TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: M-115-MSESPM-2018-2020

Analysis on AC-DC Hybrid Power Supply System: A Case Study for a Hospital Building in Kathmandu, Nepal

by

Bikram Gaihre

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENERGY SYSTEM PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

July, 2020

COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Analysis on AC-DC Hybrid Power Supply System: A Case Study for a Hospital Building in Kathmandu, Nepal"**, submitted by Bikram Gaihre in partial fulfillment of the requirement for the degree of Masters of Science Engineering in Energy System Planning and Management.

____

Supervisor, Prof. Dr. Laxman Poudel
Campus Chief
Pulchowk Campus, IOE, TU

____

External Examiner, Er. Bodh Nath Neupane
Assistant Manager
Nepal Electricity Authority,

____

Committee Chairperson, Dr. Nawaraj Bhattarai
Head of Department,
Department of Mechanical and Aerospace Engineering

Date: July 31, 2020

ABSTRACT

Because of some limitations found to use either completely Direct Current (DC) supply system or completely Alternating Current (AC) supply system, hybrid AC-DC supply system become prone topic of the discussion for effective power supply solution as it helps to reduces multiple conversion losses that may occur from generation to end use point. Implementation of hybrid supply system within the hospital building can save the energy as maximum numbers of DC loads like Light Emitting Diode (LED) lights, fan and computer charging system are operated for maximum number of hours in comparison with other buildings.

This research includes the development of hybrid supply system for a hospital building in which all lighting devices, fan and computer charging system were supplied from DC side and remaining loads being supplied from existing AC line. 48 volt DC line has been developed by converting existing AC supply. Required AC-DC and DC-DC converter with regulator is designed and simulated in PLECS (Piecewise Linear Electrical Circuit Simulation) software. Wire sizes required to develop DC wiring model is selected by maintaining 4 percent voltage drop limit from DC source point (AC to DC conversion point). Based on the simulation results losses in developed model is calculated and energy saving opportunity on implementing this model is evaluated and found 18.6 kWh of energy saving opportunity while supplying 18.853kW of DC load and 10kVA uninterruptible power supply (eliminating need of rectification and invert process) from DC line of hybrid power supply structure. Certainty and sensitivity on energy saving with assumption in possible variation in factors like hour of operation per day and percentage of load supplied at a time is analyzed using crystal ball simulation and found a certainty of 31.5% that the energy saving being more than 18kWh.

ACKNOWLEDGEMENT

First of all I would like to express my special thanks of gratitude to my supervisor Prof. Dr. Laxman Poudel for his guidance and support in completing my research work. Beside my supervisor I am also thankful to MSESPM program coordinator Dr. Shree Raj Shakya for his encouragement with valuable suggestions from the very beginning on doing this research work.

It is my pleasure to express my sincere gratitude to the entire faculty of Mechanical and Aerospace Engineering Department for their opportunity, help and well wishes for my research work. I wish to thank Prof. Dr. Amrit Man Nakarmi and Dr. Sujan Adhikary for their support regarding the simulation software like Crystal Ball and PLECS.

I am very grateful to Helping Hands community Hospital, Chabahil for allowing me to conduct survey in such a critical place.

I also take this opportunity to express my special thanks to my family and friends who helped me directly and indirectly during the course of completing my Thesis.

TABLE OF CONTENTS

LIST OF TABLES

LISTS OF FIGURES

LISTS OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
LED	Light Emitting Diode
UPS	Uninterruptible power supply
LVDC	Low Voltage DC
PV	Photo Voltaic
PLECS	Piecewise Linear Electrical Circuit Simulation
NBC	National Building Code
NEC	National Electrical Code
PFC	Power Factor Correction
DB	Distribution Board
MDB	Main Distribution Board
PED	Power Electronic Device
NEA	Nepal Electricity Authority
PWM	Pulse Width Modulation
CCM	Continuous Conduction Mode
MCB	Miniature Circuit Breaker
ESR	Equivalent Series Resistance
DCR	DC resistance
PFC	Power Factor Correction

CHAPTER ONE: INTRODUCTION

1.1 Background

Along with the development of world's first practical light bulb by Thomas Edison in the late 1870s, Electricity was first introduced in the form of direct current (DC) (Kimbark, 1971). In 1882 Edison began to built a production and distribution system for Low Voltage Direct Current-LVDC (110 volt & 240 volt dc) electricity so as to make use of his new invention (Sulzberger, 2003). But, Edison's LVDC system, due to some limitations like restriction on long distance transmission due to high power loss in the transmission conductor and high cost of copper conductor to transmit larger power for long distance limits the supply system for small isolated areas only.

An era of AC system began by the mid of 1880s with the contribution made by Nicola Tesla and his team (De Andrade, 2012). This technology competes with DC systems with improvement in the ability to transmit power over long distance with minimum loss by using transformer. And afterward DC System starts decline.

After 1950s, with the progress in advanced power electronic devices (PEDs) technology and it's commercialization for power conversion (like: Rectifier, inverter and choppers), DC system then recognizes some major advantage over AC system (Qiu, et al., 2016). So, from past decades DC system again have becomes effective for transmission and distribution of electricity.

However, there are still some limitations found to use as either completely DC supply system or completely AC supply system, from generation point to the consumption point.

Some major drawback in use of completely AC power supply system includes followings:

- In order to connect the DC sources like Photovoltaic (PV) generators and battery storage system to the completely AC power supply system, DC to DC and then DC to AC conversion steps are required. Such multiple conversions will increases the loss (Wang, et al., 2019).

- To feed the DC loads like: LED lightings, laptop, desktop and mobile charging system, DC motors etc., from the completely AC supply system, the AC to DC conversion is needed. And that conversion process increases the loss (Wang, et al., 2019).
- Hysteresis loss, eddy current loss, skin effect, Ferranti effect and capacitor losses are major for AC system.

Some major drawback in use of completely DC power supply system includes followings:

- If generation technologies are of AC type (like: Hydro Generator, Diesel Generator etc.), in order to connect them to the completely DC power grid only, AC to DC conversion step is required. Such conversion increases the loss (Wang, et al., 2019).
- To feed the AC loads such as fan, heater, AC induction cooker, refrigerator, water pump etc., from the completely DC supply system then the conversion from DC to AC is needed. Such conversion increases the loss (Wang, et al., 2019).

The all above mentioned drawback can be minimized by using hybrid AC-DC supply system and by connecting all DC generation technologies and DC loads to DC line and connecting all AC generation technologies and AC loads to AC line of the hybrid AC-DC supply system and can saves between 2.5 % and 10 % of the developed energy through elimination of multiple conversion loss (Wang, et al., 2019). So, energy efficiency can improve by implementing such hybrid supply system and hence the cost of energy can be optimized. So, nowadays Hybrid AC-DC supply system has gained more attention.

AC-DC hybrid power supply system consists of an AC supply line in which a DC power supply line is integrated using an AC to DC converter. AC loads are directly supplied from AC line and DC loads can be directly supplied from DC line of the AC-DC hybrid system. This type of configuration allows DC technology like roof-top solar PV with or without storage battery system to be integrated within the grid through DC supply line. Since this type of system provides dual distribution network, the system is more reliable and robust (Alipuria, et al., 2013).

Hybridization of transmission and primary distribution depends on the service provider authority (NEA in Nepal). However for large buildings like Hospital, commercial Mall etc, Owner can develop hybrid supply structure with in the building. Hybrid AC-DC supply structure within the existing building can be formed by coupling DC supply line with an existing AC supply line. DC supply line can be formed by converting AC line to DC line by using an AC to DC converter at supply entry point.

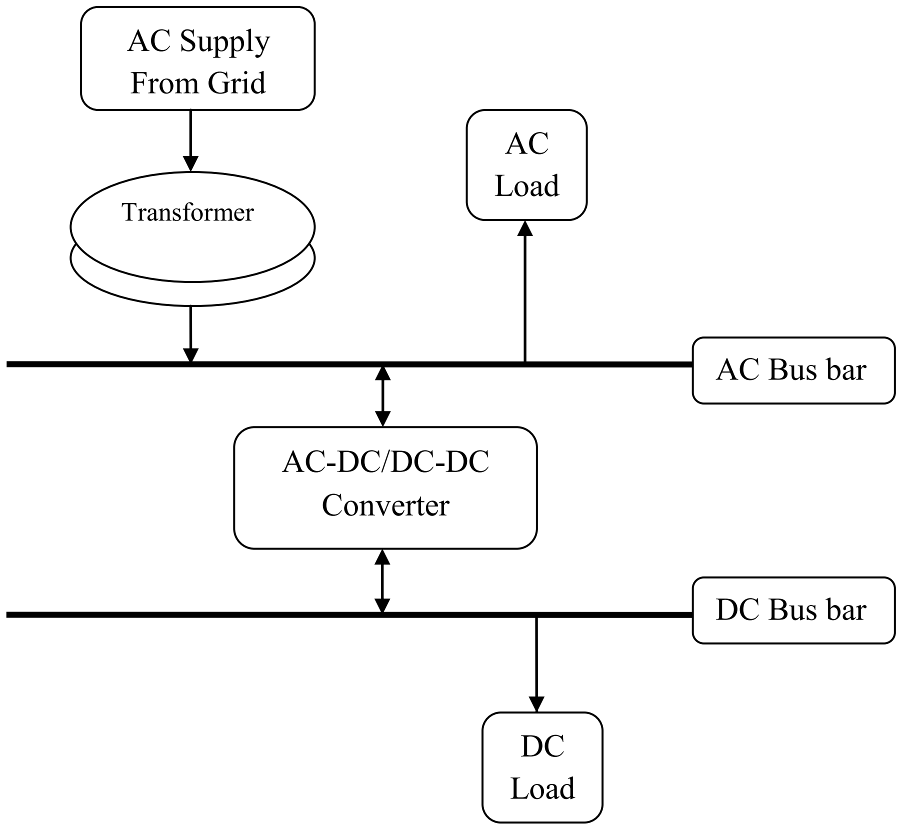


Figure 1: Schematic representation of purposed hybrid AC-DC power supply system without integration of DC source for an existing building.

In hospital building lighting loads are operated for maximum time so there is a chance of more energy being saved by replacing efficient DC lighting system in comparison with other types of building. Moreover in hospital building some of the lighting loads and other loads are very critical and it is compulsion to supply them through UPS system. Use of AC-DC hybrid supply system can eliminate the rectification and inverter losses within UPS system resulting high chances of energy saving. So, this research focuses on the effectiveness of hybrid supply structure in a building for replacing AC lighting, fan and computer charging system by DC system. This study has been carried out by taking Helping Hands Community Hospital Chabahil-Kathmandu as a reference hospital building. This study also focuses on the development of wiring model for hybrid AC-DC system for a specified building.

1.2 Problem Statement

Commercial buildings like office buildings, medical centers or hospital, hotels, malls, multifamily housing buildings, industrial buildings etc has number of AC loads (like: Fan, Heater, Refrigerator, Water pump, Iron, Printer etc) and DC loads (like: LED lights, laptop, mobile etc) which are in daily operation for number of hours. Most of the DC loads in such buildings are fed via AC source followed by AC to DC conversion process. Such additional conversion process added up the loss and makes the device inefficient to some extent. Also for lighting purpose DC based LED lights were found to be more efficient in comparison to the AC LED lights due to the comparatively high efficiency (5 to 10% better) of DC LED driver to the efficiency of AC LED driver (Jhunjhunwala, et al., 2016). But DC lights are still seems inefficient due to power loss in AC to DC conversion process while fed via AC supply system. Implementation of AC-DC hybrid system for such buildings where light loads are operated daily for long times, can save some energy consumption.

Moreover, almost in all hospital buildings critical loads were supplied from UPS (Uninterruptible Power Supply) in which multiple conversion process that is first from AC into DC and again DC into AC causes more loss. If UPS is fed from DC line of hybrid power supply structure losses due to AC to DC conversion process can be eliminate and also if the load (like: light, fan and computer charging system) were replace by DC type another loss associated with DC to AC conversion can be minimized.

1.3 Research Gap

Past studies and researches carried out up to now have suggested that implementation of hybrid AC-DC network would be effective and will provides better security, reliability and operation of the network and also will improve the power consumption efficiency of buildings (Mousavizaden and Haghifam, 2013; Alipuria, et al., 2013; Li, et al., 2018). However, past researches includes loads like refrigerators, air conditioners and air purifiers etc as a DC load and most of such load in Nepal are of AC type. Now the problem will be that, inclusion of such load as a DC side load cause the high replacement cost and also require larger size of wires for installation and exclusion of such load from DC side load decreases the energy saving opportunity and may makes the integration ineffective for a building.

So, this study focuses on the effectiveness of hybrid supply structure in a building only by replacing AC lighting, fan and computer charging system by DC system as cost of replacement of such devices are comparatively less than the cost of replacement of other devices like refrigerators, air conditioners, air purifiers etc.

1.4 Objectives

The main objective of this proposal is:

> "To develop and analyze the hybrid AC-DC power supply system model for a building to minimize the electricity consumption".

The main objectives will be accomplished with the following specific objectives:

i. To carry out AC and DC load survey of building.
ii. To develop DC side wiring model required for hybrid AC-DC power supply structure for the building.
iii. To develop and simulate model of converter and regulator (controller) necessary to make AC-DC hybrid supply system in PLECS software.
iv. To identify energy saving for using AC-DC hybrid supply system in the building.
v. Certainty and sensitivity analysis on energy saving using Crystal Ball.

1.5 Scope of the work

The main focus of this thesis work is to develop the hybrid AC-DC power supply system for an existing building in order to minimize the electricity consumption by eliminating the multiple conversion loss that occurs at various end use devices especially LED lights. As a reference building a Helping Hand Community Hospital building has been chosen. This work will develop the simulation model of the hybrid AC-DC power supply system in PLECS to verify the operational feasibility and voltage drop at different points were calculated. Moreover complete wiring network required to implement AC-DC hybrid structure for building will be developed.

Although this work is based on Hospital building this can be implemented later on commercial buildings like Hotels, Apartments, Shopping centers etc where maximum use of lighting loads and other inexpensive DC loads is expected. This work will also help to integrate available DC source (if any) at buildings which is used as a power backup system (like Solar PV system) to DC line of AC-DC hybrid supply system of building for efficient and maximum use.

1.6 Assumptions

Following assumptions will be made during the conduction of the work:

- Existing wiring system of the building were done as per NBC207 code.
- Only lighting circuit loads are supplied form DC line of hybrid AC-DC system.
- Sockets will not be provided from DC line.
- Same existing wire is assumed to be used to supply the DC power from switch board to lighting device.
- Location of DC switch board is assumed to be at same place to that of existing switch boards.

1.7 Limitations

- Only lights, fans and computer charging system is considered as a DC load.
- Parasitic components of the inductor, diode and the capacitor are neglected during small signal analysis.
- Loss by ESR of the capacitor and inductor core loss is neglected during evaluation of model efficiency.
- Energy saving is calculated considering operation hours of devices for summer season only.
- Financial feasibility is not considered.

CHAPTER TWO: LITERATURE REVIEW

2.1. AC-DC hybrid supply system

AC-DC hybrid power supply system consists of an AC supply line in which a DC power supply line is integrated using required converter and regulators. AC source and DC source are tied up to respective AC and DC supply line and AC loads, DC loads then supplied directly from respective AC line and DC line of hybrid AC-DC system. This type of configuration allows DC technology like roof-top solar PV with or without storage battery system to be integrated within the grid through DC supply line.

So many studies and research carried out up to now have suggested that implementation of hybrid AC-DC network would be effective, secure, reliable and efficient in a buildings.

(Mousavizaden & Haghifam, 2013), studied the economic design of the AC – DC hybrid power supply structure for low voltage DC system. They have studied for different areas that have different load densities by considering different load types. They have also considered the different level of distributed sources penetrations. They have categories three different scenarios for investigation. They investigated for completely AC power supply network, completely DC power supply network and AC and DC mixed hybrid power supply network. As a result they have concluded that implementation of the AC-DC hybrid power supply network found to be more economic than completely AC power supply network and completely DC power supply networks. They have also made a conclusion that for low voltage level, economics of distribution system could be better improved with the use of advance power electronics devices.

(Sannino, et al., 2003), studied and analyze a case about the operational feasibility of the DC power supply structure within the commercial facilities. In the study various loads like computers, printers, fax machine, photocopy machine, refrigerators, fans, lighting loads, coffee machine, water boiler and microwave ovens etc were considered. In the study one line diagram representing load and distance of load from main bus was developed and voltage and power drop for respective load while implementing DC supply system were calculated for voltage level of 326V DC system, 230V DC system, 120V DC system and then for 48V DC system by using following formula-

$$\Delta V_{dc} = 2R\frac{P}{V_{dc}} \text{ ... ... Equation 2.1}$$

$$\Delta P_{dc} = 2R\frac{P^2}{{V_{dc}}^2} \text{ ... ... Equation 2.2}$$

Where,

ΔV_{dc} is voltage drop in DC system.
ΔP_{dc} is power drop in DC system.
R is resistance of wire at 80°C temperature.
P is load power in watt.
V_{dc} is DC system voltage.

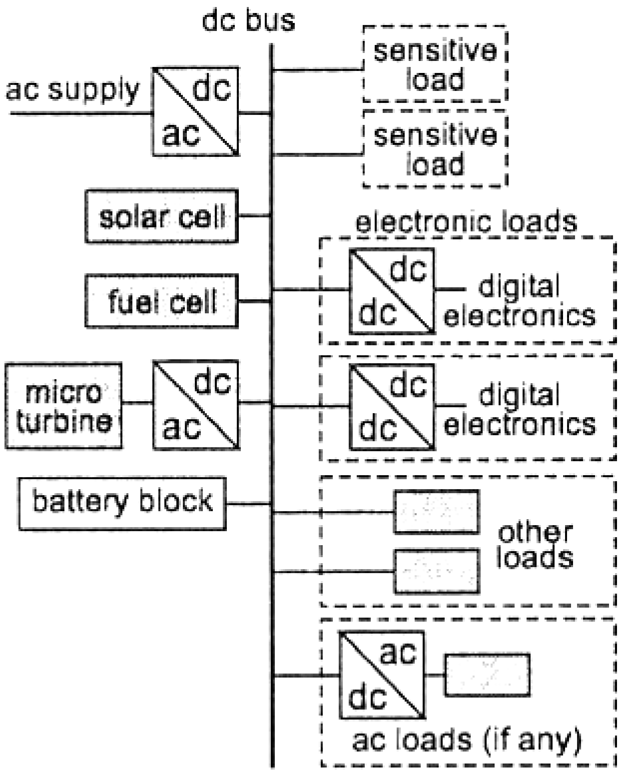


Figure 2: Purposed dc low-voltage distribution system (Sannino, et al., 2003)

The study concludes that for 48V DC use of 1.5 and 2.5 sq.mm cables being used in existing system is restricted due to too high voltage and power drops. And for voltage level of 120V, 230V, 326V DC use of existing system cables (1.5 and 2.5 sq.mm) will

be feasible considering allowable voltage drop of 5%. However the implementation of such DC voltage level need to be again step down to 12V, 24V or 48V DC in order to feed the lighting loads like LED lights.
Restriction in use of existing 1.5 and 2.5 sq.mm cable due to too high voltage drop in their study is mainly due to heavy end use devices like cooker(4500watt) coffee machine(4700watt).
So if the hybrid system is develop for commercial building in which higher loads are feed from AC line and low loads like lighting loads are feed from DC line implementation of 48V DC can be feasible to use existing system wires.

In the research conducted by (Li, et al., 2018) Practical operation of hybrid power supply structure has been verified. According to this study power Supply Company (Haimen and Nanjing Golden Cooperate) developed the hybrid supply structure for the building in order to verify whether the low voltage DC supply is feasible or not within the building. They have designed a system in which possible DC loads like: LED lamps, air conditioners, projectors, and refrigerators etc were fed from purposed integrated new DC supply structure and remaining AC loads were fed from an existing AC power supply structure available in the building. They have also developed a control system and monitoring system to manage the practicability of system operation in the building. For the protection of the AC supply system they adopt the traditional types of AC protection system and for the protection of the integrated DC supply line completely new DC protection system were developed for active as well as microcomputer protection. As a result they have observed a good operation of the developed hybrid supply structure in the building. Also they have observed the full utilization of the available solar power in the building, reliability of the power supply in the building has observed to be improving and the building efficiency in terms of power consumption was found to be improved. (Li, et al., 2018) , made the conclusion that the completely DC supply structure for the building needs an adaptation and the hybrid supply structure by integrating DC supply into existing AC supply line found to be a better solution. In their model the function of transferring AC power from available excess DC power (if any) was not added. The DC power generation from available solar system was mainly used for the DC side loads only. If the facility of converting available excess DC power in to AC power bus is added, the hybrid AC-DC supply structure will be effective and efficient.

(Alipuria, et al., 2013), performed a research and proposed the hybrid supply structure to integrate the solar home system within the power infrastructure. They simulate the operational feasibility of DC network along with its effect on the existing infrastructure. Their results show an improvement in power supply system reliability and operation of distribution network using this AC-DC hybrid infrastructure. They have verified the operation of the proposed system using MATLAB -Simulink model. In the model they have assumed the DC distribution network voltage of 200V and home DC network was assumed at 48V. The solar PV model at 48V, battery, AC and DC loads, DC grid and the AC grid were simulated in MATLAB-Simulink. They have used the converters and inverters in the DC and AC networks for two way power transmission when required. From simulation of their model they have concluded that the system design is feasible and it is possible to control operation of DC network using voltage control. Their results showed that the converters could quickly react to any change in the system to keep the voltage at a stable level.

2.2. AC and DC LED Driver

LED lamp comprises of two separate parts one is an actual diode which emits light by converting electricity and another is the LED driver. For the perfect operation of LED lights constant amount of power is necessary which is provided by the self contained LED driver. Basically LED drivers are of two types one is AC based and another is DC based.

In AC feed LED driver function of the LED driver is to provide converted stepped down DC voltage necessary for the operation of LEDs and to provide the protection against power fluctuation by maintaining constant power. Generally LED bulbs are operates at low voltage of about 1.5 V to 3.5V DC. Most of the commercially available LED bulbs were made by combination of several individual LED bulbs in series and parallel and are operate at 12V, 24V and 48V. LED driver converts the input AC source to DC and further it lowers the voltage level to 12V, 24V and 48V depending upon the requirement. The stepped down voltage and current may fluctuate with the fluctuation in main supply. In LED another driver circuit is designed to regulate the voltage or current.

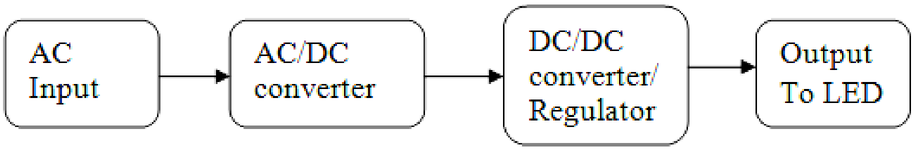


Figure 3: Block diagram for AC based LED driver

However in DC based LED function of LED driver is only to provide the protection against power fluctuation by maintaining constant power as DC based system had already a DC supply source rectification is not necessary. But if DC supply has voltage level higher than the compatible voltage level to LED bulbs then stepped down of DC voltage to a match the suitable input DC voltage of LED bulb is necessary.

Figure 4: Block diagram for DC based LED driver

Because of elimination of rectification process in DC based LED driver, driver efficiency of DC LED is assumed to better than the AC based LED driver.

(Jhunjhunwala, et al., 2016), performed an experiment on the efficiency of DC feed LED lights and AC feed LED lights by evaluating the efficiency of LED drivers for both AC LED lights and DC LED lights. As a result from the experiment DC feed LED lights were found to be more efficient with better reliability in comparison to the AC lights. They have also concluded that performance of DC drivers in comparison to AC driver is 5 to 10% more efficient, 3-10 times more reliable and have 20% lower cost. They have suggested that when the system covers the million pieces of LED lights then replacement by DC LED can saves the energy up to 7.3 GWh per year with the assumption that lights are operated for 10hrs/day.

(Gao, et al., 2018), developed an AC powered inductor less LED driver model with valley fill PFC and tested with 110V AC for 8 watt LED system and found the peak efficiency of 89%.

(Gao, et al., 2017), developed an AC based LED driver model for general lights without switching converter that can reduce flickers in low frequency. It was tested with 110V AC for 7.8 watt LED system and found the peak efficiency of 87.6%.

(Wang, et al., 2012), purposed an AC based flicker less LED driver model without electrolytic capacitor and output was tested with 90-264V AC for 33.6 watt LED system and found the peak efficiency of 85.5%.

(Meraj, et al., 2019), proposed an efficient DC based LED driver model with high brightness. This model was developed for DC power distribution system and is based on linear current regulator technology. In the study 20W driver model was simulate in spice software and the performance was validated by developing experimental prototype. The purposed model achieved an efficiency of 97%.

(Thielemans, et al., 2017), studied the smart LED based lighting from DC grid. Study focused on the effectiveness of supplying LEDs from DC source over supplying LEDs from AC source. For that efficiency of three different AC based drivers (Osram OT FIT 50/220-240/1A0 CS, Mean Well NPF-40D-42 and XP Power DLE45PS48) and DC based LED drivers (XP Power LDU4860S1000, Generic LED driver and Mean Well LDD-1000H) was measured and compared. As a result in an average efficiency of AC based driver was found to be 86% and efficiency of DC based driver was found to be 96% (10% more than that of AC based LED driver).

