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FEASIBILITY STUDY OF DC SUPPLY FOR HOME APPLIANCES

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FEASIBILITY STUDY OF DC SUPPLY FOR HOME APPLIANCES

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A Thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the Degree of Master of Science in “Power System Engineering” in the Electrical and Computer Engineering Faculty, Institute of Technology, Bahir Dar University

Advisor Name: Dr. Ing. Getachew Biru

Addis Ababa, Ethiopia

January, 2018

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/ source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Date of Submission 11/02/2019.

Place: Addis Ababa

This thesis has been submitted for examination with my approval as a university advisor.

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ABSTRACT

Not all but most of the home appliances internally operate on DC that is obtained after a transformer and a rectifier constituting a major part of the power losses. The increase uses of renewable energy sources for energy generation become widespread which require DC/AC converter. Therefore there are lots of places that you will lose energy and be inefficient. Nowadays with the advanced research in power electronics components, generation of electricity in DC by solar PV and a fuel cell that eliminates the rectification process. Transformers are replaced by the power electronics buck-boost converters. DC circuit breakers have solved the protection problems for DC distribution system. Such kinds of technological change have the possibility of requiring electrical appliances that receive DC input from home that allow the direct use of DC from onsite DC sources, thus avoiding the energy losses from converting DC power to AC and back to DC.

The study starts with an introductory overview of losses in the cables and their dependence on voltage level, cable cross-sectional area, and transmitted power. The case study shows that main losses in the overall system generally occur in power converters. This leads to the investigation of efficiencies in power converters. As part of the process to investigate DC supply system for home appliance MATLAB simulation software and straightforward mathematics are used.

In this paper 48V, DC is proposed as an optimum voltage for home distribution. Proposed DC system diminishes the power conversion stages, reduces the associated power losses by 29.05%, and improves the overall system efficiency from 0.51% – 31.45% range for various devices and has validated the cost-benefit of manufacturing the DC devices than AC devices. The assessment of all these shows that a conventional AC system can be replaced by a DC system that has many advantages by cost as well as by performance.

Keyword: *AC Power Supply, AC/DC converter, DC/DC converter, DC Power Supply, Feasibility, Home* Appliances.

TABLE OF CONTENTS

LIST OF ABBREVATIONS

AC	Alternating Current
BLDC	Brushless DC motor
DC	Direct Current
EMI	Electro Magnetic Interference
ESR	Equivalent Series Resistance
HVDC	High Voltage DC
KW	Kilo Watt
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LVDC	Low Voltage DC
MATLAB	Matrix Laboratory
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PFC	Power Factor Correction
PQ	Power Quality
PV	Photovoltaic
TV	Television
W	Watt

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CHAPTER 1
INTRODUCTION

This chapter puts this research into its historical context and sets out the underlying reasons for the need to rethink the way energy is used in the home and analyze how and what advantages are there to change from the conventional electrical supply of alternating current (AC) to direct current (DC).

1.1 General

Back to 1880s the first commercial distribution was direct current (DC) which was commissioned by Thomas Edison and in 1886 George Westinghouse began building an alternating current (AC) system that used a transformer to step up voltage for long-distance transmission and then stepped it back down for indoor lighting, a more efficient and less expensive system that directly competed for the market the Edison system was designed to serve. Following these events there were a big debate which was called '*War of the Currents*' or '*Battle of Currents*' and finally AC won out over DC as the power distribution of choice, mainly because of the ability to have large generators in a central location and With the development of a practical transformer, alternating-current power could be sent long distances over relatively small wires at a conveniently high voltage, then reduced in voltage to that used by a customer. The direct-current system generated and distributed electrical power at the same voltage as used by the customer's. This required the use of large, costly distribution wires and forced generating plants on every street or even every home, which was not possible or economically viable at the time [1].

This debate came in to light due to the development of power electronics which gives a better utilization of existing transmission and the increase uses of renewable sources for energy generation because the most widespread renewable energy generators are solar and wind, both of which provide DC voltage output.

1.2 Statement of the Problem

While most appliances internally powered by DC they are generally manufactured and sold with AC plugs which requires an AC/DC converter. To power these appliances AC needs to be rectified, filtered and regulated to provide a smooth DC. Many electronic circuits have different DC Voltages in the same device, for this reason there should be AC/DC converter in different stage and this will incur additional manufacturing cost and also have factor on the efficiency of power utilization due to power loss in the converters.

In addition, the increase uses of renewable sources for energy generation become widespread which require DC/AC converter. Let’s look at a theoretical wind turbine on a theoretical property: The wind blows –> wind turbine spins –> generator in turbine creates AC power –> AC converted to DC –> DC stored in a battery –> DC converted back to AC when needed –> AC powers devices in a home –> (possibly) AC converted back to DC for use in consumer devices.

The system contains a lot of converters to use the wind energy. As a result, there are lots of elements that cause energy losses and leads to inefficiencies. These occur in the power generation, the storage system, in the AC/DC conversion and the DC/AC conversion. It is not hard to see why this is not the preferred method of powering ones’ home.

As the "green living" evolution changes our ways of thinking, the simplest method for improving overall efficiency would be to remove one or more of those steps. One of these ways would be to convert a power scheme in a house; the less you need to convert between AC and DC, the less energy will go to waste.

The current technology of power electronics, generation of DC power from renewable energy sources like photovoltaic etc. are the main forces pushing towards the re-evaluation of the DC distribution capabilities and most of our appliances are becoming battery based system such as laptop, phone... etc., most modern-day home appliances include electronic circuits such as micro-controllers, LCD displays, etc., which need an AC/DC power supply to provide clean and regulated DC power. Other loads like LED lighting system, TV …etc. require DC supply as well. Such kinds of technological growth/change have the possibility of requiring electrical appliances that receives DC input from home.

The power industry worldwide has working in different aspect for changing demands with respect to enhancing safety and efficiency and environmental safeguards. In such an environment, it is essential that the personnel and the plant and equipment involved, perform to their optimum levels of capability. Feasibility study of DC supply for home has a role in providing a response to such demands on the industry, by enhancing the efficient power utilization, reduces manufacturing cost of home appliance by eliminating AC/DC converters required home appliances and supply DC power directly and by using environment friendly renewable energy power supply.

This study concept has proven that the use of direct DC supply from solar power for lighting, fan systems and electric vehicles charging etc. are more efficient [6].

1.3 Objective of the study

The general objective of the study is to study the feasibility of DC power supply for residential home appliance with the aim of achieving significant efficiency gain in energy consumption in comparison with AC supply.

The specific objectives include:

Identification of typical loads for home: Practically home electrical appliances are too many and some of the appliances require high power and the others require low power and some might require AC supply and others require DC supply for their operation. In order to give a specific focus to the study, identification of typical appliances for home is undertaken from the perspective of their internal voltage type and ratings.

Make analysis of the best DC voltage value: Different Electrical home appliances have different DC voltage value requirement some works 6V, 12V, 24V, 48V etc. and the power rating of the appliances, the cross sectional of the cable and the maximum length the cable can travel without exceeding the standard allowable voltage drop in the home distribution system determines the optimum DC voltage value. For this reason making analysis of the best DC voltage value are proposed as one part of the study.

Modeling of the appliances with DC Supply: One of the issues regarding the adoption of DC is that while devices may be internally powered by DC they are generally manufactured and sold with AC plugs/power supplies. By using MATLAB simulation software modeling of home appliance power supply system for direct DC supply are performed.

Comparative analysis of DC/AC supply in terms of energy efficiency, energy saving and PQ: The comparative analysis of DC/AC supply is for the checking of the existing AC supply home appliance versus modified home appliance to be supplied with DC in terms of energy saving, PQ and Efficiency.

Identify major re-engineering aspects of the AC devices for DC supply: Re-engineering aspects of the AC devices for DC supply are modeled and analyzed for the selected home appliance.

Compare the cost benefit of manufacturing DC devices against AC devices: The overall aim of comparing Cost-benefit of manufacturing the DC devices against AC devices are to identify which power supply system has a cost-benefit over the other on the manufacturing of home electrical devices.

For a comprehensive evaluation and analysis the DC supply system with the home appliances have been designed and simulated.

1.4 Scope

The feasibility study of DC power supply for home is limited on selected home appliance. The study focuses on the identification of typical loads for home, determination of best DC voltage value, modeling and of the DC Supply, making a comparative analysis of DC/AC supply in terms of energy saving, identifying major re-engineering aspects of the AC devices for DC supply and comparison of the cost benefit of manufacturing the DC devices against AC devices.

A model household is considered for the comparative analysis of the AC supply system versus a DC supply system in terms of energy efficiency, voltage regulation, Power quality and cost the equipment.

The energy consumption analysis did not include standby power usage of the appliances and the transient state of DC plugging in/out.

1.5 Significance of the Study

The study has made an attempt to analyze the feasibility of DC supply for home, in terms of loss minimization by omitting AC/DC converter, by using renewable energy source.

1.6 Research Methodology

The methodology looks at identifying and understanding the different parameters of the electrical system and the equations by which they are governed, and analyses how each affects the design process of the DC supply electrical system. A set of DC appliances is chosen for the house and the equations are used to work out voltage drop $\left(V_{drop}\right)$, maximum length of cable $\left(L_{MAX}\right)$, Power loss on the cable and converter efficiency for each appliance.

1.6.1 Data collection

The preparation phase of the study involves the collection of data; drawings and manufacture manuals were an integral part of the analysis and decision making process. The collected Materials and Documentation are:

- Lists of home appliances
- Schematic Drawings of the appliance
- Equipment manufacturer drawings and manuals

1.6.2 Analysis of sample home appliances

From a primary Data it is found that there are lots of home appliances available in the market and use. Ideally speaking the best scenario would be to be able to examine all the appliances and determine what would be the lowest DC voltage at which they will be able to operate efficiently and to analyze the appliance performance in DC supply system. However at this time this is not possible due to several reasons. Therefore some home appliances are selected to perform the study; the result obtained from the study will show us the interpretation on the rest of the appliances.

The devices which are selected to be studied are home appliances that are needed in our daily life, commonly used by most households. Afterward Understanding of their working principle; determining how the power supply system constructed and there voltage values; determining how it could be re-modeled for direct DC supply and Factors that could be affected the re-modeling are analyzed.

For the purpose of this study a two bedroom home are considered for showing the overall analysis result and seven different home appliances are selected.

Table 1.1: Power, voltage and current rating of appliance

Appliance	Power (W)	DC Voltage (V)	DC Current (A)
Refrigerator	240	24	10
Stove	1000	--	--
Food Processor	150	24	6.24
32’’ LED television	64	19.5	3.28
Radio	12	12	1
Mobile Charger	6	5	1.2
LED Light	5	5	1

1.6.3 Simulation and Analysis

As part of the process to implement the DC supply for home appliance MATLAB simulation software and straight forward mathematics were used. The simulation software is used for the purposes of re-engineering of the AC devices for a DC supply system. For the Comparative analysis of DC/AC supply energy saving and efficiency and Comparative analysis of cost benefit of manufacturing the DC devices against AC devices are made using the straight forward mathematical analysis.

1.6.4 Result Analysis

The study starts with an introductory overview of losses in the cables and their dependence on voltage level, cable cross-sectional area and transmitted power. Some advantages and disadvantages are shown especially when evaluating the possibility of using low voltage DC value which is attractive for safety reasons. Then a case study showing that main losses in the overall system generally occur in power converters. This leads to the investigation of efficiencies in power converters.

1.7 Thesis Organization

The thesis is structured as follows:

Chapter 1 Introduction: This chapter puts this research into its historical context and sets out the underlying reasons for the need to rethink the way energy is used in the home. Then to determine how and what advantages are there to change from the conventional electrical supply of alternating current (AC) to direct current (DC).

Chapter 2 Theoretical Background and Review of Literature: This chapter reviews current researches carried out so far on the area.

Chapters 3 Data Collection and Analysis: This chapter describes the analysis made with respect to selection of DC voltage value and the associated voltage drop in the conductors and the losses incurring.

Chapter 4 Design and Simulations: This chapter presents the modeling and MATLAB simulation of the system for the purposes of re-engineering of AC devices for DC supply system.

Chapters 5 Conclusions/Recommendations and Future: This chapter puts the summary of the study result.

CHAPTER 2

THEORETICAL BACKGROUND AND REVIEW OF LITERATURE

This chapter reviews the work carried out so far and compares the different papers. The parameters that affect the DC house comparing and contrasting their research. It evaluates their work to establish a framework on which this research could build. It gives also an indication of how this research differs in approach.

2.1 Renewable Energy Potential in Ethiopia

Ethiopia is a country that is very well endowed when it comes to renewable energy resources. Its vast portfolio of renewable energy includes wind, geothermal, solar as well as biomass. Due to the country's rapid economic growth and the fact that Ethiopia is serious about transitioning to the green economy makes exploiting renewable energy resource important.

According to the Ministry of Water, Irrigation and Electricity, Ethiopia has the potential of 45 thousand MW hydro-powers, five to 10 thousand MW geothermal potential and 1000GW wind energy potential among others. However, despite the headway made in exploiting this vast potential, still only a small portion of that potential remains harnessed [15].

In almost all cases both in Ethiopia and abroad the DC electrical energy generated from renewable energy generation is feeding into an AC house, which requires an inverter to provide the AC mains electricity. Then, again most appliances require either an internal or an external AC/DC converter so that it can operate at its correct DC voltage. The technology for two of the three stages of the electrical system already exists. There are the DC energy generators on the supply side and the DC loads on the demand side, all that is missing is the middle stage, the DC distribution network in the house. Therefore Feasibility study of DC supply for home provides an essential input for the missing element.

2.2 Photovoltaic Cells (PV)

Solar energy is one of the most important renewable energy sources that has been gaining increased attention in recent years. Solar energy is plentiful; it has the greatest availability compared to other energy sources. Solar energy is clean and free of emissions since it does not produce pollutants or by-products harmful to nature. The conversion of solar energy into electrical energy has many application fields. Residential, vehicular, space and aircraft and marine applications are the main fields of solar energy. Sunlight has been used as an energy source by ancient civilizations to ignite fires and burn enemy warships using “burning mirrors.” Till the eighteenth century, solar power was used for heating and lighting purposes.

Solar electricity has clear advantages in accessibility, cost, and reliability compared to traditional means of rural electrification. In the mid, to long-term solar electricity will also be competitive on the grid. The relative benefits of PV compared to the traditional alternatives are increasing because of rapidly declining costs, improving quality and reliability, and proven models of technology diffusion.

Ethiopia has a large population with a rapidly growing economy and a very low level of electrification. Photovoltaic systems are cost-effective and reliable means to increase access not only to electricity but also to information and communication through mobile devices. PV is already an important source of power for the mobile network in Ethiopia – it will also be important for of energizing social institutions such as schools, clinics, and water supply.

The outlook for the solar electricity sector in Ethiopia is for a rapid increase in installation for off-grid applications and later for grid-connected applications. Off-grid applications will be dominant in the short term but grid-connected PV may become important in the medium and long-term.

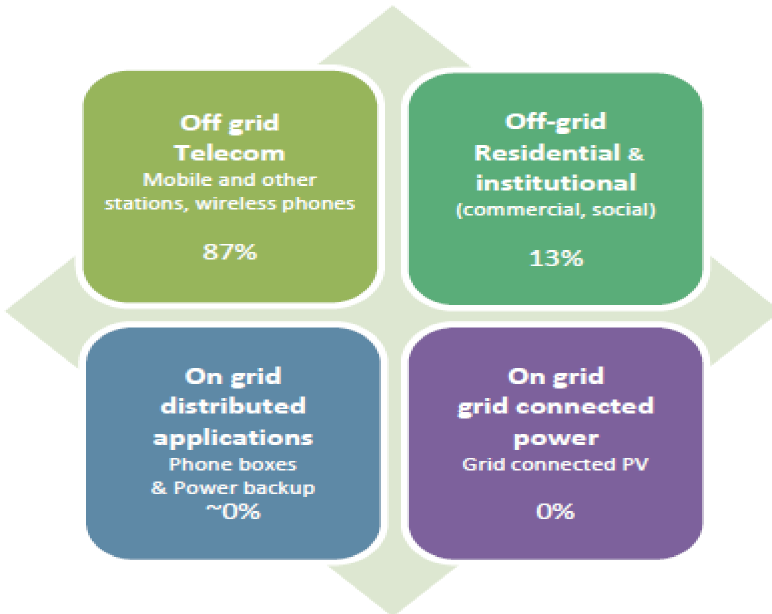

Figure 2.1: On and off grid solar power in use percentage in Ethiopia

Off-grid PV applications include home and institutional lighting, mobile charging, running audio-visual equipment, refrigeration and diagnostic equipment in health facilities, water pumping, and powering telecom stations. Off-grid PV systems range in size from the smallest 1Wp solar lamp to a village micro grid serving several hundred households and institutions.

Off-grid systems may be categorized into three segments: home systems, institutional systems (for individual institutions, for water pumping or for telecom stations), and village micro-grids [17].

2.2 DC supply System

By using a low voltage DC distribution network in the residence, AC/DC conversions losses can be omitted and the use of comparatively less efficient adapters can be discarded and also there will be no power factor issues. Only a highly efficient DC/DC converter will be needed to run some of the DC appliances. A DC distribution network in the residence will facilitate to reduce the electromagnetic interference. The majority of the devices used in households only require low power that is possible to be connected directly to the low voltage DC distribution system after removing the AC/DC conversion stage. Most of the commercially available appliances are designed with an input voltage of 12V and 24V and some of the appliances are available at input voltages of 48V. As the low voltage DC appliances have demanded of higher currents, it makes feeder losses considerable. As a result, the overall efficiency of the appliance becomes low. Feeder losses can be decreased by using higher DC voltages. Application of DC can, therefore, be more advantageous.

