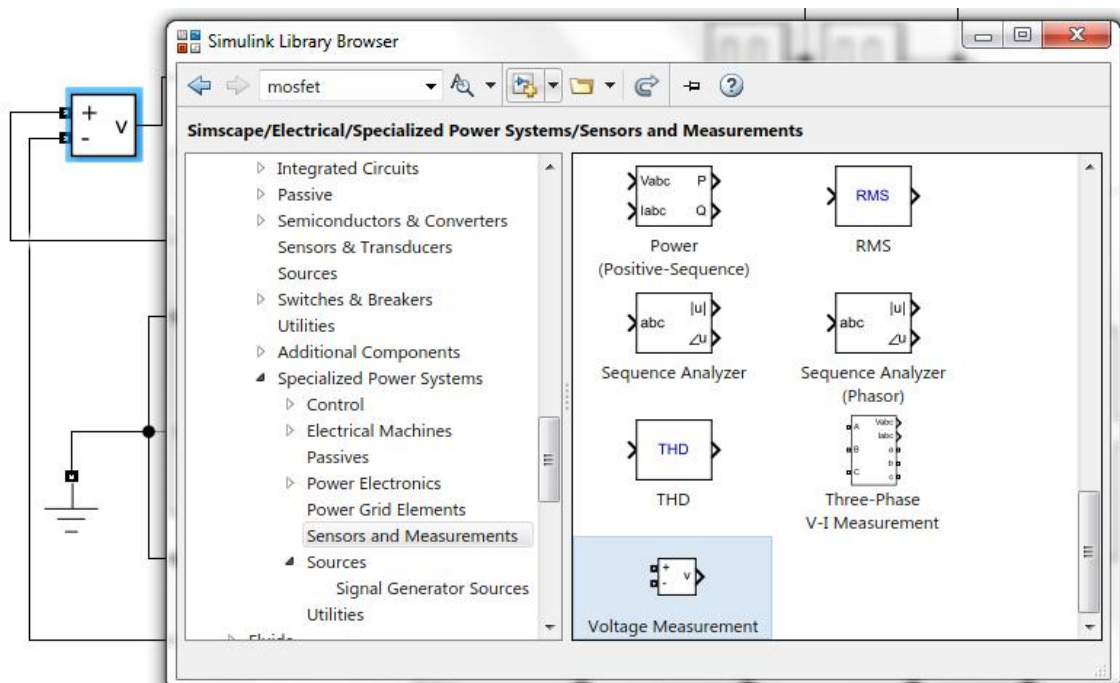


Fig. 4.8: Voltage Measurement

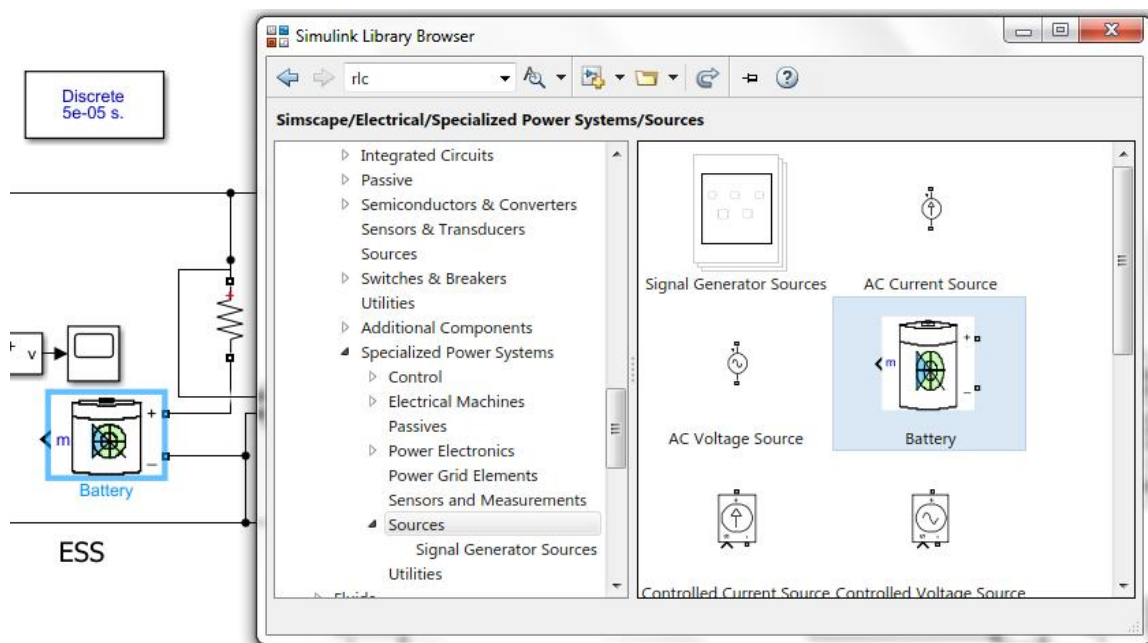


Fig. 4.9 Battery

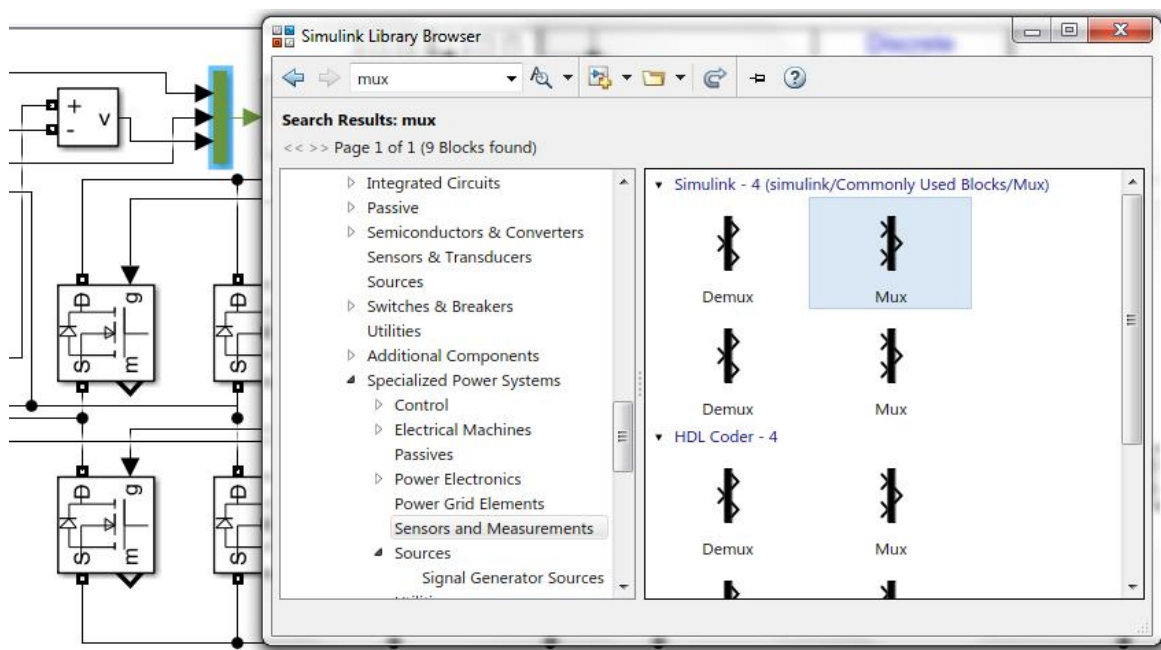


Fig. 4.10: MUX

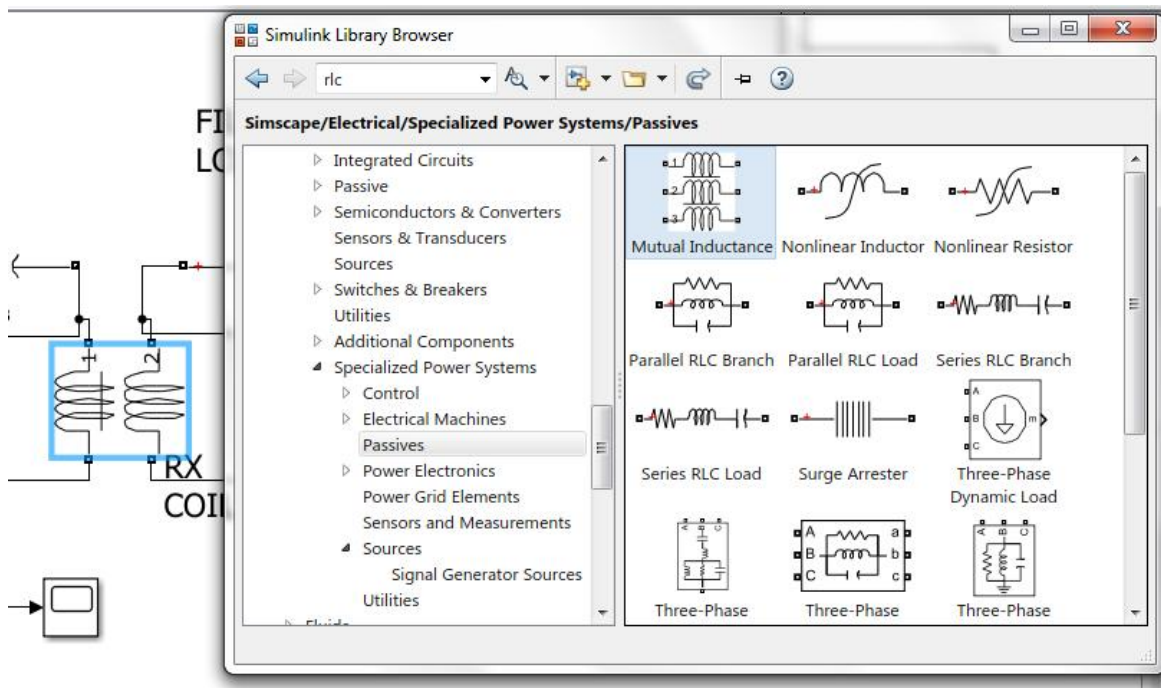


Fig. 4.11: Mutual Inductance

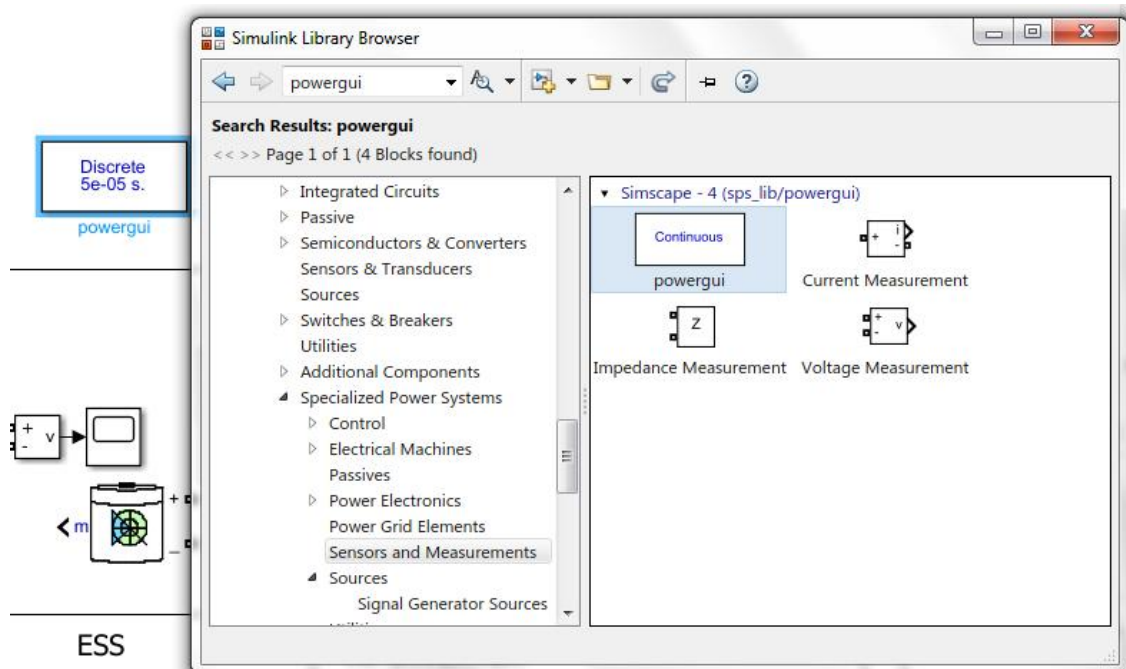


Fig. 4.12: Power GUI

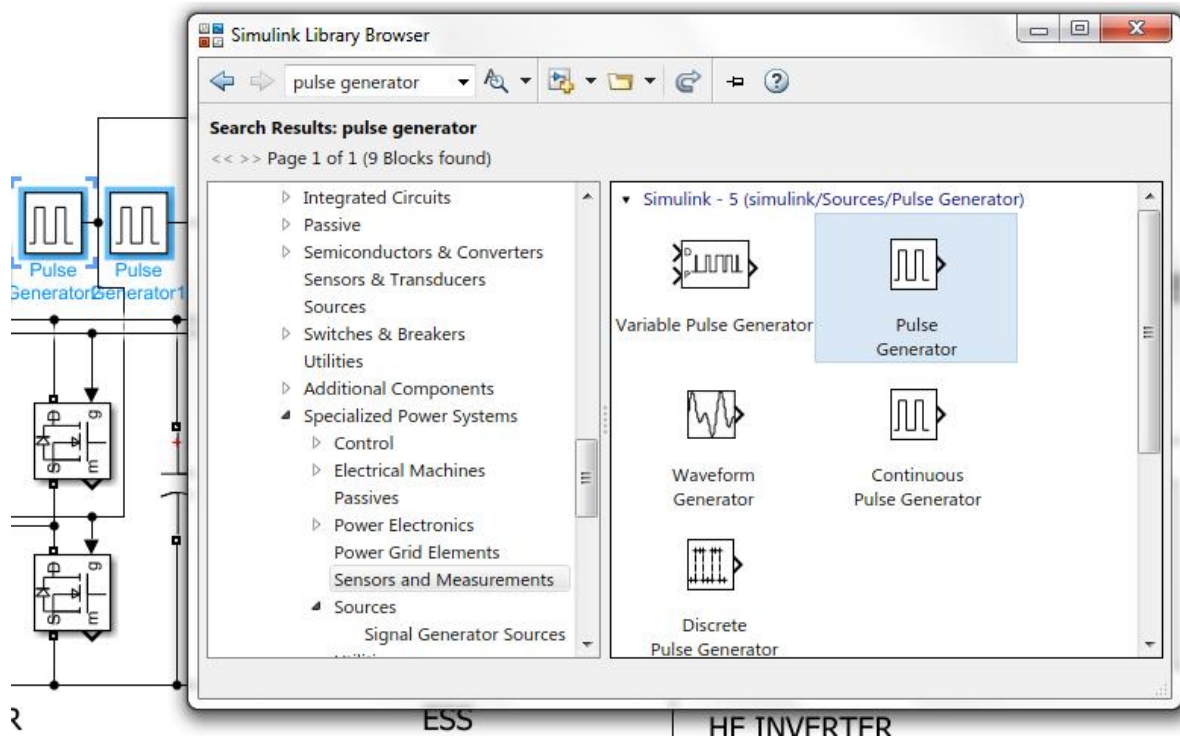


Fig. 4.13: Pulse Generator

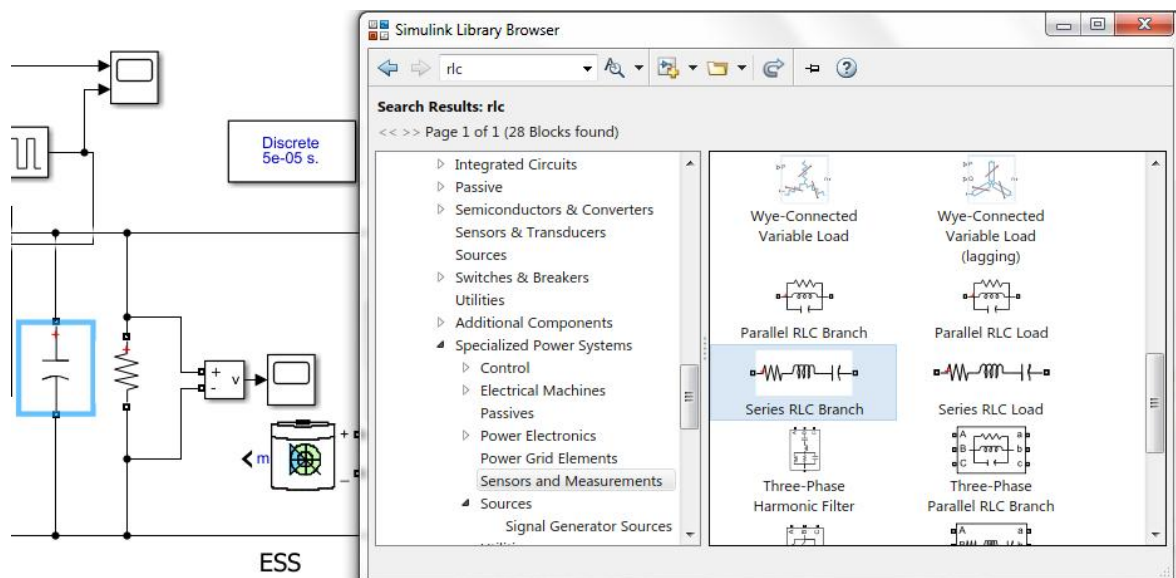


Fig. 4.14: Series RLC Branch

4.4 MATLAB/SIMULIK

Results

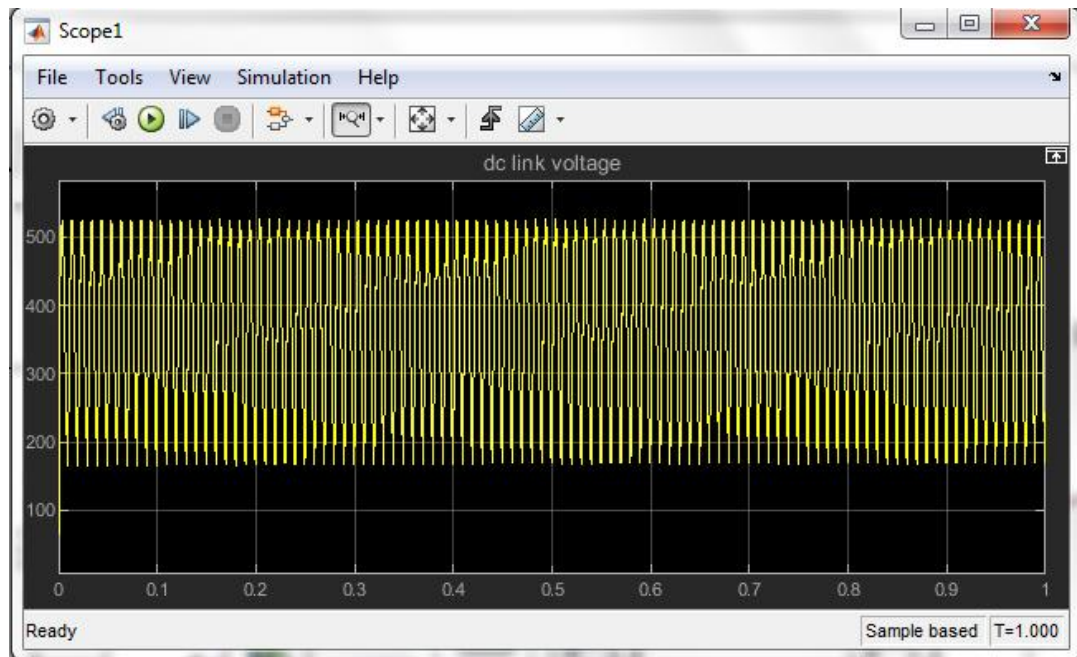


Fig. 4.15: DC Link Voltage

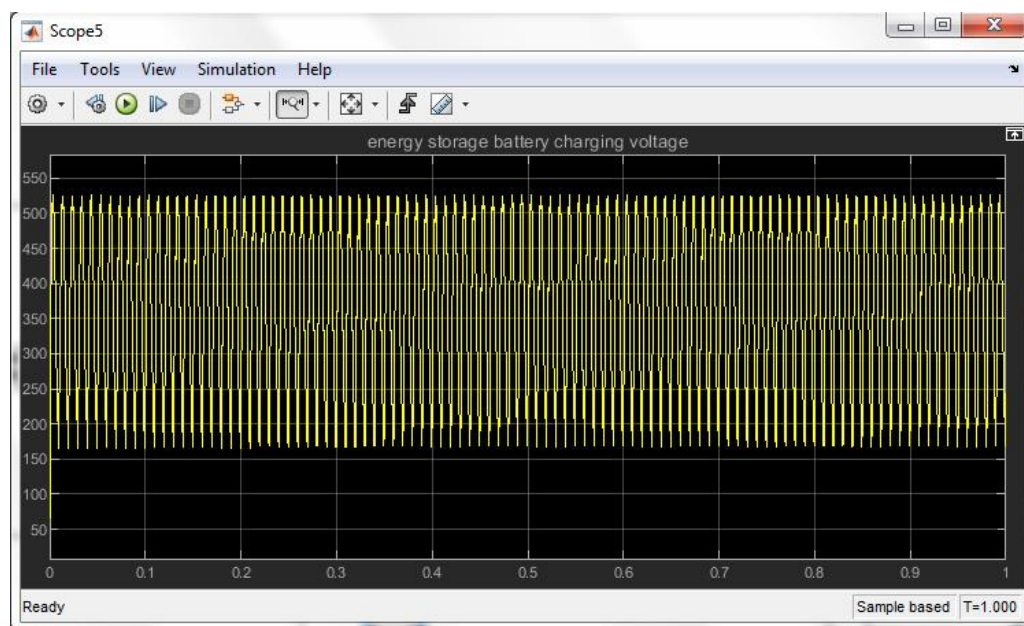


Fig. 4.16: Battery Storage Voltage

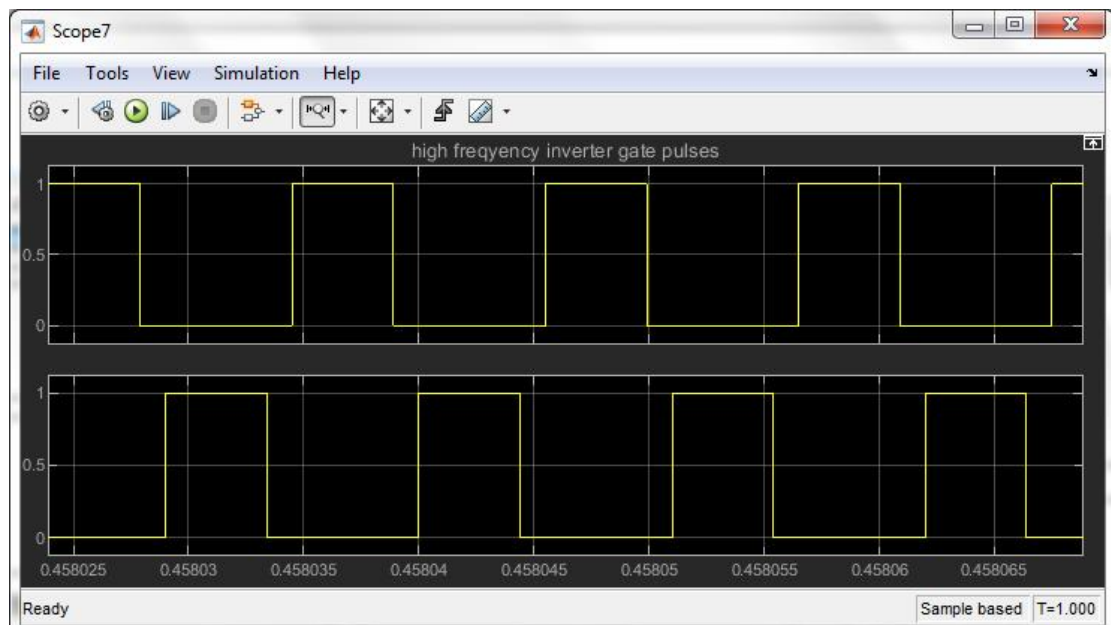


