POWER MANAGEMENT AND CO-ORDINATION CONTROL OF HYBRID AC DC MICROGRID IN GRID CONNECTED AND ISLANDED CONDITIONS

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SUBMITTED BY:

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UNDER THE SUPERVISION OF

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DECLARATION

I RAVI KANTA JENA, Roll No.2K17/C&I/14,Students of M.Tech control& instrumentation Department of Electrical Engineering ,hereby declare that the project Dissertation titled **"Power Management and Co-ordination Control Of Hybrid AC DC Microgrid In Grid Connected and Islanded Conditions"** which is submitted by me to the Department of Electrical Engineering ,Delhi Technological University ,Delhi in Partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation ,This work has not previously formed the basis for the award of any Degree, Diploma Associateship ,Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled **“Power Management and Co-ordination Control Of Hybrid AC DC Microgrid In Grid Connected and Islanded Conditions”** which is submitted by Ravi Kanta Jena (2K17/C&I/14) Department of Electrical Engineering ,Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the Master of Technology, is a record of the project work carried out by the students under my supervision .To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

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Ravi Kanta Jena (2K17/C&I/14)

ABSTRACT

In remote rural areas, which are far from the primary grid network, mostly renewable power generators are introduced and there is the chance of a fragile transmission line connection. The rapidly growing demand and grid integration of renewable energies has laid the foundation for ac / dc microgrid. DGs ' interconnection with the utility / grid through interlinking converters has raised concerns about secure operation and equipment surveillance. The microgrid can be meant for the client to satisfy their needs and requirements; for example, improving local reliability, minimizing feeder losses, supporting local voltages, enhancing utilization by using waste heat, tension decrease or continuous power supply. The work's objective is to reconstitute control switching to suffer minimal transients in the microgrid. MATLAB / SIMULINK simulates the project. This report introduces a decentralized mechanism of power management for the hybrid microgrid to coordinate and promote the interacted sub-grids. First, considering the features of the popular bus setup, a $P_{dc} - v^2$ dc droop control approach is suggested to sustain the common bus voltage and obtain energy sharing among storage sub grids. Secondly, as the interaction between numerous sub-grids is more problematic than the standard hybrid, a coordinated energy control strategy based on common bus voltage, ac sub-grid frequency, and dc sub-grid voltage is intended for the BADCs and BDDCs to grasp the power interaction between varying sub-grids. In addition, the proposed strategy reflects the capacities and load types of each sub grid; consequently, it is still necessary when sub grid capacities are not matched, and it can ensure the power quality of the sub grids with a high proportion of critical loads. This work suggests a revised topology of a hybrid ac / dc microgrid, where bidirectional ac / dc converters (BADCs) and bidirectional dc / dc converters (BDDCs) connect numerous sub-grids in the framework to the common bus.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
VSI	Voltage Source Inverter
MPP	Maximum Power Point
DG	Distributed generation
RES	Renewable energy sources
MG	Microgrid
MPPT	Maximum Power Point Transfer
SOC	State of charge
BADC	Bidirectional AC to DC Converter
BDDC	Bidirectional DC to DC Converter
ILC	Interlinking converters
ZCP	Zero crossing point
DER	Distributed Energy resources
WED	Wind energy distribution system
DEG	Diesel energy generator
HV	High voltage
PEE	Photo electric effect
WG	Wind Generator
DG	Diesel Generator
MT	Micro Turbine
P&O	Per-tube and Observe
Inc-Cond	Incremental conductance
NN	Neural Network
PB	Primary Battery
BESS	Battery energy storage system

CHAPTER 1

INTRODUCTION TO MICROGRID

1.1 Background

Basically, energy sources are divided into inexhaustible (RES) and exhaustible energy sources. Inexhaustible or non-conventional energy is the energy generated from the source that is not depleted when used and are continuously replenished. It consists of solar, wind, hydro, biomass, geothermal energy and biofuels. The merits of renewable energy sources are their clean, accurate design, and above all they are eco safe, unlike non-renewable energy technologies. More study is under way today in order to improve the technology to effectively transform renewable energy sources into meaningful energy sources. India is fourth in wind power globally, fifth in renewable electricity and sixth in integrated solar energy capacity. As of 31 December 2018, a total of 74,49 GW of solar capacity was installed in the country, with 35,14 GW of wind and 4,52 GW of small hydraulic power. Because of gradual depletion of fossil fuels, low energy efficiency and environmental pollution, a new trend was adopted to generate electricity locally by including non-conventional sources such as wind energy, photovoltaics, fuel cells and microturbines along with storages. This electricity supply is considered DG and the energy supply is called DER. The microgrid provides the supply, transport and request system for local power supply to neighbouring users, capable of managing both grids connected (normal) and islanding condition. MGs provide both heat and electricity from the user view, improving local effectiveness, reducing pollution, improving outstanding power via voltage assistance and lowering voltage dips, with lower energy costs. Uses of distributed energy supplies are expected to decrease requirement for storage and transmission plants. Clearly, distributed generation near loads is intended to decrease transmission and storage circuit cycles with two significant impacts: Limited failures and the ability to replace network capacity.

Moreover, the existence of near demand generation could improve end-customer service quality. Microgrids can sustain the network during stress by suppressing disruption and supporting error repair. The idea is that DG devices are accessible and created using viable and very low emission micro-sources [5]. There are enormous technical issues in microgrid procedures and laws. Increased control strategies for microgrid inverters to provide arbitrarily different supplies of stable frequency and voltage are required to ensure sustainability and power quality in the off-grid settings during network disturbance [5].

1.2 Literature review

The microgrid idea operates as a means of solving the issue of incorporating big amounts of microgeneration without ending Power generation transmission and distribution network operations. The MG will create fewer problems for the utility network and coordinate them properly and smartly [10].

In the light of developments in DGs and microgrids, different interfaces for the vital power conditioners and the associated control are developed in order to link several micro-sources to the microgrid and connect it to existing energy systems. The MG system with this interconnection is highly versatile [11].

Many dropping policies for ac and dc microgrids have been discussed [6], [7], [8],[9]. While the microgrid is independent, conventional droop methods cannot achieve a power transfer between ac and dc.

In MPPT mode frequently changing AC and DC sub-grid DGs have investigated in-depth. Several publications have investigated in detail [12]– [15] MPPT control methods

The constantly increasing demand for alternative energy sources and their inclusion in the grid laid the foundations for the ac / dc microgrid. In order to maintain sustainability and durability of the microgrid, continuous power resources provide the need for energy storage. If the system is exposed to a subsequent shift of energy or source of load, the dc-link voltage will be disrupted [16].

However, the control system in [16] will not ensure storage system involvement when it comes close to the SOC boundary, making it null. It is also not clear how the battery is recharged when the SOC threshold is reached. In [17]- [18], the control of off-grid does not correct a system outline for the idle power scenario.

In [19], Due to the low energy density of the battery relative to the super capacitors, the hybrid MG scheme cannot prevent transients resulting in the incidence of transients in voltage regulation at the load end.

In [20], grid-linked inverter power configuration creates transients on the system when separate inputs retain a certain DC link voltage, rendering the system too complex to use in standard constructions.

In [21] the current participation of supercapacitors is selected to create the SC response lagged, triggering stress control, by using the Low Pass Filters (LPF).

THE ac / dc hybrid microgrids have been widely used for the integration into the power scheme of renewable energies with their excellent efficiency and strong mobility [22],

[23].

A master slave command method centred on the fast interaction methods was studied in [24] and [25]. But critical communication devices are necessary for such a strategy, and communication dysfunctions are difficult to pass through the scheme which degrades its efficiency.

The decentralized command methods and modified variants of idc − vdc droop are studied widely [26]- [32], to enhance device efficiency.

[27] proposes to show the seamless switches that unify the command system in several parameters to a distributed control strategy centred on a drop command.

Idc − vdc droop limitations are explored in [28] and the efficiency of the DC current distribution is reinforced, and the voltage difference eliminated by means of average voltage and frequency average depending on a small frequency system.

In the [30] and [31] secondary commands are also used to solve the drawbacks of the standard idc − vdc droop. But the effects of constant energy (CPL) are still not reflected in these control strategies.

[33] Schedule hybrid microgrid power operations and propose models for hybrid micro-grid development. The power management strategy is to improve energy communication in accordance with uniform frequency and voltage dc in [34].

With regard to balance power, the AC ILC in the hybrid microgrid constructs an ac – dc droop control mechanism based on f− Pac and V 2 dc − Pdc characteristics, which enables the flow of power between the Multiple sub-grid to be controlled [35].

A new AC ILC topology is recommended in [36] and this form of AC ILC should be used with a dc link which contains hybrid microgrid storage.

The recommended power management and monitoring technology is for a MG covering Hybrid AC DC and DS sub grids, with the consideration of the distributed storage (DS) [37].

The recommended technique comprises three stages: regional, global and storage power control sharing that could decrease useless energy and lengthy service life losses.

For the hybrid microgrid in a typical hierarchical control system such as natural ac or dc microgrid are developed [38].

Modern sources hence render them uncontrollable depending on environmental and climatic circumstances. Distributed green sources operate as supervised current source in grid attached mode with excess energy redirected to other remote loads by the mains [41].

1.3 Chapter Summary and Thesis Outline

In chapter 1 A short overview of the background of the work submitted in this thesis

Chapter 2 briefly discusses different kinds of microgrid, including comparison. The hybrid microgrid system's general setup has been introduced using MATLAB / SIMULINK.

Detailed PV array modelling with MPP tracking implantation is outlined in Chapter 3. The battery cell model, the super capacitor, has been evaluated.

Chapter 4 dissects about dq transformation theory along with droop control and microgrid coordination is briefly discussed.

In addition to grid operation and modelling and control of the converters used, the droop control strategies for different sub grids in Chapter 5 are also analysed in detail.

Chapter 6 provides all the simulation outcomes identified using the MATLAB / SIMULINK environment

Chapter 7 offers a detailed overview and findings of the research conducted in this thesis, as well as recognition of future work.

CHAPTER 2

DIFFERENT KINDS OF MGs AND THEIR COMPARISON

2.1. Introduction

Two main types of microgrids are AC and DC MGs. AC microgrid is relatively simpler to design and operate, while DC MG grid synchronization is not required, so we can interlink more RES. Some of the DG sources for e.g. solar photovoltaic system or DC loads can be linked straight to DC Bus where the link to the AC bus needs DC / AC interconnecting converters to cause a loss of energy, MG becomes less effective, and these ILC inverters are also costly to raise the price of the scheme. Because of the lack of a ZCP, the significant difficulties associated with DC microgrids are designing an Appropriate system of security and maintaining their stability under severe disturbances, especially when the microgrid converters are strictly regulated.

2.2. AC Microgrid

An AC micro grid is assumed to consist of a group of integrated loads and DERs such as PV, wind generators, diesel engine turbines, fuel cells and power storage devices such as flywheel and battery storage devices For example, sources of AC. WED and DEG are synchronized to the ac bus however, converters are used to link DC sources such as PV panels and power storage devices to the MG. Due to environmental challenges with current power stations, renewable resources are connected as DGs. More and more DC loads are also connected with AC power systems to reduce energy and CO2 emissions, like LEDs and electrical vehicles. Distance HV transmission is no longer necessary when local sources of renewable energy can produce energy.

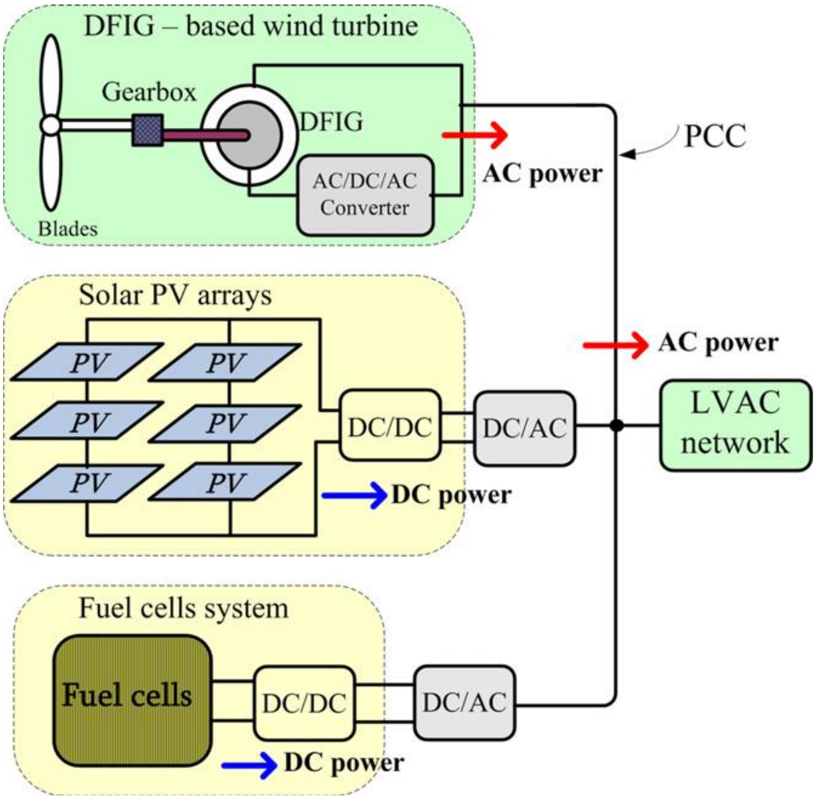


Fig 2.1 typical DG unit arrangement with LVAC network

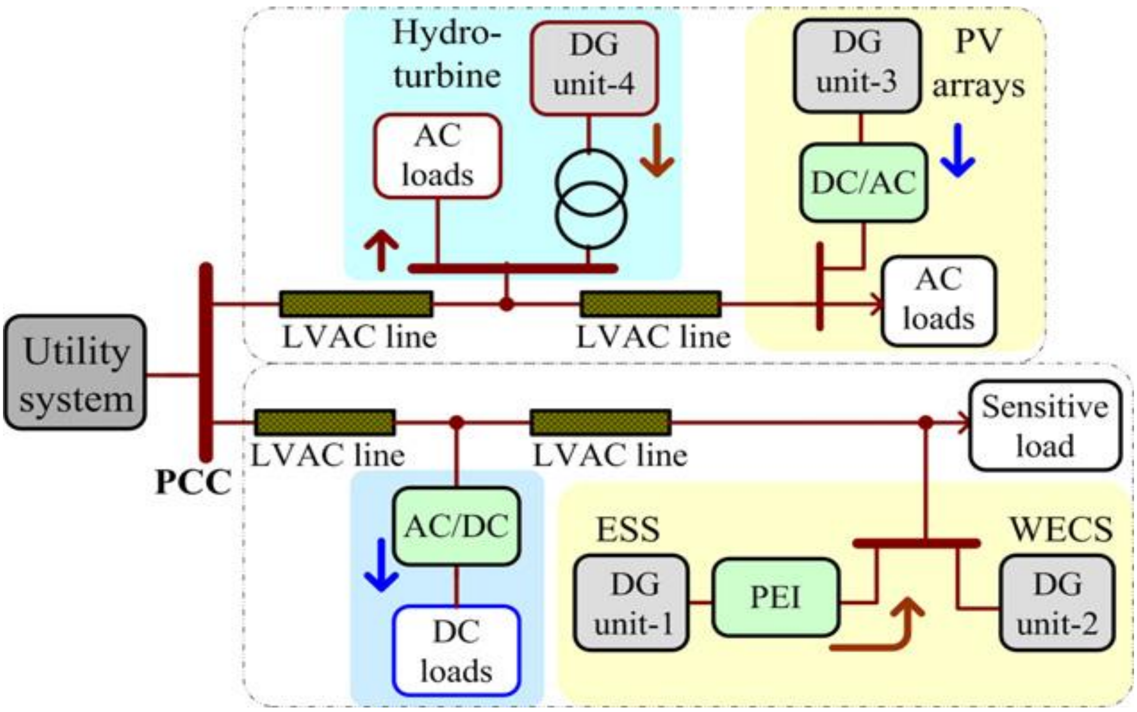


Fig 2.2 Structure of an AC microgrid

As illustrated in figure 2.1. At the PCC, the supply network linked the power grid. MGs operate either in grid-connected fashion or in off grid (in urgent situation). In transient and fault condition DG based interlinking converter helps in maintaining voltage quality and angular stability. WIND energy is the fast penetrating RES, DFIG and PMSG can be used to strengthen MG efficiency during islanding operation. Ac microgrid is viable for both non-renewable and renewable sources of AC microgrids. remote areas, commercial buildings, to improve reliability and efficiency of existing power sys and as backup for some power supply.

2.3. DC Microgrid

Computer, Low pressure gas-dissipated mercury-vapor lamp with fluorescence to make visible light, commercial, household, Manufacturing equipment need dc power for their operation as well as for interconnecting AC grids at distinct frequencies, Point-point transmission over large distances or by marine wires. DC-based DG transformed into an AC to connect it to the current AC sub grid that has subsequently been converted to DC for many end users.

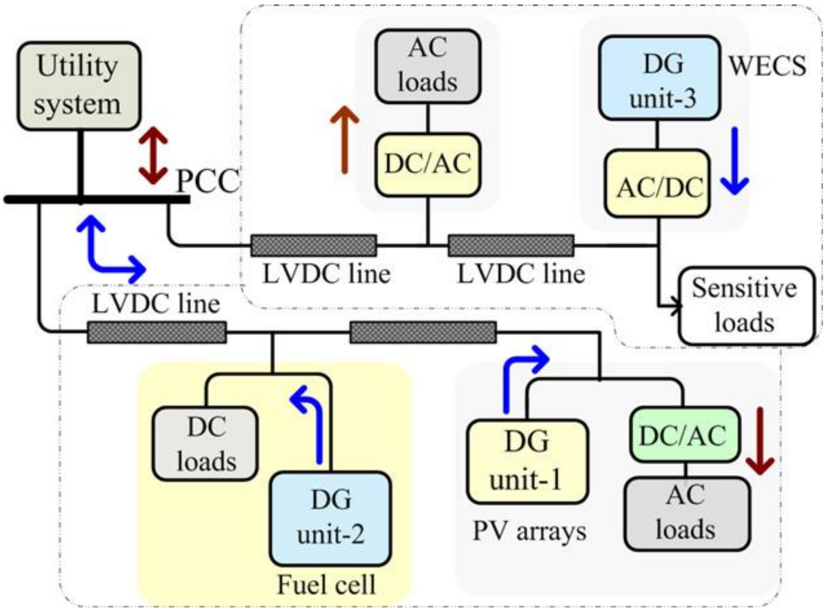


Fig 2.3 A DC microgrid system

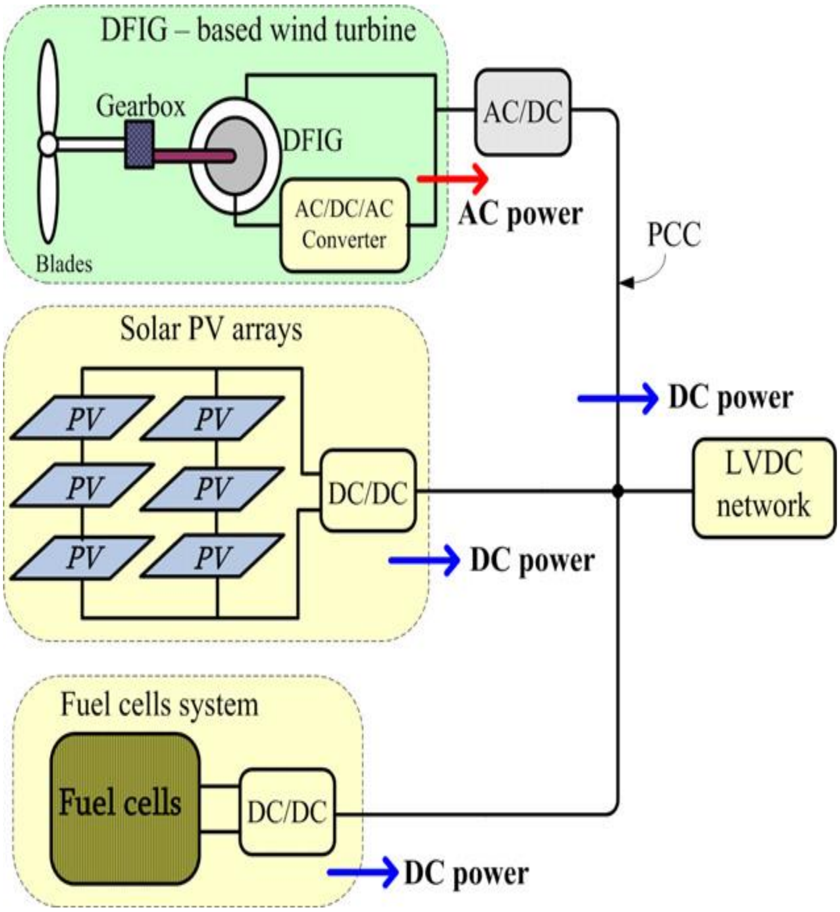


Fig 2.4 Typical DG unit arrangement with LVDC network

DC MGs have attractive structural features, low systems costs and improved overall efficiency, since there is little need for energy converters relative to AC Microgrids [42–44]. The study included an isolated DC grid that includes solar photovoltaic and unparalleled AC loads. The above figure uses the LVDC cable to link the local PV DG units.

Various techniques for evaluating DC MG's merits are:

1) By decreasing inverter conversions losses between DC inputs and loads, the performance of the approach is improved [15].

2) No grid sync and reactive scalability need to be taken into consideration.

3) When the power grid causes the blackout or voltage fall, the DC bus voltage of DC MG will not be instantly impacted by the current DC capacitor power and AC /DC voltage control.

On the other hand, DC MGs are faced with certain inconveniences to be used in practice.

1) Building of DC MGs private distribution lines.

2) Since in DC schemes there's no zero-voltage transversal, safety is damn hard in relation to AC devices.

3)The loads adjusted for DC energy supply are necessary for exceptionally high system effectiveness.

Since most power grids today are AC, ac Micro Grids continue to be dominant and only DC Micro Grids are not expected to appear in power grids. Therefore, although in subordinate, dc microgrids are likely to develop in ac forms.

Consequently, in latest studies [45]– [48] Connecting the microgrids with the microgrids of ac and using the advantages of both microgrids became essential.

The idea is to combine the Ac and dc microgrids with a two-way Ac / Dc converter and to develop a hybrid Ac / dc microgrid, in which power sources and loads of the ac and dc types can be intelligently integrated into the microgrids.

2.4. Hybrid microgrid

For societies and industrial or commercial facilities, cost-effective electricity has been a challenge without access to a powerful utility grid. They must depend on power generator sets, which generate energy at much greater costs than big utilities. A stronger system is now being developed that mixes newly efficient viable wind or renewable power with standard petrol or gas-fuelled transmission. Hybrid Microgrids, including hotels and mining facilities, far away towns, tiny reefs, and many more, have been well-adjusted to suit a variety of apps with strong wind and suns and minimum fuel-related energy storage.

Reference [45] proposes an ac / dc hybrid microgrid, which connects renewables and storages to the primary ac-grid. In the traditional three-phase power supply system, a dc Transmission line and a power conversion system are used to bring distributed domestic renewable energy sources. Local energy is the primary concept and the net's energy consumption is lowered.

The hybrid microgrid has a sparing dc grid with an ac grid to remove fluctuation in the dc bus voltage by controlled load and stabilize the grid with dc and ac.

The power scheme should support both types of operation as well as changes between these types.