DC application has some limitations. Fault currents in DC distribution systems are comparatively higher than in AC distribution systems due to the absence of limiting self-inductance. The problem can arise during switching of DC circuits and hence special consideration is required for interruption of DC. Interruption of a DC arc is more difficult than the interruption of an AC arc due to the absence of zero current crossing for the DC current. The arc is cleared by increasing the voltage to a point at which the arc is unstable and where the conductivity of the arc is low. DC system in the open air has a typical problem of corrosion and the corrosion problem is comparatively larger than in AC system. Several factors have increased the recent interest in the DC power system.

Another factor is the increasing number of distributed resources such as solar photovoltaic arrays and fuel cells which produce DC power and batteries or other technologies store it in DC form. Batteries of plug-in hybrid vehicles store DC power, which is coming more in near future. Less complicated conversion system with less waste heat of DC distribution network would result in lower maintenance requirement, longer life of system components and lower cost of operation. Moreover, solid state switching can quickly interrupt the faults in the DC distribution system and results in better reliability and power quality [18].

2.3 Literature Review

The issue of using AC or DC power supply system seems like an unresolved issue and ‘war of current’ is still on. The debate again came into light due to recent development in power electronics which gives a better utilization of existing transmission system with high voltage DC connections. High voltage DC transmission allows more power to be transmitted over a long distance with less loss compared to an AC transmission. Power electronics make efficient and accurate control of electrical power possible. Efficient AC/DC, DC/AC, and DC/DC conversion technology are now available on the market, where DC/DC conversion is more efficient than AC/DC conversion [2].

It has been known for a long time that direct current (DC) is potentially more convenient, in terms of efficiency, in the transmission of electrical energy than three-phase current and single phase current. Losses that occur in cables are potentially lower for DC than AC because the cable can be used to its highest insulation rating. However, AC possesses some unique characteristics that have made it the main form of currently used for electrical transmission. In fact, AC voltage can be easily raised in magnitude, thanks to Transformers, and power carried over long distances with a small amount of loss. Further, the development of low-cost, rugged and efficient AC machines, to dominate the electrical machines panorama paved the way towards the international adoption of AC for electrical transmission. However, the increasing penetration of power electronics in the electrical, electronic and electromechanical engineering is at the base of the potential switch towards the use of DC for the same objective. Power electronics plays a key-role posing challenge on the use of electrical energy in DC form, for both technical (in addition to conversion efficiencies) and economic aspects. This happens in both transmission (HVDC systems) and distribution (LVDC systems). The increasing uses of renewable sources for energy generation as well as increasing use of more efficient electrical loads based on power electronics are the main forces pushing towards the re-evaluation of the DC distribution capabilities and the potential energy savings [3].
The review on DC power distribution and photovoltaic generation clarified the following points:

- The introduction of DC-based distribution has a potential to reduce conversion losses, by eliminating the need for conversion between PV and distribution (DC/ AC), and within appliances (AC/ DC).
- An essential condition for the realization of the potential loss reduction benefits of DC lie in improved house layout.

- The total power losses in the AC house would exceed the total power losses in the DC concept house, so that introduction of DC-based distribution would mean a reduction of the total losses of electricity conversion and transport [5].

A literature review was carried out to analyze and determine the objectives, methodology, and result obtained in a different study made so far in related issue compared to each other and compared to what this study perform. Listed below are the main papers that have been reviewed on the feasibility of using DC supply for the home appliances. In addition, the following literatures with the different aspects of DC supply system have been reviewed:

- On the Feasibility of DC Home Appliance in DC Power Supply System Using Power Simulator [8].
- Robust Safety Circuits for DC Powered Home Appliance in Transient State [10].
- Comparative analysis and safety standards Guideline of AC and DC Supplied Home Appliance [11].
- Benefits of Direct Current Electricity Supply for Domestic Application [7].

The first literature is trying to analyze and determine the safety issues and technical elements for DC home appliance. And for the feasibility study, the power simulator of DC home appliance of the general specifications is designed. In order to do both concentrated experiments of the functional unit and comprehensive experiments of appliance unit, each individual board is separately designed in units of function. Especially, DC appliance safety circuit board is designed for solving various safety problems including input polarity correction circuit which can automatically correct the polarity at the moment of plug-in. And heavy load control board suitable for DC home appliance is newly designed to use MOSFET which has excellent DC breaking ability to enhance the safety [8].

The second literature is trying to analyze and determine problems triggered by the DC transient state of DC home appliances are classified in detail, through a comparative analysis between AC and DC home appliances. Multi-circuit countermeasures are also analyzed and experimentally verified using a standard test bed (5kW DC power supply system and 2.5kW DC home appliances). From these comprehensive evaluations, the most suitable techniques for solving the transient state problems inherent to DC home appliances are proposed [10].

The third literature is trying to analyze and determine safety standards setup as developing suitable appliances for DC distributed system. Virtual DC appliance model and existing AC appliance are analyzed comparatively and international safety standards of Ac appliances ‘‘Safety of Household and similar Electrical Appliances’’ are analyzed as a reference material. Through a series of the process, a theoretical guideline for DC appliance safety standards setup is proposed [11].

The fourth literature is trying to assess and determine whether DC voltage could be used in the home avoiding any constraints imposed by how electricity is used today. A novel bottom-up approach is proposed starting with real DC loads that are found on the open market. These DC loads are apportioned to different zones, power sockets, and cable spurs to determine the DC voltage peak power that directly correlates with real DC loads. Even given the constraints of voltage drops along the cables, this approach allows for the use of 4mm2 cables in the design and enables micromanagement of the loads [7].

As part of their process, the literature analyze safety standards for implementing DC supply for home appliances, development of experimental test bed was used by ‘‘Robust Safety Circuits for DC Powered Home Appliance in Transient State’’ and ‘‘Comparative analysis and safety standards Guideline of AC and DC Supplied Home Appliance’’. A straightforward mathematical analysis was used by ‘‘Benefits of Direct Current Electricity Supply for Domestic Application’’ study.

2.3.1 Conclusion

The main papers reviewed are all looking into how DC can be used in the home by implementing the safety and reliability standards; each one has their own perspective, with their slightly different objectives. However, they all correspond in trying to see the safety and reliability issue of DC supply system for home compared to the conventional AC electrical system and how could DC house be practical and how it could be implemented.

The objective of this research was not to determine how safety and reliability of DC supply for home appliance could apply when the power supply system in home changed from AC to DC. Rather it was to verify the feasibility of DC power supply for a residential home with the aim of achieving significant efficiency gain in energy consumption in comparison with AC supply. Then afterward to assess what advantages DC could offer over AC.

This research employs both straightforward mathematical analysis and use of MATLAB simulation software as part of the process to implement the DC home appliance.

CHAPTERS 3
DATA COLLECTION AND ANALYSIS

In this part, an attempt is made on selecting the optimum DC voltage value for DC home system and analyses of the associated voltage drop in the conductors, the losses incurring and converters efficiency. The appropriate conductor length has also been calculated for different voltage value. The electrical integrity of the design is evaluated and values for yearly power usage are worked out.

3.1 AC Power Supply System

Figure 3.1 shows a scheme of 220 volt AC system including distributed generation sources. The DC power sources such as a solar cell can be connected with the AC distribution system of a house. For a solar cell, a DC/AC converter is required in this power system. To utilize the DC power sources from solar cell involves three stages of energy conversion (DC/AC, AC/DC and DC/DC) there are some losses in this conversion. These losses could be minimized by introducing a DC grid.

A typical AC/DC converter consists of four stages transformer, rectifier, filter, and voltage regulator. Strictly speaking, all that is required for conversion from AC to DC but if voltage transformation is not required the transformer can be eliminated. For this particular study, **only rectification loss will be considered** for the AC and DC supply system comparison.

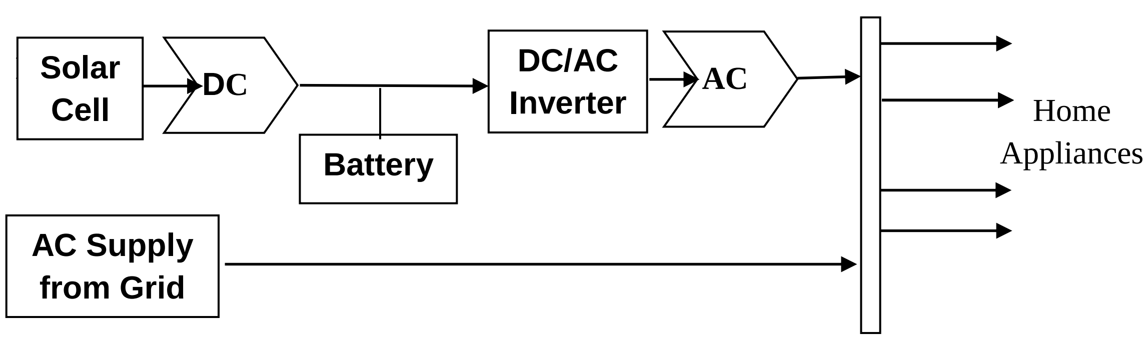

Figure 3.1: 220 volt AC Power Supply System

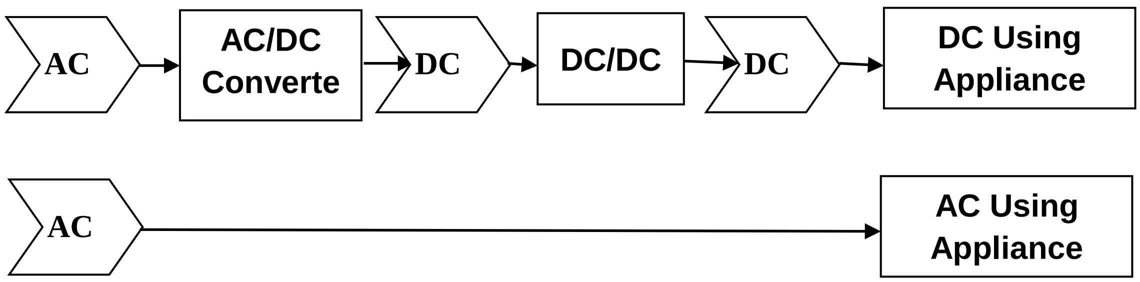

Figure 3.2: Appliance Power Supply System from AC Plug

Power losses and voltage drops across the cable for 220 V AC system

The losses and voltage drop over the feeder cable can be calculated for the selected appliance by considering the cable resistance (R) with the supply voltage (V) and circuit current (I).To simplify the mathematical step **inductive effects are neglected** for this specific study both in voltage drops and power loss calculation of the feeder cable.

The current in the appliances circuit is

$$I = \frac{P}{V} \tag{3.1}$$

The losses on the feeder cable are

$$P_{loss} = R * I^2 \tag{3.2}$$

And the DC resistance of the Cable is

$$R = \frac{\rho l}{A} \tag{3.3}$$

(ρ= resistive of the conductor, l = length of the cable and A = cross-sectional area of the conductor). The resistive value for a copper conductor is equal to $1.7X10^{-8}$ Ω/m.

The cross-sectional area of the conductor used for the above-stated appliances will be 1.5 mm^2, 2.5 mm^2 and 4mm^2. From equation 3.3 the DC resistance of 1.5 mm^2 is 0.0113 Ω/m, for the 2.5 mm^2 is 0.0068 Ω/m and for 4mm^2 is 0.0042Ω/m.

Table 3.1: Conductor Resistance

Cross-sectional area of the conductor	Resistivity of the conductor	Resistance of the conductor per meter
1.5 mm^2	$1.7X10^{-8}$Ω/m	0.0113 Ω/m
2.5 mm^2	$1.7X10^{-8}$Ω/m	0.0068 Ω/m
4 mm^2	$1.7X10^{-8}$Ω/m	0.0042 Ω/m
6mm^2	$1.7X10^{-8}$Ω/m	0.0028 Ω/m

The voltage drop across the feeder cable is

$$V_{drop} = I * R \qquad (3.4)$$

Energy Loss for the 220V AC system

To identify the typical load for home on this particular study first let us list the type of appliance selected for the study and their power rating: Refrigerator (240W), Stove (1000W), Food Processor (150W), 32'' LED television (64W), Radio (12W), Mobile Charger (6W) and LED lights (5W). Then from the two bedroom sample house let us see the number of appliance that would be available: Refrigerator = 1, stove = 1, Food Processor = 1, 32'' LED television = 1, Radio = 1, Mobile Charger = 2 and LED lights = 9. The total installed load of the household by considering only the selected appliance would be the sum of the individual appliance power rating multiplied by the number of appliances available.

Total Installed Load = (1* refrigerator power rating + 1* stove power rating + 1* food processor + 1* 32'' LED television power rating + 1* Radio power rating + 2 * mobile charger power rating + 9 * LED light power rating)

= (1 * 240 + 1 * 1000 + 1 * 150 + 1 * 64 + 1 * 12 + 2 * 6 + 9 * 5)

= **1.523 KW**

The total installed power value is usually used when sizing up the solar power generator.

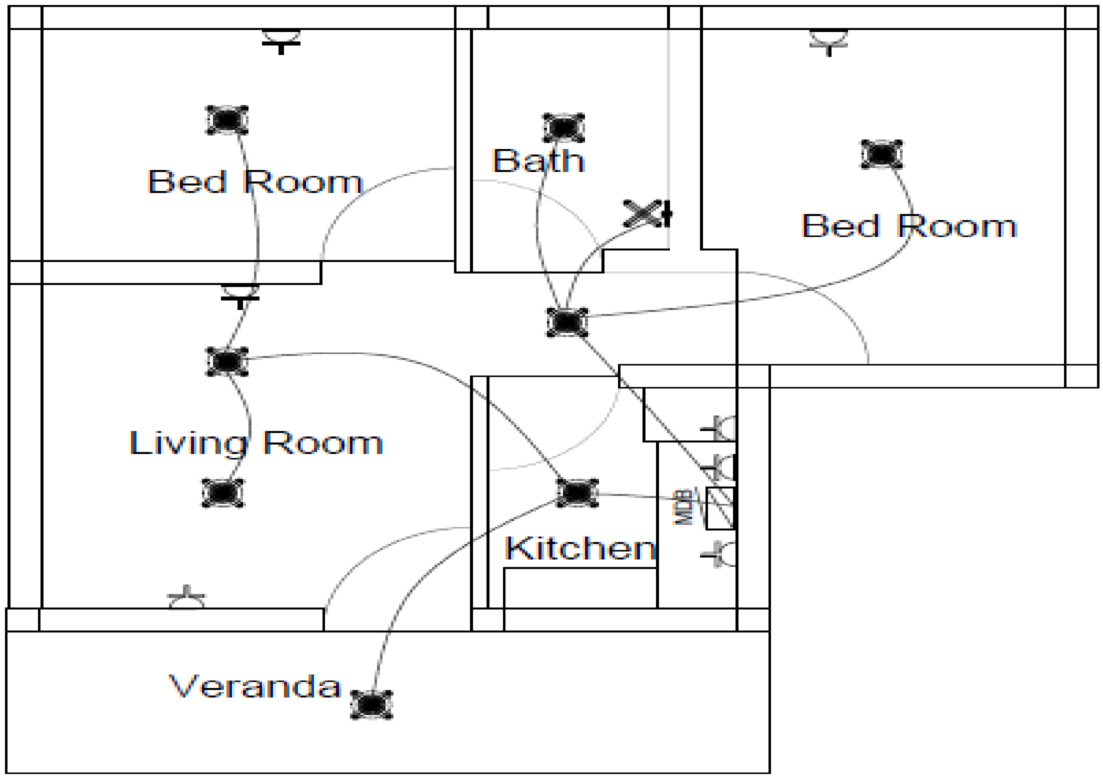

Figure 3.3: Schematic of the house

Let us make the following assumptions for the calculation of energy loss within the sample house. The length of the feeder wire including phase and neutral is 24 m for the lighting, TV, Radio and mobile charger and 10m for Refrigerator, Stove and Food Processor taking in too account the area of two bedroom condominium house and the location of the appliance within the house the main distribution or power source is near to refrigerator, stove and food processor.

Every household, even if they have the same size of the house, the same number of family and having the same type and number of appliances; one family may use more energy than the other. The main objective of analyzing this information is to identify the maximum power demand required by the sample house. What is now needed is how long each appliance is used each day. To perform detailed analysis by physically measuring people's homes on a daily basis and deriving a statistical average from all measurements would be beyond the scope of this study. Therefore the study made the following assumption for the appliance on time per day.

Table 3.2: Power rating of appliance, feeder wire length and on time per day

Appliance	Number of Appliance	Power (W)	Current at 220V (A)	Wire Length (m)	On time per day (h)
Refrigerator	1	240	1.09	10	12 hr
Stove	1	1000	4.54	10	2 hr
Food Processor	1	150	0.681	10	0.15 hr
32’’ LED television	1	64	0.29	24	6 hr
Radio	1	12	0.054	24	2 hr
Mobile Charger	2	6	0.027	24	1 hr
LED Light	9	5	0.022	24	8 hr

Appliances using DC voltage for operation are connected directly to the DC supply without any converting stage. If the appliance is supplied with DC the losses in the AC/DC rectifier and this can be eliminated.

In case of the AC system, there will be rectification losses in the system but if the main power supply is DC, then there is no rectification losses except when a different value of DC Voltage is required than the supplied value.

