A SUSTAINABLE AND ECONOMICAL MICROGRID DESIGN FOR ELECTRIC POWER DISTRIBUTION OF TKMCE CAMPUS

A PROJECT REPORT

submitted by

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the APJ Abdul Kalam Technological University

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T.K.M COLLEGE OF ENGINEERING, KOLLAM

CERTIFICATE

This is to certify that the report entitled **'A SUSTAINABLE AND ECONOMICAL MICROGRID DESIGN FOR ELECTRIC POWER DISTRIBUTION OF TKMCE CAMPUS'** submitted by **Ashik Y** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electrical and Electronics Engineering is a bonafide record of the Project work carried out by him under our guidance and supervision. This Project report in any form has not been submitted to any other University or Institute for any purpose.

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ABSTRACT

The electric power demand and electricity prices are increasing day by day. The increase in EVs, new automatic machinery and increased load demand puts a high burden on the utility. A localised solution incorporating the areas' renewable sources is needed to accommodate future demands. The rising demand of electricity in the TKMCE campus and increasing tariffs are a major concern. The aim of this project is to design a Hybrid microgrid architecture using a PV system as renewable resource, incorporate other generation and loads for the TKMCE campus to reduce the future electricity cost. The project cost analysis is also done to analyse the economic viability. Different cases and scenarios are proposed and analysed and study on the existing system, protection, primary control method and the PV system design is done. A droop control method as part of the primary control of the hierarchical control, to share the power between the inverter-based sources and to regulate the voltage and frequency at the PCC bus is designed and simulated. A concept of "Zero electricity bill" and the modifications that needs to be introduced to attain this concept is also proposed.

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Abbreviations and Notations

1. VMR: Voltage Monitoring Relay
2. MSB: Main Switch Board
3. UV/OV: Under Voltage/ Over Voltage
4. PV : Photo Voltaic
5. DER : Distributed Energy Resource
6. MEG : Micro Energy Grid
7. PCC : Point of common coupling
8. PLL : Phase Locked Loop
9. ETN : Electrical transportation network

Chapter 1

Introduction

The power sector is currently undergoing a transition towards a decentralized structure, wherein the consumers are no longer reliant on a single utility. Instead, they are generating and consuming power locally, using renewable resources and distributed generations, along with a control strategy. This localized generation of power, combined with the management of local loads, falls under the purview of a microgrid. A microgrid represents an integrated system comprising electricity generation, distribution infrastructure and energy storage facilities (if necessary) that can maintain power even when disconnected from commercial grids. The two distinctive features of a microgrid are its collection of generation and load centers with fixed limits/boundaries and its capacity to function under both grid-connected and islanded modes.

Designing a microgrid poses a major challenge in terms of electrical system protection. A pre-microgrid design necessitates the inclusion of protective devices that can expediently identify and isolate the faulty circuit feeder to prevent damage to the circuit and the system as a whole. During the pre-microgrid investigation, a reverse power flow from the UPS system to the main switchboard (MSB) was discovered. As such, it is essential to address and rectify this reverse power flow issue with alacrity. As such, the pre-design of the microgrid for the TKMCE campus incorporates an automatic reverse power flow protection system that can be manually controlled to address and rectify the identified issue.

In any microgrid, the control scheme is a crucial component that ensures stability by maintaining a fixed range of voltage and frequency at the PCC. To this end, a primary control method called the Droop control method has been proposed as part of this project's hierarchical control scheme. This method employs drooping of active power against frequency and reactive power against voltage across all inverter-based sources in the system. The objective is to ensure load sharing between sources and regulate frequency and voltage at the PCC. A MATLAB/SIMULINK model of the droop control technique along with the Microgrid supervisory control is designed.

A comprehensive analysis was carried out to gather information on the load and consumption patterns at TKMCE campus. The entire system was examined, and various potential scenarios were evaluated to suggest a cost-effective microgrid architecture that is tailored to the campus' power requirements and utilizes renewable sources such as PV systems and backup batteries. The cost of installation, maintenance and operation for each case was also taken into account as part of the cost-benefit analysis and an economical model is presented.

1.1 Motivation

It has been found that the TKMCE campus incurs an average monthly energy bill of 3,21,000 Rupees, which includes a fixed cost of 1,08,000 Rupees. Given that the college operates between 9.00 AM to 4.00 PM, there is a significant potential to harness a substantial amount of solar energy for day-to-day usage. With the utility electricity prices on the rise, it is imperative to prioritize the use of available renewable energy sources, which can significantly reduce the dependence on the main grid (KSEB) and ultimately lead to reduced energy costs for the campus.

The reverse power flow from the UPS to the MSB can result in a host of issues, including light flickering in the electrical machines lab when the KSEB supply is disrupted, the power flowing back to the MSB, which can potentially flow to other circuits and endanger personnel working in the lab or other circuits. Furthermore, the reverse power may also flow back to the utility side, posing a risk to people working in the utility.

1.2 Objectives

- To conduct an extensive study for the electricity consumption behaviour of TKMCE.
- Design and setup a circuit using MATLAB simulation for the reverse power flow issue.
- Implement Hardware using VMR to rectify the identified issue.
- Design and simulate a Droop control for the inverter based sources in Microgrid suitable for campus.
- Design background and analysis based on case studies for microgrid setup in TKMCE campus.
- Prepare a cost/benefit analysis for the proposed system.

1.3 Structure of thesis

1.3.1 Chapter 1

This chapter introduces the thesis by describing the necessity for renewable energy sources and microgrids. A reverse power flow problem and a microgrid primary control system are also mentioned. This section also briefly examines the thesis's motivation, objective, and structure.

1.3.2 Chapter 2

This chapter discusses the literature that was reviewed in preparation for the project's implementation. Various existing literature on subjects relating to the proposed system was thoroughly researched and examined.

1.3.3 Chapter 3

This chapter gives an overview of the electrical scheme of TKMCE campus. The scheme, electricity bills, load demand etc. are studied as part of the pre-design of the microgrid. The design of PVs required and battery systems are mentioned. This chapter also addresses the identified issue of reverse power flow from the UPS system along with the hardware details. A microgrid primary control strategy for controlling and regulating the voltage and frequency of inverter-based microgrid sources as part of a hierarchical control scheme is discussed at the end of the section.

1.3.4 Chapter 4

This chapter describes the Simulation of the proposed Reverse power flow protection along with the program for the UV relay used. The droop control simulation in MATLAB/SIMULINK is also discussed in this, Different cases and sub-cases which are considered for the economical design of the microgrid for TKMCE campus is analysed in this section.

1.3.5 Chapter 5

This chapter deals with the results from the simulations done. The results are explained using plots obtained from the simulation and is discussed. The hardware set-up implemented in the campus is shown. A cost-benefit analysis is also done in this section for the different cases considered for the campus' microgrid.

Chapter 2

Literature Survey

2.1 Introduction

This chapter provides an overview of the topics that supplied the ideas for this project. The following sections examine the previous works which have been done on similar topics.

2.2 Literature Survey

2.2.1 Design and Implementation of a Microgrid Energy Management System.

This research paper introduces the Microgrid Platform (MP), an advanced Energy Management System (EMS) designed for optimal microgrid operations. The MP is developed to address both the functional requirements of a microgrid EMS, such as optimization, forecasting, human-machine interface, and data analysis, as well as the engineering challenges of interoperability, extensibility, and flexibility.

To validate the effectiveness of the MP design in practical scenarios, a prototype system is created and implemented in two smart grid testbeds: the UCLA Smart Grid Energy Research Center and the Korea Institute of Energy Research. Through these testbeds, a series of experiments are conducted to verify the feasibility of the MP and its ability to efficiently communicate with various energy devices while performing energy management tasks.

The outcomes of the testbeds and experiments demonstrate that the Microgrid Platform successfully meets the desired objectives. It showcases its capability to facilitate seamless communication with diverse energy devices and effectively execute energy management functions.

2.2.2 Adaptive protection scheme for smart microgrid with electronically coupled distributed generations

The objective of this research paper is to create a model for an electronically coupled distributed energy resource and develop an adaptive protection scheme for it. The electronically coupled distributed energy resource refers to a microgrid configuration where renewable energy sources are electronically interconnected. The proposed adaptive protection scheme aims to provide effective protection to the microgrid under various fault conditions, regardless of whether it is operating in grid-connected mode or islanded mode.

One notable feature of the adaptive protection scheme is its ability to monitor the microgrid in real-time and dynamically adjust relay fault currents based on system variations. This ensures that the protection scheme remains up to date with the changing conditions of the microgrid. Additionally, the proposed scheme incorporates auto reclosures, enabling the microgrid to recover faster from faults and enhance its overall reliability.

To evaluate the effectiveness of the adaptive protection scheme, time domain simulations are conducted using the PSCADnEMTDC software environment. These simulations provide valuable insights into the performance and behavior of the adaptive protection scheme in different scenarios, demonstrating its efficacy in safeguarding the microgrid.

2.2.3 Paving the Way to Smart Micro Energy Grid: Concepts, Design Principles, and Engineering Practices

This research paper focuses on the benefits of interconnecting independent energy infrastructures and how it enhances system flexibility and efficiency. By integrating these infrastructures at the distribution level, the implementation of integrated energy system functionalities becomes more streamlined. The paper introduces the concept and design principles of a smart Micro Energy Grid (MEG), which is designed to accommodate microgrids, distributed poly-generation systems, energy storage facilities, and associated energy distribution infrastructures.

The energy management system plays a crucial role in ensuring the intelligent operation of the MEG while considering multiple criteria such as safety, economy, and environmental protection. To achieve the vision of a smart MEG, the paper investigates an energy management system based on engineering game theory, which possesses self-approaching-optimum capability.Building upon the proposed concepts, design principles, and energy management system, the paper presents a prototype of China's first solar-based smart MEG, implemented at Qinghai University. This prototype serves as a practical demonstration of the ideas and principles discussed in the paper, showcasing the potential of smart MEGs in real-world applications.

2.2.4 Microgrid design guide 2016 for naval facility

This paper introduces a methodology in which microgrid design for any site can be implemented. Various steps taken in the pre-design, site specific design and post design and implementation of the microgrids in the NAVFAC is discussed. The economical, engineering and environmental considerations that should be taken while performing each steps along with the standard procedures that is to be followed is mentioned.

2.2.5 Dynamic Operation and Control of a Multi-DG Unit Standalone Microgrid

This paper addresses the challenge of managing different sources with varying capacities in a Microgrid, particularly during autonomous operation when the Microgrid is disconnected from the main grid. In addition to supplying the total load and power sharing among the sources, it is crucial to meet the voltage and frequency requirements of the connected loads.

To tackle this issue, the paper proposes the implementation of a droop control strategy in a standalone multi-converter-based power system. The droop control ensures that the frequency and voltage vary in response to changes in active and reactive power, respectively. To regulate the load voltage and output current of the converters, PI voltage and inner current controllers are designed based on the dynamic equations of the system. Furthermore, a three-phase Phase-Locked Loop (PLL) is developed for each converter.To validate the effectiveness of the proposed approach, the entire system is simulated using MATLAB/Simulink software. The simulation results demonstrate the successful implementation of load sharing between the converters during the autonomous operation of the microgrid, thus verifying the feasibility and functionality of the approach.

Chapter 3

System Model

3.1 Introduction

This chapter reviews and analyses the existing electrical scheme of TKMCE campus. The connected load, maximum demand, contract demand, power consumption, load pattern is reviewed in this section. A general design of a microgrid is reviewed along with the reverse power flow issue identified and a droop control method is also mentioned.

3.2 Existing Electrical System of TKMCE Campus

A transformer with a rating of 500kVA 11/433 kV oil-cooled is supplied by KSEB to power the TKMCE campus. A buscoupler connects the two buses that are present inside the MSB. Bus 1 and Bus 2 are connected, respectively, to a 500kVA and 200kVA three-phase diesel generator. The connected load of TKMCE is 823kW + 241kVA with an average maximum demand of 240kVA and contract demand with KSEB is 300kVA. There are 10 sub-circuits connecting the loads from the MSB named as SB1 to SB7, APFC panel and spare. A 120kVA central UPS system is connected to the MSB, which serves the critical loads in the main block of the campus. Two other UPS systems rated at 30kVA each are also present in the campus.

