“ DC Micro Grid ”

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Electrical Engineering

(Electrical Power System)

By

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Undertaking for Originality of the Work

I **Ashish Pravinchandra Shah**,Roll No.**11MEEE15**,give undertaking that the Major Project entitled **"DC Micro Grid"** submitted by me,towards the partial fulfillment of the requirements for the degree of Master of Technology in **Electrical Power System,Electrical Engineering**,under Institute of Technology of Nirma University,Ahmedabad,is the original work carried out by me and i give assurance that no attempt of plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere,it will result in serve disciplinary action.

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CERTIFICATE

This is to certify that the Major Project Report entitled **"DC Micro Grid"** submitted by **Mr. Ashish P. Shah(11MEEE15)**,towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Electrical Power System** of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project,to the best of my knowledge,have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Today,world wide power consumption is increasing day by day due to modernization.Modernization brings automated technology which cause the more power demand.Though we live in developed or developing countries the power demand is not fulfilled.For solution of this situation world wide so many research is going on which helps to improve the efficiency of the devices.As the demand is not fully fulfilled,the idea came that why we are not going for the on site generation with the help of renewable sources.Now,as the AC power system references available we are aware that this type of system has less efficiency, means it has more losses.This losses may be reduced by on site power generation ,transmission or consumption.So,As DC has less losses why it should not be used at local level(or for village electrification).Now combining the benefit of the renewable energy and DC bus concept we can satisfactorily save the power by reducing losses and also help to reduce the pollution.This DC microgrid can be connected to the main grid if it is available or else it work in islanded mode for remote village electrification.DC microgrid simulation is carried out with the help of PSCAD software and parameters observed for the practical system.

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Abbreviations

PSCAD .... Power System Computer Aided Design
DC .... Direct Current
DOE .... Department of Energy
CEC .... California Energy Commission
DER .... Distributed Energy Resources
DG .... Distributed Generation
PV .... Photo Voltaic
MPPT .... Maximum Power Point Tracking
P&O .... Perturb and Observe
INC .... Incremental Conductance
IGBT .... Insulated Gate Bipolar Transistor
SOC .... State of Charge
Ebat .... Battery internal voltage

Nomenclature

I_d .... Diode Current
V_d .... Voltage across the Diode
I_{sh} .... Shunt branch Current
R_{sh} .... Shunt Resistor
R_{sr} .... Series Resistor
T_c .... Cell Temprature
Tc_R .... Reference Cell Temprature
G_R .... Reference Solar Radiation
I_{scR} .... Short Circuit Current
α_t .... Temperature Coefficient of Photo Current
I_{oR} .... Dark current at the reference Temperature
V_{pv} .... Voltage across PV Array
V_{pvref} .... Reference PV Array Voltage
I_{pv} .... Current Produced in PV Array
V_{mppt} .... Maximum Power Point Tracking Voltage
E_0 .... Battery Voltage Constant
P_0 .... Rated real power per phase
Q_0 .... Rated reactive power (plus inductive) per phase
V_o .... Rated load voltage (RMS, L-G)

Chapter 1

Introduction

1.1 History

In the end of the 19th century[1], the battle of the currents between Thomas Alva Edison and George Westinghouse took place . Edison worked with direct current (dc) systems, and Westinghouse with alternating current (ac) systems. Who won the fight everybody knows, but is ac still the right choice for the 21st century?

When the battle began, cities were illuminated by gas or arc light powered by dc dynamos.The arc light was produced between two carbon tips and gave a glaring light with an open came and noxious fumes, and the tips needed periodically to be renewed. The arc light was suitable for streets and in large indoor places like train stations and factories.

Edison saw a possibility to replace the arc lighting with incandescent lamps. The problem of finding a suitable filament was solved when Edison with some ideas from Joseph Swan made the carbonized cotton filament burn for more than 13 hours. Edison and his team developed dc dynamos with constant voltage output, meters, lamp sockets, switching equipment and fuses. The first incandescent lighting system with a central dc generating station was demonstrated at Holborn Viaduct in London, England, beginning in January 1882. The more known Pearl Street Station in New York began in September 1882. The success resulted in many installed systems in cities across the continent. Edison's lighting systems had some drawbacks. They were operated with low-voltage dc, 100 or 110 V, which resulted in small isolated systems to reduce the losses. A big system would have resulted in a large amount of copper.

In 1881 the first ac system was demonstrated in London by Lucien Gaulard and John Gibbs. Westinghouse took the ideas back with him to the U.S., and William Stanley improved the design. In 1886 the Westinghouse Electric Company had designed equipment for an ac lighting system. In 1887 Nikola Tesla filed for seven U.S. patents in the field of polyphase ac motors, power transmission, generators, transformers and lighting. Westinghouse purchased these patents, and employed Tesla to develop the ac system. In 1891 Westinghouse made history by setting up a 13 mile long transmission line. At that time an ac system was a proper choice. The loads were mainly incandescent lamps and machines, and the possibility to transform the voltage from one level to another made ac suitable for transmitting electric power over long distances. Also ac machines could be made more robust with less maintenance compared with dc machines.

1.2 Existing DC System

DC systems can today be found in special applications. It is of interest to investigate where dc systems can be found and how dc is used before presenting a future dc distribution system. Focus of this section are high power dc systems, and key issues like grid design, operating voltage level, voltage control, energy storage, grounding and protection.

1.2.1 Telecommunication

The telecommunication system [2]uses a low-voltage dc power system, and it was developed when the centralized battery system was built. The nominal voltage of the system is -48 V with the anode connected to ground. The dc system is supplied from the ac mains via voltage controlled rectifiers. The system uses transient limiting distribution, i.e. high impedance distribution, to limit the fault current in case of a short circuit, and to maintain the non-faulted equipment in operation. Battery back-up is installed to supply the system if a disturbance occurs on the ac mains. The size of the batteries are 3 to 8 hours of operation.It is also possible to have standby generation, e.g. a diesel engine, connected to the system, which can be started if the duration of the fault is long. In the beginning the telecommunication system was using copper wire to distribute the phone calls. Today almost all backbone communication is going through optical wires. The equipment inside the stations is computer based and consumes high power. Since the system is using low voltage the currents become very high, and studies have therefore been carried out to investigate usage of a higher voltage level to reduce the currents. A typical telecommunication power system is shown in below Figure.

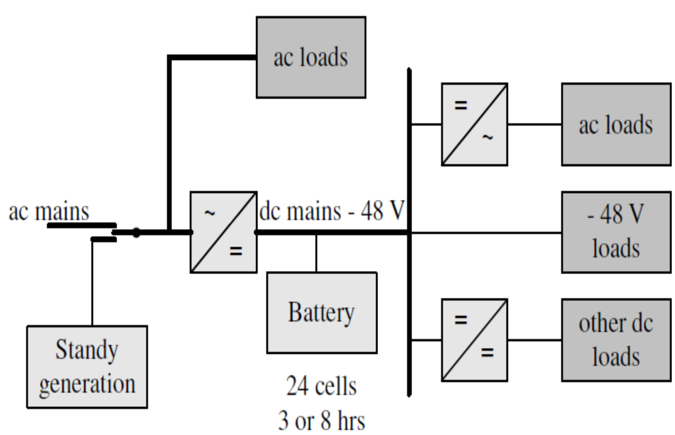

Figure 1.1: Layout of distribution system for telecommunication

1.2.2 Vehicles and Ships

High power dc systems are also used in vehicles and ships which have electric propulsion. The basic idea of hybrid electric vehicles (HEV)[3] is to run the internal combustion engine with small power variation to minimize to environmental effects. Instead the power variations can be taken from the electric system. When the car accelerates, power to the wheels is supplied by the electric machines, and when the car decelerates the electric power generated is stored in batteries. The electric power is also used to supply the loads in the car. The system must handle high power, and a high voltage dc system is required, where a 300 V system is suited for full hybrid vehicles.The power system of the HEV consists of starter/generator (engine), electric machine with associated converter, energy storage (battery) with associated chargers, converters to adjust high voltage to required load voltage.

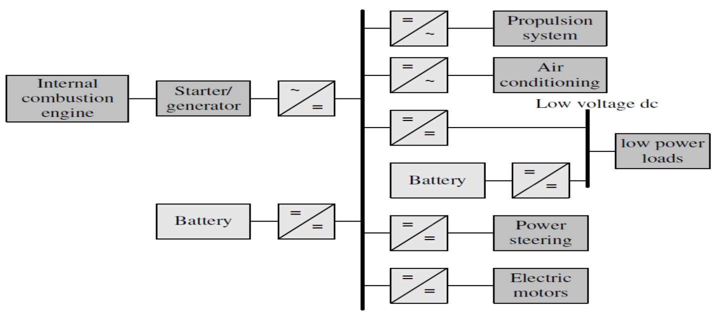

Figure 1.2: Layout of hybrid electrical vehicle power system.

Ships can also use an electric propulsion system. The electric power is generated by diesel engines, and used for supplying electric loads and the electric machines used for propulsion. The electric system uses both ac or dc depending on the application. Naval ships and submarines use also other types of power sources like stirling machines or nuclear power, which can be used underwater. Eliminating the mechanical link between the power plant and the propulsor will enable reduction of noise and vibrations, which is important to minimize the risk of detection.