Rectifier power loss

Conduction loss in the full-bridge diode rectifier P_r can be calculated as a function of the equivalent diode conduction parameters V_{ON}, R_{ON}, and the current through the devices. The forward voltage drop of a diode is different from the different types of diode 0.8V forward voltage (V_F) is considered on this calculation.

$$P_r = 2 * V_{on} * I \quad (3.5)$$

Rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} \quad (3.6)$$

$$P_{loss} = P_{ac} - P_{dc} \tag{3.7}$$

Table 3.3: Power loss & Voltage Drop on the feeder cable and Rectification loss and rectification efficiency on 220V AC supply system

Appliance	**Power (W)**	**Current (A) on 220V**	**Cross-sectional Area (mm2)**	**Wire Resistance (Ω)**	**Power loss on the wire (W)**	**Voltage Drop on the wire %**	**Rectifier Power Loss (W)**	**Rectification Efficiency (%)**
Refrigerator	240	1.09	2.5	0.068	0.08	0.074	15.98	93.34
Stove	1000	4.54	4	0.042	0.865	0.19	--	--
Food Processor	150	0.681	2.5	0.068	0.031	0.046	9.98	93.34
32’’ LED television	64	0.29	2.5	0.163	0.014	0.047	5.23	91.82
Radio	12	0.054	2.5	0.163	0.0005	0.008	1.58	86.83
Mobile Charger	6	0.027	2.5	0.326	0.00024	0.008	1.9	68.3
LED Light	5	0.022	1.5	2.44	0.0106	0.053	0.315	93.7

For calculating the rectifier power loss the current is multiplied by a transformer ratio because the current flowing through the bridge rectifier is the secondary side current. Beside the rectification loss on each appliance that operates on DC internally, there are also other losses on the main AC supply system. If we assume this sample house is powered by solar power source, in order to supply the home with a 220V AC supply need to be inverted into AC as shown in Figure 3.1.

The following energy consumption analysis is made on the selected seven appliances. In addition, the **energy consumption analysis will not include standby power usage** of the appliances.

The energy consumption of the selected appliance for sample house in a year can be obtained by summing up the energy consumption of the selected appliances.

The amount of energy loss in a year due to loss on the wire is: Energy loss due to loss on the wire in a year is equal to the Power loss of the appliance due to loss on the wire (W) multiplied by appliance on time per day (h) times 365 days.

The amount of energy loss in year due to rectification is: Energy loss due to rectification in a year is equal to Power loss of the appliance due to rectification on the wire (W) multiplied by appliance on time per day (h) times 365 days.

Table 3.4: Energy loss on the wire and rectification loss per year

Appliance	Energy loss on the wire (kwh/year)	Rectification Loss (kwh/year)	Loss of energy in year (kwh/year)
Refrigerator	0.35	69.99	70.34
Stove	0.631	0	0.631
Food Processor	0.001	0.546	0.547
32’’ LED television	0.03	11.453	11.483
Radio	0	1.153	1.153
Mobile Charger	0	1.387	1.387
LED Light	0.031	0.919	0.95
Total	**1.043**	**85.448**	**86.491**

For the AC system, the total losses can be divided into three types, the losses due to the inverter in the solar power generator, losses due to resistive losses in the feeder and losses due to the rectification. From the calculation of losses for the appliances listed above, it is observed that the total resistive losses are 1.043kWh per year and rectification losses for all appliances are 86.491kWh per year. The rectification loss is higher than the resistive loss and it is 98.79% of the total losses.

3.2 DC power supply system

Many household appliances operate internally on DC voltage where an alternating voltage of 220V is step down and rectified to a low DC voltage. The scheme of proposed

DC system presents in Figure 3.3. The solar cell is connected to the DC bus when we compared to AC system, the DC energy sources have eliminated one DC/AC conversion stage. The energy storage system can be connected directly with the DC bus without any converter. To connect the DC distribution system with the existing AC system an additional AC/DC converter is required which is a drawback. As mentioned before, many household appliances operate internally on DC and when supplied with AC voltage AC is transformed to a low voltage DC. In this work, it is assumed that these loads can be connected directly to the DC supply without any conversion. In reality may be a DC/DC converter can be needed to adapt the voltage level.

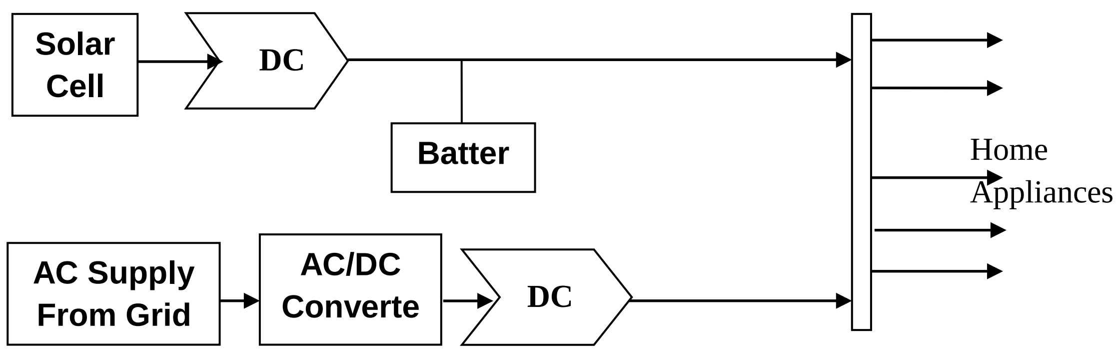

Figure 3.4: Home DC Power Supply System

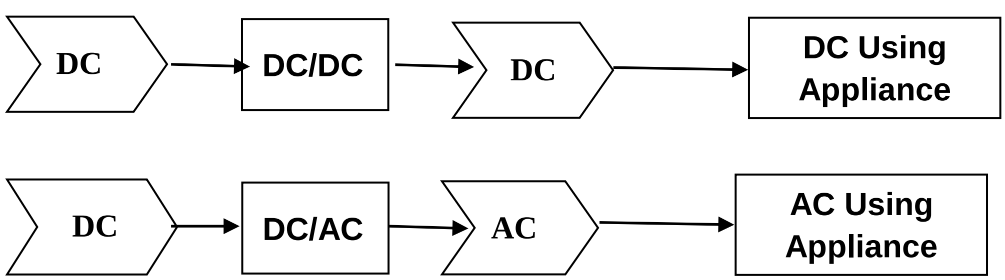

Figure 3.5: Appliance Power Supply System from DC plug

Power Loss calculations for the DC distribution system

The losses and voltage drop over the feeder cable can be calculated for the selected appliance by considering the cable resistance (R) with the supply voltage (V) and circuit current (I).

The current in the appliances circuit is

$$I_{dc} = \frac{P}{V_{dc}} \tag{3.8}$$

The losses on the feeder cable are

$$P_{loss} = R * I_{dc}^{2} \tag{3.9}$$

The voltage drop across the feeder cable is

$$V_{drop} = I_{dc} * R \tag{3.10}$$

3.3 Analysis of the best DC voltage value

The optimal DC voltage value for home power distribution system is analyzed by different study but they have not reached on an agreed value. Some prefer to use low voltage DC values as this has been a long-standing voltage that already has many applications and would like this to be the Standard for use and the other prefer to use high voltage DC for their applications and see the low voltage DC as having disadvantages.

The selected appliances for the study have a DC voltage rating of 24V and less except the stove. Thanks to power electronics technology stepping up and down of DC voltage is possible through buck-boost converters. Since the study try to study DC supply for home appliances it better to consider safety issues when selecting DC voltage values. For safe use of DC voltage without specific insulating precautions, the voltage must not exceed 50 V [19]. Therefore choosing a low DC voltage value would be preferable for many reasons.

Based on the above stated reason, the study takes three different DC voltage values (12V, 24V and 48V) to calculate the power loss and voltage drop calculation and to compare the result among the different voltage value and choose the best DC voltage value for this particular study.

There is always a trade-off between the maximum length of cable, and the amount of current that can be drawn through that cable, therefore there is no optimum voltage for the DC house so far.

When designing a DC house what we need is a simple way of finding out how the different design parameters will affect the overall design. However with at least 4 parameters, manual calculations can be very time consuming. One of the easiest ways of presenting a complex system with multiple variables is graphical representation.

To get a quick perspective of the different cable gauges and lengths of the cable, voltages and currents that make up the system parameters, a set of graphical tools are developed for two different power rating of the appliances for the food processor and stove.

Let us see a graphical representation of two power ratings 150W and 1000W for different voltage values to illustrate the maximum length of the feeder cable. Using Equation 3.12:

Table 3.5: Maximum Length of cable for 150W for 12V, 24V, 48V and 60V DC

Voltage (V)	**Max. Length of cable (m)**				
	1.5 mm^2	**2.5 mm^2**	**4 mm^2**	**6 mm^2**	**10 mm^2**
12	1.65	2.67	4.36	6.57	10.9
24	6.62	10.67	17.45	26.3	43.63
48	26.4	42.67	69.81	105.2	174.54
60	41.3	66.67	109.09	164.38	272.72

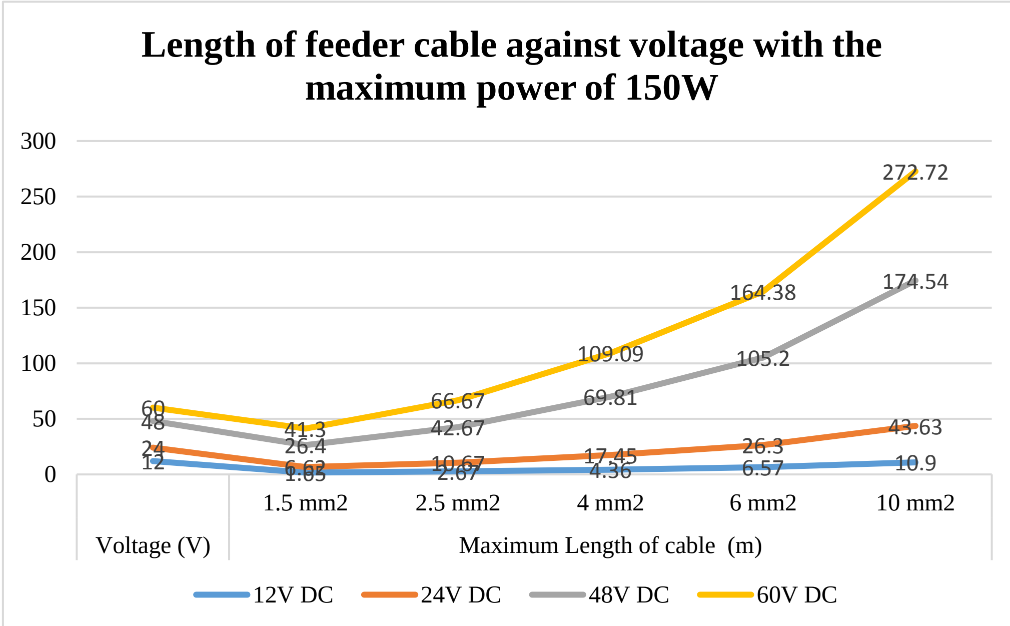

Figure 3.6: Length of feeder cable against voltage with the maximum power of 150W

Table 3.6: Maximum Length of cable for 1000W for 12V, 24V, 48V and 60V DC

Voltage (V)	Max. Length of cable (m)				
	1.5 mm^2	2.5 mm^2	4 mm^2	6 mm^2	10 mm^2
12	0.25	0.40	0.65	0.99	1.64
24	0.99	1.60	2.62	3.94	6.54
48	3.97	6.40	10.47	15.78	26.19
60	6.21	10.00	16.36	24.65	40.9

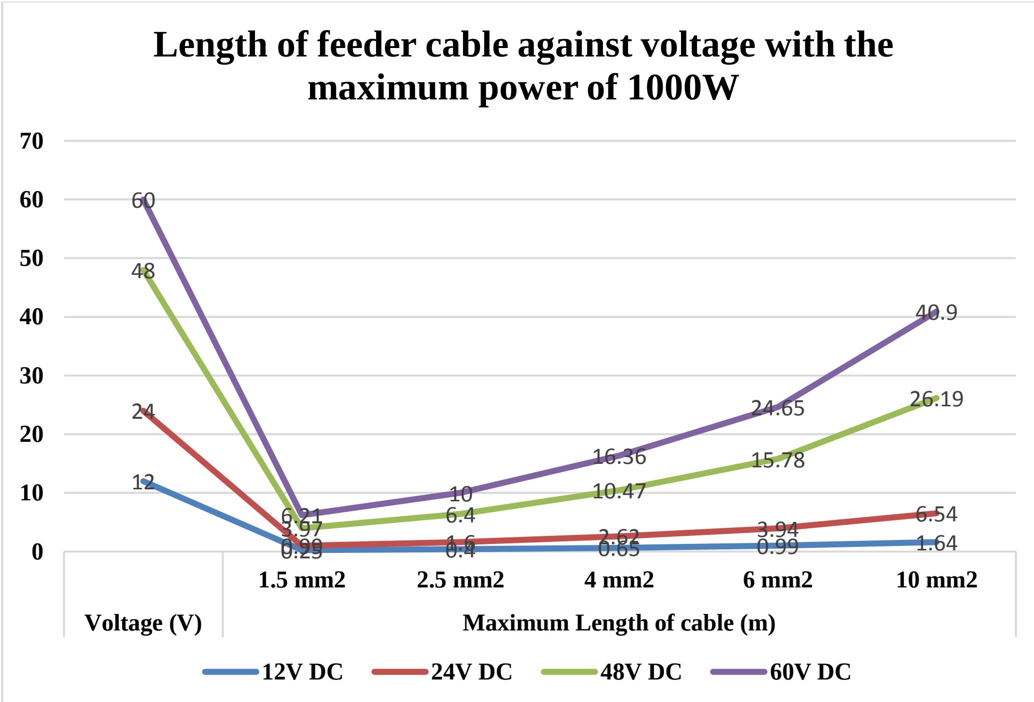

Figure 3.7: Length of feeder cable against voltage with the maximum power of 1000W

Table 3.7: Power loss and Voltage drop on the feeder cable for 48V DC

Appliance	Power (W)	Current (A) on 48V DC	Wire Cross-sectional Area (mm2)	Wire Resistance (Ω)	Power loss on the wire (W)	Voltage Drop %
Refrigerator	240	5	2.5	0.068	1.7	0.34
Stove	1000	20.83	4	0.042	18.22	0.875
Food Processor	150	3.125	2.5	0.068	0.664	0.212
32’’ LED television	64	1.33	2.5	0.163	0.288	0.216
Radio	12	0.25	2.5	0.163	0.010	0.040
Mobile Charger	6	0.125	2.5	0.326	0.005	0.040
LED Light	5	0.104	1.5	2.44	0.237	0.253

Table 3.8: Power loss and Voltage drop on the feeder cable for 24V DC

Appliance	Power (W)	Current (A) on 24V DC	Wire Cross-sectional Area (mm2)	Wire Resistance (Ω)	Power loss on the wire (W)	Voltage Drop %
Refrigerator	240	10	2.5	0.068	6.8	0.68
Stove	1000	41.67	4	0.042	72.92	1.75
Food Processor	150	6.25	2.5	0.068	2.65	0.425
32’’ LED television	64	2.67	2.5	0.163	1.16	0.435
Radio	12	0.5	2.5	0.163	0.04	0.081
Mobile Charger	6	0.25	2.5	0.326	0.02	0.081
LED Light	5	0.208	1.5	2.44	0.95	0.507

Table 3.9: Power loss and Voltage drop on the feeder cable for 12V DC

Appliance	Power (W)	Current (A) on 12V DC	Wire Cross-sectional Area (mm2)	Wire Resistance (Ω)	Power loss on the wire (W)	Voltage Drop %
Refrigerator	240	20	2.5	0.068	27.2	1.36
Stove	1000	83.33	4	0.042	291.67	3.5
Food Processor	150	12.5	2.5	0.068	10.625	0.85
32’’ LED television	64	5.33	2.5	0.163	4.63	0.868
Radio	12	1	2.5	0.163	0.163	0.163
Mobile Charger	6	0.5	2.5	0.326	0.081	0.16
LED Light	5	0.417	1.5	2.44	3.82	1.02

Table 3.7, 3.8 and 3.9 shows that the DC voltage value has a great impact on the power loss and Voltage drop of the feeder cable. For the same length and cross sectional area of

wire and feeding the same power demand but with different DC voltage value will have different Voltage drop and power loss.

