ENERGY MANAGEMENT OF THE COMMERCIAL BUILDING USING SIMULATION MODELLING

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MASTER OF ENGINEERING
IN
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CERTIFICATE

I hereby certify that the work which is being presented in this dissertation entitled,"**Energy Management of the commercial building using simulation modelling"**, in partial fulfillment of the requirements for the award of degree of *Master of Engineering in Power Systems* at Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mrs. Suman Bhullar**, Assistant Professor (EIED). The matter embodies in this dissertation has not been submitted for the award of any other degree to any other university.

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ABSTRACT

Due to an increase in the development of country, there has been an increase in demand of energy. This increase in energy could not be wholly met by conventional sources of energy as they are fastly depleting. At the same time power sector has gone through privatization. Also, deregulation in energy sector has brought competition in the power sector.

To get rid of the problem of power crises, energy management has been taken as an alternative. It reduces the energy consumption, increases reliability and efficiency keeping in view the customer's comfort. In this dissertation, a hybrid system consisting of photovoltaic system and wind energy conversion system is acting as renewable source. The hybrid system is connected to the utility grid. Both the energy sources are parallel linked through a DC/DC converter. The DC/AC converter converts the DC power available from PV array into three phase AC power. Simulation results shows that hybrid system provides constant power to the loads even when the power is not available from the utility grid. Excess energy, if available, could be stored in battery storage system.

In this dissertation, energy management of the critical and non-critical loads of commercial building is proposed. The energy management of the commercial building is done in which there are critical loads and non-critical loads. The energy management is done by assigning priorities to the different non-critical loads in such a way that they enter into power saving mode by means of a control agent that is an intelligent control system.

LIST OF ABBRIVATIONS

DFIG	-	Doubly Fed Induction Generator
DG	-	Distributed Generation
EEM	-	Enterprise Energy Management
CPU	-	Central Processing Unit
DVR	-	Dynamic Voltage Restorer
BJT	-	Bipolar Junction Transistor
MOSFET	-	Metal Oxide Silicon Field Effect Transistor
GTO	-	Gate Turn Off Thyristor
IGBT	-	Insulated Gate Bipolar Transistor
MPPT	-	Maximum Point Power Tracking
PWM	-	Pulse Width Modulation
STATCOM	-	Static Synchronous Compensator
SPWM	-	Sinusoidal Pulse Width Modulation
VSI	-	Voltage Source Inverter
WECS	-	Wind Energy Conversion System
TSR	-	Tip Speed Ratio

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

In the present scenario, electric industry has gone through privatization. Also, deregulation in the energy sector has brought competition in the electric industry. The relationship between the utility and the customer has changed drastically due to an overall change in the market.

Energy management had been a concern for large industrial and commercial users but was abandoned and taken as a secondary activity. Now, due to increased competition in the market, energy management is gaining importance.

Beyond price, large energy consumer demands more value on their energy investments. Different sectors which are a part of economy require a higher value of reliability and quality of electricity.

To achieve good quality of energy various factors are considered on both demand and supply side of energy to seek better strategies to manage the cost and quality of energy product.

Challenges which are faced by enterprises are:

(a) Efficient purchase and use of energy at moderate prices.
(b) To supply higher level of power quality and reliability.
(c) Supplying increasing demand of energy in accordance with the market based pricing system.

These challenges could be addressed by internet enabled enterprise energy management system that delivers real time information and control through an efficient economical and scalable architecture.

Energy management system works on the goal of reducing energy consumption, improving energy efficiency and using reusable resources without compromising product quality, safety and cost.

In this report, Energy Management of a commercial building is done to increase efficiency. In order to achieve it, critical loads, non-critical loads are managed in such a way that total energy consumption reduces. As conventional sources alone cannot meet the energy requirements, renewable energy is the solution of the problem. An hybrid system consisting of photovoltaic system and wind energy conversion system acting as renewable sources. The hybrid system is connected to the utility grid. Both the energy sources are parallel linked through a DC/DC converter. The DC converter converts the DC power available from PV array into three phase AC power.

Even after managing the critical loads the energy level if not satisfied, non-critical loads were managed by taking them into energy saving mode by assigning them priorities. Only essential loads were allowed to operate and so again energy saving is thus obtained without sacrificing customer's comfort. The hybrid system consisting of photovoltaic system and wind energy conversion system provides constant power to the loads even when the supply is not available from the utility grid. Excess energy, if available, could be stored in battery energy conversion system.

1.2. Literature Review

Van Gorp, J. C.[2004] explained an EEM information system supported strategic energy management by capturing data about current energy performance, assisting in the creation and tracking of energy performance goals and communicating results to energy project participants.

Schellong W[2006] focused on a multi-disciplinary approach to the development of energy information systems which combined mathematical and informational methods with energy generation and saving technologies. The mathematical modeling by linear regression analysis provided a wide range of useful applications within the context of the optimization of the energy generation and consumption.

JInrui N. *et al.*[2006] explained current electric vehicles power trains comprise of energy storage and traction drive where the batteries used for energy storage was expensive or heavy or both and required regular maintenance. As a best practice we could use super capacitors with batteries, reducing deep charge and discharge cycle and battery size. Calculations obtained showed that the average energy consumption with super capacitors was reduced.

Wang Aihua *et al.*[2006] developed energy management system which was based on the concept of "evolutionary fuzzy system". The proposed power controller demonstrated the development technique and proved that fuzzy controller could be implemented to control the power flow between the main components of the parallel hybrid electric vehicle.

Wang Sibo *et al.*[2008] presented fuzzy logic energy management stategy. The variable speed motor drive system would frequently absorb or regenerate large energy in short time when accelerating or decelerating respectively, which may lead to energy waste and voltage fluctuation. A solution was found by using super capacitor-based energy storage device to shave the power demand and absorb the braking energy.

Narasimhan Seetharam *et al.*[2010] presented a motivation for designing a generic energy management system which was capable of managing the acquisition, mixing, delivery and storage of energy for an arbitrary collection of electrical energy sources and users. The energy allocation procedure tried to maximize the energy utilization efficiency of the sources while satisfying the demand of the users in order of their associated priorities, without starving an already allocated user.

Chao Kuo-Ming *et al.*[2010] discussed energy management system which use energy profiles of electrical appliances to detect and diagnose abnormalities in energy consumption and then recommended remedial actions to the household in order to remove or minimize the effects of abnormalities.

Jing-xiao *et al.*[2010] developed the energy saving chain management of building project which targeted at maximizing the energy saving performance.

Zhao peng. *et al.*[2010] developed an application of multi-agent system for cyber enabled energy management of building structure. The efficient building energy management system was expected to be achieved through both physical and cyber aspect of the building, such that the building, cooling, heating, power model provided an applicable building physical aspect for energy efficient buildings, while the cyber enabled energy management system model added the cyber aspect on the building heating cooling power model, which optimized the energy generation and distribution.

Zhong bocheng[2012] explained energy consumption monitoring and designing of management system. The design of the system provided a real example for the building energy-saving and emission-reduction and the fine-grained management.

Qina Quing *et al*. [2012] described the concept of micro-grid and energy management system and it also introduced the research on the micro-grid energy management system at home and abroad. Micro-grid energy management system also gradually reveals many problems, such as, communication problems, access control problem, the unpredictable character of new and renewable energy power.

Asare-Bediako *et al*.[2012] investigated the cost and demand supply optimizations with Simulink model for a household. The cost optimization option was much influenced by the type of feed in tariff. The demand supply optimization was effective for peak shaving and minimization of energy losses. Smart home energy management system was developed which enabled technologies to improve the efficiency and realized savings through automated actions.

Byun Jinsung *et al.*[2012] explained the advancement in micro-grid and distributed renewable energy have facilitated more efficient home energy management systems. Due to characteristics of renewable energy such as intermittent energy generation, home energy management systems were inefficient and the recent systems therefore cannot be successfully applied to existing home.

Satoh Fumiko *et al.*[2012] developed the energy management system for a cloud with sensor management. The system provides unified access to the sensors and enables the sensors to be shared among multiple applications. A tool was developed which provided an optimized virtual management allocation by analyzing the histories of CPU utilization of electric power usage.

S.D. Smitha *et al.*[2013] explained intelligent energy management system which was environmental friendly and also ensured the use of micro grid technology. The energy consumption within the building was minimized with proper control of critical loads, non-critical loads and micro grid.