Fig. 4.17: Inverter Pulse for Mosfet

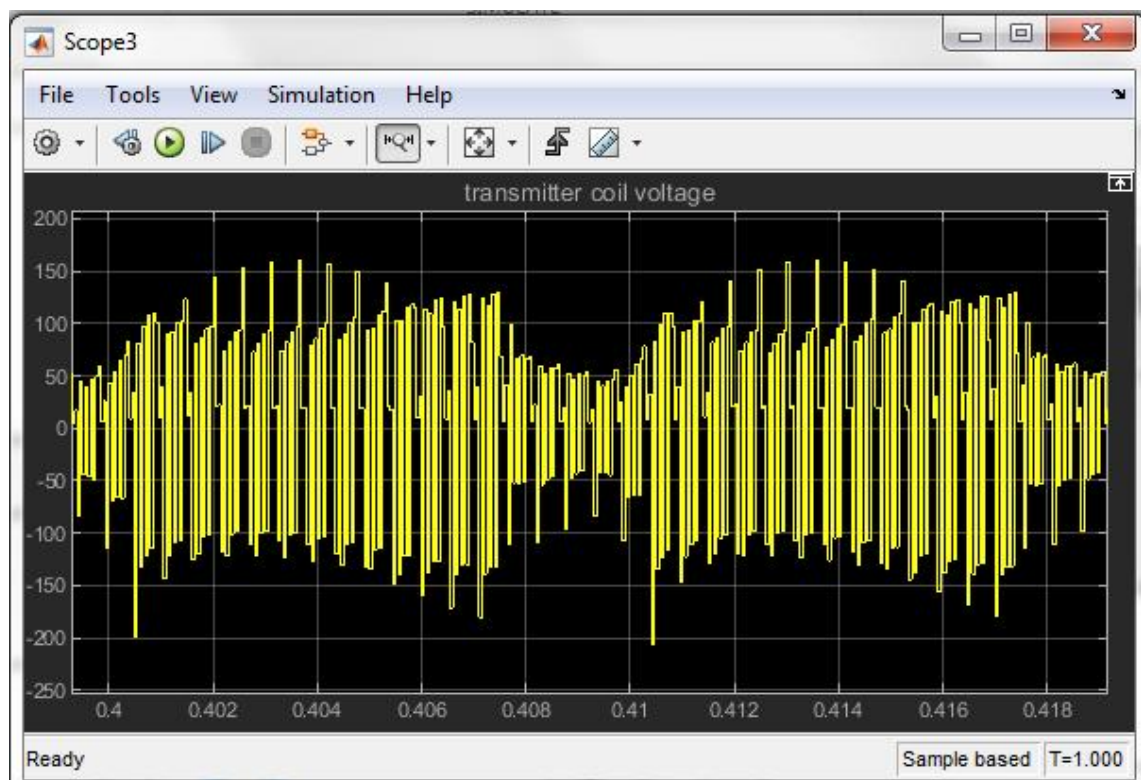


Fig. 4.18: Transmission Coil Voltage

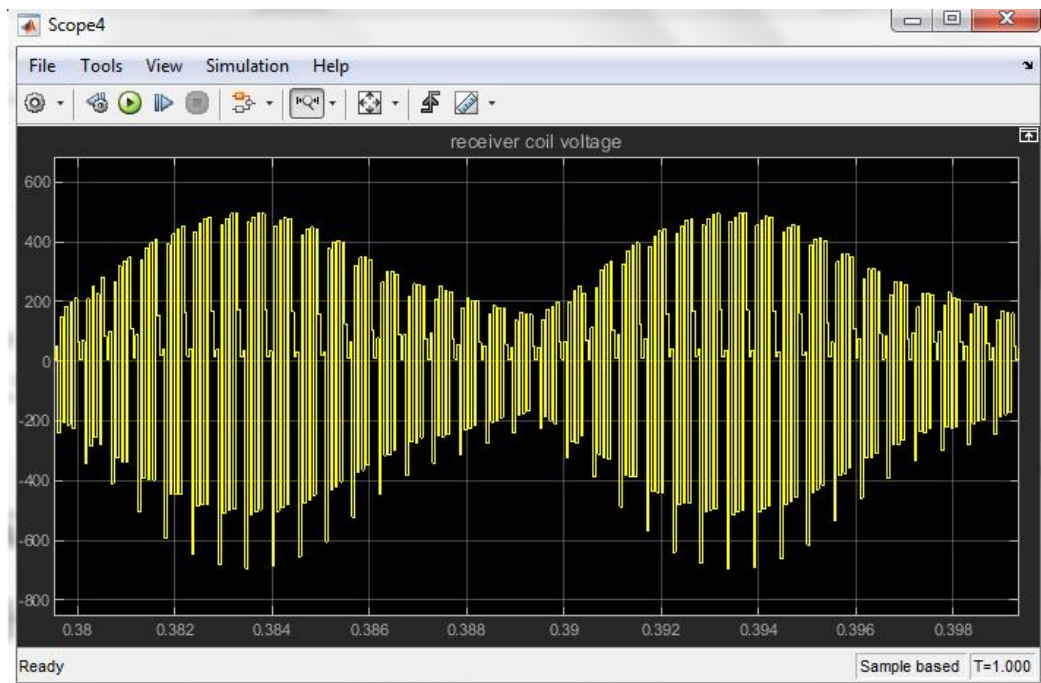


Fig. 4.19: Receiver Coil Voltage

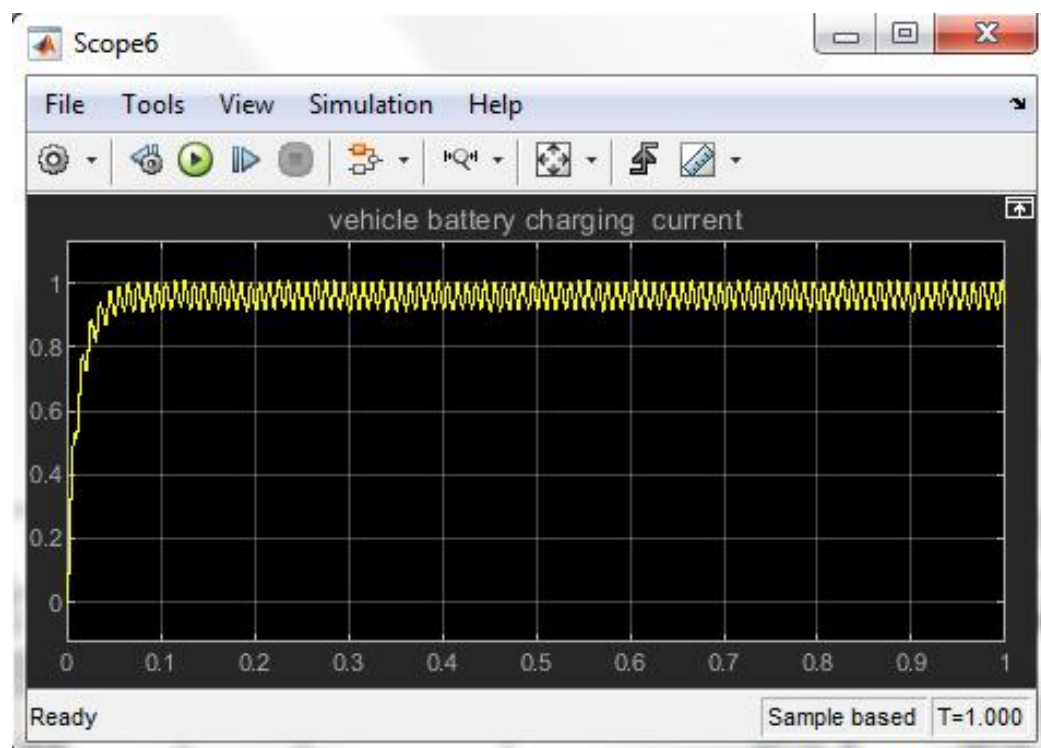


Fig. 4.20: Battery Charging Current

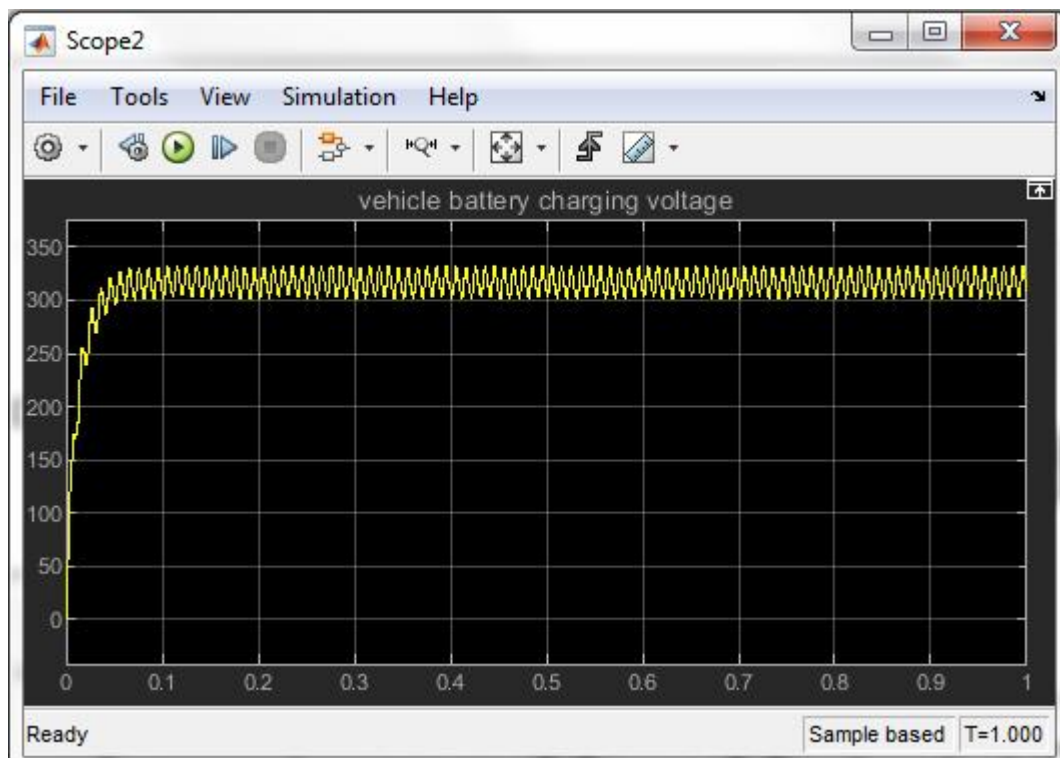
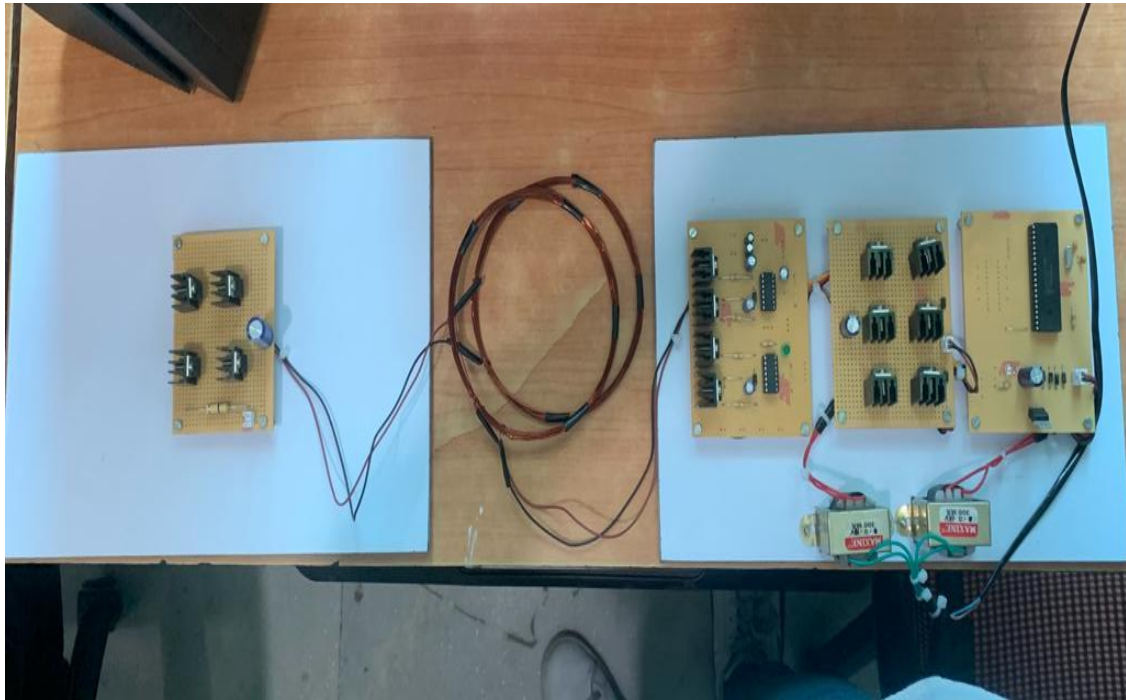


Fig. 4.21: Battery Charging Voltage

CHAPTER 5

HARDWARE IMPLMENTATION



5.1 HARDWARE

Required components

- STEP DOWN TRANSFORMER
- VOLTAGE REGULATOR 7805
- CAPACITOR
- DIODE
- PIC16F877A MICROCONTROLLER
- HS CRYSTAL OSCILATOR
- LED

- MOSFET (IRF840)
- ALUMINIUM HEAT SINK
- GATE DRIVER FOR MOSFET
- TRANSMISSION COIL
- RECEIVER COIL
- RESISTORS