2.3. DC-DC Buck Converter

Buck converter generally used for stepping down the available DC voltage to a desirable DC output voltage which has similar function like of step down transformer used in AC power system. General buck converter circuit is illustrated in figure 5 below which consists of a DC supply (V_s), a switch (S), a Diode (D), and passive components like: Inductor (L), load resistor (R) and a Capacitor (C).

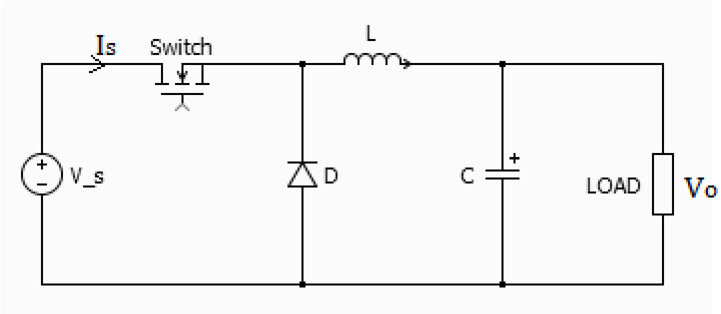


Figure 5: Basic Buck Converter circuit

For DC-DC buck converter it's operatio can be described in two different modes, Buck converter is in mode1 operation when switch (S) is closed and in mode 2 operation when switch (S) is open.

In mode1 operation switch (S) is closed and buck converter diode (D) operates in reverse biased condition so the current is flowing through inductor to load and in this case inductor current rises linearly. In this operating mode the energy is stored in inductor. The stored energy in the inductor can be obtained by using equation 2.3.1 (Rashid, 2007).

$$E = \frac{1}{2} L {I_L}^2 \text{ ... ... Equation 2.3.1}$$

This stored energy will decrease during mode 2 operation where switch (S) will be open thus the inductor current (I_L) decreases as illustrated below in figure 6.

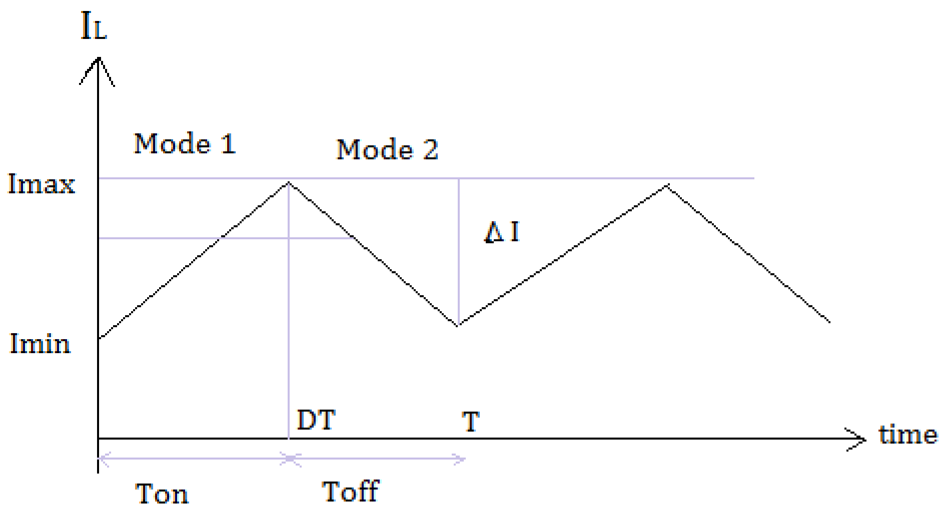


Figure 6: Inductor current waveform

In mode1 of operation basic buck converter circuit seems as shown in circuit of figure 7 below.

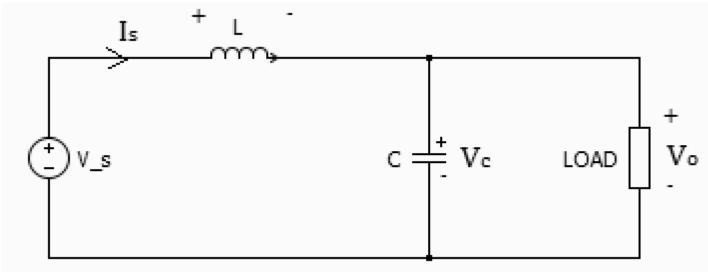


Figure 7: General Circuit of buck converter for model 1 operation

Using KVL in the circuit of mode1 operation, voltage across inductor (V_L) will be

$$V_L = V_s - V_o \ldots\ldots\ldots\ldots \text{Equation 2.3.2}$$

Equation 2.3.3 below also gives the voltage across inductor (V_L);

$$V_L = L\frac{dI_L}{dt} \ldots\ldots\ldots\ldots\ldots \text{Equation 2.3.3}$$

So, from equation 2.3.2 and equation 2.3.3,

$$\Delta I = I_{Lmax} - I_{Lmin} = \int_0^{t\ on} \frac{V_L}{L}\, dt = \frac{V_s - V_o}{L} t_{ON} \ldots\ldots\ldots \text{Equation 2.3.4}$$

Where t_{On} = Duty cycle (D)*T

Similarly, in mode2 operation switch (S) will be open and stored energy in inductor in mode1 operation acts as a soure. The diode (D) operates at forward biased condition so the current is supplied to load through inductor. Now current through the inductor decreases linearly as shown in figure 6. In mode2 operation equivalent circuit of buck converter seems as in figure 8 below.

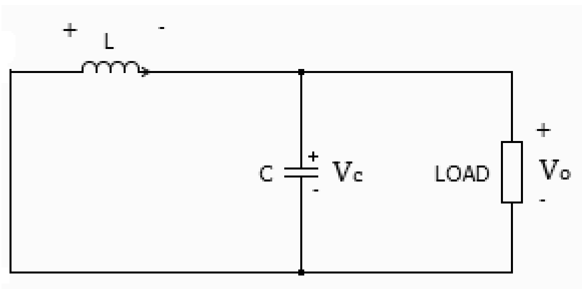


Figure 8: General Circuit of buck converter for mode 2 operation

Using KVL in circuit of mode II operation, voltage across the inductor (V_L) will be;

$$V_L = -V_o \ldots\ldots\ldots\ldots \text{Equation 2.3.5}$$

From equation 2.3.3 and equation 2.3.5,

$$-\Delta I = I_{Lmin} - I_{Lmax} = \int_{T_{on}}^{T} \frac{V_L}{L}\, dt = \frac{-V_o}{L} t_{OFF} \text{........... Equation 2.3.6}$$

Where $t_{OFF} = (1\text{-}D)*T$

From equation 2.3.4 and equation 2.3.6,

$$\frac{V_s - V_o}{L} t_{ON} - \frac{V_o}{L} t_{OFF} = 0$$

$$(V_s - V_o)DT - V_o(1 - D)T = 0$$

$$V_o - V_s D = 0$$

$$D = \frac{V_o}{V_s} \text{ ... ... Equation 2.3.7}$$

Since value of the duty cycle is always less than one and greater than zero (i.e, $0 < D < 1$), so from equation 2.3.7 value of the output voltage (V_O) should be always less than the value of the input (source) voltage (Vs). By adjusting the value of duty cycle desired step down voltage can be obtained.

The value of the average Inductor current and the value of average load current will be same so,

$$I_L(avg) = \frac{V_0}{R} \text{ ... ... Equation 2.3.8}$$

To find the value of critical inductance $I_{L\ min}$ can be use. From wave form shown in figure 6 value of minimum inductor current $I_{L\ min}$ can be calculated using the equation below (Rashid, 2007)-

$$I_{Lmin} = I_{L(avg)} - \frac{|\Delta I_L|}{2} = \frac{V_0}{R} - \frac{V_o(1 - D)T}{2L}$$

$$I_{Lmax} = I_{L(avg)} + \frac{|\Delta I_L|}{2} = \frac{V_0}{R} + \frac{V_o(1 - D)T}{2L}$$

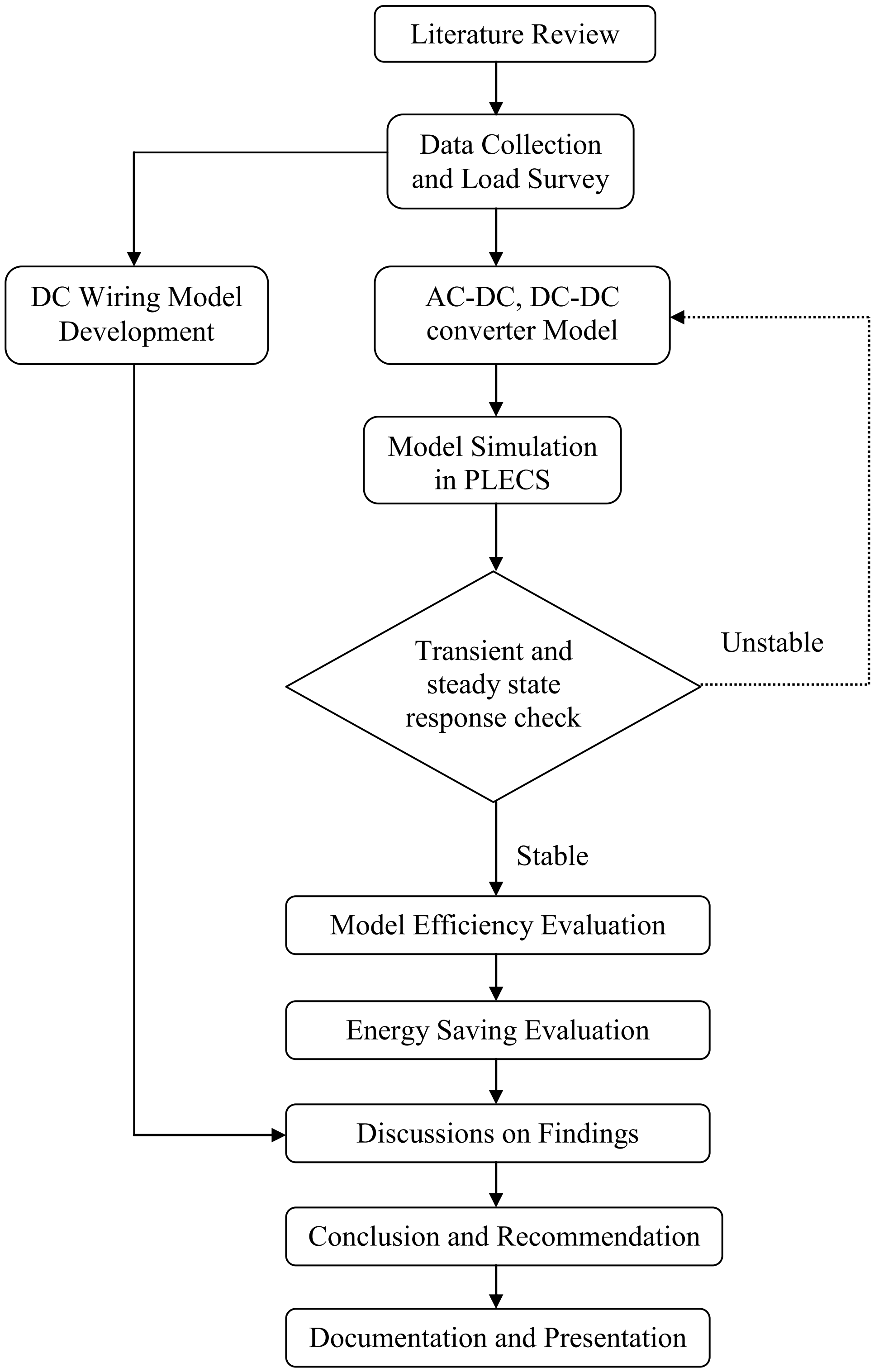
When I_{Lmin} is set to zero then,

$$I_{L(avg)} = \frac{V_0}{R} = \frac{V_o(1 - D)T}{2L}$$

$$L = \frac{V_0(1 - D)T}{2I_{L(avg)}} \text{ ... ... Equation 2.3.9}$$

CHAPTER THREE: RESEARCH METHODOLOGY

This research has been carried out based on the following methodological flowchart:



3.1. Literature Review

First of all, knowing the degree to which past research has been carried out on the field of hybrid supply system play a vital role to identify the problem regarding to hybrid AC-DC supply structure for the buildings. In order to know about the coverage from past research, all related past research articles and related journal papers has been reviewed. Moreover various theories regarding development and operation of the hybrid power supply structure, converter models and DC wiring system has been reviewed. The summary of those research works were listed in chapter two.

3.2. Data Collection

Data related to AC and DC Load of the building is required to develop the simulation model of required converter and regulators needed to develop the DC side supply line of AC-DC hybrid system and to analyze whether the amount of energy that can be save from implementation of hybrid AC-DC supply system or not. This work is intended to use primary data of the building like; types of fixture used in the building, power rating of those fixtures, total numbers of such fixtures used in whole building, location of electrical main panel, distance of distribution board (DB) from main panel, distance of lighting circuit point from respective distribution board etc. In order to collect data regarding to number and types of fixtures used and their respective load, load survey has been carried out. To collect data regarding to distances between circuit point, DB point and main distribution board (MDB), it has been measured with the help of architectural drawing of the building. Details of measured distances of distribution boards (DBs) from main panel and distance of lighting circuit points from respective distribution board are listed below in Table 1.

Table 1: Measured distance of distribution boards (DBs) from main panel and distance of lighting circuit points from respective distribution board

DB	LOCATION	DISTANCE FROM MDB (meter)	LIGHTING CIRCUIT NUMBER	DISTANCE FROM DB (meter)
DB-0	BASEMENT	8	L1	5
			L2	5
			L3	10
			L4	18
			L5	18
DB-1	GROUND FLOOR	15	1L1	15
			1L2	15
			1L3	15
			1L4	15
			1L5	9
			1L6	6
			1L7	8
			1L8	18
			1L9	25
			1L10	35
			1L11	45
			1L12	20
			1L13	25
			1L14	20
			1L15	12
			1L16	10
DB-2	FIRST FLOOR	19	2L1	20
			2L2	13
			2L3	7
			2L4	15
			2L5	14
			2L6	13
			2L7	20
			2L8	10
			2L9	16
			2L10	22
			2L11	22
			2L12	8

DB-3	SECOND FLOOR	23	3L1	13
			3L2	10
			3L3	7
			3L4	8
			3L5	8
			3L6	20
DB-4	THIRD FLOOR	27	4L1	13
			4L2	10
			4L3	8
			4L4	7
			4L5	11
			4L6	13
			4L7	17
			4L8	20
			4L9	14
DB-5	FOURTH FLOOR	31	5L1	13
			5L2	7
			5L3	11
			5L4	14
			5L5	14
			5L6	11
			5L7	8
			5L8	16
			5L9	20
DB-6	FIFTH FLOOR	35	6L1	20
			6L2	15
			6L3	10
			6L4	14
			6L5	12
			6L6	15
			6L7	14
			6L8	13
			6L9	6
			6L10	7

3.3. Load Survey

Load survey of the hospital building has been carried out by direct observation of number of load fixtures and power rating of respective fixtures used in that building. In existing supply system all types of load is fed from 500 KVA Transformer. Details of total numbers of various fixtures, their ratings and total DC loads of different categories are listed in Table 2 and load per distribution boards (DBs) are listed below in Table 3.

Table 2: Details of number and load (Watt) for different load categories

S.N	TYPE OF LOAD	Total Number	Total load (Watt)
1	18 watt LED tube light	578	10404
2	10 watt mirror light	36	360
3	8 watt dome light	83	664
4	50 watt OT light	5	250
5	X-ray view board (15 watt)	25	375
6	Fan (60 watt)	35	2100
7	Computers (100 watt)	27	2700
8	A/C CIRCUIT	50	60000
9	POWER CIRCUIT (with 0.2 Demand factor)	104	62400
10	X-RAY MACHINE (51 KW)	1	51000
11	X-RAY MACHINE (36 KW)	1	36000
12	Lift	1	6700
13	10 KVAUPS	1	
14	500 KVA Transformer	1	
	Total Load (KW)		232.953
	Total lighting Circuit load that can be replaced by DC (KW)		16.853

Since this work focuses on development of AC-DC hybrid supply system in which AC circuit, Power socket circuit, X-ray machines and Lift being supplied from AC line and remaining lighting fixture, computer charging system and Fan will be feed from DC line.

In order to identify the total number of fixture and load that can be replace by DC system, types of fixture and their respective numbers and load per floor has been identified and are listed on Table 3.

3.4. DC Wiring Model Development for the Building

DC wiring model has been developed using AutoCAD software. Detail drawing is shown in Appendix B. Following steps has been carried out to develop the DC wiring model-

3.4.1 Voltage level selection

Selection of voltage level is very crucial for DC network design as it affects the size of wire and breaker. Selection of low voltage will cause the higher current to be flow for same load compare to that of high voltage. Higher load current means need of large size of wire and breaker which is more costly. On the other hand selection of high voltage is restricted due to unavailability of low power consumption devices like LED lights at such high voltage. Mostly commercial DC LED lights are available in three different voltage level 12V/24V and 48V. Since this work is intended to design DC system only for lighting fixture 48V will be effective.

3.4.2 Cable/Wire size selection

Selection of wire size depends on system voltage, allowable voltage drop and length of the wire to be run. Generally size of wire is selected on the basis of current carrying capacity and allowable voltage drop. Normally first approach is applied for selection of wire for AC system in which current carrying capacity of wire is provided in product catalogue in tabular form. However for DC system current carrying capacity as well as voltage drops both must be consider.

In this work size of the wire is firstly selected taking the reference of current carrying capacity of the wire as provided by the product catalogue of the wire manufacturer company (for reference product catalogue of Lumbini Vidyut Udyog Pvt. Ltd. is consider which is shown in Appendix C and then voltage drop for respective wire size has been calculated from following equation-

$$\Delta V_{dc} = 2R\frac{P}{V_{dc}} \quad \text{.................... Equation 3.4.1}$$

Where,

ΔV_{dc} is the voltage drop in DC system.

R is the resistance of wire at 80°C temperature.

If Value of R is provided at other temperature reference than it must be converted at reference of 80°C temperature using following formula.

$$R = R_0(1 + \alpha\Delta T) \quad \text{.................. Equation 3.4.2}$$

Where $\alpha = 0.0039/°C$ for copper

P is the load power in watt.

V_{dc} is the DC system voltage.

Voltage drop that has been calculated is then compared with the allowable voltage drop and if voltage drop calculated lies within the allowable limit then the selected wire size is correct if not increased value of wire size is to be chosen and again voltage drop for respective wire size is to be calculated. This process is continuing until desire value of wire is obtained.

According to National Electrical Code (2011), voltage drop between entry point of supply at the building and end use devices or fixtures connected at that building should be no more than 4% of the available voltage supply for that building.

For this project length between supply terminals to fixed current using equipment is divided into three sections and hence voltage drop for each section is categories as follow-

- Length between lighting circuit points to respective fixtures. In this building 2*2.5 sq.mm copper flexible wire is used for this section which as an estimated DC resistance of 0.00887 ohm/meter as per reference catalogue. Assuming maximum length for the lighting fixture of this section of about 20 meter calculated value of voltage drop will be 0.1%. So for this work wire of this section remain unchanged.
- Length between distribution boards to the respective lighting circuit points where new wire is needed to be installed. For this allowable voltage drop is assumed to be 2%.
- Length between main distribution board which is near supply terminal of DC source (here AC-DC, DC-DC converter) to distribution boards where new cable is needed to be installed. For this allowable voltage drop is assumed to be 2%.

Based on the above information the size of the wire for each segment has been calculated.

List of the wire sizes based on current carrying capacity and voltage drop for respective wire size for supply to each distribution board from MDB are listed below in table 3 and list of the wire sizes (corrected) require to satisfy the allowable voltage drop of 2% are listed below in table 4.

Table 3: Wire sizes based on Ampacity and voltage drop for supply to each distribution board from MDB

System Voltage			48V DC				
Allowable voltage drop			2%				
DBs	**Total load (watt)**	**load current (Amp)**	**wire size based on Ampacity (sq.mm)**	**DC resistance at 80 deg C (ohm/meter)**	**length of wire required from MDB (meter)**	**voltage drop (Volt)**	**voltage drop (%)**
DB-0	756	15.75	4	0.00612064	8	1.542	3.213
DB-1	4793	99.854	50	0.00047632	15	1.427	2.973
DB-2	2206	45.958	16	0.00149314	19	2.608	5.432
DB-3	1652	34.417	10	0.00235694	23	3.731	7.774
DB-4	1614	33.625	10	0.00235694	27	4.279	8.916
DB-5	1982	41.292	16	0.00149314	31	3.822	7.964
DB-6	1932	40.25	10	0.00235694	35	6.640	13.834
DB-7	1918	39.958	10	0.00235694	35	6.592	13.734

Table 4: Wire sizes required to satisfy the allowable voltage drop of 2%.

System Voltage			48V DC				
Allowable voltage drop			2%				
DBs	**Total load (watt)**	**load current (Amp)**	**wire size Required (sq.mm)**	**DC resistance at 80 deg C (ohm/meter)**	**length of wire required from MDB (meter)**	**voltage drop (Volt)**	**Voltage drop (%)**
DB-0	756	15.75	6	0.0040722	8	0.831	1.7325
DB-1	4793	99.854	50	0.00047632	15	1.156	2.40898
DB-2	2206	45.958	35	0.00068364	19	0.967	2.01564
DB-3	1652	34.417	35	0.00068364	23	0.877	1.82726
DB-4	1614	33.625	35	0.00068364	27	1.006	2.09568
DB-5	1982	41.292	50	0.00047632	31	0.988	2.05875
DB-6	1918	39.958	50	0.00047632	35	1.079	2.2493

Similarly the wire sizes based on ampacity and voltage drop (to satisfy the allowable voltage drop of 2%) for respective wire size for supply to each lighting circuit points from respective distribution boards are listed below in table 5.

Table 5: List of the wire sizes based on ampacity and voltage drop for supply to each lighting circuit points from respective distribution boards.

DB	Lighting circuit number	Load per circuit (watt)	Load current with extra 20% load (Amp)	Wire size required (sq.mm)	DC resistance at 80° C (Ω/m)	Distance from DB (meter)	Voltage drop (%)
DB-0	L1	180	4.5	2.5	0.00914	5	0.857
	L2	144	3.6	2.5	0.00914	5	0.685
	L3	144	3.6	2.5	0.00914	10	1.371
	L4	144	3.6	4	0.00612	18	1.652
	L5	144	3.6	4	0.00612	18	1.652
DB-1	1L1	230	5.75	6	0.00407	15	1.463
	1L2	216	5.4	4	0.00612	15	2.065
	1L3	90	2.25	2.5	0.00914	15	1.285
	1L4	54	1.35	2.5	0.00914	15	0.771
	1L5	90	2.25	2.5	0.00914	9	0.771
	1L6	90	2.25	2.5	0.00914	6	0.514
	1L7	160	4	2.5	0.00914	8	1.219
	1L8	174	4.35	4	0.00612	18	1.996
	1L9	128	3.2	4	0.00612	25	2.04
	1L10	138	3.45	6	0.00407	35	2.048
	1L11	138	3.45	6	0.00407	45	2.634
	1L12	216	5.4	6	0.00407	20	1.832
	1L13	144	3.6	6	0.00407	25	1.527
	1L14	100	2.5	2.5	0.00914	20	1.904
	1L15	216	5.4	4	0.00612	12	1.652
	1L16	114	2.85	2.5	0.00914	10	1.085
DB-2	2L1	72	1.8	2.5	0.00914	20	1.371
	2L2	198	4.95	4	0.006120	13	1.641
	2L3	168	4.2	2.5	0.00914	7	1.123
	2L4	214	5.35	4	0.00612	15	2.046
	2L5	54	1.35	2.5	0.00914	14	0.720
	2L6	92	2.3	2.5	0.00914	13	1.139
	2L7	216	5.4	6	0.00407	20	1.832
	2L8	72	1.8	2.5	0.00914	10	0.685
	2L9	54	1.35	2.5	0.00914	16	0.822
	2L10	224	5.6	6	0.00407	22	2.09
	2L11	70	1.75	2.5	0.00914	22	1.466
	2L12	268	6.7	2.5	0.00914	8	2.042

DB-3	3L1	270	6.75	6	0.00407	13	1.488
	3L2	242	6.05	4	0.00612	10	1.542
	3L3	168	4.2	2.5	0.00914	7	1.12
	3L4	268	6.7	2.5	0.00914	8	2.042
	3L5	216	5.4	2.5	0.00914	8	1.645
	3L6	132	3.3	4	0.00612	20	1.683
DB-4	4L1	180	4.5	4	0.00612	13	1.491
	4L2	242	6.05	4	0.00612	10	1.542
	4L3	216	5.4	2.5	0.00914	8	1.645
	4L4	168	4.2	2.5	0.00914	7	1.12
	4L5	44	1.1	2.5	0.00914	11	0.461
	4L6	152	3.8	2.5	0.00914	13	1.882
	4L7	88	2.2	2.5	0.00914	17	1.424
	4L8	132	3.3	4	0.00612	20	1.683
	4L9	90	2.25	2.5	0.00914	14	1.2
DB-5	5L1	198	4.95	4	0.00612	13	1.641
	5L2	168	4.2	2.5	0.00914	7	1.12
	5L3	116	2.9	2.5	0.00914	11	1.215
	5L4	278	6.95	6	0.00407	14	1.650
	5L5	322	8.05	6	0.00407	14	1.912
	5L6	80	2	2.5	0.00914	11	0.838
	5L7	180	4.5	2.5	0.00914	8	1.371
	5L8	88	2.2	2.5	0.00914	16	1.341
	5L9	72	1.8	2.5	0.00914	20	1.371
DB-6	6L1	72	1.8	2.5	0.00914	20	1.371
	6L2	134	3.35	2.5	0.00914	15	1.914
	6L3	144	3.6	2.5	0.00914	10	1.371
	6L4	140	3.5	2.5	0.00914	14	1.866
	6L5	126	3.15	2.5	0.00914	12	1.44
	6L6	216	5.4	4	0.00612	15	2.065
	6L7	162	4.05	4	0.00612	14	1.446
	6L8	144	3.6	2.5	0.00914	13	1.783
	6L9	144	3.6	2.5	0.00914	6	0.822
	6L10	144	3.6	2.5	0.00914	7	0.96

3.4.3 Location selection for placement of DBs

Location selection for placement is also crucial as it play a vital role reduction of wire length which in turn helps to minimize the voltage drop and hence help to reduce the size of wire that is required. For this work location of DBs has been set to middle of the building floor which is shown in the lighting layout drawing in Appendix B.