1.2.3 Traction

DC has been used for a long time in traction systems[4], and the reason is because dc machines are very easy to speed control by simply changing the series resistance. The traction power system is supplied from the ac systems via six, 12 or 24-pulse rectifiers depending on the configuration. A higher number will reduce the current ripple. Standard voltages are 600 or 750 V for urban metros and 1.5 up to 3 kV for regional systems. The power is supplied to the train through a conductor rail laid on insulators on one side of the running rail, or through an overhead catenary. The return path is usually the grounded tracks. The dc power systems is protected by circuit breakers controlled by relays which will trip the breakers in case of over current, ground fault and short circuits. Today ac machines are more used than dc machines due to less maintenance, and this requires inverters which are very convenient to supply with dc. AC is more economical to use for high-speed trains, which consume high power.

1.2.4 HVDC

High Voltage DC[5] is a technique to transmit electric power using dc voltage instead of ac voltage. HVDC makes it possible to transmit power over a long distance or using underground cable. The absence of reactive power decreases the losses. Another advantage with HVDC is that two ac systems with different frequency can be connected. The rectifier/inverter stations are using thyristors or IGBT's depending on the installation.

The thyristor based rectifier/inverter operates as a Current Source Converter (CSC), which is a line-commutated converter. The CSC needs an ac voltage provided by the grid to operate. HVDC with CSC is used for high voltage, high power transmission. The dc-link voltage is determined by the transmitted power, and the polarity of the dc-link is changing with the direction of the power. Since the CSC is line-commutated there will be low-frequency harmonics present. These can be removed by using transformers, which will increase the pulse number from 6 up to 12 or 24, and tuned filters. A HVDC system with CSC has an operating dc-link voltage up to 1200 kV, and special dc circuit breakers must be used. The more expensive IGBT-based rectifier/inverter operates as a VSC, which is a self commutated converter with controllable voltage magnitude, frequency and phase. The VSC produces only current harmonics at multiples of the switching frequency and its side band, and they are easy to filter. The consumed active and reactive power of the converter can be controlled individually at both ends of the HVDC link. A HVDC system with VSC has an operating dc-link voltage ranging from 20 to 300 kV. The IGBT-based HVDC can be used for black start operation, which is not possible for the thyristor-based HVDC. A scheme of a HVDC system connected between two ac systems is shown in Figure.

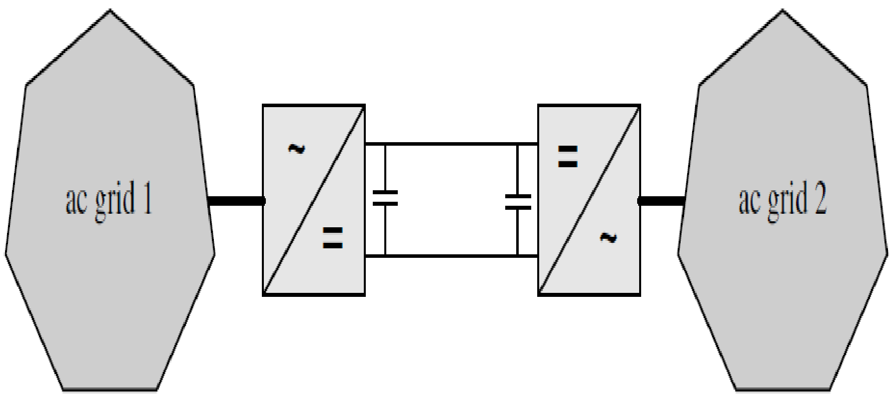

Figure 1.3: Layout of HVDC system.

1.2.5 Low-Voltage DC Distribution System

The type of loads used in a power system today are very different from the loads used 100 years ago, when resistive loads and machines were dominating. The fast development of semiconductors make the power electronic loads dominate today, which are using a different voltage than the supplying grid, both in amplitude and frequency. Converting the grid voltage to the required load voltage is a problem, and efforts have to be put on the design so it fulfills the EMC standards, and this costs both energy losses and money. Since most electronic loads are utilizing a dc link[6], is it then possible to overcome this problem by using dc instead of ac in distribution systems?

Today, reliability has become a hot issue. A power outage with a duration longer than a couple of hours has a great impact on our modern society, which is highly dependent on electric power. Most public services need computers and communication equipment to operate, but fail in case of a power outage. Some back-up systems are installed to feed the most critical loads but after a few hours they need maintenance to continue to operate. If the communication systems do not work it is difficult to arrange and perform the service. A distribution system which could be operated either connected to the large power grid utilizing all its advantages or in island in case of disturbances, would solve the above mentioned problem. In case of a disturbance of the supplying main grid, the distribution grid is disconnected from the main grid, and all sensitive loads are supplied with the local energy storage and the local generation. This type of network design creates .microgrids., which is a growing research issue about future power systems.

1.3 Motivation

Interest in direct-DC is motivated by a combination of factors: the very rapid increase in residential and commercial photovoltaic (PV) power systems worldwide, the rapid expansion in the current and expected future use of energy efficient products that utilize DC power internally, the demonstrated energy savings of direct-DC power use in commercial data centers, and the current emergence of direct-DC power standards and products designed for grid-connected residential and commercial products.

In the hypothetical future direct-DC building, power from DC power systems or storage devices would be sent directly to DC appliances, rather than first converting it to AC. That is, power distribution within the house is in DC form. While such systems do not yet exist at the whole building scale, we note that some products are emerging on the commercial market that begin to approach this goalnamely, the Armstrong Flexzone ceiling system operating with Nextek Power Systems components and products.

1.4 Literature Review

In this paper[8] Power grid of India is discussed in detailed from the independence.Paper also describes the government bodies which control the power project in india.At the middle, paper mention distributed generation and the benefits of the renewable energy resources.This topic also give some suggestion regarding the how we can electrify villages with help of renewable sources.The brief details of the policies regarding renewable is described at the later part.At the end author has concluded that India is on the right path for achieving the full energy independence with the help of policy correction for captive power plant.

This paper[10] presents the development of simulation tools required for solar with grid interconnection studies. The simulation tools were developed in the popular electromagnetic transient simulation program PSCAD/EMTDC and include a PV array model, maximum power point tracking controller model, and a grid connected inverter. An example of an interconnection study using the developed simulation tools is presented.

This paper[12] describes operational analysis results of the DC micro-grid using detailed model of distributed generation. Detailed model of wind power generation, photo-voltaic generation, fuel cells generation was implemented with the user-defined model of PSCAD/EMTDC software that is coded with C-language.Various simulation results confirm that the DC micro-grid can operate without any problem in both the grid-tied mode and the islanded mode. The operational analysis result confirms that the DC micro-grid make it feasible to provide power to the load stably. And it can be utilized to develop an actual system design and building.

The study[13] delivers information on DC-micro grid in an isolated island. The proposed method is composed of gearless wind power generation system, battery, and DC loads in DC distribution system. The battery can avoid DC over-voltages by absorbing the PMSG power during line-fault.high-reliable power can be supplied to DC distribution system during line-fault, and stable power supply from PMSG to the electrical power system after line-fault clearing can be achieved. The effectiveness of the proposed method is performed in a MATLAB/Simulink environment.

The study[14] delivers information on how the power is transmitted through dc distribution line and converted to required ac or dc voltages by converters placed near loads.The dc power line is composed of 3 wires: +170 V line, neutral line and -170 V line.a voltage balancer for dc distribution are proposed and studied. Computer simulation results demonstrated that dc micro-grid was able to supply both ac and dc power to loads simultaneously and stably by 3-wire dc distribution line and load side converters.

The paper[15] is on DC micro-gird architecture and its control have been proposed in this paper. A bidirectional PWM rectifier is used as a backup for DC micro-grid to balance the power when the management ability of the local micro-grid is limited. A power management algorithm is also proposed based on this configuration. The DC zonal micro-grid proposed here has the advantage of maximum utilization of local distributed resource and smooth transition among different modes. Simulation results are given to verify the effectiveness of the theory.

The study[16] along with consuming of fossil energy step by step,crisis of energy has been appeared. The solar energy, which is endless, is a kind of renewable energy. Radiation of sun coming to earth in a day is equal to the energy, which is released by trillion buckets of oil. The research of solar energy generation has stepped into a very active period. This paper analyses the physical characteristic of photovoltaic array firstly, then researches the mathematical model applying in engineering, and designs the total simulation model based on power electronic circuit at the end. In order to validate the correctness and validity, this paper makes a simulation as an example. The scheme can express the V-I characteristic of photovoltaic array very well.

This paper[17] show how to test complete solar systems, a PSCAD model solar was developed for both centralized and distributed MPPT systems, and the solar irradiation was randomly varied. This allowed for observation of the stability and quality of the output voltage for each system.

1.5 Software Used

1.5.1 PSCAD(Power System Computer Aided Design)

PSCAD (Power Systems CAD) is a powerful and flexible graphical user interface to the world-renowned, EMTDC solution engine. PSCAD enables the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment. Online plotting functions, controls and meters are also included, so that the user can alter system parameters during a simulation run, and view the results directly.