- CONNECTORS
- CONNECTING WIRES

Hardware Description

Step Down Transformer-(220v AC to 12v)

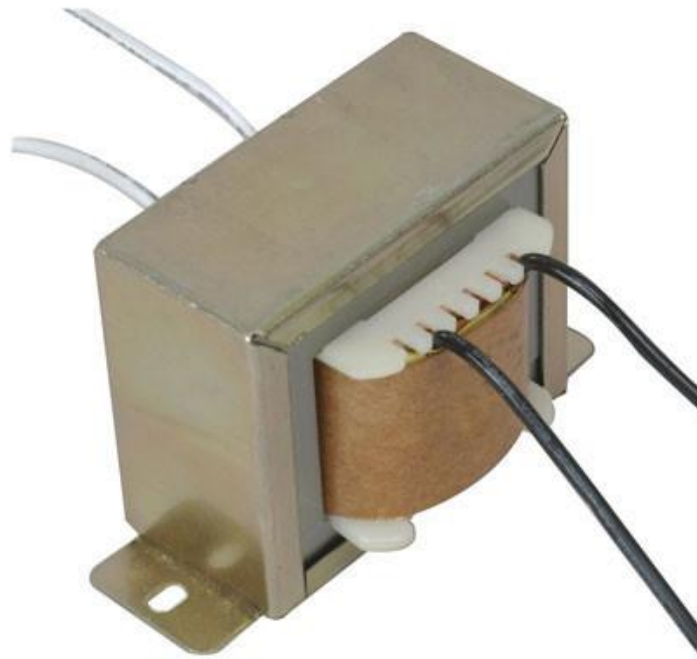


Fig. 5.1: Step Down Transformer-(220v AC to 12v)

Transformer has 230V primary winding and non-center tapped secondary winding. The transformer has flying colored insulated connecting leads (Approx 100 mm long). The Transformer act as step down transformer reducing AC - 230V to AC - 12V.

A step-down transformer is an electrical device that reduces the voltage of an alternating current (AC) power supply. It consists of a primary winding, a secondary winding, and an iron core. When an AC voltage is applied to the primary winding, it creates a fluctuating magnetic field in the iron core.