2.4.1 PROPOSED HYBRID AC / DC MICROGRID for grid integrated mode to retain continuous dc voltage with energy sharing between various sources and loads

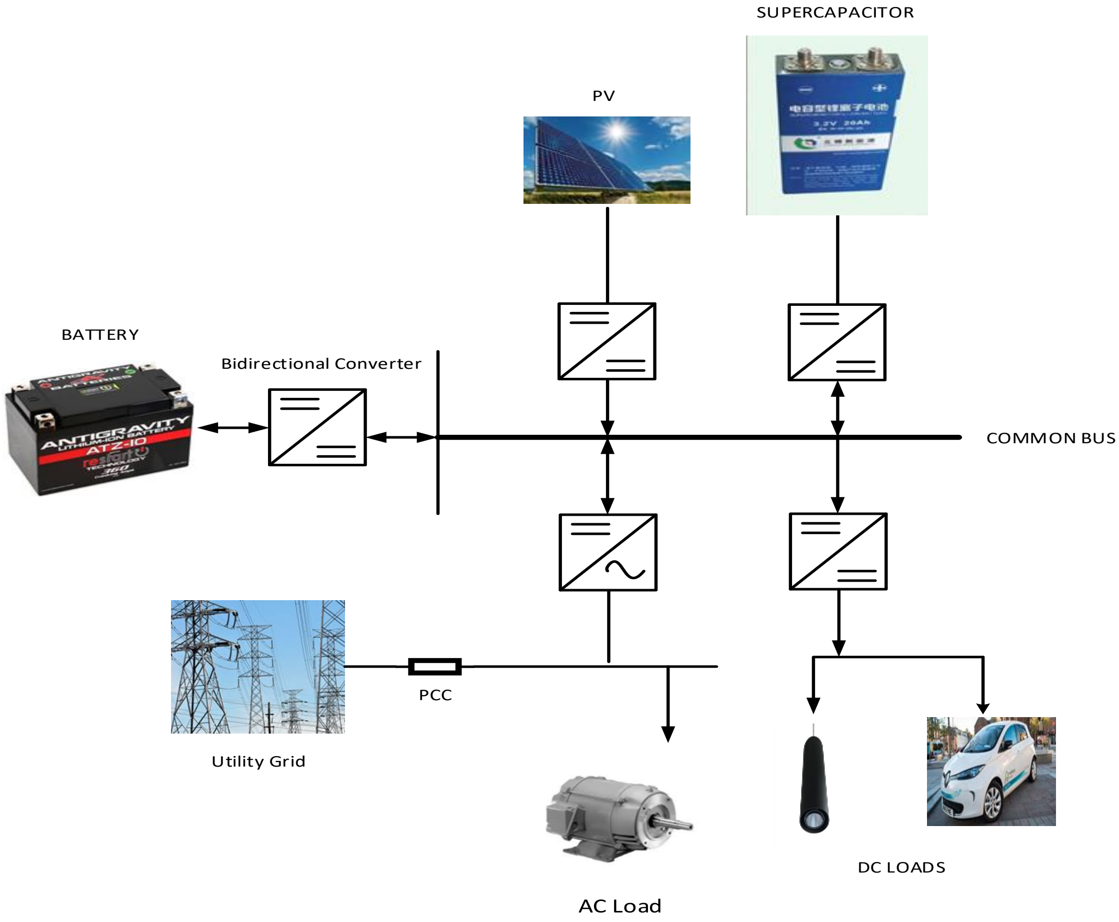


Fig 2.5 Example of a hybrid microgrid setup

The combined hybrid microgrid battery-supercapacitor system integrated with the grid is illustrated in Fig 2.5

The combined battery-supercapacitor hybrid grid system is linked to the DC connection via a bidirectional converter enabling power flow in both directions.

The real power flow between the utility and the ac load is possible owing to VSC interface. Proposed MG structure responsible for producing reference current, method of power balance, reference voltage and lastly gate pulse generation for interconnecting converter and DC bus control in different operating modes. From the Vdc control, the total current is obtained, to decrease the lag relative to the low-pass (LPF) filter reference current obtained from Vdc control passes through moving average filter and average current is produced.

Reference current for supercapacitor generated by taking difference between these two currents the power management system regulates the power flow to loads.

Super capacitor controls the energy needed for loading during power surplus as well as the deficiency phase.

When load demand is lower, excess energy is useful for battery charging and super capacitor charging. The remaining energy is returned to the source when the battery and SC are charged to the maximum limit.

The suggested hybrid MG structure runs in a grid-connected way.

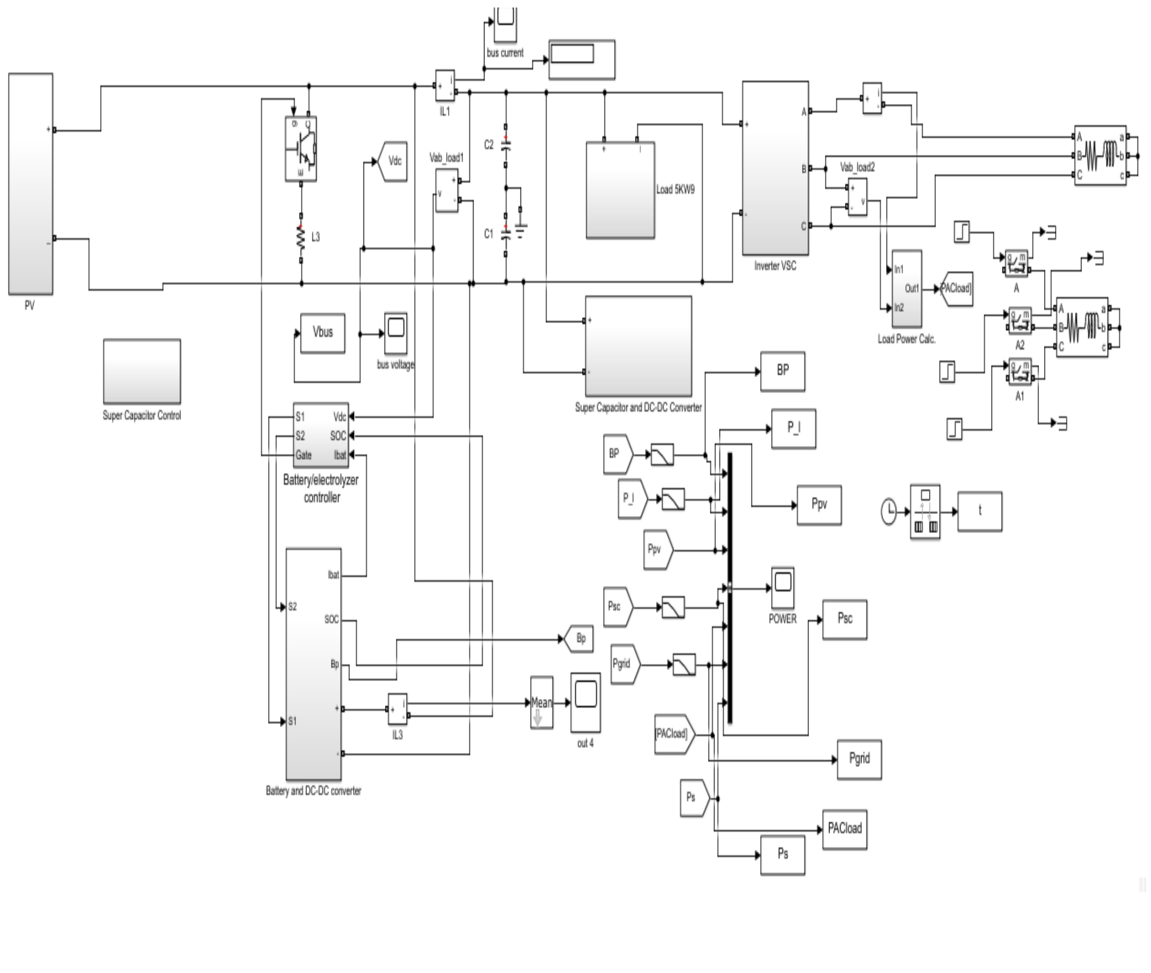


Fig 2.6 MATLAB/SIMULINK model of hybrid MG setup

2.4.2 Hybrid MG configuration with various sub-grids linked in islanding mode

The suggested topology for hybrid MG is shown in Fig.2.7. The Hybrid MG includes various sub-grids with multiple ac and dc frequencies and DC voltage. The standard frequency in the US is 60 Hz, while in India it is 50 Hz. Consequently, some loads at one location may not be suitable for another location if they are subject to the system's only one type of frequency. due to high efficiency and low harmonic distortion, ac system with higher efficiency widely used for e.g. High-pressure tanks such as high-frequency compressor, induction motors. On the other hand, the various DC loads embedded in the DC bus operate at various voltage levels for e.g. LED lights, electrical vehicles Therefore, application range is restricted if the hybrid system only operates at standard controlled frequency and voltage. To address this issue well, we develop an advanced hybrid MG that can handle the different frequencies of AC / DC MG as well as DC Voltage.

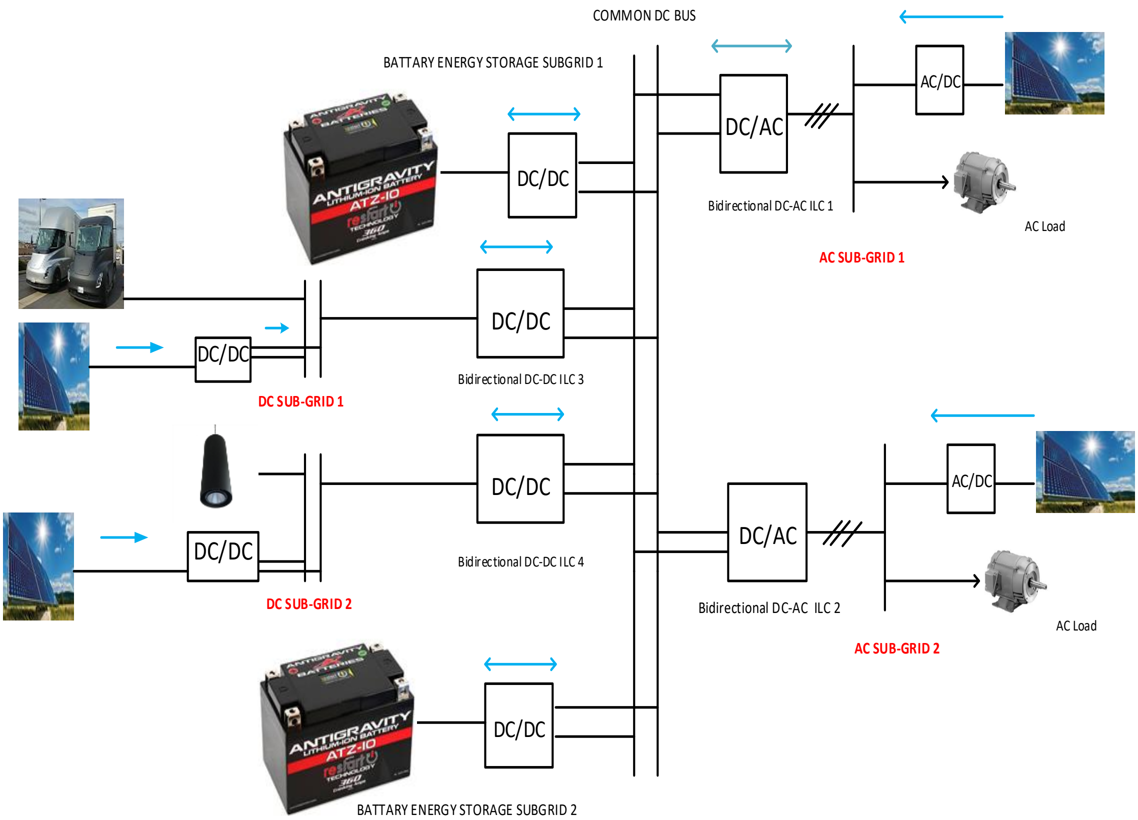


Fig 2.7 Example of a hybrid microgrid setup with multiple sub-grids

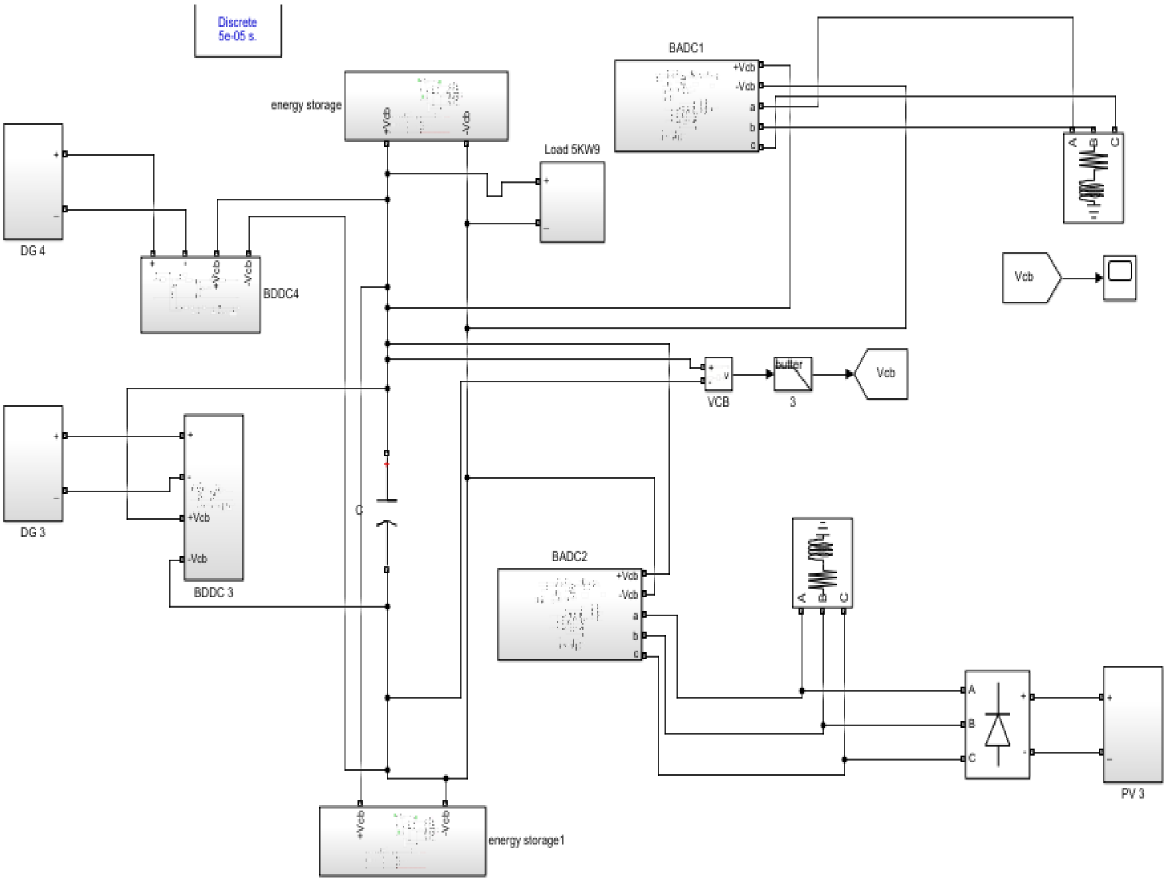


Fig 2.8 MATLAB/SIMULINK model of hybrid microgrid setup with Multiple sub-grids

CHAPTER 3

HYBRID MICRO-GRID COMPONENTS

3.1 Overview of Solar Photovoltaic

A solar cell is also called a photovoltaic (PV) cell. "Photo" means light, and "Voltaic" means electricity generation. The photovoltaic system is intended to use one or more solar panels to produce electricity and to supply the ac or dc load. The history of microgrids is long. In 1839, Alexandre Edmond Becquerel gave the concept of producing electricity from light energy sources, which he later called PEE. Albert Einstein found 1 st solar cell in 1905 and theoretically explains the photoelectric effect. he was later awarded the Nobel Prize for his job in 1921. Fuller and Gerald manufactured a silicon PV module at Bell Labs in 1954.

3.1.1 Operation of PV cells

Solar cells comprise of two forms of semiconductor material of type P and type N and photoelectric impact is the fundamental concept behind PV cell operation. When the sunlight of certain wavelength drops on the surface of the PV cell, it is absorbed by a semiconductor and produces electron and hole pair when the energy consumed is higher than the semiconductor's bandgap energy. When the PN junction is exposed to light, photons with more energy than the silicon cell bandgap are absorbed, causing electron-hole pairs to emerge. Under the impact of electrical fields in the junction, these carriers are segregated, producing a current proportional to the incidence of solar irradiation. Solar cells convert solar energy to DC current.

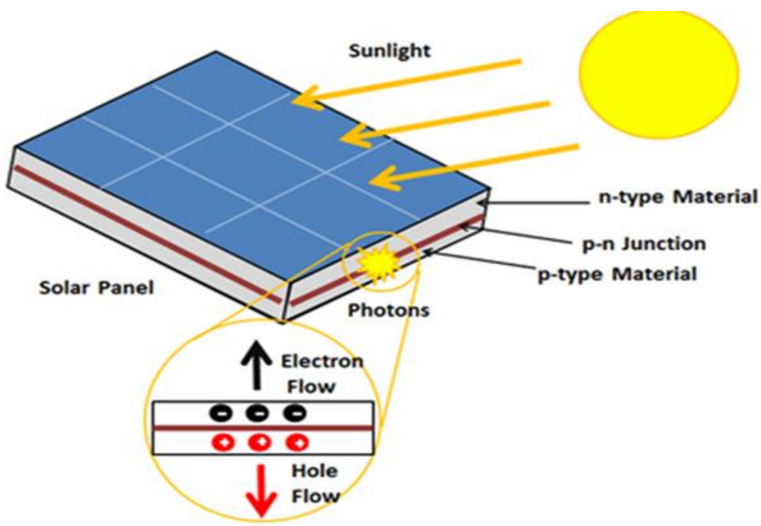


Fig 3.1 PV Cell working

3.1.2 PV composition

3.1.2.1 PV cells

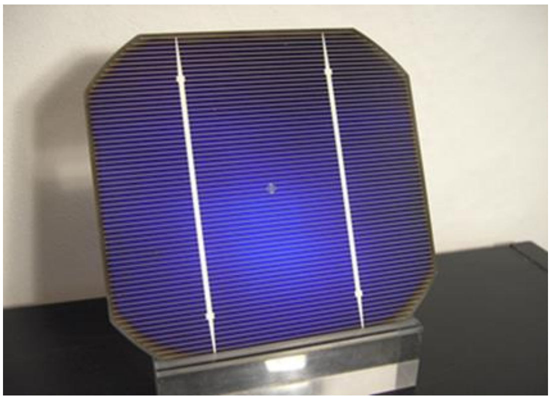


Fig 3.2 Basic PV Cell

PV substratum made of crystalline silicon is positioned on top of it with phosphorous and boron parts, the phosphorous layer is very thin, while the boron layer is a little thicker. Electric field generated at this two-material junction point, popularly known as the depletion region. When sunlight knocks a photo-voltaic cell's surface, the valence electrons of semiconductor material leave the wafer moving in the direction of the electrical field. The current flows when we connect an external load to it. PV cells are usually found in circular or square form.

.3.1.2.2 PV Module

A solar panel or PV module is a group of PV cells installed in a Sustainable Framework. When sunlight hits on the silicon wafer's surface, the loose electron moves from the electron rich zone to the electron deficit side, thus producing a potential difference by forming a PN junction, this voltage difference or potential difference is very tiny around 0.5 volt. Loads connected to solar PV require a large amount of power that cannot be supplied individually by fundamental PV cells, so we make a series or parallel arrangement of solar cells known as PV module in order to get the intended output. In case of partial and complete load shading very small voltage generated by the PV module a reverse current flows to the source side of the PV which can harm the panels by overheating it, so we attach a blocking diode in parallel to prevent harm .If we have solar cell strings, we also need a bypass diode to continue the power supply with decreased voltage, these are linked in parallel with the solar cells. Commercial modules are generally comprised of 36 and 72 cells, and are made up of transparent front, embedded PV cell and back of the module. In general, the frontal side material is made of low-iron and tempered glass. The effectiveness of the PV module is lower than that of the PV cell due to the reflected radiation of the glass cover and the shadowing of the frame etc.

Fig 3.3 PV module

3.1.2.3 PV Array

Electrical panel or module group linked together electrically. Power generated by a single module is not enough to support business process needs so that modules are attached to the form array to generate greater amount of power. In urban areas, arrays are generally mounted on the top of the roof, and the output of the PV array can be fed directly to the DC motor for agricultural use.

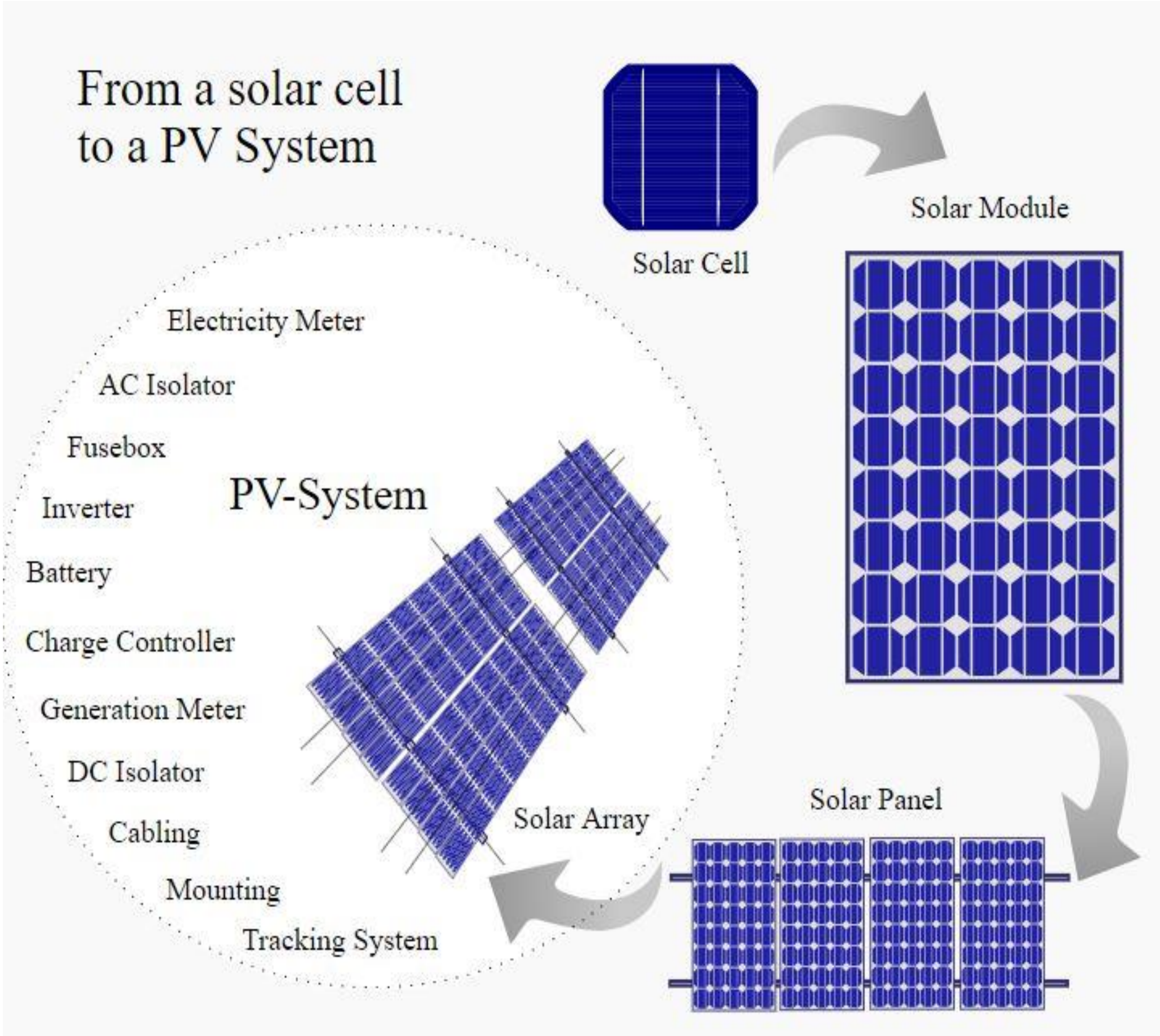


Fig 3.4 System of photovoltaics

3.2 Types of PV system

3.2.1 Stand-alone PV system

This type of photovoltaic system comprised of a battery storage scheme to supply energy to the load must also be large enough to supply energy to all charging stations and recharge the batteries, useful when there is little or no sunlight mainly during off grid mode [4].

a) Stand-alone uncontrolled system

Because the energy storage system is lacking in this structure, energy is only supplied during the day and not at night. This is usually used for low-energy applications. It cannot function at full efficiency due to the absence of a PV cell controller.

Figure 3.5 Stand-alone uncontrolled system

b) Controlled standalone system

A DC-DC converter is placed between the panel and the DC load, duty of whose switch can be controlled by using MPPT Method so that the solar panel always gives maximum power [4].

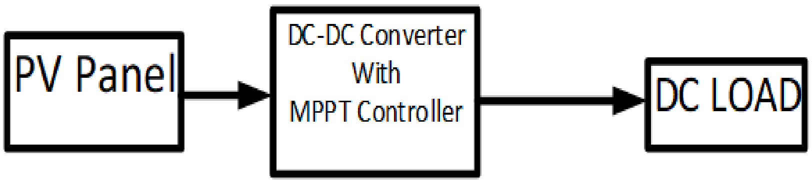


Figure 3.6 Controlled standalone system

c) Stand-alone system with battery supported

We implemented a battery-energy storage system compared to the earlier framework in this scheme. This stores the PV cell's extra energy during off-peak load time. It provides energy when the solar cell alone is unable to supply the required amount of energy during peak load time [4].

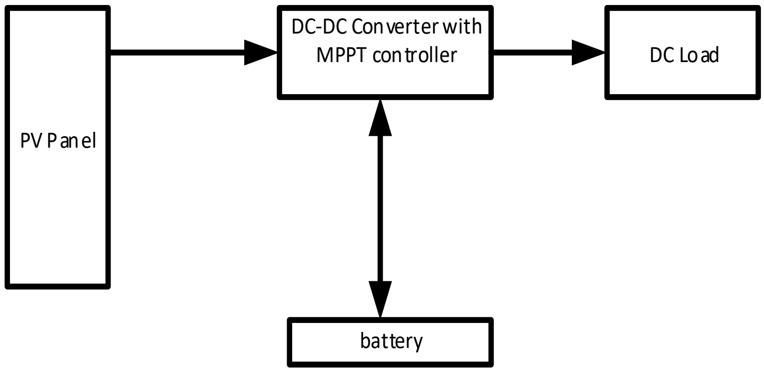


Fig 3.7 Stand-alone system with battery supported

d) Battery Powered AC and DC load

Due to presence of AC load we must connect an inverter in between DC bus and ac load but system cost and complexity increases.