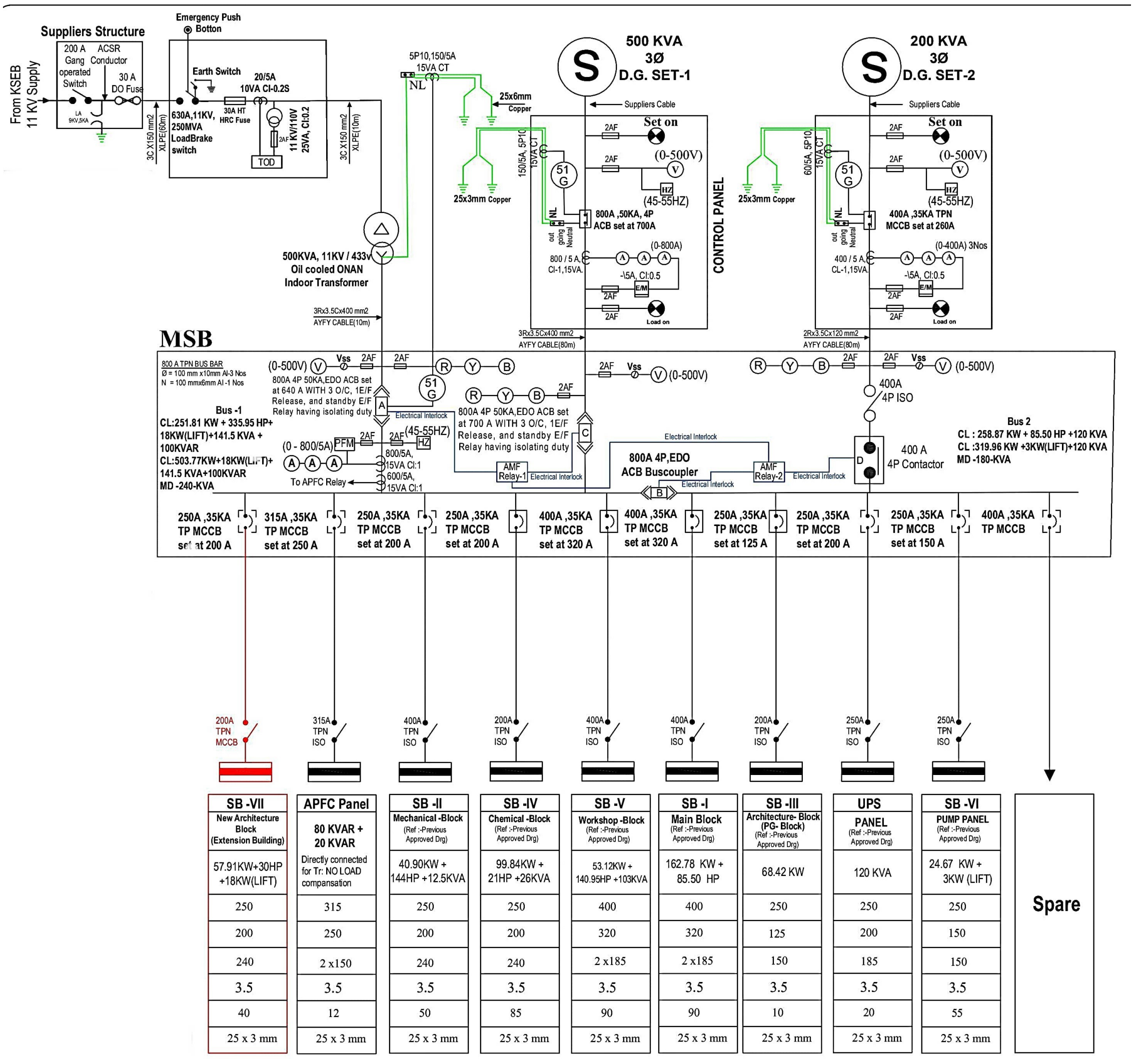

Fig. 3.1: Electrical scheme of TKMCE campus

3.2.1 Buildings and Assets

The entire campus is divided into 5 blocks. The main block consist of 4 departments - civil. electrical, computer science and electronics. There are various labs associated with each departments and common facilities such as APJ Hall, PTA Hall, Jubilee Hall are all located inside the main block. The administrative office and the Principal's cabin is also located inside this block. The total air conditioning load in the main block is 35kW. SB1 from Bus-2 of the MSB provides the electrical power for the main block.

The mechanical block houses lab facilities, the staff rooms for mechanical faculty, drawing halls and classrooms. SB2 from Bus-1 feeds power to this block. An 18kW solar PV system has already been installed in the premises of this block. The connected load for this block is 40.9kW + 144HP + 12.5kVA. The average daily power consumption of this block is 80kWh.

The architecture block has a connected load of 68.42kW which is connected from the MSB's Bus-2. In this block there are architecture studios, classrooms, faculty rooms and lab facilities.

The chemical block consumes the second most electrical power in the campus with a connected load of 99kW + 21 HP + 26kVA. The average daily consumption for this block is 140kWh. It is connected to the second bus in the MSB.

The workshop block has classrooms, CAD/CAM lab, AI lab, mechanical workshop etc. The connected load for the workshop is 53kW + 140.9 HP + 103kVA. This block is fed through Bus-1 from MSB.

3.2.2 Central UPS System

The central UPS system is rated at 120kVA and feeds all the critical loads in the campus in case of outages. There are 64 batteries to support the UPS system which acts as a load when connected to the utility. The batteries are Li-ion and each battery has a rated voltage of 24V. There are two other UPS systems that serves locally at the workshop block and the main block.

3.3 Microgrid

A microgrid is a self-contained electricity system that includes power generation, distribution infrastructure, and energy storage, designed to maintain power even when disconnected from the main power grid. Microgrids are distinct from other grid modernization initiatives, such as smart grids and virtual power plants, due to their two distinctive features: a microgrid comprises of fixed limits for both generation and load centers, and it can operate in both grid connected and isolated (island) modes.

The design of microgrid includes analysing the loads and consumption of the existing system in the campus, the load data was taken from the existing drawings and consumption data was collected through electricity bills of the campus from the last 10 years. Another major aspect is to define the boundaries of the microgrid that needs to be designed. The microgrid in TKMCE campus should include all the facilities inside the campus boundary walls thus the boundary was defined. A Hybrid microgrid system is Designed for the TKMCE campus.

3.3.1 Hybrid Microgrid

The microgrids can be classified into 4 main categories according to their application:Grid connected microgrid, Continuously islanded microgrid, Hybrid microgrid, Community resiliency microgrid. The microgrid which works connecting to the main grid and forms a microgrid only when there is a power interruption from the main grid is called a grid connected microgrid. The microgrid setup which will not connect to a grid utility and works always in the microgrid islanded mode is an islanded microgrid. A hybrid microgrid is a type of microgrid designed to serve as an emergency backup that can operate independently to support the grid. It is capable of integrating renewable energy sources, improving power factor, utilizing battery power, and incorporating smart technologies.The main aim of a hybrid of microgrid is to reduce the dependency on the main grid and to supply reliable power to the consumers.

3.3.2 Solar PV system

The renewable energy incorporation is another step in designing the microgrid. In the TKMCE campus the average energy consumption per month is found to be 36000kWh. Most of the load is consumed between the campus working time from

9.00am-4.00pm. During this time the Solar availability in the area is high around the year on all seasons. So a solar system that can support the demand of the campus was designed to generate the electricity to form a microgrid.

Two different possible cases are considered in designing the microgrid with PV system for the campus.

- A single solar PV system that can supply the entire campus.
- A main solar PV system that can supply the demand of the campus along with 3 sub microgrids within the microgrid supported by PV systems and backup batteries.

The solar irradiance data was collected from the weather department. In kollam district the solar irradiance From February to October during 9.00 am to 4.00pm is more than 250W/m.sq and reach upto 850W/m.sq which is sufficient to produce the electricity for the campus. From November to January The solar irradiance reaches 250W/m.sq only after 10.00am and The maximum irradiance is around 400W/m.sq.

3.3.3 Standards and regulations

There are certain standards that should be followed when installing a microgrid or PV system as prescribed by the main utility (KSEB).

- Cumulative capacity of PV system installed shall not exceed 80 % of the transformer capacity.
- Net meter should be installed by the licensee.
- Prosumer shall comply with specs and standards as provided by KSEB and shall install manually operated isolating switch.
- Upon connecting to the grid, the phase voltage should be in the range of 192 – 264 V.
- Frequency should be between 49.5 – 50.5 Hz.
- Once grid power is lost, the system should wait 1 min. before attempting reconnection.

3.3.4 Classification of loads

The loads are then classified into 4 categories namely:

- Microgrid Essential - The assets and buildings that is essential for the microgrid to form. In TKMCE campus, the main solar PV system, backup generators, main block, UPS system and pump panel are selected as microgrid essential assets and buildings.
- Microgrid supported - These are assets and buildings that are part of the microgrid and supported by the microgrid during most of the time of its operation. These include Architecture block, Auditorium, and new architecture block.
- Microgrid Discretion - The microgrid discretion buildings will be a part of

the microgrid on the discretion of the microgrid controller. When the power generated by the microgrid is more than that to feed the microgrid essential and microgrid supported loads, then microgrid discretion loads are added one by one. In the TKMCE campus, AC(air conditioning) loads can be separated from all the buildings and can be connected to the MSB as a separate connection. The AC loads in the campus is then considered as microgrid discretion loads. Mechanical block, Workshop block and Chemical block are also taken as microgrid discretion loads.

3.3.5 Design of PV required

The average electrical power consumed by the TKMCE campus is per month is 36000kWh. 70% of the consumption is during the working hours from monday to friday. 25200 kWh is consumed on working days of the month.

Average Consumption/day = 25200/22 = 1146kWh

A 1KW solar PV system can produce an average of 5kWh of electricity/day

Total solar PV required = 1146/5 = 229kW

A 250kW solar PV system considering margin and future expansions has been designed.

400 watt PV modules are selected for the application

V(open circuit) of each module = 50.9V

The number of modules required for a 250kW system = 250000/400 = 625

Number of series strings = required voltage/Voc of each PV module

430/50.9 = 8.5 (can be taken as 9)

Number of parallel strings = 625/9 = 70

A single 250kVA solar inverter can be used to convert the DC produced by the

PV system to AC. This is the cost effective way but this reduces the reliability of the system.

Area of one 400 watt panel = 22.45sq.ft

Total roof area required = 625 x 22.45 = 14031sq.ft of shadowless roof top area is required.

3.3.6 PV systems for each block

Three blocks which consumes the most electricity is taken and designed to work as individual microgrids when the main microgrid system does not produce enough electricity. Battery energy storage systems are also provided in each of these blocks.

The 3 blocks selected are Chemical block, Workshop block and Mechanical block

3.3.7 Chemical block

Average daily Electricity consumed in the block = 140kWh

A 1KW solar PV system can produce an average of 5kWh of electricity/day

Total solar PV required = 140/5 = 28kW

A 30 kW solar PV system is designed for this block.

Total number of PV modules required = 75

A 30kVA solar inverter is also installed.

Number of series strings = required voltage/Voc of each PV module

430/50.9 = 8.5 (can be taken as 9)

Number of parallel strings = 75/9 = 9

Area of one 400 watt panel = 22.45sq.ft

Total roof area required = 75 x 22.45 = 1683sq.ft. of shadowless roof top area is required.

Battery backup required

Battery Bank capacity in Ah = U*D*1000/DOD*Vsys= 686Ah

Where U is the electricity consumed per day in kWh, D is the number of days of autonomy required (taken as 2), DOD is the depth of discharge (0.95) and Vsys is the system voltage (430V).

Total number of batteries = B*1000/Vnom*C1 = 295*1000/25.6*180 = 65 batteries

B is the battery bank capacity in kW, C1 is the ah rating of each battery and Vnom is the nominal voltage of the battery.

24V 180Ah Lithium-ion batteries are selected as these batteries have a longer life and better efficiency.

3.3.8 Workshop block

Average daily Electricity consumed in the block = 90kWh

A 1KW solar PV system can produce an average of 5kWh of electricity/day

Total solar PV required = 90/5 = 18kW

A 20 kW solar PV system is designed for this block.

Total number of PV modules required = 50

A 20kVA solar inverter is also installed.

Number of series strings = required voltage/Voc of each PV module

430/50.9 = 8.5 (can be taken as 9)

Number of parallel strings = 50/9 = 6

Area of one 400 watt panel = 22.45sq.ft

Total roof area required = 50 x 22.45 = 1122sq.ft. of shadowless roof top area is required.