3.4.4 Fuse size selection

Although 48V DC system does not need any kind of protection system against direct contacts (Sannino, et al., 2003) however protection system for lighting circuit protection is essential. Selection of proper size of fuse is very essential for the protection of the lighting circuit, as higher sizes of fuse will not protect the circuit and lower size of fuse make obstruction even in normal operation. Fuse of current rating 25% more than the full load current has been selected.

3.5. Development of simulation model in PLECS

Converter and controller required to operate DC system of AC- DC hybrid system has been designed, modeled and it is simulated using Piecewise Linear Electrical Circuit Simulation (PLECS) software. Details of model development are described in chapter four in details.

3.6. Certainty and Sensitivity analysis using Crystal Ball software

Amount of energy that can be save using hybrid power supply structure depends on factors like amount of load that can be replaced by DC load, size of UPS system, time of operation of such load and percentage of load supplied at any time. Some of these factor are uncertain so there is a chances of energy saving being changes. To know about the certainty or probability of energy saving being positive and to know about the sensitivity or contribution of such parameters in the variation in amount of energy saving, simulation has been performed and details of which is described in chapter five in details.

3.7. Discussion on Findings

The results of load survey, DC wiring model results, PLECS model simulation results and Crystal Ball simulation results are explained in detail in chapter five.

CHAPTER FOUR: DEVELOPMENT OF SIMULATION MODEL IN PLECS

4.1 AC-DC converter circuit

Since building has existing three phase power supply line and tapping of load of about 15KW from single phase supply will cause the unbalance of the system. So this work is intended to use three phase full bridge rectifier.

Output DC voltage for three phase full bridge rectifier can be found from the formula below-

$$V_{dc}(avg) = 1.35 \times V_L = 2.338 \times V_P \text{.............................} \text{Equation 4.1}$$

For our system Phase voltage $V_P = 220V$, so average DC output voltage will be;

$$V_{dc}(avg) = 514.36V$$

For load of 15KW,

$$I_{dc}(avg) = 29.16 \text{ Amp}$$

So power diode must be chosen that satisfy the voltage rating and current rating as calculated above. For this work power diode (1N1190) has been chosen as a reference which has following specifications-

Repetitive Peak Reverse Voltage (V_{RRM}) = 600V

Continuous forward current (I_F) = 35A

Diode forward voltage (V_F) = 1.2V

Forward resistance (R_{on}) = 0.03428Ω

Due to the voltage drop of 2.4V (=2*1.2V) in practical diode the actual output voltage will be about 512V.

4.2 Filter circuit

DC output voltage obtained from rectifier circuit contains high amount of pulse. In order to smooth out the pulsating DC output, an inductor-capacitor (L-C) filter has been designed in which capacitor helps to smooth out the voltage pulse and inductor helps to smooth out the current pulse.

Taking reference of past research, to design L-C filter, capacitor value is normally selected to be 25 % of the value which is needed for the reduction of the output ripple within allowable value (about 3%) when used alone in the filter circuit (capacitor filter circuit only) and then value of inductor is selected randomly until output ripple factor will obtained within 3% (Pyakuryal & Matin, 2013).

The output ripple factor can be obtained from (Pyakuryal & Matin, 2013)

$$\mathrm{RF}(\%) = \frac{0.707 \times \text{peakvalue of ripple voltage } (\mathrm{V_p})}{\text{Average DC output voltage } (\mathrm{V_0})} \times 100 \ldots\ldots \text{Equation 4.2.1}$$

Figure 9 below shows the sample waveform of voltage signal.

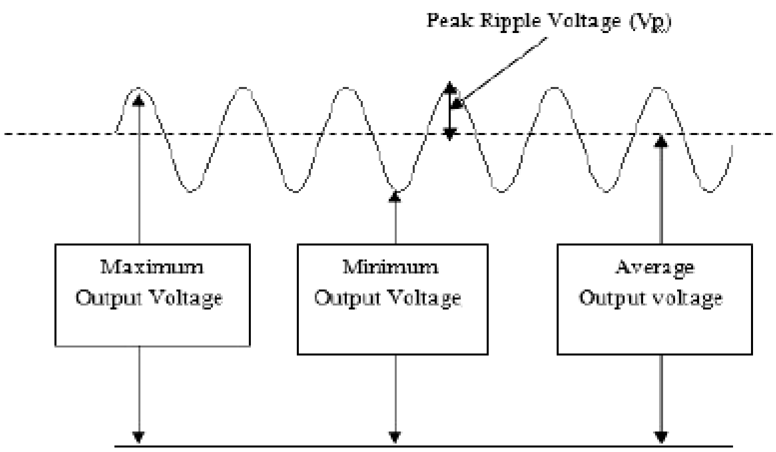


Figure 9: Voltage waveform showing ripple

And required value of capacitor to reduced the ripple within the allowable limit when used alone in the filter circuit can be calculated from (Rashid, 2007)

$$\mathrm{RF} = \frac{1}{\sqrt{2} \times (2\mathrm{f_r RC} - 1)} \ldots\ldots\ldots\ldots\ldots \text{Equation 4.2.2}$$

Where, C is required value of capacitance (F), RF is the allowable ripple factor (about 3%), R is the value of load resistance in ohm and f_r is the frequency of output ripple (=2×frequency of AC source).

Using this approach value of inductor and capacitor required to limit the ripple factor within 3% are found to be 10μH and 1000μF respectively and the developed circuit model of AC-DC converter along with filter circuit in PLECS software is shown below in figure 10.

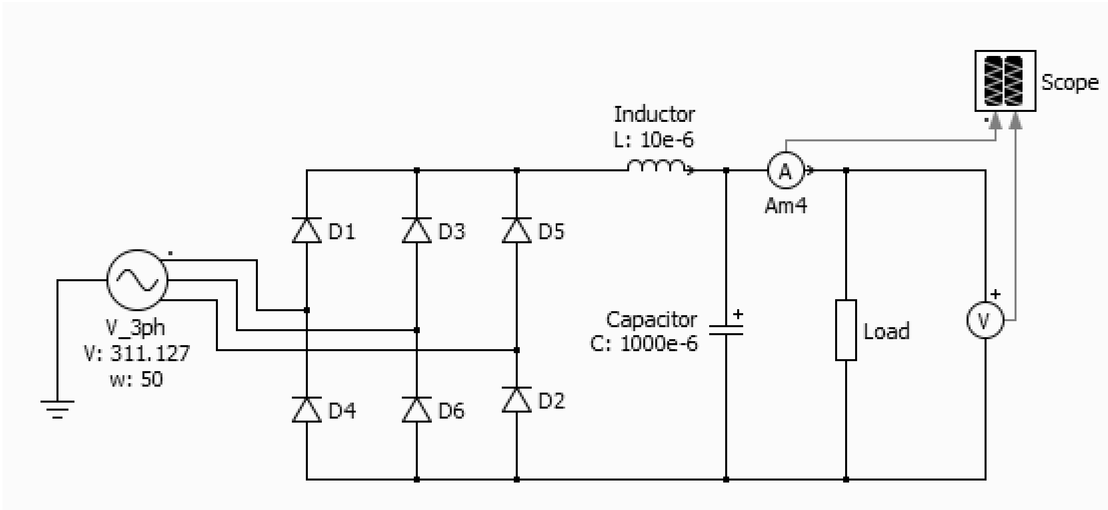


Figure 10: Three phase full bridge rectifier with filter circuit

4.3 DC-DC Buck Converter Circuit

4.3.1 Open Loop Buck Converter

The rectified output voltage (512V DC) will be the input voltage for DC-DC buck converter where 512V DC is step down to 48V DC.

In order to design open loop buck converter required parameters were calculated using given (or observed) parameters as follow-

Input voltage (V_s) = 512 V DC

Output voltage (V_0) = 48 V DC

Load power (P) = 15 KW

Minimum load (P_{min}) =1 KW (assumed)

Maximum load (P_{max}) = 20 KW (assumed)

Switching frequency (f_s) = 100 kHz (assumed)

Output voltage ripple factor (K_p) = 1% (assumed)

$$\text{Duty cycle (D)} = \frac{V_o}{V_s} = 0.09375$$

$$\text{Average load current (Iavg)} = \frac{P}{V_0} = 312.5A$$

$$\text{Minimum load current (Imin)} = \frac{P_{min}}{V_0} = 20.8A$$

$$\text{Load Resistance (RL)} = \frac{V_0^{\,2}}{P} = 0.1536\ \Omega$$

$$\text{Inductance (L)} = \frac{V_0(1-D)T}{2I_{min}}) = \frac{48(1-0.09375)}{2*20.8*100000} = 10\mu H$$

$$\text{Capacitance (C)} = \frac{V_0(1-D)}{8L\Delta Vf^2} = \frac{(1-0.09375)}{8*0.7*0.01*1000000000} = 1618\ \mu F$$

$$\text{Capacitance (C)} = 2000\mu F\ \text{(selected)}$$

$$\text{Frequency of pulse generator} = \frac{f_s}{D} = 1066667\ \text{Hz}$$

Using above calculated parameter rectifier and buck converter circuit (for open loop system) has been designed.

4.3.2 Small Signal Analysis of DC-DC Buck converter

By assuming converter operated at CCM, by assuming the ideal switches with no switching losses, by assuming semiconductor switches with zero lead inductance and capacitance and by neglecting the parasitic resistance of inductor and capacitor small signal analysis has been carried out. From the small signal analysis transfer function of control (duty cycle) to output voltage [$V_o(s)/d(s)$], transfer function of inductor current to output voltage [$V_o(s)/i_l(s)$], transfer function of control to inductor current [$i_l(s)/d(s)$] and transfer function of input voltage to output voltage [$V_o(s)/V_i(s)$] which is further necessary to design close loop controller parameter of buck converter has been obtained. Circuit model for small signal analysis buck converter at CCM is shown in figure 11 below.

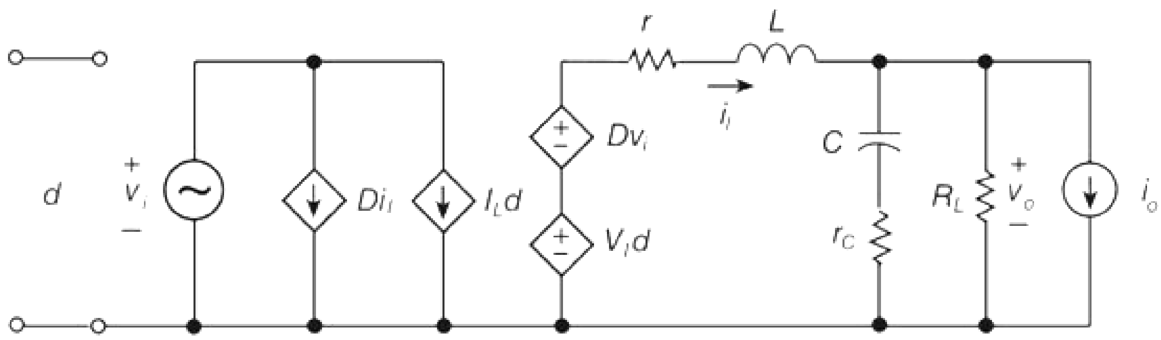


Figure 11: Circuit model for small signal analysis of buck converter at CCM (Kazimierczuk, 2016)

Let,

$$z_1 = r + SL \; and \;\; z_2 = \frac{R_L(r_c + \frac{1}{SC})}{R_L + \; r_c + \frac{1}{SC}}$$

Neglecting ESR of inductor (r) and capacitor (r_c) then,

$$Z_1 = SL \; and \; Z_{2=} \frac{R_L}{1 + \; R_L \, CS}$$

In circuit of small signal model as shown above in figure 11, considering zero ac input voltage (V_i) and zero ac load current signal (i_0) gives the circuit block to find transfer function of duty cycle to output voltage, transfer function of inductor current to output voltage and transfer function of inductor current to output voltage (Kazimierczuk, 2016). Reduced form of small signal model circuit for zero ac input voltage (V_i) and zero ac load current signal (i_0) is shown below in figure 12.

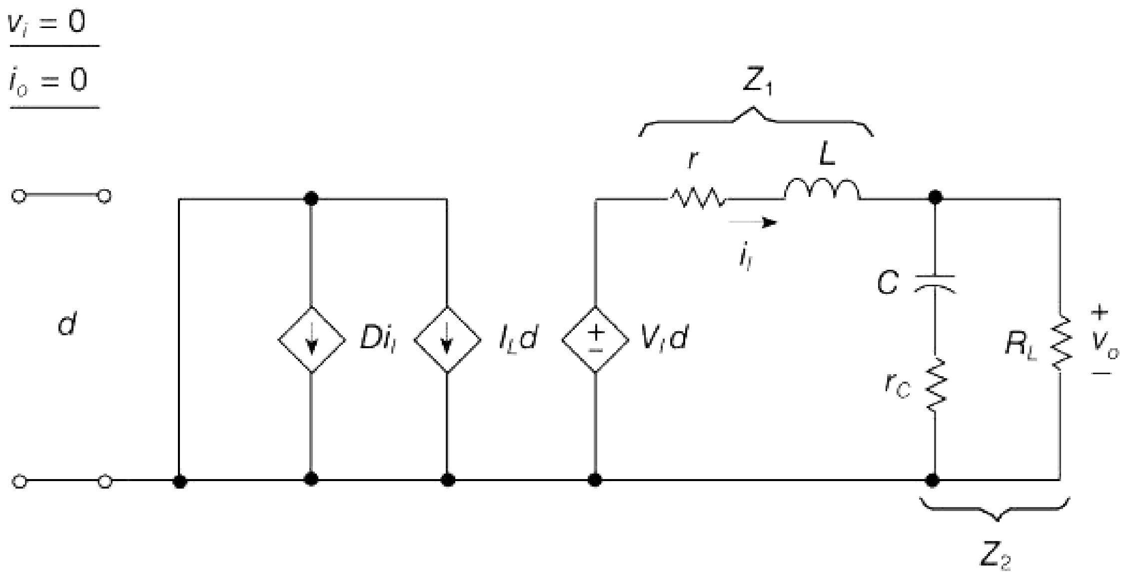


Figure 12: Circuit model for small signal analysis of buck converter to find open loop duty cycle to output voltage transfer function

As shown from circuit in figure 12, duty cycle to output voltage transfer function $[T_p(S)]$ can be obtained as below-

$$T_{dv}(S) = \left.\frac{V_0(S)}{d(s)}\right|_{V_i = i_o = 0}$$

$$T_{dv}(S) = V_I \frac{Z_2(S)}{Z_1(S) + Z_2(S)}$$

$$T_{dv}(S) = \frac{V_I . R_L}{R_L LCS^2 + LS + R_L} \ldots \ldots \ldots . Equation\ 4.3.1$$

Now, Duty cycle to inductor current transfer function [$T_{di}(S) = \frac{i_l(S)}{d(s)}\Big|_{V_i = i_o = 0}$] can be obtained as-

$$i_l(S) = \frac{V_i d(S)}{Z_1(S) + Z_2(S)}$$

$$\frac{i_l(S)}{d(s)} = \frac{V_i}{SL + \frac{R_L}{1 + R_L CS}} = \frac{V_i(1 + R_L CS)}{R_L CLS^2 + LS + R_L} \ldots \ldots \ldots . Equation\ 4.3.2$$

Similarly, inductor current to output transfer function [$T_{iv}(S) = \frac{V_o(S)}{i_l(S)}\Big|_{V_i = i_o = 0}$] can be obtained as-

$$T_{iv}(S) = \frac{V_o(S)}{i_l(S)} = Z_2 = \frac{R_L}{R_L CS + 1} \ldots \ldots \ldots . Equation\ 4.3.3$$

Similarly input voltage to output voltage transfer function can be found by setting d = 0 and $i_0 = 0$ (Kazimierczuk, 2016). To find input voltage to output voltage transfer function small signal model circuit is shown in figure 13 below-

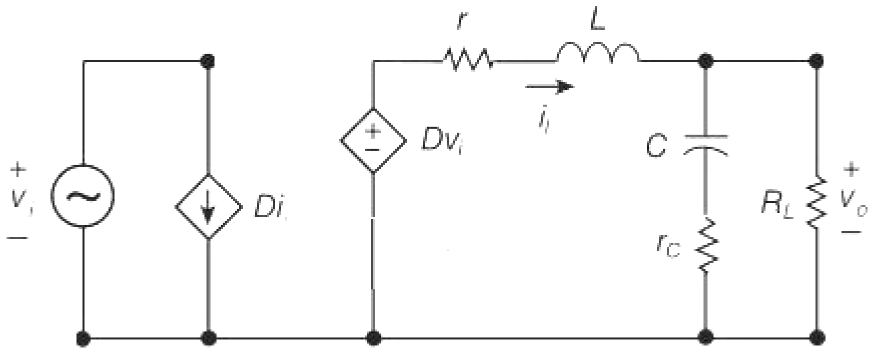


Figure 13: Small signal circuit model of PWM buck connecter to find open loop input to output transfer function

$$T_{V_iV_o}(S) = \left.\frac{V_o(S)}{V_i(S)}\right|_{d=i_o=0} = \frac{D \times Z_2(S)}{Z_1(S) + Z_2(S)}$$

$$\frac{V_o(S)}{V_i(S)} = \frac{DR_L}{R_LLCS^2 + LS + R_L} \ldots\ldots\ldots.Equation\ 4.3.4$$

4.3.3 Closed loop control design for DC-DC Buck Converter

In order to maintain constant output voltage as well as to regulate output current from designed buck converter model, closed loop control block has been needed to be designed. For this work to design closed loop control block the two loop average current control with PI controller has been used. Block diagram of two loop average current control is shown in figure 14.

This type of control approach consists of two control loops one is outer voltage control loop where output voltage of the buck converter model is first compared with a preset value of reference voltage (desire constant voltage) and any deviation results an error signal. Then obtained error signal is feed to PI controller which is processed to generate reference value of the inductor current signal which helps to regulate output voltage. And another is inner control loop to control the current. In this inner control loop the inductor current is compared with the reference signal of inductor current generated from outer control loop. The final control signal then feed to PWM generator in order to control the switch. Parameters of PI controller (K_p and K_I) are estimated using bode plot.

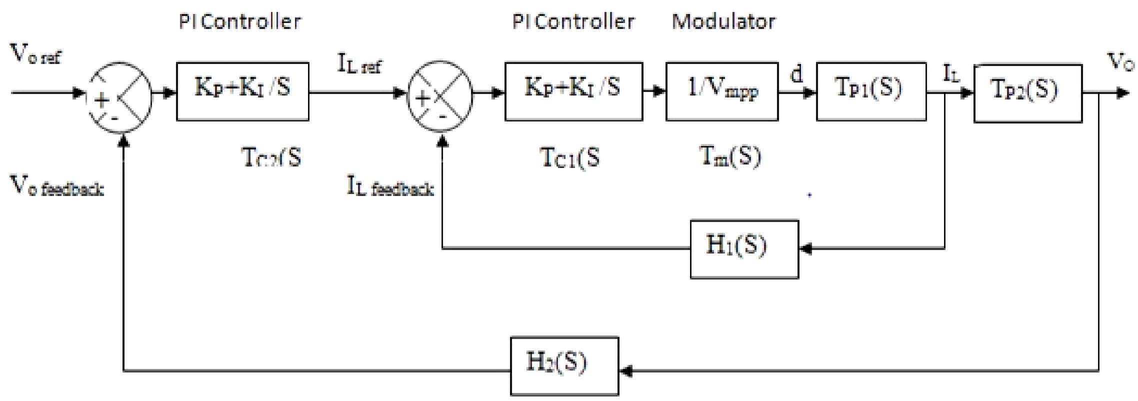


Figure 14: General Block diagram of for two-loop average current control system

4.3.3.1 Inner current control loop design

Figure 15 below represents the general block diagram for inner control loop. In the figure below the block represented by $T_{P1}(s)$ is the transfer function of duty cycle (control) to inductor current, transfer function of modulator is represented by $T_M(s)$ and $T_{C1}(s)$ is the transfer function of PI controller.

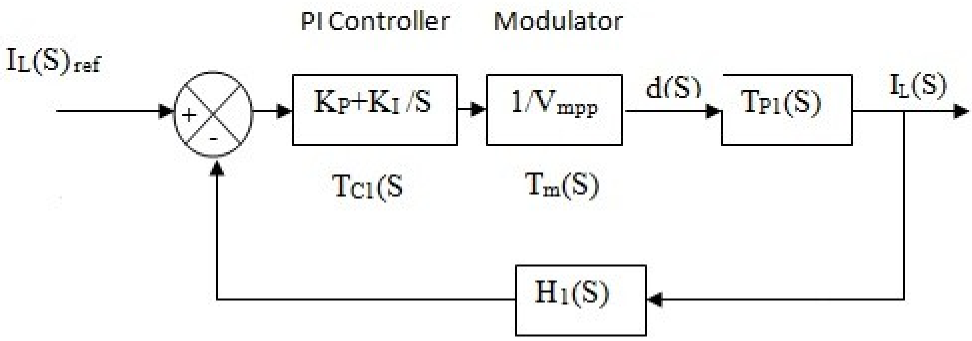


Figure 15: General block diagram for inner current control loop

In current control loop PI controller parameters (i.e, K_p and K_i) has been estimated for achieving stability criteria. To design inner control block, transfer function $T_{P1}(s)$ has been derived using small signal analysis buck converter for CCM and neglecting parasitic resistances of passive components which can be expressed as (Kazimierczuk, 2016)

$$T_{P1}(s) = \frac{i_l(S)}{d(S)} = \frac{V_I(1 + R_L CS)}{R_L LCS^2 + LS + R_L}$$

Where, R_L is the load resistance in ohm, C and L are the value of capacitor in Farad and inductor in Henry that is used in the buck converter circuit. By using those values in above transfer function [$T_{P1}(s)$], it will be-

$$T_{P1}(s) = \frac{5.5 \times 10^8 (S + 3255)}{S^2 + 3300S + 5.12 \times 10^7}$$

Bode plot of $T_{P1}(s)$ is shown below in figure 16. From bode plot of $T_{P1}(s)$ phase margin (PM) of 90^O is obtained at cross over frequency (ω_c = 550 M rad/sec).