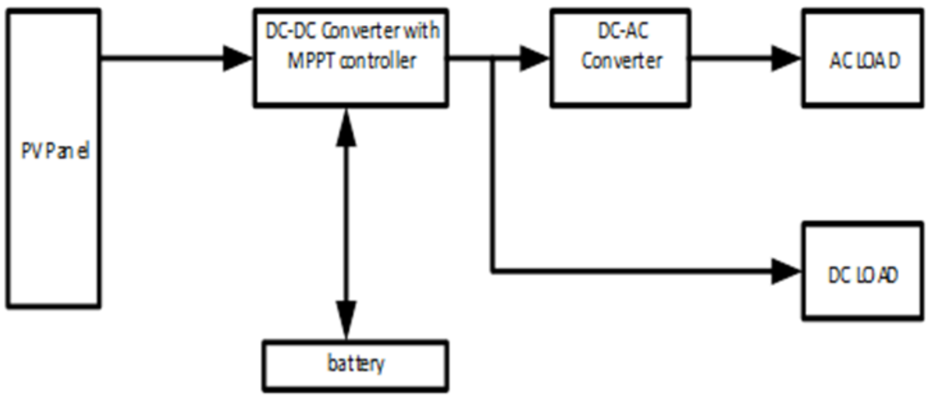


Fig 3.8 Standalone controlled battery, AC & DC loading scheme

3.2.2 PV system with integrated grid

PV delivers additional energy to the utility in this form of scheme.

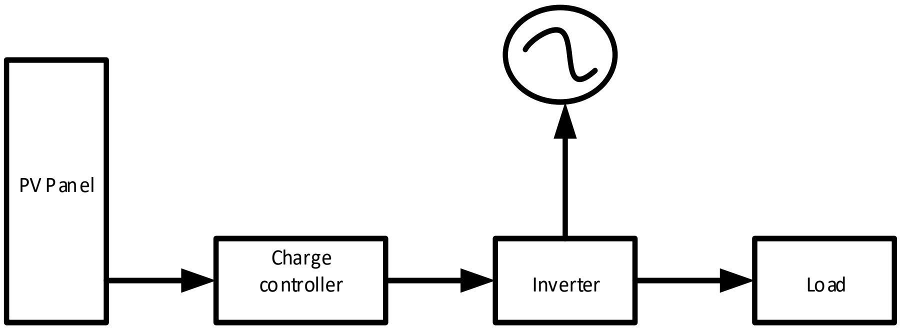


Fig 3.9 Interactive grid PV system

3.2.3 Hybrid PV system

Together with WG, DG, MT, etc., the PV system is used.

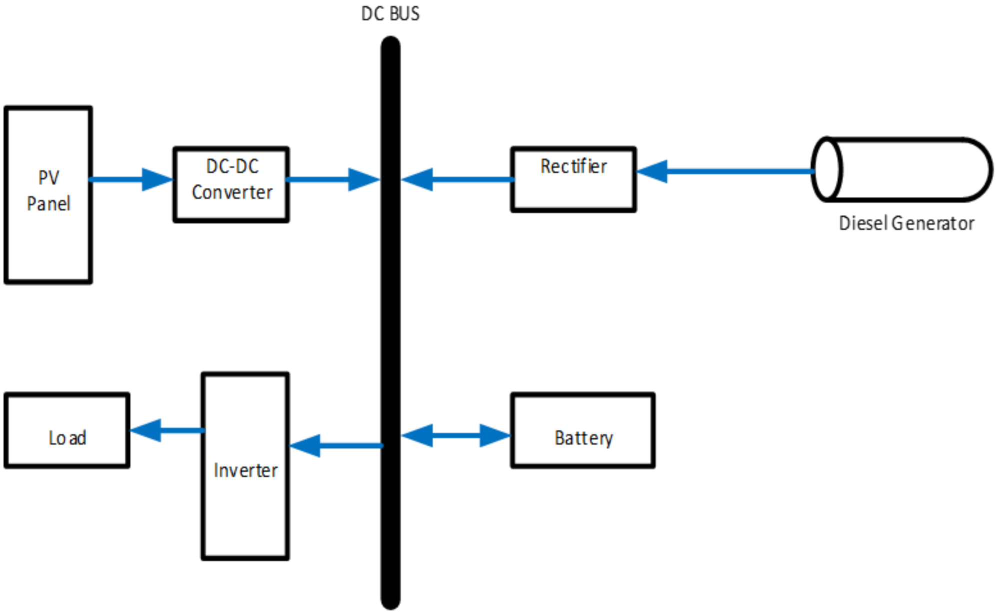


Fig 3.10 hybrid system

3.3 PV cell modelling

A PV cell can typically be modelled by a current source and a parallel connected diode. Solar cells have their own shunt and resistant series. Shunt resistant is due to the recombination of the electron hole before reaching the load, while the resistant series is resistant to the diode.

Pv cell output current:

$$\mathrm{I_{pv}} = \mathrm{I_{ph}} - \mathrm{I_d} - \mathrm{I_{sh}} \tag{3.1}$$

$$\mathrm{I_{pv}} = \mathrm{I_{ph}} - \mathrm{Is}\ \exp\left[\frac{\mathrm{q}(\mathrm{v_{pv}}+\mathrm{I_{pv}}\mathrm{R_S})}{\mathrm{A{\cdot}k{\cdot}T}}\right] - \frac{v_{pv}+I_{pv}R_S}{R_{54}} \tag{3.2}$$

Pv cell output voltage:

$$\mathrm{v_{pv}} = \frac{\mathrm{A{\cdot}k{\cdot}T}}{\mathrm{q}}\left[\frac{\mathrm{I_{ph}}+\mathrm{I_d}-\mathrm{I\_pv}}{\mathrm{I\_pv}}\right] - \mathrm{R_s}\mathrm{I_{pv}} \tag{3.3}$$

q = 1.6×10^{-19} c

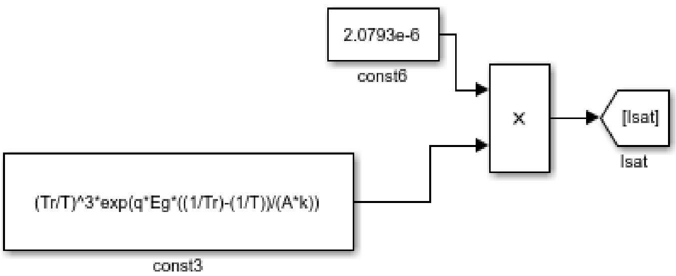
k = 1.38×10^{-23} j/k (Boltzmann constant)

T = 273.15 +c (kelvin)

A = ideality factor of diode

Rs, Rs = losses of metal contacts and leakage of pn jn

Calculations:



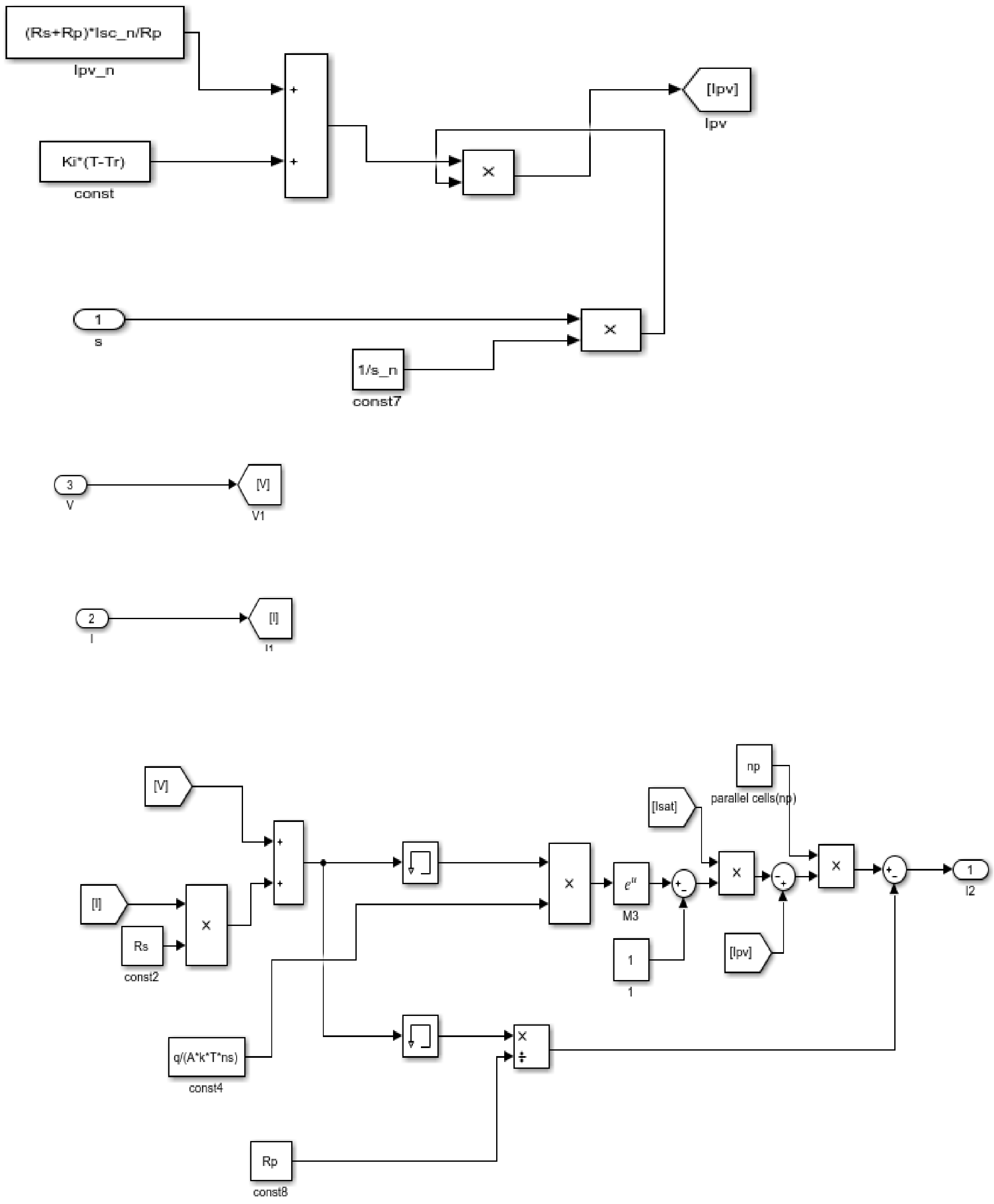


Fig 3.11 SIMULINK model of PV Equations

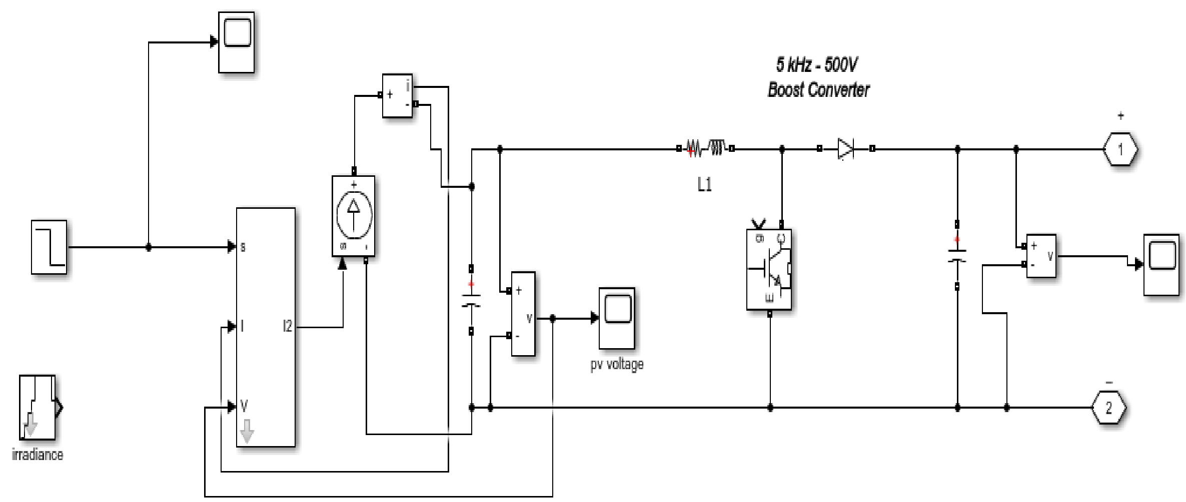


Fig 3.12 Basic SIMULINK model of equivalent PV module

Optimum operating voltage(Vmp)	30 V
Optimum operating current (Imp)	8.7 A
Open circuit voltage (Voc)	37.1 V
Short circuit current (Isc)	8.74 A
Series resistance	0.01
Parallel resistance	375
No of series cell	475
No of parallel cell	3

Table 3.1 Electrical Characteristics of PV Module

3.4 MPP tracking

The efficiency of the PV module is very small, so that various techniques are used to improve the performance of the PV module. This method is used to obtain the maximum possible power from a varying source. I-V curve of photovoltaic cell is nonlinear; therefore, it is difficult to feed power to certain load in that case we use boost converter whose duty cycle is varied by using a MPP algorithm. A boost converter is used on the load side and solar panel is used to power this converter.

3.4.1 Methods often used for MPPT

Some of the MPPT tools that are most common are:

1. P & O or hill climbing

2. Inc-Cond technique

3. Fractional SC current

4. Fractional OC voltage

5. Fuzzy logic

6. NN

7. DC link capacitor droop control

8. Ripple Correlation control

9. dp / dv or di/dv control

10. current sweep

11. load current or load voltage maximization

Among several methods listed above, P&O and In-Cond algorithms are most common owing to their simplicity, flexibility of application and excellent efficiency when irradiation is constant. Both algorithms are based on "hill-climbing" principle, where operation point of PV array in the direction of increasing power [3]. The technique used in MPPT is inc-cond work.

3.4.2 Inc-Cond method

The array terminal voltage is always adjusted according to the Max power point voltage [3]

using voltage and current sensors to identify the output voltage and current of the PV array.

$$P = V \cdot I \tag{3.4}$$

Differentiating w.r.t voltage we get

$$\frac{dP}{dv} = \frac{d(v \times I)}{dv} \tag{3.5}$$

$$\frac{dP}{dv} = I \cdot \left(\frac{dv}{dv}\right) + V \cdot \left(\frac{dI}{dv}\right) \tag{3.6}$$

$$\frac{dP}{dv} = I + v \cdot \left(\frac{dI}{dv}\right) \tag{3.7}$$

When MPP is reached the slope $\frac{dP}{dv} = 0$,hence

$$\frac{dP}{dv} = 0 \tag{3.8}$$

$$I + v \cdot \left(\frac{dI}{dv}\right) = 0 \tag{3.9}$$

$$\frac{dI}{dv} = -\frac{I}{v} \tag{3.10}$$

the basic equations of this method are as follows.

$$\frac{dI}{dv} = -\frac{I}{v} \quad \text{at Max power point} \tag{3.11}$$

$$\frac{dI}{dv} > -\frac{I}{v} \quad \text{Left Max power point} \tag{3.12}$$

$$\frac{dI}{dv} < -\frac{I}{v} \quad \text{Right of Max power point} \tag{3.13}$$

Where I and V are the current and voltage output of the PV array. The left side of the equation is inc-cond above three equations 3.11-3.13 and the right side is the instantaneous conductance. Max power point reached If the ratio of output conductivity transformation is equal to negative output conductivity.

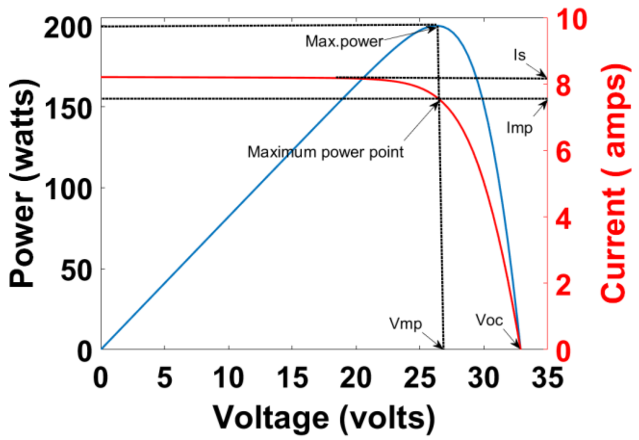


Fig 3.13 Basic idea of incremental conductance of the solar module PV curve

Fig 3.13 shows that slope of solar PV power curve is zero at the maximum power point.

This technique monitors the quickly evolving irradiation more exactly than the P&O technique. This method needs many sensors to function less efficiently economically.

Flow chart for inc-cond algorithm:

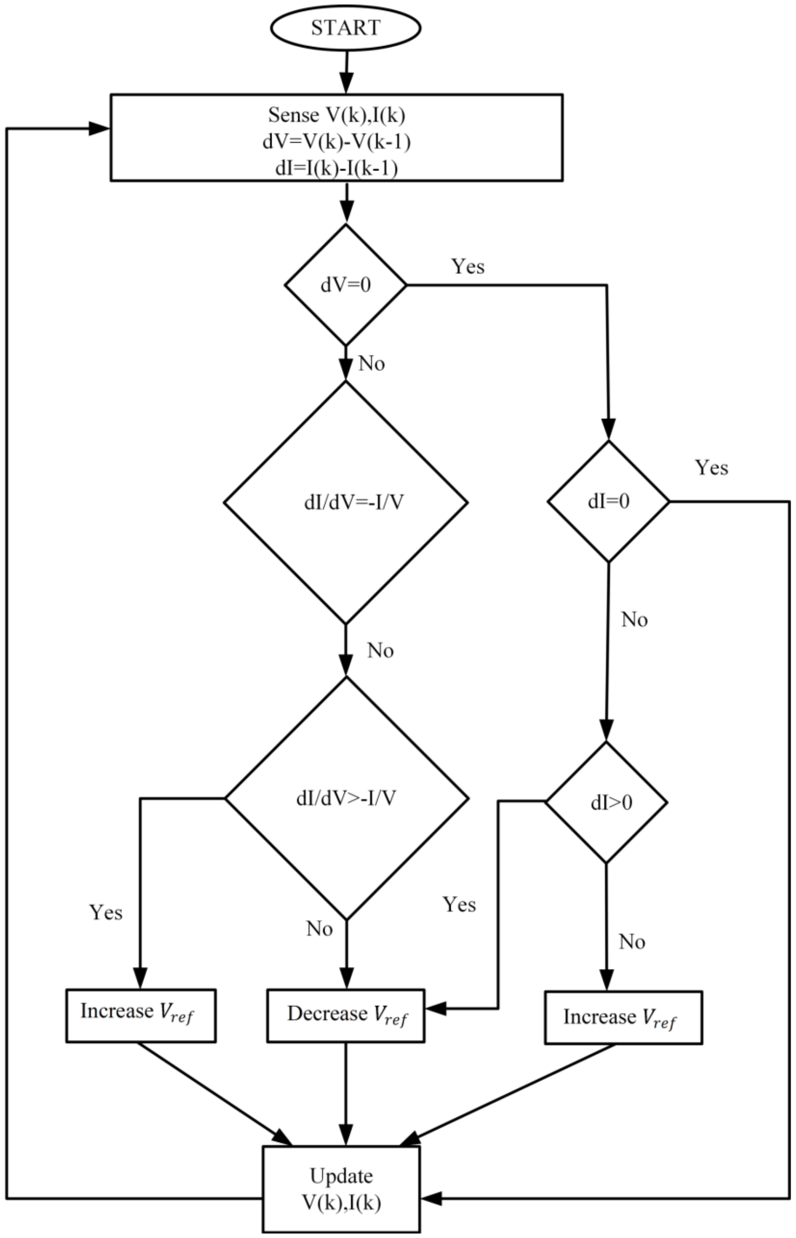


Fig 3.14 Flow chart for inc-cond algorithm

This algorithm is implemented using the embedded MATLAB function of Simulink, where the codes are written inside the function block are utilized to vary certain signals with respect to the input signals.

3.5 Battery storage system

Usually excess energy from the PV stored in the battery bank. Depending on the scheme requirement, mostly batteries are used as backups in stand-alone systems [3]. In a PV arrangement, the primary functions of a battery are:

(a) **Voltage and current stabilization:**
In general, the battery suppresses transients in PV output voltage and current and offers stable electrical output to the load.

(b) **The supply of surge currents:**
To supply electrical equipment with elevated peak currents

(c) **Energy storage capability and autonomy:**
To Store electrical energy when produced by PV array and feed energy to loads as desired.

Because of the wide range of accessibility, low cost and the performance features are chosen quite well, lead-acid batteries are primarily used in PV systems whereas Ni-cad cells are rarely used in PV systems because starting costs are very high, so we use Ni-cad batteries for low-temp applications .Batteries are mainly classified as primary batteries and secondary batteries, PB is not rechargeable, but energy can be stored and supplied for e.g. lithium and carbon-zinc batteries, PB are not used in PV system Whereas sec batteries can be recharged and these batteries can store and supply electrical energy depending on their performance features w.r.t the need of a particular application, some e.g. cells used in PV and automobiles.

3.5.1 Modelling of battery

The voltage of the battery terminal is highly nonlinear and depends on temperature, charge or discharge rate and SOC , simulation focuses on detecting the battery's SOC by relating it to a steady charging and discharging charge[3].

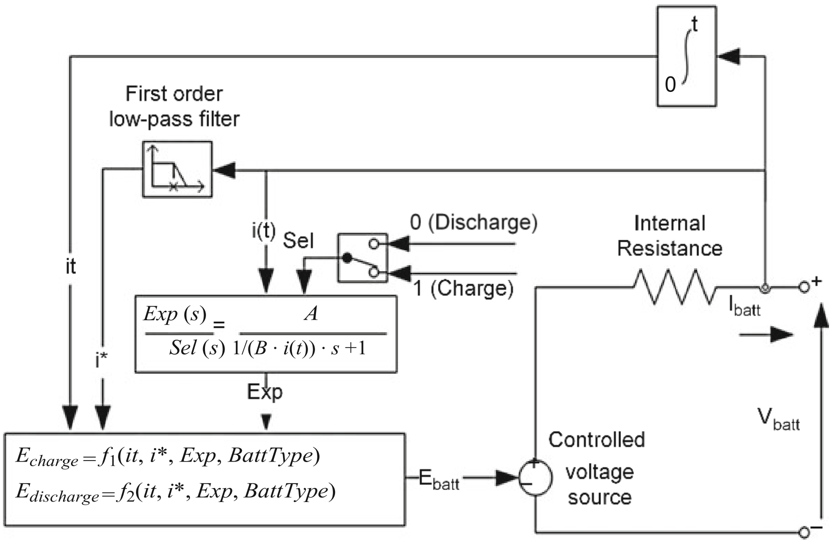


Fig 3.15 modelling of battery

Charge model of BES ($i^* < 0$)

$$f_2\ (it, i^*, i, Exp) = \mathrm{E_0} - \mathrm{k} \cdot \frac{\mathrm{Q_0}}{|\mathrm{it}| + 0.1\mathrm{Q}} \mathrm{i}^* - \mathrm{k} \cdot \frac{\mathrm{Q}}{\mathrm{Q - it}} \cdot \mathrm{it}$$

$$+ Laplace^{-1}\left(\frac{Exp(s)}{sel(s)} \cdot \frac{1}{s}\right) \quad (3.14)$$

Discharge model of BES ($i^* < 0$)

$$f_1(it, i^*, i, Exp) = \mathrm{E_0} - \mathrm{k} \cdot \frac{\mathrm{Q}}{\mathrm{Q - it}} \cdot \mathrm{i}^* - \mathrm{k} \cdot \frac{\mathrm{Q}}{\mathrm{Q - it}} \cdot \mathrm{it}$$

$$+ Laplace^{-1}\left(\frac{Exp(s)}{sel(s)} \cdot 0\right) \quad (3.15)$$

Where

$\mathrm{E_0}$ = constant voltage

$\mathrm{Exp(s)}$ = dynamics of exponential zone dynamics (v)

$\mathrm{sel(s)}$ = represents the battery mode, $sel(0)$ = battery discharge mode, $sel(s)$ = 1 during battery charge

K = Polarization constant ($\mathrm{A}h^{-1}$)

i^* = low frequency current dynamics (A)

it = Extracted Capacity (Ah) Q = Maximum battery capacity (Ah)

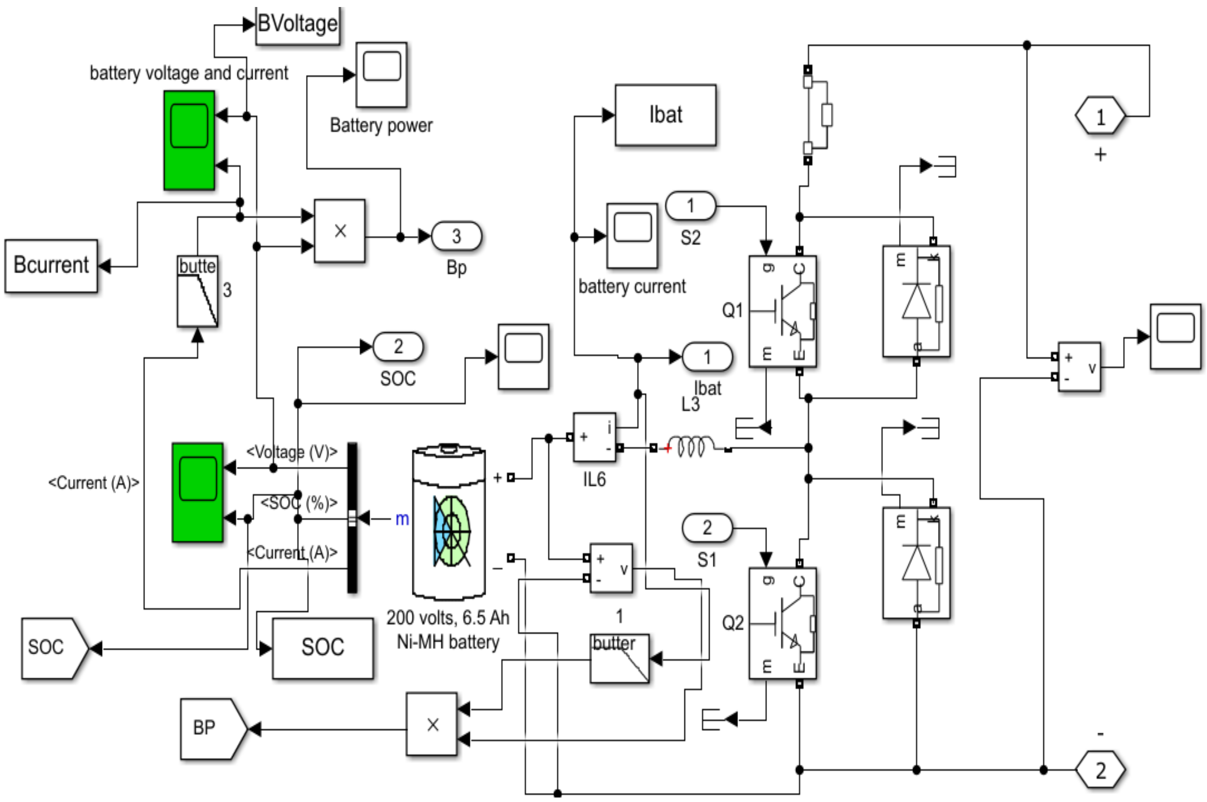


Fig 3.16 MATLAB SIMULINK model of Battery energy storage system

3.6 Super capacitor:

Super capacitor connected to grid via bidirectional buck boost converter. The equivalent circuit models of super capacitor comprise of equivalent series resistance amount to the charging and discharging, equivalent parallel resistance constitutes lose due to self-discharging and a capacitor across it.