Battery backup required

Battery Bank capacity in Ah = U*D*1000/DOD*Vsys= 440Ah

Where U is the electricity consumed per day in kWh, D is the number of days of autonomy required(taken as 2), DOD is the depth of discharge (0.95) and Vsys is the system voltage (430V).

Total number of batteries = B*1000/Vnom*C1 = 190*1000/25.6*180 = 41 batteries

B is the battery bank capacity in kW, C1 is the ah rating of each battery and Vnom is the nominal voltage of the battery.

3.3.9 Mechanical block

Average daily Electricity consumed in the block = 90kWh

A 1KW solar PV system can produce an average of 5kWh of electricity/day

Total solar PV required = 90/5 = 18kW

An 18 kW system already exist in this block, this system can be modified and can be used as part of the microgrid

Battery backup required

Battery Bank capacity in Ah = U*D*1000/DOD*Vsys= 389Ah

Where U is the electricity consumed per day in kWh, D is the number of days of autonomy required(taken as 2), DOD is the depth of discharge (0.95) and Vsys is the system voltage (430V).

Total number of batteries = B*1000/Vnom*C1 = 169*1000/25.6*180 = 37 batteries

B is the battery bank capacity in kW, C1 is the ah rating of each battery and Vnom is the nominal voltage of the battery.

3.3.10 Reverse Power Flow Issue

During the investigation for the pre-microgrid design, a reverse power flow was detected in the system originating from the UPS system to the main switchboard (MSB). It is imperative to promptly address and rectify this reverse power flow issue.

The occurrence of reverse power flow from the UPS to the MSB has resulted in several issues, including flickering lights in the electrical machines lab during KSEB supply outages. The back-flow of power to other circuits poses a safety risk to individuals working in those circuits and the lab. Furthermore, the reverse power flow may also reach the utility side, creating a potential safety hazard for those working in the utility. To address this problem, an automatic reverse power flow protection system has been designed for the TKMCE campus microgrid pre-design, which can be manually controlled as well.

The design procedure of The reverse power flow protection is realized by using a voltage monitoring relay, a 4 pole contactor at the UPS side and other components as shown in the Fig 3.2 below:

The molded case circuit breaker (MCCB) is present at both the main switchboard (MSB) panel and the incoming panel of the UPS. A control circuit is employed to regulate a 4-pole contactor that manages the MCCB, as illustrated in the Fig 3.2.

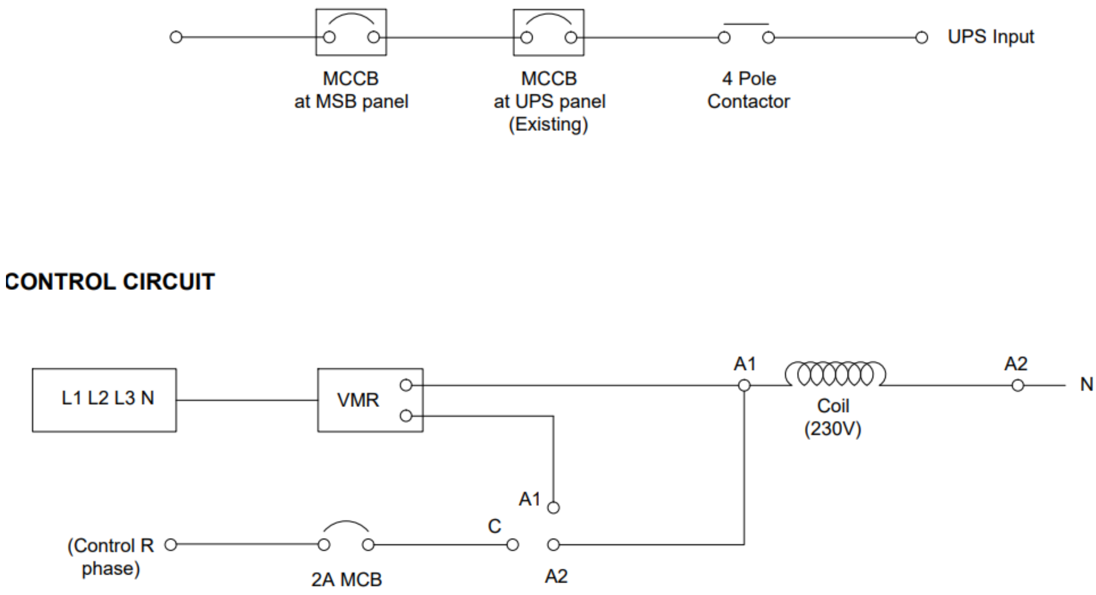

Fig. 3.2: Connection diagram of automatic Reverse power flow protection

When operating in automatic mode, the control phase that energizes the voltage monitoring relay (VMR) is connected to point C of a selector switch, which is set to position A1, thereby connecting to the VMR. The VMR monitors the values of L1, L2, L3, and N, and if phase R is present, the VMR becomes active and energizes the 230V coil of the 4-pole contactor. To disconnect the VMR from the circuit, the selector switch can be set to position A2, thereby disabling the VMR's control over the circuit, allowing for manual operation. To manually interrupt the circuit, a 2A MCB is used for manual control.

It is taken that the undervoltage setting as 80 % of the normal RMS voltage, i.e 0.8 x 230 = 194V

also Over voltage is set at 110 % of rms voltage, i.e 1.1 x 230 = 253V

A time delay of 0.2 seconds is choosen.

Voltage Monitoring Relay VMR

The voltage monitoring relay (VMR) is designed to ensure that only safe and acceptable voltages are supplied to a system. These relays are capable of monitoring voltage levels in both single-phase and three-phase circuits. Housed in a self-extinguishing plastic enclosure, the VMR provides protection against under voltages, over voltages, phase imbalances, and phase losses within a circuit.

To configure the VMR, rotary switches are utilized, allowing users to adjust settings such as under voltage, over voltage, and trip time delay. The trip time delay can be set within a range of 0.1 to 10 seconds, determining the duration before the VMR responds to abnormal voltage conditions. Additionally, the UV/OV settings can be selected, specifying the acceptable voltage thresholds as a percentage of the nominal voltage (Un), with a range typically spanning from 70 % to 125 % of Un.

3.3.11 Hardware details

The UPS is rated at 120KVA with 3 phase supply feeding it and 3 single Phase loads connected to the UPS system

The MCCB provided is rated at 250A

Voltage Monitoring Relay - Tele

250A 4 pole contactor - L&T

6A MCB, 20A Automanual selector switch - L&T

3.4 Droop control on inverter based sources in the microgrid

As in any microgrid the control of the microgrid is an important area where there is a need to keep focus on. A hierarchical control scheme is usually employed in microgrids. Hierarchical control of Microgrid consist of 3 types of control :

- Primary control: Locally implemented at each DER, voltage stability, frequency stability (P/Q Droop Control)

- Secondary control: Communicates with primary and tertiary control, compensates voltage and frequency deviations from primary control, regulates and control voltage at PCC etc. (Restoration and Synchronization)

- Tertiary control: Controls power flow and energy management (Import/Export power)

The voltage and frequency at the PCC should always stay in limits inorder for the system to be stable. Primary control is always implemented using droop control while secondary control depends on converter type. In the system considered 3 inverter based sources : a 500kVA generator, a 300kW PV and a 200kVA generator. The voltage and frequency needs to be controlled locally at each sources. The voltage control can be employed by controlling the reactive power(Q) and frequency is controlled by controlling active power (P). In this system, a droop control scheme is implemented for each converter to enable load sharing based on local measurements. This means that each Distributed Generation (DG) unit is assigned its own local frequency, which is determined using a phase lock loop (PLL) for accurate frequency measurement.The control unit allows for the distribution of active power among the loads by adjusting the frequency in relation to the output active power of the converter. Additionally, the control unit enables the distribution of reactive power by adjusting the output voltage magnitude of the converter in response to its output reactive power.The control unit utilizes two coefficients to regulate the rate at which frequency and voltage change in response to variations in active and reactive power, respectively.

$$\omega_i * = \omega_n - m_{pi} P_{si} \tag{3.1}$$

$$V_{mi} * = V_n - n_{qi} Q_{si} \tag{3.2}$$

Where Wn, Vn are rated frequency and rated voltage of the system. mpi, nqi, Psi and Qsi are active power droop coefficients, reactive power droop coefficient, output active power and output reactive power of converter, respectively.

3.4.1 Frequency control

The droop characteristics of active power and frequency is shown in the Fig 3.3. A 1 % droop is allowed for the frequency. The nominal frequency of the system is

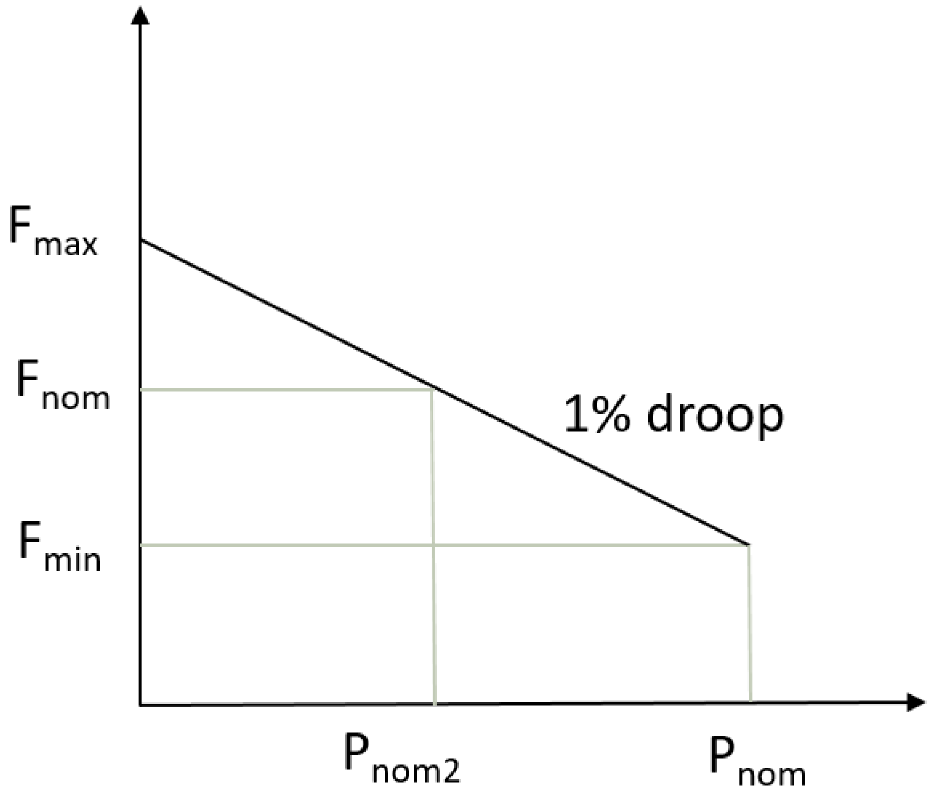

Fig. 3.3: Frequency droop characteristics

selected as 60Hz. For a 1 % droop the frequency can vary from 59.7Hz to 60.3Hz. Fmax (max allowed frequency) reaches when there is no active power produced by the source. Fmin is reached when the active power of the source gets to the nominal active power i.e. Pnom. The active power droop coefficient is determined by the maximum allowable change in frequency, typically set at 1%, in relation to the maximum change in active power of the converter. The maximum change in active power corresponds to the nominal power of the converter.

$$m_{pi} = \frac{\Delta\omega}{\Delta P_{simax}} \tag{3.3}$$

3.4.2 Voltage control

The droop characteristics of Reactive power and Voltage is depicted in the Fig 3.4.