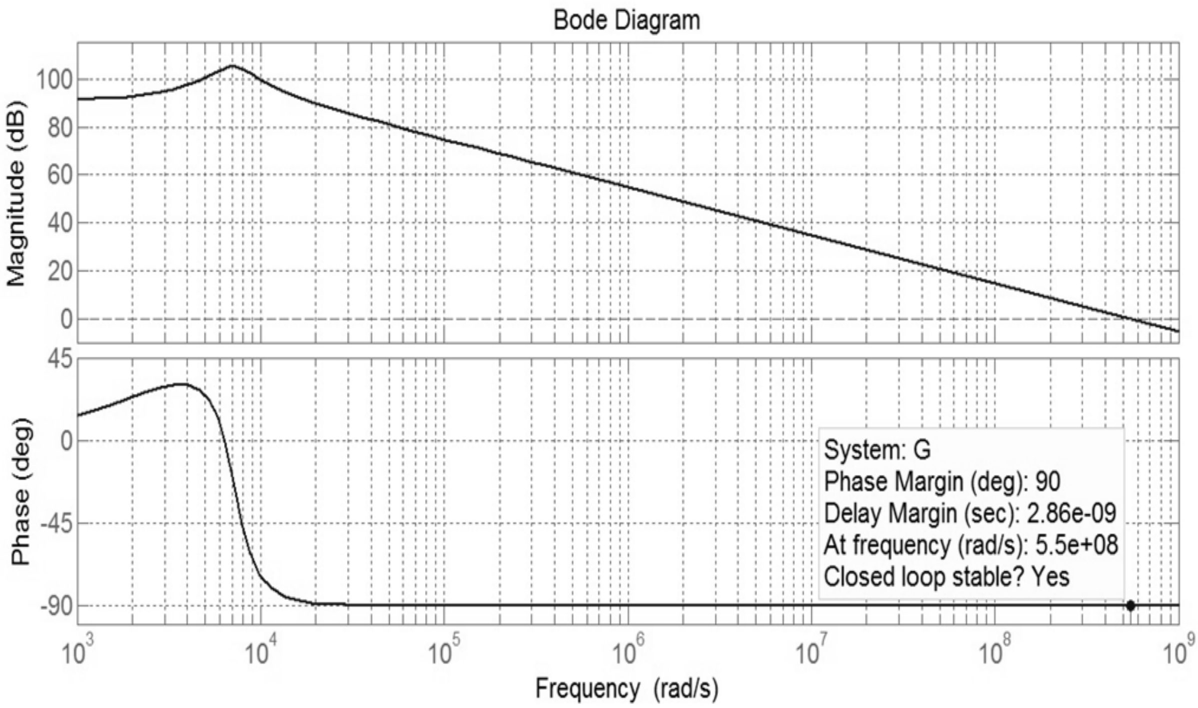


Figure 16: Bode plot of the control (duty cycle) to current transfer function [$T_{P1}(s)$]

Designing for 100% efficiency current loop feedback gain [$H_1(s)$] will be 1, assuming amplitude of modulating signal ($V_{m\ p\text{-}p}$) of 1V, transfer function of modulator [$T_M(s)$] is also assumed to be 1 and transfer function of PI controller for inner current control loop can be obtained as,

$$T_{c1}(S) = K_p + \frac{K_i}{S}$$

To minimize the steady state error and to improve low frequency gain PI controller has been designed to have phase margin of 60^0 at selected crossover frequency of 50 kHz (ω_c = 314 k rad/s).

Now for inner current loop the open loop transfer function [$T_{OL1}(S)$] can be obtained as,

$$T_{OL1}(S) = T_{c_1}(S).T_m(S).T_{p1}(S).H_1(S)$$

$$T_{OL1}(S) = \frac{K_p(S + \frac{K_i}{K_p})}{S} \times \frac{5.5 \times 10^8(S + 3.255 \times 10^3)}{(S^2 + 3300\,S + 5.12 \times 10^7)} \ldots\ldots\ldots\ldots \text{Equation 4.3.5}$$

$$T_{OL1}(j\omega c) = \frac{1750\, K_p\left(j3.14\times10^5 + \frac{K_i}{K_p}\right)(j3.14\times10^5 + 3255)}{(-j9.85\times10^{10} - 1.036\times10^9)}$$

The parameter of PI controller (K_p and K_i) has been calculated by applying gain condition and phase angle condition.

From gain condition, the open loop system gain should be unity at designed cross over frequency. So,

$$|T_{OL1}(S)| = 1$$

$$\left|1750\, K_p\left(j3.14\times10^5 + \frac{K_i}{K_p}\right)(j3.14\times10^5 + 3255)\right| = |(-j9.85\times10^{10} - 1.036\times10^9)|$$

$${K_p}^2\left[9.86\times10^{10} + \left|\frac{K_i}{K_p}\right|^2\right] = 3.213\times10^4 \dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation 4.3.6}$$

Using phase angle condition, according to which phase angle of the open loop system should be $[T_{OL1}(S)] = PM - 180^0$ at designed cross over frequency. PI controller has been designed to have PM of 60^0 for open loop system at the gain crossover frequency of 50 kHz (ω_c = 314 k rad/s). So, for 60^0 phase margin phase angle of the open loop will be,

$$\angle T_{OL1}(S) = 60^0 - 180^0 = -120^0.$$

$$\angle\left(\frac{1750\, K_p\left(j3.14\times10^5 + \frac{K_i}{K_p}\right)(j3.14\times10^5 + 3255)}{(-j9.85\times10^{10} - 1.036\times10^9)}\right) = -120^0$$

Or,

$$\tan^{-1}\left(\frac{3.14\times10^5\, K_p}{K_i}\right) + \tan^{-1}\left(\frac{3.14\times10^5}{3255}\right) - \tan^{-1}\left(\frac{-9.85\times10^{10}}{-1.036\times10^9}\right) = -120^0$$

Or,

$$\frac{K_i}{K_p} = 181288 \dots\dots\dots\dots\dots.. \text{Equation 4.3.7}$$

Solving equation 4.3.6 and equation 4.3.7 gives the value of $K_p = 0.0005$ and $K_i = 90$.

Stability of the current control loop for above calculated value of PI controller parameters has been checked by plotting bode for open loop transfer function of current control loop which can be obtained after replacing value of K_p and K_i in equation 4.3.5.

After replacing the value of K_p and K_i in equation 4.3.5 gives,

$$T_{OL1}(S) = \frac{2.75 \times 10^5 S^2 \ + 5.07 \times 10^{10} + 1.62 \times 10^{14})}{S^3 + 3300\ S^2 + 5.12 \times 10^7 S)}$$

Bode plot of open loop transfer function of current control loop $[T_{OL1}(S)]$ is shown below in figure 17, which shows that positive phase margin of 60° as per designed has been obtained at crossover frequency of 317 k rad/s and positive margin shows the system is stable.

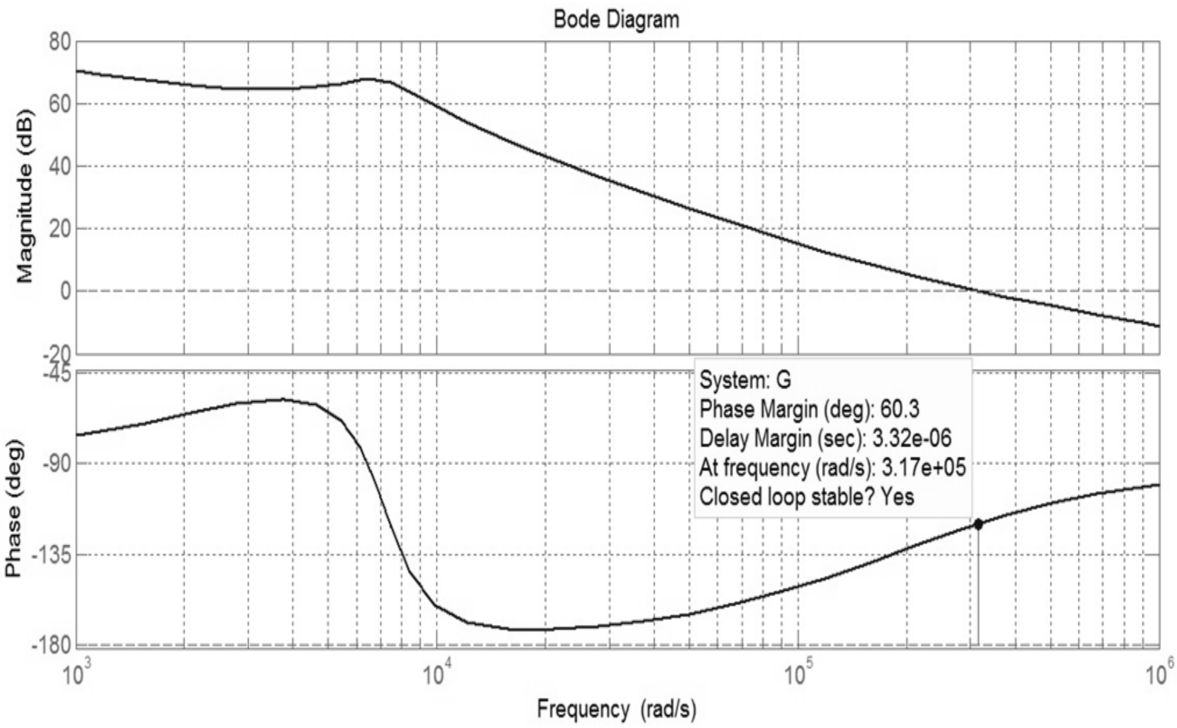


Figure 17: Bode plot of open loop transfer function of current control loop

4.3.3.2 Outer voltage loop design

Figure 18 below represents the general block diagram for outer voltage control loop. The block $T_{P2}(s)$ here represents the transfer function of inductor current to output voltage and $T_{C2}(s)$ is the transfer function of PI controller.

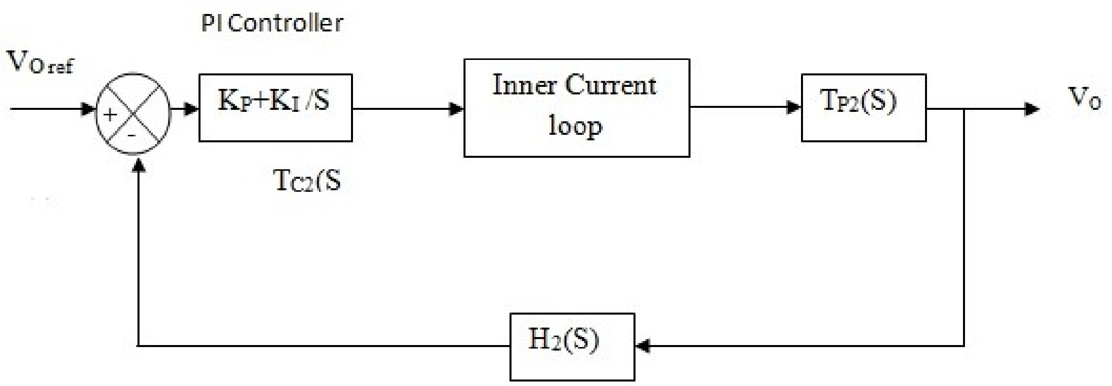


Figure 18: General block diagram of outer voltage control loop

In voltage control loop also the parameters of PI controller (K_p and K_i) has to be estimated by achieving stability criteria. To design controller, the transfer function of inductor current to output voltage T_{P2}(s) has been derived from small signal analysis after neglecting the parasitic resistances of passive components which can be expressed as (Kazimierczuk, 2016)

$$T_{P2}(S) = \frac{V_0(S)}{i_l(S)} = \frac{R_L}{(1 + R_L CS)} = \frac{0.1536}{1 + 3.072 \times 10^{-4} S} \ldots\ldots\ldots.. \text{Equation 4.3.8}$$

From bode plot of transfer function [T_{P2}(s)] as shown in Figure 19 system found to be unstable.

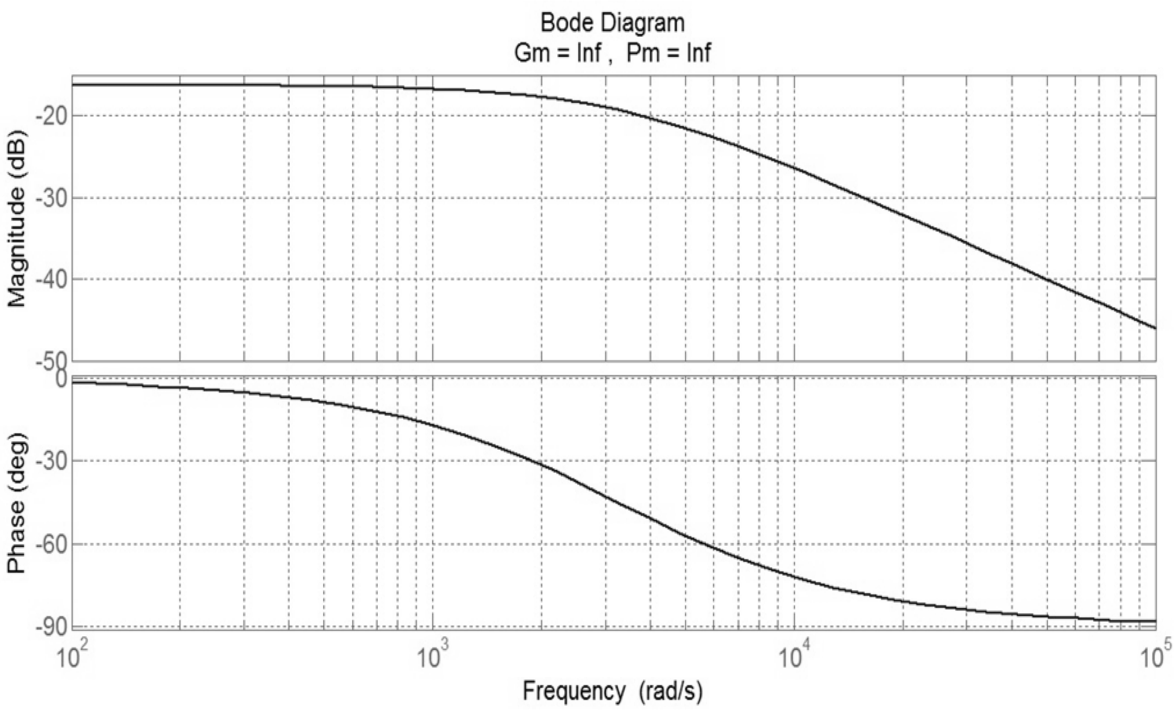


Figure 19: Bode plot for inductor current to output voltage transfer function [T_{P2}(s)]

Now a PI controller as a compensator has been designed to enhance the low frequency gain by maintaining the PM of 60^0 at designed crossover frequency of 1 kHz ($\omega_c = 6.283\,\mathrm{k\,rad/s}$) which is almost 50 times slower than inner current control loop. For outer voltage control loop transfer function of PI controller is of same nature to that of inner loop but with different value of controller parameters, $.e, T_{C2}(S) = K_{P2} + \frac{K_{I2}}{S}$. Magnitude of reference output voltage signal is selected to be 10 V ($V_{oRef} = 10v$) so, feedback gain will be- $H_2(S) = \frac{10}{48} = 0.208$.

Since inner loop being designed faster (about 50 times faster than of outer loop for this research) so the inner current loop dynamics can be neglected in the design of outer voltage loop (Prasanna & Rathore, 2013).

For the open loop transfer function of the outer voltage control loop it can be expressed as,

$$T_{OL2}(S) = T_{c2}(S).T_{P2}(S).\ H_2(S)$$

$$T_{OL2}(S) = 0.208 \times \frac{0.1536}{1 + 0.0003072\,S} \times \frac{K_p}{S} \times \left(S + \frac{K_i}{K_p}\right)$$

$$T_{OL2}(S) = \frac{104K_p\left(S + \frac{K_i}{K_p}\right)}{S(S + 3252)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4.3.9}$$

$$T_{OL2}(j\omega_c) = \frac{0.0165K_p\ (j\,6283 + \frac{K_i}{K_p})}{j3252 - 6283} \ldots\ldots\ldots\ldots \text{Equation 4.3.10}$$

Applying gain condition, the system gain should be unity at crossover frequency, i.e.$|T_{OL2}(S)| = 1$. So,

$$\left|0.0165K_p\ (j\,6283 + \frac{K_i}{K_p})\right| = |(j3252 - 6283)|$$

$$K_p^{\,2} \times \left[3.95 \times 10^7 + \left|\frac{K_i}{K_p}\right|^2\right] = 1.83\ \times 10^{11} \ldots\ldots\ldots\ldots\ldots \text{Equation 4.3.11}$$

Applying phase angle condition, phase angle of the open loop system at crossover frequency should be equals to $PM - 180^0 = 60^0 - 180^0 = -120^0$.

$$\angle \frac{0.0165K_p\,(j\,6283 + \frac{K_i}{K_p})}{j3252 - 6283} = -120^0$$

Or,

$$\tan^{-1}\left(6283\frac{K_p}{K_i}\right) - \tan^{-1}\left(\frac{3252}{-6283}\right) = -\,120^0$$

Or,

$$\frac{K_i}{K_p} = 9811.4 \ldots\ldots\ldots\ldots\ldots \text{Equation 4.3.12}$$

Solving equation 4.3.11 and equation 4.3.12, gives the value of $K_p = 36.7$ and $K_i = 360216$.

Now stability of the voltage control loop for above calculated value of PI controller parameters has been checked by plotting bode for open loop transfer function of voltage control loop which can be obtained after replacing value of K_p and K_i in equation 4.3.9.

Replacing value of K_p and K_i for voltage control loop in equation 4.3.9 gives,

$$T_{OL2}(S) = \frac{3816.8\,S\ + 3.74 \times 10^7}{S^2 + 3252S)}$$

Bode plot of open loop transfer function of voltage control loop $[T_{OL2}(S)]$ is shown below in figure 20, which shows that positive phase margin of 60° as per designed has been obtained at crossover frequency of 6.28 k rad/s and positive margin shows the system is stable.

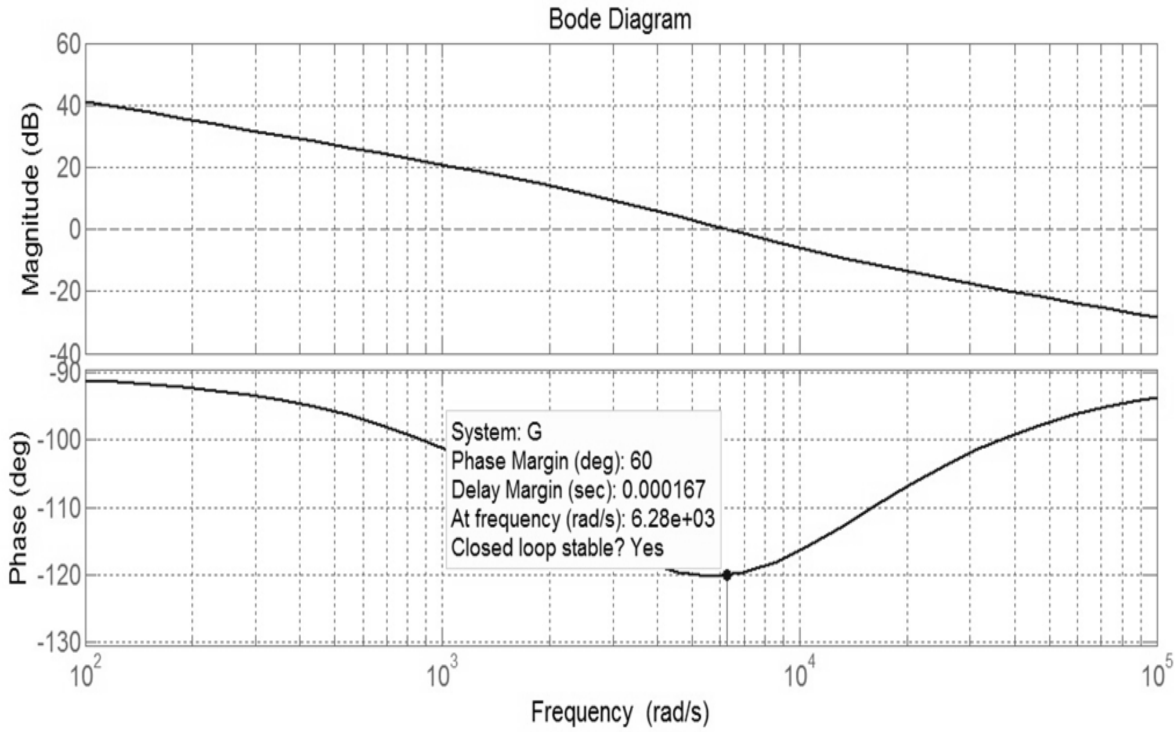


Figure 20: Bode plot of open loop transfer function of voltage control loop

Using all the calculated parameters, a complete closed loop controlled buck converter has been modeled in PLECS as shown below in Figure 21.

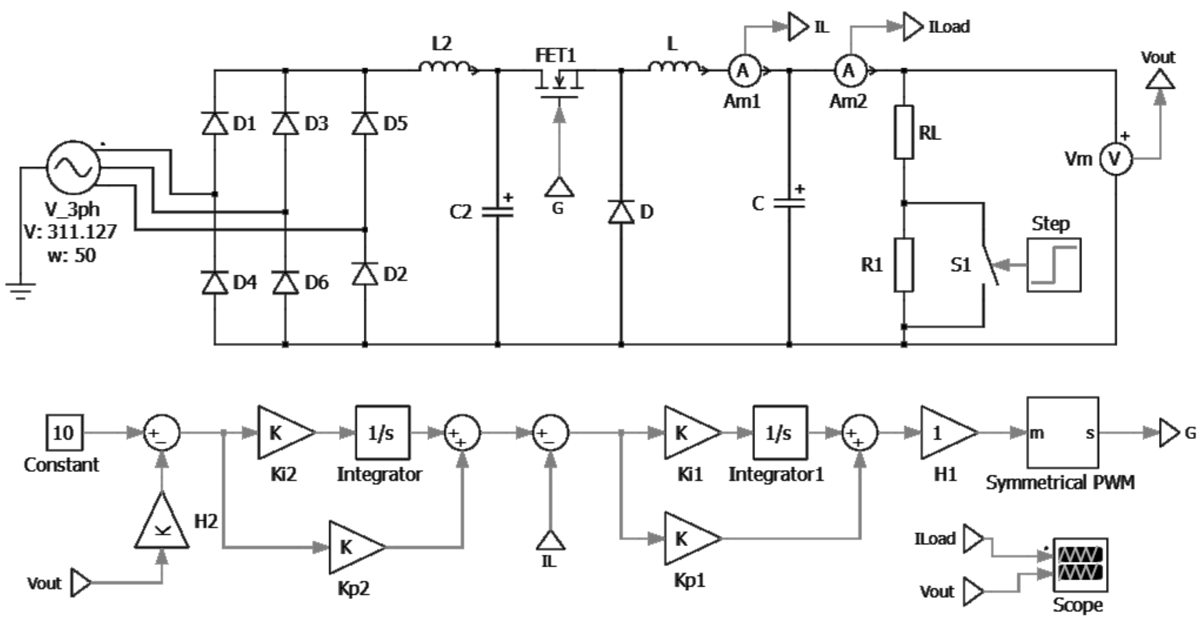


Figure 21: Complete closed loop controlled buck converter simulation model in PLECS

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 DC Wiring Model Result

DC side wiring model has been developed for 48 V DC System. Detail of development procedure has been explained in section 3.4. As a result from DC side wiring model development it has been found that end use devices like DC LED lights, DC fan and DC based computer charging system can be fed using existing 2.5 sq. mm wire so there is no necessity for replacement of this wire section. For the wire section that is necessary to supply power from DC distribution board to lighting circuit points (or literally it can consider as a switch board points) necessity of three different sizes 2.5 sq. mm, 4 sq. mm and 6 sq. mm of wire has been found in order to maintain voltage drop below 2% in this section. Out of those wires 2.5 sq. mm wire was already used in an existing wiring but approximately 249 meter of 4 sq. mm and 223 meter of 6 sq. mm wire new has to be replaced for existing 2.5 sq. mm wire. For the section that is necessary to supply power from DC main distribution board (near to converted DC source) to DC distribution boards necessity of additional approximately 8 meters of 6 sq. mm wire, 69 meters of 35 sq. mm cable and 81 meters of 50 sq. mm of cable has been found to be installed in order to maintain voltage drop below 2% in this section.

DC side wiring model developed in Auto CAD has been included in appendix B in which each DC loads has been designed to supply from existing switch boards by using an existing wiring system. Switch boards of each floor are designed to be supplied from a single DC distribution board located at middle of each floor. And each DC distribution boards are designed to be supplied from DC main distribution boards which is recommended to install near converted DC source point. By doing so overall voltage drop has been found to be maintained below 4%.

In an existing wiring system for AC, all lighting circuits were protected from 6 ampere MCB following NBC 207 code. But for new purposed DC system for this specific building 48V, 10 ampere DC fuse will work as it has maximum of about 300 watt load used in an existing single lighting circuit and 48V, 10 ampere DC fuse can be used for up to 480 watt. However for other cases where load per lighting circuit may be more than 480 watt and which has developed as per NBC207 code (according to which maximum of 800 watt can be wired in a single lighting circuit) 48V, 20 ampere DC fuse will be sufficient for the protection of DC lighting circuit.

Similarly for DC fuses at DC main distribution board for the protection of DC distribution boards at each floor 10A, 35A, 40A, 50A, 60/63A, 80A, 90A, 100A, 125/130/135A and 150/160A DC fuses of some selected brand were available in the market and for this building as per load distribution through each distribution board one number of 20A, 48V DC fuse for distribution board at basement, one number of 125A 48V DC fuse for distribution board at ground floor, one number of 60/63A 48V DC fuse for distribution board at first floor and five number of 50A, 48V DC fuse for distribution board at second floor to sixth floor has to be used which can protect up to 25% more load than of existing load.

Although single DC distribution board provision to supply all switch boards of each floor has been used during design of DC wiring system for this building, number of DC distribution board per floor can be increased which helps to decrease the size of cable needed to supply from DC main distribution boards to floor distribution boards and to supply from floor distribution board to respective switch boards by decreasing the distance between them. But on the other hand cost of the system may increased due to necessity of additional distribution boards and additional length of cable required to feed added distribution boards from main distribution boards.