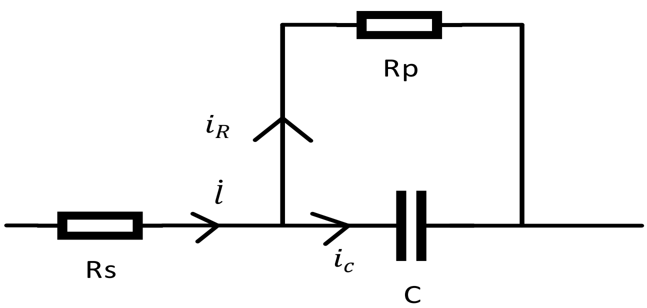


Fig 3.17 super capacitor equivalent model

$$v_t = v_C - R_S \cdot i \tag{3.16}$$

$$v_C = v_C(0) - \frac{1}{C}\int_0^t i_C \, dt \tag{3.17}$$

Applying KCL across the node:

$$i_C = i + i_R \tag{3.18}$$

$$i_R = \frac{v_c}{R_p} \tag{3.19}$$

Taking Laplace transform on both L.HS. and R.H.S sides

Transfer function becomes:

$$G(s) = \frac{v(S)}{I(S)} = \frac{R_S + R_p + R_S \cdot R_P \cdot C \cdot S}{1 + R_P \cdot C \cdot S} \tag{3.20 }$$

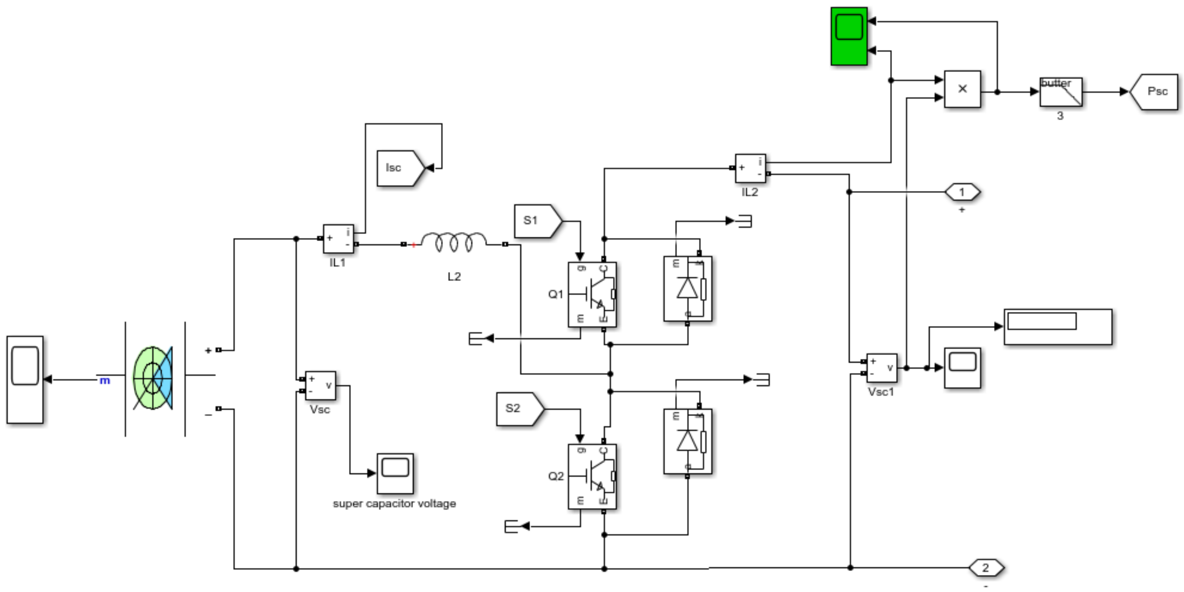


Fig 3.18 MATLAB SIMULINK model of supercapacitor

CHAPTER 4

BRIEF IDEA OF DIFFERENT CONTROL TECHNIQUES

Two-dimensional frames are categorized as αβ-frames and dq-frames. Weather we operate in a three-phase VSC system or a modified equivalent of αβ and dq-coordinate we receive the same advantage as later one [2]. Proportional – integral can only be used to control the DC command. Using above two conversion methods, sinusoidal ac detection issue transformed into an equivalent DC issue.

- Some specific type of electrical machine model displays time-varying inductance of mutual coupling In abc-frame it is feasible to convert in dq-frame into equal constant parameters so that it is easy to regulate [1].
- Modules of larger power systems are frequently formulated and analyzed in dq-frame, so we demonstrate VSC systems in dq-frame [1].

4.1 CLARKE & PARK TRANSFORMS

We commonly used Clarke transform to detect I d (Real) and Iq (imaginary) current, whereas Park Transform can be used to transform real and imaginary currents from stationary to moving ref frames.

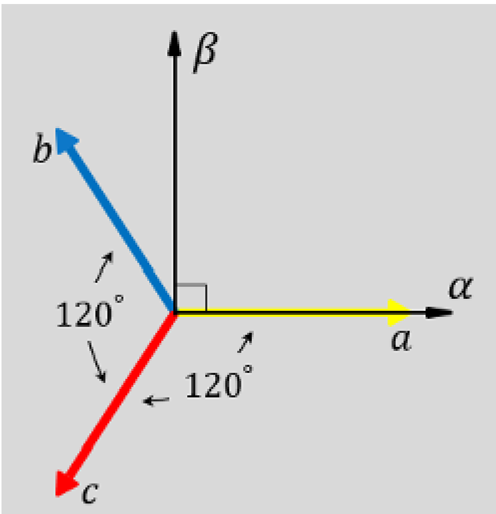


Fig 4.1 Phasor diagram of Clarke transform (abc- αβ0)

Using above two transformation theory, 3-ϕ currents ia, ib, ic transformed to iα and iβ again into moving ref isd and isq-current parts.

4.2 MATHEMATICAL CLARKE TRANSFORM

Clarke transform mainly used to convert 3-ϕ system in to equivalent two phases

$$i_\alpha = \frac{2}{3} \cdot i_a - \frac{1}{3}(i_b - i_c) \quad (4.1)$$

$$i_\beta = \frac{2}{\sqrt{3}}(i_b - i_c) \quad (4.2)$$

$$i_0 = \frac{2}{3}(i_a + i_b + i_c) \quad (4.3)$$

Where iα and iβ are orthogonal frame components.

4.3 MATHEMATICAL PARK TRANSFORM

using vector rotation block α, β rotated over an angle θ

$$i_{sd} = i_\alpha \cdot cos(\theta) + i_\beta \cdot sin(\theta) \quad (4.4)$$

$$i_{sq} = -i_\alpha \cdot \sin(\theta) + i_\beta \cdot \cos(\theta) \quad (4.5)$$

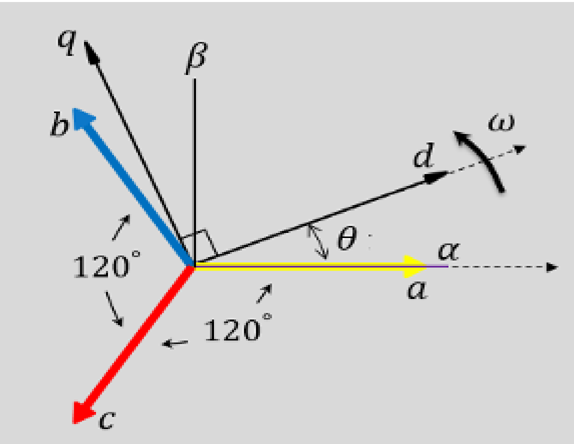


Fig 4.2 phasor diagram of parks transform (αβ0-dq0)

4.4 DROOP CONTROL OF MICROGRID

4.4.1 Droop features in standard power systems

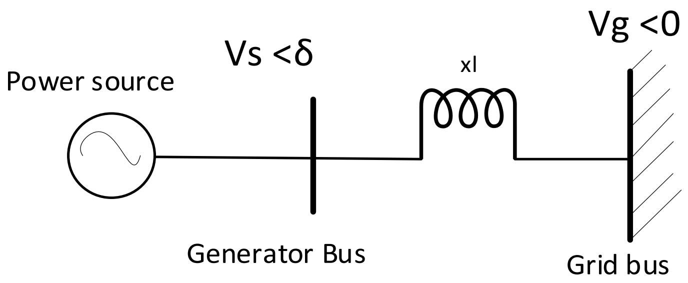


Fig 4.3 Infinite bus system

Consider the figure above an infinite bus system. The alternator swing equation describing the load power imbalance mechanisms is given by [2].

$$M\frac{d\omega}{dt} + D(w-1) = P_m - P_e \tag{4.6}$$

Where,

Pm = input mechanical power

Pe is the electrical power output can be calculated as

$$Pe = \frac{v_5 v_g \sin\delta}{x_q' + x_l} \tag{4.7}$$

x_d' = transient reactance of the generator

x_l = line reactance

w = angular velocity

M = inertia constant

D = co-efficient of damping

Vs = voltage of generator (RMS)

Vg = infinite grid voltage

δ = source generator Rotor angle

From the equation 4.6, assuming the voltages Vs and Vg are constant, and the output power deviation of the generator is provided by:

$$\Delta P_e = \frac{v_s v_g \cos\delta_0}{x'_d + x_l}\,\Delta\delta \tag{4.8}$$

$$\Delta\delta = \delta_s - \delta_g \tag{4.9}$$

Flow of active power to the MG proportional to the voltage angle, if active power increase then voltage angle must decrease and vice versa.

Control Feedback loop for generator control equation:

$$f - f_0 = -k_p(P - P_0) \tag{4.10}$$

Where P_0 and f_0 are reference active power and ref frequency

Frequency characteristics can be expressed as active power drop

$$\text{Kp (Hz / pu MW)} = \frac{\Delta f}{\Delta P} \tag{4.11}$$

The interconnecting generating units chase the changes in load and adjust accordingly to the common frequency. When attached to the load, two gen units with distinct drop features operate at an idiosyncratic nominal frequency with distinct o / p energy, When a transition in load happens, each device decreases its velocity and the controls inc o / p energy until they achieve a standard working frequency [2].

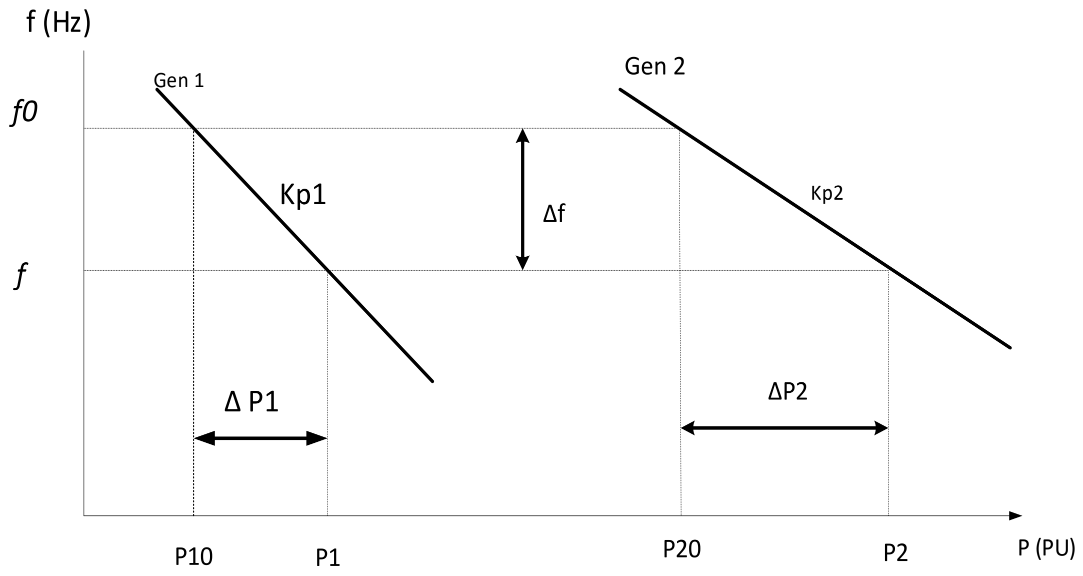


Fig 4.4 Load tracking by generators with various droops.

Likewise, it is possible to articulate the relationship between reactive Vars and voltage

$$v - v_0 = -k_q(Q - Q_0) \qquad (4.12)$$

Inverter output voltage controlled by the output reactive power forasmuch as frequency of MG system controlled by the output active power. these approaches are known as f/P or V/Q control.

$$\Delta P_i = \frac{\Delta \cdot f}{k_{Pi}} \qquad (4.13)$$

Hence,

$$\frac{\Delta P_1}{\Delta P_2} = \frac{k_{P_2}}{k_{p_1}} \qquad (4.14)$$

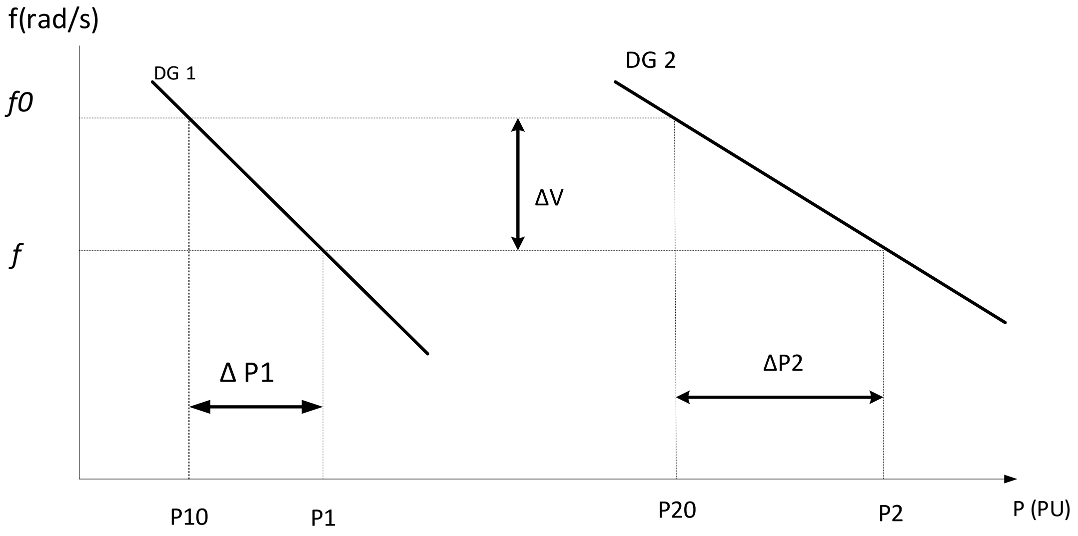


Fig 4.5 f-p Droop characteristics of inverter based DGs

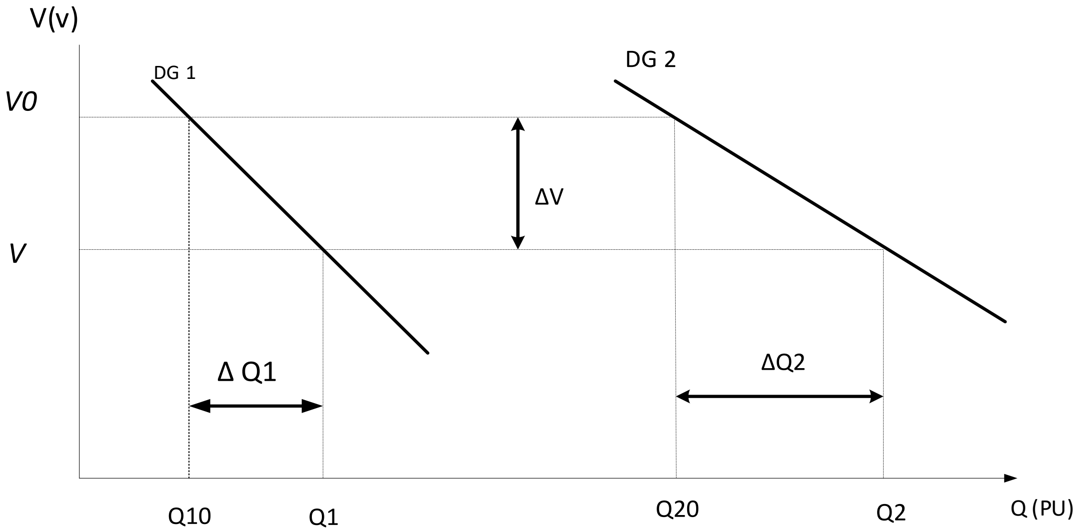


Fig 4.6 V-Q Droop characteristics of inverter based DGs

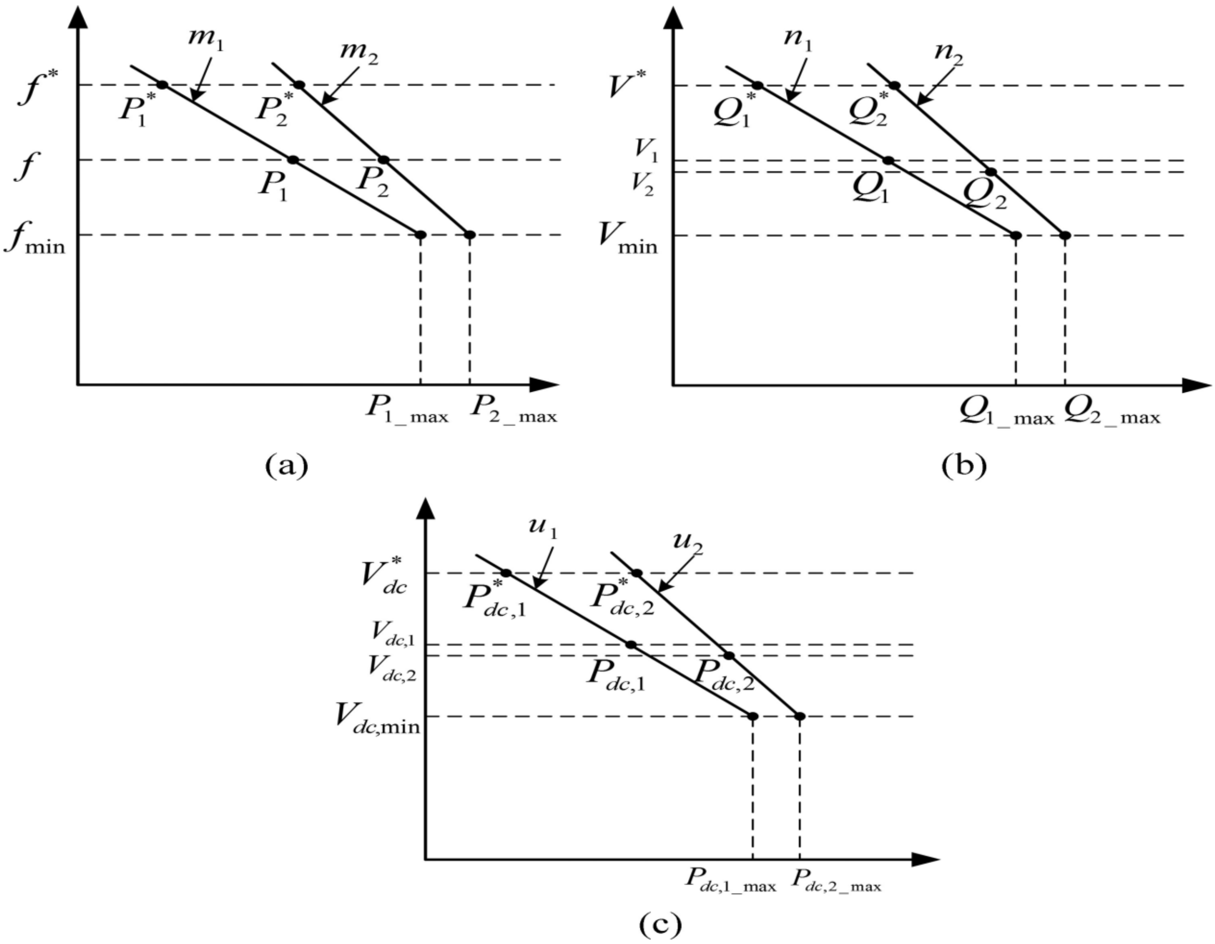


Fig 4.7 Droop characteristics of AC sub grid (a,b) and DC sub-grid (c)

P1 *, P2 *, Q1 *, Q2 *, f *, V * are rated active and reactive vars , reference frequency and voltage of MG, whereas m1, m2, n1, n2 are droop coefficients. These falling slopes are adjusted to adjust f * and v * , thus invert drop control (P-f and Q-V droop control) incorporated with direct drop control of these frequency and voltage differences. Dc droop control technique needs P-V droop control, which makes it simpler compared to the Ac droop control.

4.5 Co-ordination control of MG

We can define co-ordination control as Hybrid MG dc voltage and frequency increase or decrease at the same time when a load fluctuation happens and all the fluctuation can be handled in synchronization.. under various load condition for stable operation and smooth flow of power in between AC/DC sub grid co-ordination control method adopted. MG having multiple sub grids so interaction among them is very much complicated therefore co-ordination control rule is adopted in order to make smooth power flow among multiple sub grids If there is any fluctuation between the ac and dc sub grids, it is necessary to share variations in coordination. If there is surplus power or (shortage of power) in sub grids, ac frequency and DC Voltages becomes higher (lower) & interlinking converters release (absorb) power from the common bus and DC bus voltage will become higher (lower). in general dc voltage and ac frequencies represent the change in power inside dc or ac sub grids whereas Common bus voltage represents power changes throughout the whole microgrid system, so we developed a control rule for above coordination control.

Control law expressed as:

$$\delta f_j = \left(k_P, j + \frac{k_{i,j}}{S}\right)\left(\frac{v_{cb} - v_{cb}^*}{v_{cb}^{max} - v_{cb}^{min}} - \lambda_j \cdot \frac{f_j - f_j^*}{f_j^{max} - f_j^{min}}\right) \quad (4.15)$$

$$\delta V_k = \left(k_{p,k} + \frac{k_{i,k}}{S}\right)\left(\frac{v_{cb} - v_{cb}^*}{v_{cb}^{max} - v_{cb}^{min}} - \lambda_k \cdot \frac{v_{dc,k} - v_{dc,k}^*}{v_{dc,k}^{max} - v_{dc,k}^{min}}\right) \quad (4.16)$$

where

Kp,j = PI controller proportional coefficient

Ki,j = integral coefficient.

Correction co-efficient λ_j

The AC / DC sub-grid capability and load characteristics of a Hybrid MG have a considerable impact on the impacts of coordinated control. If the capacity of one sub grid is higher than another, then a powerful sub-grid is involved in power management and weak sub-grid Contribution is limited. if there is any load fluctuation strong sub-grid should absorb or release more power. use of correction co-efficient is mainly to improve the power quality of Sub-grids having higher number of critical loads because Sub-grids with more critical loads do not significantly change their electrical parameters. it can be also useful when capacities of sub-grids are mismatched.