Sreekala C.S *et al.*[2013] explained voltage and frequency control of wind-hydro hybrid system in isolated location. It used a rectifier and pulse width modulated controlled insulated gate bipolar transistor based voltage source converter with the battery energy storage system at D.C. links. The developed system could flow the active and reactive power bi-directionally which in turn controls the magnitude and frequency of the load voltage.

Wang Z *et al.*[2010] presented a new control system which used intelligent optimizer that could be applied in smart and energy efficient buildings for energy and comfort management. The control system contains agent controllers. The central coordinator agent at higher level and local control agent at the lower level. These agent controllers minimizes the main conflict in terms of power consumption and customers' comfort in smart and energy efficient buildings.

Jiang Y. ***et al.*[2011]** presented a solar photovoltaic module in which the power generated depands upon the irradiance and surrounding temperature. The developed simulation model contains solar P-V cells, a power stage converter and could be expanded to add maximum power point tracking control. The model simulates V-I characteristics curves and P-V characteristics curves under uniform and partial shading conditions.

Goel P. K. *et al.*[2009] explained wind hydro hybrid generation system feeding a three phase four wire local load. The developed hybrid system consists of squirrel cage induction generator driven by hydro turbine and a permanent magnet synchronous generator driven by variable speed wind turbine. The MATLAB simulated wind-hydro hybrid system have the capability of bidirectional flow of active and reactive power and control the magnitude and frequency of load voltage.

Johnson, G. L.[1978] illustrated wind records which were used to select the rated wind speed for wind electric generators. A good wind system was developed by plotting the graphs for maximum specific output and for a specific load factor. In the paper it was said that at a wind speed of 9 m/sec a specific output of 80% of the maximum was obtained.

Guan X. *et al.*[2010] described a micro grid technology for improving the efficiency of energy consumption in buildings. It could be done by coordinating and optimizing the operation of various energy sources and loads. The main objective is to reduce the lot of electricity and natural gas while satisfying the energy balance within the buildings.

Zhang F. ***et al.*****[2008]** described the working principle, controller hardware and control method of intelligent wind solar controller. The simulation method described in the paper reduces the difficulty of hardware debugging, shorten debugging time and reduces the research expenditure.

Qian H. ***et al.*****[2011]** proposed a grid tie lithium ion battery based energy storage system with a bi directional ac-dc converter. The battery management system takes notice of state of charge and condition of each battery cell. It also balances the charge of all cells in the pack. The ac-dc converter acts as an interface between battery and ac grid.

Syed M. H. ***et al.*****[2013]** explained micro grid which have an ability to run when connected with grid and during islanded mode. Fault triggering islanding causes large fluctuations in voltage and frequency causing disconnection of distributed generation thereby resulting in threatening of grid integrity. In the paper dynamic voltage restorer as series compensation was proposed for successful islanding without violating the specified standards.

Rezkallah M. ***et al.*****[2012]** explained the control strategies of hybrid wind diesel battery energy storage for grid isolated system. The control of frequency and voltage depands upon real and imaginary power balance between distributed energy resources and the loads. The battery used feeds loads during low wind speed, increases efficiency of system and reduces power delivered by diesel engine. The proposed system was verified using MATLAB simulation under different conditions.

Khadkikar V. ***et al.*****[2011]** presented a system for photovoltaic power system with multiline transmission network. The P.V. power plant was connected in such a way that two adjacent power networks could be interconnected. The inverter module in PV power plant was connected back to back in multiline system thus forming interline PV system. With the proposed I-PV system both active an reactive power flow control in multiline system was achieved.

Sebastian R. ***et al.*****[2006]**explained wind-diesel hybrid system under diesel mode only, wind diesel and wind only mode. A distributed control system was simulated for frequency control in wind operated mode. It consists of wind turbine generator, a synchronous machine, a consumer load, battery energy storage system discrete dump load. Graphs for frequency, voltage and active power for consumer loads at different wind speeds were drawn by taking 400 HZ frequency as reference.

Conti S. *et al.*[2003] explained the difficulties that arises when analyzing the amount of power that distributed generation could inject into LV distribution feeders without violating voltage constraints and thermal ratings. In the paper maximum value of power that could be supplied to the feeder by diesel generator without violating thermal constraints was compared with that of voltage constraints in order to find out which of the two constraints were most restrictive under given operating conditions.

Sebastián R *et al.*[2010] explained wind diesel hybrid system under wind diesel mode, wind only and diesel only mode. The wind-diesel hybrid system consists of diesel engine, synchronous machine, wind turbine generator, consumer load, battery energy storage system and dump load. The performance of the developed wind-diesel hybrid system was tested through MATLAB simulation model.

Jiang Z. *et al.*[2009] explained an integrated power generation for doubly fed induction generator based wind turbine system for steady power output. A battery energy storage system connected to doubly fed induction generator was used to smooth out the power output with the variation of wind. The model was developed using MATLAB simulation which contains doubly fed induction generator, wind turbine, PWM inverter, D.C. link capacitors, and a battery.

Layadi T. M. *et al.*[2013] presented a dynamic simulator which takes into account the data of renewable sources for sizing each element composing of electric generation system. The system contains photovoltaic panel, a wind turbine, a diesel generator and storage battery. The power minimization was obtained by starting and stopping the diesel generators according to the state of charge of battery.

Colak I. *et al.*[2011] modelled three separate solar farms using Matlab/Simulink. Each farm provides 15 KW of power and have 170W photovoltaic panels. The DC power generated by photovoltaic panels then applied to the full bridge inverter to generate three-phase AC voltage at the output. The energy conversion was performed by maximum power point tracking (MPPT) algorithm.

Valarmathi R. *et al*[2012] simulated a hybrid photovoltaic and wind energy system using Matlab. A AC/DC converter converts three phase variable frequency wind turbine AC power into variable DC power. The DC/DC converter maintains the variable power from solar array DC. The hybrid system provided the constant power to the loads.

1.4 Organization of the Thesis

Chapter first provides an introduction, objective, brief literature review pertaining to proposed problem.

Chapter second presents the basic introduction of Solar and Wind Energy Conversion System.

Chapter third describes the realization of the simulation modelling.

Chapter four discusses simulation result and comparison of different proposed techniques.

Chapter fifth describes the scope of future extension of the work.

CHAPTER 2

SOLAR AND WIND ENERGY CONVERSION SYSTEM

Renewable energy constitutes to about 85,000 MW in India from commercially exploitable sources. Wind accounts to about 45,000 MW, Solar Photovoltaic and Solar thermal energy constitutes to about 35 MW per square kilometer. The most promising aspect of energy available from renewable energy sources is that it is almost pollution free. The first Solar Photovoltaic plant was developed in 1980. Since 1990’s there has been a significant development in the Wind Power and in the last few years considerable improvement is obtained

2.1 ENERGY MANAGEMENT

2.1.1 Definition:

Energy management refers to a system in an organization to achieve energy efficiency through well laid out procedures and methods, and to ensure continual improvement, which will spread awareness of energy efficiency throughout an entire organization.

Energy management system is a computer aided tools used by operators of electric utility grid to monitor, control and optimize the performance of the generation or transmission system.

When it comes to energy saving, energy management is the process of monitoring, controlling, and conserving energy in a building or organization. Typically it involves the following steps:

1. Metering energy consumption and collecting the data.

2. Finding opportunities to save energy, and estimating how much energy each opportunity could save.

3. Taking action to target the opportunities to save energy.

4. Tracking the progress by analyzing meter data to see how well energy-saving efforts have worked.

2.1.2 Importance of Energy Management: Energy management is the key to saving energy in your organization. Much of the importance of energy saving stems from the global need to save energy - this global need affects energy prices, emissions targets, and legislation, all of which lead to several compelling reasons why you should save energy at your organization specifically.we need to save energy in order to:

• Reduce the damage that we're doing to our planet, Earth.

• Reduce our dependence on the fossil fuels that are becoming increasingly limited in supply.

2.1.3 Controlling and reducing energy consumption at organization: Energy management is the means to controlling and reducing your organization's energy consumption. It enables to:

• Reduce costs – this is becoming increasingly important as energy costs rise.

• Reduce carbon emissions and the environmental damage that they cause.

• Reduce risk – the more energy you consume, the greater the risk that energy price increases or supply shortages could seriously affect profitability, or even make it impossible for a business/organization to continue.