5.2 PLECS Simulation Results

The designed model has been simulated on PLECS For estimated value of PI controller parameter for current control loop (K_{P1}=0.0005 and K_{I1}=90) and for voltage control loop (K_{P2}=36.7 and K_{I2}=360216). Closed loop system response simulated for 15kW load is shown below in figure 22. From waveform overshoot of 40.7 volt (= 84%) and settling time of 2.4 m sec and negligible steady state error has been observed with oscillation. This indicates good steady state response but the poor transient response which may lead to an unstable operation of the system during changing load condition. To improve transient response of the system parameter of PI compensator has been manually tuned.

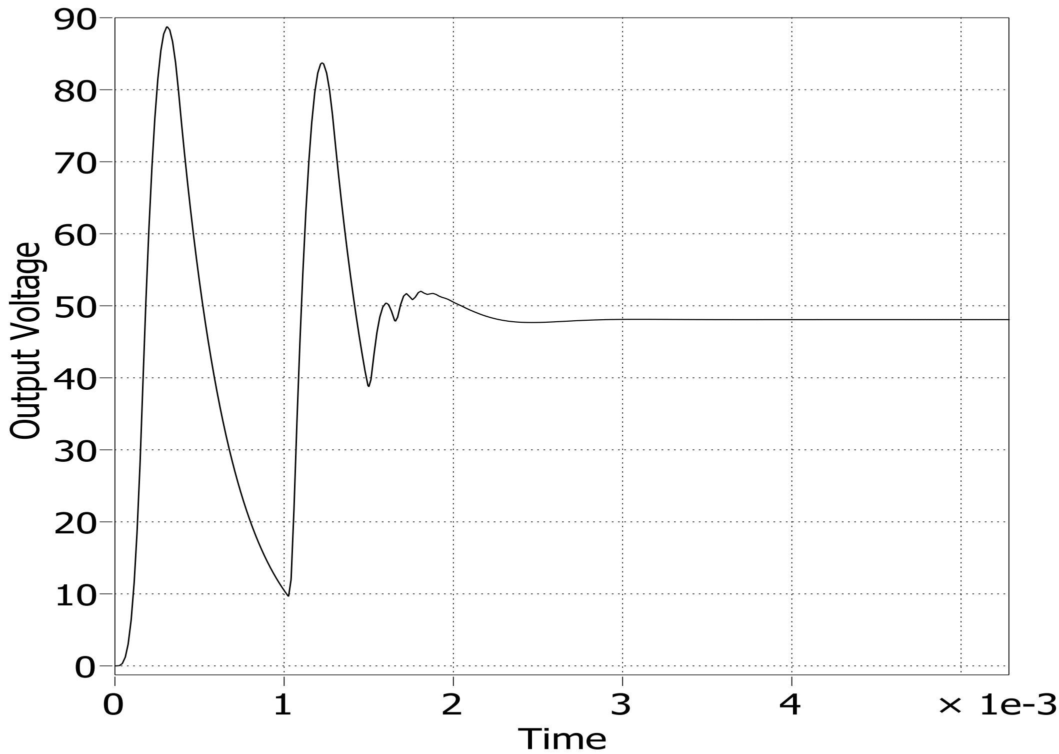


Figure 22: Closed loop output voltage response for K_{P1}=0.0005, K_{I1}=90 and K_{P2}=36.7, K_{I2}=360216.

Although increasing the proportional gain constant parameter (K_P) minimizes steady state error as well as rise time but after reaching the certain level of improvement on rise time as well as on steady state error and then further increase in the proportional gain constant parameter (K_P) only leads to overshoot and oscillation of the system response. So, one reason behind the higher percentage of overshoot may be due to the higher value of voltage loop proportional gain constant (K_{P2}) which has initial estimated value of 36.7.

Moreover for integral gain constant (K_I) increasing its value eliminates steady state error as well as it help to improve rise time little bit but after some limit further increase will results a increase in overshoot. So another reason for maximum overshoot may be due to high value of voltage loop integral gain constant (K_{I2}) which has initial estimated value of 360216.

To make better response of the closed loop system, voltage loop proportional gain constant (K_{P2}) is manually tuned to 18.35 (half of the initial estimated value of 36.7). By doing so decreasing in percentage overshoot (=30%) has observed with settling time of 2.0 m sec but oscillation still remains as shown below in figure 23.

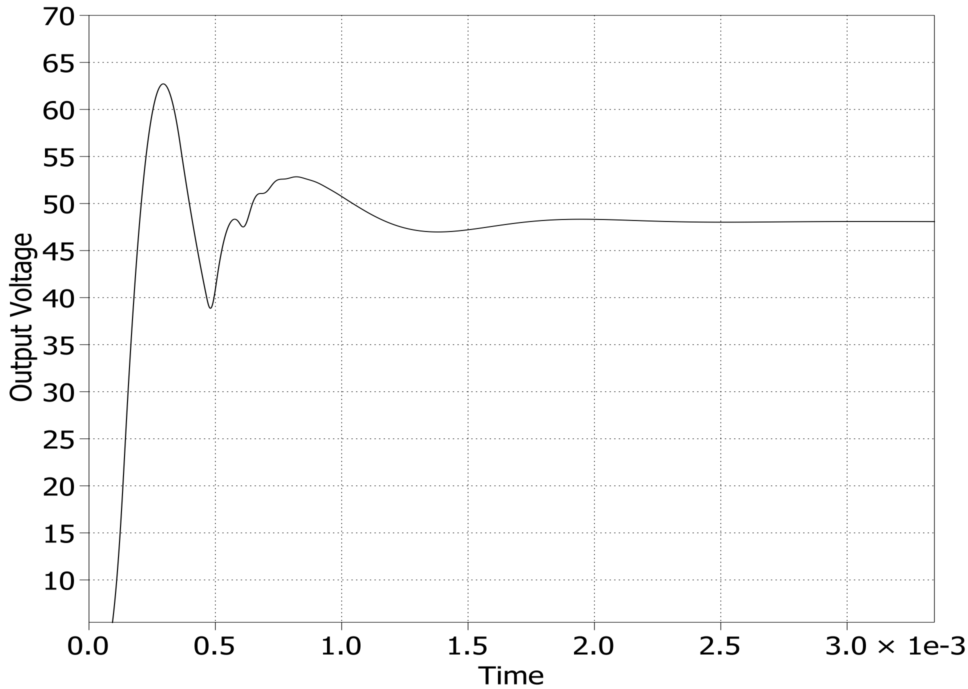


Figure 23: Closed loop output voltage response for K_{P1}=0.0005, K_{I1}=90 and K_{P2}=18.35, K_{I2}=360216.

Further decreasing the value of voltage loop proportional gain constant (K_{P2}) to 9.175 (one fourth of the initial estimated value of 36.7) nearly eliminates overshoot but oscillation still present and the peak value of oscillation is about 60 volt as shown in waveform in figure 24, which is slightly more than the value of overshoot with previous tuned value of K_{P2} equals 18.35. This indicates further decrease in value of

K_{P2} will not improves the oscillation instead oscillation starts increasing again causing higher percentage overshoot.

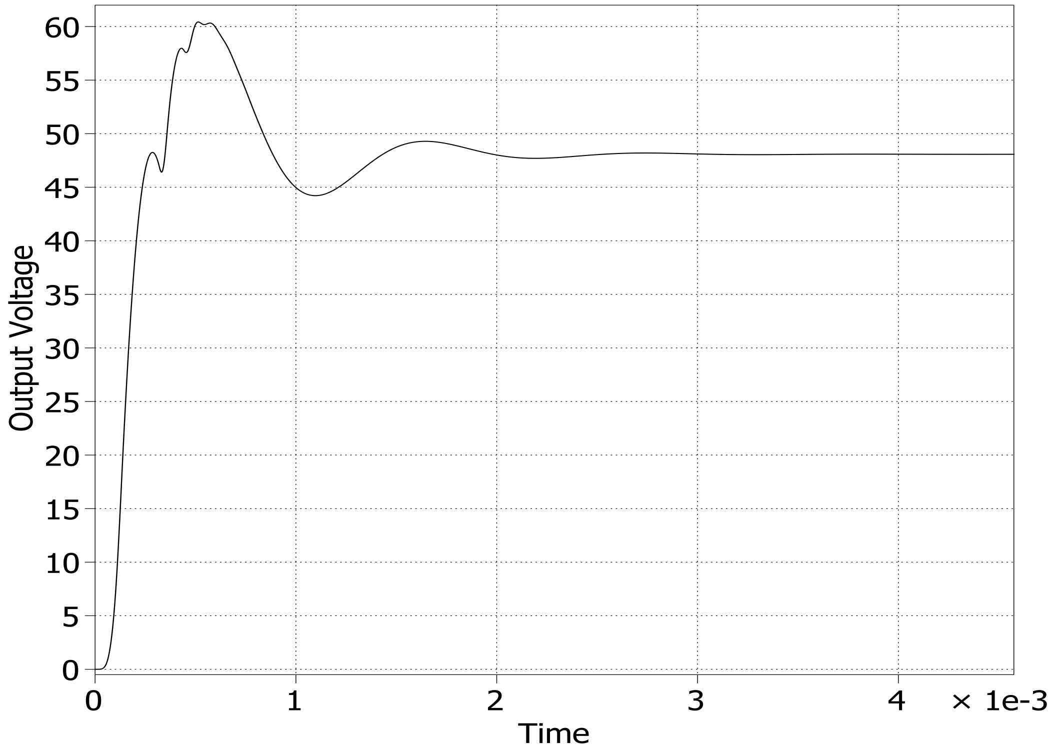


Figure 24: Closed loop output voltage response for K_{P1}=0.0005, K_{I1}=90 and K_{P2}=9.175, K_{I2}=360216

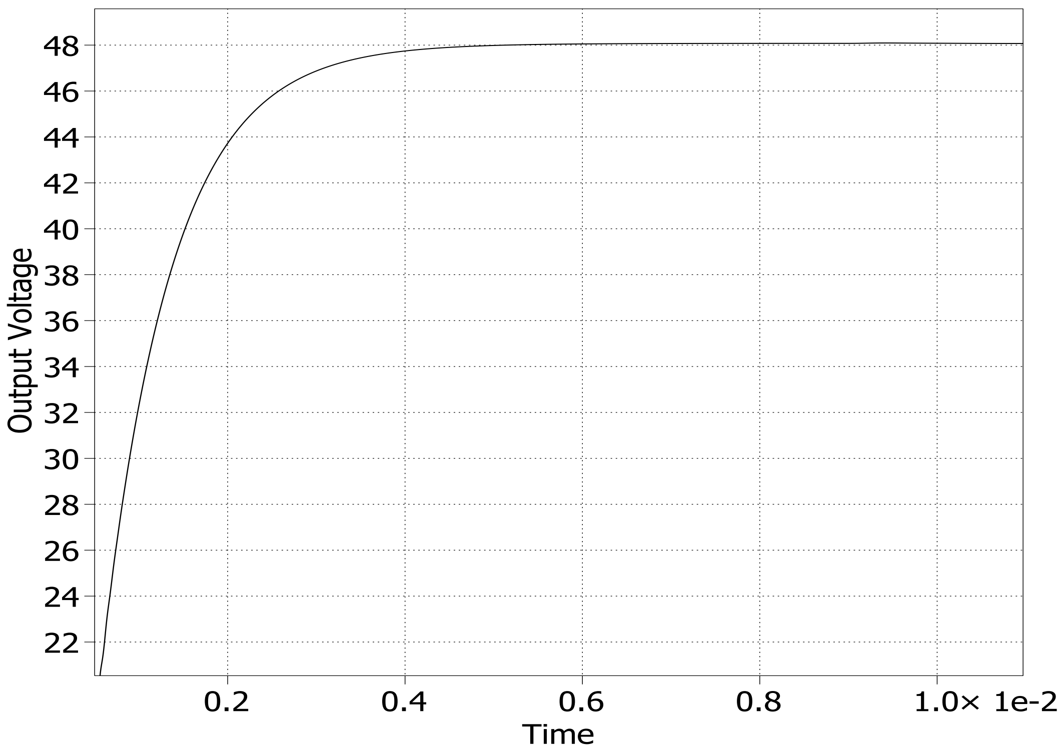


Figure 25: Closed loop output voltage response for K_{P1}=0.0005, K_{I1}=90 and K_{P2}=9.175, K_{I2}=36021

In next step voltage loop integral gain constant (K_{I2}) is manually tuned to 36021 (one tenth of the initial estimated value of 360216). By doing so percentage overshoot and oscillation both improved (almost eliminated) with settling time of 2.0 m sec as shown above in figure 25.

For tuned value of PI controller parameters for voltage loop (K_{P2}=9.175 and K_{I2} = 36021) and for current loop (K_{P1}=0.0005 and K_{I1} = 90) the output voltage ripple factor below designed criteria of 1% has been obtained. Waveform of output voltage ripple is shown below in Figure 26.

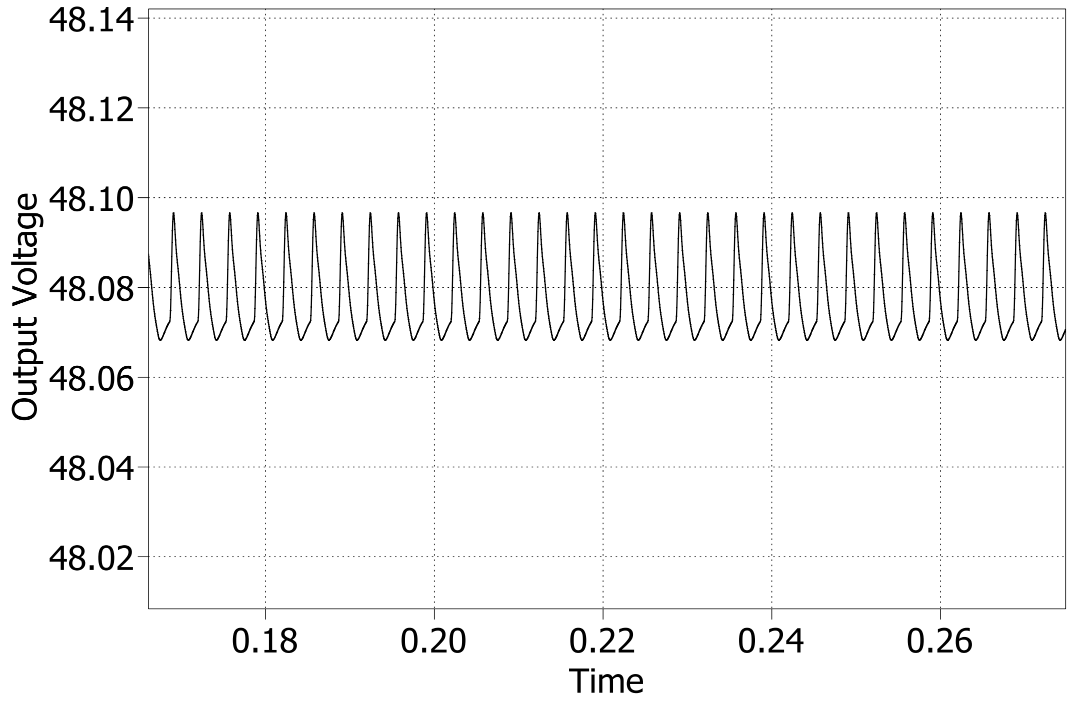


Figure 26: Waveform of output voltage ripple

Output from the designed model of buck converter is simulated in PLECS for 10kW, 15kW and 20kW of load by modeling 0.2304Ω, 0.1536Ω and 0.1152Ω resistor respectively. Waveform of load current and voltage for all three load level is shown in Figure 27. For 10kW load simulation a current of 208A with constant voltage of 48V has been observed. When load is increased to 15kW and 20kW load current is increased to 312.5A and 416.5A however voltage is maintained at constant value of

48V which shows modeled converter properly regulates the output voltage to a desire value of 48V.

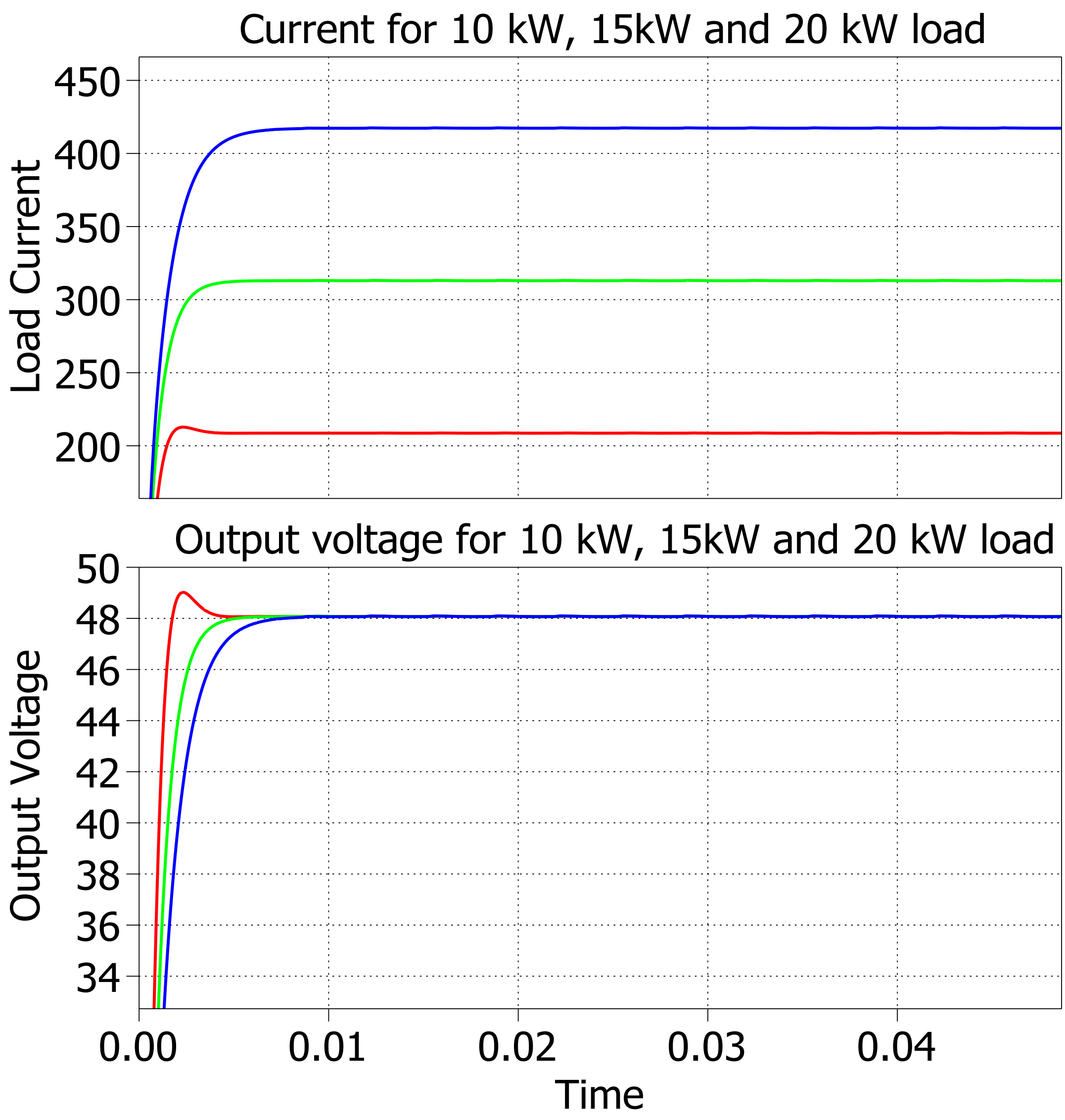


Figure 27: Load current and Voltage waveform for three different operating load conditions

Waveform in Figure 28 shows the response of load current and output voltage simulated for change in step load from 15kW to 20kW after 0.3 second. Initially 15kW load has been modeled by R_L (0.1152Ω) + R_1 (0.0384Ω) = 0.1536 Ω. After 0.3 second step signal generated which closes the switch S_1 shown in Figure 21 results in the elimination of R_1(0.0384Ω) and resulting R_L(0.1152Ω) models for 20kW load. As shown in the waveform of Figure 28 for 15 kW load current is 312.5A at voltage level of 48V. After 0.3 second when load is suddenly increased to 20kW voltage level attains a negative overshoot of about 8V at attains steady level of 48V after about 3.5 m sec.-Voltage overshoot is negative due to sudden addition of load and for sudden decrease in load overshoot will be positive. Amount of overshoot depends on the magnitude of load added or removed. If higher amount of load is suddenly changed overshoot will be more and for gradual change in small amount of load overshoot will be small. From simulation for step load change of 500W, voltage overshoot was only 0.8V.

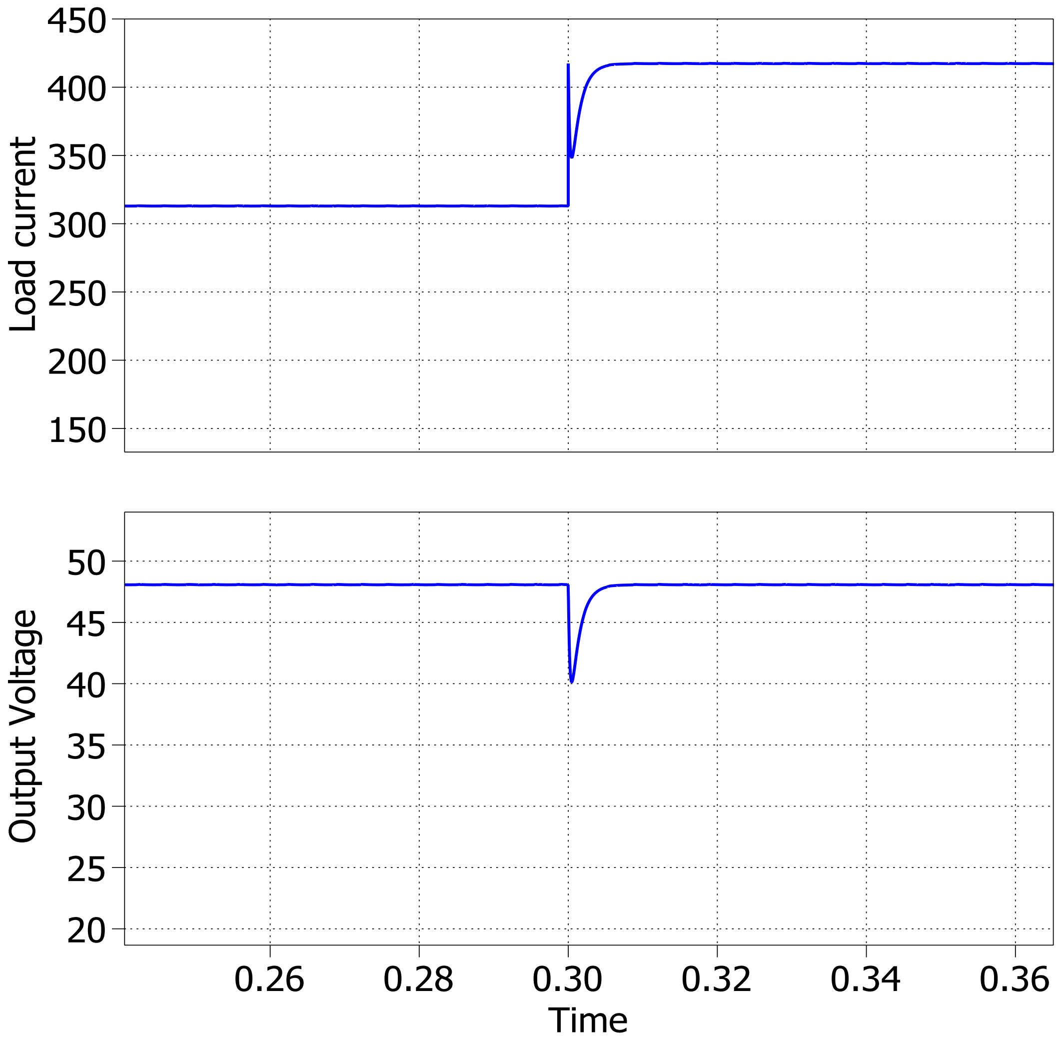


Figure 28: Response of load current and voltage for step load change from 15kW to 20kW

5.3 Energy saving evaluation

Amount of energy saving has been evaluated by obtaining the various losses in the developed model and by calculating amount of energy saving option while implementing AC –DC hybrid power supply structure.

5.3.1 Efficiency evaluation of AC-DC and DC-DC buck converters

Overall efficiency of converter model has been evaluated by calculating the power losses in rectifier, filter and buck converter circuit.