Voltage Regulator 7805

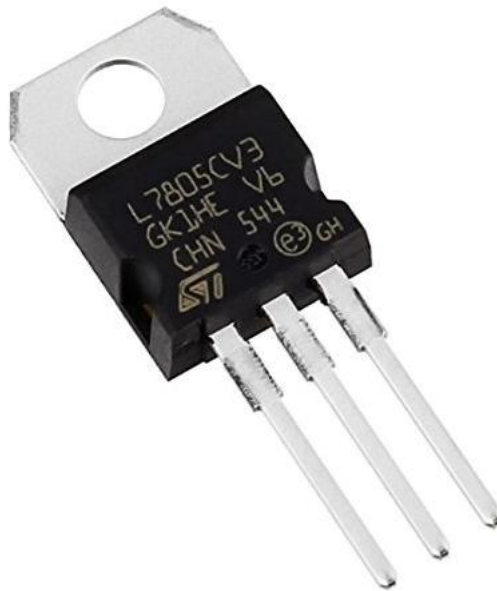
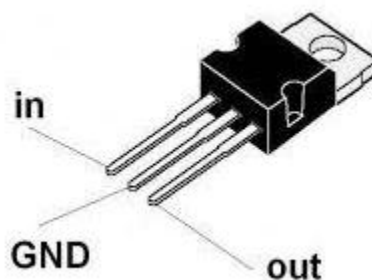


Fig. 5.2: Voltage Regulator 7805

The voltage regulator IC 7805 is actually a member of the 78xx series of voltage regulator ICs. It is a fixed linear voltage regulator. The xx present in 78xx represents the value of the fixed output voltage that the particular IC provides. For 7805 IC, it is +5V DC regulated power supply. This regulator IC also adds a provision for a heat sink. The input voltage to this voltage regulator can be up to 35V, and this IC can give a constant 5V for any value of input less than or equal to 35V which is the threshold limit.



1-Input

The function of this pin is to give the input voltage. It should be in the range of 7V to 35V. We apply an unregulated voltage to this pin for regulation. For 7.2V input, the PIN achieves its maximum efficiency.

2-Ground

We connect the ground to this pin. For output and input, this pin is equally neutral (0V).

3-Output

This pin is used to take the regulated output.

Capacitor



Fig. 5.3: Capacitor

A capacitor is a two-terminal electrical device that can store energy in the form of an electric charge. It consists of two electrical conductors that are separated by a distance. The space between the conductors may be filled by vacuum or with an insulating material known as a dielectric.