$$n_{qi} = \frac{\Delta V}{\Delta Q_{simax}} \tag{3.4}$$

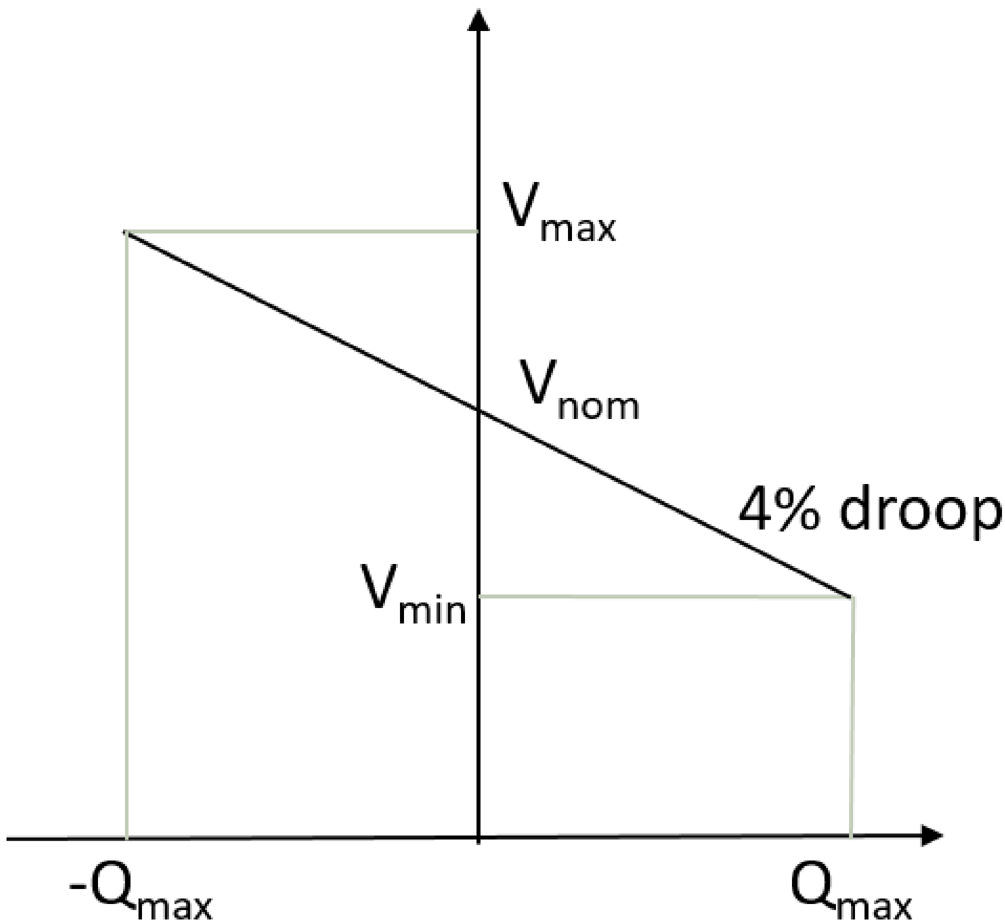

Fig. 3.4: Voltage droop characteristics

The droop allowed for the voltage to be in limits is 4 %. The system nominal voltage is taken as 430V and Vmax(438.6V) is reached when the reactive power is at the negative maximum. When reactive power Q reaches positive maximum the voltage will reach Vmin (421.4V).

For the whole system to have same frequency,

$$\omega_n - m_{p1}P_{s1} = \omega_n - m_{p2}P_{s2} \tag{3.5}$$

$$\frac{m_{p1}}{m_{p2}} = \frac{P_{s2}}{P_{s1}} \tag{3.6}$$

If it is consideridered that the nominal power of the second converter is twice that of the first converter, then the active power droop coefficient of the second converter should be chosen to be half of the first converter's coefficient, given this scenario.

3.4.3 Microgrid supervisory control

A microgrid supervisory control is also designed as part of the droop control to control the voltage and frequency at PCC. The Voltage at PCC is taken as input by the microgrid supervisory control, the Vpcc is given to a 3 phase PLL and then to a filter network to generate the value for Fpcc(frequency).A saturation is also added to make sure the frequency will not go off limits. Vpcc is also given to a Demux and the PLL output is taken to update the value of Vpcc. The Vpcc and Fpcc is then compared with Vnom and Fnom respectively and then passed through a PI controller to generate Vref and Fref.

3.4.4 Droop control inside each sources

Inside the inverter based sources, the DC is converted to AC by an IGBT converter. An LC filter circuit is provided and a transformer to bring the inverter voltage to the required voltage. The primary voltage(Vprim) and primary current(Iprim) of each inverter is taken as inputs to the control system for droop control. The Vref and Fref generated by the supervisory control is taken as inputs to the control system. Also droop control on signal enables when the control should start working.

Active power and reactive power measured from the output of each inverter is taken as input to the droop control also Vref and Fref are given to the input of the droop control, The values are then compared to the droop allowed and output voltage Vout, output frequency Fout and angle (wt) are generated. Voltage and current regulators are also there inside the control block.

Chapter 4

Simulation and cases

4.1 Introduction

Simulation is done in matlab simulink. While MATLAB is primarily designed for numerical computing, it includes an optional toolbox that utilizes the MuPAD symbolic engine, providing access to symbolic computing capabilities. Furthermore, Simulink, another package, offers graphical multi-domain simulation and model-based design features for dynamic and embedded systems.

Also different cases of microgrid considered for the campus is also discussed in this chapter

4.2 Simulation

4.2.1 Undervoltage Relay Reverse Power protection

The simulation of an Under voltage relay is shown in the Fig 4.1. This relay mimics the working of a Voltage monitoring relay. The relay is set to work when the voltage of the relay falls below a predetermined voltage 320V (80 %) of the voltage level which is taken as 400V. The protected load is the UPS system of the campus, When the main supply is absent the UV relay detects under voltage and blocks the path of the UPS to feed back power thereby eliminating the issue of reverse power flow. Fig 4.2 shows the subsystem of UV relay Where the relay logic is programmed.

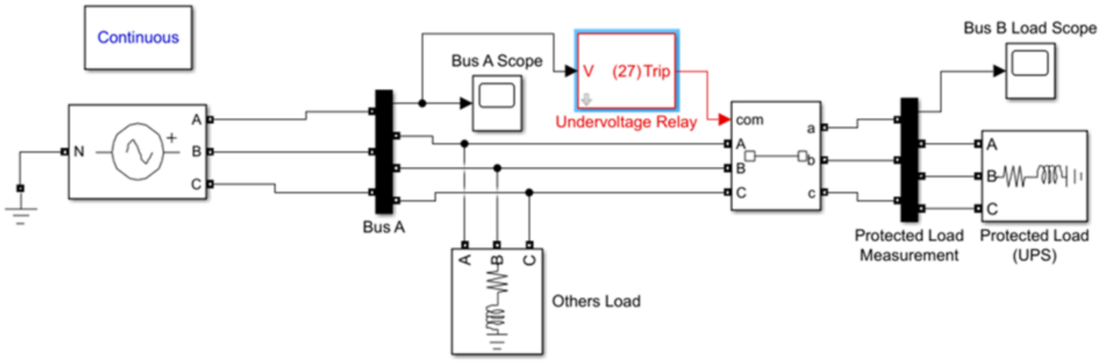

Fig. 4.1: Reverse power protection using undervoltage

4.2.2 Subsystem

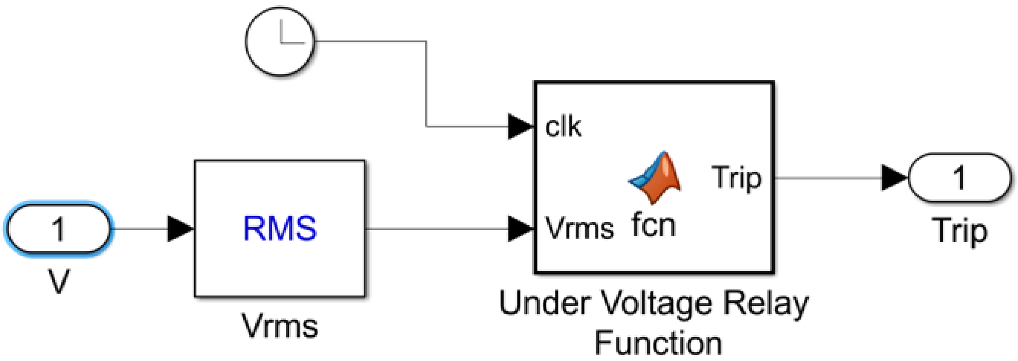

Fig. 4.2: Subsystem of Protection system

4.2.3 Program for Reverse power flow protection

```
function Trip = fcn(clk,Vrms,Vn,UVset,delay)

    persistent RelayState TripTime CaptureClk StopClk

    if isempty(RelayState)

    RelayState = 0;
```

```
TripTime = inf;

CaptureClk = 0;

StopClk = 0;

end

if min(Vrms)¡=(Vn-(Vn*(UVset/100)))

if (CaptureClk == 0)

StopClk = clk + delay;

CaptureClk = 1;

end

if (RelayState == 0)(clk-StopClk ¿= 0)

TripTime = clk + 0.02;

RelayState = 1;

end

else

CaptureClk = 0;

end

Trip = (clk ¡= TripTime);
```

4.2.4 Simulation of Droop control

The microgrid supervisory control which has been simulated is shown in this section on Fig 4.3. Also the simulation of the droop control for 3 inverter based sources in the microgrid can be seen in Fig 4.4. The Subsystem of a single Inverter based source is shown in the Fig 4.5 where droop control is employed, This subsystem shows an inverter-based source rated at 500kVA and the control system for the droop control.

The active power at the beginning was set at 450kW and reactive power is set at 100kVAR. At t=1s the active power is increased to 850kW and reactive power is increased to 200kVAR. The droop control is enabled at t=3s and the microgrid supervisory control acts at t=5s