Hence, we can define correction co-efficient as

$$\lambda_j = \left(\frac{p_j^{Sum}}{P^{sum}}\right)^{-1} \cdot \frac{P_j^{cri}}{p_j^{sum}} \tag{4.17}$$

p_j^{sum} = total capacity

p_j^{sum} = critical load capacity

P^{sum} = Total capacity of the whole hybrid MG

Hence correction co-efficient of sub grid is larger if number of critical loads is more and capacity of the sub grid is small, and In accordance with the control law, changes in dc voltage and ac sub-grid frequency will be reduced.

mathematically for the system is in steady state

$$\frac{v_{cb}-v_{cb}^*}{v_{cb}^{max}-v_{cb}^{min}} = \lambda_1 \cdot \frac{f_1-f_1^*}{f_1^{max}-f_1^{min}}$$

$$= \lambda_2 \cdot \frac{f_2-f_2^*}{f_2^{max}-f_2^{min}}$$

$$= \ldots.$$

$$\vdots$$

$$= \lambda_k \cdot \frac{v_{dc,k}-v_{dc,k}^*}{v_{dc,k}^{max}-v_{dc,k}^{min}}$$

$$= \lambda_{k+1} \cdot \frac{v_{dc,k+1}-v_{dc,k+1}^*}{v_{dc,k+1}^{max}-v_{dc,k+1}^{min}}$$

$$= \ldots\ldots\ldots\ldots.. \tag{4.18}$$

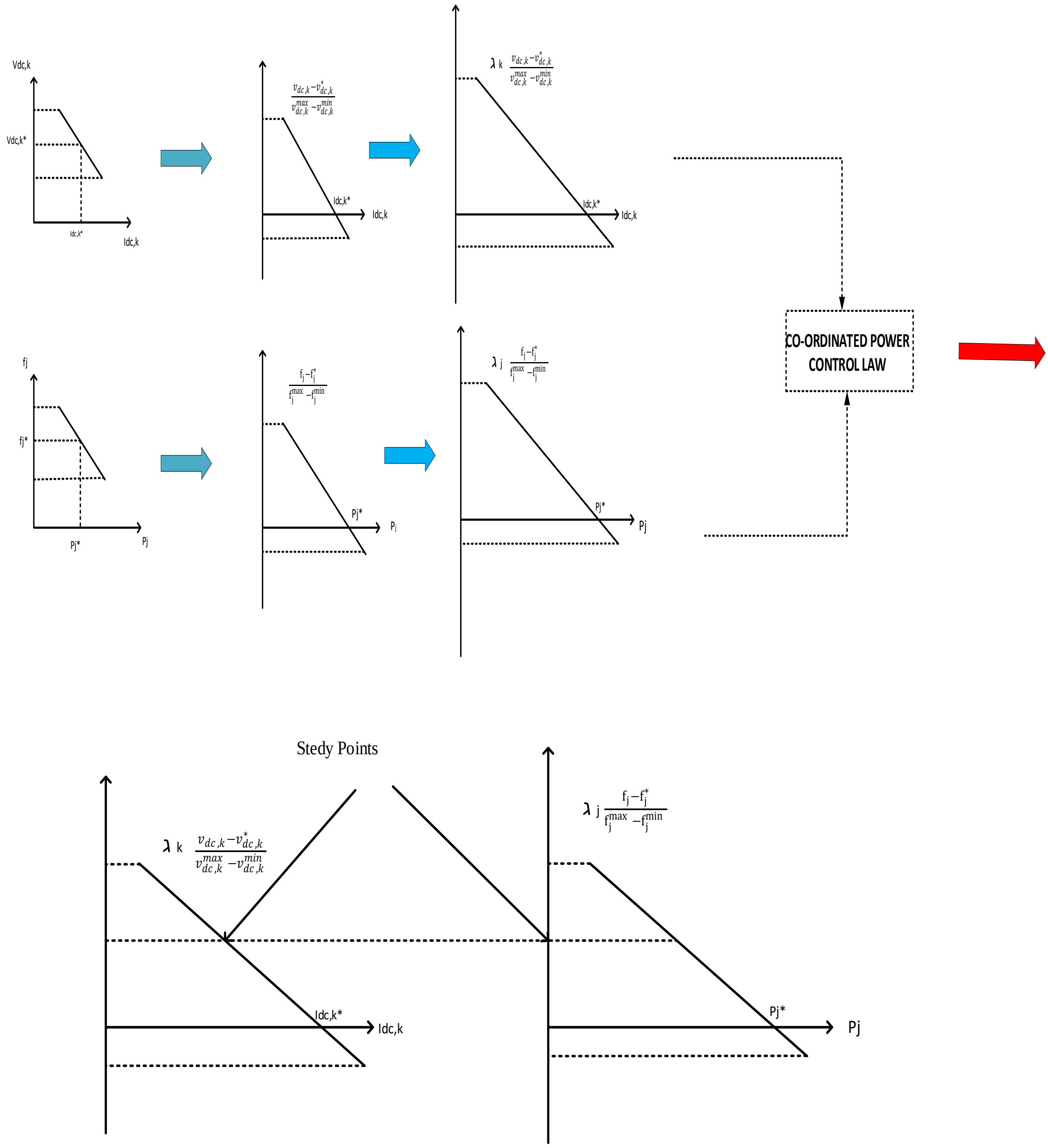


Fig 4.8 Control impacts of co-ordinated energy control

From the above figure we can conclude that the ac frequency and the dc voltage were equally represented by using the suggested coordinated energy control to bring the system into a stable position.

CHAPTER 5

CONTROL TOPOLOGY

Hybrid MG generally has two operating stages.

(1) Grid supplied

(2) Decentralised Hybrid MG system

5.1 Grid tied mode

5.1.1 PV system control

Dc microgrid is linked to the solar PV system by means of a boost converter. In boost converter integrated solar Photovoltaic output DC voltage of PV controlled by the converter additionally it increases the dc output voltage as desired. The MPPT unit is responsible for providing maximum power produced by PV cells over the load changes at specified temperature and irradiance. when load demand increases the PV, cell operate at boost mode and Step-up converter duty obtained with voltage and PV current. After calculating the SOC of the battery if the battery SOC is above or at its threshold limit , we can see a shift in the hybrid microgrid power level which is the main cause of the voltage imbalance and the grid becomes unstable after that, Error obtained by subtracting Photo voltaic power and three-phase load power, resulting in the necessary duty for controlling the power converter when passing through the proportional-integral controller.

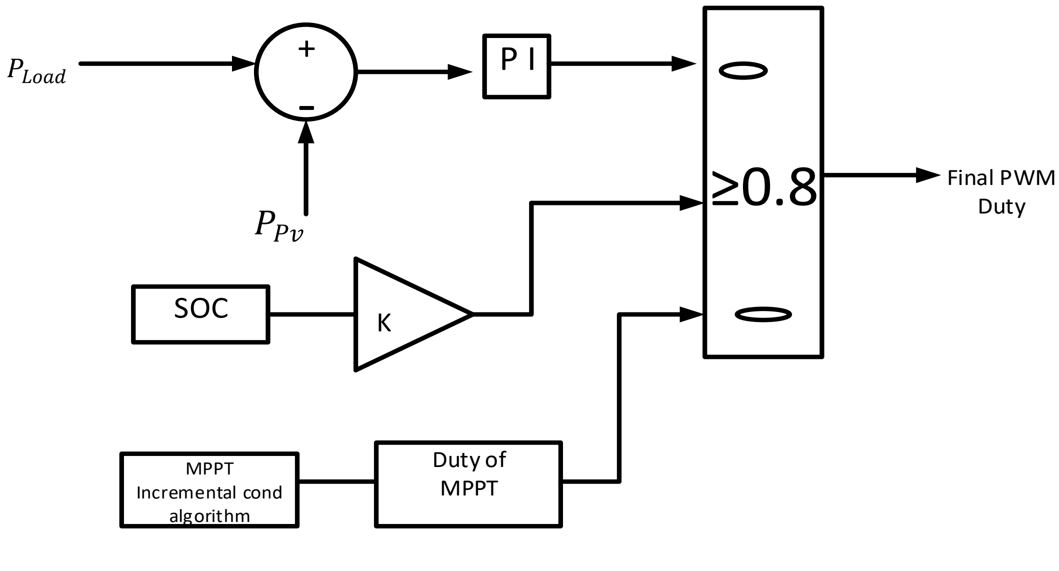


Fig 5.1 PV system control in grid connected mode

5.1.2 Control of battery

In hybrid MG battery used for providing additional power requirement of the Load and storage of generated surplus amount of power. battery energy storage system controlled by the bidirectional power converter, And for this we had to generate duties for the bidirectional buck boost converter, duties S1 and S2 generated basically by the hysteresis controller which takes the difference between Ibat and Iref for the pulse generation so mainly we have to generate reference current . In order to produce the reference current, we must first take the distinction between the rated DC and DC bus voltage which causes error. When the error passed through the PI produces iref later. BESS takes Part in charging & discharging and maintain DC bus voltage. DC bus mainly control and supplied by PV when SOC of BESS Above threshold limit. below threshold limit battery charged by the utility grid.

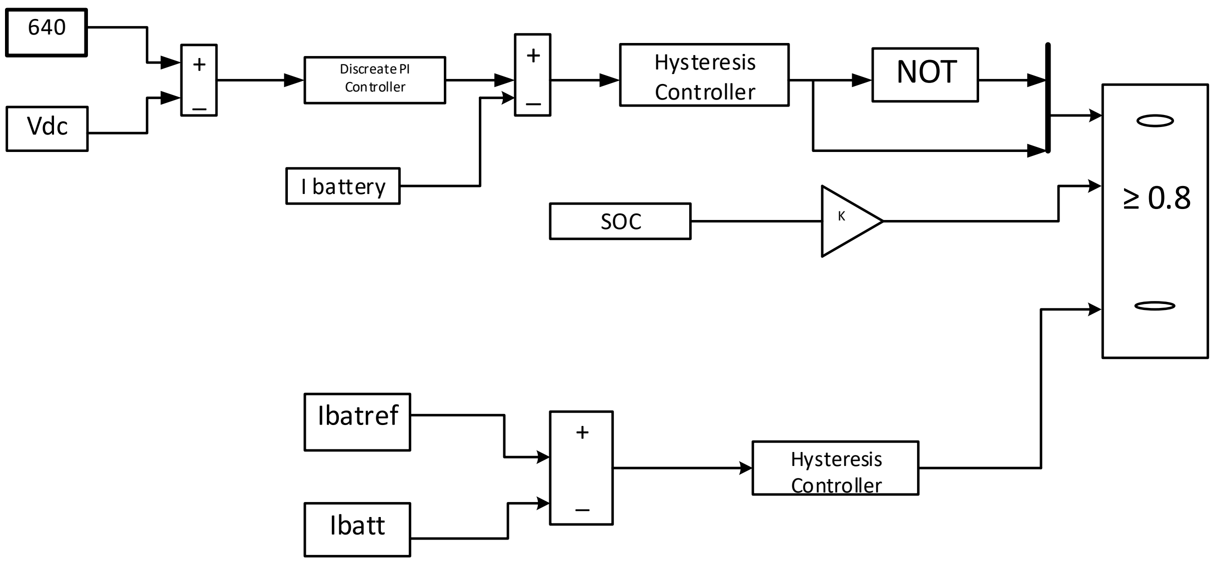


Fig 5.2 BES control in grid connected mode

5.1.3 Super capacitor system control

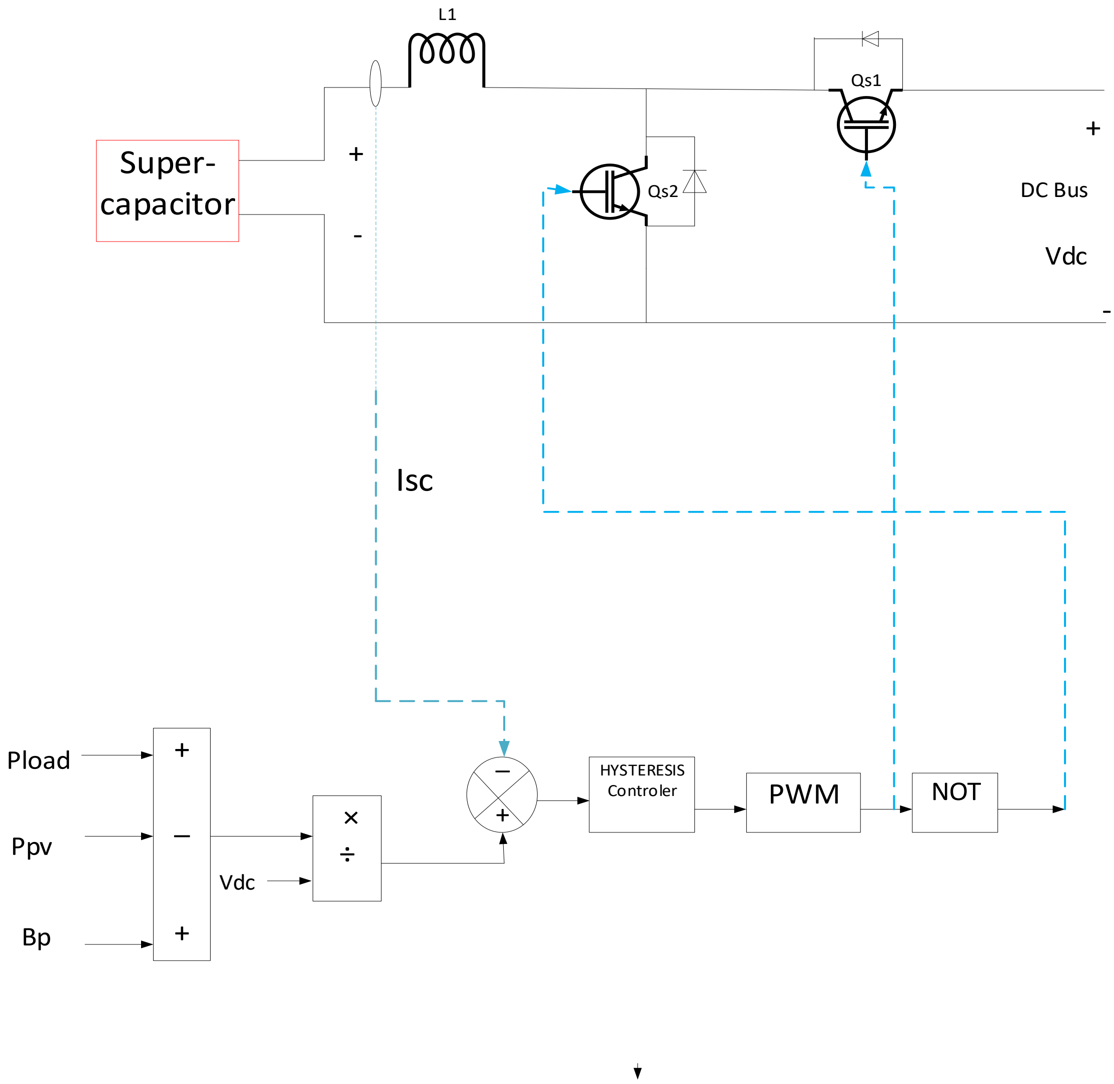


Fig 5.3 super capacitor control

When there is a sudden fluctuation of load and transients in the hybrid MG structure and power changes quickly Supercapacitors come into practice.SC taken care of these by remaining off during this condition and it will discharge during this process .bidirectional DC-DC converter that either works as a buck or as a boost converter depending on the necessity. super capacitor controlling can be done by duty S1 and S2 gate pulse S1 and S2 for bidirectional converter can be generated by the Hysteresis controller which takes error generated by dividing Hybrid grid voltage from the difference of load, BESS and PV power.

5.1.4 Grid side inverter control

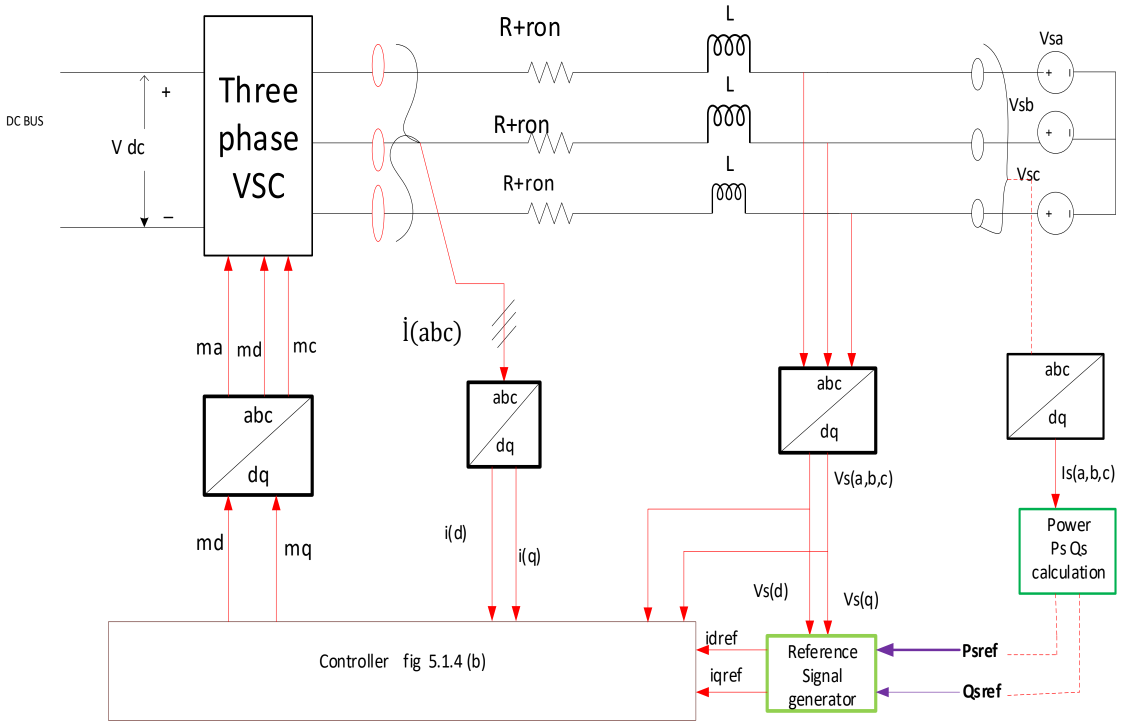


Fig 5.4 schematic diagram of VSC system

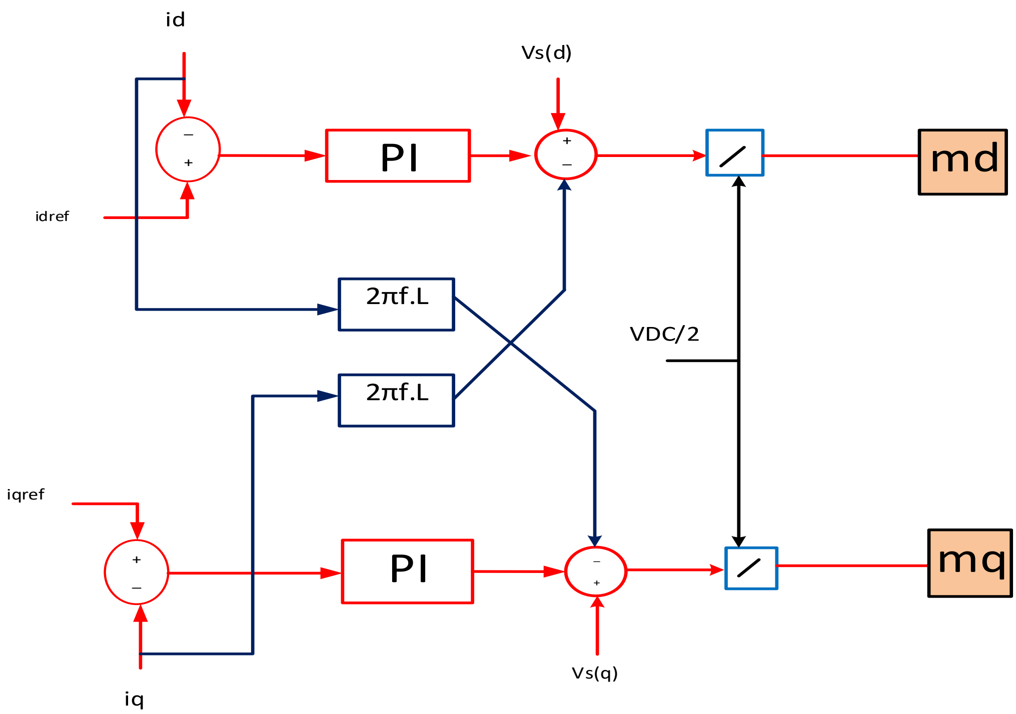


Fig 5.5 control block diagram of VSC system

when the load is ac type or to feed the ac-sub grids inverter is connected to the AC bus In grid connected mode ac sub grid voltage maintained by the utility grid Here we followed Current control topology to control the inverter and for this we required to generate pulse for VSC inverter. The current reference takes the feed forward path to generate md and mq and by decoupling the feed forward we generate switching pulses for the inverter.

5.2 islanding mode with multiple sub-grids

Power management of hybrid microgrid more complex due co-existence and interaction of ac or dc sub grids. When multiple sub grids are connected to the common bus by interlinking converters, we found that rated frequency and dc voltage of ac or dc sub grid is different for different applications so controlling power flow among multiple sub-grids is more complicated and the system isn't so reliable. Conventional hybrid MG usually contains either one ac sub-grid or dc sub-grid so they have to deal with single kind of AC frequency and DC voltage but problem occurs when we have to deal with hybrid MG having multiple ac or dc sub-grids having different rated ac frequencies & dc voltages. During off grid mode we integrate battery storage system to the grid in order to maintain common bus dc voltage, Different ac and dc sub-grids are connected through bidirectional interlinking converters to this common bus. storage sub grid uses co-ordinated control methodology to manage power flow among various sub grids. mater slave control using critical communication device is one way of overcome this difficulty of controlling the power flow among various sub grid of hybrid MG but there may be chance of communication error hence we adopted decentralized droop control method in addition some improvement measures to improve the performance of the droop control method.

conventional $\mathrm{i}_{\mathrm{dC}} - \mathrm{v}_{\mathrm{dC}}$ droop control has some limitation and drawbacks which can be avoided by using distributed secondary control. to control power flow among various ac sub grids and to share the power fluctuation in coordination $\omega - P_{ac}$ and $v_{dc}^2 - P_{dc}$ droop control method developed.

Proposed coordinated power control method also suitable for sub grids having different or mismatched power capacities. Hybrid MG if containing one frequency and one dc voltage, scope of application is limited for e.g. ac frequency in India is 50 HZ whereas typical ac frequency in north America is 60 HZ therefore some loads made in one place unadopted to another place.

All sub-grids are integrated to common DC bus either directly if it is DC load or a dc DG or through some interlinking converters (ILCs) if it ac sub grid power flow in two ways .

(i) Distributed generator (PV, Wind. Etc) to sub grid, sub grid to load

(ii) From battery storage system to sub grids, sub grid to load

All the sub-grid connected DGs operated in MPPT mode.