Diode

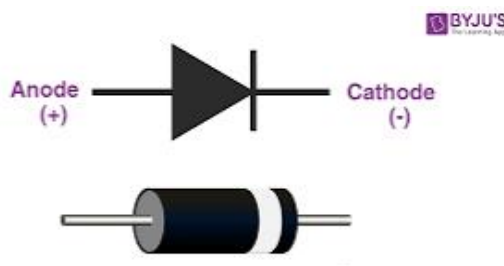


Fig. 5.4: Diode

A diode is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.

5.2 PIC16F877A – (MICROCONTROLLER)

PIC Controller

Description

PIC and PIC micro are registered trademarks of Microchip Technology. It is generally thought that PIC stands for Peripheral Interface Controller, although General Instruments' original acronym for the initial PIC1640 and PIC1650 devices was "Programmable Interface Controller".

PIC microcontrollers are a family of specialized microcontroller chips produced by Microchip Technology in Chandler, Arizona. The acronym PIC stands for "peripheral interface controller," although that term is rarely used nowadays. A typical microcontroller includes a processor, memory, and peripherals.

The microcontroller is a device that can perform a specific function according to the coding/program burnt into its program memory. The microcontrollers are special purpose devices used in many application like automobile, medical, instrumentation, battery management, smart phones accessories, motor and control drives, USB and wireless technology etc.



Fig. 5.5: PIC Controller Board

PIC Controller Board

One of the most reputed manufacturers of micro-controller is MICROCHIP. PCB design. They have the vast series of micro-controllers from 8bit, 16, 32 bit controllers both in SMD and through whole package.

This board is build with PIC16F877A as a microcontroller unit. The input supply to the board can be fed from both ac and dc. It uses a crystal oscillator for generating frequency. A serial communication is achieved by an UART protocol. This board is specially designed for connecting digital and analog sensors which has input voltage range 5 or 12VDC as well as it can be interfaced with serial communication devices, relay boards etc. The output can be monitored in LCD as well as pc. Data EEPROM is used to store data defined by the user. PCB design. When a variable is defined it is stored in program memory and the value of the variable is stored in data EEPROM Synchronous serial ports are used to communicate with other peripheral devices like serial EEPROMS, A/D converters And shift registers. PCB design. They have two modes. 1- SPI Serial Peripheral Interface 2- I2C Inter Integrated Circuit

Features

- Input Supply: Ac or Dc (9 to 12v)
- 8bit LCD
- RS232 output
- Analog channel: 5 sensor inputs
- Crystal frequency: 4mHz

Applications

- Real time applications
- Academic applications

PIC16F877A IC

Description

The PIC16F887 is one of the latest products from *Microchip*. It features all the components which modern microcontrollers normally have. For its low price, wide range of application, high quality and easy availability, it is an ideal solution in applications such as: the control of different processes in industry, machine control devices, measurement of different values etc. Some of its main features are listed below.

The 16F877A is a capable microcontroller that can do many tasks because it has a large enough programming memory (large in terms of sensor and control projects) 8k words and 368 Bytes of RAM. This is enough to do many different projects (see links at end of this page for some example projects on this site).



Fig. 5.6: PIC16F877A IC

The 40 pins make it easier to use the peripherals as the functions are spread out over the pins. This makes it easier to decide what external devices to attach without worrying too much if there are enough pins to do the job.

One of the main advantages is that each pin is only shared between two or three functions so its easier to decide what the pin function (other devices have up to 5 functions for a pin)

40-Pin PDIP

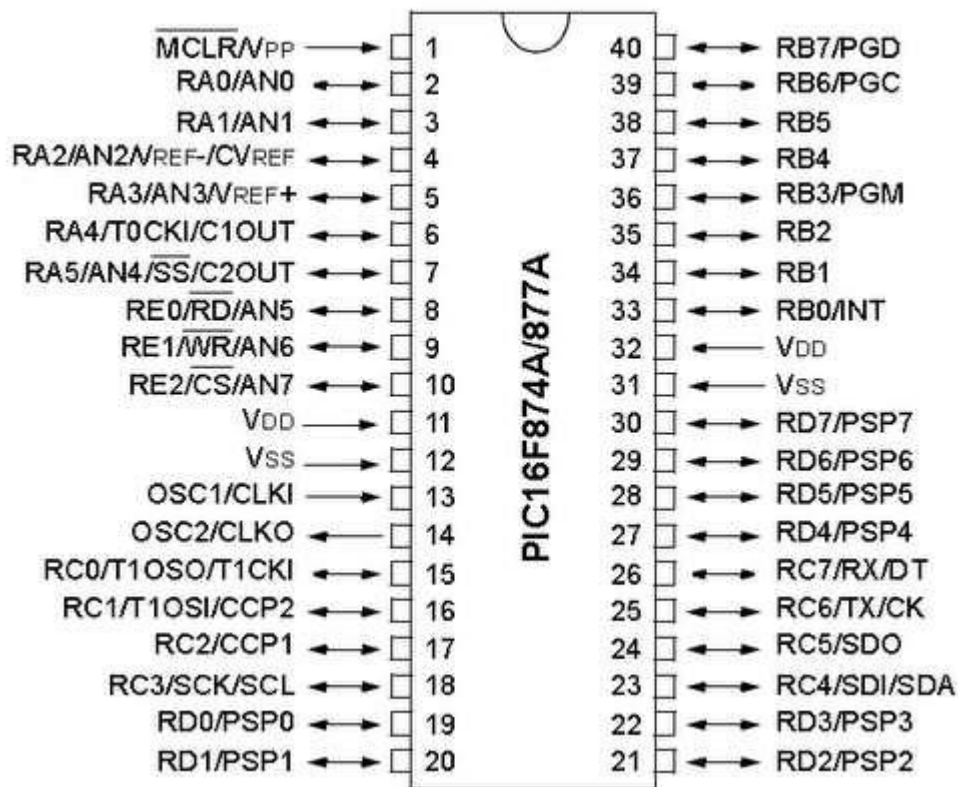


Fig. 5.7: Pin Diagram

- *RISC architecture*
 - Only 35 instructions to learn
 - All single-cycle instructions except branches
- *Operating frequency 0-20 MHz*
- *Precision internal oscillator*
 - Factory calibrated
 - Software selectable frequency range of 8MHz to 31KHz
- *Power supply voltage 2.0-5.5V*
 - Consumption: 220uA (2.0V, 4MHz), 11uA (2.0 V, 32 KHz) 50nA (stand-by mode)
- *Power-Saving Sleep Mode*
- *Brown-out Reset (BOR) with software control option*

- *35 input/output pins*
 - High current source/sink for direct LED drive
 - software and individually programmable *pull-up* resistor
 - Interrupt-on-Change pin
- *8K ROM memory in FLASH technology*
 - Chip can be reprogrammed up to 100.000 times
- *In-Circuit Serial Programming Option*
 - Chip can be programmed even embedded in the target device
- *256 bytes EEPROM memory*
 - Data can be written more than 1.000.000 times
- *368 bytes RAM memory*
- *A/D converter*
 - 14-channels
 - 10-bit resolution
- *3 independent timers/counters*
- *Watch-dog timer*
- *Analogue comparator module with*
 - Two analogue comparators
 - Fixed voltage reference (0.6V)
 - Programmable on-chip voltage reference
- *PWM output steering control*
- *Enhanced USART module*
 - Supports RS-485, RS-232 and LIN2.0
 - Auto-Baud Detect
- *Master Synchronous Serial Port (MSSP)*
 - supports SPI and I2C mode