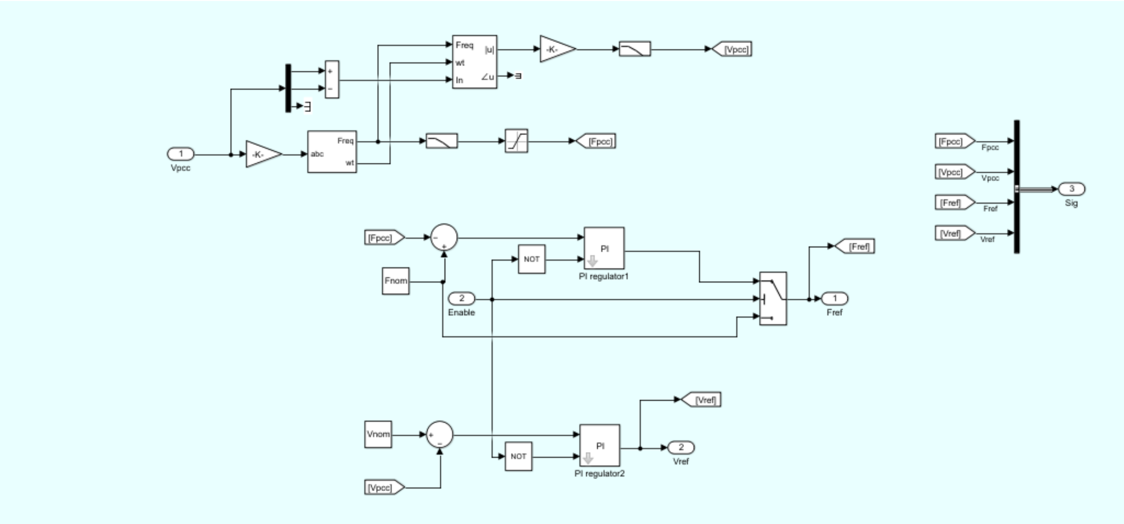

Fig. 4.3: Microgrid supervisory control

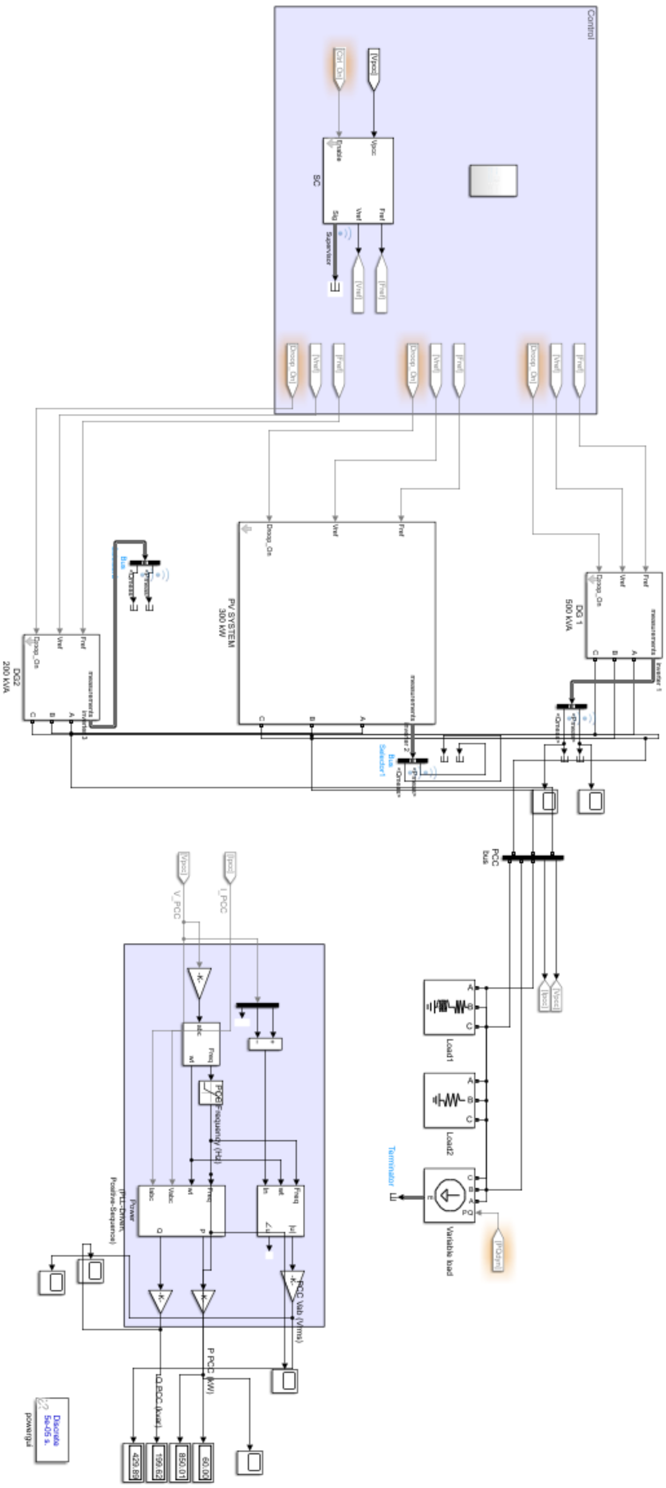

Fig. 4.4: Droop control for inverter based sources in microgrid

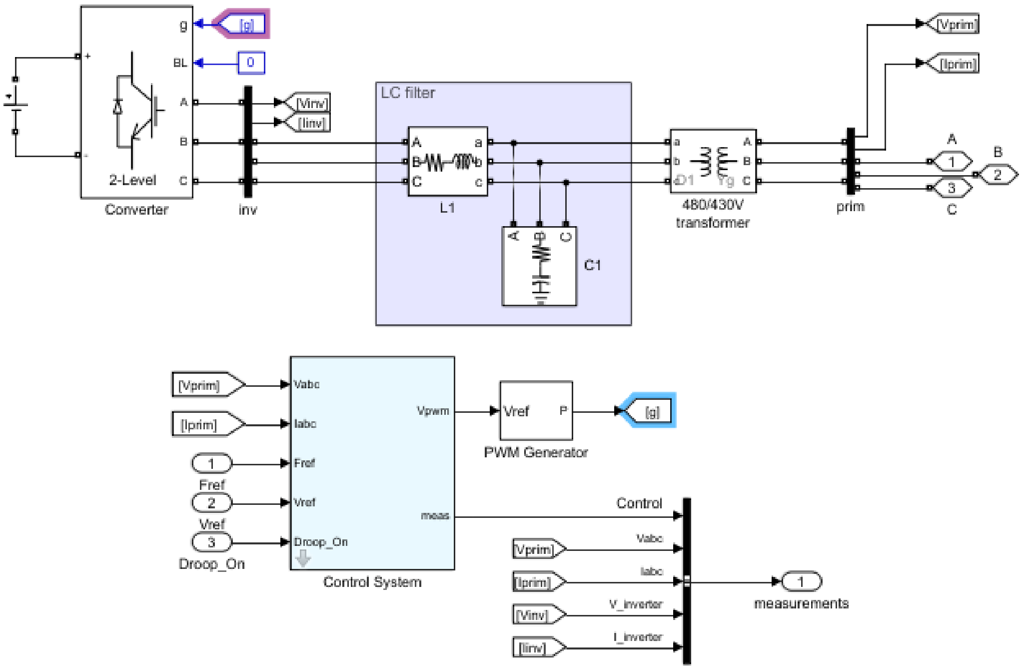

Fig. 4.5: Subsystem inside droop control is employed

4.3 Cases considered for microgrid

The campus will disconnect from the utility grid when there is power failure from the main grid. Also planned disconnect from the utility is done when there is enough PV output to support the microgrid, this will be the normal working for which the microgrid is designed for i.e. to work between 9.00am and 4.00pm without depending on the main grid.

4.3.1 Case1

In this case the microgrid can be employed by using a single PV system designed for the entire campus. The system is rated at 250kW peak and can generate electricity for the campus' requirement. But as the PV output varies with time and solar radiance is not guaranteed throughout the year, this possess a issue with reliable supply. The arrangement of the system can be seen in Fig 4.6. If the utility grid is not supplying and the solar PV cannot produce enough electricity to meet the campus' demand (which occurs many times throughout an year), the supply for the campus will often be interrupted or should be supported by the diesel generators. The point A shown in the Fig 4.6 is the PCC of the microgrid.

The Air Conditioning loads of the campus is separated and fed through a different line which can be connected/disconnected at the microgrid's discretion. Even though this will reduce the demand, reliable supply cannot be guaranteed at most times when forming a microgrid. The diesel generators will work as backup for the microgrid during low PV output which will increase the running cost of the system. The Fig shows the microgrid with a single 250kW PV system installed.

4.3.2 Case2

The microgrid is designed to work with uninterupted supply for the loads. To achieve this a main PV system with 250kW peak is designed to supply the load demand of the campus during most times. Three blocks with most electricity consumption is selected and they are given a seperate PV system and battery backup.

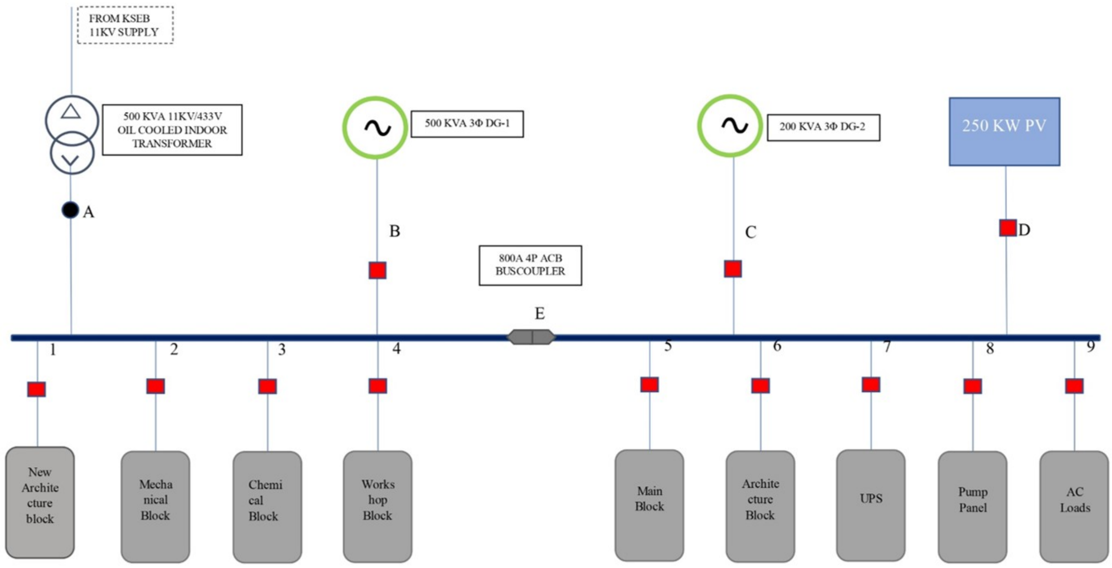

Fig. 4.6: 250kW solar PV system for the campus

They can form a sub-microgrid system and work indepndently from the main microgrid when needed.

The chemical block is equipped with a 30kW PV system along with battery backup for 2 days, which requires 65 batteries. The mechanical block already has a 18kW PV system installed a 37 battery energy storage system is designed to serve as backup for 2 days. The workshop block is given a 20kW solar PV system to meet the load demand with a battery backup consisting of 41 batteries. The microgrid controller controls the microgrid loads and generations by connecting and disconnecting the loads according to priority that is set. Automatic switches are given at each blocks, generators and PV systems as shown in the Fig 4.7. The automatic switches is shown in red colour.

The Air Conditioning loads of the campus is seperated in this case also to cut-off the AC loads when there is less PV output.

When the 250kW PV can support the demand

When the PV output produces electricity to meet the demand of the campus, the PV is connected all the loads in the campus. The 3 blocks seperated will also be

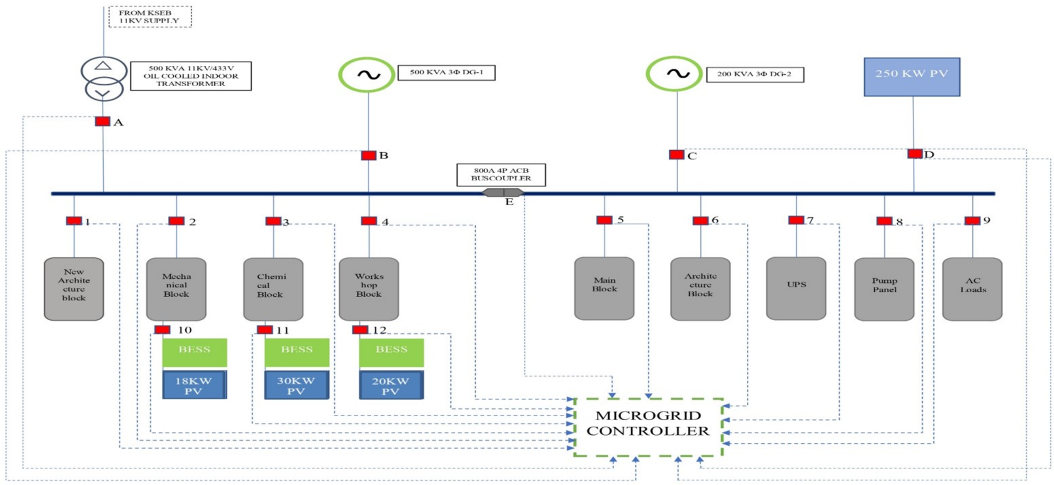

Fig. 4.7: 250kW solar PV system along with sub microgrid systems for the campus

fed from the main PV source and the battery system in the seperated blocks will be charged through the PVs installed in the respective blocks. This is the normal working of the microgrid system Which is depicted by the Fig 4.8.

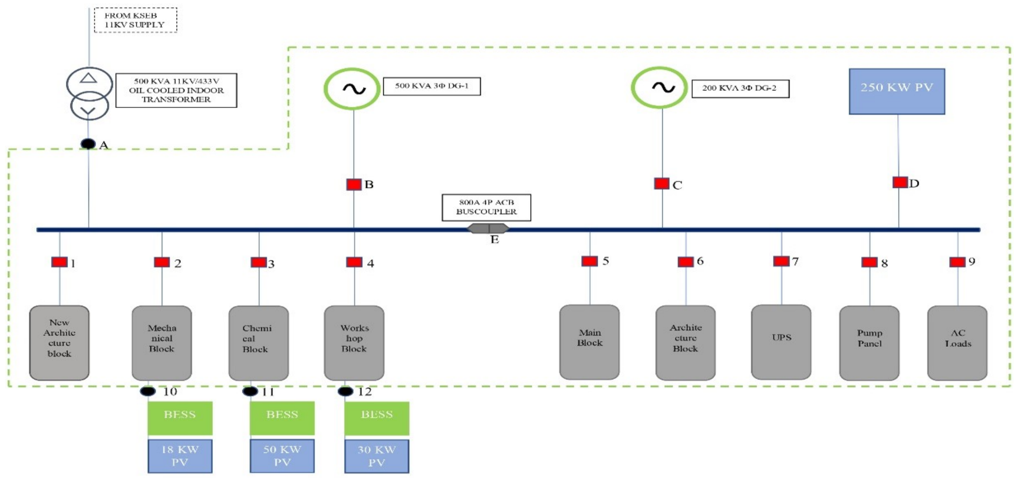

Fig. 4.8: 250kW solar PV system supporting the entire microgrid

When the PV output is low

When the 250kW PV output is low, firstly will disconnect the Air Conditioning loads from the microgrid. Then if the output goes lower further the microgrid discretion loads (the 3 separated blocks) are disconnected from the microgrid in an order (block with max consumption will be disconnected first). These blocks then work as individual microgrids with the PVs installed in them feeds the load demand and if the PV output is less then the batteries will feed the loads. Fig 4.9 shows the arrangement of microgrid during this time.