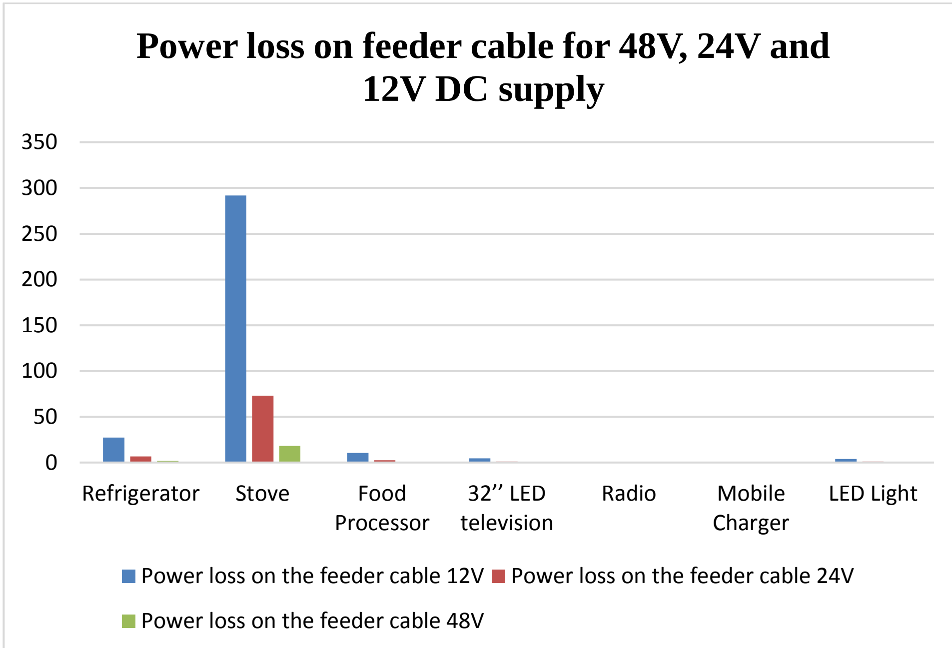

Figure 3.8: Power loss on feeder cable for 48V, 24V and 12V DC supply

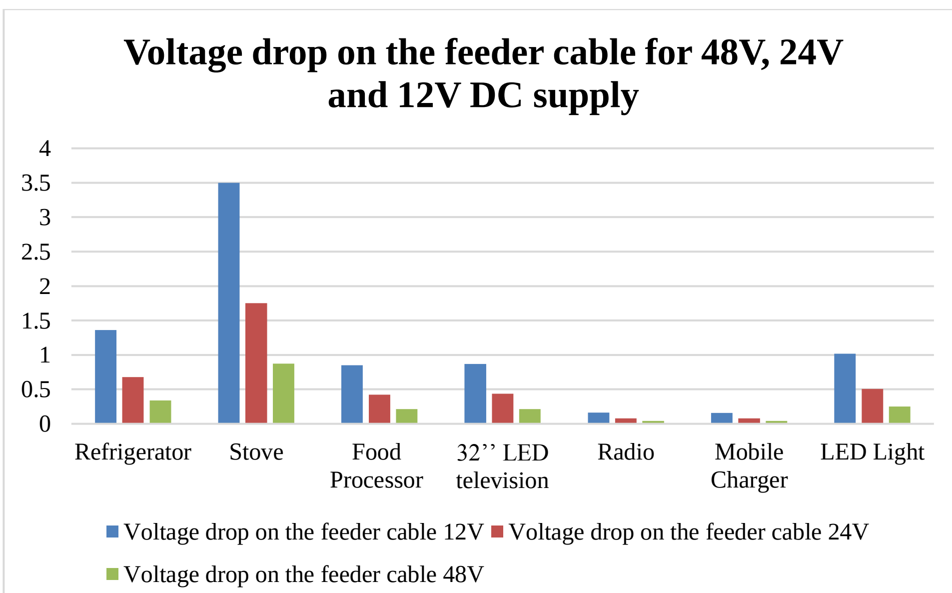

Figure 3.9: Voltage drop on feeder cable for 48V, 24V and 12V DC supply

Voltage Drop

The size and the length of the conductors shall be such that the voltage drop between the supply terminal and the load shall not exceed 4% of the nominal voltage of the supply line when the conductors are carrying the full load current according to Ethiopian building code standards 10 Edition Chapter 4 Section 4.5.4.

Let us take 5% for this study, because this is a commonly used value. Therefore the permissible voltage drop across the feeder cable for different supply voltage value will be

V_{drop}= 0.6V for 12V supply;

V_{drop}= 1.2V for 24V supply; and

V_{drop}= 2.4V for 48V supply

From Table 3.7, 3.8 and 3.9, one can see the voltage drop across the feeder cable exceed the 5% limit partially for 12V and 24V DC supply system. For a low DC voltage value, the power loss and voltage drop value is very high. To mitigate these problem two options can be taken in to account the first is use of large cross sectional area cables with increased costs or the second is use of lower power more expensive appliances.

For AC supply system, voltage drop across the feeder cable for home is not significant but for DC supply system if one chooses a low voltage DC value the voltage drop across the feeder cable become an issue. Therefore in order to alleviate this problem calculating the maximum cable length for a given cross sectional area of the wire and the power rating of the appliance is important.

$$V_{drop} = V_{tab} * I * L \quad (3.11)$$

Where

V_{drop} Total voltage drop across the given length of cable

V_{tab} Tabulated voltage drop in mV/A/m

I Current in Ampere

L Length of the cable in meter

To calculate the maximum length of the cable in which the voltage drop would be within the pre-defined limit (which is 5% drop) one can drive a formula from equation (3.11).

$$L_{\max} = \frac{V_{drop}}{V_{tab} * I} \qquad (3.12)$$

Tabulated voltage drop per ampere per meter V_{tab} (mV/A/m) for the five different type of cable cross-sectional area : V_{tab} = 29mV/A/m for 1.5mm^2,V_{tab} = 18mV/A/m for 2.5mm^2,V_{tab} = 11mV/A/m for 4mm^2, V_{tab} = 7.3mV/A/m for 6mm^2, V_{tab} = 4.4mV/A/m for 10mm^2 and taken from Ethiopian Building Code Standard Electrical Installation of Buildings 10 Edition Section 4 Annex B Table B.2 assuming that the conductors are at their maximum permitted normal operating temperature that is 70 ^{o}C [13].

Where a more accurate assessment of voltage drop is desirable, the following methods can be used.

Correction for operating temperature shall be carried as follows. For cables having conductors of cross-sectional area 16mm^2 or less, the design value of mV/A/m is obtained by multiplying the tabulated value by a factor C_t, given by

$$C_t = \frac{230 + t_p - \left(C_a^2 C_g^2 - \frac{I_b^2}{I_t^2} \right)(t_p - 30)}{230 + t_p} \qquad (3.13)$$

Where

t_p is the maximum permitted nominal operating temperature, ^{o}C.

I_t is the tabulated current-carrying capacity

C_a is the correction factor for ambient temperature

C_g is the correction factor for grouping

The above equation applies only where the over current protective device is other than a fuse and where the actual ambient temperature is equal to or greater than 30^{o}C [13].

Table 3.7 shows among the three voltage value 48V is more suitable for the selected appliance in terms of required cable length, power loss, and voltage drop on the feeder cable are much less than with other voltage values and the current carrying capability of the cables are also within a permissible range.

A DC voltage value of 48V even is more suitable if the cross-sectional area of the feeder cable changed to their next level. By changing the cross-sectional area from 2.5mm^2 to 4mm^2 and 4mm^2 to 6mm^2, the resistive power loss will reduce from 21.12W to 14.28W for the stove with the same voltage value. Even if the change in conductor size increases the installation cost, the running cost will significantly reduce by 32.35%.

Table 3.10: Power loss and Voltage drop on the feeder cable for 48V DC after a change in cross-sectional area of the feeder cable

Appliance	Power (W)	Current (A) on 48V DC	Wire Cross-sectional Area (mm2)	Wire Resistance (Ω)	Power loss on the wire (W)	Voltage Drop %
Refrigerator	240	5	4	0.042	1.05	0.21
Stove	1000	20.83	6	0.028	12.15	0.58
Food Processor	150	3.125	4	0.042	0.410	0.131
32’’ LED television	64	1.33	4	0.1008	0.178	0.134
Radio	12	0.25	4	0.1008	0.0063	0.0252
Mobile Charger	6	0.125	4	0.2016	0.0031	0.0125
LED Light	5	0.104	1.5	2.44	0.237	0.253

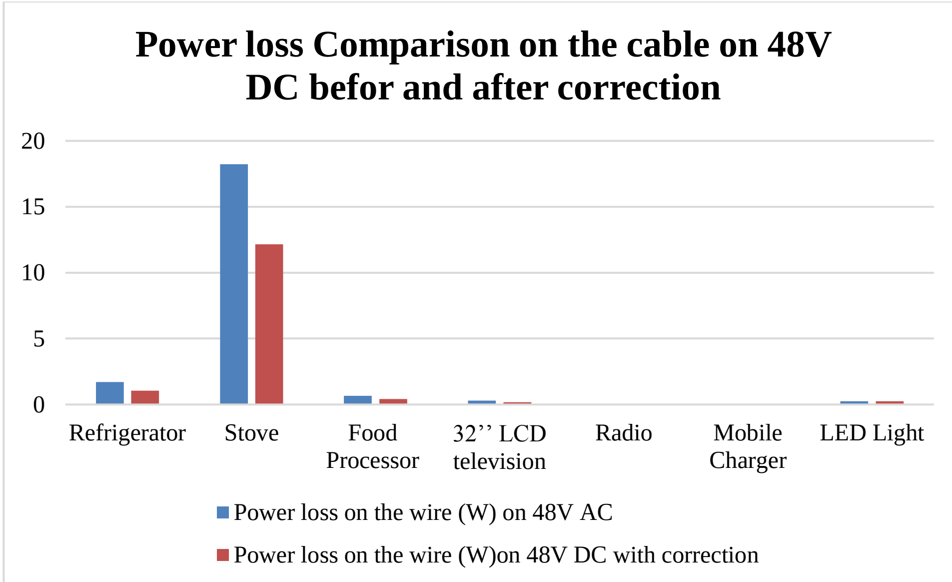

Figure 3.10: Power Loss Comparison on the cable on 48V DC before and after correction

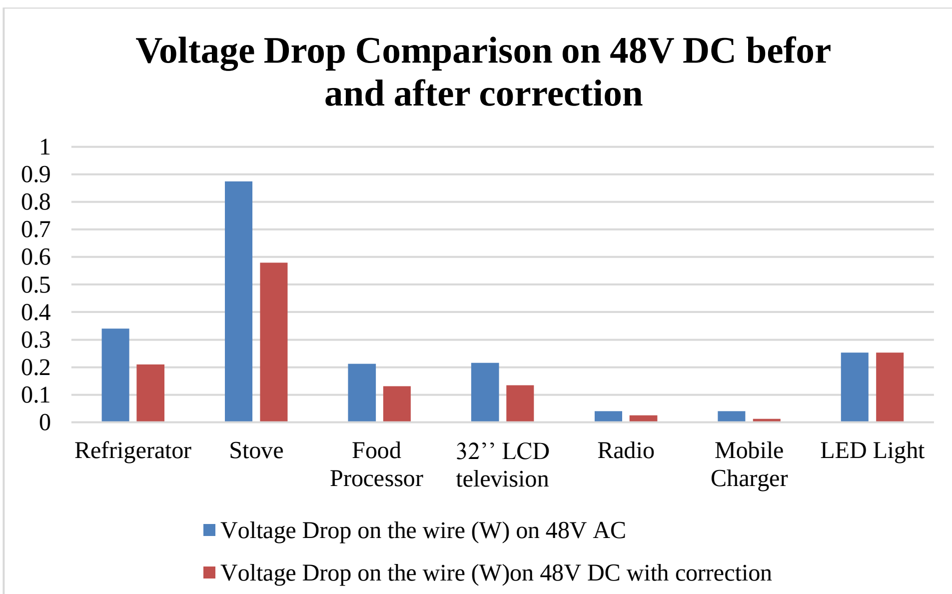

Figure 3.11: Voltage drop Comparison of the cable on 48V DC before and after correction

For this particular study, 48V DC supply is suitable for the provision of DC supply for the appliances under study, as per the results presented in Table 3.10and 3.11.The Table shows modified 48V DC voltage is more suitable than the other voltage value due to less power loss on the feeder cable (Table 3.10), voltage drop across the cable is within the permissible value (5%) (Table 3.10) and the required length of cable for the appliances can only be obtained on the modified 48V value (Table 3.5 and 3.6). Therefore for these reasons the choice of 48V DC voltage value for the selected home distribution is optimum.

This conclusion gives only a single scenario picture. However as the power rating of the appliance and the physical electrical layout of the house changes it is only required to understand how each change will going to affect the overall system in terms of DC voltage value, maximum cable length, cross-sectional area of the cables and gone through the same step and come up to the new requirements.

The study considers a DC/DC converter on the terminal of the appliances which converts 48V DC to a voltage level suitable for the appliances.

For those appliances which require different DC voltage value for their operation than the supplied DC voltage (48V) a step down (buck) DC/DC converter will be included. The DC/DC converter eliminates the necessity of providing separate DC power supplies to different appliances working in different voltage levels. Detail DC/DC converter design is discussed in chapter 4 of this chapter.

3.4 Re-engineering of the AC devices for DC supply

The power supply system designs of the selected home appliance for operation in a DC distribution system are given below. Considering the new design conditions, the power conversion scheme is changed from the one shown in Figure 3.2 to the one in Figure 3.4. In this new architecture, the rectifier is no longer needed. The power converter design is also significantly modified for the considered dc distribution system. First, the rectifier stage is no longer needed. This implies a reduction of cost as well as an improvement of the efficiency.

The next section details the design considerations when re-designing the main parts of the appliances which are the power supply system of the appliance. Since 48V DC supply system are selected for the sample home, a DC/DC converter which converts 48V DC to a suitable value of voltage for each appliance shall be considered, to do this first let us see the principle of conversion and parts in the converter.

The principle of DC/DC converter is to convert a given constant DC voltage into a variable average DC voltage across a load by placing a high-speed static switch between the DC source and the load. When the switch is closed, the DC supply voltage is applied across the load and when it is open, the load is disconnected from the supply. By varying the ratio of the switch-closed time (T_{ON}) to the switch-open time (T_{OFF}) at a fixed frequency, the value of the average output DC voltage can be controlled [14].

$$DutyCycle = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \quad (3.14)$$

$$V_o = V_{IN} * \frac{T_{ON}}{T} = V_{DC} * \frac{T_{ON}}{T_{ON} + T_{OFF}} = f * T_{ON} * V_{IN} \quad (3.15)$$

$V_o = K * V_{IN}$ (3.16)

Where

T is the chopping Period

K is the duty cycle of the chopper

f is the chopping frequency

The duty cycle K can be varied from 0 to 1 by varying switch on time, period T or switching frequency. Therefore the output voltage V_o can be varied from 0 to V_{in}, by controlling K.

The duty cycle of the DC/DC converter for 48V to 24V conversion is 0.5, for 48V to 19.5V conversion is 0.406, 48V to 12V conversion is 0.25, and for 48V to 5V conversion is 0.104.

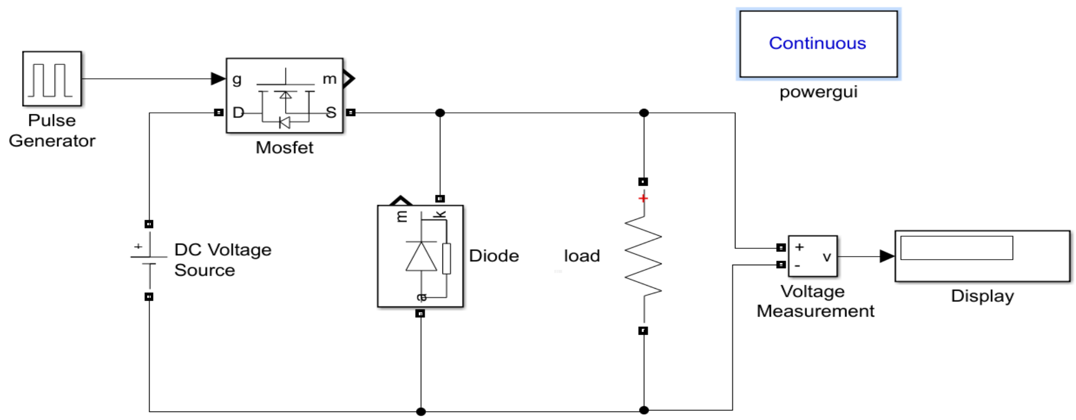

Figure 3.12: DC-DC converter Circuit without filter circuit

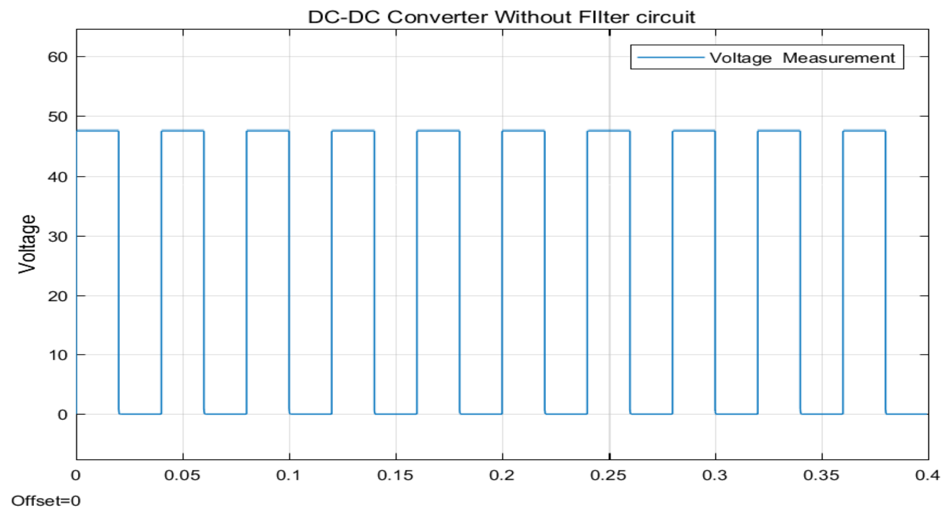

Figure 3.13: DC-DC Converter without filter circuit Output Voltage (24V)

As Figure 3.13 shows the DC/DC converter output contains harmonics and a DC filter is needed to smooth the ripple.

The filter circuit includes inductor and capacitor, selecting these important components has a major impact on performance and characteristics of the DC/DC convertor. When designing a step-down DC/DC converter, inductor selection is important.