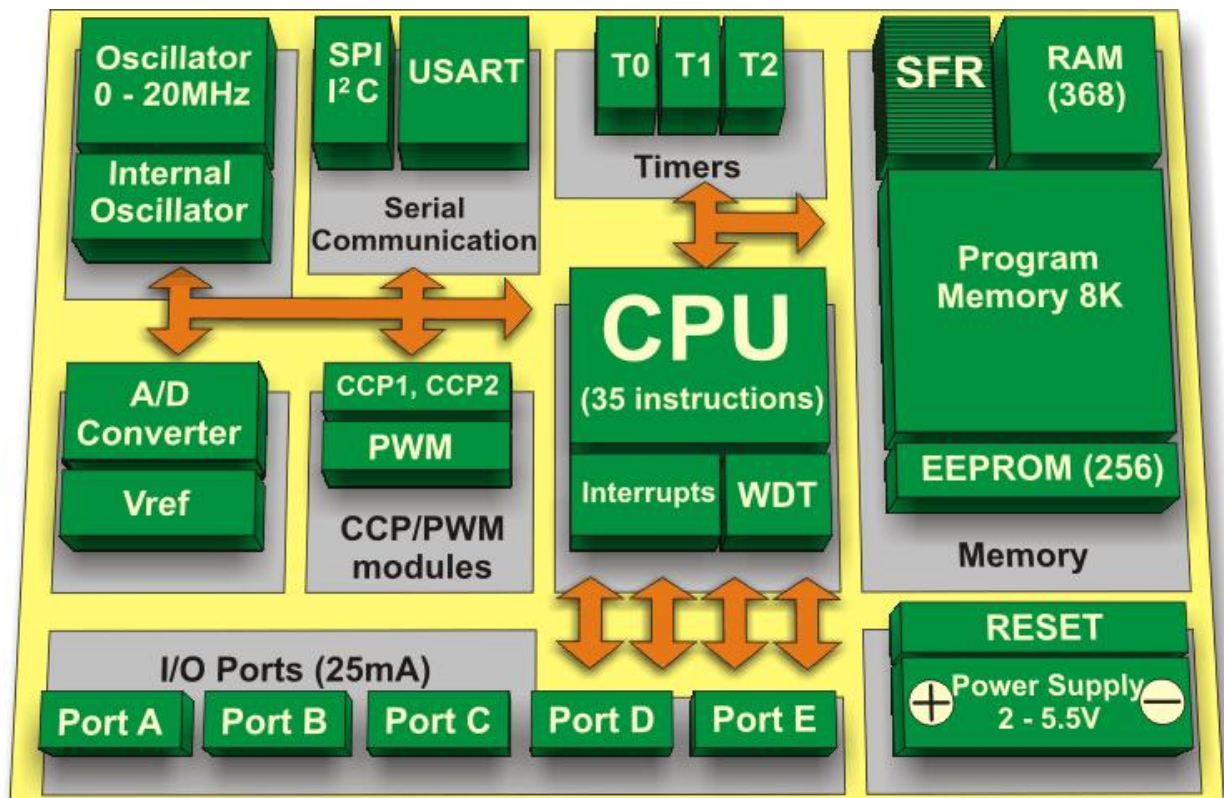


Fig. 5.8: Architecture

This powerful (200 nanosecond instruction execution) yet easy-to-program (only 35 single word instructions) CMOS FLASH-based 8-bit microcontroller packs Microchip's powerful PIC® architecture into an 40- or 44-pin package and is upwards compatible with the PIC16C5X, PIC12CXXX and PIC16C7X devices. The PIC16F877A features 256 bytes of EEPROM data memory, self programming, an ICD, 2 Comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions, the synchronous serial port. Transmitter (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications.

Central Processor Unit (CPU)

I'm not going to bore you with the operation of the CPU at this stage, however it is important to state that the CPU is manufactured with in RISC technology an important factor when deciding which microprocessor to use.

RISC *Reduced Instruction Set Computer*, gives the PIC16F887 two great advantages:

- The CPU can recognize only 35 simple instructions (In order to program some other microcontrollers it is necessary to know more than 200 instructions by heart).
- The execution time is the same for all instructions except two and lasts 4 clock cycles (oscillator frequency is stabilized by a quartz crystal). The Jump and Branch instructions execution time is 2 clock cycles. It means that if the microcontroller's operating speed is 20MHz, execution time of each instruction will be 200nS, i.e. the program will be executed at the speed of 5 million instructions per second.

Memory

This microcontroller has three types of memory- ROM, RAM and EEPROM. All of them will be separately discussed since each has specific functions, features and organization.

ROM Memory

ROM memory is used to permanently save the program being executed. This is why it is often called "program memory". The PIC16F887 has 8Kb of ROM (in total of 8192 locations). Since this ROM is made with FLASH technology, its contents can be changed by providing a special programming voltage (13V).

Anyway, there is no need to explain it in detail because it is automatically performed by means of a special program on the PC and a simple electronic device called the Programmer.

EEPROM Memory

Similar to program memory, the contents of EEPROM is permanently saved, even the power goes off. However, unlike ROM, the contents of the

EEPROM can be changed during operation of the microcontroller. That is why this memory (256 locations) is a perfect one for permanently saving results created and used during the operation.

RAM Memory

This is the third and the most complex part of microcontroller memory. In this case, it consists of two parts: general-purpose registers and special-function registers (SFR).

Even though both groups of registers are cleared when power goes off and even though they are manufactured in the same way and act in the similar way, their functions do not have many things in common.

General-Purpose Registers

General-Purpose registers are used for storing temporary data and results created during operation. For example, if the program performs a counting (for example, counting products on the assembly line), it is necessary to have a register which stands for what we in everyday life call “sum”. Since the microcontroller is not creative at all, it is necessary to specify the address of some general purpose register and assign it a new function. A simple program to increment the value of this register by 1, after each product passes through a sensor, should be created.

Therefore, the microcontroller can execute that program because it now knows what and where the sum which must be incremented is. Similarly to this simple example, each program variable must be preassigned some of general-purpose register.

SFR Registers

Special-Function registers are also RAM memory locations, but unlike general-purpose registers, their purpose is predetermined during manufacturing process and cannot be changed. Since their bits are physically connected to

particular circuits on the chip (A/D converter, serial communication module, etc.), any change of their contents directly affects the operation of the microcontroller or some of its circuits. For example, by changing the TRISA register, the function of each port A pin can be changed in a way it acts as input or output. Another feature of these memory locations is that they have their names (registers and their bits), which considerably facilitates program writing. Since high-level programming language can use the list of all registers with their exact addresses, it is enough to specify the register's name in order to read or change its contents.

RAM Memory Banks

The data memory is partitioned into four banks. Prior to accessing some register during program writing (in order to read or change its contents), it is necessary to select the bank which contains that register. Two bits of the STATUS register are used for bank selecting, which will be discussed later. In order to facilitate operation, the most commonly used SFRs have the same address in all banks which enables them to be easily accessed.

Stack

A part of the RAM used for the stack consists of eight 13-bit registers. Before the microcontroller starts to execute a subroutine (CALL instruction) or when an interrupt occurs, the address of first next instruction being currently executed is pushed onto the stack, i.e. onto one of its registers. In that way, upon subroutine or interrupt execution, the microcontroller knows from where to continue regular program execution. This address is cleared upon return to the main program because there is no need to save it any longer, and one location of the stack is automatically available for further use.

It is important to understand that data is always circularly pushed onto the stack. It means that after the stack has been pushed eight times, the ninth push overwrites the value that was stored with the first push. The tenth push overwrites the second push and so on. Data overwritten in this way is not recoverable. In addition, the programmer cannot access these registers for write or read and there is no Status bit to indicate stack overflow or stack underflow

conditions. For that reason, one should take special care of it during program writing.

Interrupt System

The first thing that the microcontroller does when an interrupt request arrives is to execute the current instruction and then stop regular program execution. Immediately after that, the current program memory address is automatically pushed onto the stack and the default address (predefined by the manufacturer) is written to the program counter. That location from where the program continues execution is called the interrupt vector. For the PIC16F887 microcontroller, this address is 0004h. As seen in Fig. 1-7 below, the location containing interrupt vector is passed over during regular program

Part of the program being activated when an interrupt request arrives is called the interrupt routine. Its first instruction is located at the interrupt vector. How long this subroutine will be and what it will be like depends on the skills of the programmer as well as the interrupt source itself. Some microcontrollers have more interrupt vectors (every interrupt request has its vector), but in this case there is only one. Consequently, the first part of the interrupt routine consists in interrupt source recognition.

Finally, when the interrupt source is recognized and interrupt routine is executed, the microcontroller reaches the RETFIE instruction, pops the address from the stack and continues program execution from where it left off.

Features

- External gate.
- Volt Reference.
- Nano Watt.
- Internal Clock.
- 2 PWM 10-bit

Applications

- House hold appliances
- Office equipment
- Instruments
- Peripheral devices
- Motor control

5.3 HS CRYSTAL OSCILATOR

Crystal Oscillator

Description

A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a precise frequency.

An electronic oscillator is an electronic circuit that produces a periodic, oscillating electronic signal, often a sine wave or a square wave. Oscillators convert direct current (DC) from a power supply to an alternating current (AC) signal. They are widely used in many electronic devices.



Fig. 5.9: Crystal Oscillator

Inside a quartz clock or watch, the battery sends electricity to the quartz crystal through an electronic circuit. The quartz crystal oscillates (vibrates back and forth) at a precise frequency: exactly 32768 times each second.