For 15kW load simulation following parameters has been measured-

I_{out} (Rectifier) = 30A

I_{rms} (Inductor) = 313A)

I_{rms} (MOSFET) = 97A

I_{rms} (Diode) = 298A

Above parameters measured has been validated by comparing with theoretically calculated value as below-

$$\Delta I = \frac{V_s - V_0}{L} DT = \frac{512 - 48}{10 * 10^{-6}} \times \frac{0.09375}{100000} == 43.5 \text{ A}$$

$$I_{max} = I_{load} + \frac{\Delta I}{2} = 312.5 + \frac{43.5}{2} = 334.25 \text{ A}$$

$$I_{rms}\text{ (inductor)} = \frac{\Delta I}{\sqrt{3}} + I_{max} - \Delta I = \frac{43.5}{\sqrt{3}} + 334.25 - 43.5 = 315.86 \text{ A}$$

$$I_{rms}\text{(MOSFET)} = \sqrt{D} \times I_{rms}\text{ (inductor)} = 96.7 \text{ A}$$

$$I_{RMS}\text{ (diode)} = \sqrt{1 - D}\left(I_{load} - \frac{\Delta I}{2} + \frac{\Delta I}{\sqrt{3}}\right) = 300 \text{ A}$$

From datasheet following parameters has been found-

From datasheet of 1N1190 diode,

R_{on}(Diode) = 0.034 Ω

From datasheet of WURTH ELEKTRONIK 744364100 model,

DCR of inductor (10 μH) =2.4 mΩ $R_{DS\text{-}ON}$ (MOSFET) = 66 mΩ,

From data sheet of FCH47N60F-F085 MOSFET,

Total gate charge of MOSFET (Q_g)=190 nC

Output capacitance of MOSFET (C_o) =3200 pF

Rise time (t_r)=160 n sec

Fall time (t_f)=120 n sec

Gate voltage (V_{drive}) =10 V (maximum)

By using above parameters different losses were calculated as below-

Power loss in rectifier circuit

In rectifier power loss is occurs due to forward resistance (R_{on}) of diode. In three phase full bridge rectifier power loss can be calculated as below-

$$P_{loss}(\text{Rectifier}) = 2 \times I_{load}{}^2 \times R_{on} = 2 \times 29.2^2 \times 0.034 = 61\ watt$$

Power loss in filter circuit

In filter circuit power loss is occurs mainly due to dc resistance of inductor (DCR) and loss in the capacitor can be neglected. For 10μH inductor of WURTH ELEKTRONIK, 744364100 Model, DCR is 2.4 mΩ. So power loss in the filter can be calculated as below-

$$P_{loss}(\text{Filter}) = I_{load}{}^2 \times DCR = 30^2 \times 0.0024 = 2\ watt$$

Power loss in buck converter

In buck converter power loss is due the loss that occurs in inductor, switch and diode. Loss in capacitor can be neglected.

Power loss in inductor

Inductor used in this buck converter is of 10μH. As a reference, inductor of WURTH ELEKTRONIK, 744364100 model (as a reference) having DCR is 2.4 mΩ has been considered. So power loss due to inductor can be calculated using equations as below-

$$P_{loss}(\text{Inductor}) = I_{rms}{}^2 \times DCR = 313^2 \times 0.0024 = 235 \text{ watt}$$

Power loss in MOSFET switch

For this work power MOSFET FCH47N60F-F085 with 600V, 47 A rating has been chosen as a reference which has following specification as per datasheet.

$R_{DS\,ON}$ nominal (at25^0) = 66 mΩ

total gate change $\left(Q_{g\,total}\right) = 190$ nc at $V_{GS} = 10$ V, $I_D = 47$ A

Output capacitance (Coss) = 3200 pF

Rise time $(t_{rise}) = 160$ ns

$Fall\ time\ (t_{fall}) = 120\ ns$

Voltage applied to the MOSFET gate ($\mathrm{V_{drive}}$) $= 10$ V maximum

Basically two types of power losses occur in MOSFET switch. One is conduction loss which occurs due to the fixed voltage drop on the switch and another is switching loss which is due to switching action of MOSFET. Conduction loss can be calculated using equations below-

$$\mathrm{P_{conduction}} = (\mathrm{I_{RMS}(MOSFET)})^2 \times \mathrm{R_{DS-ON}} = 621 \text{ watt}$$

Similarly switching loss can be calculated using equations below-

$$\mathrm{P_{loss}}\text{ (due to gate charge)} = \frac{1}{2} * \mathrm{Q_{g\,total}} * \mathrm{V_{drive}} * \mathrm{F_{SW}} = 0.095 \text{ watt}$$

$$\mathrm{P_{loss}}\text{(due to MOSFET capacitance)} = \frac{1}{2}\,\mathrm{Coss} * \mathrm{V_{in\,\mathit{FET}}}^2 * \mathrm{F_{SW}} = 42 \text{ watt}$$

$$\mathrm{P_{loss}}\text{(during rise and fall time)} = \frac{1}{2} \times (\mathrm{t_{rise}} + \mathrm{t_{fall}}) \times \mathrm{I_{RMS}} \times \mathrm{V_{drive}} \times \mathrm{F_{SW}}$$

$$= 14 \text{ watt}$$

$$\mathrm{P_{loss}}\text{(Switching)}$$

$$= \mathrm{P_{loss}}\text{ (due to gate charge)} + \mathrm{P_{loss}}\text{(due to MOSFET capacitance)}$$

$$+ \mathrm{P_{loss}}\text{(during rise and fall time)} = 56 \text{ watt}$$

Total loss in MOSFET switch is,

$$\mathrm{P_{loss}}\text{(MOSFET)} = \mathrm{P_{loss}}\text{(conduction)} + \mathrm{P_{loss}}\text{(switching)} = 677 \text{ watt}$$

Power loss due to diode

Power loss that occur in buck converter diode can be obtained from equations below-

$$\mathrm{P_{loss}}\text{(diode)} = \mathrm{I_{rms}}\text{(diode)} \times \mathrm{V_F} = 238.4 \text{ watt}$$

Total loss in buck converter is,

$$\mathrm{P_{loss}}\text{(buck converter)} = \mathrm{P_{loss}}\text{(inductor)} + \mathrm{P_{loss}}\text{(MOSFET)} + \mathrm{P_{loss}}\text{(diode)}$$

$$= 1150.4 \text{ watt}$$

Overall efficiency of DC system components

Above losses are calculated for 15kW load. Neglecting some losses like; loss due to capacitor ESR, diode forward and reverse recovery loss and inductor core loss total loss of the designed system is,

$$P_{loss}(\text{Total}) = P_{loss}(\text{Rectifier}) + P_{loss}(\text{filter}) + P_{loss}(\text{buck converter})$$
$$= 1213.4\text{watt}$$
$$\text{Efficiency} = \frac{P_{load}}{P_{loss}(\text{total}) + P_{load}} = 92.5\ \%$$

To evaluate energy savings, areas in the hospital building were categories based on the turn on hours of lighting, fan and computer load per day. In passages, stairs, toilet area all lighting fixtures are estimated to be turned on for 12 hour and 50% of them are turned on for remaining 12 hour. In areas like nursing stations, wards, cabin, ICU, pharmacy all lighting fixtures are estimated to be turned on for 12 hour and 50% of them are turned on for remaining 12 hour. In operation theater area all lighting fixture are estimated to use for 10 hour. In areas like OPD, doctor's room, administration area 50% lighting fixture are estimated to use for 8 hour. In testing room area like x-ray, USG, ECG etc all lighting fixture are estimated to use for 8 hour and 50% lighting fixture are estimated to use for another 8 hour. In sterilization area all lighting fixture are estimated to use for 10 hour. In areas like store, changing, utility etc all lighting fixture are estimated to use for 3 hour. Similarly, computers and fan in nursing stations are estimated to use for 12 hour and in administration for 8 hour.

Energy saving has been then evaluated based on the efficiency improvement options carried out in the past researches. From past research, DC based LED driver are 10% more efficient than that of AC based LED driver (Thielemans, et al., 2017). That means in general if AC LED lights were replaced by equivalent DC LED lights, 10% energy can be saved. Similarly DC based computer charging system are 4.25% more efficient than AC based computer charging system and DC fans are 24% more efficient than AC fans (Santos, et al., 2018) and for UPS with 90% efficiency and for full load operation 8% energy can be saved with elimination of rectification process and inverter with in UPS (Kutsmeda, 2015).

From energy saving evaluation as shown below in the table 6, it has been found that 18.6 kWh of electrical energy per day can be saved by implementing AC – DC hybrid power supply structure for the specified hospital building.

Table 6: Energy saving evaluation

S.N.	LOCATION	FIXTURES	Number of fixture	Total watt	Operation time in a Day (Hour)		Per day energy consumption (Wh)
					100% load	50% load	
1	Passage, stairs, toilet area	18 watt LED light	184	3312	12	12	59616
		8 watt Dome light	39	312	12	12	5616
		10 Watt Mirror light	23	230	12		2760
2	Nurse stations ward, ICU, Pharmacy Area	18 watt LED light	209	3762	12	12	67716
		8 watt Dome light	27	216	12	12	3888
		Computer	15	1500	12		18000
		Fan	12	720	12		8640
3	OT Area	18 watt LED light	46	828	10		8280
4	OPD, Doctor room Administration Area	18 watt LED light	56	1008	8		8064
		8 watt Dome light	6	48	8		384
		10 Watt Mirror light	9	90	8		720
		Computer	10	1000	8		8000
		Fan	23	1380	8		11040
5	Testing rooms	18 watt LED light	22	396	8	8	4752
		8 watt Dome light	1	8	8		96
		10 Watt Mirror light	4	40	8	8	480
		Computer	2	200	8		1600
6	Store, changing	18 watt LED light	31	558	3		1674
		8 watt Dome light	10	80	3		240
7	Sterilization area	18 watt LED light	27	486	9	2	4860
		Computer	1	100	9	2	1000
TOTAL ENERGY CONSUMPTIOM BY LIGHTING DEVICES (kWh)							169.146
TOTAL ENERGY CONSUMPTIOM BY FAN (kWh)							19.68
TOTAL ENERGY CONSUMPTIOM BY COMPUTER (kWh)							28.6
Energy saving by replacing AC LED lights with 10% more efficient DC LED lights (kWh)							16.9146
Energy saving by replacing AC based computer charging system with 4.25% more efficient DC based charging system (kWh)							1.2155
Energy saving by replacing AC fan with 24% more efficient DC fan (kWh)							4.7232
Per day energy loss in AC-DC and DC-DC converter model(92.5% efficiency) used for DC system							16.30695
Efficiency of existing 10kVA online UPS system							90%
Efficiency improvement with removal of rectifier and inverter in existing UPS							8%
Percentage of load supplied for 24 hour (approximately)							70%
Per day energy saving in UPS system due to efficiency improvement (kWh)							12.096
NET ENERGY SAVING PER DAY (kWh)							**18.64235**

5.4 Crystal Ball simulation results

Although evaluation shows for 18.6 kWh of per day energy saving opportunity, there is a chance in amount of energy saving being varied as operation time and operating load condition being uncertain.

In order to know about the certainty on amount of energy saving and sensitivity on variation of energy saving due to possible variation chances in parameters like operation hour and operating load condition simulation has been done in Crystal Ball software. Crystal Ball simulation model is included in appendix D.

Simulation has been carried to know about the certainty of energy saving being 18.6 kWh if operation time for devices has been varied in between 50% to 100% of possible turn on time for day and night time. For this operation time has been defined as an assumption with triangular distribution by setting minimum, likeliest and maximum value for day time and night time as per in table 7 below. Similarly percentage of load supply by UPS has been set in between minimum of 50% to maximum of 100% with likeliest value of 80%. Percentage of load that may operate at day time has been set to minimum of 50% to maximum of 100% with likeliest value of 80%. Since, with the elimination of the rectifier and inverter losses with in the UPS, the efficiency of the UPS system can increase up to 98% or 99% and for UPS system operating below 40% has a 4% to 8% increase in efficiency (Kutsmeda, 2015). So, possible improvement in the UPS efficiency due to elimination of multiple conversion process has been set to 4% to 8%.

Considering all above assumptions certainty of energy saving and sensitivity of different parameters on the variation on amount of energy saving has been simulated on Crystal Ball software

Table 7: Distribution of input parameters for energy saving evaluation

S.N	Location	Fixtures	Operation time in a Day (Hour)					
			Night time (6 pm to 6 am)			Day time (6am to 6 pm)		
			Mini-mum	Likeliest	Maxi-mum	Mini-mum	Likeliest	Maxi-mum
			50%	Observe time	100%	50%	Observe time	100%
1	Passage, stairs, Toilet area	18 watt LED light	6	12	12	6	12	12
		8 watt Dome light	6	12	12	6	12	12
		10 Watt Mirror light	6	12	12	6	12	12
2	Nurse stations, Doctor's room ward, ICU, Pharmacy Area	18 watt LED light	6	12	12	6	12	12
		8 watt Dome light	6	12	12	6	12	12
		Computer	6	12	12	6	12	12
		Fan	6	12	12	6	12	12
3	OT Area	18 watt LED light	6	12	12	6	12	12
4	OPD and Administration Area	18 watt LED light				6	8	12
		8 watt Dome light				6	8	12
		10 Watt Mirror light				6	8	12
		Computer				6	8	12
		Fan				6	8	12
5	Testing rooms	18 watt LED light	6	9	12	6	8	12
		8 watt Dome light	6	9	12	6	8	12
		10 Watt Mirror light	6	9	12	6	8	12
		Computer	6	9	12	6	8	12
6	Store, Changing	18 watt LED light	3	3	12	3	8	12
		8 watt Dome light	3	3	12	3	8	12
7	Sterilization area	18 watt LED light	0	3	12	6	9	12
		Computer	0	3	12	6	9	12

	Minimum	Likeliest	Maximum
% load operated at day time	50%	75%	100%
% load Supplied by UPS	50%	80%	100%
Efficiency Improvement of UPS	4%	7%	8%

Figure 29 and figure 30 shows the simulation result of crystal ball about certainty of energy saving. Simulation result shows that there is 99.84 % chance of energy saving being more than 11.13 kWh, there is about 31.5% chance of energy saving being more than 18kWh and there is no chance of energy saving being more than 22.84 kWh.

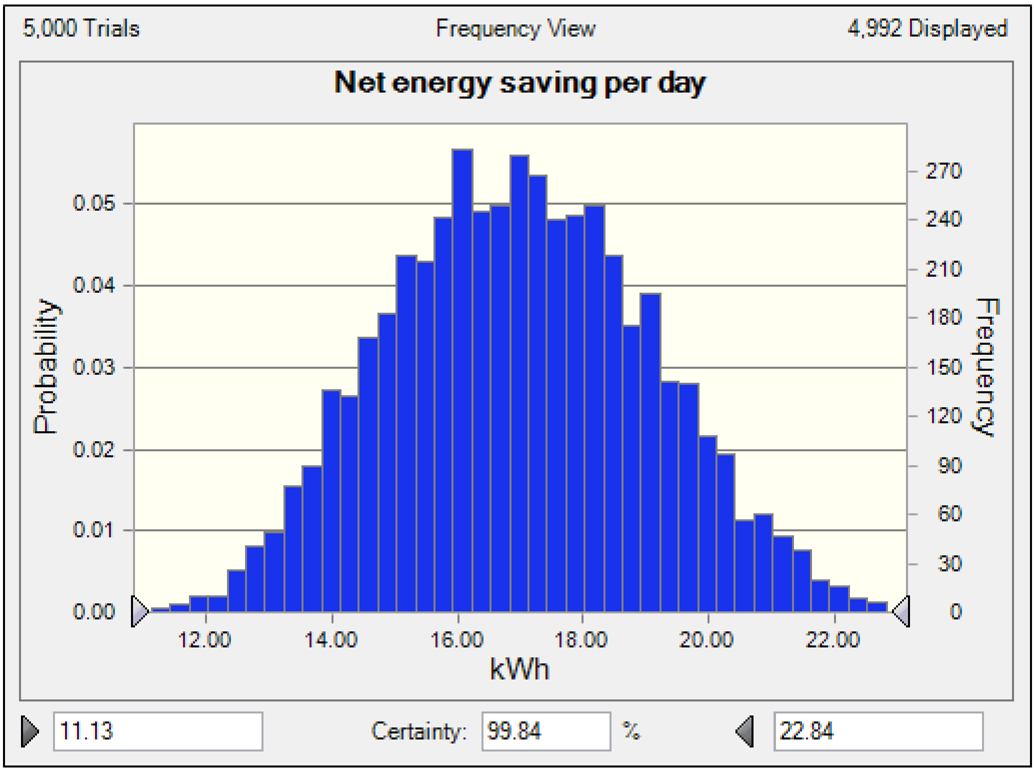


Figure 29: Simulation result of crystal ball about certainty of energy saving

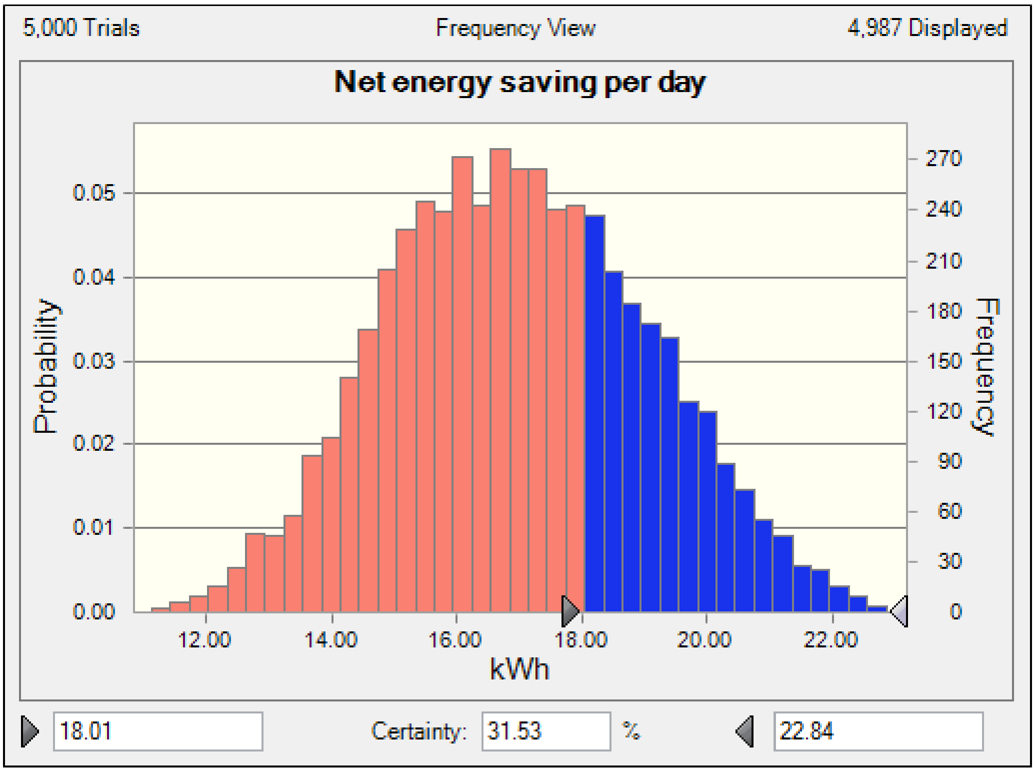


Figure 30: Simulation result of crystal ball about certainty of energy saving being more than 18kWh

Sensitivity data showing the contribution of different assumption in parameters on variance of net energy saving per day is shown in figure 31 and in table 8. Simulation shows that assumption on percentage of load supplied by UPS has greatest impact on net energy saving variation with contribution of 45.73%. Similarly assumption on possible improvement in UPS system efficiency due to elimination of rectification and inverter process also have a high impact with contribution of about 44.83% on net energy saving variation. Assumption on percentage of load supplied (load being turned on) at day time has significant impact on net energy saving variation with contribution of about 5.28%. Whereas other factors like assumption on turn on time of lights, fan and computers at different areas has very less (about 4% all together) impact on net energy saving variation.

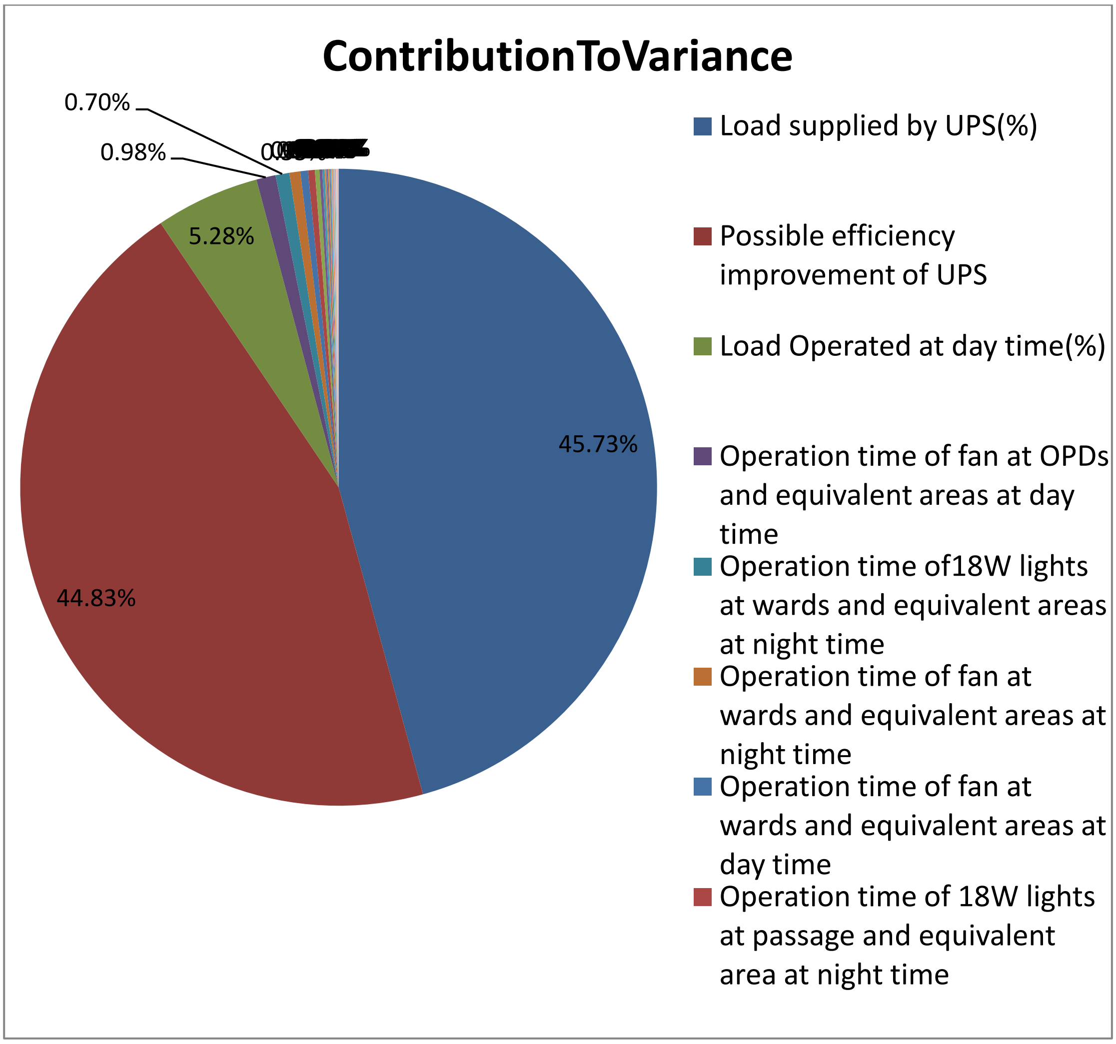


Figure 31: Simulation result of crystal ball about sensitivity of parameters on energy saving variation

Table 8: Sensitivity data with contribution of different assumption on variance of net energy saving per day

Assumptions	Contribution to Variance
Load supplied by UPS (%)	45.73%
Possible efficiency improvement of UPS	44.83%
Load operated at day time (%)	5.28%
Operation time of fan at OPDs and equivalent areas at day time	0.98%
Operation time of 18W lights at wards and equivalent areas at night time	0.70%
Operation time of fan at wards and equivalent areas at night time	0.55%
Operation time of fan at wards and equivalent areas at day time	0.39%
Operation time of 18W lights at passage and equivalent areas at night time	0.34%
Operation time of computers at wards and equivalent areas at night time	0.22%
Operation time of 18W lights at store and equivalent areas at night time	0.15%
Operation time of 18W lights at wards and equivalent areas at day time	0.12%
Operation time of 18W lights at passage and equivalent area at day time	0.07%
Operation time of 10W lights at passage and equivalent area at night time	0.06%
Operation time of 10W lights at passage and equivalent area at day time	0.06%
Operation time of 8W lights at passage and equivalent area at day time	0.05%
Operation time of 8W lights at wards and equivalent areas at night time	0.05%
Operation time of 10W lights at OPDs and equivalent areas at day time	0.05%
Operation time of computers at wards and equivalent areas at day time	0.05%
Operation time of 18W lights at store and equivalent areas at day time	0.04%
Operation time of computers at testing rooms and equivalent areas at day time	0.04%
Operation time of 18W lights at testing rooms and equivalent areas at day time	0.04%
Operation time of 18W lights at sterilization and equivalent areas at night time	0.03%
Operation time of 18W lights at sterilization and equivalent areas at day time	0.03%
Operation time of computers at sterilization and equivalent areas at day time	0.03%
Operation time of 18W lights at OT and equivalent areas at night time	0.02%
Other	0.08%

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

Conclusion

Following conclusions are made from this research-

- Out of total existing load of 233 kW of building load, 16.853kW load (including 12053 watt of lights, 2100 watt of fan and 2700 watt of computer load) and 10kVA UPS system can be supplied from DC side of hybrid AC – DC power supply system.
- For development of DC side wiring of hybrid supply structure same existing wiring system can be used to supply end use DC devices from switch board. Whereas wiring system necessary to supply DC power from converted DC source to switch board through DC distribution boards has to be installed with increased cable size and additional DC protection system.
- AC-DC converter, filter, DC-DC buck converter with regulator required to make 48V DC supply line from existing 380V three phase AC supply line is developed which provides stable steady state and transient operation in changing load condition by maintaining output voltage ripple below 1%.
- Implementing AC-DC hybrid power supply structure for the specified building is found to be technically feasible with possibility of electrical energy saving of 18.6 kWh per day. However amount of energy saving is found to be highly dependent on saving factors like amount of load that can be replaced by DC load, amount of load supplied through UPS system and hour of operation.
- With assumption in possible variation in different input parameters for energy saving evaluation certainty of energy saving being more than 18 kWh is found to be 31.5 % but the chances of energy saving being more than 11.13 kWh is found to be 99.84 %. Possible variation in percentage load supplied by UPS, improvement in UPS efficiency with the removal of multiple conversion process and percentage of DC load supplied at day time has significant impact on variation on net energy saving with the contribution of 45.73%, 44.83% and 5.28% respectively. Whereas contribution of possible variation on operating time of lights, fan and computers have negligible impact on variation on net energy saving.