PSCAD comes complete with a library of pre-programmed and tested models, ranging from simple passive elements and control functions, to more complex models, such as electric machines, FACTS devices, transmission lines and cables. If a particular model does not exist, PSCAD provides the flexibility of building custom models, either by assembling them graphically using existing models, or by utilising an intuitively designed Design Editor.

The following models found in systems studied using PSCAD:

- Resistors, inductors, capacitors
- Mutually coupled windings, such as transformers
- Frequency dependent transmission lines and cables (including the most accurate time domain line model in the world)
- Current and voltage sources
- Switches and breakers
- Protection and relaying
- Diodes, thyristors and GTOs
- Analog and digital control functions
- AC and DC machines, exciters, governors, stabilizers and inertial models
- Meters and measuring functions

- Generic DC and AC controls
- HVDC, SVC, and other FACTS controllers
- Wind source, turbines and governors

PSCAD, and its simulation engine EMTDC, have enjoyed close to 30 years of development, inspired by ideas and suggestions by its ever strengthening, worldwide user base. This development philosophy has helped to establish PSCAD as one of the most powerful and intuitive CAD software packages available.

The following types of studies routinely conducted using PSCAD:

- Contingency studies of AC networks consisting of rotating machines, exciters, governors, turbines, transformers, transmission lines, cables, and loads
- Relay coordination
- Transformer saturation effects
- Insulation coordination of transformers, breakers and arrestors
- Impulse testing of transformers
- Sub-synchronous resonance (SSR) studies of networks with machines, transmission lines and HVDC systems
- Evaluation of filter design and harmonic analysis
- Control system design and coordination of FACTS and HVDC; including STATCOM, VSC, and cycloconverters
- Optimal design of controller parameters
- Investigation of new circuit and control concepts
- Lightning strikes, faults or breaker operations.

- Steep front and fast front studies.
- Investigate the pulsing effects of diesel engines and wind turbines on electric networks.

1.6 Objective of the thesis

The primary purpose of this project is to investigate the viability and energy-savings potential of using direct current (DC) generated by on-site renewable energy systems in its DC form, rather than converting it first to alternating current (AC) for distribution to the loads.

1.7 Outline Of the Thesis

Since this thesis is basically concerned on DC micro grid isolated operation having on site solar power generation and this generated power is stored in batteries to supply power to the load when solar power is not available.

In the 1^st chapter the history of DC system,Existing DC system,and the motivation behind the project is briefly mentioned.

The 2^{nd} chapter mention the calculations for pv array data, MPPT algorithm along with buck converter signal control based on Incremental conductance algorithm.The data calculation for MPPT is not required because it is decided with PVSYST software.Inverter is modelled according to the ieee paper and the battery model data is calculated considering the each battery having 160 cells.

The 3^{rd} chapter in thesis show the circuit configurations for solar power generation,mppt ,buck triggering,inverter and load.Each component every parameter value is mentioned so that the the designed configuration is understandable.

In the 4^{th} chapter Simulation result were given and discussed for each configuration. The 5^{th} chapter is to demonstrate the possible energy saving in residential or commercial building with help of renewable energy resources.

Chapter 2

DC Micro Grid

2.1 Micro Grid

Defining microgrid[7] is important for our discussion, but not necessarily simple. The DOE and the CEC jointly commissioned a report from Navigant Consulting in 2005 that wrestled with this definition. The final report identified two Points of Universal Agreement of what constitutes a microgrid, which remain valid today:

- A microgrid consists of interconnected distributed energy resources capable of providing sufficient and continuous energy to a significant portion of internal load demand.

- A microgrid possesses independent controls, and intentional islanding takes place with minimal service interruption (seamless transition from grid-parallel to islanded operation).

Note: These two definitions work easily in both the AC and DC domain.

2.1.1 Types of Micro Grid

AC: It can utilize the existing AC grid technologies , protections and standards

Problem:

- Synchronization, and reactive power demand

DC: Need to define Standards

Problem:

- Protection is difficult

2.1.2 Various Microgrid Configuration

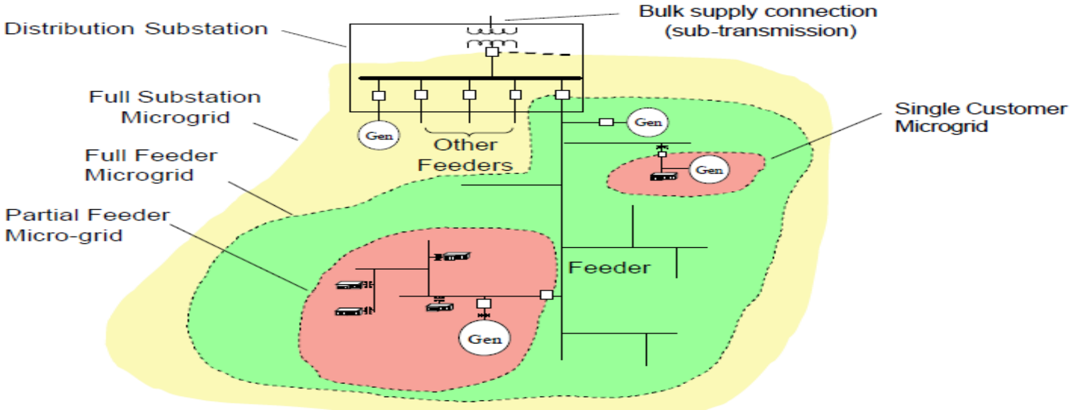

Figure 2.1: Micro Grid

Microgrids are **Local Energy Networks**

- **Consumer Microgrid:**single consumer with demand resources on consumer side of the point of delivery,(e.g. sports stadium).
- **Community Microgrid:** multiple consumers with demand resources on consumer side of the point of delivery, local objectives, consumer owned, (e.g., campus, etc.)

- **Utility Microgrid:**supply resources on utility side with consumer interactions, utility objectives.

2.1.3 Micro Grid Characteristics

A micro-grid may take on many forms:

- Peak Electrical Load: 1 kW up to 100 MW
- Thermal Load (if any): 0.5 MJ/hr up to 1000 MJ/hr
- Number of Customers Served: 1 to 50,000
- Type of customers: residential, commercial, or industrial
- Area served: from one house up to 10 square kilometers
- Part Time Microgrid - may be configured to switch between islanded and non-islanded operating modes based on the state of the bulk supply
- Full time Microgrid - always operates independently of the bulk supply
- AC or DC, Low voltage or high voltage architectures may be used
- Radial or networked designs with one or more generators
- Ability to integrate variable renewables

2.1.4 Micro Grid Technologies

Generation and Energy Storage:

- Renewable energy (PV, wind)

- Distributed generation (micro-turbines, fuel cells, diesel)
- Combined heat and power
- Energy storage (thermal storage, batteries)

T&D

- Communications (wireless, PLC, internet)
- Advanced metering infrastructure & smart meters
- T&D equipment health monitors (transformers)

Consumers

- Plug-in electric vehicles and charging stations (PEV)
- Smart appliances & programmable thermostats
- Home Area Networks & In-Home Displays
- Energy management systems

2.1.5 Micro Grid Problem

- Safety,
- Islanding Operation,
- Restoration from Scheduled and Unscheduled Shut Downs,
- Protection Coordination,
- Capacity and Reserve Management,
- Reliability and Power Quality Liability,
- Cost Development in the Needed Interconnection Technologies

2.2 DC Micro Grid

DC micro grid[7] is a new concept in existing power system and it is used for load distribution.Now if we add one more concept of distributed generation like solar then it is much more efficient then the only DC microgrid because here you are also avoiding the one AC-DC conversion stage.

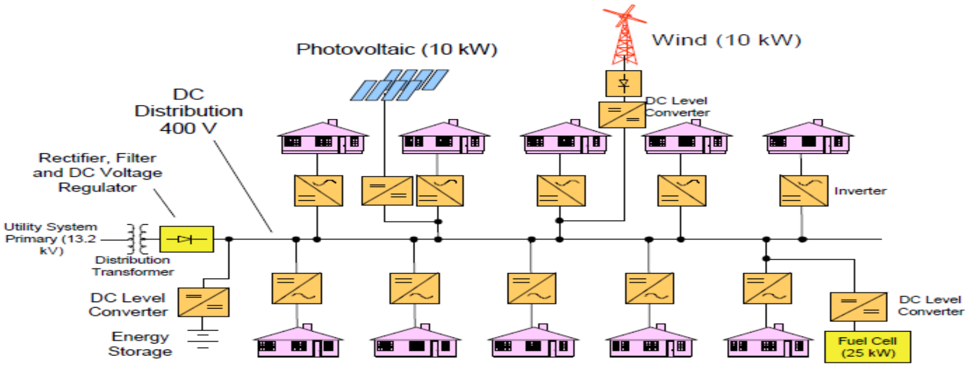

Figure 2.2: DC Micro Grid

2.2.1 Why DC Micro Grid

- Electronic devices (such as computers, florescent lights, variable speed drives, and many other household and business appliances and equipment) need direct current (DC) input.
- However, all of these DC devices require conversion of the buildings AC power into DC for use, and that conversion typically uses inefficient rectifiers.
- Moreover, distributed renewable generation (such as rooftop solar) produces DC power but must be converted to AC to tie into the buildings electric system, only later to be re-converted to DC for many end uses. These AC-DC conversions (or DC-AC-DC in the case of rooftop solar) result in substantial energy losses.