1.3 ENERGY MANAGEMENT MODEL: To obtain better energy management system, following model is followed:

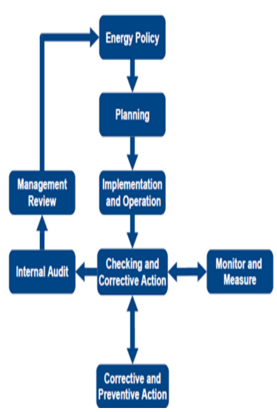

Figure 2.1 Energy Management Model

Management Commitments: Energy management system requires commitment from senior personnel of the organization to facilitate energy efficiency. It requires improvement of plans of energy savings, and their implementations on regular basis. It can be achieved by:

(a) Providing training to the employees.
(b) Setting targets to achieve the goals of energy savings.
(c) Holding management reviews of energy management.
(d) Preserving energy management equipment in good conditions.

Energy Policy: For a good operation energy management sets standards to create energy policies. Energy policies include:

(a) Reducing energy consumption, increasing efficiency and having regular maintenance without compromising product quality, safety and cost.
(b) Should be abide by laws and regulations.
(c) Setting energy targets.
(d) Providing training materials for employees to understand energy policies.

Planning: For achieving energy targets an action plan should be kept in line according to the national and international standards. The plan should:

(a) Identify energy performance.
(b) Sticking to the rules.
(c) Setting energy targets
(d) Designing an energy management base.

Identifications Of Energy Factors: Stressing on the energy performance indicators is important for the planning process.

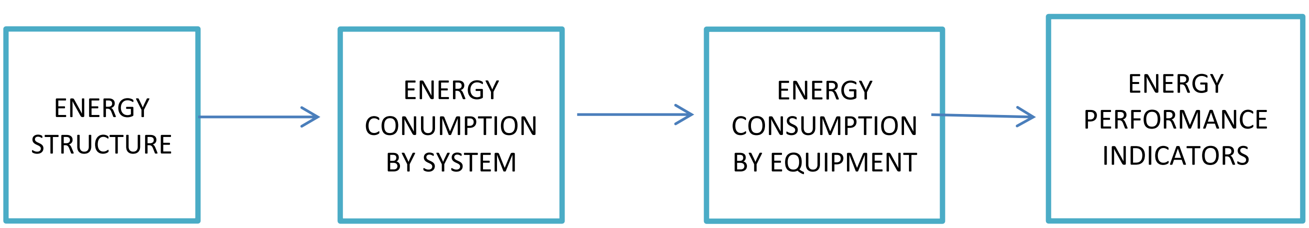

Figure 2.2 Identifications Of Energy Factors

Implementation: The next stage of energy management is to implement the plan. It includes:

(a) Information sharing among employees.

(b) Having record control.

(c) Control measures on energy management system.

(d) Preparation for emergency and response.

Management Review: The last step is "ACTION" which means management review. The review includes:

(a) Personnel: It means participation of all personnel in energy management activities.

(**b**) **Time:** It includes starting and ending period.

(c) Contents: It includes progress of improvement plans, and their proposals for improvement.

(**d**) **Report:** It includes improvement measures, change in policy and benchmarks.

2.2 SOLAR CELL: The working of the PV cell is same as that of the p-n junction diode. When light falls on the junction, the energy of the absorbed photon is transferred to the electron system of the material, which results in the creation of the charge carriers that are separated at the junction. The charge carriers include electron-hole pairs in a solid semi-conducting material or it may be electron-ion pairs in a liquid electrolyte. It is shown the figure 2.3.

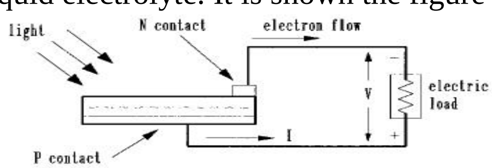

Figure 2.3: Photovoltaic effect converts the photon energy into voltage across the p-n junction

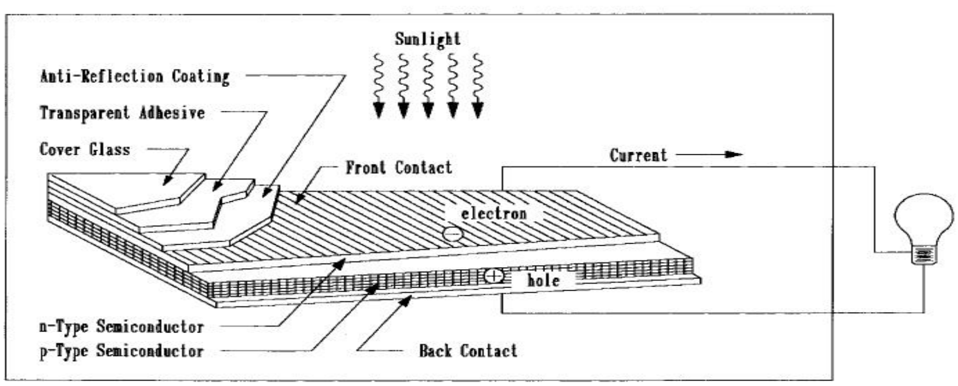

Figure 2.4:Basic construction of pv cell with performance enhancing features (current collecting mesh, anti-reflective coating and cover glass protection).

The charge carriers, thus, produces potential gradient which gets accelerated under the electric field and flows in the form of current in the external circuit. The power converted into electricity is obtained by squaring the current and multiplying the resistance in the circuit. The remaining power of the photon increases the temperature of the cell.

The photovoltaic potential arises because of the difference in the chemical potential, Fermi level, of the electrons in two isolated materials. When these two materials joins the junction reaches to a new thermodynamic equilibrium. The equilibrium is obtained when the Fermi level in the two materials are equal. It occurs by the flow of electrons from one material to the another till the voltage difference is established in between the two materials which have the potential equal to the initial difference of the Fermi level and that potential arises the photocurrent.

2.2.1 Construction: The construction of the PV cell is shown in the figure 2.4. On both the sides of the junction metallic contacts are provided for collecting the photocurrent and to collect the electrical current developed by the photons on one side. Conducting foil is provided on the bottom surface and on one of the edge of the top surface. The remaining part of the top surface collects the current and let the light pass through it. There is spacing in between the conducting fibers in the mesh to minimize the blocking of the light. In addition to the basic elements some enhanced features are also included in the construction, which includes, anti-reflective coating to absorb as much light as possible by reducing the reflection. Cover glass with the transparent adhesive provides the mechanical protection.

2.2.2 Types of pv cell: In producing the pv power, the cost of the pv cell depands upon two parameters the photovoltaic energy conversion efficiency and capital cost per watt.

The conversion efficiency of the pv cell:

$$\eta = \frac{electrical\ power\ output}{solar\ power\ impinging\ the\ cell} \qquad (2.1)$$

The efforts made for developing more efficient and low cost cells has resulted in different types of pv technologies. It’s different types could be discussed as below:

(a) Single Crystalline Silicon: The single crystalline silicon is available in abundance and is widely used in industry. In the preparation of the material, the raw material of silicon is first melted and purified in a crucible. A seed crystal after placing in the liquid silicon is drawn at a slow constant rate which results in a solid, single-crystal cylindrical ingot(Figure 2.5). The obtained ingot is then sliced into 200 to 400 µm (.005 to .010 inch) thick wafers using a diamond saw. The wafers are then cut into rectangular cells that could be arranged in the rectangular panel

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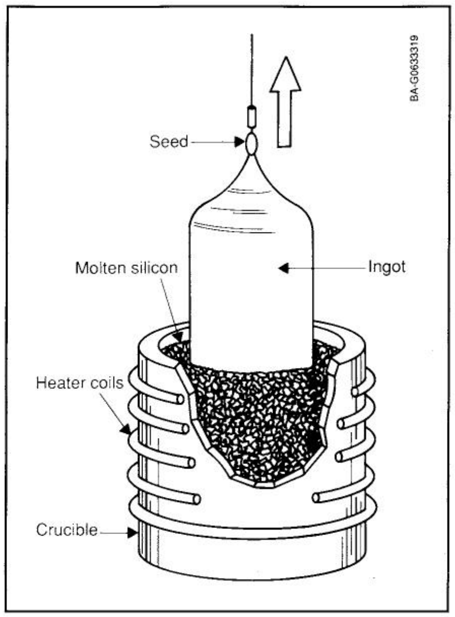


Figure 2.5: Single Crystalline Cell

(b) Thin films: In this type of photovolatic, copper Indium, diselenide, cadmium telluride, and gallium arsenide and thin film materials of the order of few µm or less in thickness, directly deposited on glass, stainless steel, ceramic or other substrate materials. The material required for this technology is less as per square area of the cell and is less expensive per watt of power generated.