Recommendation for future work

- Because of the replacement needed for some cable section, load fixture and necessity of converter model financial analysis can be perform to know about the financial feasibility for upgrading an existing building.
- In future with a possibility of power distribution system being advanced with hybridization and bidirectional energy trade system, hybrid supply system for building by replacing backup Diesel Generator by solar PV system to enhance building efficiency (by eliminating rectification process needed to make DC supply line) could be a topic for further study.
- Research can be done further for a cluster of residential area together by making hybrid supply system for secondary distribution by converting AC to DC at distribution transformer point to develop DC line for hybrid system and making facility to interconnect individual solar home system to DC distribution line.

REFERENCES

Alipuria, B., Bediako, B. A., Slootweg, J. & Kling, W., 2013. "*Application of DC micro-grids for integration of solar home systems in smart grids*". Hamburg, VDE.

De Andrade, L. a. d. L. T. P., 2012. "*A brief history of direct current in electrical power systems*". *Third IEEE history*.

Gao, Y., Li, L. & Mok, P. K. T., 2017. "*An AC Input Switching Converter free LED Driver With Low Frequency Flicker Reduction*". *IEEE Journal of Solid State Circuits*, 52(5), pp. 1424-1434.

Gao, Y., LI, L. & Mok, P. K. T., 2018. "*An AC Input Inductor-Less LED Drive for Efficient Lighting and Visible Light Communication*". *IEEE Journal of Solid State Circuits*, 53(8), pp. 2343-2355.

Gonzalez, M. P. & Rios, M. A., 2018. "*Comparison of HVDC-Grid and HVAC into Transmission Expansion Planning*". *IEEE ANDESCON.*

Hertem, D. v., Gomis-Bellmunt, O. & Liang, J., 2016. "*HVDC Grids: For Offshore and Supergrid of the Future*". *Wiley-IEEE Press.*

Jhunjhunwala, A. et al., 2016. *"Energy efficiency in lighting: AC vs DC LED lights".* Chennai, IEEE.

Kazimierczuk, M. K., 2016. *"Pulse width modulated DC-DC power converters".* second ed. Hoboken: Wiley.

Kimbark, E. W., 1971. *"Direct Current Transmission".* New York: Wiley Interscience.

Kutsmeda, K., 2015. "*Evaluating UPS system efficiency*". CONSULTING-SPECIFYING ENGINEER, 11 June.

Li, Q. et al., 2018. *"Demonstration and application of AC/DC hybrid power supply system in building".* Beijing, IEEE.

Meraj, M., Rahman, S., Iqbal, A. & Brahim, L. B., 2019. "*High Brightness and High Voltage Dimmable LED Driver for Advanced Lighting System*". *IEEE Access,* Volume 7, pp. 95643-95652.

Mousavizaden, S. & Haghifam, M. R., 2013. *"Integrated AC/DC network planning".* Stockholm, IET.

Prasanna, U. R. & Rathore, A. K., 2013. *"Two loop average current control implementation using cypress PSoC with closed loop experimental results".* Denver, IEEE.

Pyakuryal, S. & Matin, M., 2013. "*Filter Design for AC to DC Converter*". *International Refereed Journal of Engineering and Science (IRJES),* June, 2(6), pp. 42-49.

Qiu, Y., Dai, C. & Jin, R., 2016. *"Impact of power electronic device development on power grids".* Prague, IEEE.

Rashid, M. H., 2007. "*Power Electronics Handbook*". In: Massachusetts: Academic Press.

Sannino, A., Postiglione, G. & Bollen, M. H., 2003. "*Feasibility of a DC Network for commercial facilities*". *IEEE Transactions on Industry Applications,* 39(5), pp. 1499-1507.

Santos, A. F. B., Duggan, G. P., Lute, C. D. & Zimmerle, D. J., 2018. *"An efficiency comparison study for small appliances operating in DC and AC in minigrids".* San Jose, , IEEE, pp. 1-2.

Sulzberger, C. L., 2003. "*Thomas Edison's 1882 Pearl Street Generating Station*". *IEEE Global History Network.*

Thielemans, S. et al., 2017. "*DC Grids for Smart LED Based Lighting: The EDISON Solution*". *Energies,* 10(10), p. 1454.

Wang, P., Goel, L., Liu, X. & Choo., F. H., 2013.. "*Harmonizing AC and DC: A Hybrid AC/DC Future Grid Solution*". *IEEE Power and Energy Magazine.*

Wang, S. et al., 2012. "*A Flicker-Free Electrolytic Capacitor-Less AC-DC LED Driver*". *IEEE Transactions on Power Electronics,* 27(11), pp. 4540-4548.

Wang, Z. et al., 2019. *"Research on the structures and application scenarios of medium voltage AC-DC hybrid distribution network",.* Chengdu, IEEE.

PUBLICATION

Gaihre, B. & Poudel, L., 2020. "*Analysis on AC-DC Hybrid Power Supply System: A Case Study for Hospital Building in Kathmandu, Nepal*" *(Accepted)*. Kathmandu, IOE Graduate Conference.

Appendix A: Detail Load Survey Data

Ground Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED					
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	Fan	Computer	X-ray view boards
1	Lobby	20					
2	NURSE STATION +ROOM	2	1		1	1	
3	Janitors Room + Utilities	3					
4	Emergency Ward	16	2				1
5	Pharmacy	5				3	
6	Registration + Record room	3				2	
7	X-RAY	4				1	1
8	Control Room	1				1	
9	Waiting + report collection	8					
10	ECG	2		1			
11	UROFLOWMETRY	3	1	2			
12	WASHROOM+ CHANGING	0	2				
13	USG	2		1			
14	MCH	2					
15	OPD-1	2		1	1		1
16	OPD-2	2		1	1		1
17	DOTS	2		1			
18	TREATMENT	4					
19	SLUICE	1		1			
20	Guards room	1					
21	Other OPD'S	21	4	6	21		21
22	Stairs	3	4				
	TOTAL	**107**	**14**	**14**	**24**	**8**	**25**

First Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED						
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	OT light	Fan	Computer	X-ray view boards
1	Lobby	14						
2	Janitor's room	1						
3	Toilet	4	7	4				
4	Gynae Ward	10	2					
5	Nurse room, Nurse Station, clean and Dirty Utility	4				1	1	
6	Store	2						
7	Dirt utility	1						
8	General Ward	9	2					
9	Nurse station, changing Room, clean Utility	3	1			1	1	
10	Store, Janitor room, Sluice	3						
11	Delivery room	3						
12	Doctors room	1					1	
13	Active Patient	3						
14	Operation Theater	2			1			
15	Lobby-2	6		2				
16	Instrument Preparation, Nurse Station	2				1	1	
17	Recovery	2						
18	New Born Care	2						
19	Changing room	3	2					
20	Stairs	3						
	TOTAL	**78**	**14**	**6**	**1**	**3**	**4**	

Second Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED					
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	Fan	Computer	X-ray view boards
1	Lobby	14					
2	Janitor's room	1					
3	Medical Ward	25	1				
4	Pediatric Ward	10	2				
5	Changing room, Nurse Station, Clean and Dirty Utility	4			1	1	
6	Changing room, Nurse Station, Clean and Dirty Utility	5	3		1	1	
7	Toilet	4	7	4			
8	Stair, outside area	3					
	TOTAL	**66**	**13**	**4**	**2**	**2**	

Third Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED					
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	fan	computer	X ray view boards
1	Lobby-1	11					
2	Toilet	4	7	4			
3	Surgical Ward	25	1				
4	Janitor room	1					
5	Changing room, Nurse Station, Clean and Dirty Utility	5	3		1	1	
6	Dirty Utility	1					
7	Cabin-1	2	1				
8	Cabin-2	2	1				
9	Cabin-3	2	1				
10	Cabin-Lobby	2					
11	Nurse Station, Changing room, Clean Utility	5	1		1	1	
12	Stair	3					
	TOTAL	**63**	**15**	**4**	**2**	**2**	

Fourth Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED					
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	Fan	Computer	X-ray view boards
1	Lobby	14					
2	Toilet	4	7	4			
3	HDCU WARD	10					
4	Changing room, Nurse Station, Clean and Dirty Utility	4	2		1	1	
5	Duty Room, Changing, Dirty/clean Utility, Lobby	6	2				
6	Post Operation Room, Nurse station	14			1	1	
7	Isolation Room	2					
8	ICU	12					
9	Duty Room, Changing, Dirty/clean Utility, Nurse station	6	3		1	1	
10	Stairs, Outside area	3					
	TOTAL	**75**	**14**	**4**	**3**	**3**	

Fifth Floor

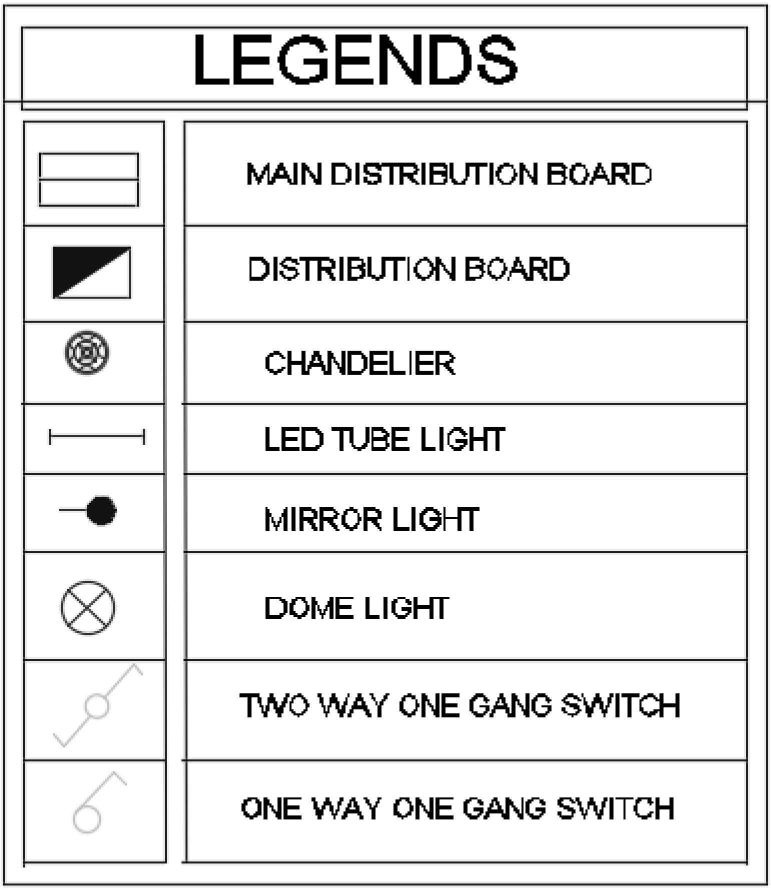
S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED						
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	OT light	Fan	Computer	X-ray view boards
1	Lobby	3						
2	Janitor's room	1						
3	Changing	1						
4	Preparation Room	2						
5	Preparation Room	4						
6	Nurse Station, Lobby	8				1	1	
7	Doctors Room	2					1	
8	Recovery	7						
9	Major OT-1	12			1			
10	Sluice, Instrument Preparation	2						
11	Major OT-2	8			1			
12	MINOR OT	8			1			
13	Major OT-3	8			1			
14	Changing, WC	4	4					
15	Stairs, Outside area	10						
	TOTAL	**80**	**4**	**0**	**4**	**1**	**2**	

Purposed Sixth Floor

S.N	Location	NUMBERS OF DIFFERENT FIXTURES USED					
		18 watt LED tube light	8 Watt Dome light	10 Watt Mirror light	Chandelier	Fan	computer
1	Lobby	7					
2	Janitor's room	1					
3	Admin, Account	4					2
4	Reception, Waiting	4					
5	Pantry	1					
6	Record Room	4					1
7	Meeting Room	4			2		
8	Superintendent Room	3	1				1
9	Matron Room	3	1				1
10	Packing	2					
11	Sterilization	2					
12	Wash and storage	4					
13	Issue	2					1
14	Intake & sorting	2					
15	Washing	2					
16	Waiting	2					
17	Intake & sorting	3					
18	Sterilization	2					
19	Packing	2					
20	Storage, Packing	4					
21	Toilet	6	7	4			
22	Stairs	3					
	TOTAL	**67**	**9**	**4**	**2**	**0**	**6**

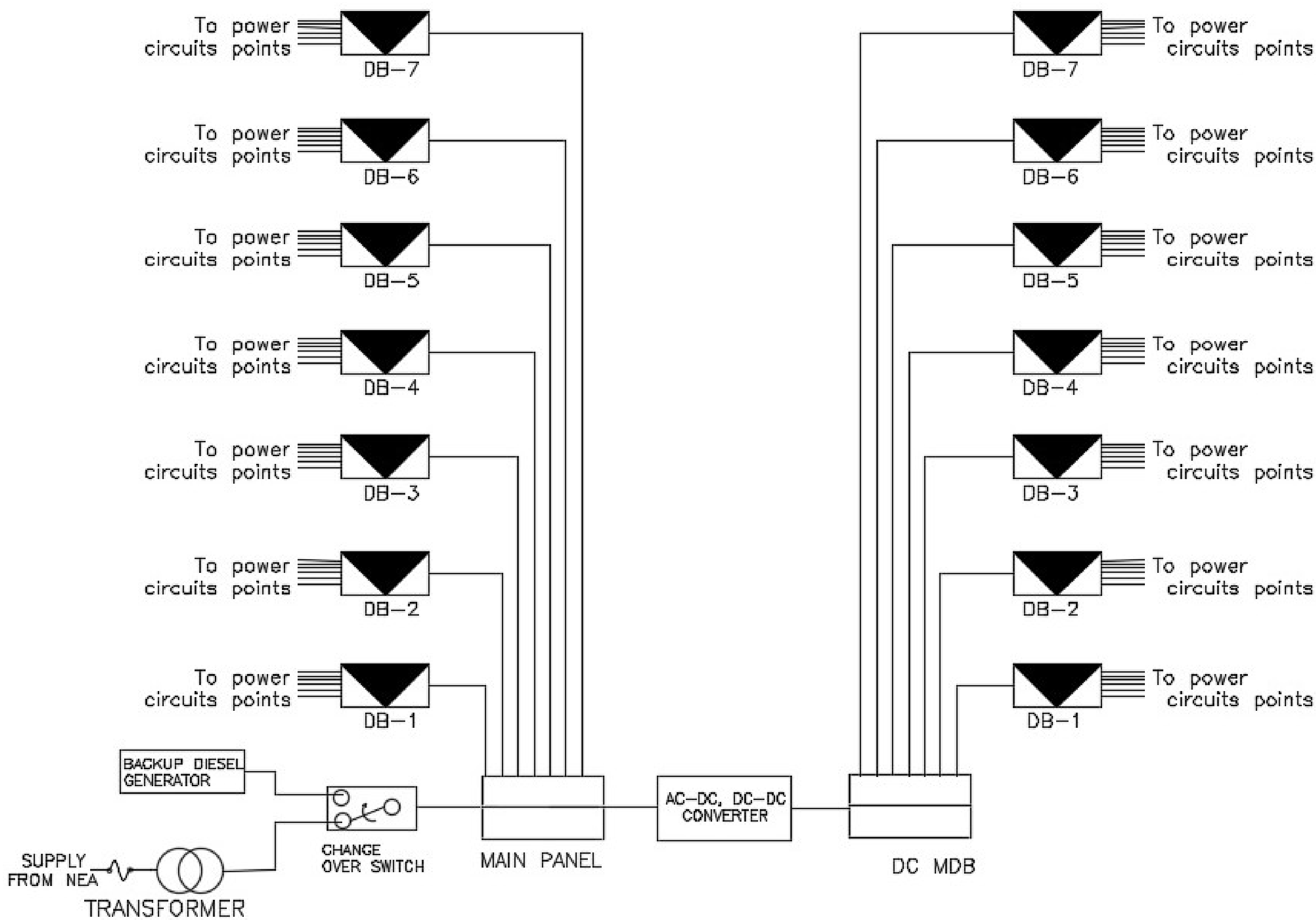
Appendix B: Wiring Layout of Lighting Fixtures