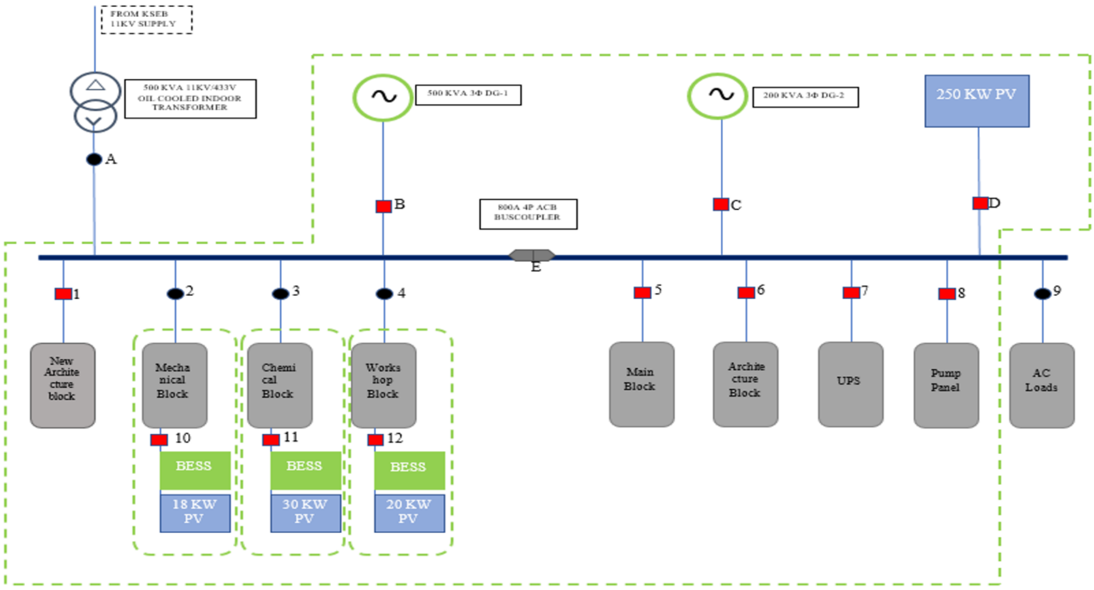

Fig. 4.9: 250kW solar PV system and individual microgrids working during low PV output

Flowchart

The PV output is directly proportional to the solar irradiance. Solar irradiance is taken as the parameter to find the solar output to connect and disconnect various loads to the microgrid system. The flowchart for the same is shown in the Fig 4.10.

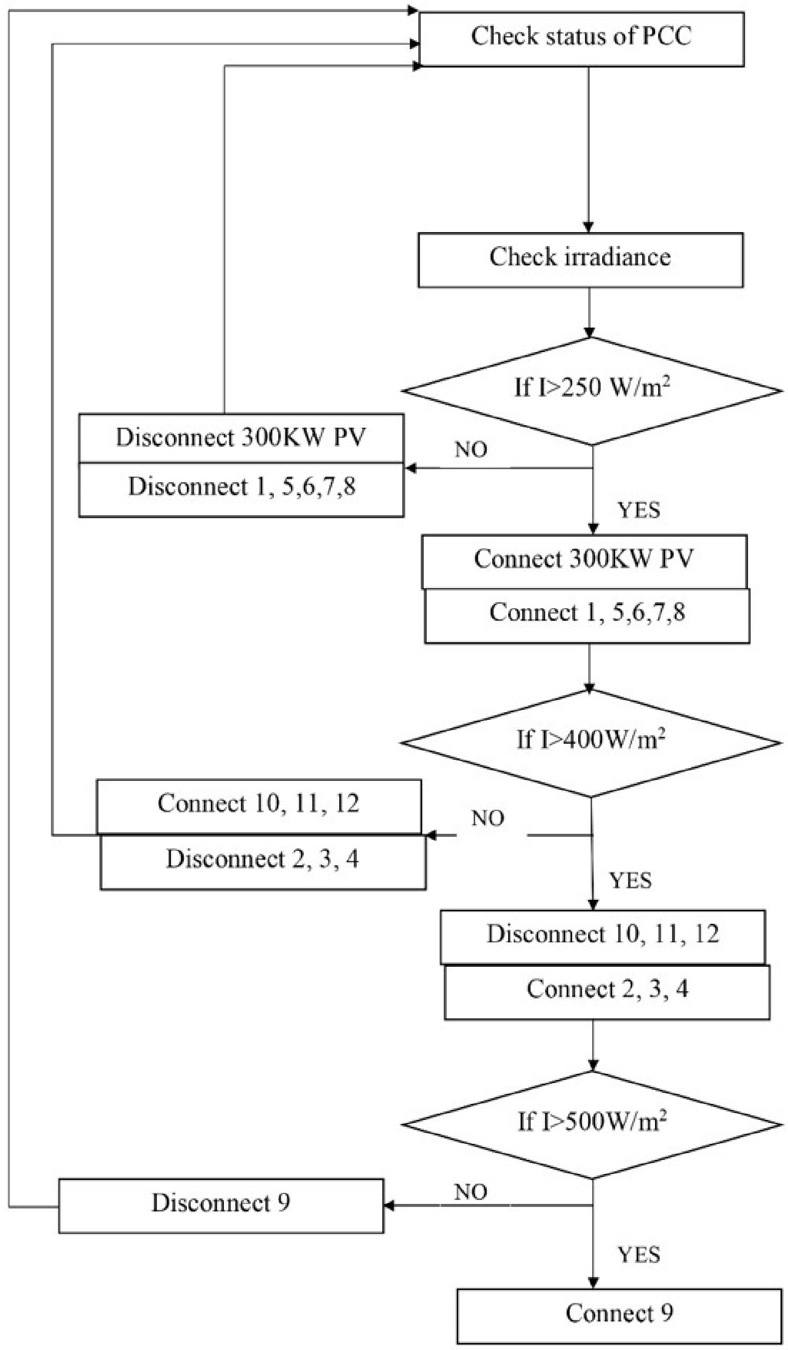

Fig. 4.10: Flowchart of connect/disconnect of microgrid loads

Chapter 5

Results and Discussions

5.1 Introduction

The Results for the simulations done on the Reverse power flow protection and Droop control is shown and discussed in this section. The Hardware implemented is also shown. The Cost benefit analysis of the proposed system is also discussed.

5.2 Results of Reverse power flow protection

The Results for the simulations done for the undervoltage relay to protect the UPS system from reverse power flow issue is shown in the Fig 5.1

The input voltage is given as 400V for the 3 phase input, an undervoltage is set to occur at 0.1 second which last till 0.5 second is given to the circuit. the undervoltage is set at 90 % of Vrms. From the Fig 5.1 it is seen that the voltage drops below 90 % at 0.1 and continues till 0.5s At 0.1 s a undervoltage event occurs the relay program starts to run, as it has been given 0.2 s delay time + 0.02s mechanical relay mimic time, the interruption takes place at 0.32 seconds. It can be observed that there is no voltage after 0.32 seconds which implies the path between them are made open using the contactor/CB. This can be seen from Fig 5.2

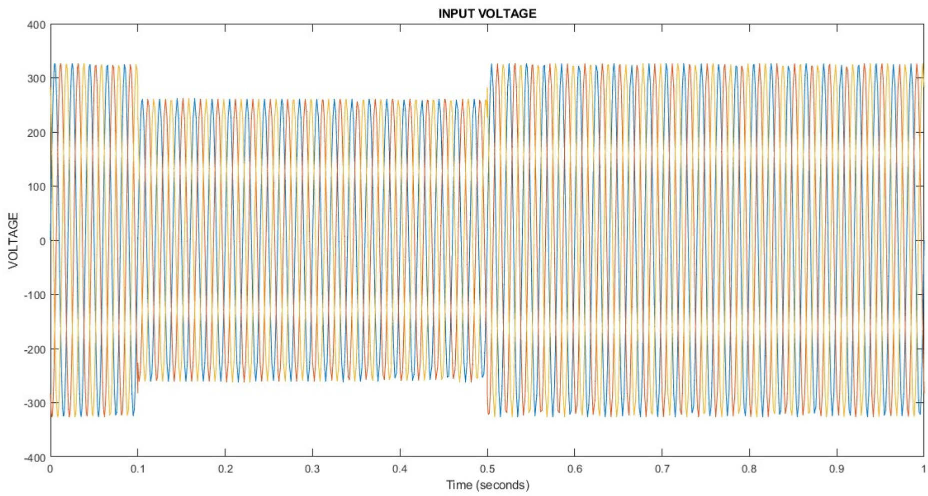

Fig. 5.1: Input Voltage with UV occuring at 0.1-0.5s

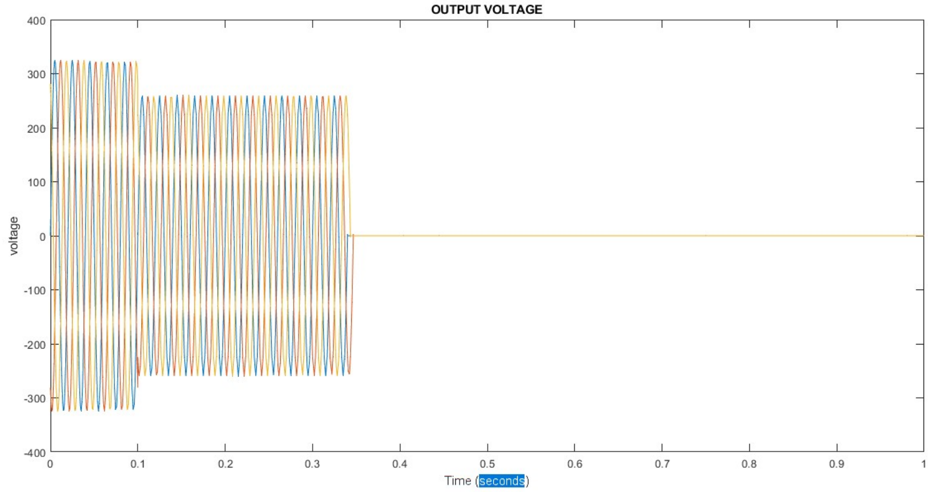

Fig. 5.2: Output Voltage after interruption

5.3 Hardware

The implemented hardware that is set to block the reverse power flow is shown

Fig. 5.3: UPS incomer where the hardware is installed

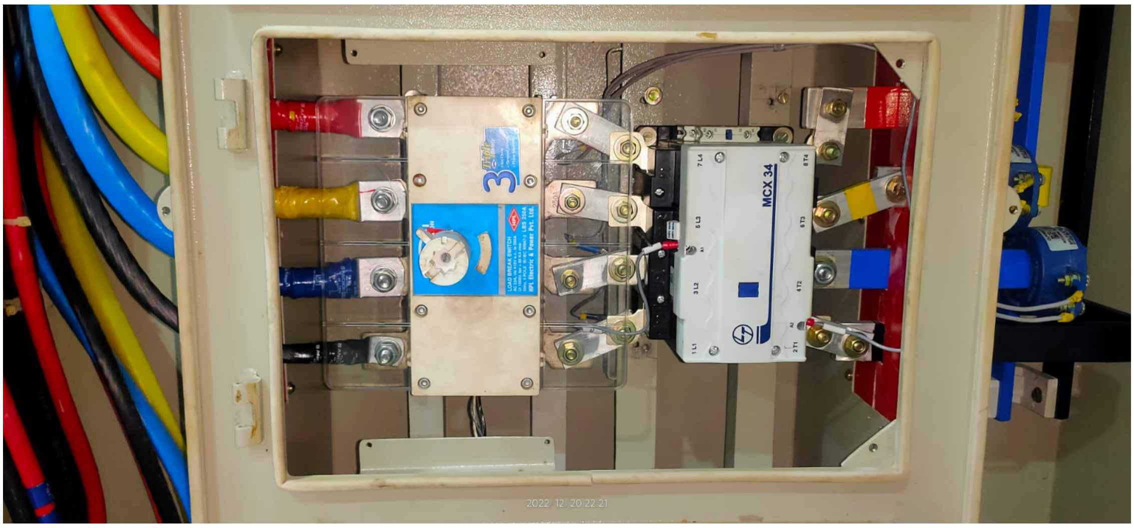

Fig. 5.4: 4 pole contactor

Fig. 5.5: Voltage monitoring relay connected to the line

5.4 Droop control

The active power(P) and reactive power(Q) at PCC bus of the microgrid is shown in the Fig 5.6 and 5.7. As it is seen from the Fig the Ppcc increases from 450 to 850kW at t=1s. Qpcc increases from 100kVAR to 200kVAR.