(c) Polycrystalline and semi-crystalline: This is low cost and fast process to produce thick crystalline cells. The molten silicon is cast into ingots instead of drawing single crystals using seeds. Multiple crystals are formed here. As the cost is less, conversion efficiency is lower, the cost per watt of power is less.

(d) Amorphous Silicon: In this technology, on amorphous (glassy) films with stainless steel rolls, sizing 2000 feet long and 13 inches wide amorphous silicon vapour is deposited (Figure 2.6). On comparing with crystalline silicon, this technology used only 1 percent of the material. It's efficiency is half of the crystalline silicon, but the cost per watt generated is projected to be lower.

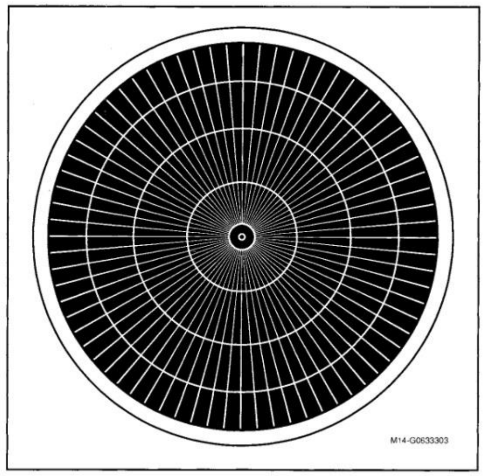


Figure 2.6: Amorphous Silicon

(e) Concentrated cells: The conversion efficiency could be improved by using concentrated cells. The sunlight is concentrated into hundred of times the normal sun intensity by focusing on small area using low cost lenses (Figure 2.7). The advantage obtained is that only small fraction of area is required as compared to the normal cells. The total module area required would be same as before. In addition of increase in power and reduction in the size and number of cells, the advantage is that cell efficiency increases. The disadvantage is that additional focusing optics are required which add to the cost.

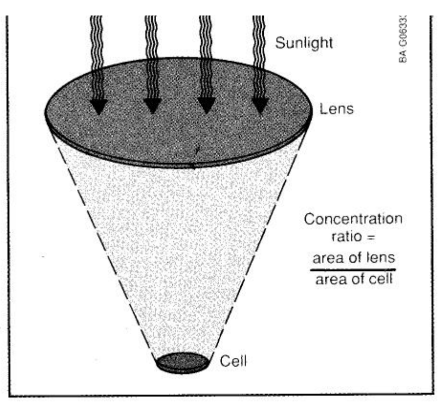
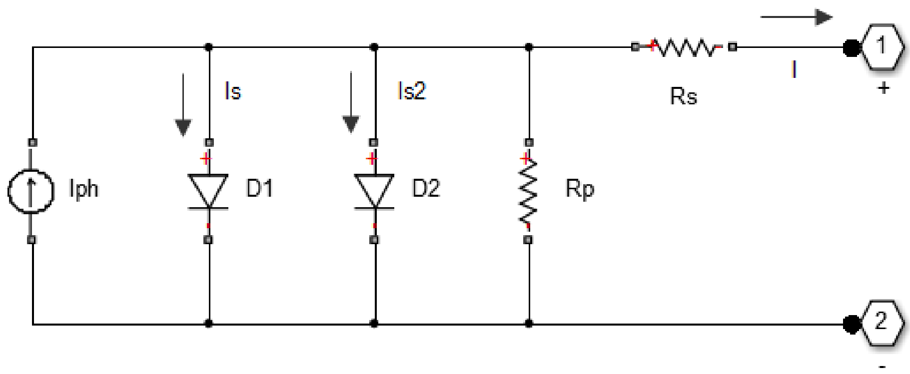


Figure 2.7: Concentrated Cell

2.2.3 Equivalent Electrical Circuit: The equivalent circuit of a PV cell is shown as:



The output current I is:

$$I = I_{ph} - I_S * \left(e^{\frac{V+I*R_S}{N*V_S}} - 1\right) - I_{S2} * \left(e^{\frac{V+I*R_S}{N_2*V_S}-1}\right) - (V + I * R_s)/R_P \quad (2.2)$$

where:

$I_{ph}$is the solar-induced current: $I_{ph} = I_{pho} * \frac{I_r}{I_{r0}}$

where:

I_r is the irradiance (light intensity) in W/m2 falling on the cell.

I_{ph0} is the measured solar-generated current for the irradiance Ir0.

I_s is the saturation current of the first diode.

I_{s2} is the saturation current of the second diode.

V_t is the thermal voltage, kT/q, where:

k is the Boltzmann constant.

T is the Device simulation temperature parameter value.

q is the elementary charge on an electron.

N is the quality factor (diode emission coefficient) of the first diode.

N_2 is the quality factor (diode emission coefficient) of the second diode.

V is the voltage across the solar cell electrical ports.

2.2.4 Open circuit voltage and short circuit current: To know the electrical performance of the cell important parameters are open circuit voltage V_{OC} and short circuit current I_{SC}. To measure the short circuit current output terminals are shorted and current is measured under full illumination. It ignores the diodes and ground leakage currents under zero terminal voltage.

Under open circuit conditions, maximum photo-voltage is produced and it ignores ground leakage current. The open circuit voltage is expressed as:

$$V_{oc}=\frac{AKT}{Q}\log_n\frac{I_L}{I_D}+1 \qquad (2.3)$$

The constant $\frac{KT}{Q}$ is the absolute temperature expressed in voltage (300 K =.026). Also, in photocells the photocurrent is several orders of magnitude greater than reverse saturation current. So, the open circuit voltage is several times the magnitude of $\frac{KT}{Q}$ value. When the illumination is constant $\frac{I_L}{I_D}$ is the function of all temperature and the solar cell shows the negative temperature coefficient of open circuit voltage.

2.2.5 Module and Array: The solar cell is the basic element of the pv power system. It's size is in few square inches and produces one watt of power. For obtaining higher amount of power the solar cells are connected in series and parallel arrangement on a panel to form a module. It is shown in the figure…. . When a group of modules are joined in series and parallel combination it forms solar array or panel to generate required amount of voltage and current. Figure….shows various configurations of mounting the modules.

Array Design: The main factors that include the design of a solar array could be listed as: sun intensity, the operating temperature, sun angle, and the load matching for maximum power.

(a) Sun Intensity: The magnitude of photovoltaic current is maximum under full intensity of the brightness of the sun. On the partially sunny day, the photocurrent decreases directly in proportion to the sun intensity. The i-v characteristics shifts downwards at a low sun intensity. On the cloudy day, the decrease in the open circuit voltage is small but short circuit current decreases.

The photo-conversion efficiency is independent of solar radiations. In the figure 2.9, it is observed that conversion efficiency at 500 W/m^2 is same. So, on the cloudy day, we get low power output because of the lower solar radiation falling on the cell. However, the conversion efficiency will be same.

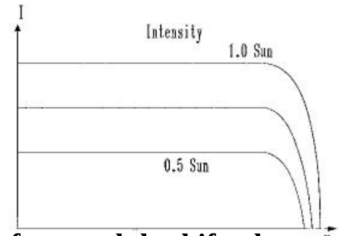


Figure 2.8: I-V characteristic of pv module shifts down at lower sun intensity, with small reduction in voltage

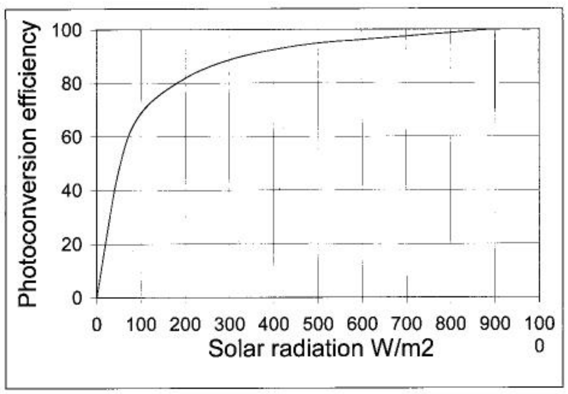


Figure 2.9:Photoconversion efficiency versus solar radiation. The efficiency is practically constant over a wide range of radiation.