Legends

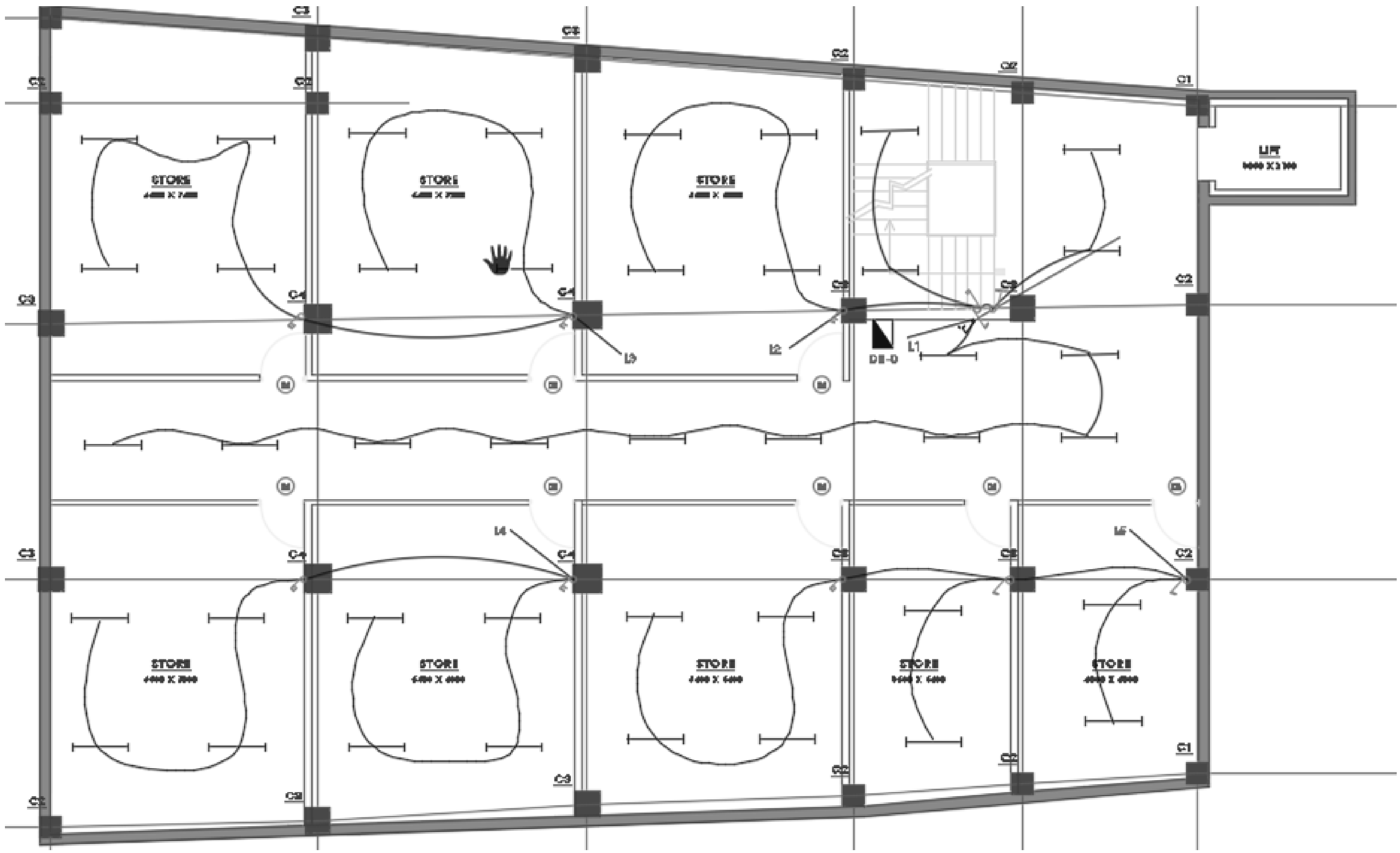


NOTE:
nLm- Represents the m^{th} lighting circuit feed from n^{th} DB

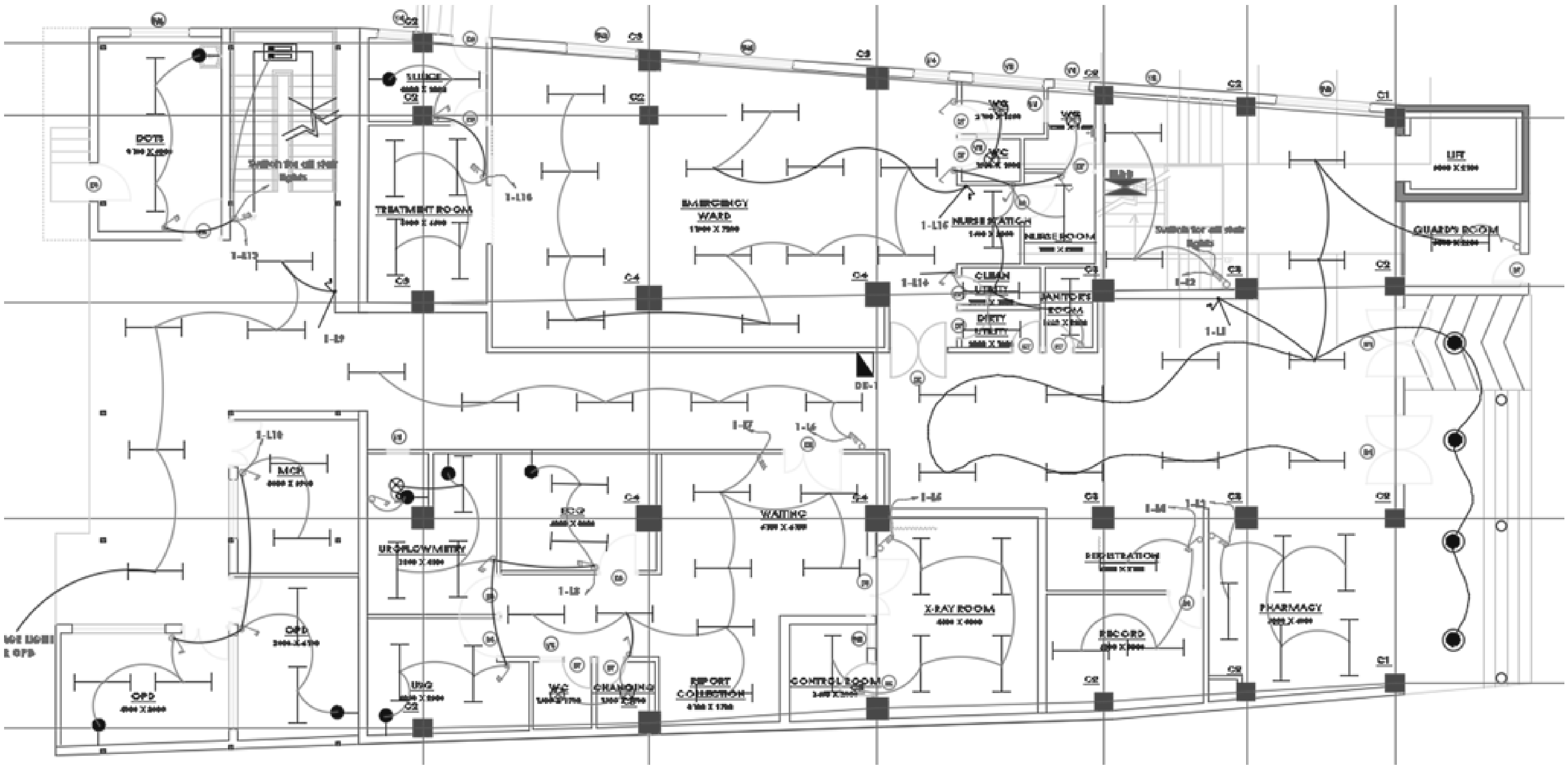
Power Raiser Diagram



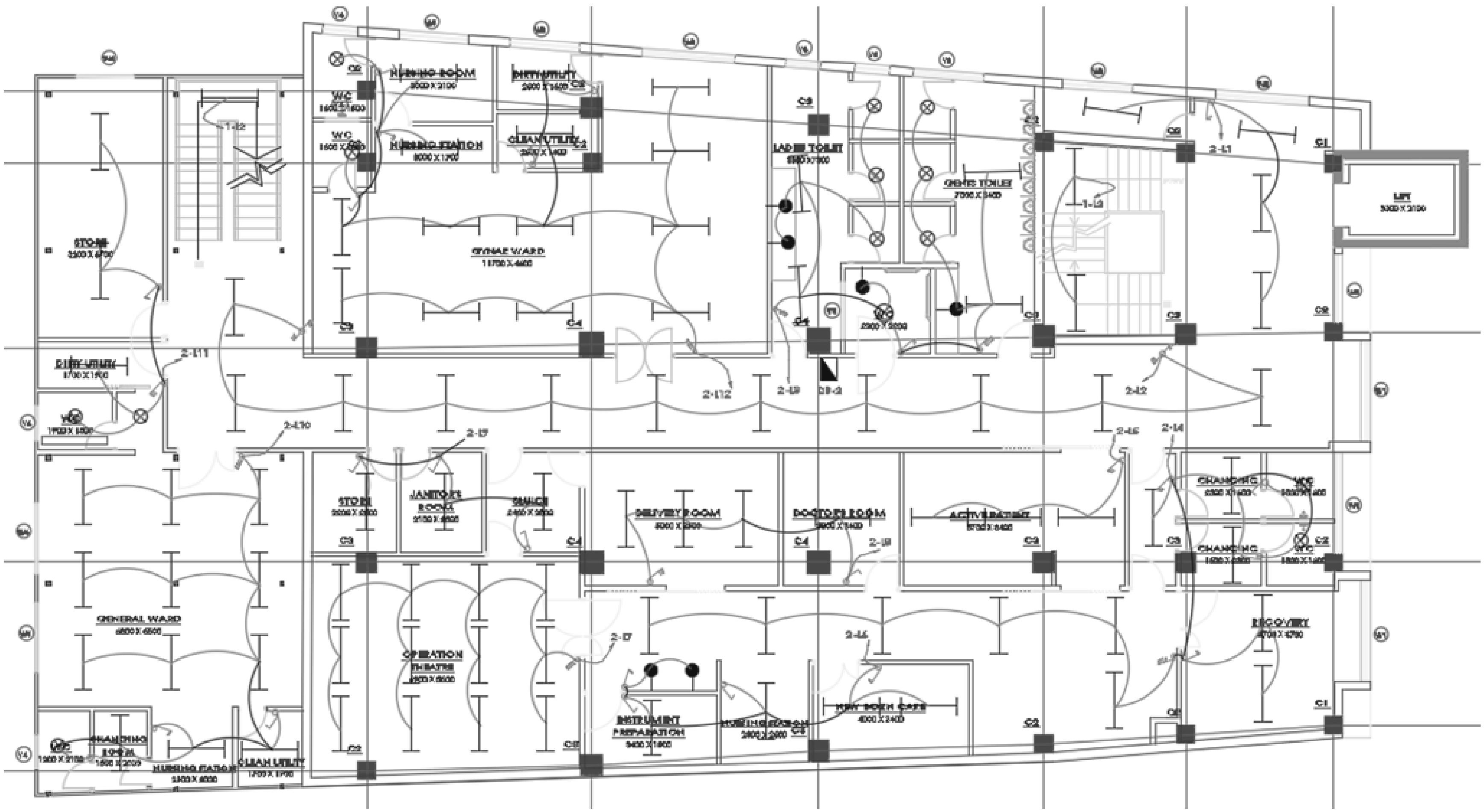
Basement Lighting Layout



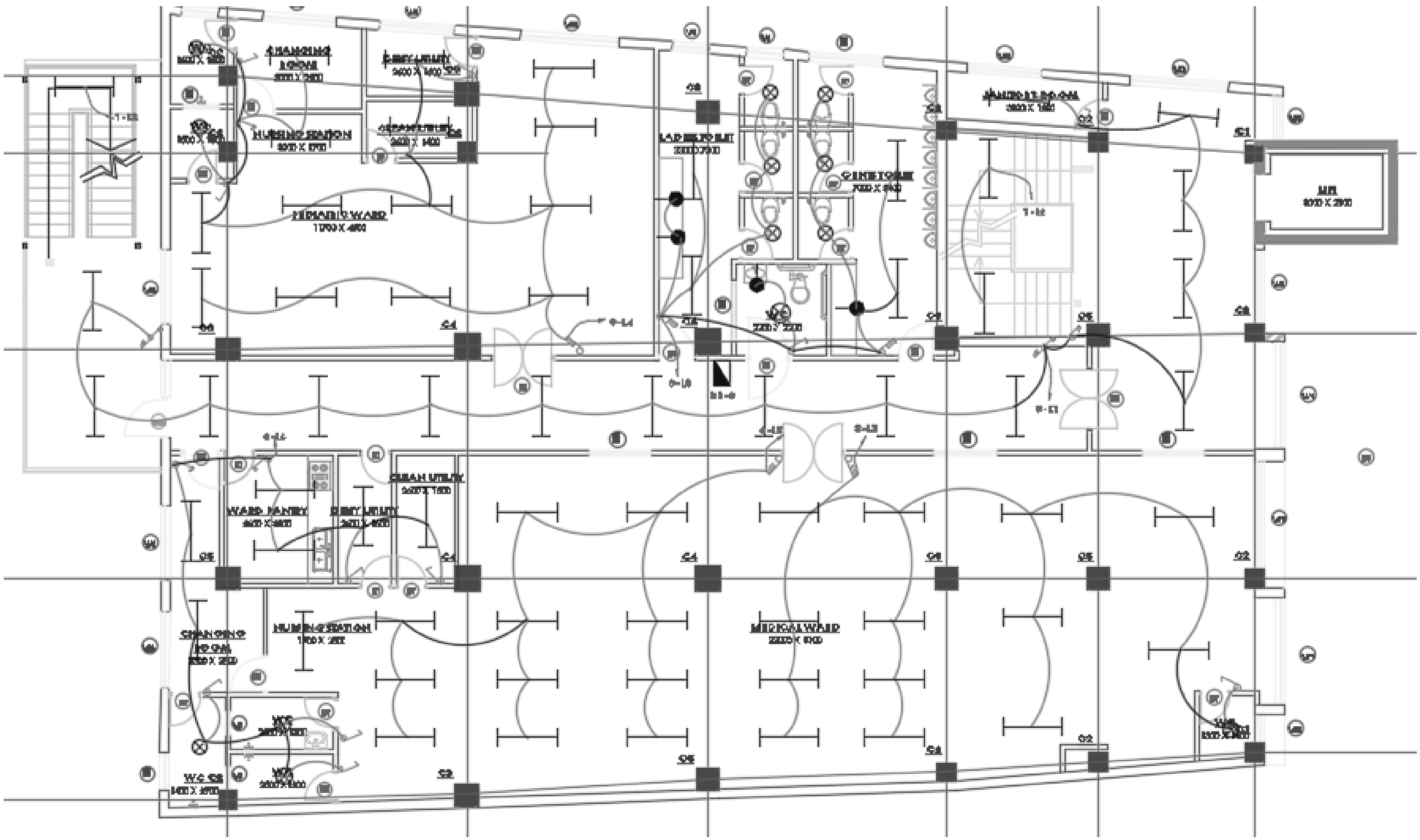
Ground Floor lighting layout



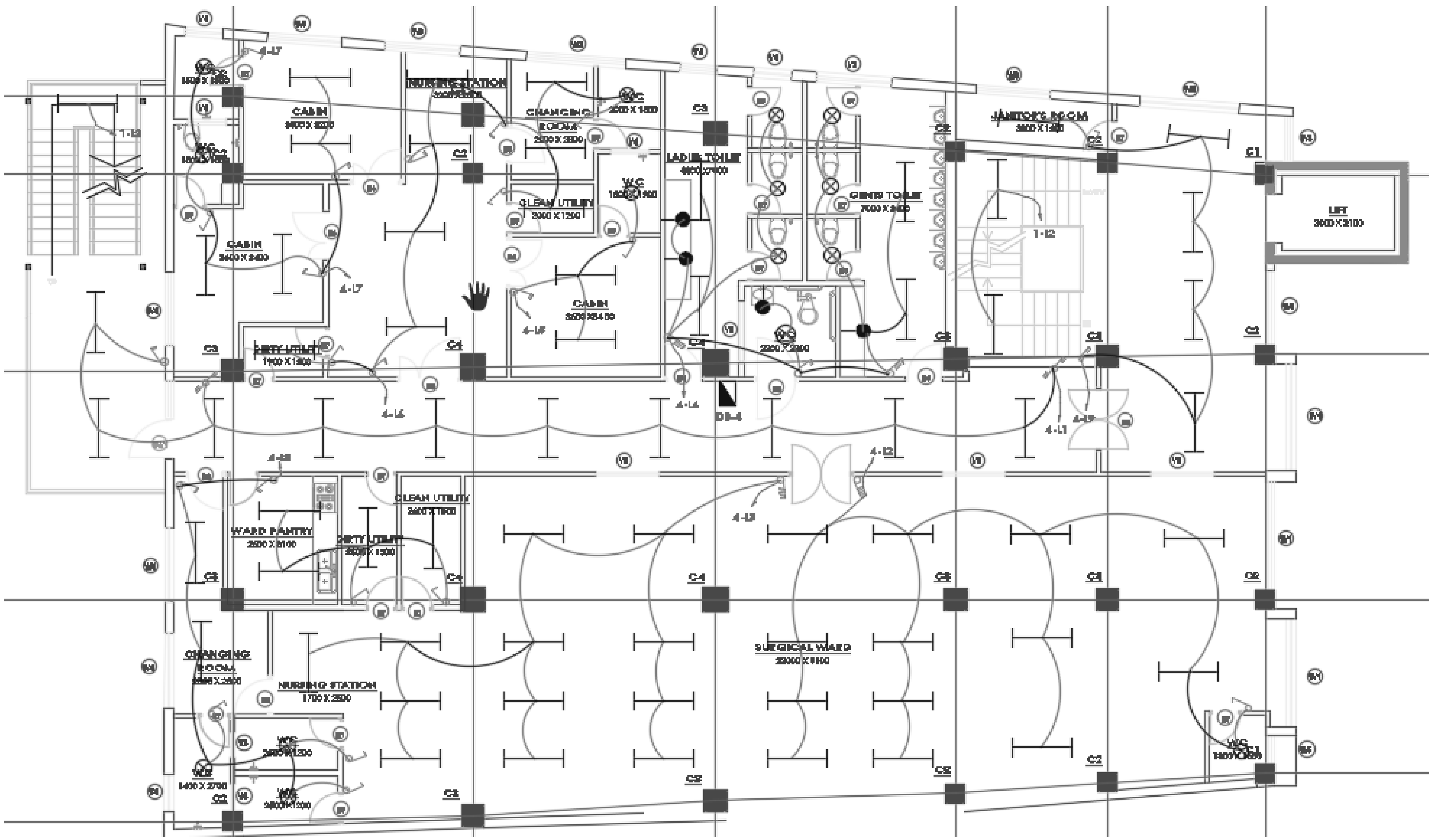
First Floor lighting layout



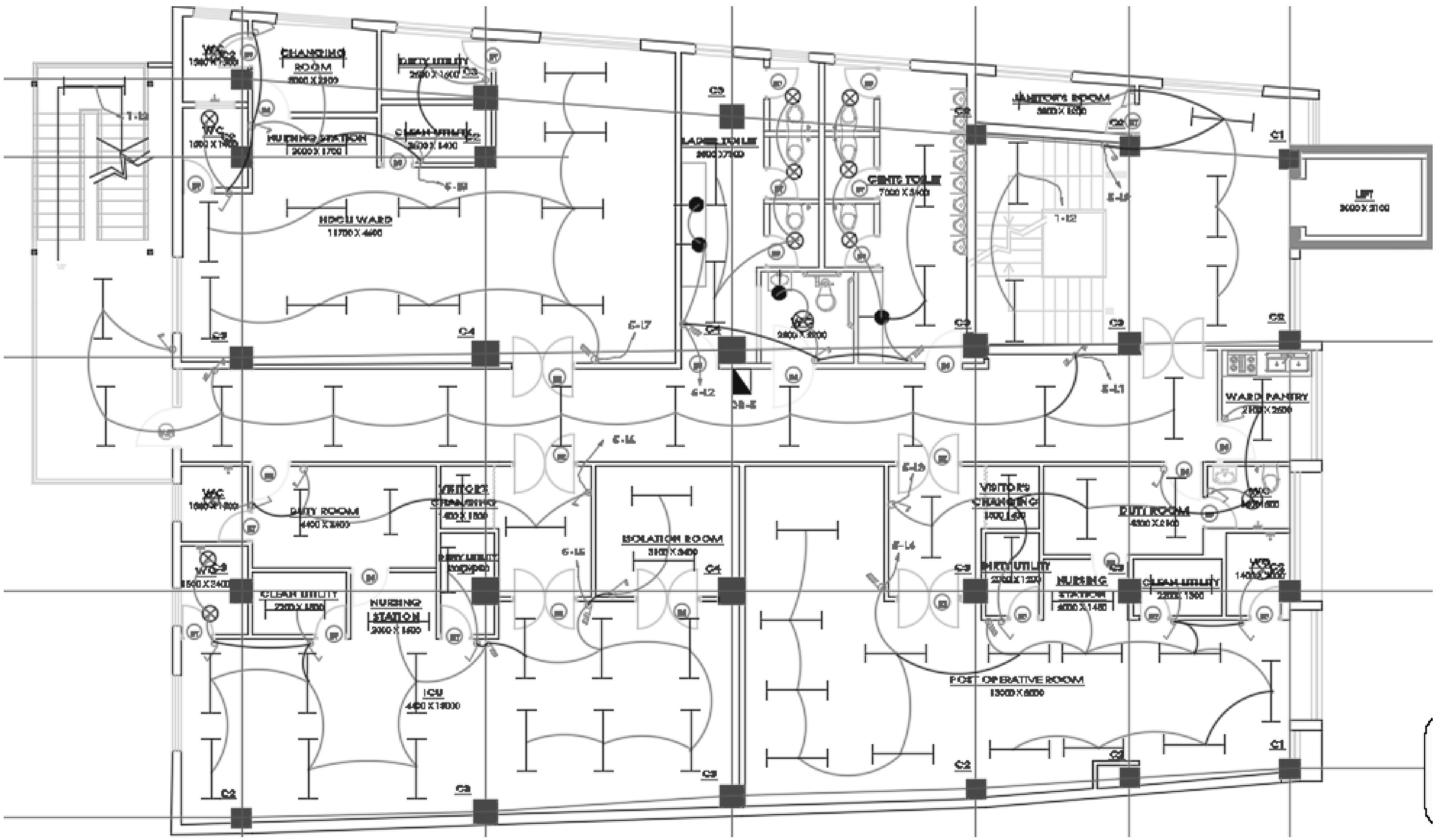
Second Floor lighting layout



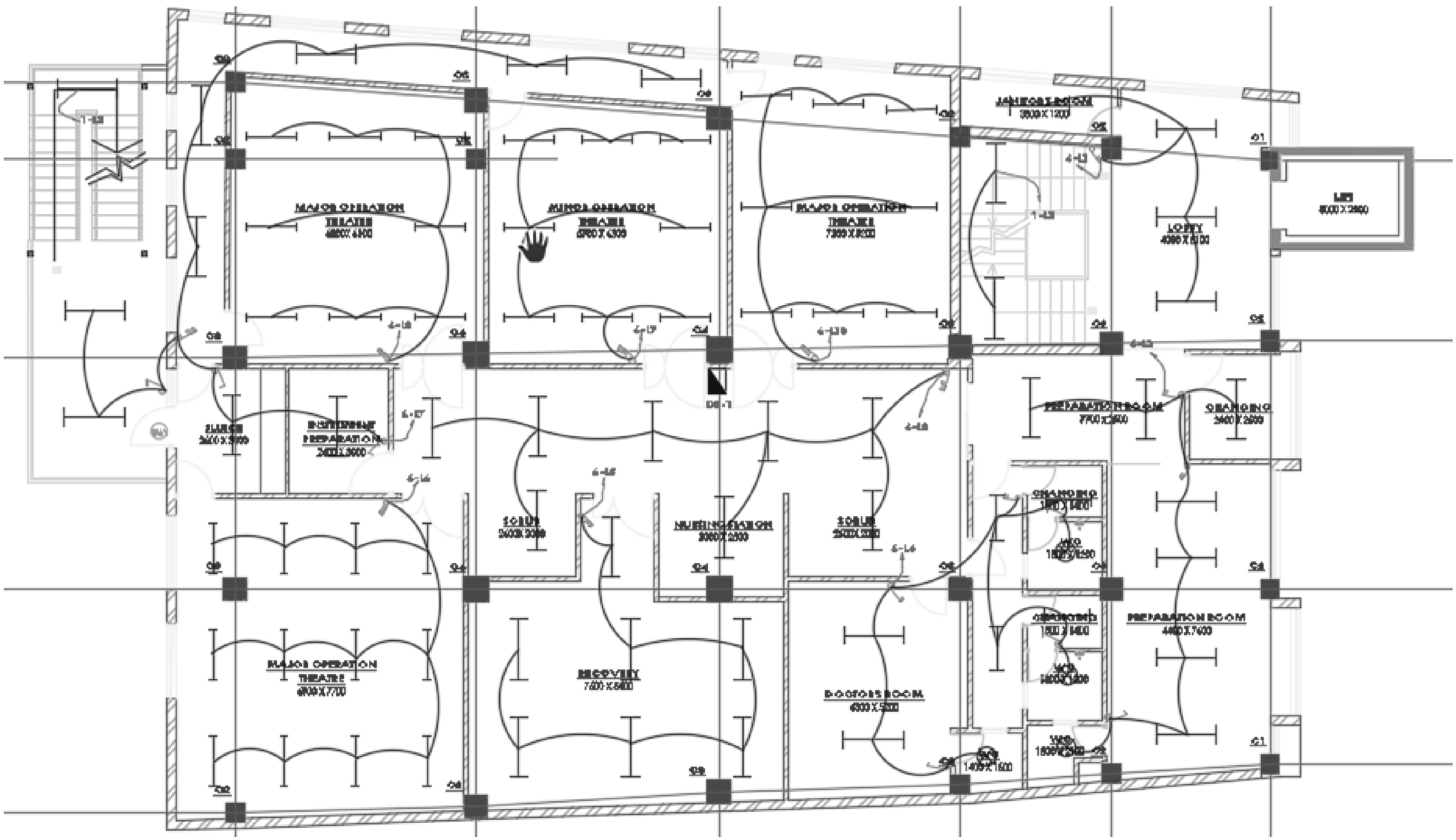
Third Floor lighting layout



Fourth Floor lighting layout



Fifth Floor lighting layout



Appendix C: Product Catalogue of Lumbini Vidyut Udyog Pvt. Ltd.

Nomial CS area of conductor (sq mm)	Number and dia of wires (mm)	Nomial thickness of Insulation (mm)	Conductor resistance ohm/km (max) at 20 C	Current carrying capacity in conduit/ trunking (amps)	2 cables single 0 enclosed clipped directly to a surface or on cable trays (amps)
1.00	14/0.3	0.7	18.1	11	12
1.5	21/0.3	0.7	12.1	13	16
2.5	36/0.3	0.8	7.41	18	22
4.0	56/0.3	0.8	4.96	24	29
6.0	85/0.3	0.8	3.3	31	37
10	80/0.4	1	1.91	42	51
16	126/0.4	1	1.21	57	68
25	196/0.4	1.2	0.78	71	86
35	276/0.4	1.2	0.554	91	110
50	396/0.4	1.4	0.386	120	145

Table 2 : Litmus Single Core PVC Insulated Multistrand Copper Conductor (unsheathed) heavy duty cables for flexible wiring voltage grade650/1100 V.

Appendix D: Crystal Ball Simulation Model

	A	B	C	D	E	F	G	H
1	CRYSTAL BALL SIMULATION MODEL							
2								
3	S.N	LOCATION	FIXTURES	Number of fixture	Total watt	Operation time in		Per day energy consumptio
4						Night tim	Day time	
5						100%	50%	
6	1	Passage,stairs, toilet area	18 watt LED light	184	3312	12	12	59616
7			8 watt Dome light	39	312	12	12	5616
8			10 Watt Mirror light	23	230	12	12	4140
9	2	Nurse stations, Doctor's room ward, ICU, Pharmacy	18 watt LED light	212	3816	12	12	68688
10			8 watt Dome light	27	216	12	12	3888
11			Computer	17	1700	12	12	30600
12			Fan	12	720	12	12	12960
13	3	OT Area	18 watt LED light	46	828	12	12	14904
14	4	OPD and Administration Area	18 watt LED light	53	954		8	3816
15			8 watt Dome light	6	48		8	192
16			10 Watt Mirror light	9	90		8	360
17			Computer	8	800		8	3200
18			Fan	23	1380		8	5520
19	5	testing rooms	18 watt LED light	22	396	12	12	7128
20			8 watt Dome light	1	8	12	12	144
21			10 Watt Mirror light	4	40	12	12	720
22			Computer	2	200	12	12	3600
23	6	store,changing	18 watt LED light	31	558	3	3	2511
24			8 watt Dome light	10	80	3	3	360
25	7	Sterlization area	18 watt LED light	27	486	3	9	3645
26			Computer	1	100	3	9	750
27	TOTAL ENERGY CONSUMPTIOM BY LIGHTING DEVICES (kWh)							175.728
28	TOTAL ENERGY CONSUMPTIOM BY FAN (kWh)							18.48
29	TOTAL ENERGY CONSUMPTIOM BY COMPUTER (kWh)							38.15
30	**by replacing AC LED lights with 10% more efficient DC LED lights (kWh)**							17.5728
31	**Energy saving by replacing AC based computer charging system**							1.621375
32	**ergy saving by replacing AC fan with 24% more efficient DC fan (kWh)**							4.4352
33	**Per day energy loss in AC-DC and DC-DC converter model(92.5%**							17.42685
34	Efficiency of existing 10kVA online UPS system							90%
35	Efficiency that can be improved with removal of rectifier and inverter in existing UPS							7%
36	Percentage of load supplied for 24 hour (approximately)							80%
37	**aving in UPS system with removal of rectifier and inverter in UPS (kWh)**							12.096
38	**NET ENERGY SAVING PER DAY (kWh)**							18.298525

	J	K	L	M	N	O
1	Operation time in a Day (Hour)					
2	Night time (6 pm to 6 am)			Day time (6am to 6 pm)		
3	100%			50%		
4	Minimur	Likeliest	Maximum	Minimur	Likeliest	Maximum
5	50%	Dvserved tim	100%	50%	Dvserved tim	100%
6	6	12	12	6	9	12
7	6	12	12	6	9	12
8	6	12	12	6	9	12
9	6	12	12	6	9	12
10	6	12	12	6	9	12
11	6	12	12	6	9	12
12	6	12	12	6	9	12
13	6	12	12	6	9	12
14				6	8	12
15				6	8	12
16				6	8	12
17				6	8	12
18				6	8	12
19	6	9	12	6	9	12
20	6	9	12	6	9	12
21	6	9	12	6	9	12
22	6	9	12	6	9	12
23	3	3	12	3	3	12
24	3	3	12	3	3	12
25	0	2	12	6	9	12
26	0	2	12	6	9	12
28				Minimum	Likeliest	Maximum
29	% load operated at day time			50%	75%	100%
30	% load Supplied by UPS			50%	80%	100%
31	Efficiency Improvement of UPS			4%	7%	8%

Appendix E: Originality Report

ORIGINALITY REPORT

12%	6%	8%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Informatics Education Limited Student Paper	1%
2	Submitted to University of Strathclyde Student Paper	<1%
3	creativecommons.org Internet Source	<1%
4	hdl.handle.net Internet Source	<1%
5	Submitted to Middle East Technical University Student Paper	<1%
6	Adrian Ioinovici. "Power Electronics and Energy Conversion Systems", Wiley, 2013 Publication	<1%
7	Submitted to NCC Education Student Paper	<1%
8	Submitted to University of Nottingham Student Paper	<1%
9	Submitted to University of Newcastle upon Tyne	

10	Submitted to The Hong Kong Polytechnic University Student Paper	<1%
11	www.freepatentsonline.com Internet Source	<1%
12	A. K. Rathore. "Closed Loop Control Design of Two Inductor Current-Fed Isolated DC-DC Converter for Fuel Cells to Utility Interface Application", 2008 IEEE Industry Applications Society Annual Meeting, 10/2008 Publication	<1%
13	technav.ieee.org Internet Source	<1%
14	Submitted to Universiti Teknologi Malaysia Student Paper	<1%
15	flipkarma.com Internet Source	<1%
16	Rongfu Zhong, WAN Siwei, XIA Yunfeng, WEI Dongliang, HE Wenzhi. "Analysis of DC inter-electrode fault overvoltage in AC/DC hybrid power system", IOP Conference Series: Earth and Environmental Science, 2020 Publication	<1%