5.2.1 control strategies for different sub grids

5.2.1.1 Droop control for storage sub-grid

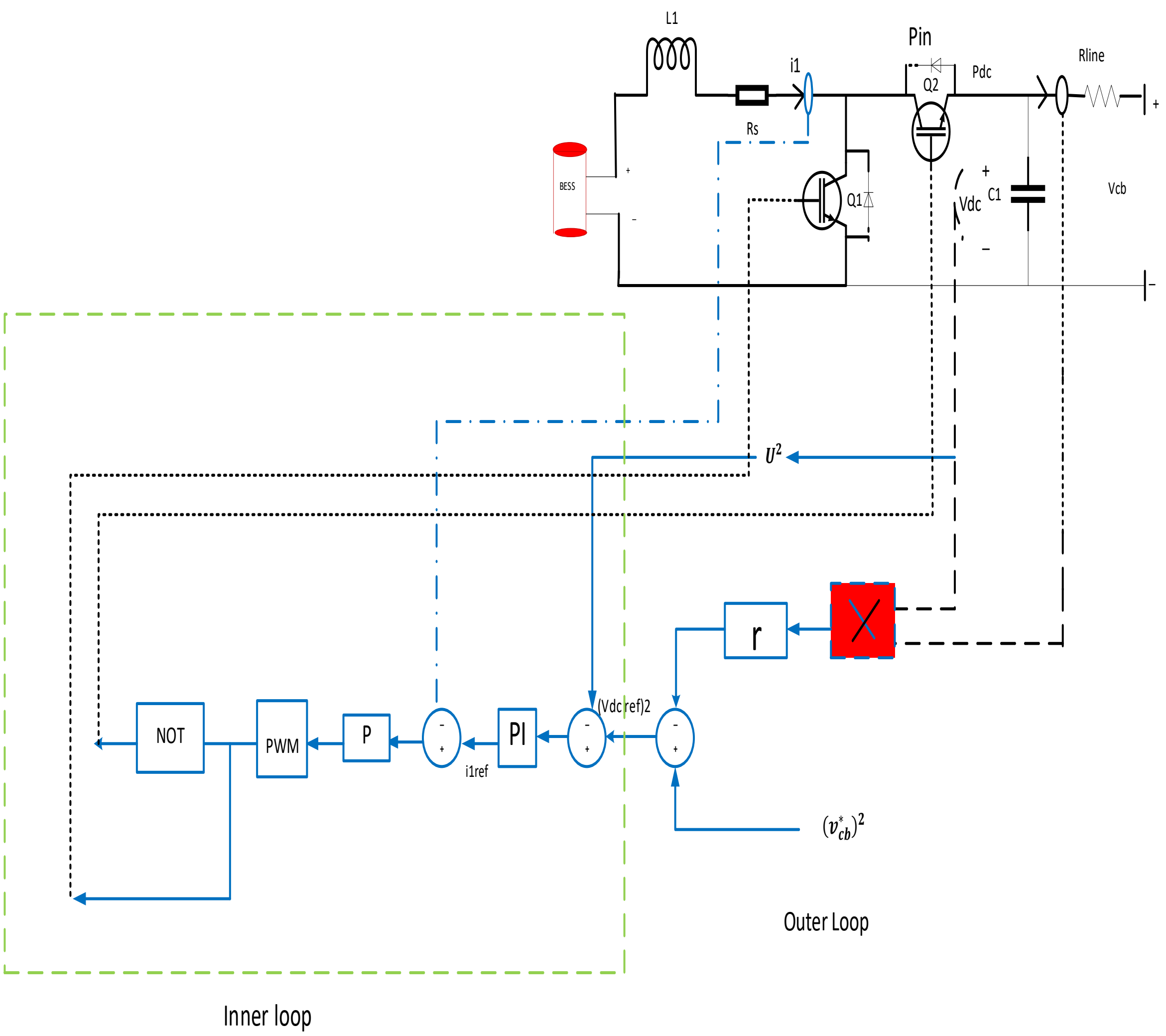


Fig 5.6 control strategy for storage system

Storage sub grid, battery is connected to common dc bus through bidirectional dc-dc Interlinking converters, It is mainly to retain the common DC bus voltage and power of the

HYBRID MG when grid is not connected to the MG. in our work we use two battery energy storages for power management to share large amount of power. in conventional droop control strategy if the storage is connected to the Constant power load Performance of system degraded, relationship between idc-Vdc is non-linear hence we use Pdc-v_{dc}^2 (new droop control strategy).

$P_{dc} - v_{dc}^2$ droop control technique:

$$\frac{1}{2} C_S \frac{dv_{dc}^2}{dt} = P_{in} - P_{0ut} \tag{5.1}$$

$$P_{dc} = \frac{v_{dc}^2}{R_{l0ad}} + P_c \tag{5.2}$$

P_{in} = input power

P_c = output power

From the above two equation we can prove that the relationship between $P_{dc} - v_{dc}^2$ is linear '

Above proposed droop control method is a two-loop control strategy,

(i) Inner loop control
(ii) Outer loop control

inner loop control idea can be designed from the boost converter average model equation as follows assuming inductive and switching losses are zero.

$$\frac{1}{2} c_S \frac{dv_{dc}^2}{dt} = v_S \cdot i_1 - P_{dC} \tag{5.3}$$

$$\frac{L_S \, di_1}{dt} + R_S \cdot i_1 = v_S - v_1 \tag{5.4}$$

Ls = filter inductance

Rs = Parasitic resistance

Vs = battery voltage

I1 = output current of battery

$P_{dc} - v_{dc}^2$ control law:

$$\left(v_{dC,k}^{ref}\right)^2 = (v_{cb}^*)^2 - r_k\left(P_{dC,k} - P_{dc,k}^*\right) \tag{5.5}$$

v_{cb}^* = rated common bus voltage

$P_{dC,k}$ = output dc power

$P_{dc,k}^*$ = rated output dc power

r_k = droop co-efficient

$v_{dC,k}^{ref}$ = rated value for output dc voltage

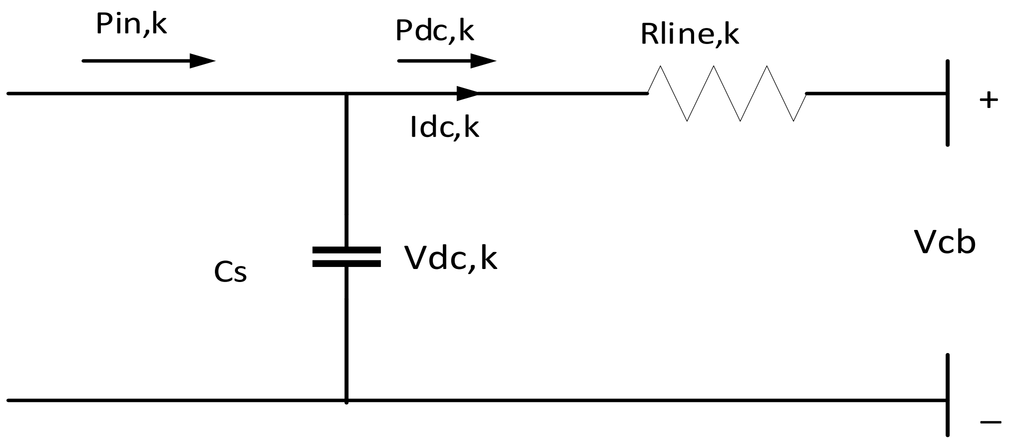


Fig 5.7 Simplified circuit diagram for Kth storage

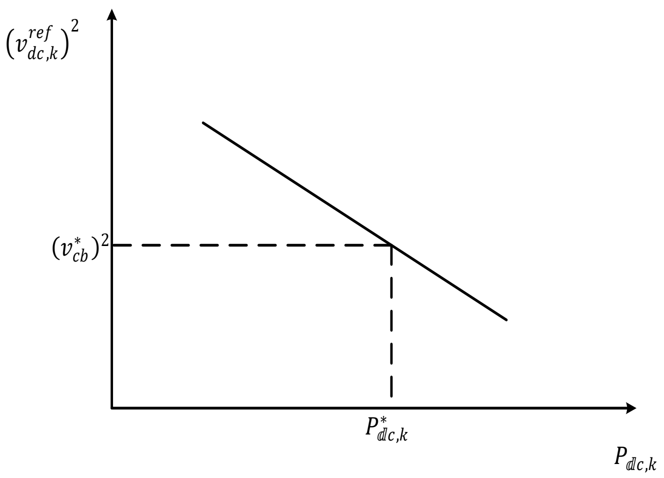


Fig 5.8 $P_{dc} - v_{dc}^2$ droop curve

By using above $P_{dc} - v_{dc}^2$ droop control law reference voltage for inner loop control generated. Square of Difference reference voltage and output dc voltage generate some static error which when passed through the "PI controller" to generate reference current for battery. Finally difference of battery reference current and actual battery current passed through the "P controller" to improve system stability and increase the system damping and it generates the switching pulse for the bidirectional buck Boost converter according to the application.

Symbol	Value
VS	600 V
Vcb*	1000 V
Rs	1 mΩ
Ls	1.5 mH
Cs	8 mF
Rline1	10 mΩ
Rline2	7 mΩ
r1	0.8 V^2/W
r2	0.8 V^2/W
Kp (PI)	0.0007 A/V^2
KI (PI)	0.07 A/V^2 s
Kp (P)	8 V/A

Table 5.1 Parameters of STORAGES

5.2.1.2 Control of AC sub grid

(a) Droop Control of AC sub grid

AC bus connected to the common bus through the bidirectional ac to dc interlinking converter.

Dc side of ILC is connected to the DC bus and ac side to the ac sub grid. here controlling done on dq-reference frame by transforming all the ac parameters such as three phase ac voltage and current.

Due to dq transformation all the variable is in DC and it is easier to control DC quantities in steady state.

In this case conventional droop control adopted for the bidirectional Interlinking VSC converter. when there is load fluctuation controlling of MGs is done by co-ordination control and change in voltage and frequency of sub-grid of hybrid MG represents the change in power.

Here operating frequency not imposed by the ac system, but it is controlled by the VSC system itself [1]. In this control technique voltage and frequency at the point of common coupling (PCC) are controlled known as "controlled frequency VSC system ".

ac load is interfaced with the ac sub-grid through the RLC Filter. RLC filter composed of series RL Branch and shunt Capacitor Cf .

importance of cf

(I) we need cf to ensure that the RL branch is terminated to a node with some degree of voltage support [1].

(II) it prevents switching current harmonics generated by the Voltage sourced inverter from penetrating into the load by providing low impedance path.

Controlled frequency VSC controlled in dq-mode where three phase voltage (RLC filter capacitor voltage) and three phase currents are transformed in to dq -frame by abc to dq transformation, Vd &Vq generated are used to generate refence power P* and Q* by using following control law:

Real and reactive power at Point of common coupling;

$$P_S(t) = \frac{3}{2}[v_{Sd}(t)id(t) + Vsq(t)\, iq(t)] \quad (5.6)$$

$$Q_s(t) = \frac{3}{2}[-v_{Sd}(t)iq(t) + Vsq(t)\, id(t)] \quad (5.7)$$

After generation of reference active and reactive power system controlling starts.

Here conventional droop control technique is adopted and controlling done in two loop control

Reference for inner loop generated from outer loop droop control, P-f or Q-V droop control.

Control law for outer loop control:

$f^{ref} = (f^{*} + \delta f) + m\ (P^{*} - P)$ (5.8)

$v^{ref} = V^{*} + n\ (Q^{*} - Q)$ (5.9)

f^{ref} = reference output frequency

v^{ref} = reference output voltage

f*, V* are rated frequency and output voltage

m, n are droop coefficients

P*, Q* rated real and reactive power

P, Q actual active and reactive power

In this work Hybrid MG having two ac sub-grids and grid interlinking converters BADC ILC 1 and BADC ILC 2 are operated at 50 HZ and 60 HZ frequency respectively.

δf generated as a result of co-ordination control topology.

Then reference voltage v^{ref} and θ generated transformed in to the dq-frame. now controlling done in dq-frame here compensator used in current controlled mode as shown in below figure and the current reference generate md and mq and by decoupling we generate controlling pulses for the inverter.

Controlled frequency VSCs control block diagram

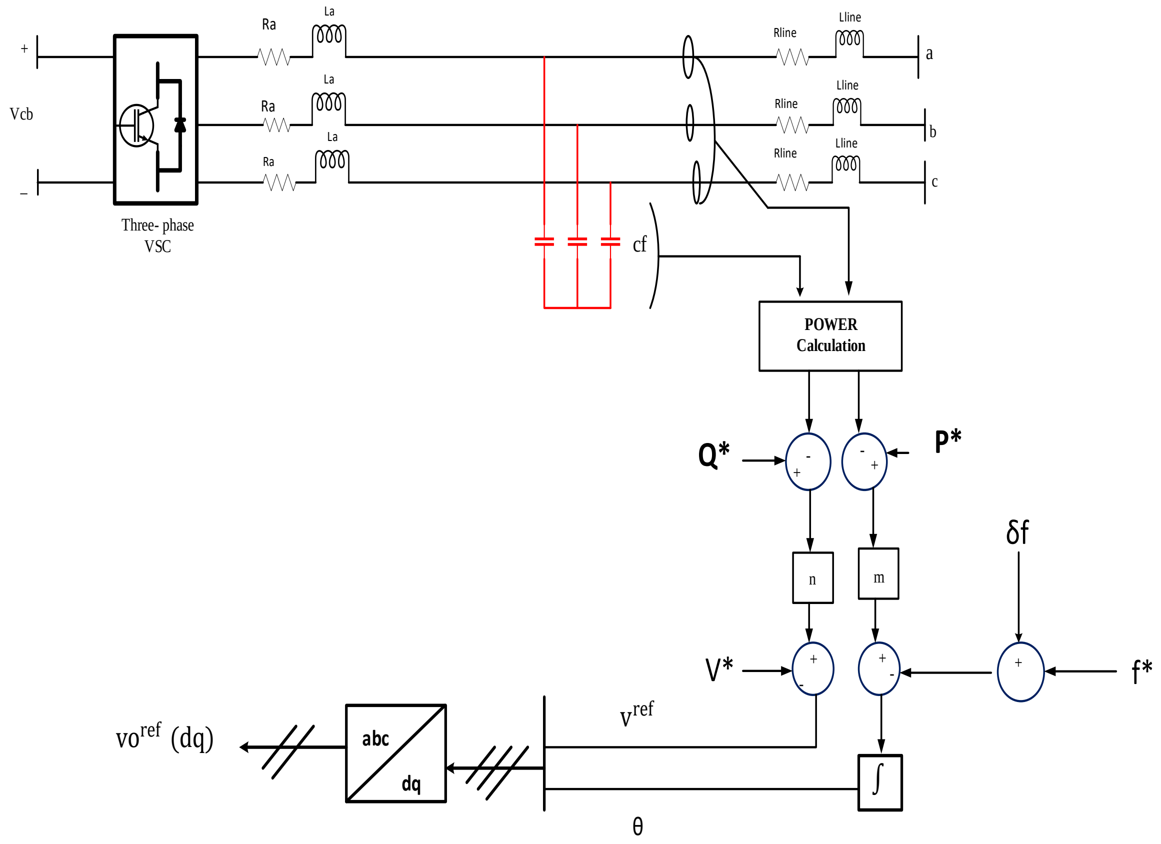


Fig 5.9 schematic diagram of control frequency VSC system

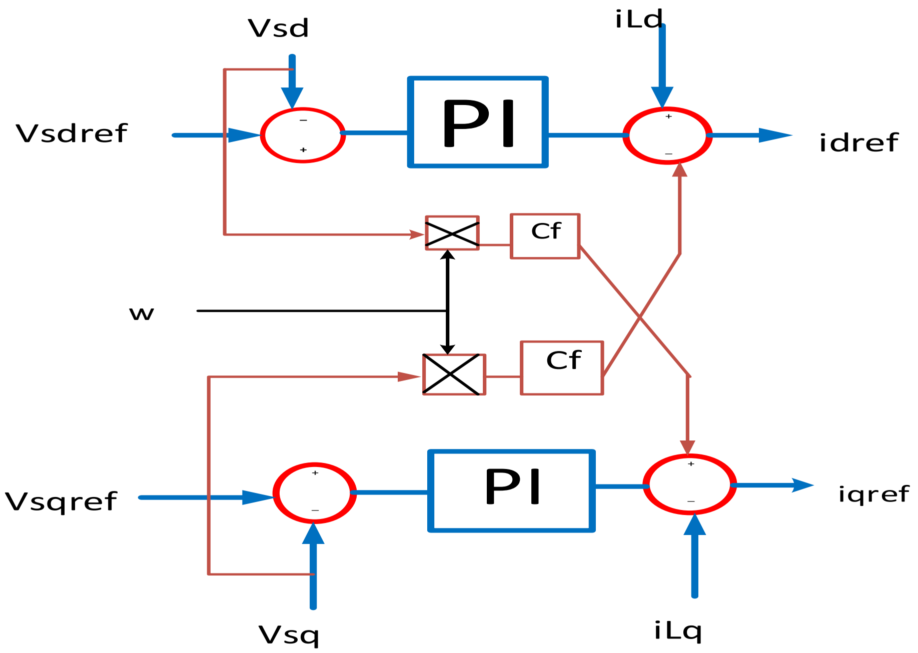


Fig 5.10 control diagram of reference current generator

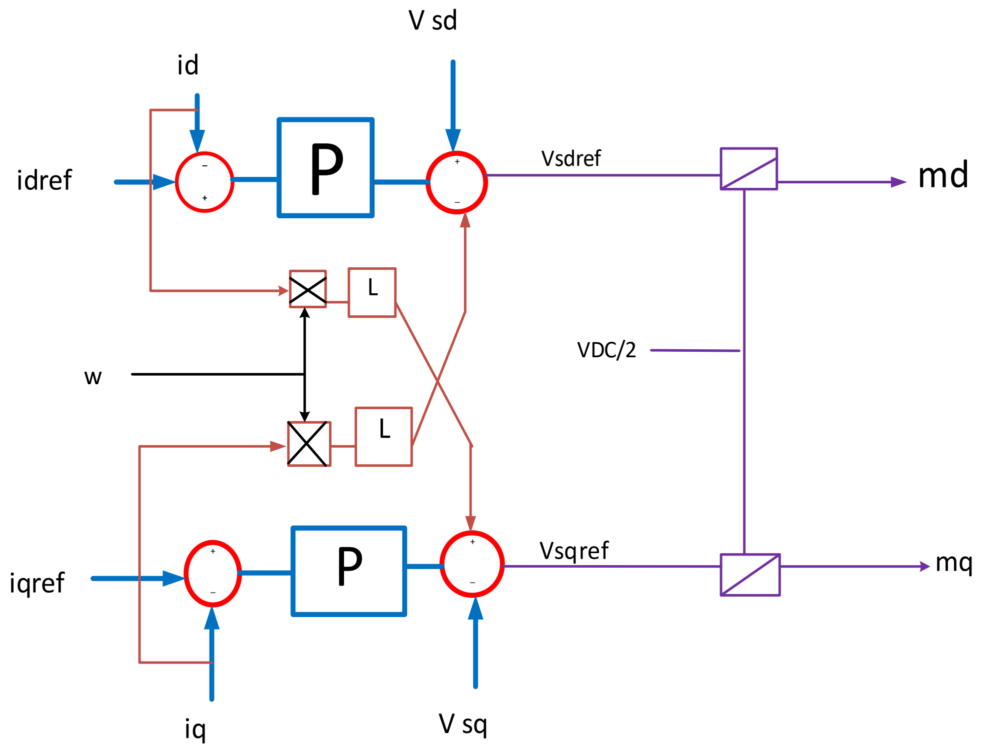


Fig 5.11 control diagram of current controlled VSC system

Symbol	Value BADC 1	Value BDDC 2
Vcb*	1000 v	1000 v
Vm	311 v	311 v
fk*	50 HZ	60 HZ
La	2.5 mH	2.5 mH
Ra	1 mΩ	1mΩ
Ca	2 mF	2 mF
Zline	0.8 mH+1mΩ	0.8mH+1mΩ
P*	20 kw	40 kw
Q*	10 Kvar	10 Kvar

Table 5.2 Parameters of BADC

Symbol	Value
m1,2	5 z/MW
n1,2	0.1 V/kVar
V1,2*	311 V
KP (PI)	0.8 A/V
Ki (PI)	100 A/Vs
Kp (P)	4 V/A

Table 5.3 Parameters of Droop-control of BADC

(b) Co-ordinated power control of AC sub-grid

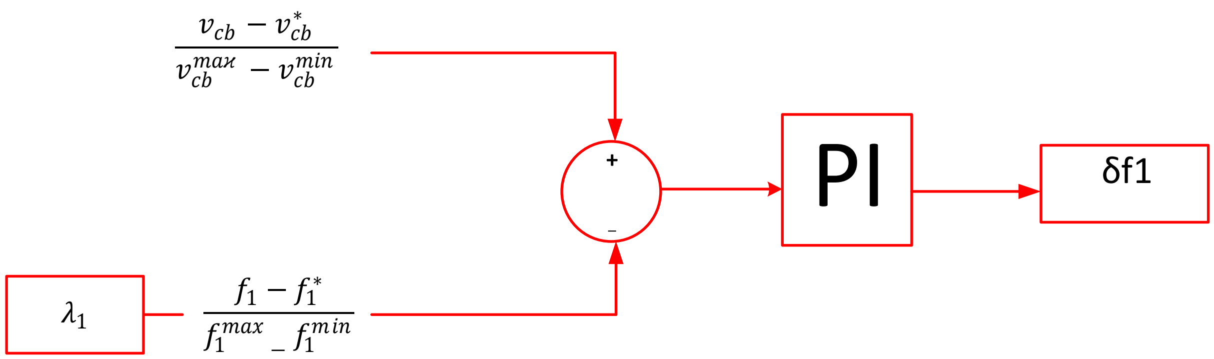


Fig 5.12 co-ordinated control of BADC 1

δf1 generated as a result of co-ordination control of "ac sub-grid 1" using co-ordination control law. δf1 sent to ac sub-grid 1 for generation of reference frequency for controlled frequency VSC system.

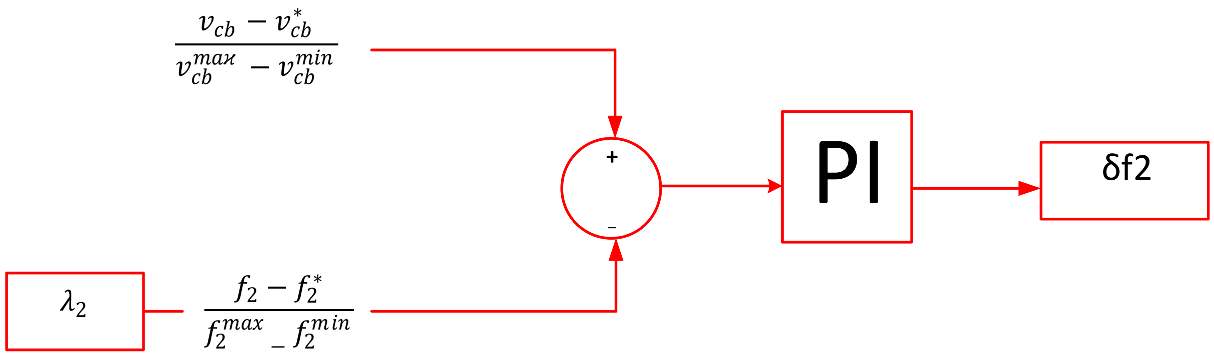


Fig 5.13 co-ordinated control of BADC 2

δf2 generated from co-ordinated control of ac subgrid-2 using co-ordinated control law sent to the sub-grid 2 for generation of reference frequency for Controlled-frequency VSC system.

Symbol	Value
$\lambda 1$	4
$\lambda 2$	0.75
Kp	0. Hz
Ki	3 Hz/s

Table 5.4 Parameters for co-ordinated control of BADC

5.2.1.3 Control method of bidirectional dc-dc converter of DC sub-grid

Dc sub-grid connected to common DC bus through Bidirectional dc-dc converter and LC filter. common bus voltage higher than the DC sub-grid voltage so this bidirectional dc-dc interlinking converter act as a buck converter. Controlling of DC sub-grid can be done by controlling the DC voltage.

Controlling of sub-grid can be done in two ways

(i) inner loop control

(ii) outer loop control

to control inner loop, we must generate reference voltage by implementing control law for outer loop.

Control law for output loop of BDDC:

$$v_{dc}^{ref} = (v_{dc}^{*} + \delta v) - r \cdot i_{dc} \tag{5.10}$$

v_{dc}^{*} = rated dc voltage

I dc = actual output DC current

r = droop coefficient

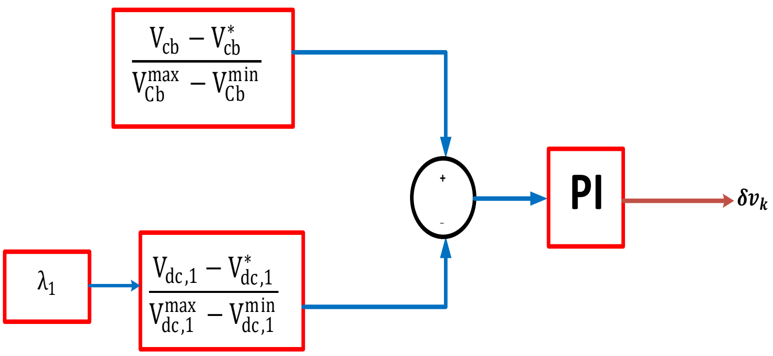
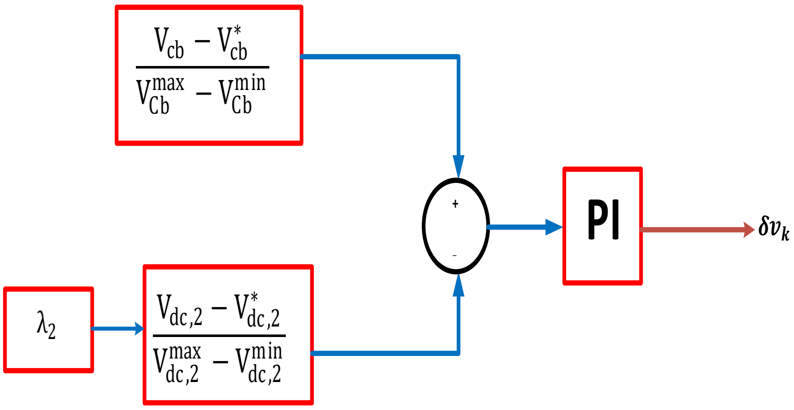


Fig 5.14 co-ordinated control of BDDC 1



5.15 co-ordinated control of BDDC 2

Symbol	Value
$\lambda 1$	1.41
$\lambda 2$	0.9
Kp	1.5 V
Ki	150 V/s

Table 5.5 Parameters for co-ordinated control of BDDC

δv is the result of co-ordination control of BDDC using co-ordination control law for BDDC Interlinking converter.

voltage difference of generated reference dc voltage and actual dc bus voltage passed through the PI controller to generate reference currents further difference between actual and The P controller passed reference current to create the pulse for the bi-directional ILC.