2.2.2 Benefits of DC Micro Grid

- Reduced Energy Costs
- Security Against Higher Utility Costs
- More Efficient Energy Use (10 to 40 %)
- More Reliable Service
- Safer Power at 24V
- Highly Scalable System Designs
- Flexible plug & play Components
- Reduced Future Renovation Costs

2.3 DC Grid Energy Source

The concept of distributed generation [8] is very helpful to generate electricity for remote area and also help to reduce the pollution.Some of distributed resources are mentioned below.

Sources:

- Diesel engines with very large storage tanks (five days are common)
- Reciprocating engines similar to diesels that burn natural gas from a pipeline
- Micro turbines on natural gas
- Wind turbines
- Solar arrays
- Geothermal

- Stream turbine from a small local stream
- Wave
- Tide
- Human or animal powered (really retrogressive)

2.3.1 Distributed Generation

"Small, modular, decentralized, grid-connected or off-grid energy systems located in or near the place where energy is used."

Goals:

- Environmentally friendly
- Efficient
- Affordable
- Reliable

Benefits of Distributed Generation:

- Easy and quicker installation on account of prefabricated standardized components
- Lowering of cost by avoiding long distance high voltage transmission
- Environment friendly where renewable sources are used
- Running cost more or less constant over the period of time with the use of renewable sources
- Possibility of user-operator participation due to lesser complexity
- More dependability with simple construction, and consequent easy operation and maintenance

2.4 PV array Technology

The photoelectric effect was first noted by French physicist Edmund Becquerel in 1839.He proposed that certain materials have property of producing small amounts of electric current when exposed to sunlight. In 1905, Albert Einstein explained the nature of light and the photoelectric effect which has become the basic principle for photovoltaic technology. In 1954 the first photovoltaic module was built by Bell Laboratories.

A photovoltaic system makes use of one or more solar panels to convert solar energy into electricity. It consists of various components which include the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

1. **Photovoltaic cell:**

   PV cell[9] are basically semiconductor diode. This semiconductor diode has got a p-n junction which is exposed to light. When illuminated by sunlight it generates electric power.PV cell are made up of various semiconductor materials. But mono-crystalline silicon and poly-crystalline silicon are mainly used for commercial use.

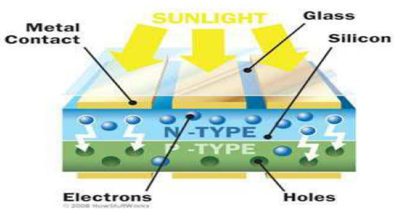

Figure 2.3: Photovoltaic cell

<u>Materials used in PV cell are mentioned next:</u>

- **Mono-crystalline Silicon:** Earlier mono-crystalline silicon has been extensively used in the making of PV cells but nowadays polycrystalline silicon has replaced it. Mono-crystalline Silicon was in use just because of its stability and desirable chemical and physical properties of silicon.

- **Polycrystalline Silicon:** This material has surpassed mono-crystalline silicon because it is cheaper. The cost of silicon comprises of a major portion of the total cost of a cell. The manufacturing cost of poly-crystalline silicon is less. This results in cheaper cells.

- **Micro-crystalline Silicon:** Micro-crystalline also known as nano-crystalline is a form of porous silicon. It is an allotropic form of silicon with para-crystalline structure. Nano-crystalline differs from poly-crystalline in a way that the former contains small grains of crystalline silicon within the amorphous phase whereas poly-crystalline consists solely of silicon crystalline grains. The factor that differentiates poly-crystalline and micro-crystalline silicon is the grain size. It has got several advantages over mono-crystalline and poly-crystalline. It has got increased stability and also it is easier to fabricate.

- **Cadmium Telluride (CdTe):** It is a crystalline compound formed from cadmium and tellurium. In the formation of p-n junction photovoltaic solar cell cadmium telluride is usually sandwiched with cadmium sulfide.

- **Copper Indium Selenide:** It is a compound semi conductor material. It is composed of copper, indium and selenium. The material is a solid solution of copper indium selenide. Unlike amorphous silicon, light-induced degradation does not take place in CIS solar cells.

2. **Photovoltaic module:**

   The power produced by a single PV cell[9] is not enough for general use. So by connecting many single PV cell in series (for high voltage requirement) and in parallel(for high current requirement) can get us the desired power. Generally a series connection is chosen this set of arrangement is known as a module. Generally commercial modules consist of 36 or 72 cells. The modules consist of transparent front side, encapsulated PV cell and back side. The front side material is usually made up of low-iron and tempered glass. The efficiency of a PV module is less than a PV cell. This is due to the fact that some radiation is reflected by the glass cover and frame shadowing etc.

3. **Photovoltaic Array:**

   A photovoltaic array[9](PV system) is a interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is seldom enough for commercial use, so modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current. In urban uses, generally the arrays are mounted on a rooftop. In agricultural use, the output of an array can directly feed a DC motor.

Chapter 3

PSCAD Modeling

DC Micro Grid model is build in PSCAD software and in this chapter the solar model is the micro grid source.

3.1 PSCAD Master Library Solar Component

The below figure shows the required component for solar model and they are provided in the pscad software master library.

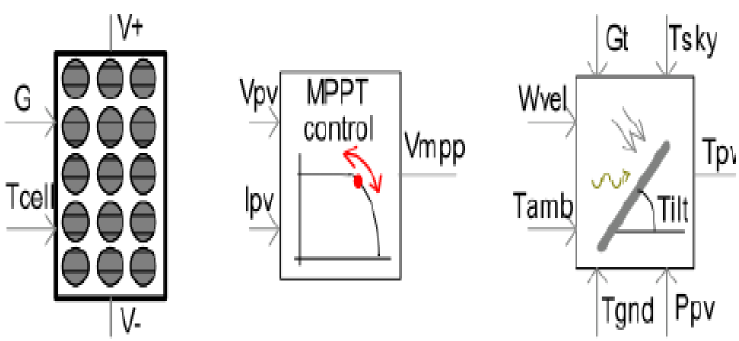

Figure 3.1: PSCAD Master Library Component

The first two from the left side are the PV array and the Maximum Power Point Tracker(MPPT).The third component on the right is a thermal model for calculating the PV temperature given solar radiation, wind velocity, ambient temperature, tilt angle of array, surface emissivity, etc.Since the thermal time constants are much larger than electrical time constants, in most EMT (Electromagnetic Transient) simulations use of constant cell temperature should be sufficient therefore, the thermal model is not used.

3.1.1 Mathematical Calculations

Solar Cell:

It can be modeled [10] using an electrical equivalent circuit that contains a current source anti-parallel with a diode, a shunt resistance and a series resistance shown in figure 2.1.

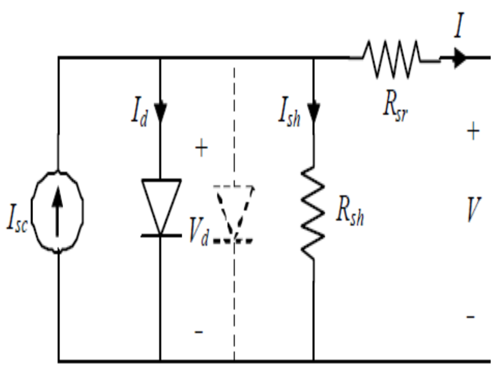

Figure 3.2: PV Cell Equivalent Circuit

- The DC current that is generated when the cell is exposed to light varies linearly with solar irradiance.Solar cells are characterized by their nonlinear I-V curve. Figure 2.2 shows a typical PV cells I-V characteristic.

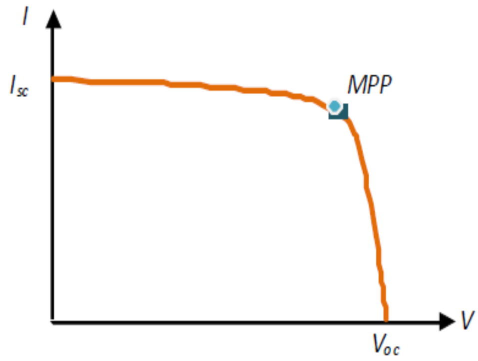

Figure 3.3: Typical I-V Characteristics of Solar Cell

- Apply Kirchoffs current law to the above equivalent circuit shown in figure 2.1

$$I = Isc - Id - Ish \tag{3.1}$$

- After substitution of the equivalent diode current expression for Id and the shunt branch current Ish, equation (2-1) becomes the following equation:

$$I = Isc - Io[exp(\frac{V + I.Rsr}{nkTe/q}) - 1] - (\frac{V + I.Rsr}{Rsh}) \tag{3.2}$$

- Isc is the photo current and it is a function of the solar radiation on the plane of the solar cell G and the cell temperature Tc. The photo current equation is as follows.

$$Isc = Iscr.G/G_R.[1 + \alpha_T(Tc - Tc_R)] \tag{3.3}$$

- Isc_R is the short circuit current at the reference solar radiation G_R and the reference cell temperature Tc_R. The parameter $_T$ is the temperature coefficient of photo current. The current Io in equation 2.2 is called the dark current. It is a function of cell temperature only, and is given by,

$$Io = Io_R(\frac{Tc^3}{Tc_R^3})exp[(\frac{1}{Tc_R}) - (\frac{1}{Tc})(\frac{qe_g}{nk})] \tag{3.4}$$

- Io_R is the dark current at the reference temperature. The other parameters appearing in 2.2,2.3 and in 2.4 are the electron charge q, the Boltzman constant k, the band-gap energy of the solar cell material eg, and the diode ideality factor n.