(b) Temperature Effect: with the increase in temperature, open circuit voltage decreases and short circuit current increases. The temperature effect could be studied by examining the voltage and current separately. Here, V_o and I_o are open circuit voltage and short circuit current respectively at a reference temperature T, and α and β are the temperature coefficients. If the operating temperature is increased by δT, then the new current and voltage is given as:

$$I_{sc}=I_o(1+\alpha.\ \delta T) \qquad (2.4)$$

$$V_{oc}=V_o(1-\beta.\ \delta T) \qquad (2.5)$$

Since the operating voltage and current changes in the same proportion as the open circuit voltage and short circuit current respectively. The new power is as follows:

$$P=V.I= I_o(1+\alpha.\ \delta T)\ .\ V_o(1-\beta.\ \delta T) \quad (2.6)$$

On simplification,

$$P=P_o[1+(\alpha-\beta).\delta T] \quad (2.7)$$

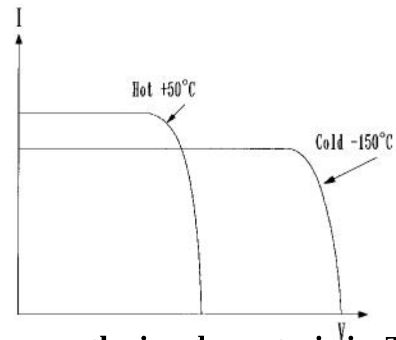
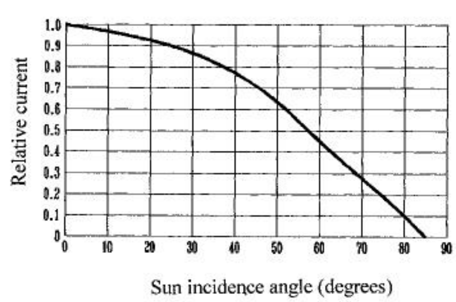


Figure 2.10: Effect of temperature on the i-v characteristic. The cell produces less current but greater voltage, with net gain in the power output at cold temperature.

The effect on power output by the variation of temperature is shown in the power versus voltage characteristics at two operating temperatures as shown in the figure2.10. It is observed that maximum power available at lower temperature is higher than that of higher temperature. Thus, cold temperature is good for a pv cell, as it generates more power.

(c) Sun Angle: The cell output current is I=I_O.cosθ , where I_o is the current with the normal sun and θ is the angle of the sun line measured from the normal. The cosine law holds good for sun angle for 0 degree to 50 degree.



When the angle goes beyond 50 degrees, the power output reduces significantly from cosine law and as the angle goes beyond 85 degrees. The cell produces no power. The actual power angle curve and Kelly cosine is shown in the figure.

(d) Shadow Effect: The pv array consists of parallel connected series cells. It is shown in the figure 2.11 . If the pv array is large then part of the array may get partially shadowed because of the structure interference with the sun line. If it gets totally shadowed then, it would loose the photo-voltage, but it would carry current as it is connected in series. If the pv is not internally developing voltage then it would not develop power. Moreover, it acts as load and produces I^2R loses and heat. The remaining cells must produce higher voltage to make up shadowed cell voltage.

It could be seen in the v-i characteristics of the string in figure 2.12. that higher voltage is produced in healthy cells and it means lower string current. The current loss is not proportional to the shadowed area, and may go unnoticed on a small area having mild shadow.

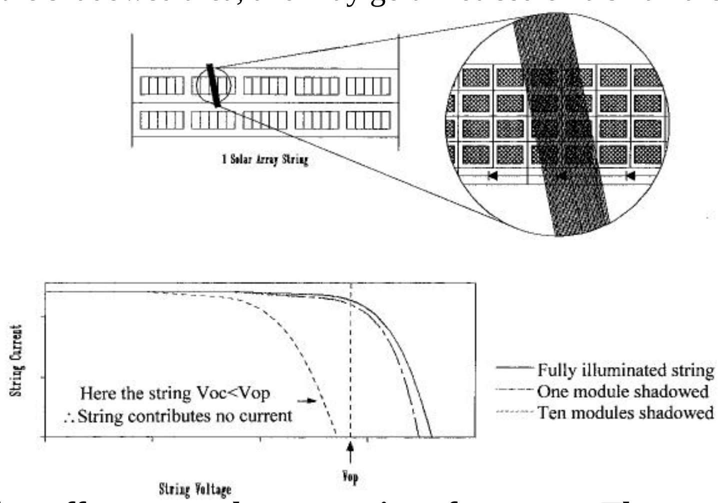


Figure 2.11:Shadow effect on one long pv string of an array. The power degradation is small until shadow exceeds the critical limit.

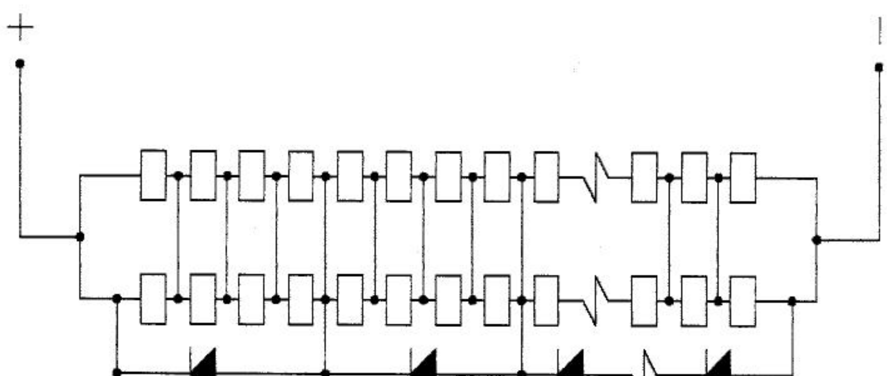


Figure 2.12: Bypass diode in pv string minimizes the power loss under heavy shadow.

If more number of cells are shadowed, the i-v curve gets below operating value of the string and string current falls to zero losing all power of the string. The method adopted to eliminate the loss of string due to shadow effect is by subdividing the circuit length in several segments by the bypass diodes (figure 2.12) . Now, with this arrangement there would be proportionate loss in the voltage and current but without losing the power.

2.2.6 Sun Tracking: The amount of the energy collected would be more if the pv module is installed on the tracker, with an actuator which follows the sun. The sun tracker could be classified as:

(a) One axis tracker, which follows the sun from east to west during the day.
(b) Two axis tracker, which follows the sun from east to west during the day and from north to south during the season of the year.

A pv module installed on the sun tracker, increases the energy produced by 40 percent as compared to fixed array design.

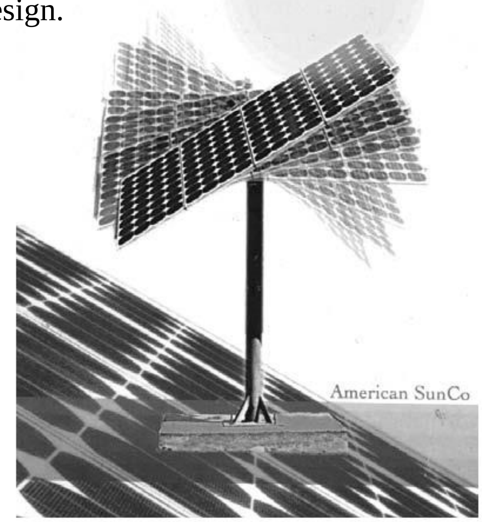


Figure 2.13: Dual-axis suntracker follows the sun like a sunflower around the year.

2.2.7 Peak Power Point Operation: The pv module installed on the sun tracker to face the sun to collect maximum solar radiation does not guarantee the maximum power output. As shown in the figure 2.13 .The pv module should be operated at some certain voltage to give peak power point under given operating conditions.

If the pv array is working at voltage V and current I on i-v curve the power generated is P=V.I watts. Now, if the operating point shifts, such that current is (I+ δI) and voltage is (V+δV) so the power is (P+δP)= (V+δV).(I+ δI) (2.8)

On simplifying, δP=ΔV.I+ΔI.V (2.9)

At peak power point δP is zero, which lies in the flat neighbourhood. The expression becomes, $\frac{dV}{dI} = -\frac{V}{I}$ (2.10)

Here, $\frac{dV}{dI}$ is the dynamic impedance and $\frac{V}{I}$ is the static impedance.

For extracting the peak power point from the module, various methods are adopted. They are explained as:

(a) In the first method, a small signal of current is injected in the module. The dynamic bus impedance $Z_d=\frac{dV}{dI}$ and static bus impedence $Z_s=\frac{V}{I}$ are measured. Then, the operating point is shifted up and down. The point when $Z_d = -Z_s$ is obtained, that point corresponds to the maximum power.