An oscillator is a device that can give you a clock at a certain frequency given a constant voltage. One part of the oscillator is a crystal that is basically a very good filter. Most microcontrollers only require a crystal because they contain all other parts of an oscillator already.

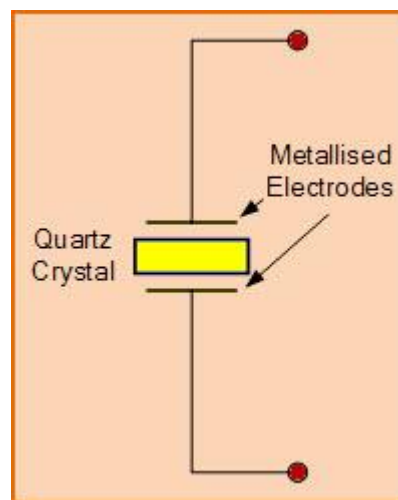


Fig. 5.10: Circuit Diagram

In general, we know that, crystal oscillators are used in the microprocessors and microcontrollers for providing the clock signals. Let us consider 8051 microcontroller for which an external crystal oscillator circuit of 12MHz is essential, even though (based on model) 8051 microcontroller is capable to run at 40 MHz (max). 8051 requires 12 clock cycles for one machine cycle, such that to give effective cycle rate at 1MHz (considering 12MHz clock) to 3.33MHz (considering maximum 40MHz clock). This crystal oscillator is used to generate clock pulses required for the synchronization of all the internal operations.

Application of Crystal Oscillator in Military and Aerospace

The use of crystal oscillator in military and aerospace, is to establish an efficient communication system, for the navigation purpose, electronic warfare, in the guidance systems, and so on.

Use of Crystal Oscillator in Research and Measurement

The crystal oscillator is used in research and measurement for celestial navigation, space tracking purpose, in the measuring instruments and medical devices, and so on.

Industrial Applications of Crystal Oscillator

There are a huge number of industrial applications of crystal oscillator such as in computers, digital systems, instrumentation, phase locked loop systems, marine, modems, sensors, telecommunications, disk drives, and so on.

Use of Crystal Oscillator in Automotive

Crystal oscillator is used for engine controlling, stereo, clock and to trip computer, and in GPS system.

Consumer Applications of Crystal Oscillator

Crystal oscillators are used in many consumer goods such as cable television systems, personal computers, video cameras, toys and video games, radio systems, cellular phones, and so on.

MOSFET (IRF840)

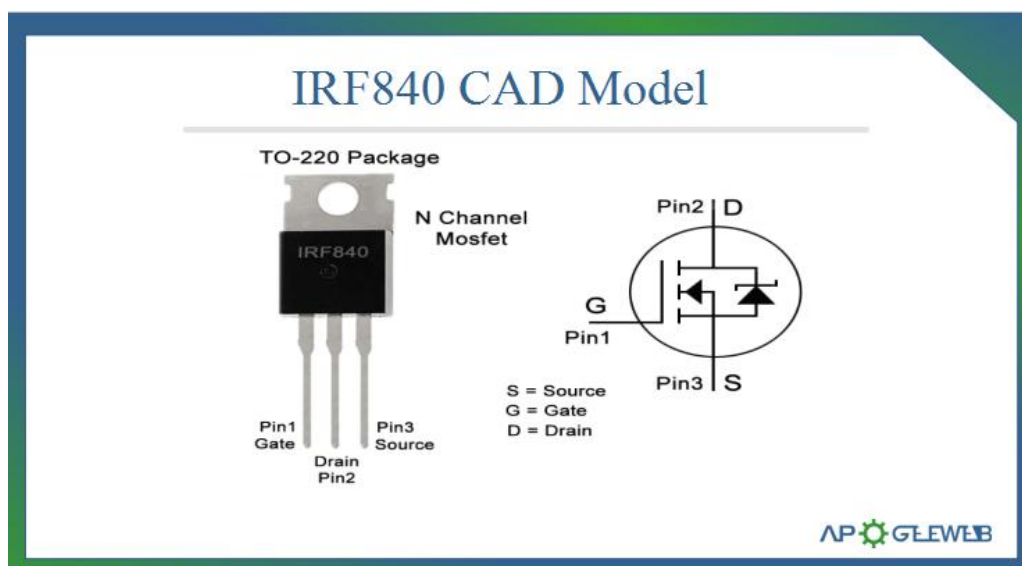


Fig. 5.11: IRF840 CAD Model

IRF840 Applications

- The IRF840 is used in the following applications.
- Used in Inverter Circuits and DC-DC Converters.
- Incorporated in High-Speed switching applications.
- Used for switching high power devices.
- Employed in Control speed of motors and LED dimmers or flashers.

Heat Sink

The purpose of using a heat sink is to properly remove heat from device components to improve device performance and extend its life. And usually, a heat sink incorporates a fan or other mechanism to reduce the temperature of a hardware component, such as a processor.

MOSFET gate driver

In order to turn on a MOSFET, a voltage higher than the rated gate threshold voltage V_{th} must be applied to the gate. • While in a steady on or off state, the MOSFET gate drive basically consumes no power. • The gate-source capacitance of a MOSFET seen by the driver output varies with its internal state.

Transmission Coil

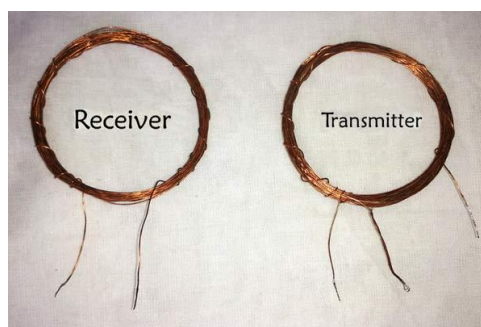


Fig. 5.12: Transmission Coil

Coil, in an electric circuit, one or more turns, usually roughly circular or cylindrical, of current-carrying wire designed to produce a magnetic field or to provide electrical resistance or inductance; in the latter case, a coil is also called a choke coil (see also inductance).

Receiver Coil

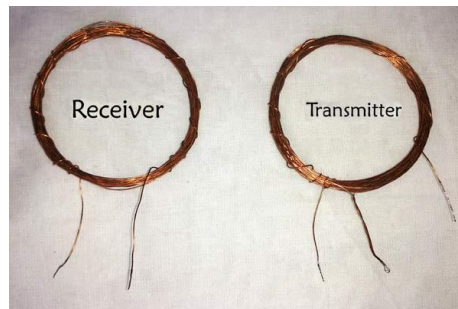


Fig. 5.13: Receiver Coil

Coil, in an electric circuit, one or more turns, usually roughly circular or cylindrical, of current-carrying wire designed to produce a magnetic field or to provide electrical resistance or inductance; in the latter case, a coil is also called a choke coil (see also inductance).

Resistor

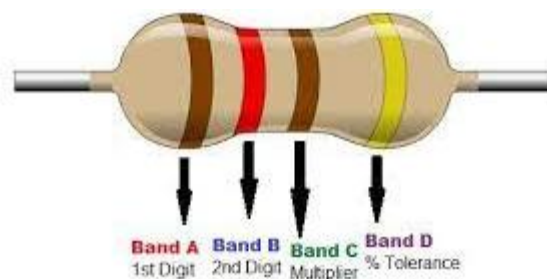


Fig. 5.14: Resistor

Resistor is defined as. A passive electrical component with two terminals that are used for either limiting or regulating the flow of electric current in

electrical circuits. The main purpose of resistor is to reduce the current flow and to lower the voltage in any particular portion of the circuit.

Connectors

Connectors are parts or devices used for electrically connecting or disconnecting circuits etc. They can connect and disconnect by hands or with simple tools without requiring special tools or processes such as soldering.

Connecting Wires



Fig. 5.15: Wires

A connecting wire allows travels the electric current from one point to another point without resistivity. Resistance of connecting wire should always be near zero. Copper wires have low resistance and are therefore suitable for low resistance.

CHAPTER 7

CONCLUSION

This information depicts a real technique for dealing with various ground clearances in wireless power transfer systems. The measurements taken for the aforementioned parameters produce trustworthy findings for the suggested theme. The prototype has a visible zero. The used relays' heating was warned against. Numerous simulations were run. Despite earlier research, we looked at several real-world charger placement restrictions in the surveillance area, such walls and ground clearance. Because it employs inverters, rectifiers, and filters to manage various coupling factors, the system just presented is affordable and extremely advantageous. When the ground clearance is within 200mm, a separate control system is activated, immediately tapping the transmitter coil to send power to the battery.

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