Note: Constants value taken from ieee papers

3.2 Solar Power Generation Configuration

3.2.1 PV Array

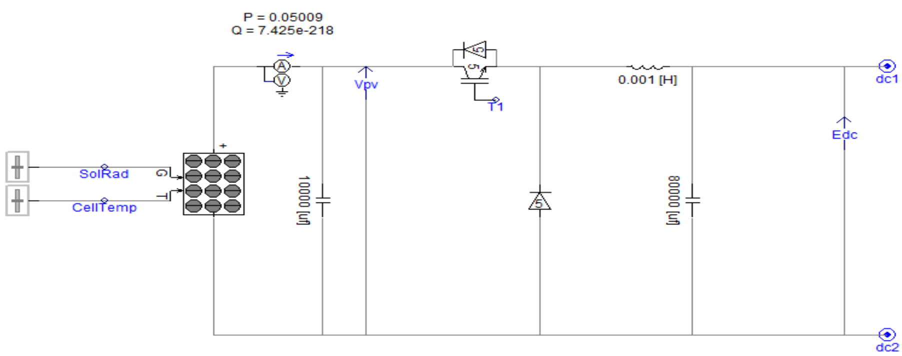

Figure 3.4: solar power generation circuit

PV Array component is taken from the master library and it requires both PV array and PV cell data to produce a planned solar power.The power generation [10] configuration is suggested by Athula D. Rajapakse.

Table I: **PV Cell Data**

Effective area per cell	0.01
Series resistance per cell	0.02ohm
Shunt resistance per cell	1000ohm
Diode ideality Factor	1.5
Band gap energy	1.103eV
Saturation current at reference condition per cell	1e-9A
Short circuit current at reference condition per cell	2.5A
Temperature coefficient of photo current	0.001

Table II: **PV Array Data**

PV array name	PVarray1
Number of modules connected in series per array	20
Number of module strings connected in parallel per array	5
Number of modules connected in series per array	108
Number of cell strings connected in parallel per array	4
Reference Irradiation	1000
Reference Cell Temperature	25

3.3 The MPPT Model

A Maximum Power Point Tracker (MPPT) [10] is a DC-DC converter that is placed between a PV array and its load to ensure that the PV array operates at its optimum point despite varying temperature, insolation, and load. The DC-DC converter is also necessary to regulate and step-down the high voltage of the PV array.

There are a number of different MPPT algorithms. A popular implementation is the Perturb and Observe algorithm, but it has limitations. The algorithm used is based on the Incremental Conductance method. The advantage that this algorithm has over the P & O method is that it can stop and determine when the maximum power point is reached without having to oscillate around this value. It can also perform MPPT under rapidly varying irradiation conditions with higher accuracy than the P & O method.

However, a disadvantage of the INC method is that it can produce oscillations and can perform erratically under rapidly changing atmospheric conditions. Also, the computation time is longer than that of the P & O method due to the slowing down of the sampling frequency resulting from the higher complexity of the algorithm.

Table III: **MPPT Parameters**

PV array Short Circuit Current	5A
PV array Output Voltage	3548 V
Sampling Interval	0.1[s]
Tracking Algorithm	Name for Incremental Conductance

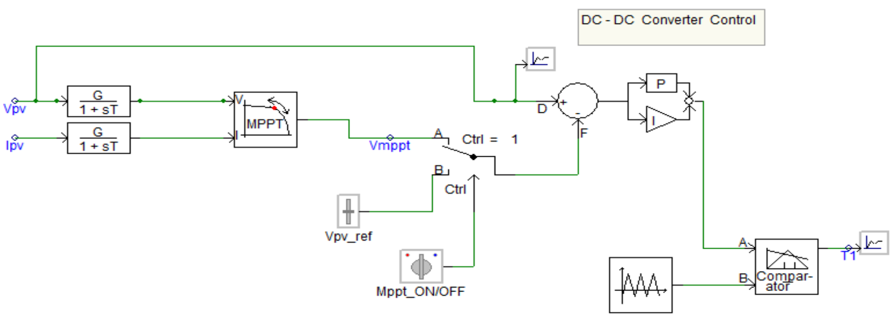

Figure 3.5: Triggering Pulse T1 based on INC Algorithm

3.4 Inverter

Inverters [10] form an essential part of any photovoltaic system,converting the DC power output from the photovoltaic panel or array into AC power for grid distribution or local use. The general tasks that such an inverter must accomplish are they must convert, as efficiently as possible, DC power to AC power, and they must accomplish this in a way that does not expose the photovoltaic panel or array to damaging amounts of feedback from the grid connection.

A wide variety of inverter designs exist, but normally contain many common components. Usually in a full H bridge setup the transistor elements utilized in the inverter design topology can be IGBTs, MOSFETs, or JFETs.They are switched at high-frequencies.This conversion is done after the MPPT converter, taking the output power from that portion of the system and converting to usable AC power.

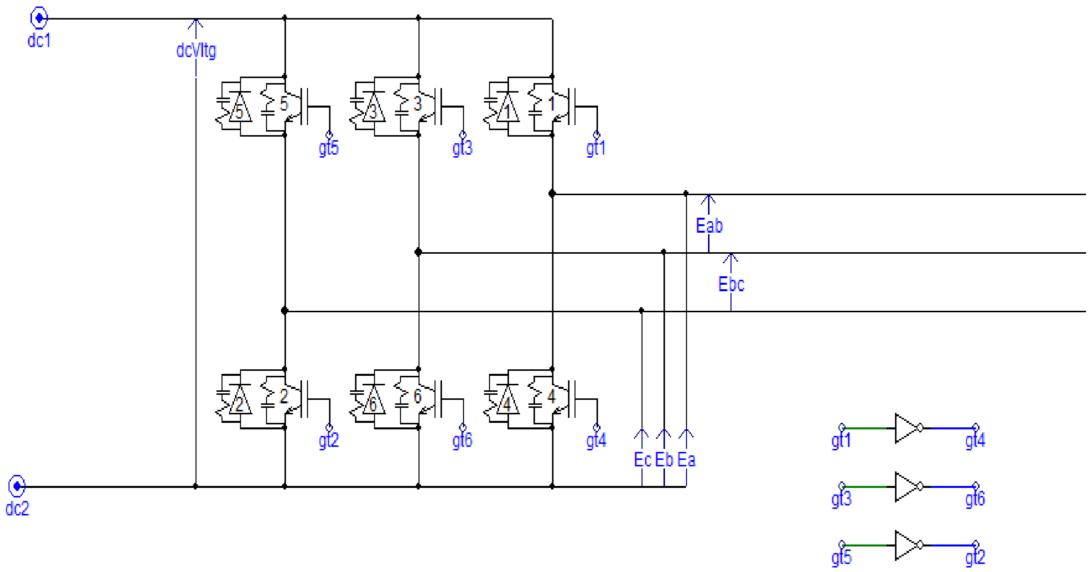

Figure 3.6: Inverter

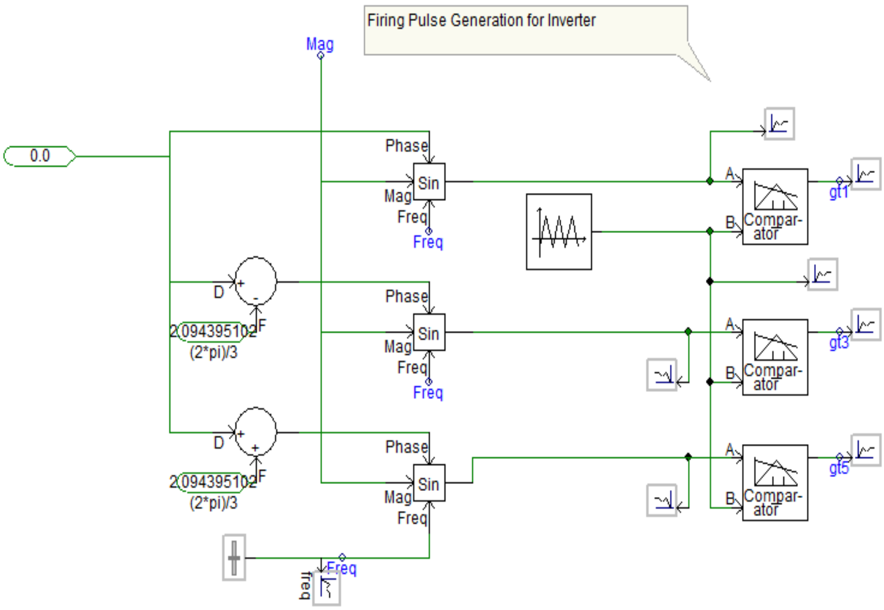

Figure 3.7: Inverter Gate Triggering

3.5 Fixed Load

To model the load [10] of the building, a three-phase fixed load was used.The fixed load component models the load characteristics as a function of voltage magnitude and frequency using the following characteristic equations:

$$P = Po * (\frac{V}{Vo})^{NP} * (1 + K_{PF} * dF) \tag{3.5}$$

$$Q = Qo * (\frac{V}{Vo})^{NQ} * (1 + K_{QF} * dF) \tag{3.6}$$

Where:

- P = Equivalent load real power
- Po = Rated real power per phase

- V = Load voltage
- V_0 = Rated load voltage (RMS, $L - G$)
- NP = dP/dV Voltage index for real power
- K_{PF} = dP/dF Frequency index for real power
- Q = Equivalent load reactive power
- Qo = Rated reactive power (+inductive) per phase
- N_Q = dQ/dV Voltage index for reactive power
- K_{QF} = dQ/dF Frequency index for reactive power

NOTE: dQ, dP, dV, and dF are all in per-unit quantities

- In order to model a constant power load, set $NP = NQ = KPF = KQF = 0$. This will simplify the original characteristic equations to:

$$P = Po \tag{3.7}$$

$$Q = Qo \tag{3.8}$$

- In order to model a constant impedance load, set $NP = NQ = 2$ and $KPF = KQF = 0$. This will simplify the original characteristic equations to:

$$P = Po * (\frac{V}{Vo})^{NP} \tag{3.9}$$

$$Q = Qo * (\frac{V}{Vo})^{NQ} \tag{3.10}$$

3.6 Battery Model

An electrochemical battery model [11] was used to model distributed energy storage System in PSCAD. The battery model was provided by PSCADs Technical Support Team and will be incorporated into PSCADs Master Library in the future.There are four main cell chemistries in use for rechargeable batteries: lead-acid, nickel-cadmium (Ni-Cd), nickel metal hydride (Ni-MH), and lithiumion (Li-ion).

The charge characteristic has a similar profile to that of the discharge characteristic. Hence for this system model, the charge and discharge characteristic can be described by the same equation if the battery hysteresis effect is neglected. Figure shows the charge and discharge characteristic of a typical battery cell.

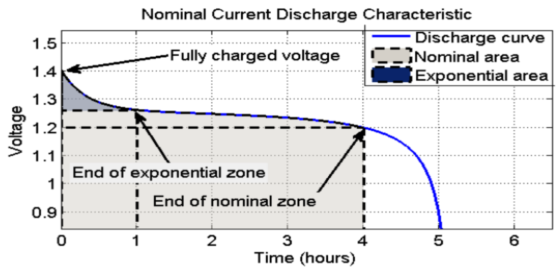

Figure 3.8: Charge and Discharge Characteristics of Battery

The parameters of the four electromechanical models are:

- **Nominal Voltage (V):** The nominal voltage represents the end of the linear zone of the discharge characteristics.
- **Rated Capacity (Ah):** The rated capacity is the rated capacity of the battery
- **Initial Capacity (Ah):** It is used as an initial condition for the simulation and does not affect the discharge curve.

- **Nominal capacity (Ah):** It is extracted from the battery until the voltage drops under the nominal voltage.
- **Voltage at exponential point (V):** The voltage corresponds to the end of the exponential zone
- **Maximum Voltage (V):** The fully charged voltage.
- **Internal Resistance (ohm):**It is the constant for all electromechanical models.

The battery is modeled by a controlled voltage source in series with a constant resistance, as shown in Figure.

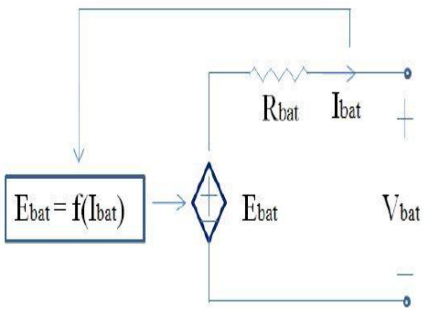

Figure 3.9: Equivalent circuit of Battery

The equivalent circuit above is represented by the following equations which are based on Shepherds equation.

$$Ebat = Eo - K.\frac{1 - SOC}{SOC}.Q + Ae^{-B(1-SOC).Q} \quad (3.11)$$

$$Vbat = Ebat - Rbat.Ibat \quad (3.12)$$

Where:

- **Ebat:** internal voltage (V)
- **Eo:**battery voltage constant (V)
- **SOC:**state of charge (%)
- **Q:**battery capacity (Ah)
- **A:** exponential zone amplitude (V)
- **B:** exponential zone time constant inverse (1/Ah)
- **Vbat:** terminal voltage (V)
- **Ibat:** battery current (A)
- **Rbat:** internal resistance (ohm)
- **K:**polarization constant (V/Ah) or polarization resistance(ohm)

The model is based on a few simplifying assumptions:

- **The internal resistance is assumed constant during the charge and discharge cycles and doesnt vary with the amplitude of the current**
- **The models parameters are deduced from the discharge characteristics and assumed to be the same for charging**
- **The capacity of the battery doesnt change with the amplitude of the current (i.e. no Peukert Effect).**
- **The temperature doesnt affect the models behavior**
- **The self-discharge of the battery is not represented**

- **The battery has no memory effect**
- **Charging and discharging history does not affect battery characteristics (i.e. no hysteresis)**

Table IV: **Battery Parameters**

Nominal voltage	12V
Nominal Capacity	31Ah
Internal Resistance	0.2ohm

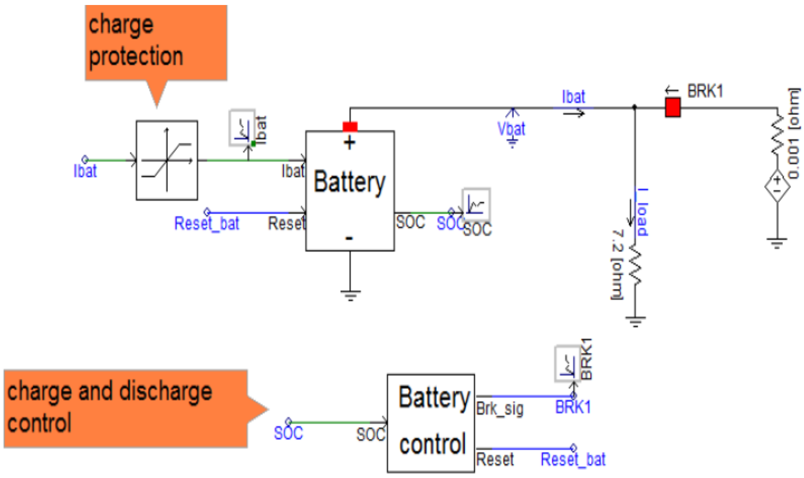

Figure 3.10: Charging and Discharging Circuit

Chapter 4

Simulattion Results

This results were captured at the end of 10sec simulation run.Simulation of solar model show that inverter output for 1 ϕ is 230Volt and for 3ϕ it is 415Volt.

4.1 PV Array

Iout: This window clearly mention the A is generated at the output terminal and in next part of circuit this is used for battery charging.

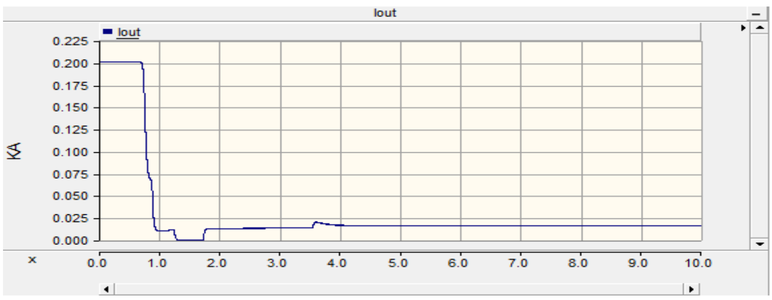

Figure 4.1: Iout

Vout: This window show almost 3.5458V output.

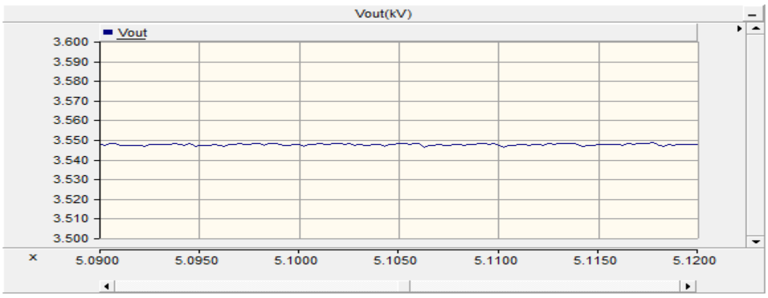

Figure 4.2: Vout

I-V Characterstics: This curve show that the maximum power point tracking system is working and give maximum output.The power generation is 50kw.

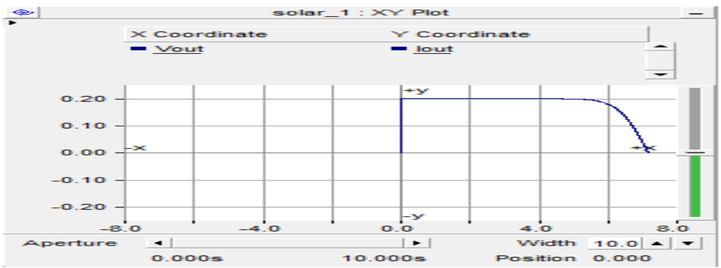

Figure 4.3: I-V curve

T1: This signal is necessary to trigger the buck converter which is designed for 50-90 kw rating and is depend on the INC algorithm.