Symbol	Value
Vcb*	1000 V
Vdc3*	500 V
Vdc4*	800 V
Ld	2 mH
Rd	1 mΩ
Cd	8 mF
Rline	10mΩ
r3	0.7 V/A
r4	0.7 V/A
Kp(PI)	0.6 A/V
Ki(PI)	50 A/Vs
Kp (P)	3 V/A

Table 5.6 control parameter of BDDC

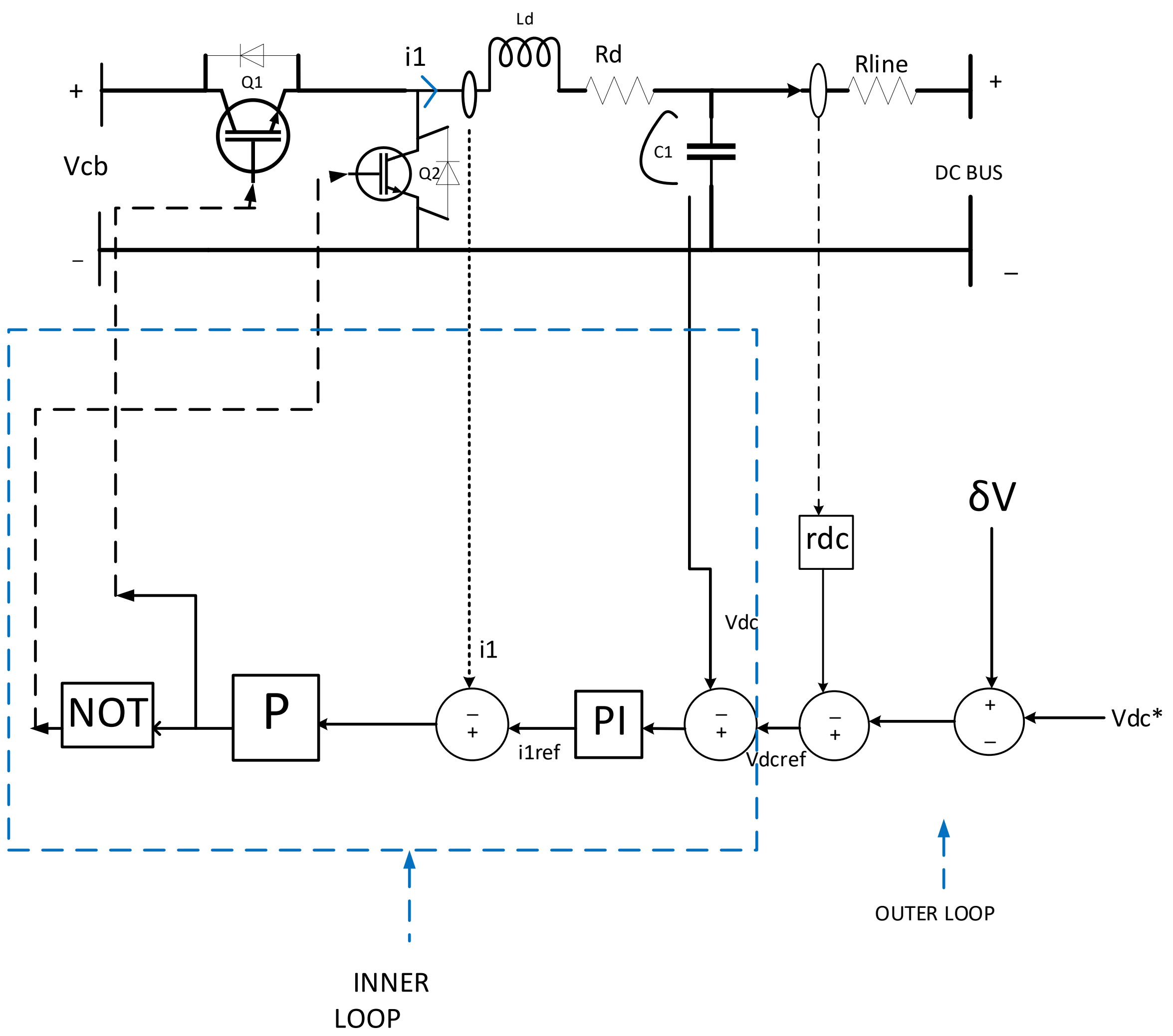


Fig 5.16 control of BDDC

CHAPTER 6

RESULTS AND DISCUSSION

The MATLAB / SIMULINK combined ac / dc microgrid system architecture has been developed and its findings shown. The grid supplied and off grid Decentralized operation is performed. The efficiency of the battery energy storage system, photovoltaic system, super capacitor are evaluated in conjunction with the hybrid microgrid. Analysis of performance is accomplished using simulated outcomes detected using MATLAB.

6.1 Hybrid grid simulation outcomes

Figures (6.1) – (6.14) represent the different traits of the hybrid microgrid. The primary converter functions in the PQ mode throughout this mode and the utility grid balances energy. The power grid maintains AC bus voltage and the primary converter supports DC bus voltage. The scheme consists of a single PV and two storage systems, batteries and Super capacitor. The super capacitor has a large power density relative to the battery, and often only works in the transient scenario.