The voltage at PCC is to be measured and to be maintained within limits. As it is seen from the Fig 5.8 The PCC voltage takes a small dip when the load is increased at t=1s, and is bought back to its nominal value 430V by droop control and microgrid supervisory control.

Fig 5.9 shows the frequency variations at PCC. When the microgrid load is increased, it is seen that the frequency tends to increase and go beyond the limits but is curtailed by the controller within the limit that is set (60.3Hz).

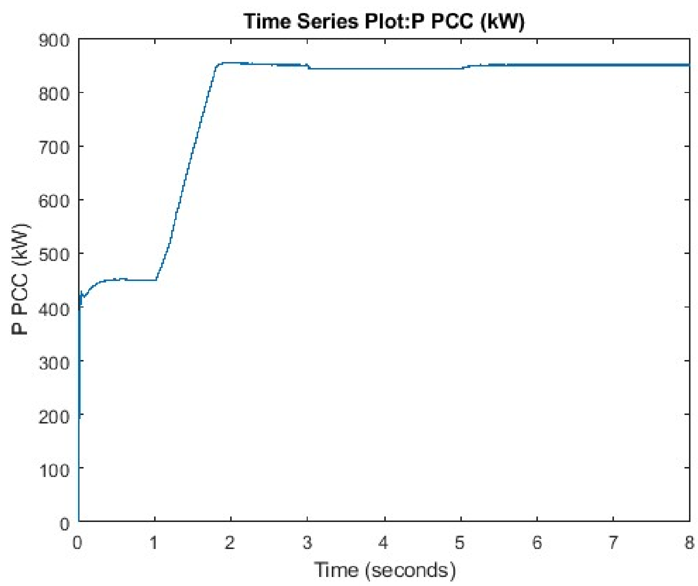

Fig. 5.6: Active power at PCC

Also it can be seen that when the droop control is enabled the frequency is brought down and going to the minimum set limits and the limit is not crossed. at t=5s microgrid supervisory control is enabled and the frequency is maintained at nominal value.

The active power (P) and reactive power (Q) at each inverter-based sources is shown in the Fig 5.10. The three coloured lines represents the three phases.The Y axis shows the per unit values of active and reactive power. At t=1s the load is increased and the inverter source's active power and reactive power contribution increases. When the droop control is enabled at t=3s, the active power of all the phase converges and will give a steady value. In droop control, control of active power is the main concern to keep frequency in limits. This Fig shows the output of the 500kVA inverter based source as the other two have similar characteristics.

The FFT toolbox in the MATLAB SIMULINK library was used to find the Total Harmonic distortion of Voltage at the PCC bus. The max allowed THD for this system is 8 %, The THD in the system is found to be 6.66 % which is allowable. The THD is shown in Fig 5.11

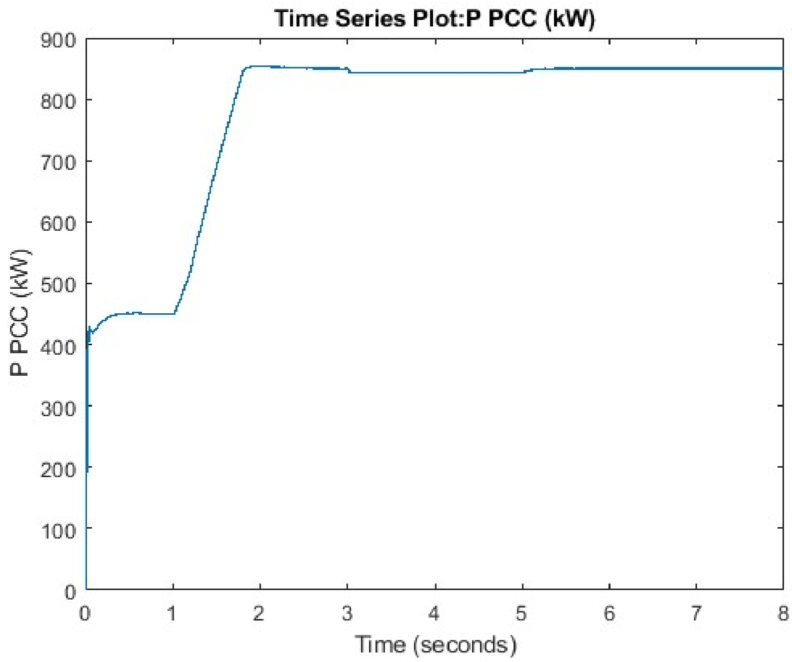

Fig. 5.7: Reactive power at PCC

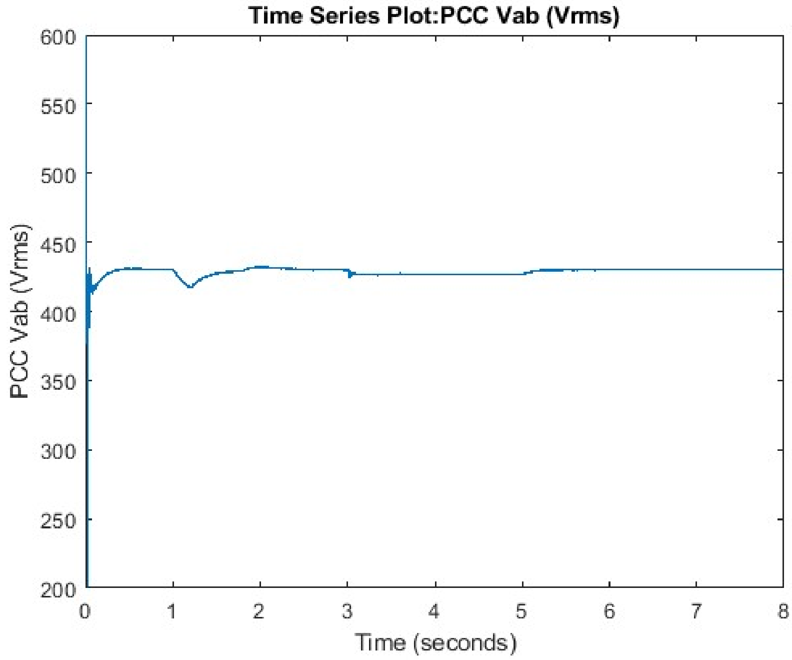

Fig. 5.8: Voltage at PCC

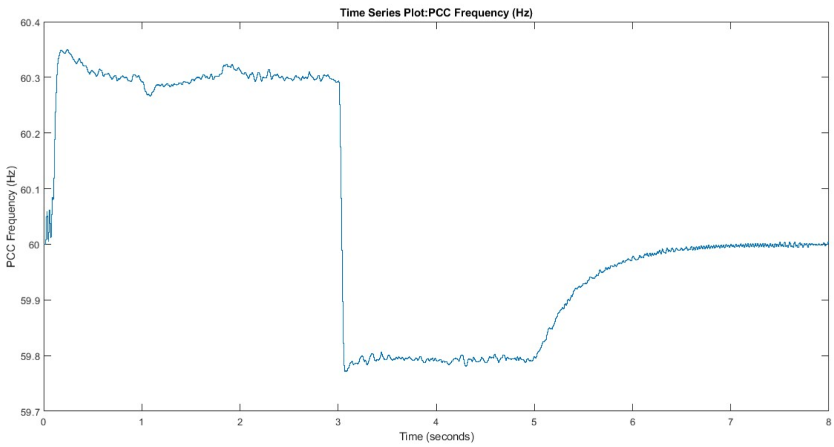

Fig. 5.9: Frequency at PCC

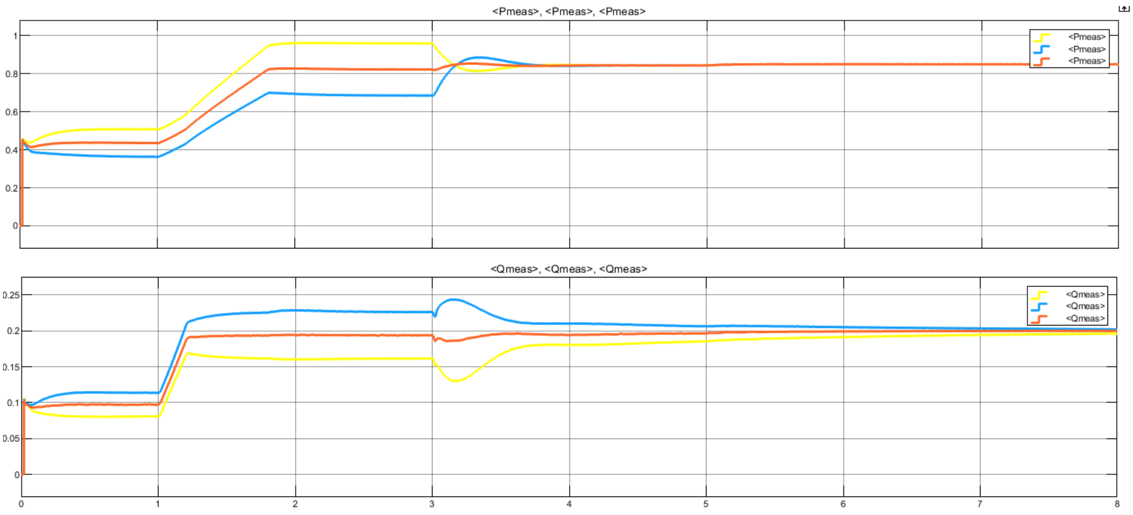

Fig. 5.10: Active and Reactive power of Inverter-based source

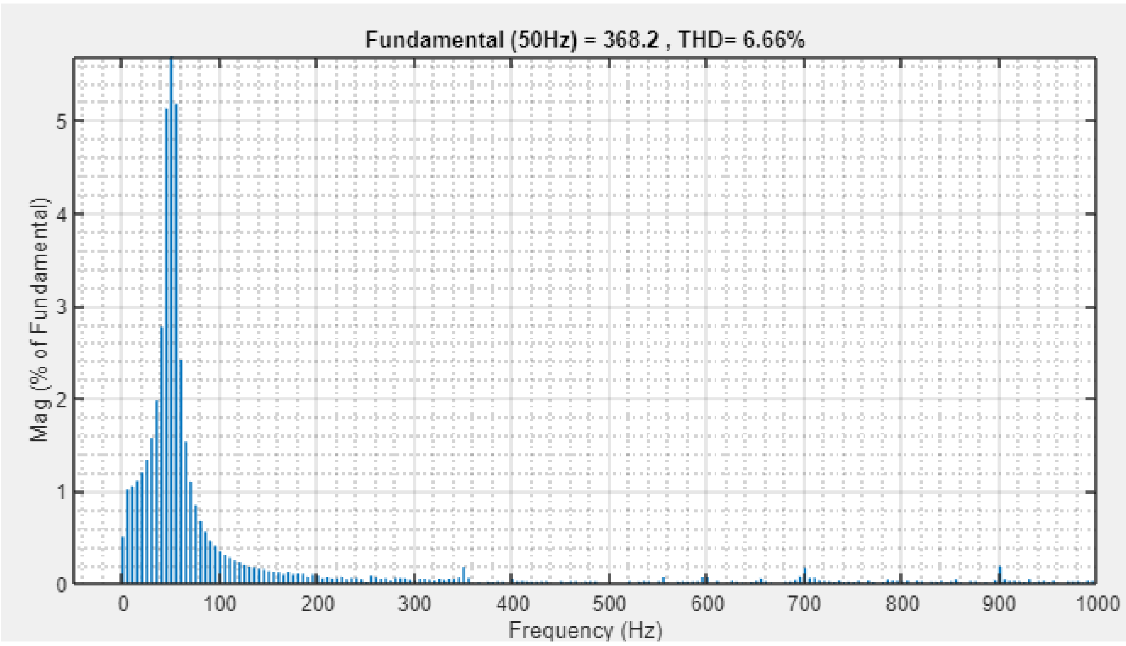

Fig. 5.11: THD at PCC

5.5 Cost Benefit Analysis

The TKMCE campus's electricity and energy costs for next 10 years are discussed in this section considering 3 scenarios: 1. Continuing without any changes 2. Installing a 250kW PV system 3. Installing a complete microgrid system with a 250kW main microgrid and 3 sub microgrids as discussed in the previous section.