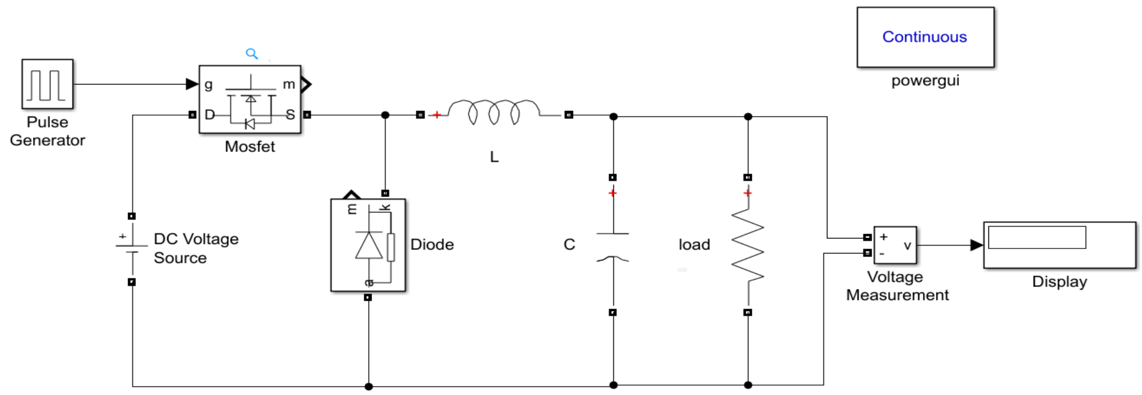

Figure 3.14: DC-DC Converter with filter circuit 48V to 12 V

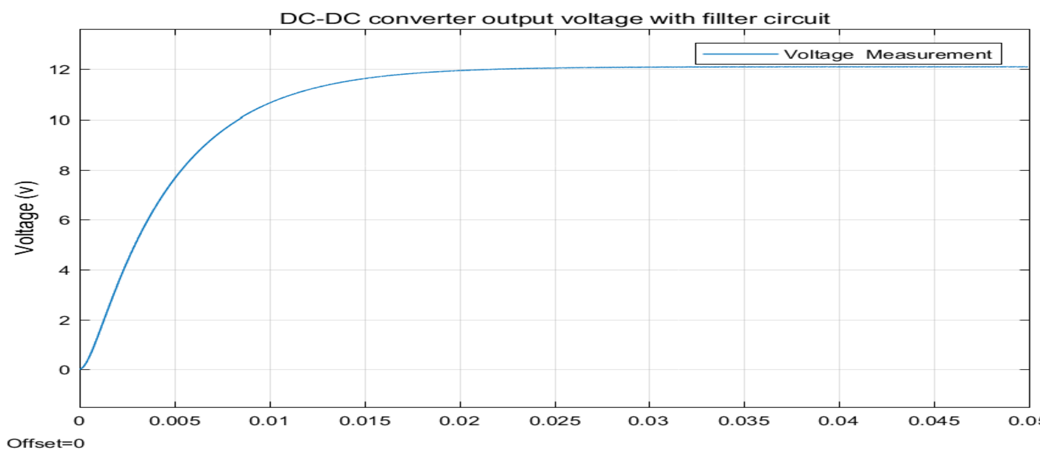

Figure 3.15: DC-DC Converter 12V Output Voltage with a filter circuit

When we re-engineer the AC device for DC supply the device internal power supply system will look like the circuit shown in Figure 3.14 above.

The simulation of the proposed power converter of the appliances for operation in a DC distribution system is performed focusing on the system efficiency, and it is compared with the conventional AC distribution system. The main power losses considered in DC/DC converter are the conduction losses and a switching loss but since the frequency is not as such high to consider the switching frequency.

$$P_{loss} = I^2 * R_{(on)} \tag{3.17}$$

Where

R - is the switch on resistance value

(MOSFET on state resistance is 0.1Ω)

And the average load current

$$I = \frac{V_o}{R} = \frac{K * V_{in}}{R} \tag{3.18}$$

To calculate the converter efficiency

$$Convertereffeciency = \frac{P_o}{P_{in}} \tag{3.19}$$

The output power of the convertor

$$P_o = \frac{K(V_{in} - V_{drop})^2}{R} \tag{3.20}$$

The input power to the converter

$$P_{in} = K * V_{in} * \frac{(V_{in} - V_{drop})}{R} \tag{3.21}$$

Converter efficiency

$$\eta = \frac{(V_{in} - V_{drop})^2}{V_{in} * (V_{in} - V_{drop})} \tag{3.22}$$

Table 3.11: DC/DC converter loss and efficiency

Appliance	Power (W)	Voltage (V)	Current (A)	DC-DC converter loss (W)	Converter efficiency (%)
Refrigerator	240	24	10	10.00	97.91
Stove	1000	48	20.83	0	-
Food Processor	150	24	6.24	3.89	98.70
32’’ LED television	64	19.5	3.28	1.07	99.31
Radio	12	12	1	0.1	99.79
Mobile Charger	6	5	1.2	0.144	99.75
LED Light	5	5	1	0.1	99.79

Table 3.12: Energy loss on the wire and conversion loss per year

Appliance	Energy loss on the wire (kwh/year)	DC-DC Converter Loss (kwh/year)	Loss of energy In year (kwh/year)
Refrigerator	4.599	43.8	48.399
Stove	8.869	0	8.869
Food Processor	0.036	0.213	0.249
32’’ LED television	0.389	2.343	2.732
Radio	0.004	0.073	0.077
Mobile Charger	0.001	0.052	0.053
LED Light	0.692	0.292	0.984
Total	**14.59**	**46.77**	**61.36**

3.5 Comparative analysis of DC versus AC supply

3.5.1 In terms of energy saving

In general term, AC/DC converters employ copper wound metal transformers and other electrical components, while modern DC/DC converters employ electronic components.

It is therefore understood that less energy will be lost in a DC/DC conversion than an AC/DC conversion. It is also obvious that AC/DC converters use up more raw materials in their manufacture than the DC/DC converters. The less you need to convert between AC and DC, the less energy will go to waste.

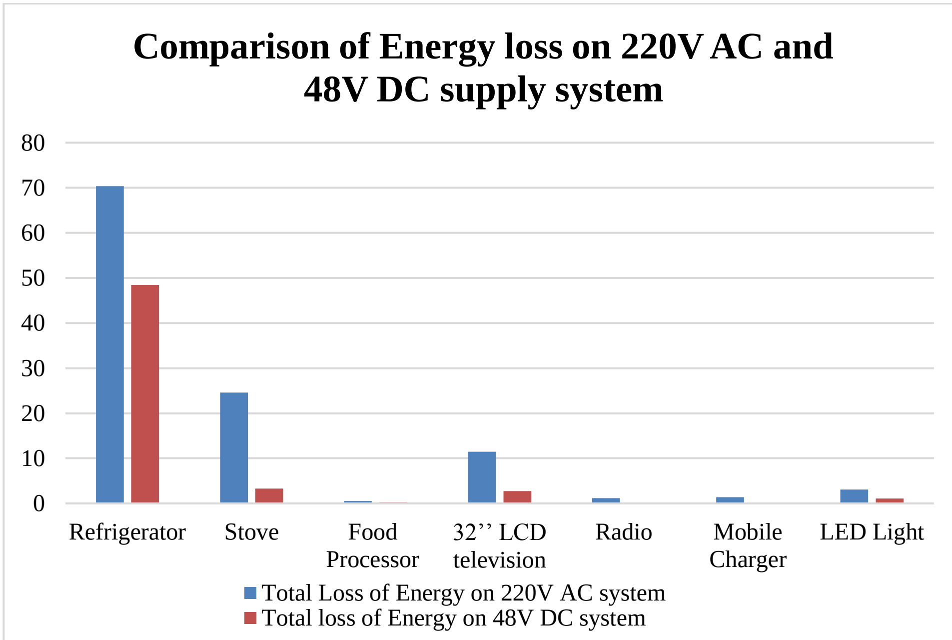

Figure 3.16: Comparison of Energy loss on 220V AC and 48V Dc supply system

Figure 3.16 shows that annually 29.05% energy saving can be obtained by changing the home power supply system into the DC supply system and excluding the AC/DC converter in between.

3.5.2 In terms of efficiency

As pointed out in the previous section, the biggest impact of losses in AC distribution networks is due to power converter losses. It's thus of primary importance to focus on the efficiency of converters to better understand whether it's possible to save energy with DC distribution and what conditions.

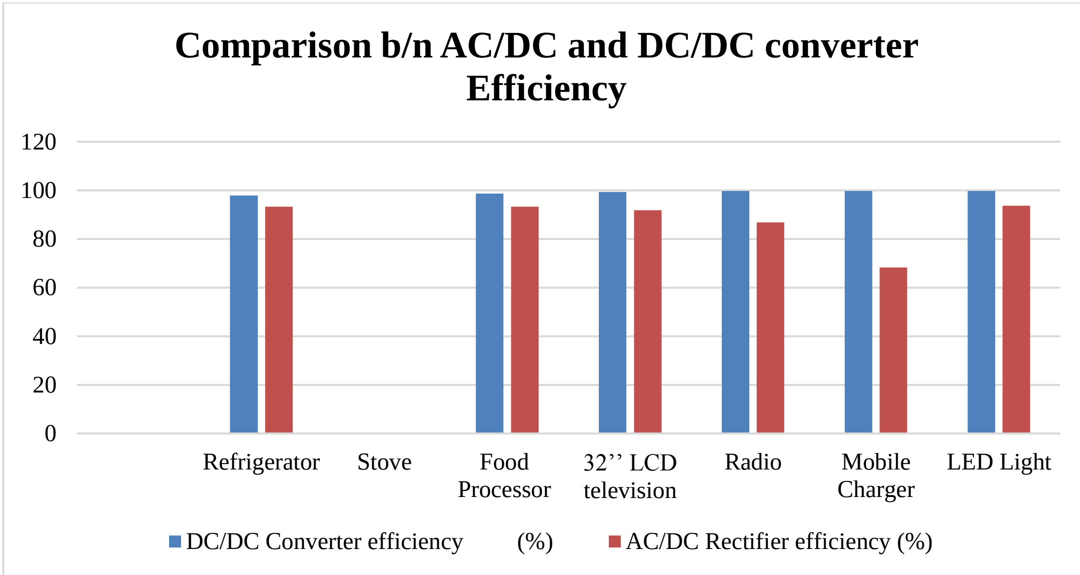

Figure 3.17: Comparison b/n AC/DC and DC/DC converter Efficiency

Figure 3.17shows that eliminating AC/DC converters from the appliances and use DC/DC converter improve the overall system efficiency in the range 0.51% – 31.45% for the various cases.

3.5.3 In terms of power loss and voltage drop:

The Power loss and voltage drop analysis for DC system shows what happens on the system for different choices of DC voltage value. Therefore 48V DC voltages values are taken in to account to make the comparison with 220V AC system.

Use of low voltage DC increase power losses and voltage drops on the feeder cables at the same conditions when we compare with a 220V AC and replacement of already installed cable may also be required but the main reason of using low voltage DC are to eliminate power loss due to power conversions in different stages which is normally higher than the power loss on the feeder cable and to get the benefit which comes along from DC system like unity power factor, better electrical safety for a low voltage DC, no protection against direct contacts is required.

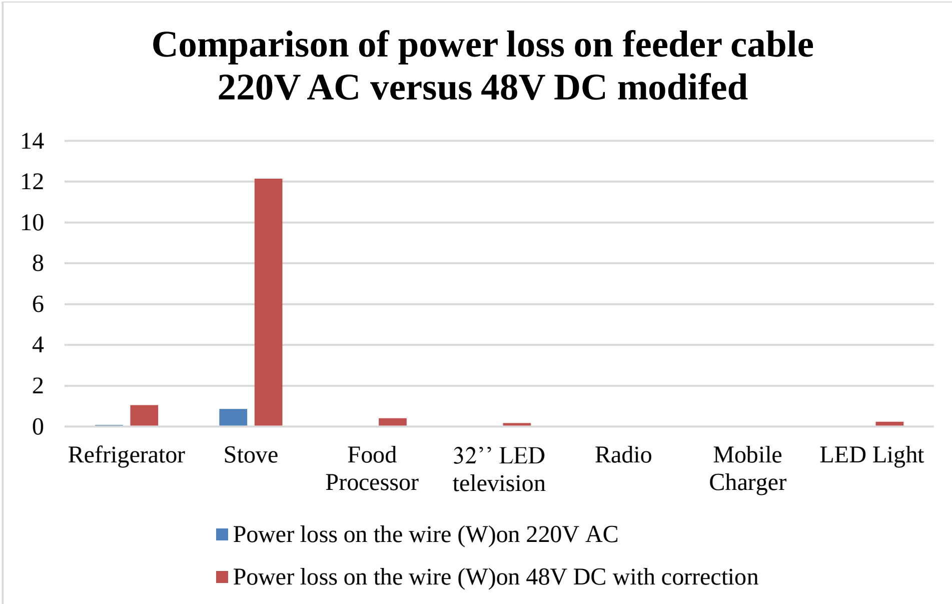

Figure 3.18: comparison of power loss on feeder cable 220V AC Versus 48V DC

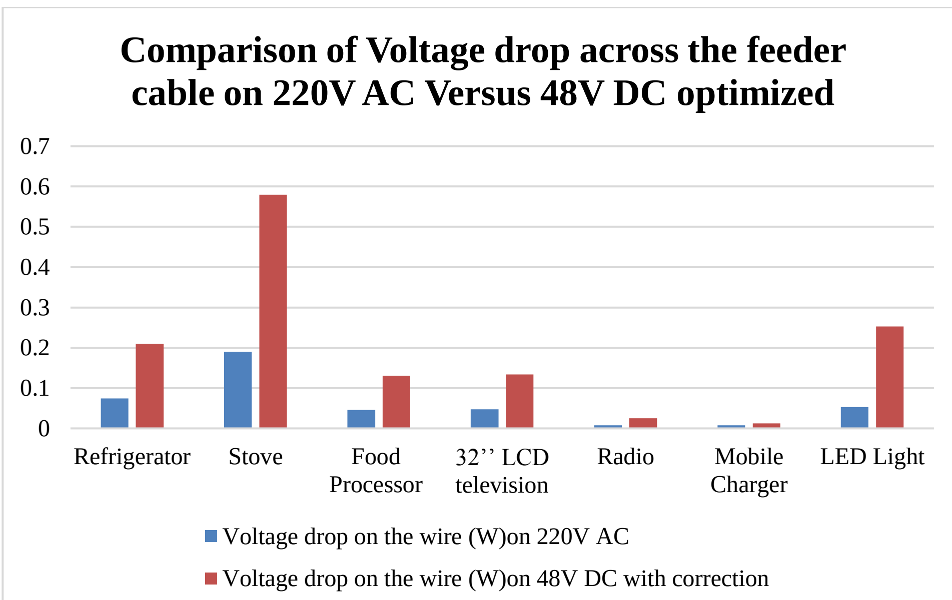

Figure 3.19: Comparison of Voltage drop on feeder cable 220V AC Versus 48V DC

Figure 3.18 and 3.19 shows that use of 48V DC supply for home distribution increase the power loss and the voltage drop on the feeder cable when we compare with conventional 220V AC system but the voltage drop is within a permissible range and the power loss also are not as such significant.

3.5.4 In terms of conversion loss

When we compare the power loss due to feeder cable power loss and a voltage drop across it with the power loss occurred in power conversion stages the conversion loss is much higher.

Power conversions exist both on feeding powers to the house and inside home appliances. As already mentioned, losses in all these energy conversions play the main role in the efficiency of the distribution system, losses occurring in cables generally negligible. So the focus will be on the efficiency of electronic power converters.

In general term, AC/DC converters employ copper wound metal transformers and other electrical components, while modern DC/DC converters employ electronic components. It is therefore understood that less energy will be lost in a DC/DC conversion than an AC/DC conversion. It is also obvious that AC/DC converters use up more raw materials in their manufacture than the DC/DC converters.

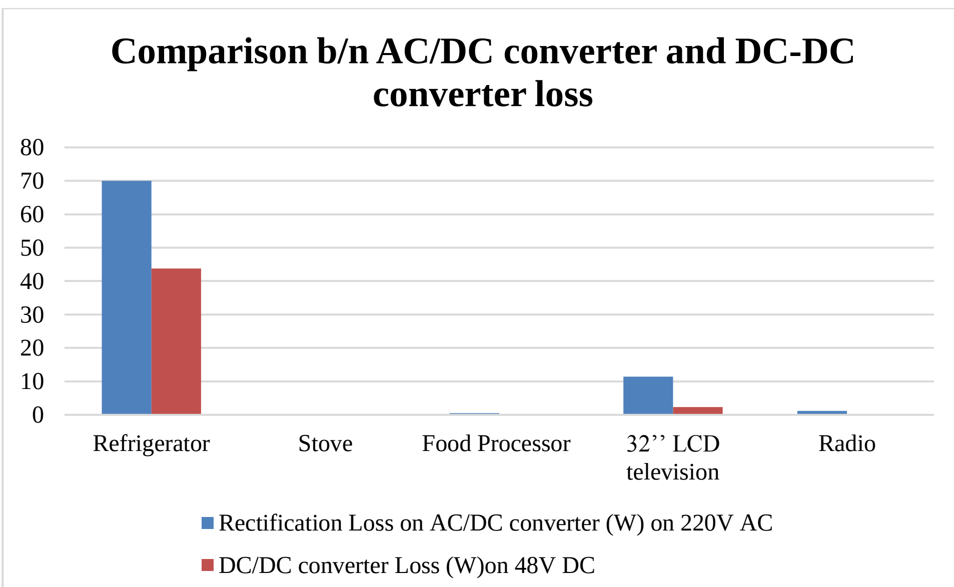

Figure 3.20: Comparison b/n AC/DC converter and DC/DC converter

Figure 3.20 shows that AC/DC converter consumes more energy than the DC/DC converter and since the stove directly uses 48V there is no conversion loss.