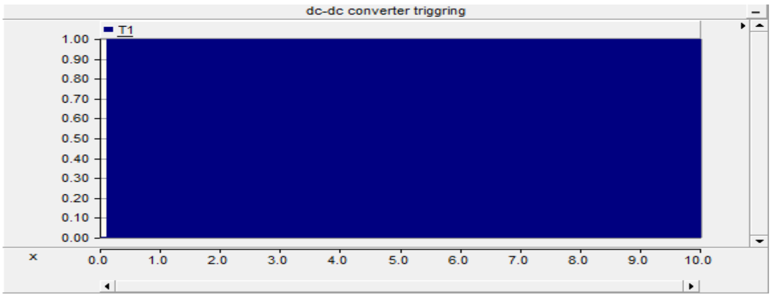

Figure 4.4: Buck Triggering

4.2 PV Array Output with MPPT On or Off

To check whether mppt is working or not mppt switched on and off and then PV output power is measured.Here the insolation variation is taken randomly and this variation is done by slider position variation in model.From the reading it is clear that mppt is necessary to produce maximum power from PV array.It is considered that the solar insolation variation in a normal day time is between 900 to 1200 W/m^2.

Table I: **MPPT Tracking**

	MPPT On	MPPT Off
Insolation(W/m^2)	PV Power(W)	PV Power(W)
940	38200	35740
967	39010	36210
990	40100	37421
1005.231	40400	37280
1020	40860	37990
1031	40900	38960
1040	41940	39060
1100	42148	40976

4.3 Inverter

dcVltg: Inverter is given the 800Vdc and output of the inverter is almost 230Vac.So,this rating indicate that this is stepping down the voltage.

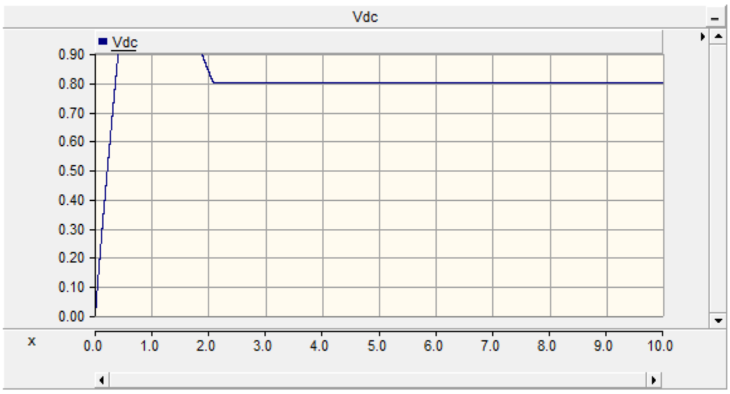

Figure 4.5: Inverter Input Voltage

Freq: It is kept 50Hz for inverter.

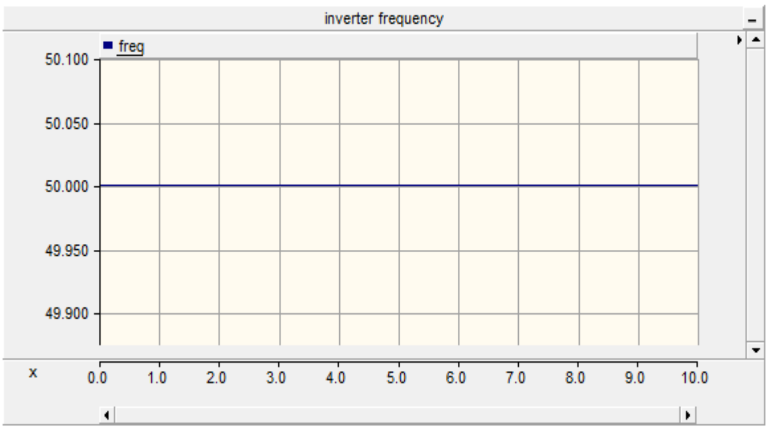

Figure 4.6: Inverter Frequency

gt1:

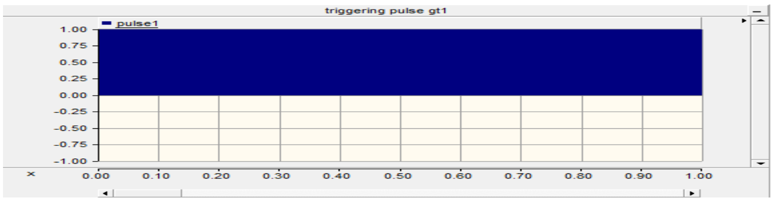

Figure 4.7: Inverter Gate1 triggering

gt3:

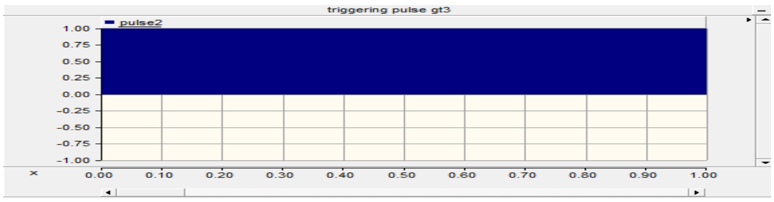

Figure 4.8: Inverter Gate3 triggering

gt5:

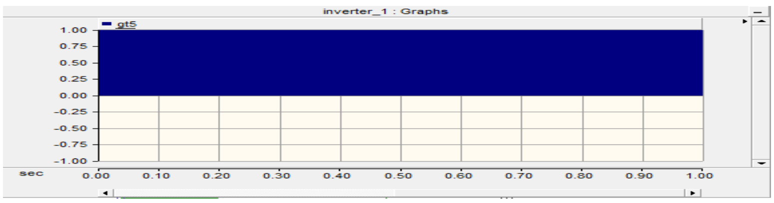

Figure 4.9: Inverter Gate5 triggering

Above windows for gt1,gt3,gt5 clearly display that IGBT's were continuously triggered this triggered signals help to trigger gt2,gt4,gt6.

4.4 Fixed Load

The load which is connected at the inverter end is representing residential load as a fixed load .The load voltages of the 1 ϕ & 3ϕ load is given below.

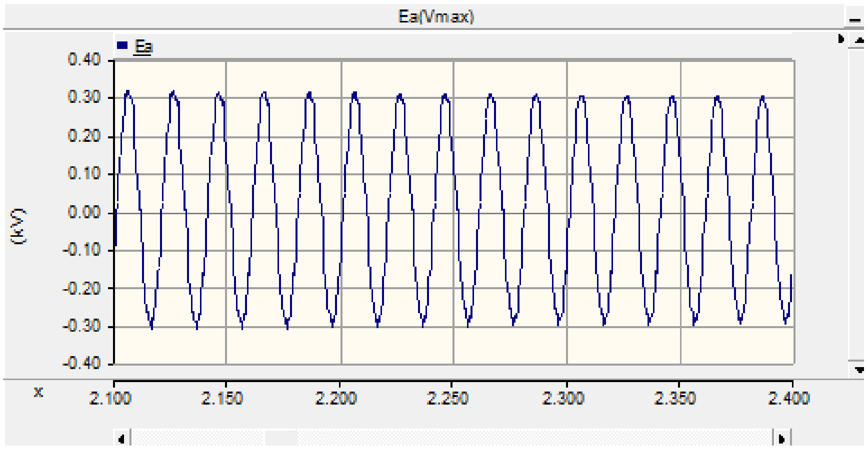

Figure 4.10: Phase Voltage

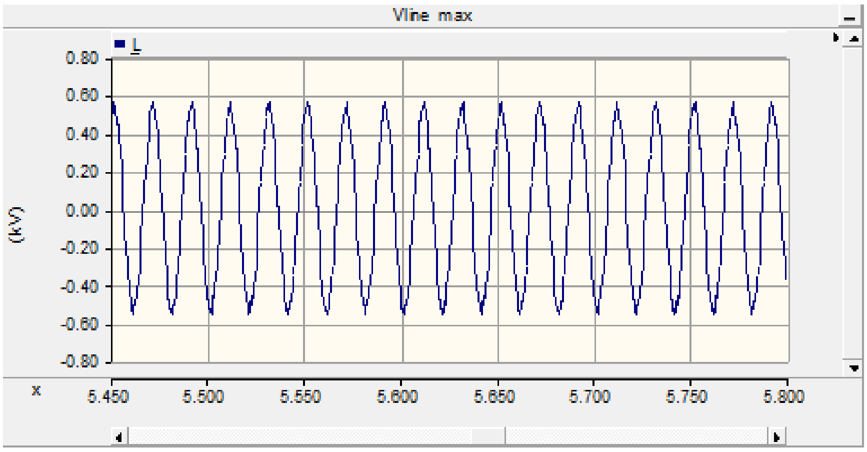

Figure 4.11: Line Voltage

4.5 Battery

Battery of 12V,31Ah Capacity is used to store the pv power.All 67 batteries were connected in series to give the 800V.As solar power generation vary from season to season and also day to day ,it is assumed that the maximum load requirement is of 25kW is fulfilled by battery when solar power is not available.The charging and discharging is done on a solar dc grid of 800V.