(b) In the other method, the voltage is increased as long as $\frac{dP}{dV}$ is positive that is the voltage is increased as long as we get more power. If $\frac{dP}{dV}$ is measured as negative, then the voltage is decreased. The voltage is kept if $\frac{dP}{dV}$ is near zero within the preset dead band.

2.3 Wind Energy Conversion System: The generation of electricity using wind energy is a complex system as it requires the knowledge from various fields such as mechanical, electrical, aerodynamic and civil engineering which comes together. The main elements of the wind energy conversion system are rotor, rotor blades, and nacelle (which transfers mechanical power to the generator) and generator (Figure 2.14).

The wind turbine have the kinetic energy of wind with the help of two or more rotor blades and rotor is mechanically coupled to the electrical generator. The mechanical assembly consists of gearbox, which converts slower rotational speed of wind turbine to the higher for the electrical generator. Using supervising techniques and control the electricity generation from the system is maintained as per given specifications. Using these control techniques the protection of the overall system could be achieved.

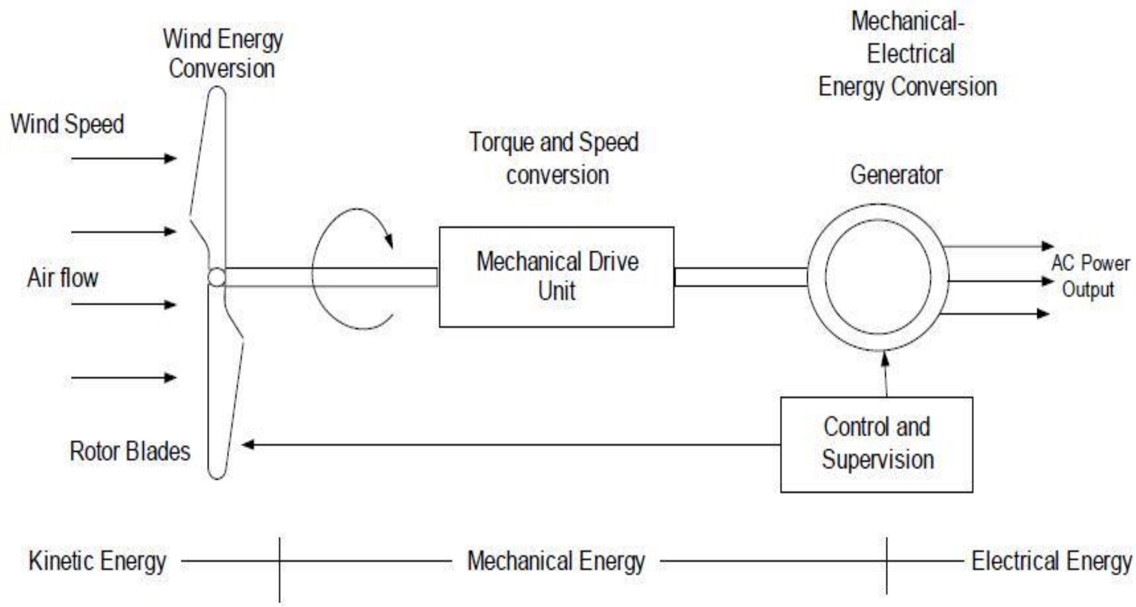


Figure 2.14: Power conversion in a wind energy conversion system.

The wind turbines could be designed under distinct designs. First is in vertical axis and other is in horizontal axis. The other name of the vertical axis machine is Darrieus rotor which was named after it's inventor and it has a shape resembling an egg beater. However, in majority of wind turbines models horizontal axis design is used.

As previously discussed, a wind energy conversion system is a complex system which transforms wind energy to mechanical energy and then to electrical energy. The power output and torque developed in wind turbines depands upon various parameters such as wind speed, type and size of the turbine etc. To design the dynamic model of the wind turbine, behavior of the turbine under these parameters should be realized considering it's region of operation. With the study of wind turbine behavior, desired operational characteristics can be achieved using control techniques.

2.3.1 Input and Output of a Wind Turbine:

1. Energy given to the wind turbine is decided by wind speed that is independent input quantity.

2. Turbine's rotor geometry and arrangement describes the specific input quantities of the machine

3. Rotor blade tilt, turbine speed and rotor blade pitch angle come up from the transmission system of the wind energy conversion system.

4. By changing the above three inputs, turbine output quantities that is drive torque or power can be controlled.

2.3.2 Power Extraction from the air stream [35].

With the understanding of the input and output variables of the wind turbine, it is possible to relate these two values by deriving an expression. The derivation of the relation between the wind speed and power is as follows:

The kinetic energy of air having mass m moving with speed V is given by:

$$\text{Kinetic energy} = \frac{1}{2}.m.V^2 \quad (2.11)$$

The power in moving air flow is the flow rate of kinetic energy per second.

$$\text{Power} = \frac{1}{2}.(mass\ flow\ rate\ per\ second)\ .V^2 \quad (2.12)$$

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers. Therefore, equation 2 results in:

$$P = \text{Power} = \frac{1}{2}.(mass\ flow\ rate\ per\ second)(V^2 - Vo^2) \quad (2.13)$$

Where:

P is the mechanical power extracted by the rotor in watts.

V is the upstream wind velocity at the entrance of the rotor blades in m/s.

Vo is the downstream wind velocity at the exit of the rotor blades in m/s.

Let p be the air density in (kg/ m^3) and A is the area swept by the rotor blades in (m^2); then the mass flow rate of air through the rotating blades in m^2; then the mass flow rate of air through the rotating blades is given by multiplying the air density with the average velocity.

$$\text{Mass flow rate} = p \ . \ A. \frac{V+V_O}{2} \qquad (2.14)$$

From equation 3 and 4, the mechanical power extracted by the rotor is given by:

$$P = \frac{1}{2} .[\ p \ . \ A. \frac{V+V_O}{2}] \ . (V^2 - Vo^2) \qquad (2.15)$$

After algebraic rearrangement of the terms, we have:

$$P = \frac{1}{2} . p \ . A. V^3 C_p \qquad (2.16)$$

Where,

$C_p = \frac{(1+\frac{V_O}{V})(1-(\frac{Vo^2}{V^2}))}{2}$ is the fraction of the upstream wind power, which is captured by the rotor blades and has a theoretical maximum value of 0.59. It is also referred as the power coefficient of the rotor or the rotor efficiency. In practical designs, the maximum achievable C_p is between 0.4 and 0.5 for high speeds two blade turbines and between 0.2 and 0.4 for slow speed turbines with more blades [35] .

From equation 6, we see that the wind speed, wind flow conditions of the rotor and the effective area of the rotor blades determines the operating conditions and power absorption of the turbine. Thus, by changing the flow conditions and by varying the effective area of the rotor system the output power of the turbine can be varied, which forms the base for the control of the wind energy conversion system.

2.3.3 Tip Speed Ratio: The tip speed ratio (TSR) is defined as the linear speed at the tip of the blade to the free stream wind speed. It is denoted by λ [35]

$$\text{TSR} = \lambda = \frac{\omega R}{V} \qquad (2.17)$$

Where:

R is the rotor blade radius in meters.

ω is the rotor angular speed in radians/ sec.

TSR is related to the operating point of wind turbine for extracting maximum wind power. At a particular TSR, the maximum rotor efficiency C_p is achieved. This value is specific ro the aerodynamic design of the turbine. To keep the TSR constant at the optimum levels at all times, the rotor must turn at low speed at low wind speed and at high speed at high wind speed. The larger the value of TSR, wind turbine will rotate faster at a given wind speed. Turbines with high speed are preferred for efficient electricity generation. From equation 7, for a particular value of wind speed V, turbines with large blade radius R result in low rotational speed **ω**, and vice versa. Wind turbines with high tip speed are preferred for operation over a wide range of wind speeds.

2.3.4 Operating Schemes Of a typical Wind Turbines:

The wind energy conversion system could be classified into two types: fixed or constant speed wind turbines which operates at constant speed which is predetermined according to the design of generator and second is variable speed wind turbine. The controlling of the wind turbine is decided by the operating strategy of the system for example, the power output of the turbine at very high speed is controlled using pitch angle control and maximum energy could be captured using rotor torque control. But in case of fixed stall regulated turbines, there is no method for controlling input. These turbines are made to operate at a fixed pitch angle of turbine blades to operate at specific wind speed with optimal tip speed ratio. The disadvantage of these turbines is that when speed increases, it increases the angle of attack and exposes the large area of blade to wind. As a result, of which it results in reduced rotor efficiency, and limits power output. The concept of the stall region, can be varied by operating the turbine at two separate constant operating speeds. It could be achieved by either changing the number of poles of electrical generator or by changing the gear ratio. The advantage of the stall control method is that it is simple. It’s disadvantage is that wind turbine with stall regulated method will be unable to capture wind energy if the speed of the wind is different other than it’s design.