3.5.5 In terms of Power Quality

An important consideration in the design of both AC and DC distribution systems is that of power quality. Power quality generally refers to the voltage quality on a power system; however, the voltage signals are not independent of the current signals. The two primary impacts of power quality issues on a distribution system are the potential for equipment operation to be adversely affected by a power quality problem and the reduction in power factor caused by certain types of harmonics. “Any power problem manifested in voltage, current, or frequency deviations that result in the failure or misoperation of customer equipment”.

AC Power Quality: Harmonic voltage distortion on AC distribution systems is a continuously observed condition due to the presence of nonlinear loads. That is, harmonic distortion is not merely a momentary transient condition of a power system but continues until the nonlinear loading effect is removed or the harmonics are otherwise compensated. Nonlinear loads draw current that is not sinusoidal in response to sinusoidal voltage and typically include nonlinear loads include variable frequency drives, switching power supplies, fluorescent lighting ballasts, battery chargers, saturated transformers, and arc furnaces. Harmonic current is of concern because of the potential to cause voltage distortion through voltage drop over line impedances, increase losses in transformers, and originate resonance interactions with capacitance on the system in the form of capacitor banks or insulated cables.

In addition, the harmonics caused by non-linear loads can also reduce the true power factor substantially. The reduction of true power factor occurs even when the displacement power factor is close to unity, and the total harmonic distortion caused by a load gives a maximum achievable true power factor.

Power Quality in DC: The power quality concerns of DC distribution systems are different in many ways from those in grid-connected AC distribution systems. The alleviation of some common AC harmonic issues is sometimes even given as a motivation for pursuing DC architectures. The differences between the study of power quality in AC distribution systems and the study of power quality in a DC distribution system come both from difference between the ideally constant voltage in a DC system and the alternating sinusoidal voltage in an AC system and from the many power electronic converters that form the backbone of DC distribution system. The four fundamental DC distribution system power quality concerns identified in the literature are harmonic currents, inrush current, fault current, and grounding.

As stated above, it is often claimed that DC systems do not experience harmonic currents or voltages. At a surface level, this is true by definition, since the fundamental frequency of a DC system is 0 Hz and integral multiple frequencies of 0 Hz other than the fundamental itself do not exist. At a practical level, however, the presence of current and voltage oscillations on a DC system similar to AC harmonics make the extension of the discussion of harmonics to DC systems relevant. For this reason, as in the references cited, the term “harmonic” will be used in this section to refer to both oscillatory voltages and currents on a DC system.

While transformer-fed AC distribution systems often have power electronic converters at the point of load that create harmonic currents or voltages on the system, DC distribution systems require converters both to connect the DC bus to an AC grid and at each point of connection to the DC bus for distributed generation with AC output, some cases of energy storage, and loads. Also, even energy storage or distributed generation that requires DC may use a bidirectional DC/DC converter to connect to the DC bus to allow independent control of the resource voltage and the bus voltage. The supply converters determine the voltage on the system, and converters and filters should be designed to minimize voltage oscillations and harmonics. As the DC bus serves as a connection between multiple power electronic converters, current harmonics and circulating currents can arise on a DC bus from nonlinear effects of the various power electronic converters. In low voltage, DC power systems, damaging resonance currents, unacceptable EMI, or problematic voltage oscillations can result from current harmonics on the DC bus, and a detailed harmonic study needs to be a consideration in the design of DC distribution systems. In addition, even though DC systems intrinsically do not have a phase displacement power factor lower than unity, the true power factor is still reduced by harmonic distortion [16].

Table 3.13: 220V AC Supply system Comparison with 12V, 24V, 48V and 48V modified DC supply System

DC Voltage level	Compared with 220V AC
12V	• Very high power loss on the cable with the same distribution network (337.18W higher) • The voltage drop across the cable exceeds the permissible voltage drop (5%) on most appliances • Required cable length cannot be obtained due to the voltage drop for most appliances • Removing the input rectifier from the appliances • Potential improvements of the voltage quality due to the absence of harmonics
24V	• Very high power loss on the cable with the same distribution network (83.53W higher) • The voltage drop across the cable exceeds the permissible voltage drop (5%) on some appliances • Required cable length cannot be obtained due to the voltage drop for some appliances • Removing the input rectifier from the appliances • Potential improvements of the voltage quality due to the absence of harmonics
48V	• high power loss on the cable with the same distribution network (20.12W higher) • The voltage drop across the cable is within the permissible voltage drop (5%) for all the appliances • Required cable length can be obtained • Removing the input rectifier from the appliances • Potential improvements of the voltage quality due to the absence of harmonics

48V modified	• moderate power loss on the cable with the same distribution network (13.28W higher) • Voltage drop across the cable is within the permissible voltage drop (5%) for all the appliances • Required cable length can be obtained • Removing of the input rectifier from the appliances • Potential improvements of the voltage quality due to the absence of harmonics

3.6 Comparison of manufacturing DC devices against AC devices

The AC device has a power converter which converts the supply AC into a suitable DC most electronic and some electrical appliances have them in combination with the plug that means external AC power supplies. The other type the converter is incorporated into the appliance on certain parts of the casing of the appliance that means internal AC power supply. In both case, there will be a manufacturing cost for the converters and they also consume energy while they work.

AC/DC converters employ copper wound metal transformers and other electrical components, while modern DC/DC converters employ electronic components. It is therefore understood that less energy will be lost in a DC/DC conversion. It is also obvious that AC/DC converters use up more raw materials than the DC/DC converters.

Since the comparison is only made based on their manufacturing cost which is the cost of power converters present in the device will be considered the operational cost which is the power loss on the converters are not included in the comparison of DC device with AC devices.

While DC appliances are struggling to become cost competitive in today's market there are two reasons why this may change in the future. Firstly, we know that demand is the biggest barrier to reducing manufacturing costs. We have seen this barrier overcome in many other hardware markets including small electronics and solar PV modules. With the increasing move towards zero net energy buildings, there is space for buildings with substantial DC distribution buildings to become more attractive. There is the potential for the demand of DC equipment and appliances to increase with this trend.

The second driving factor is the expansion of distributed energy systems. The addition of solar PV and battery storage provides the opportunity to utilize the DC side of the system. Since the DC supply infrastructure must be included for the distributed energy system we could look at the AC system as the additional infrastructure cost, flipping the traditional system on its head in the future.

Table 3.14: Manufacturing Cost of 220V AC Devices and 48V DC Devices [20]

Appliance	Power Rating (W)	Cost of AC/DC Converters 220V AC	Cost of DC/DC converters 48V DC
Refrigerator	240	US $13.71-13.78	US $10.00
32'' LED television	64	US $2.80-5.00	US $2.90-7.90
Mobile Charger	6	US $1.00-20.00	US $1.00-10.00

Table 3.14: clearly shows that manufacturing cost of AC device is a bit expensive when compared with manufacturing DC device; the comparison is made only based on the power converter cost which the appliance use in the two systems.

CHAPTER 4

DESIGN AND SIMULATIONS

This chapter looks at the drivers behind the decision making a process for the implementation options of the DC home system. MATLAB simulation software is used for the purposes of re-engineering of AC devices for DC supply system.

4.1 MATLAB Model of the appliance with AC Supply

Even though this chapter is intended for the design and simulation of the selected home appliances power supply system for the 48V DC supply system, modeling of some appliances with the existing AC supply system will help us to understand the construction of their power supply system for the two power supply system. It is only attempted to simulate what the manufacturer provides with the schematic diagram of the appliances.

4.1.1 Mobile Charger

The mobile charger contains step down transformer, rectifier, filter and regulator circuit for converting 220V AC in to smooth 5V DC voltage. LED 1 used to indicate that the charger has got power and LED 2 used to indicate that the charger is being used.

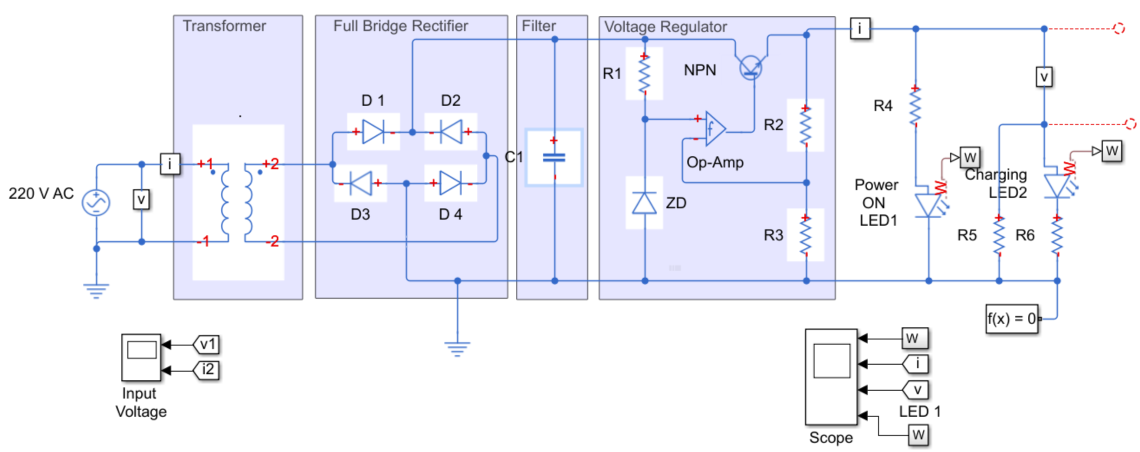

Figure 4.1: Mobile Charger with 220V AC supply

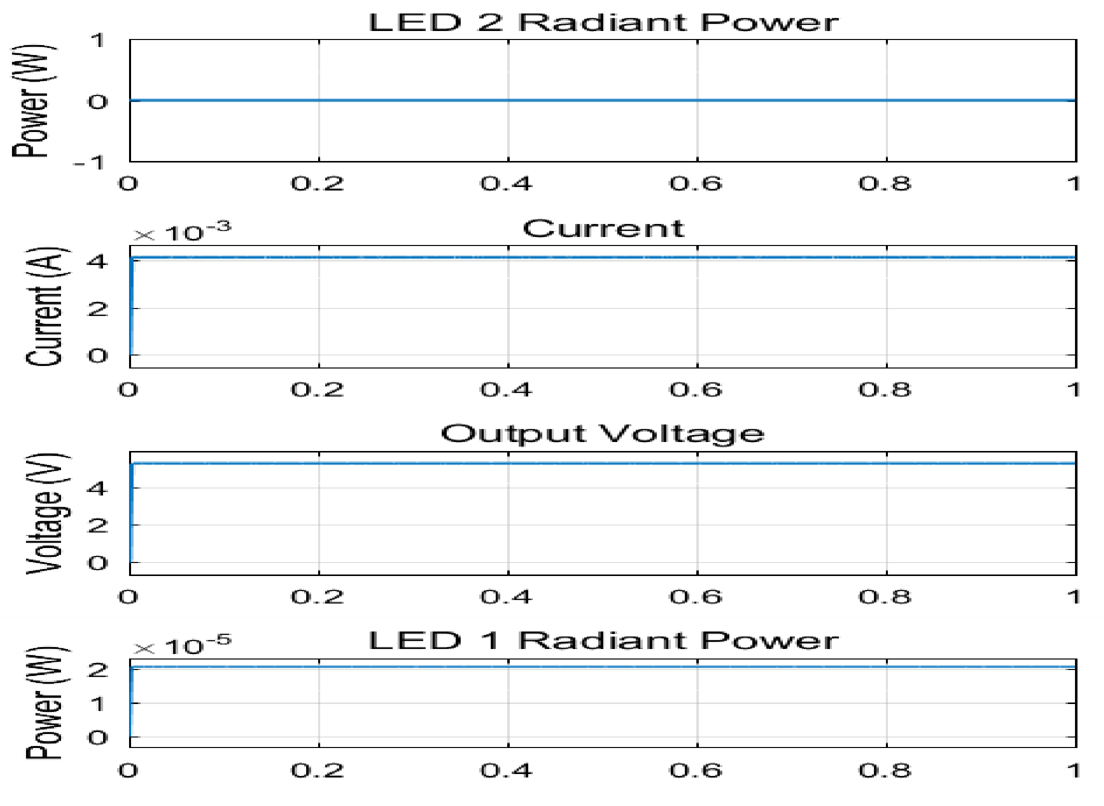

Figure 4.2 Result of Mobile Charger with 220V AC supply

4.1.2 LED light

This LED light has a transformerless AC/DC converter but a full bridge rectifier and a filter circuit with a current limiting resistor.

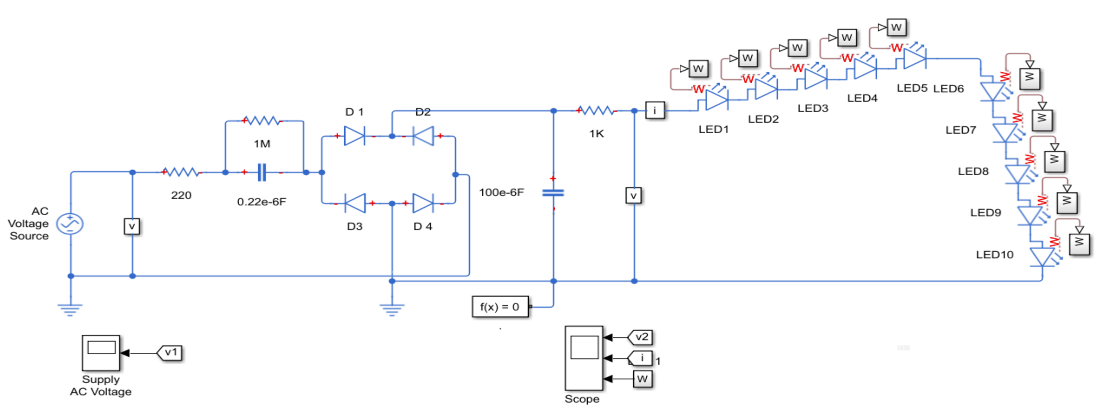

Figure 4.3: LED Light with 220V AC Supply

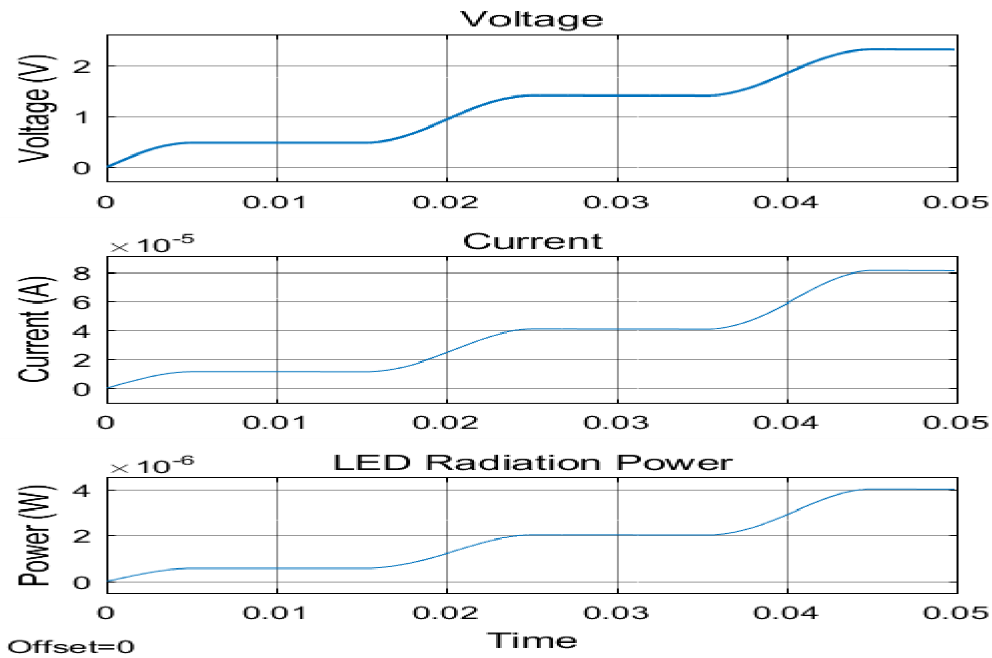

Figure 4.4 Result of LED Light with 220V AC Supply

4.2 MATLAB Model of the appliance with DC Supply

In this section, the selected home appliances (internally DC) are modeled for DC supply system specifically focusing on the power supply system of the appliances. The rest of the appliances parts are only represented with their major parts or by their equivalent circuit of the appliances.

The purpose of modeling the power supply system of the appliance is to show how the power supply system of the appliances is going to be change to directly use the 48V DC supply system.

In order to model the appliances with DC supply system, a straightforward mathematics is needed to determine the parameter and rating of different component in the converter.

Since 48V DC supply system is selected for the sample home a DC/DC converter which converts 48V DC to a suitable value of voltage for each appliance shall be considered, the conversion requires to reduce the voltage value so a buck DC/DC converter is used.

The principle of DC/DC converter is to convert a given constant DC voltage into a variable average DC voltage across a load by placing a high-speed static switch between the DC source and the load. A buck converter is a step-down DC/DC converter consisting primarily of an inductor and two switches (MOSFET and Diode). When the switch is closed, the DC supply voltage is applied across the load and when it is open, the load is disconnected from the supply. By varying the ratio of the switch-closed time (T_{ON}) to the switch-open time (T_{OFF}) at a fixed frequency, the value of the average output DC voltage can be controlled.

The duty cycle K can be varied from 0 to 1 by varying switch on time, period T or switching frequency. Therefore the output voltage V_o can be varied from 0 to $V_{in,}$ by controlling K.

Although a DC converter can be operated either at a fixed or variable switching frequency it is usually operated at a fixed frequency with a variable duty cycle.