Cost for running Generator

The generators when needed to work uses diesel as the fuel to generate electricity. There are two diesel generators in the campus (500kVA and 200kVA). The 200kVA generator is mostly used during outages the 500kVA is rarely used.

The fuel consumption of the 200kVA diesel generator during different loading conditions is depicted in the Table 5.1:

Table 5.1: Generator running cost

Load	$\frac{1}{4}$ Load hour	$\frac{1}{2}$ load / hour	$\frac{3}{4}$ load / hour
Consumption (L)	14.4	25	36
Cost (Rs.)	1400	2450	3520

The generator usually works in half loaded condition.From priliminary studies it is found that the generator works for an average of 4.5hr/week.

Fuel cost per week = 4.5 x 2450 = Rs 11025

Fuel cost per month = 11025 x 4 = Rs 44100

Fuel cost for 10 years = Rs 5,400,000

Cost of running the campus without any changes

A 5 % annual increase in Electricity cost is assumed in this section to calculate the prices. Average consumption of the campus is 36000kWh out of which :

28000kWh – Normal (5.85 Rs. per unit), 3300kWh – Peak (8.7 Rs. per unit).

4700kWh – Off-Peak (4.38 Rs. per unit)

Rs. 213,000 is the average consumption cost per month.

Average fixed cost is Rs. 108,000 per month. (The minimum amount to be paid is 75 % of contract demand as fixed cost i.e 300 x 0.75 = 225, 225 x 420 = Rs94500)

Total average = Rs. 321,000

Assuming 5 % increase annually on electricity charges for 10 years, the total cost = Rs 42,500,000

The generator fuel cost for 10 years = Rs 5,400,000

Maintenance cost for 10 years is taken as 5 % of the total cost = Rs 2,100,000

Total projected cost for 10 years = Rs 50,000,000.

The Fig 5.12 shows the pie chart of the cost For running the campus without any changes for 10 years.

Cost for setting up a 250kW system

Lowest cost for components and equipment is considered to calculate the total cost. The Table 5.2 shows the Initial cost required to set up such a system. The electricity

Table 5.2: Investnebt to setup a 250kW system

PARTICULARS	QTY	COST/ UNIT	TOTAL
400 W PV Array	625	9000	5,625,000
250 KVA Solar Inverter	1	445000	445,000
Support Structure	-	700000	700000
Cable	-	500000	500000
Labour	-	720000	720,000

produced by the PV is used by the campus on working days, and traded back to

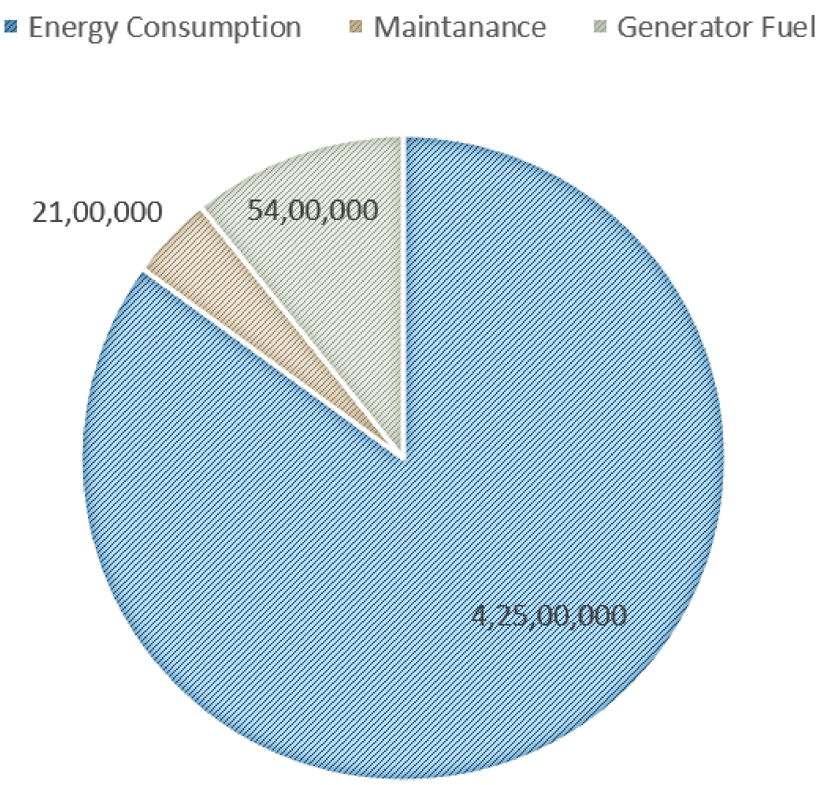

Fig. 5.12: Cost for 10 years without changes

the utility on Holidays, This will give a net zero energy consumption charge during times of high solar irradiance. But the contract demand between KSEB and the campus will remain the same and hence there will not be any deductions in the fixed charges. The dependency on utility supply alone will reduce to 10 % of what it previously was.

The total energy charges(fixed+consumption) for 10 years = Rs 23,840,000

The cost of installation of the new system = Rs 7,990,000

Generator fuel cost for 10 years = Rs 5,400,000

Maintenance for 10 years = Rs 1,501,950

Total running cost for 10 years = Rs 38,731,950

The pie chart shown in the Fig 5.13 shows the total cost of this system for 10 years.

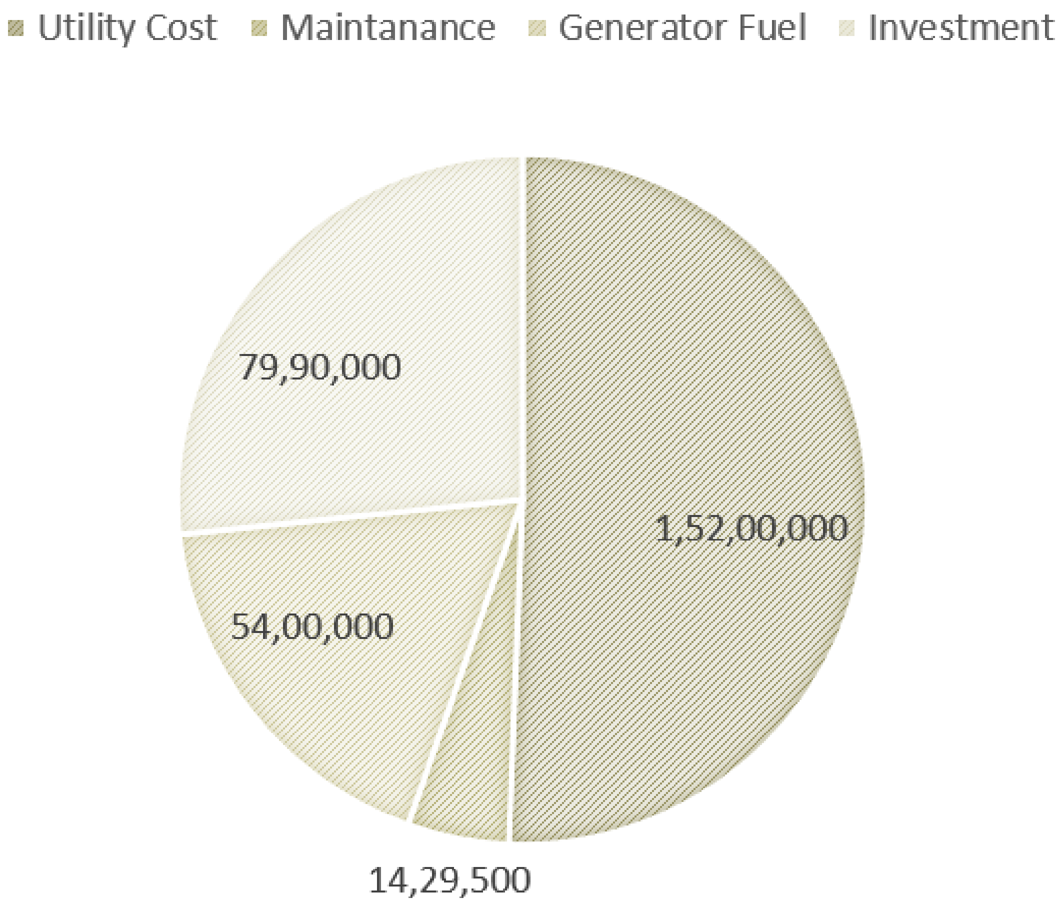

Fig. 5.13: Cost for 250kW system for 10 years

Cost for setting up the proposed microgrid

The Table 5.3 shows the cost of equipment and components for setting up the microgrid.

The number of batteries required for the system to be implemented is 143, batteries that already exist in the campus is used, another 70 batteries are to be purchased.

The microgrid implementation will reduce the dependency on the grid to 10 % annually and the contract demand is also expected to be bought down by 40

% from 300kVA to 180kVA. Also the individually working microgrids with battery backup will reduce the dependency on the diesel generator for backup upto 60 % which will further reduce the cost of fuel.

Utility cost for 10 years = Rs 15,300,000

Investment for the proposed system = Rs 13,685,000

Generator fuel cost for 10 years = Rs 1,800,000

Maintenance for 10 years = Rs 1,530,000

Total cost for running the system for 10 years = Rs 32,315,500

Total Cost and breakdown is shown in the pie chart in Fig 5.14

PARTICULARS	QTY	COST / UNIT	TOTAL
400 W PV Array	750	9000	6,750,000
250 KVA Solar Inverter	1	445000	445,000
30 KVA Solar Inverter	1	130000	130,000
20 KVA Solar Inverter	1	115000	115,000
180 AH Batteries	70	35000	2,450,000
Electrical Switchgear	1	450000	450,000
Control/Energy Management System	1	300000	300,000
Support Structure	-	1000000	1,000,000
Cable	-	800000	800,000
Labour	-	1245000	1,245,000
TOTAL		**13,685,000**	

Fig. 5.14: Microgrid installation cost

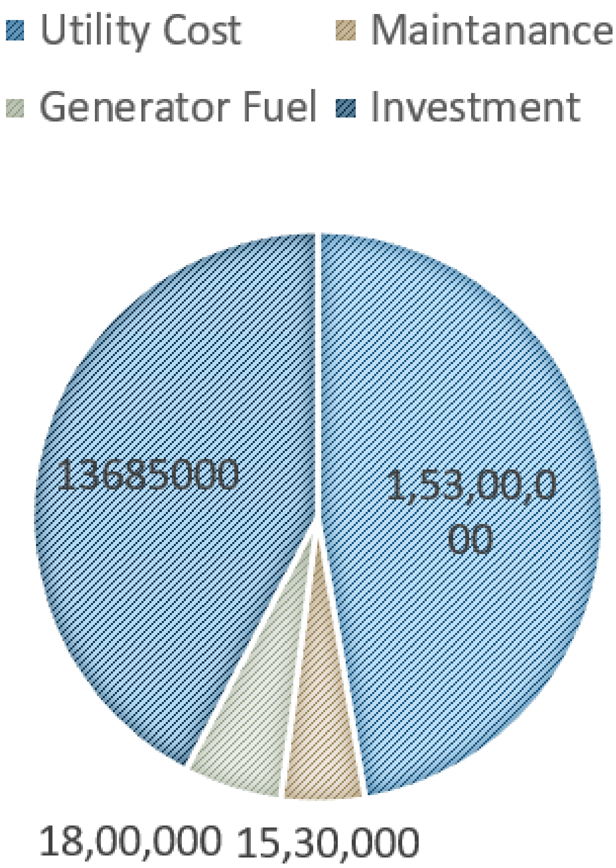

Fig. 5.15: Cost for 250kW system along with proposed microgrid for 10 years

Chapter 6

Conclusions

The pre design aspects of a sustainable and economical microgrid for the campus is developed, the loads, generation and load patterns are studied in detail. Also a reverse power flow protection For the central UPS system which was identified initially during the pre-design work was designed and simulated in MATLAB. An automatic reverse power flow protection was designed using VMRs and contactors, the hardware is implemented in the campus to protect the systems against reverse power flow from the UPS system which will ensure safety and also a standard for the design of a microgrid. It is found that the implemented system works effectively in stopping the reverse power from flowing to the MSB.

A microgrid primary control (droop control) method along with a microgrid supervisory control was designed and simulated for the inverter based sources in the microgrid using MATLAB/SIMULINK. The system is effective in maintaining the voltage and frequency of the PCC bus within limits. Various cases for a microgrid that is suitable for the campus is proposed and analysed. The cost-Benefit analysis of all the cases for 10 years was done. case-1 was found to reduce the cost for next 10 years but case - 2 was found to be more economical with a reliable power supply.

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