In fixed speed pitch regulated turbines at start up pitch regulation is used. After starting it is only used to limit the power above the rated wind speed of the turbine. The generator control torque is used for the purpose of the optimization of power output in variable speed wind turbines. The amount of energy captured increases by 20-30% with variable speed turbines as compared to fixed speed operation.

Characteristic curve for variable speed and constant speed wind turbine are shown in the Figure 2.15.

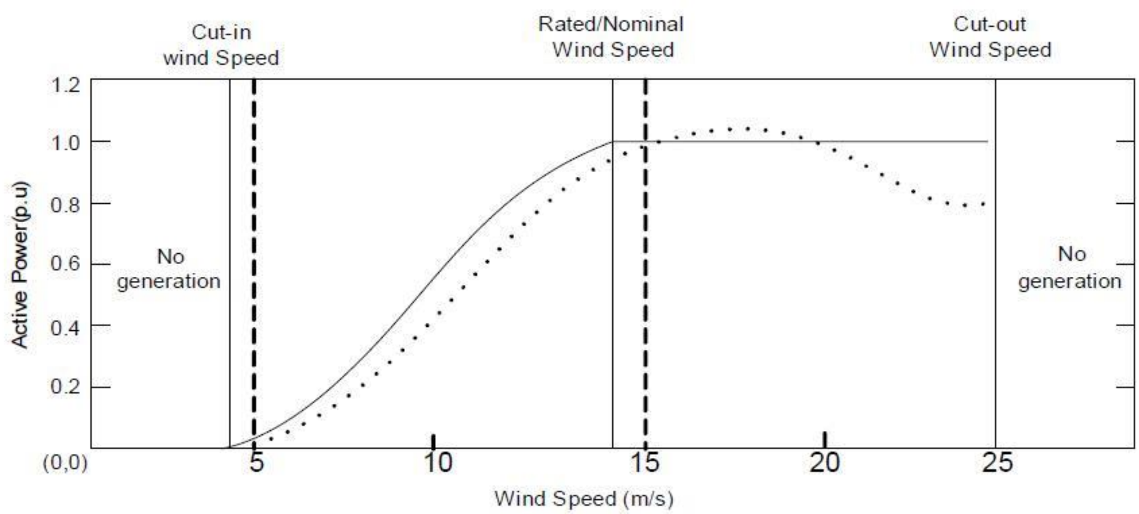


Figure 2.15 Characteristic curves for variable speed pitch controlled (solid) and constant speed stall controlled (dotted) wind turbine.

For a constant speed stall controlled wind turbine the output power increases a bit higher than the rated limit until cut-in speed of turbine is reached. This ensures that even if wind speed exceeds nominal value, the generator will not be overloaded, thus providing an element of passive power output regulation. On the other hand, with variable speed wind turbine the amount of power captured from the wind is more but by having variable speed control function it increases the cost of the overall system. So, a balance has to be maintained in between an increase in energy while designing a variable speed system.

2.3.5 Variable Speed Wind Turbine System: A variable speed wind turbine with pitch regulation is shown the figure 2.16 .The main parameters characterizing a variable speed wind turbines are listed below:

1. The rotor inertia determines the turbine cut-in speed.

2. The turbine nominal rotor speed, power coefficient curve and rotor diameter determines the nominal wind speed of the wind turbine for a given nominal power.
3. The parameters of the pitch angle controller are determined by the rated power and the allowable amount or rotor over-speeding.

The two methods that affect the turbine operation using variable speed pitch controlled wind turbine are speed change and blade pitch change. The control schemes for the operation of variable speed wind turbines are:

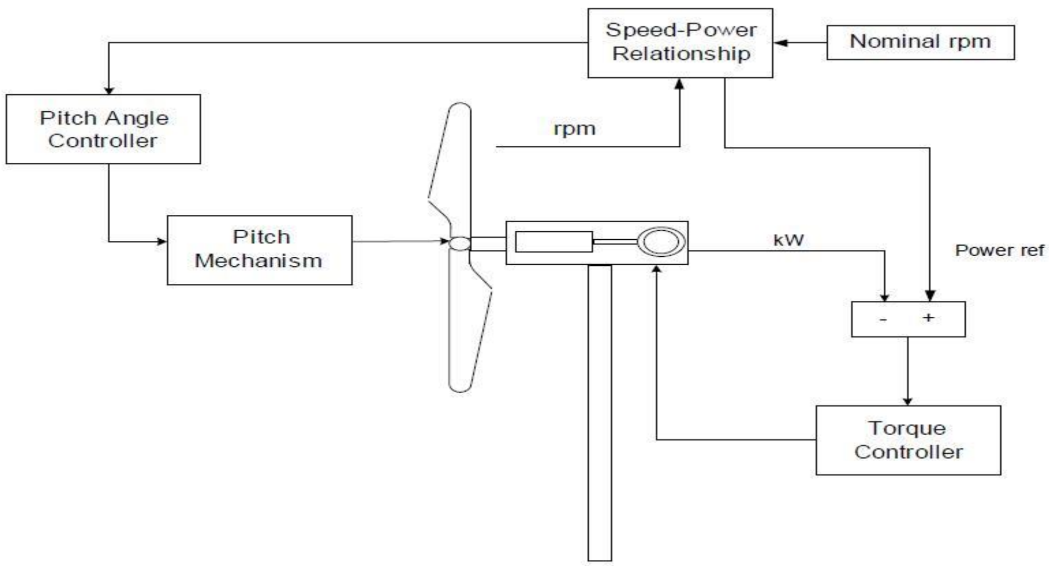


Figure 2.16: Typical variable speed pitch regulated wind turbine.

1. Power Limiting Schemes: When wind speed goes above the rated value, this method limits the output power to the rated power. It is done by decreasing aerodynamic efficiency by varying the blade pitch angle. Thus, limiting the wind turbine power to the acceptable levels.
2. Power Optimization Schemes: This scheme optimizes to energy capture ensuring the optimum tip speed ratio, when the wind speed goes below the rated limit. For this, constant wind speed is maintained corresponding to optimum tip speed ratio. If the electrical load is controlled to change the speed, it results in generator overloading for wind speeds above nominal vales. To overcome the problem, the method such as generator control torque can be used.

The above two methods with their respective regions are shown in the figure 2.17

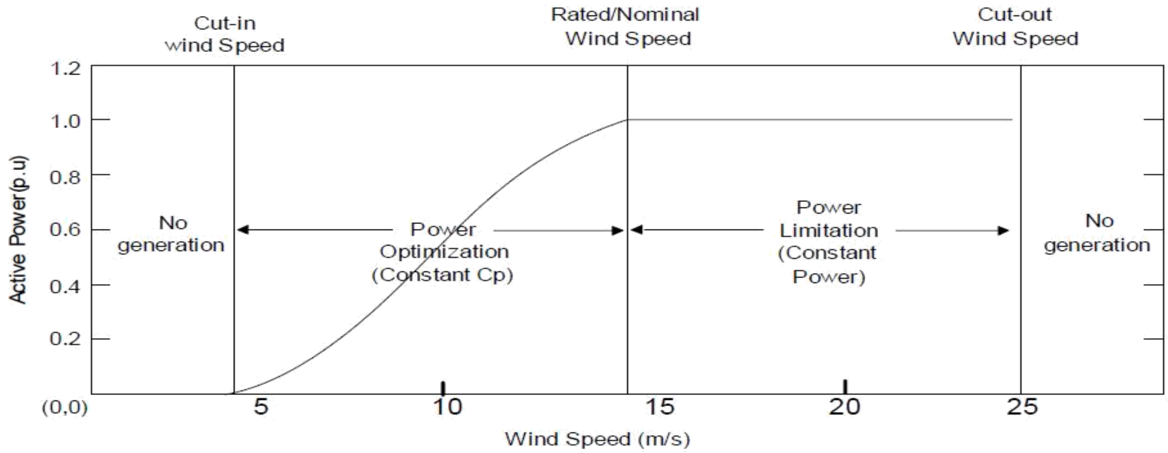


Figure 2.17 Power optimization strategies of variable speed pitch control wind turbine.