Operating frequency: The operating frequency determines the performance of the switch. Switching frequency selection is normally determined by efficiency requirements. There is now a rising trend in research work and new power supply designs in increasing the switching frequencies. The higher is the switching frequency, the smaller the physical size and component value [21].

At higher frequencies, the switching losses in the MOSFET increase, and therefore reduce the overall efficiency of the circuit. At lower frequencies the required output capacitance and inductor size increases, and the increase the efficiency of the circuit. The trade-off between size and efficiency has to be evaluated very carefully. Frequency value used for the study is 25 KHz.

From equation 3.16 the duty cycle for each converter is as follows:

Table 4.1: Duty cycle used for DC/DC converter

Appliance	Input Voltage (V)	Output voltage (V)	Duty Cycle (k)
Refrigerator	48	24	0.5
Food Processor	48	24	0.5
32’’ LED television	48	19.5	0.406
Radio	48	12	0.25
Mobile Charger	48	5	0.104
LED Light	48	5	0.104

The DC/DC converter output shall include a filter circuit in order to smooth the ripple.

Filter Circuit Design:

The filter circuit includes inductor and capacitor, selecting these important components has a major impact on performance and characteristics of the DC/DC converter. When designing a step-down DC/DC converter, inductor selection is important [21].

The procedure for inductor selection and the method for calculating inductances are as follows

Inductor Selection:

The role of the inductor is to limit the current inrush through the power switch when the circuit is ON. The current through the inductor cannot change shortly. When the current through an inductor trend to fall, it tends to sustain the current by acting as a source.

The key advantage is when the inductor is used to drop voltage, it stores energy. Also, the inductor controls the percent of the ripple and determines whether or not the circuit is operating in the continuous mode.

Peak current through the inductor determines the inductor’s required saturation current rating, which turns dictates the approximate size of the inductor. Saturating the inductor core decreases the converter efficiency while increasing the temperature of the inductor, the MOSFET and diode.

A smaller inductor value enables a faster transient response; it also results in larger current ripple, which causes higher conductor losses in the switches, inductor, and parasitic resistances. The smaller inductor also requires a larger filter capacitor to decrease the output voltage ripple.

First, the following equations are used to calculate the inductance

$$L = \frac{(1-K)*R}{2*f_{sw}} \text{ (H)} \tag{4.1}$$

Where

K - Duty cycle

f_{sw} - Switching frequency (Hz)

R - Load resistance (Ω)

Capacitor Selection:

The primary criterion for selecting the output filter capacitor is its capacitance and equivalent series resistance, ESR. Since the capacitor's ESR affects the efficiency, low ESR capacitors will be used for best performance.

For reducing ESR, it is also possible to connect a few capacitors in parallel. The output filter capacitors are chosen to meet an output voltage ripple specifications, as well as the ability to handle the required ripple current stress.

For Buck converter the peak-to-peak ripple voltage is,

$$\Delta V_c = \frac{V_s K(1-K)}{8*L*C*f_{sw}^2} \tag{4.2}$$

Where

K – Duty cycle

Vs - input voltage (V)

C – Capacitor Value (F)

L – Inductor value (H)

f_{sw} - switching frequency (Hz)

Table 4.2: Input parameter for buck DC/DC converter

Appliance	Input Voltage (V)	Output voltage (V)	Output current (A)	Switching Frequency (KHz)	Output Ripple ratio	Inductor (μ H)	Output capacitor (μ F)
Refrigerator	48	24	10	25	0.3	663.9	12.05
Food Processor	48	24	6.24	25	0.3	1328	6.02
32’’ LED television	48	19.5	3.28	25	0.3	70.567	109.35
Radio	48	12	1	25	0.3	180	33.3
Mobile Charger	48	5	1.2	25	0.3	74.67	39.93
LED Light	48	5	1	25	0.3	89.6	33.28

4.2.1 DC power supply for Refrigerator

Current home refrigerators use single phase induction motor compressor. But they are also 24V DC compressor available. The equivalent circuit is represented with parallel connected Fan motor circuit and Compressor motor circuit. Each circuit contains series connected resistance and inductance. The DC/DC converter step downs the supply 48V DC to 24V which the refrigerator requires.

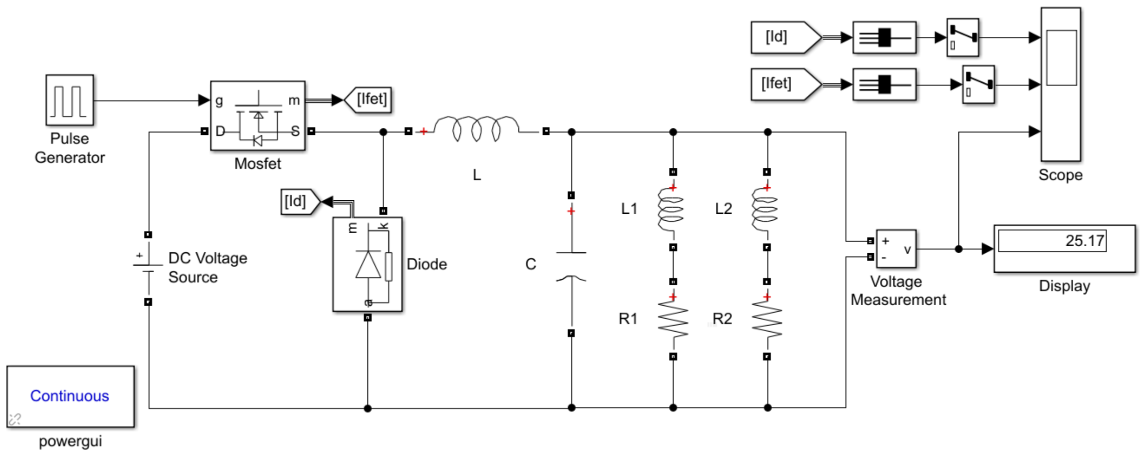

Figure 4.5:* DC power supply system for *Refrigerator

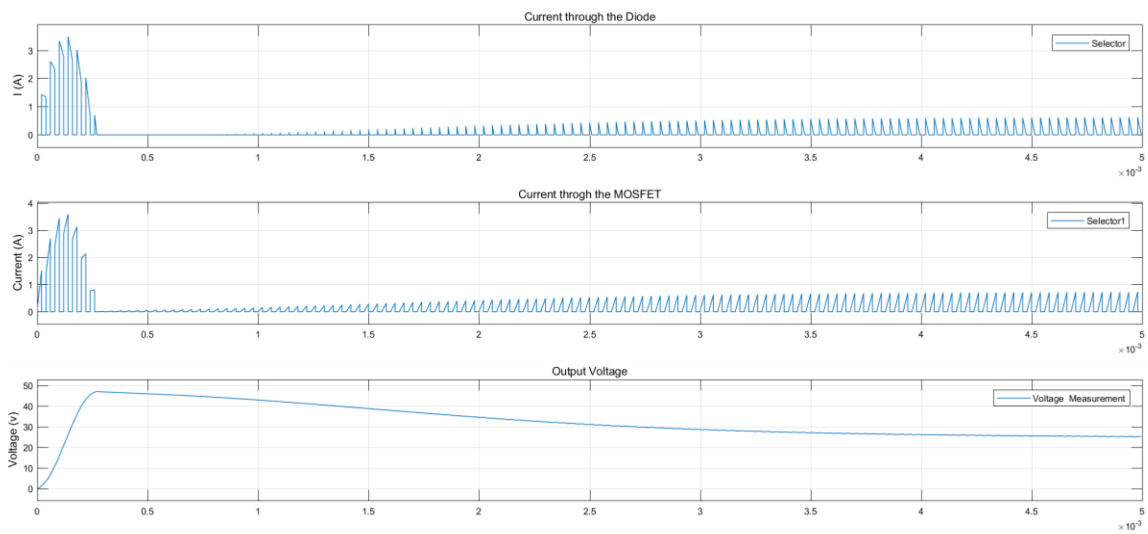

Figure 4.6 Output Voltage, Current through MOSFET and Diode

4.2.2 DC power supply for Food Processor

The food processor circuit is a DC motor with a control circuits. The equivalent circuit is represented with series connected resistance and inductance. The resistance is the sum of armature resistance and field winding resistance, the inductance is the sum of armature inductance and field winding inductance. The DC/DC converter step downs the supply 48V DC to 24V which the food processor requires.

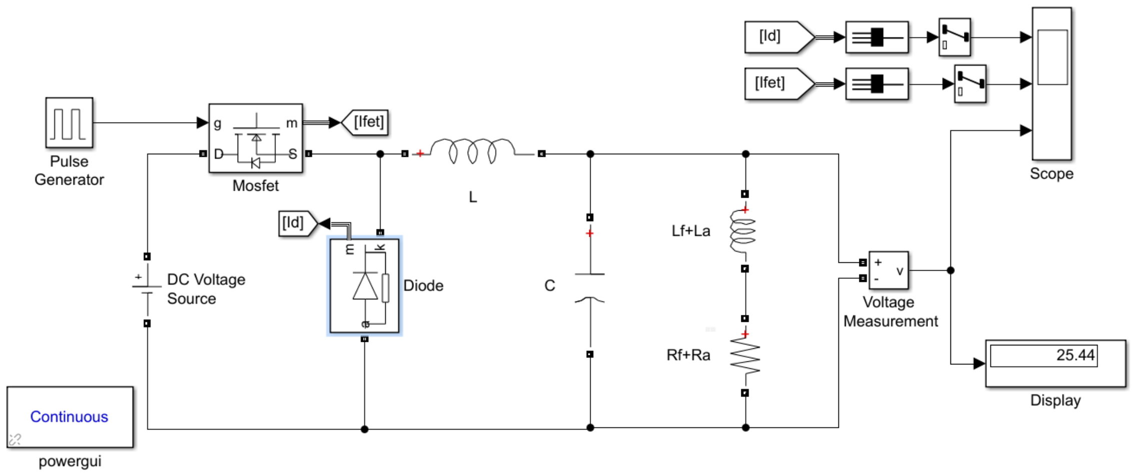

Figure 4.7: DC power supply system for Food Processor

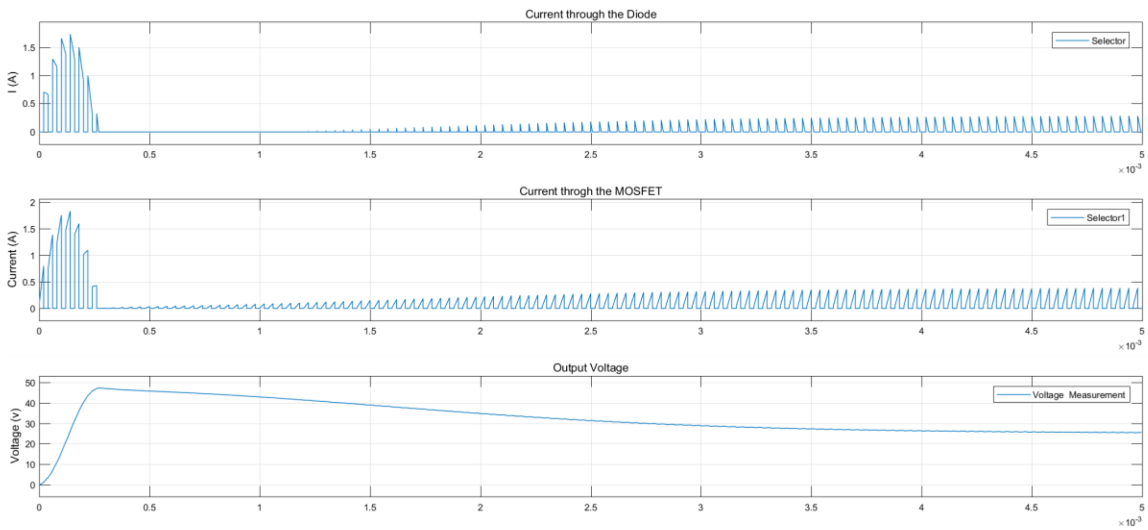

Figure 4.8: Simulation result of power supply system of food processor

4.2.3 DC power supply for 32'' LED television

In AC fed LED TVs, input AC is passed through EMI filter, transformer followed by a rectification stage and a PFC (Power Factor Correction) stage to take the input line PF close to unity. These conversion losses can be eliminated if LED TVs are operated directly on the DC distribution line. The power consumption of different television technologies of different screen sizes are different and it is also obvious that LED TV is the most efficient one among the others which can further be improved by excluding the rectification stage. The DC/DC converter step downs the supply 48V DC to 19.5V which the TV requires.

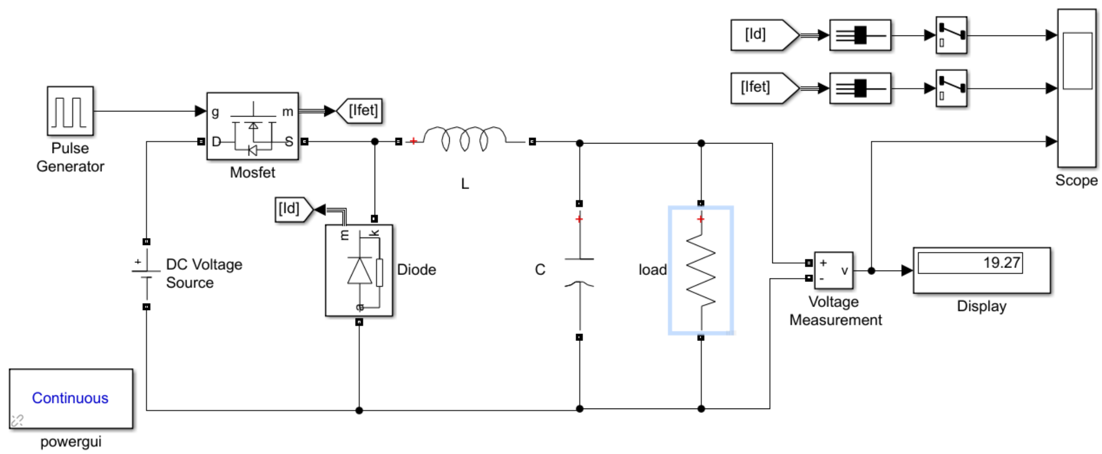

Figure 4.9: **DC power supply system for *32'' LED television***

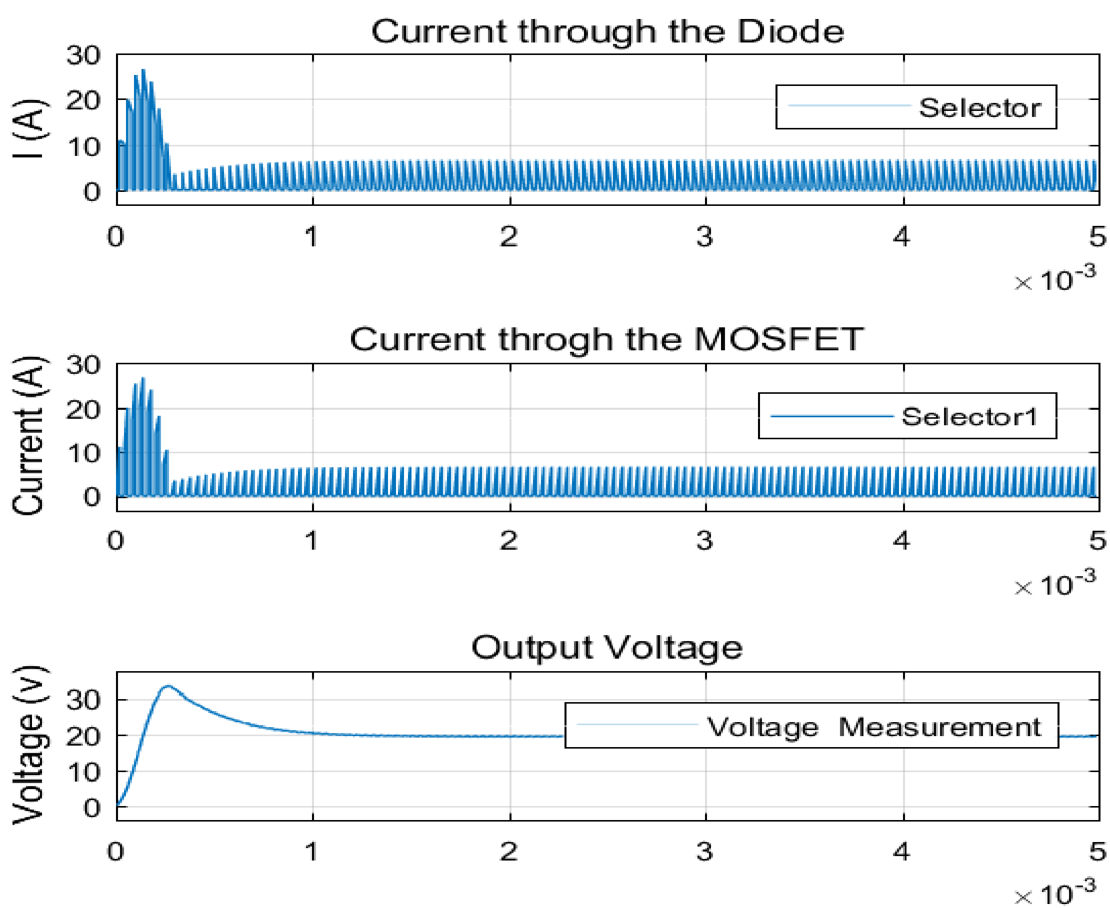

Figure 4.10: Simulation result of power supply system of 32'' LED television

4.2.4 DC power supply for Radio

The DC/DC converter step downs the supply 48V DC to 12V which the radio requires.