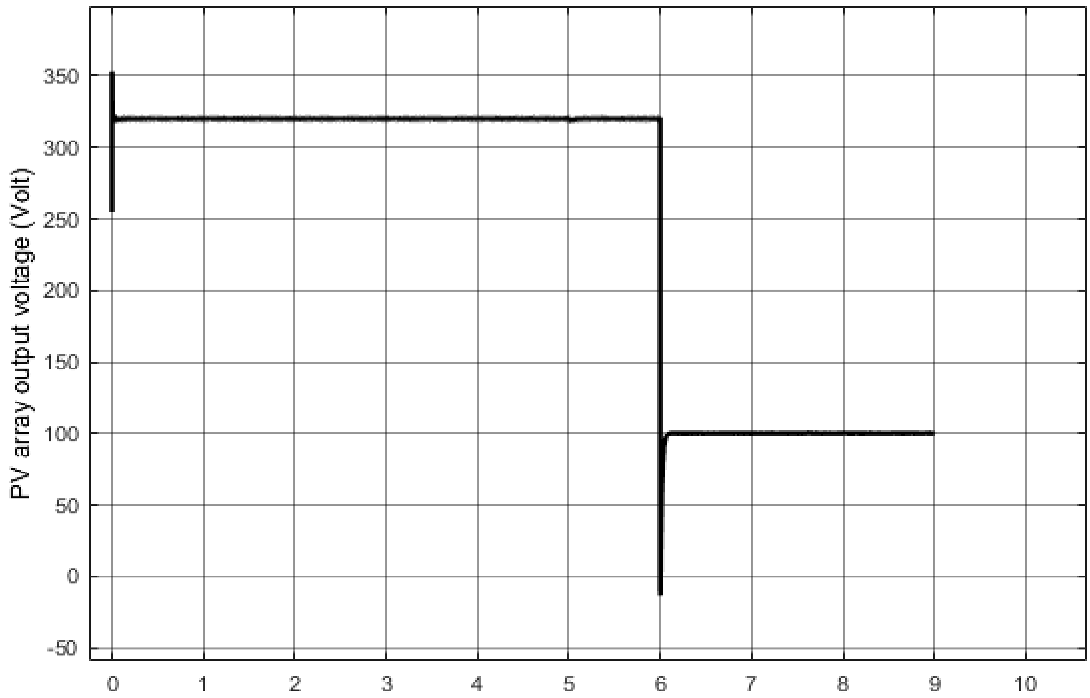


Fig 6.1 PV array output voltage

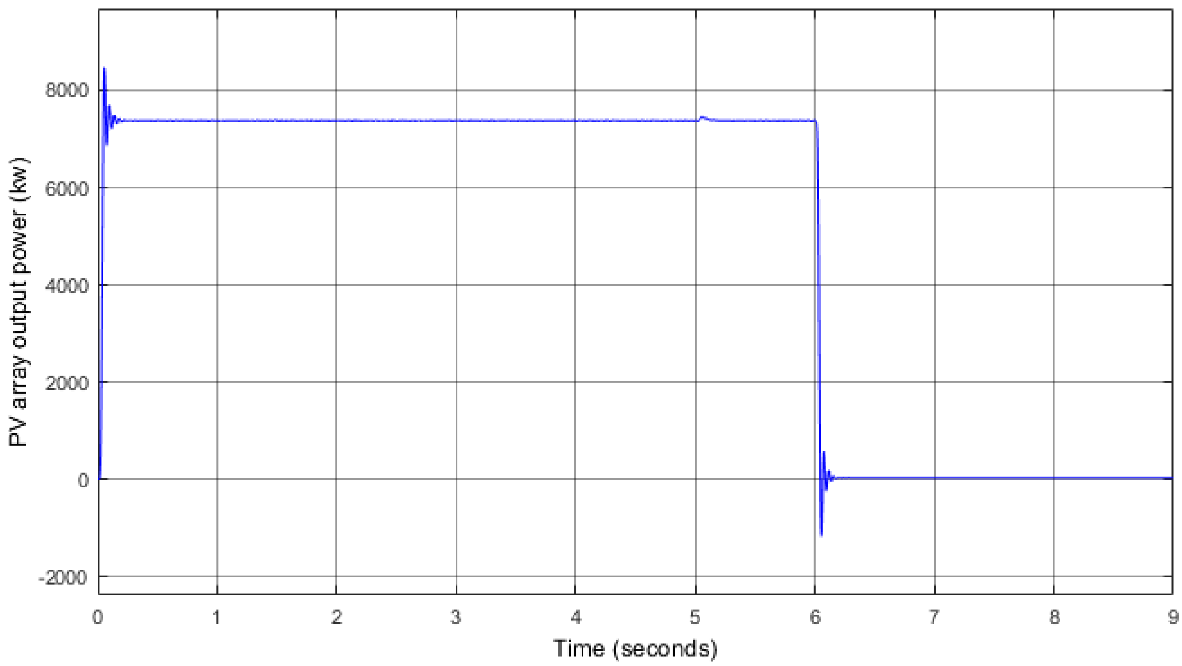


Fig 6.2 Output power of the PV grid

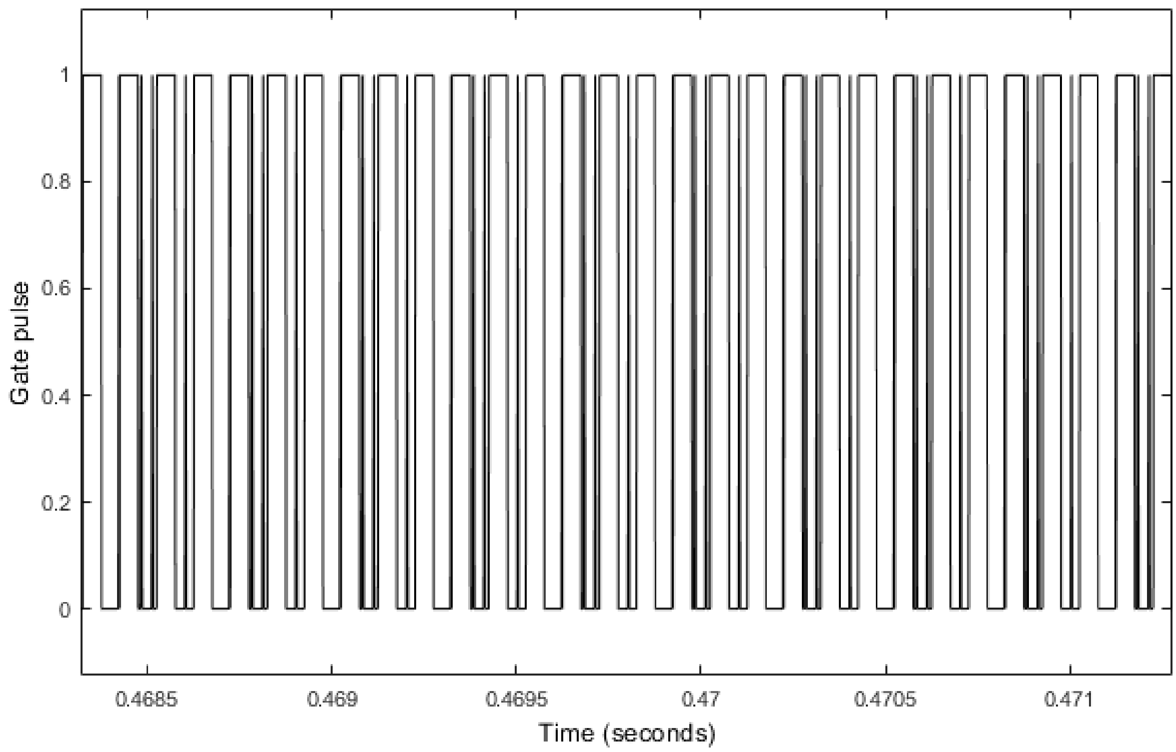


Fig 6.3 PV pulse

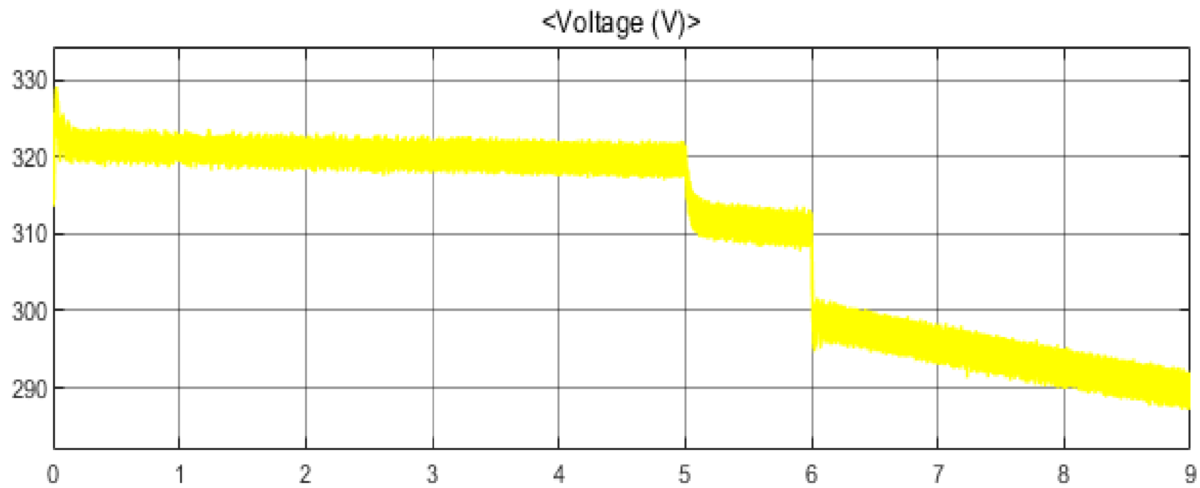


Fig 6.4 Battery voltage

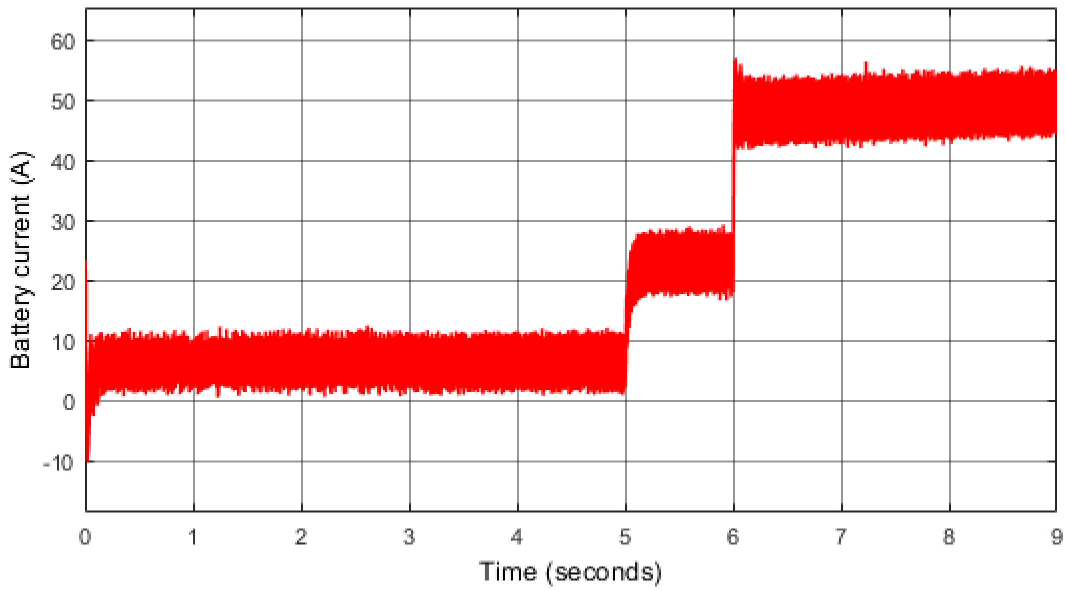


Fig 6.5 Battery current

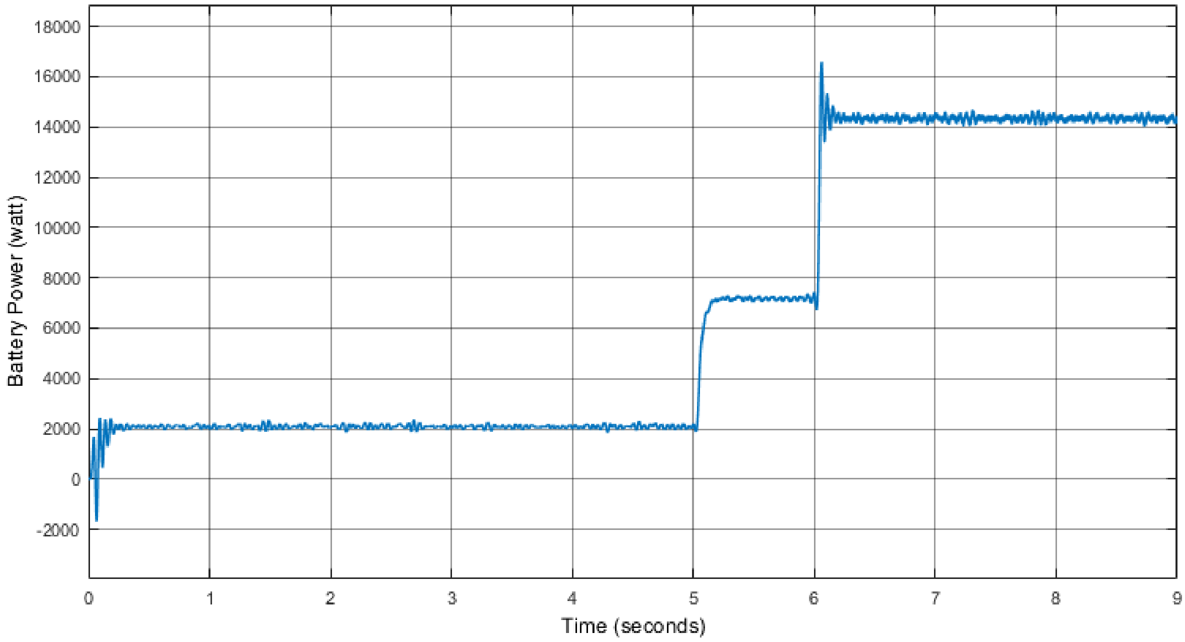


Fig 6.6 battery power

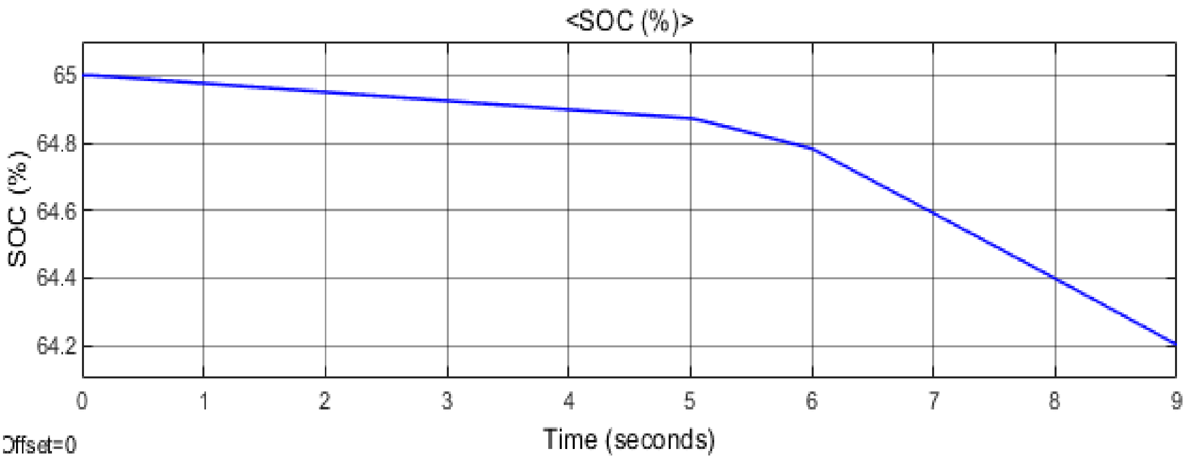


Fig 6.7 state of charge of battery

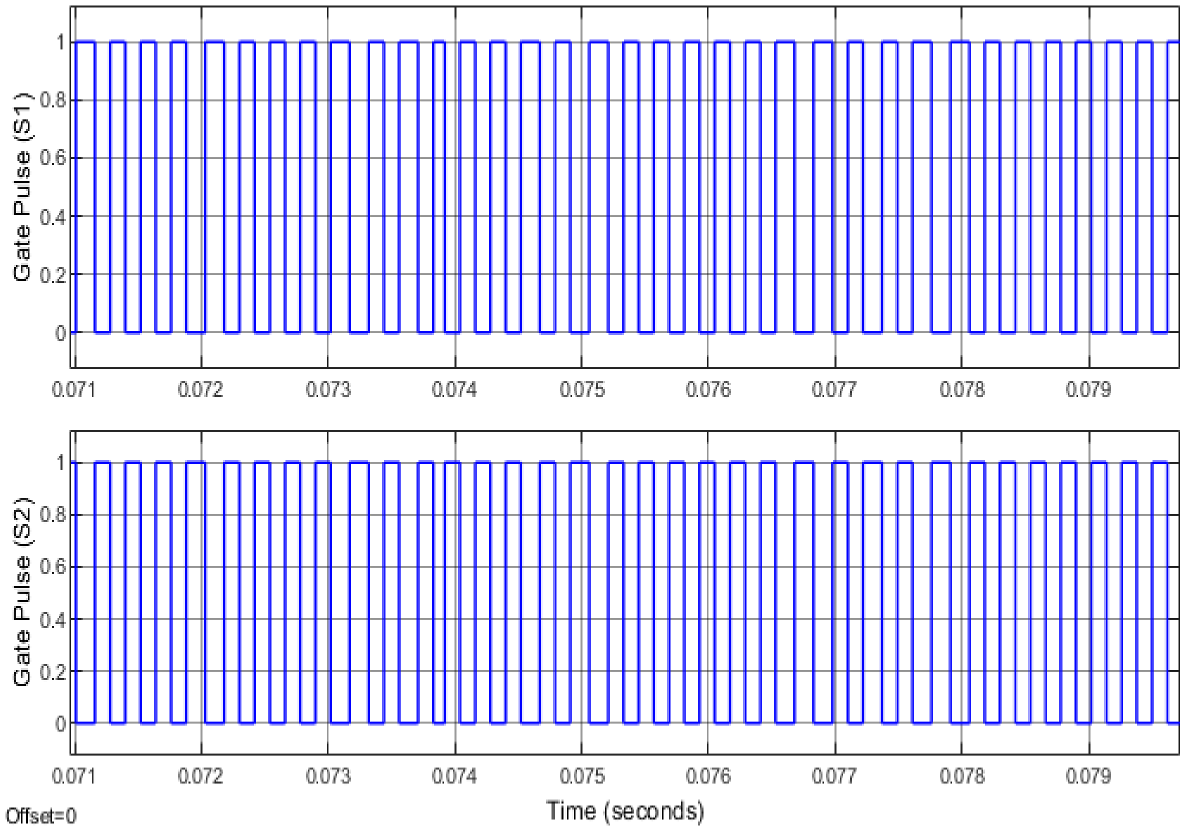


Fig 6.8 Gate pulse S1 and S2 for controlling battery energy storage system

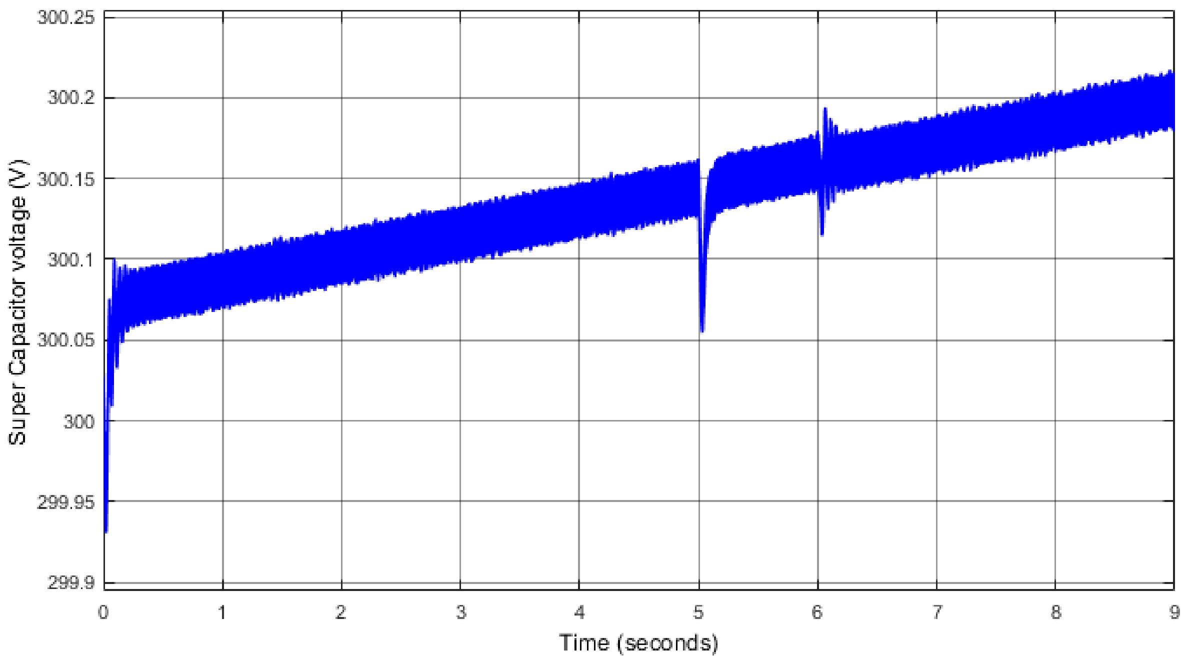


Fig 6.9 Super capacitor voltage

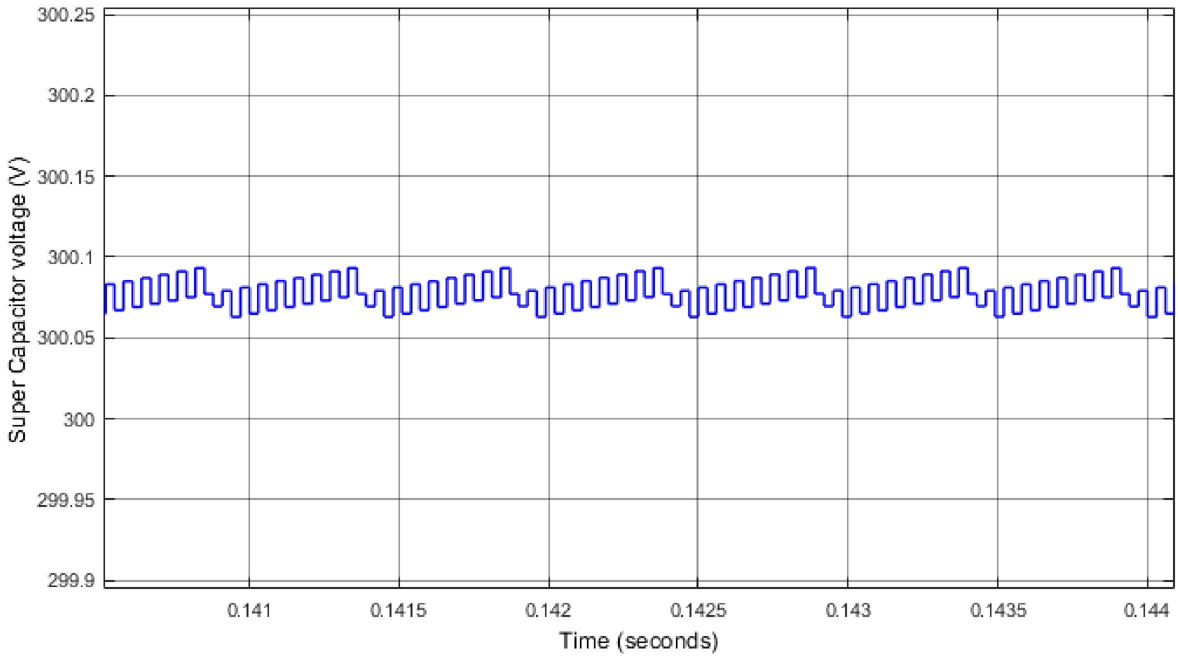


Fig 6.10 super capacitor voltage

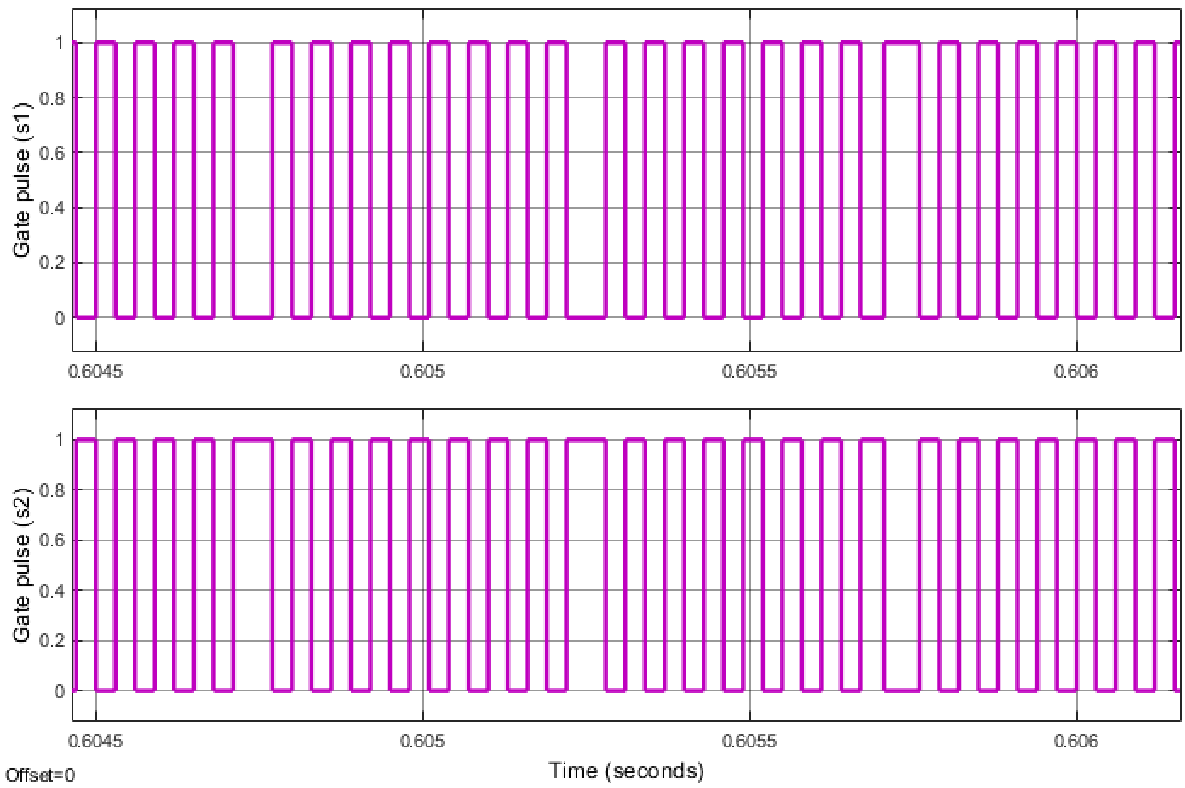


Fig 6.11 Gate pulse S1 and S2 for super capacitor control

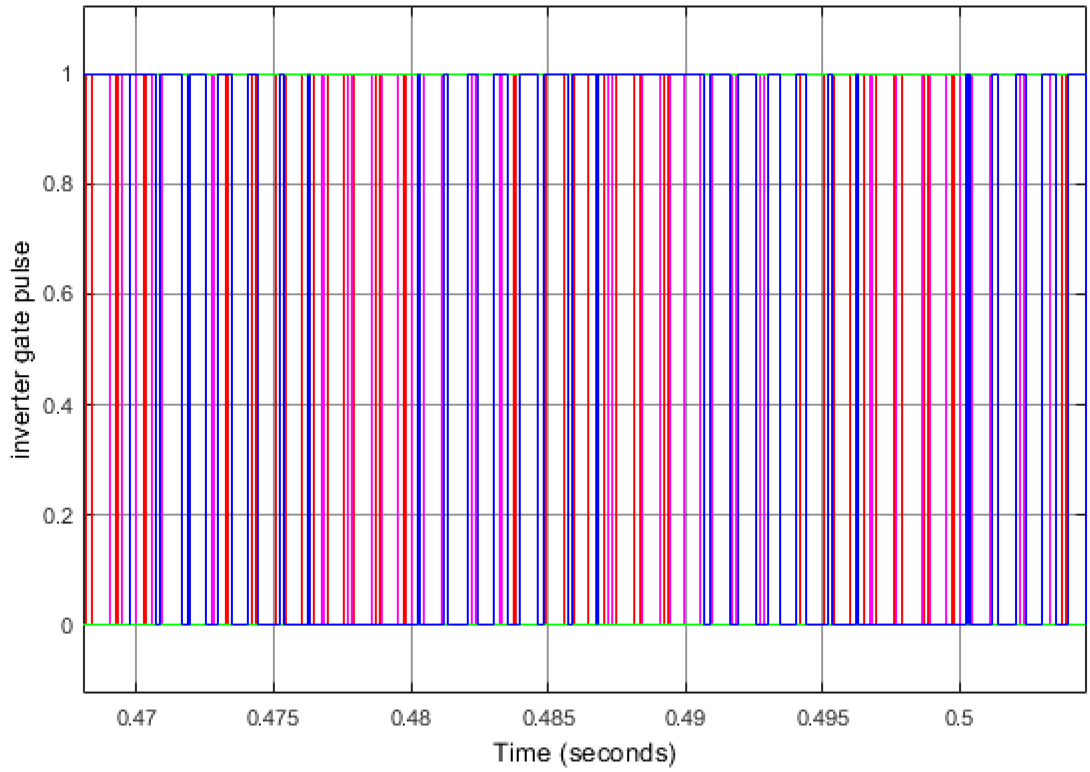


Fig 6.12 Gate pulse for controlling VSC

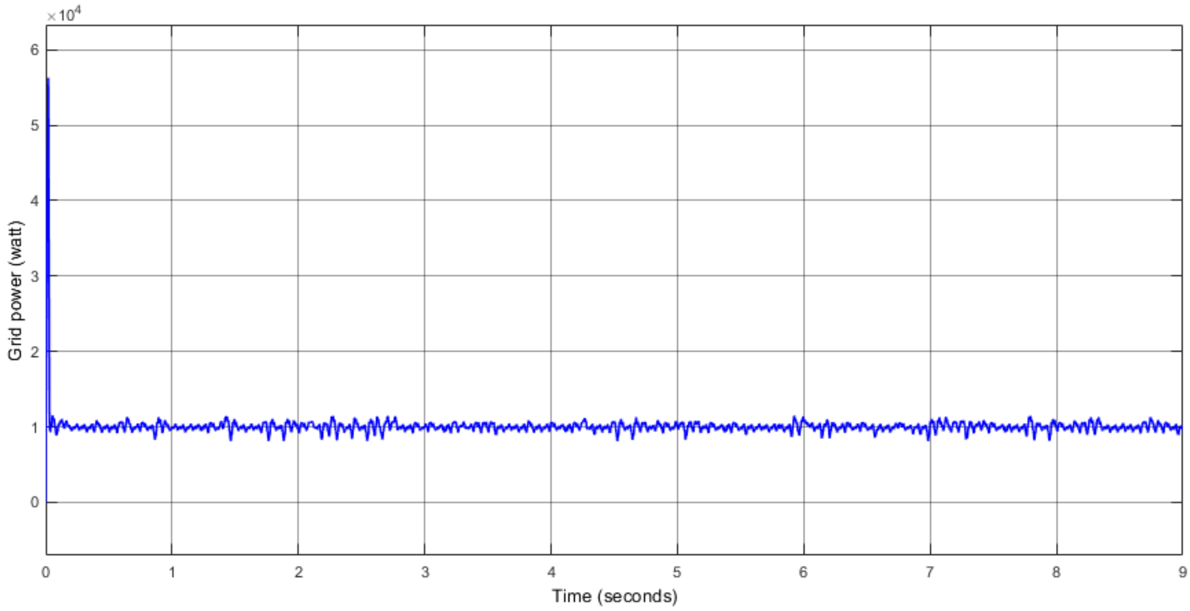


Fig 6.13 Grid power

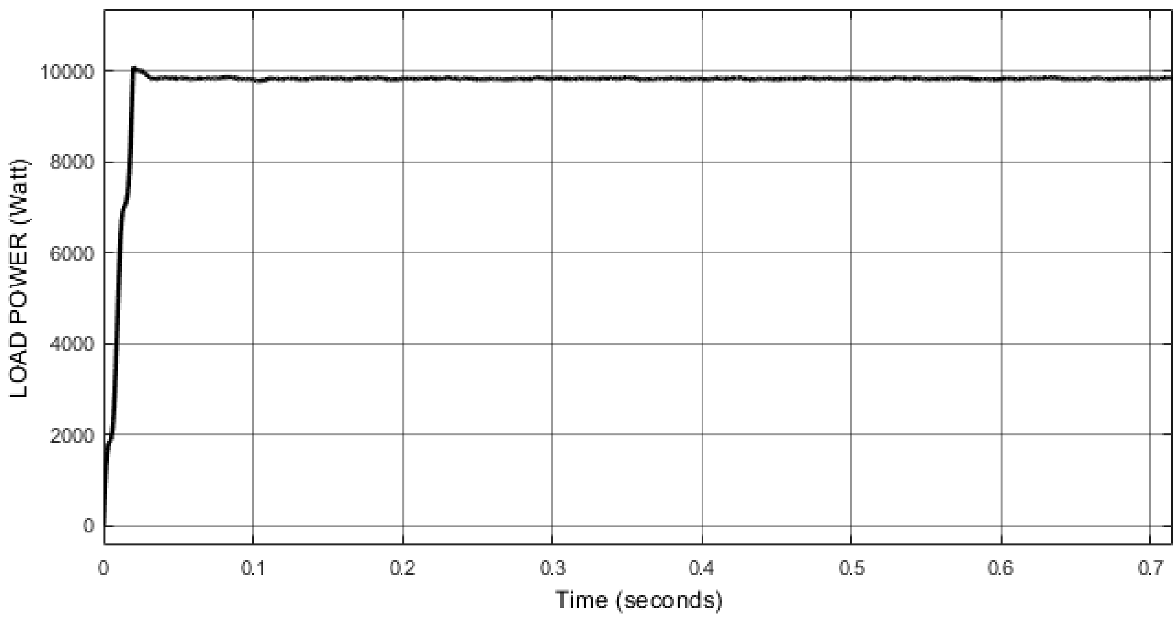


Fig 6.14 Load power

The steady DC bus voltage is shown in the complete simulation of Figure 6.15.

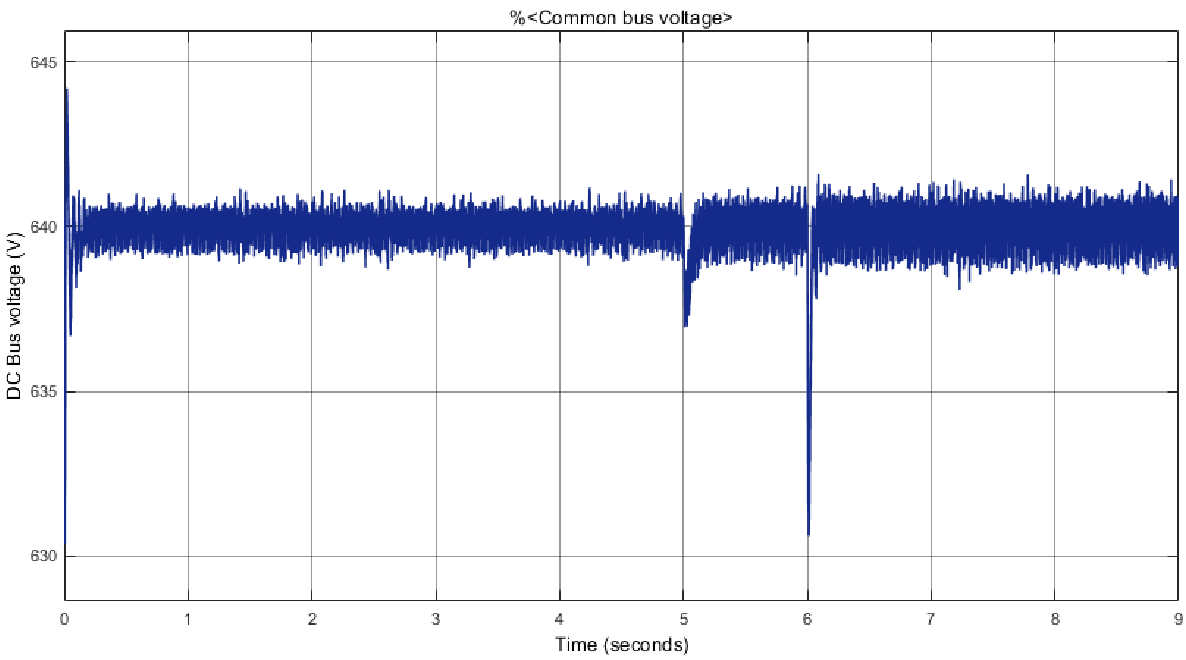


Fig 6.15 DC bus voltage for a grid-connected system

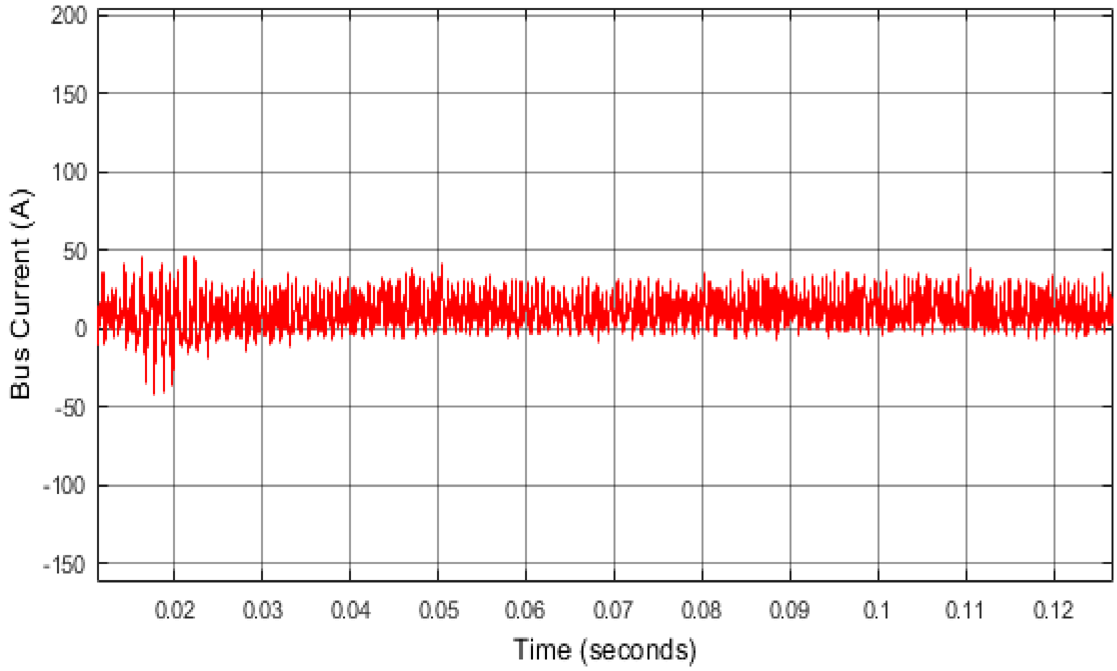


Fig 6.16   DC bus current

The sharing of energy between sources and energy storage (PV, Battery and Supercapacitor) and the change in parameters of source and load is portrayed in Fig 6.17.

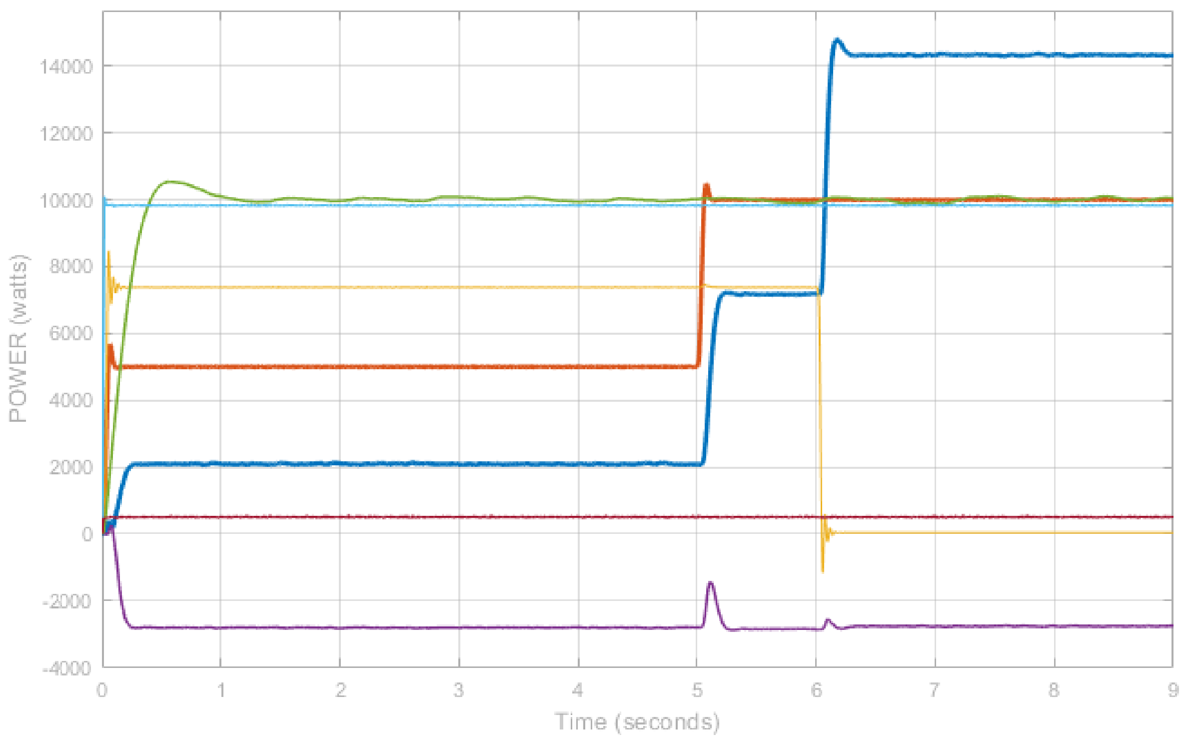


Fig 6.17 Sources and loads sharing power

Summery

In this chapter the results of the simulation are discussed briefly. The Hybrid Energy Storage System control keeps a continuous DC bus voltage and the needed power sharing between different sources and loads Microgrid AC / dc comprises of a power supply, a photovoltaic unit, a battery storage, supercapacitors and VSC power supply (Volt Source Converter). Waves are also being tracked

CHAPTER 7
CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

Hybrid microgrid modelling for setup of the energy scheme is carried out in the MATLAB / SIMULINK workplace. MG works either in grid-connected or off-grid form, an effective control and management system is implemented. The batteries and super-capacitor power the Hybrid MG.

The proposed scheme maintains a constant DC bus voltage with a consistent and efficient power distribution. The transients in the scheme are controlled by the supercapacitor because of a variation in load or source energy. This reduces the battery stress. Unlike the other associated literature, control tuning is avoided, leading in minimal disruption, Sharing authority between sub-grids, energy storage, and Appropriate DC bus voltage retrieval system.

Introduced a new combined AC / DC MG setup that worked autonomously, Bidirectional ac / dc and dc / dc ILC converters linked to the common bus with different sub-grids in this model. measured AC frequency and DC voltages are different for different applications. The proposed decentralized power management strategy allows various interconnected sub-grids to co-ordinate and support each other.

If we compare the proposed combined AC / DC sub-grid with conventional MG, in the proposed MG structure the rated frequency and DC voltage are different for different sub-grids, so the power flow between different sub-grids is complex and cannot be controlled, so we developed a coordinating control algorithm for bidirectional ILC based on common ac frequency and DC voltage to capture the energy interaction between them .

Moreover, the proposed approach takes into consideration each sub grid’s capacities and load types; therefore, when sub-grid capabilities are not matched and sub-grids with a big proportion of critical loads suggested MG design are very helpful.

7.2 Scope of future work

a. Intelligent MG Operation and Control to address the challenge of using complex / nonlinear microgrid models using ANNs, fuzzy logic.

b. A new Microgrid Protection Strategy based on Combined ANFIS and Hilbert Space Power Setting.

c. Robust control methods for H2, $H\infty$, and μ-synthesis are used to create the MG frequency control circuit

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