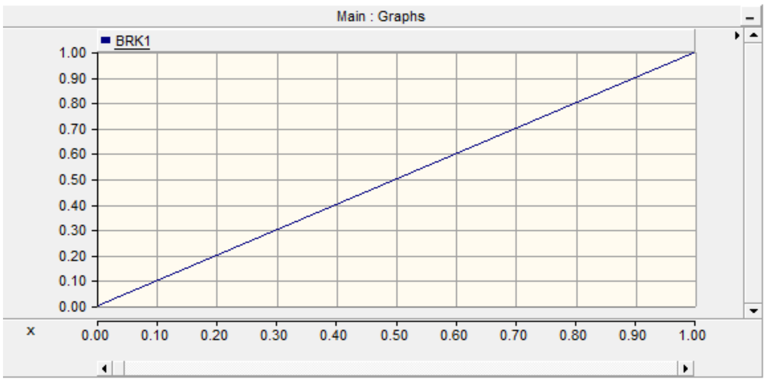

Figure 4.12: Breaker Position

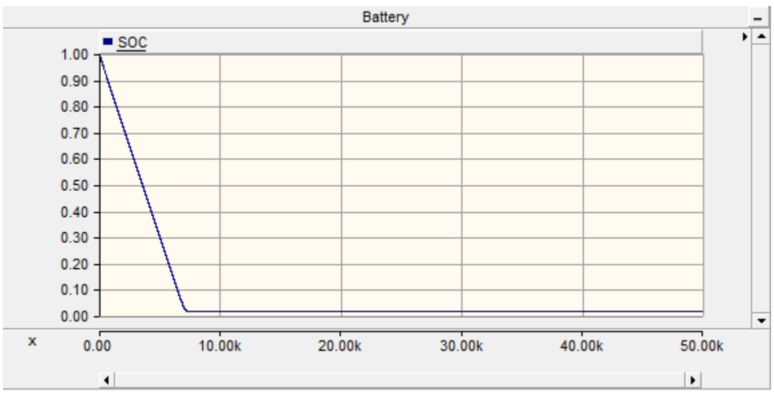

Figure 4.13: Battery SOC

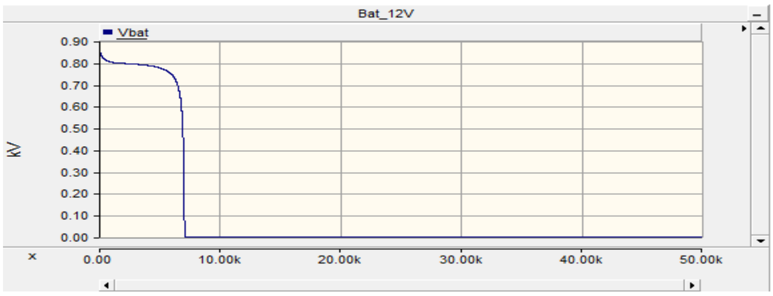

Figure 4.14: Battery Voltage

All the simulation results were discussed above and apart from this concept of energy saving related to dc micro grid and it is done by directly supplying power to dc load.The next chapter is to discuss energy saving possibilities by switching to dc Appliance.

Chapter 5

DC Micro Grid Energy Saving

5.1 Introduction

Recent developments and trends in the electric power consumption clearly indicate an increasing use of dc in end-user equipment. Computers, TVs, and other electronic-based apparatus use low-voltage dc obtained by means of a single-phase rectifier followed by a dc voltage regulator. In factories, the same input stage is used for process-control equipment, while directly-fed ac machines have been replaced by ac drives that include a two-stage conversion process.Electrical energy production from renewable sources is at dc (as in photovoltaic systems) or requires a similar two-stage conversion as in ac drives, e.g. variable-speed wind turbines and natural-gas micro turbines. By using dc for distribution systems it would thus be possible to skip one stage in the conversion in all these cases, with consequent savings and higher reliability due to a decreased number of components. Moreover, energy delivery at dc is characterized by lower losses and voltage drops in lines.

A dc distribution system also allows direct connection of battery blocks for back-up energy storage. The latter is often needed for avoiding supply interruptions in hospitals or big office buildings or in industrial complexes with high power quality demands and is presently implemented with Uninterruptable Power Supply (UPS) systems using two conversions (from ac to dc and back). A direct connection to a dc network would thus save two conversions in this case.

5.2 Loads

The electrical appliances today are designed to operate with ac, but many of them can run on dc without modification. All resistive loads like heaters, incandescent lamps, stoves, operate with both ac and dc, and the output power is equal if the RMS values are the same. All electronic loads like computers, fluorescent lamps with electronic ballast, flat screen TV, battery charger, which all internally use dc, have a bridge rectifier to convert ac to dc. This rectification will introduce current harmonics, which have a negative effect on the power system: neutral conductors become overloaded and protections malfunction. All these electronic loads can directly be supplied with dc. Rotating loads driven by a universal machine, or frequency controlled machines can also be supplied with dc. Problems arise with loads using a fix speed ac machine which utilizes a virtual phase created by a reactive component to get a rotating magnetic field. Loads with inductive parts cannot be supplied with dc, since dc creates a constant increasing current through it. Also loads with mechanical breakers designed for ac voltage cannot be supplied with dc. The breaker will be destroyed when breaking dc, due to no natural current zero.

Below table mention the name of Different residential appliances and there power ratings along with the power conversion efficiency.

Energy Saving in India Emerge Alliance[18],a group of 80 companies developing the DC products which is compatible to dc grid.The voltage ratings of DC products which emerge Alliance has developed and the cost of this Appliance is not mentioned.In table 2 it is clearly mentioned that by using DC illumination 14% energy saving is done.So,if this technology is followed in Illumination only, there is good amount of energy saving.

5.3 Residential & Commercial Appliances

Table I: **Appliances Power Rating**

Appliance	Power(Watts)	Avg AC-DC conversion (η)
Ceiling Fans	88	0.87%
Central AC	1900/6500/9200	0.89%
Clothes Washers	350-500	0.87%
Coffee Makers	900-1200	0.87%
Televisions and Set-Top Boxes	TV: 45/100/147/175/286	0.85%
Dishwashers	1200-2400	0.88%
DVDs/VCRs	See standby/low power	0.69%
Electric Clothes Dryers	2790	0.89%
Electric Cooking Equipment	Toaster:800-1400	0.88%
Electric Heat Pumps	1000-2000	0.88%
Electric Space Heaters	Portable Heater:1500	0.89%
Electric Water Heaters	1000-2000	0.88%
Freezers	540/700	0.87%
Furnace Fans	750	0.87%
Geothermal Heat Pumps	1000-2000	0.88%
Home Audio	See standby/low power	0.79%
Lighting-Fluorescent	11/16/20/30	0.79/0.81/0.82/0.84%
Lighting-Incandescent	11/16/20/30	0.79/0.81/0.82/0.84%
Lighting-Reflector	11/16/20/30	0.79/0.81/0.82/0.84%
Microwave Ovens	750-1100	0.87%
Personal Computers and etc	See standby/low power	0.8%
Rechargeable Electronics	10-20	0.8%
Refrigerators	380/420/600/800	0.87%
Room Air Conditioners	1900/6500/9200	0.89%
Security Systems	20-30	0.83%
Solar Water Heaters	1000-2000	0.88%
Spas	1000-2000	0.88%

Table II: **Power Saving**

Appliance	Energy savings from switching to DC-compatible run on AC	Energy Savings from avoided AC-DC conversion losses
Lighting-Incandescent	73%	18%
Lighting-Reflector	71%	18%
Lighting-Torchiere	69%	18%
Refrigerators	53%	13%
Freezers	53%	13%
Dishwashers	51%	12%
Electric Water Heaters	50%	12%
Electric Space Heaters	50%	12%
Spas	50%	12%
Central Air Conditioners	47%	11%
Electric Clothes Dryers	45%	11%
Room Air Conditioners	34%	11%
Furnace Fans	30%	13%
Clothes Washers	30%	13%
Ceiling Fans	30%	13%
Electric Cooking Equipments	12%	12%
Lighting-Fluorescent	1%	18%
Home Audio	0%	21%
Personal Computers and etc	0%	20%
Rechargeable Electronics	0%	20%
DVDs/VCRs	0%	31%
Security Systems	0%	17%
Color TVs and Set-Top Boxes	0%	15%
Coffee Makers	0%	13%
Electric Other	0%	13%
Microwave Ovens	0%	13%
Solar Water Heaters	0%	12%
Electric Heat Pumps	0%	12%
Geothermal Heat Pumps	0%	12%
Average Saving	33%	14%

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

DC micro grid is running normally after the 5sec and capable of producing 50kwp.The generated power is first stored and then feeded to the load.The Storage is done only once with help of circuit breaker arrangement.The Energy saving possibilities in India is only carried out by using maximum DC illumination.This saving is only in terms of power but, there may be higher installation cost for DC Appliances.So,Power saving can be done but,payback period may be higher.

6.2 Future Scope

Further,the Fault analysis and it's effect on the Solar based dc power system can be done.Also,Bidirectional inverter is used to feed load from AC grid supply.Battery management scheme is also developed for solar based power system.There is also possibility to develop Single phase Rooftop solar power system.

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