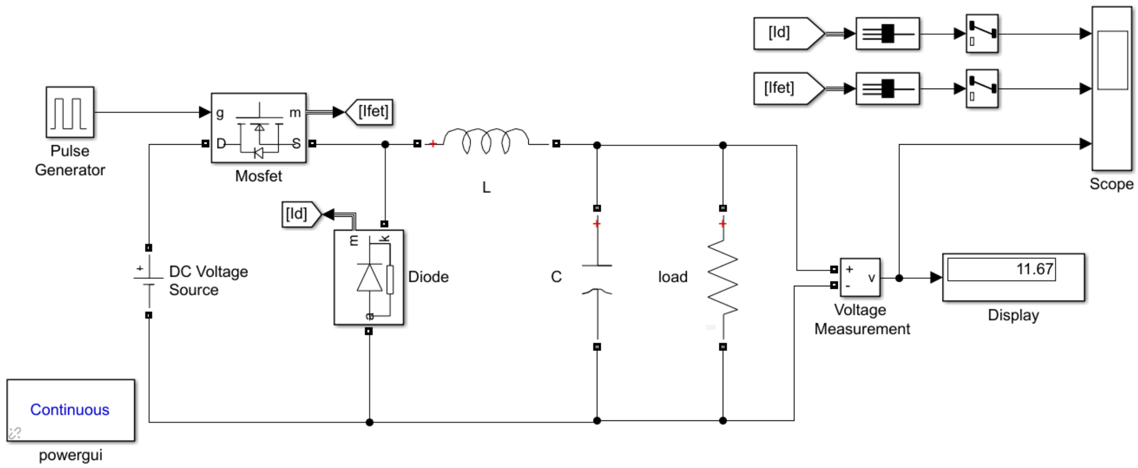

Figure 4.11: **DC power supply system for *Radio***

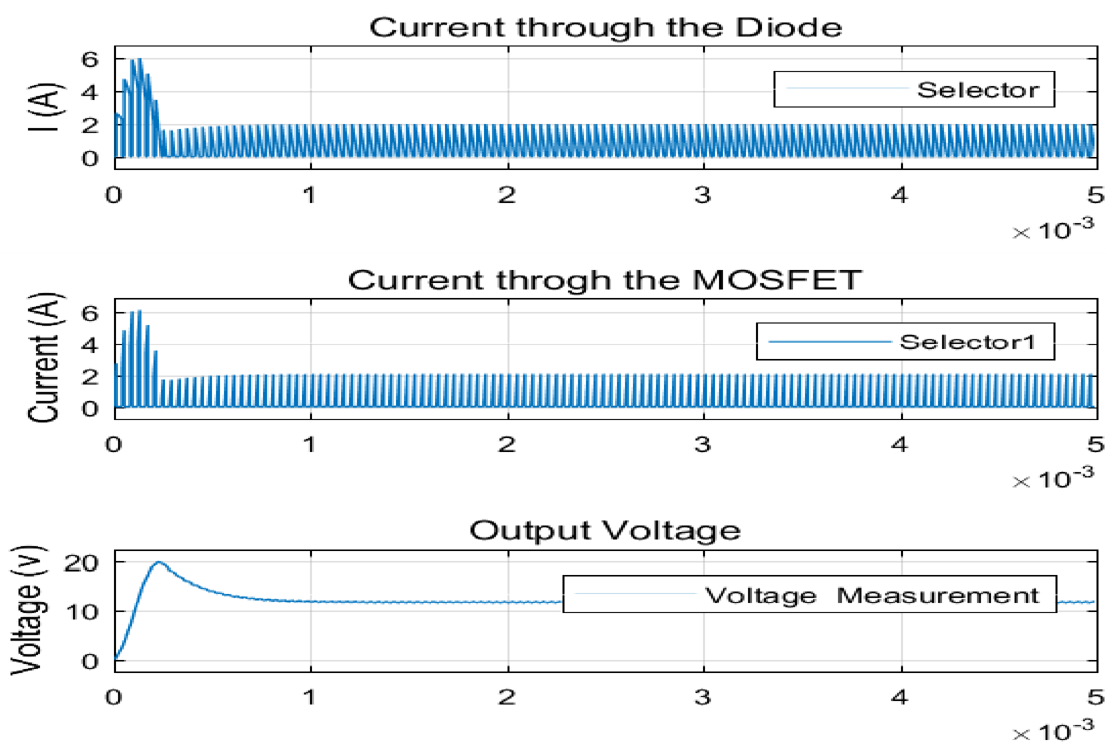

Figure 4.12: Simulation result of power supply system of Radio

4.2.5 DC power supply for Mobile Charger

The DC/DC converter step downs the supply 48V DC to 5V which the mobile charger requires.

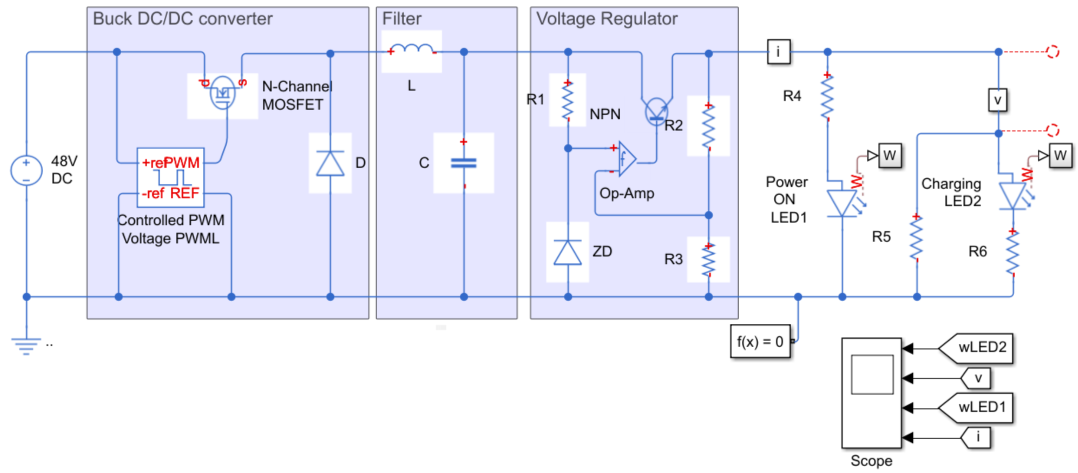

Figure 4.13: **DC power supplied *Mobile Charger***

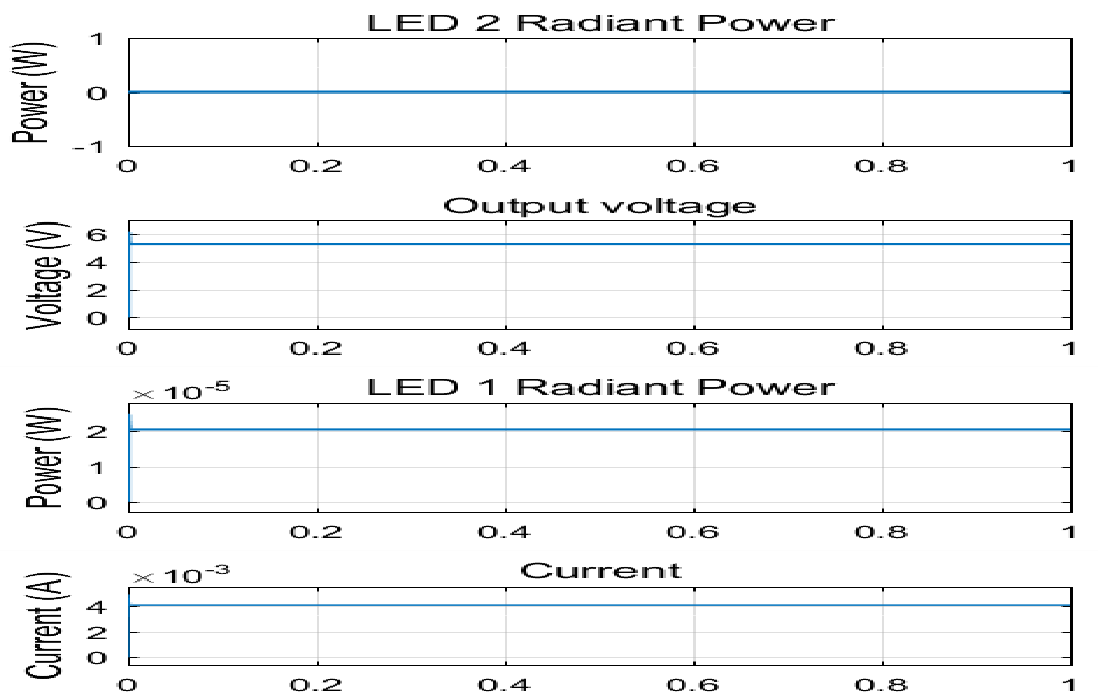

Figure 4.14: Simulation result of power supply system of Mobile Charger

4.2.6 DC power supply for LED light

Light emitting diodes (LED) are more efficient than traditional incandescent lighting. The benefits of LED light include longer operating life and reduced energy consumption. Use of DC power would further enhance the attractiveness of LED lights by eliminating the need and cost to convert AC power to DC as is currently done.

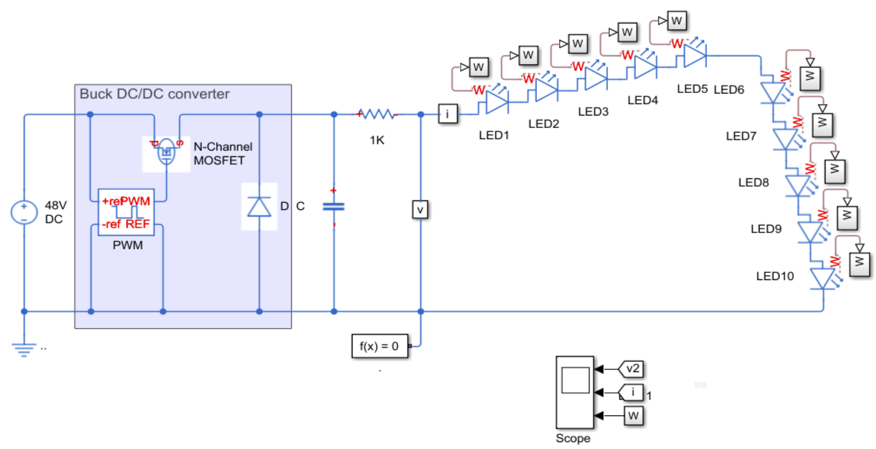

Figure 4.15: **DC power supplied *LED light***

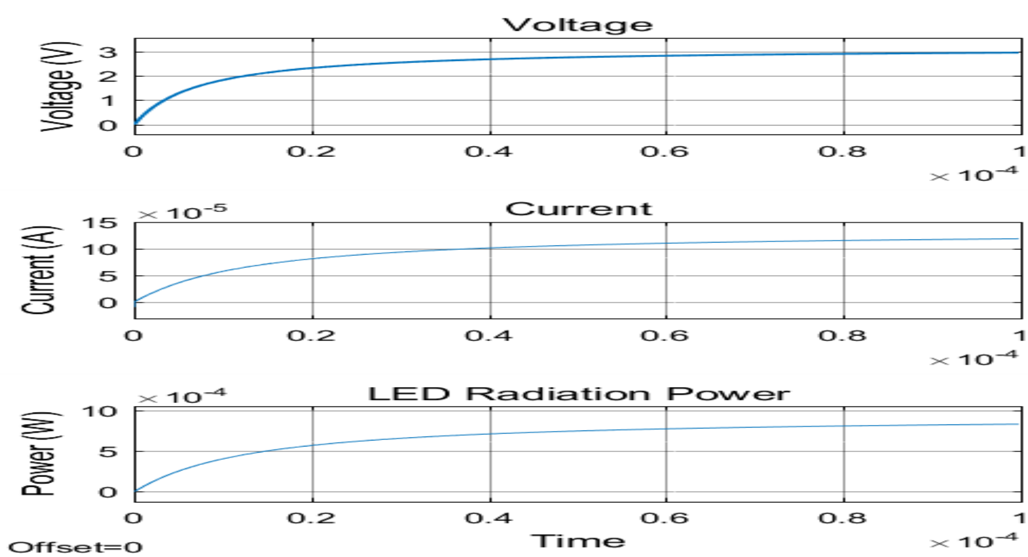

Figure 4.16: Simulation result of power supply system of LED light

CHAPTERS 5

CONCLUSIONS/RECOMMENDATIONS AND FUTURE WORK

This chapter puts the conclusion; recommendations and further work derived out from this research are brought together.

5.1 General Conclusion

If solar is going to be the power supply system and/or any other renewable energy which generate DC voltage it is inefficient to round-trip from DC/AC and back again to DC. It will be more efficient to stay DC from the solar power source to the battery to the end device, maybe only changing voltages once or twice with highly efficient DC/DC converters along the way.

Energy Saving: Use of low voltage DC increase power losses and voltage drops on the feeder cables at the same conditions when we compare with a 220V AC. But the overall study shows that there is 29.05% energy saving annually by changing the power supply system in the home to the DC system and makes the appliance compatible with the supply system. But the voltage drop is within a permissible range and the power losses also are not as such significant. In addition to the energy saving DC power supply system has other benefits like unity power factor, less insulation, better electrical safety and a possibility of using low voltage appliances without power conversion.

Energy Efficiency: As pointed out in chapter 3, the biggest impact of losses in AC distribution networks is power converter losses. Eliminating AC/DC converters from the appliances and use of DC/DC converter improve the overall system efficiency in the range of 0.51% – 31.45% range.

Manufacturing Cost: AC/DC converters employ copper wound metal transformers and other electrical components, while modern DC/DC converters employ electronic components. It is therefore understood that less energy will be lost in a DC/DC conversion. It is also obvious that AC/DC converters use up more raw materials than the

DC/ DC converters. Cost of DC/DC converter is less than the cost of AC/DC converter for the same power rating Table 3.15 is also tries to indicate this difference.

Shrinking power supplies: When we compare a single appliance who operates in DC with and without the adapter the appliance which has adapter uses more raw material than the one who does not have an adapter (this can be easily seen in mobile charge, laptop charger etc...). This will reduce the overall appliance size and manufacturing cost.

No 50 Hz hum: The native frequency of power coming out of the wall is 50Hz. This is something that we all have to deal with at home and that all electronics designs have to deal with. With an all DC system there will not be a humming noise.

Optimum DC voltage value: The power rating of the appliances, the cross-sectional of the cable and the maximum length the cable can travel without exceeding the standard allowable voltage drop (5%) in the home distribution system determines the optimum DC voltage value.

Total power losses on the cable from Table 3.7, 3.8, 3.9 and 3.10 are shown on the table below

Table 5.1: Total Power Losses on the cable at Different Voltage Levels

Voltage (V)	Power Losses On the cable (W)
12	337.18
24	84.54
48	20.12
48 modified	13.28

For this particular study, 48V DC supply is suitable for the provision of DC supply for the appliances under investigation, as per the results presented in Table 3.7, 3.8, 3.9 and 3.10.The Table shows 48V DC voltage is more suitable than the other voltage value due to less power loss on the feeder cable (Table 3.10), voltage drop across the cable is within the permissible value (5%) (Table 3.10) and the required length of cable for the appliances can only be obtained on the modified 48V value (Table 3.5 and 3.6). Therefore for these reasons the choice of 48V DC voltage value for the selected home distribution is optimum.

This conclusion gives only a single scenario picture. However as the power rating of the appliance and the physical electrical layout of the house changes it is only required to understand how each change will going to affect the overall system in terms of DC voltage value, maximum cable length, cross-sectional area of the cables, power losses on the cable and gone through the same step and come up to the new requirements.

5.2 Recommendation

5.2.1 DC safety standards

As shown in Figure 3.3, a DC home power supply system is much simpler than an AC home power supply system, owing to its minimization of the power conversion stage. The internal structure of a representative AC home appliance consists of multiple loads operated power devices.

Note that, after the AC/DC conversion stage, the steady state characteristics of this primitive model of a DC home appliance are the same as those of an existing home appliance. There are, however, significant differences in the transient state at start-up (i.e. plug-in or power-up) or under heavy DC load control, owing to differences in the type and size of supplied power. If a DC home appliance is designed with no consideration of these differences, its safety and reliability cannot be guaranteed.

Therefore the following issue shall be resolved before the implementation of DC supply for home

- Input polarity correction circuit which can automatically correct the polarity at the moment of plug-in;
- Heavy load control board suitable for DC home appliance for DC breaking the ability to enhance the safety;

- The transient state of DC plugging in/out; and
- DC safety standards that should be complimented for eliminating risk caused by the distribution system change

5.2.2 Use of Brushless DC Motor

Appliances having rotatory part use universal dc motors or 1-θ induction motors which have low efficiency because of carbon brush and mechanical commutation bearing a major maintenance cost and mechanical losses. All such motors can be replaced with Brushless DC (BLDC) motor which has a high efficiency, low noise, low power consumption and a wide range of speed.

In BLDC motor permanent magnet acts as a rotor while 3-θ DC supply is given to the static stator coil. There is low stator and rotor air gap which increases the efficiency by increasing the magnetic torque on the rotor by the stator. So no need for carbon brushes to supply the current which makes it maintenance free. But because of the presence of magnet, electronics, and sensor, BLDC motor is costly than induction and universal motor. With the adoption of DC grid and BLDC motor in industrial and residential appliances, the cost will definitely be reduced in future.

5.3 Future Work

This work only touches the surface of what is possible to be done with this topic. Future study will continue to include a larger sample of data and better define the benefit of DC supply system from the AC supply system for the home. The study will also further elaborated to include the socioeconomic advantage gained through implementing DC supply for home, by the use of renewable energy generation for electrification of rural area and changing the existing scheme of the home power distribution system.

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