Table 2.1 Comparison between the Variable Speed and Fixed Speed operations [35]

	Constant Speed	Variable Speed
Advantages	Simple and robust	Less mechanical stress
	Inexpensive electrical system	Higher energy capture
	Electrically efficient	Aerodynamically efficient
	Fewer parts, hence high reliability	Low transient torque
	No frequency conversion, hence, no current harmonics	Mechanical damping system not needed, the electrical system could provide the damping
	Lower capital cost	No synchronization problems. Stiff electrical controls can reduce voltage sags
Disadvantages	Aerodynamically less Efficient	Electrically less efficient
	Mechanical stress	Expensive
	Noisy	Sometimes, involves complex control strategies

Pitch Angle Controller: pitch angle controller controls the wind flow around wind turbine blades to control the torque exerted on turbine shaft. The pitch angle is kept constant at it's optimum value for wind speeds less than rated wind speed. The maximum rate with which the pitch angle varies is in the order of 3 to 10 degrees per second. It should be observed that due to the size of the rotor blades the pitch angle changes at finite rate, which may be at quite low values. By having the pitch angle controller the speed above the nominal values is allowed without causing problem for wind turbine structure

2.4 Power Electronics Interface: The power that is produced by photovoltaic array is in the form of D.C . To interconnect the standalone pv system to the utility grid and to convert the D.C power to the 3 phase A.C power. A power electronic interfacing circuit is required. The power electronic interface has the ability to control the output variables of the system such as voltage, frequency, to match the reference values. The circuit comprises of DC to DC converter and DC to AC inverter.

The components used in the power electronic interfacing circuit could be explained as follows:

(a) DC to DC converter: The photovoltaic power system uses DC to DC converter for battery charging and discharging.

(i) Battery Charge Converter: The DC to DC battery charge converter circuit is also called as buck converter. The device used for switching in these types of converters may be BJT, MOSFET or the IGBT. The buck converter steps down the input bus voltage to the battery voltage during battery charging. At high frequency (in tens of KHz) the transistor is made to switch ON ad OFF. The duty ratio D of the switch is defined as:

$$\text{Duty ratio D} = \frac{T_{on}}{T} = T_{on} \text{ . Switching Frequency}$$

The operation of the charge converter during one complete cycle of operation is shown in the figure 2.18

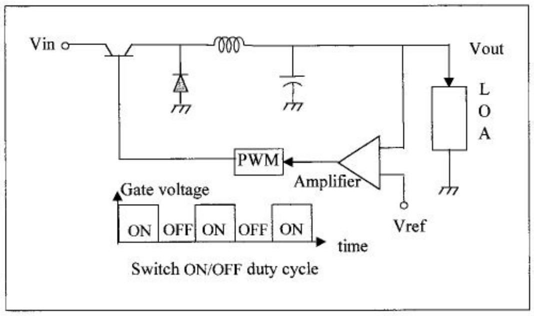


Figure 2.18: Battery charge converter for pv systems (DC to DC buck converter)

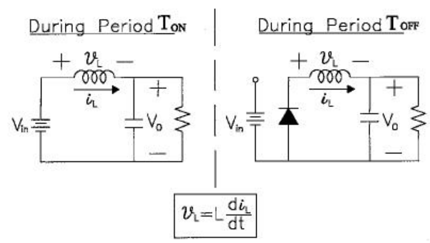


Figure 2.19: Charge converter operation during switch on-time and off-time

During the ON time, the switch is closed and the circuit operates as shown in the left of figure. During the OFF time, the switch is open and the circuit operates as shown in the right of the figure. The power drawn during the complete cycle operation is zero. However, the power is provided by the energy stored in the inductor and capacitor. The return circuit is provided by the diode. Thus, during the OFF period of the switch, the inductor and capacitor provides energy storage.

The energy balance over one period of the switching period in the power electronic circuit is done as follows:

Energy supplied to the load over the total period of repetition = Energy drawn from the source during the ON period.

Energy supplied to the load during the OFF time= Energy drawn from the inductor and capacitor during the OFF time.

The voltage and current waveform of the buck converter is shown in the figure 2.20. Voltage across the inductor is equal to L$\frac{d_{IL}}{dt}$.

During ON time, $\delta I_L . L = (V_{in} - V_{out}).T_{on}$ (2.18)

During OFF time, $\delta\, I_L . L = V_{out} . T_{off}$ (2.19)

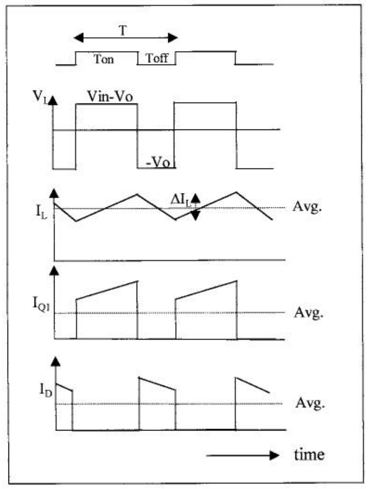


Figure 2.20: Current and voltage waveforms in the buck converter.

The output voltage controlled by the variation of duty ratio D is written as: $V_{out} = V_{in} . D$

The duty ratio is controlled by the variation of T_{on} . So, such a converter is therefore, also known as the Pulse Width Modulated (PWM) converter.

(ii) Battery Discharge Converter: The battery discharge converter is shown in the figure 2.21 .During the discharging it steps up the decrease in voltage to the required output voltage. When the switch is OFF, the inductor current is forced to flow through the diode and the load. When the switch is ON, the inductor is connected to the DC source. With the duty ratio ratio D of the switch the output voltage is given as:

$$V_{out} = \frac{V_{in}}{1-D}$$

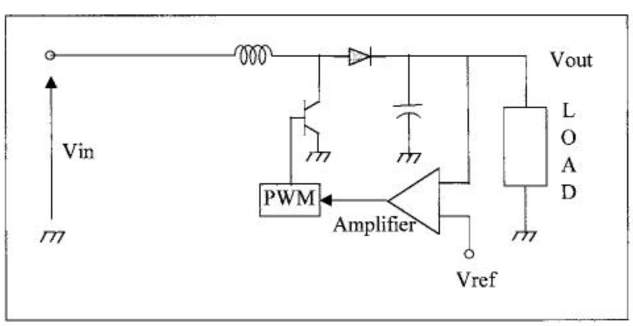


Figure 2.21: Battery discharge converter circuit for pv systems (DC to DC boost converter).

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When the value of D<1, the output voltage is greater than input voltage. Therefore, boost converter step up the voltage. On combining the buck and boost converter in cascade, gives a buck-boost converter. The voltage relation of cascading buck and boost converter can be written as: $V_{out} = \frac{V_{in.D}}{1-D}$.

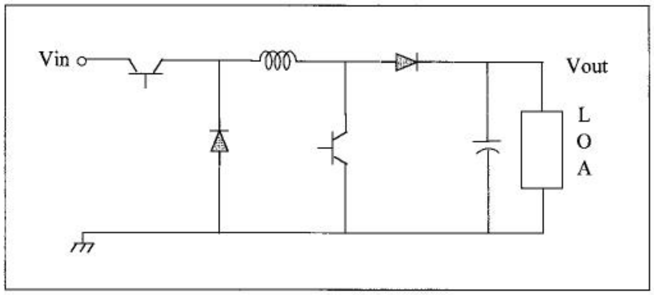


Figure 2.22: Buck-boost converter circuit (general DC to DC converter for pv systems)

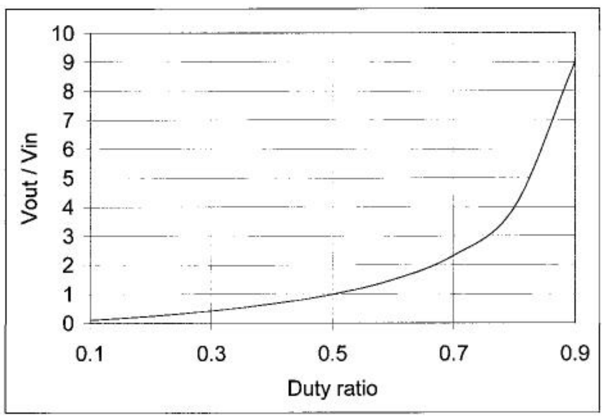


Figure 2.23: Buck-boost converter output to input ratio versus duty ratio.

2.4.1 DC to AC Inverter: The inverter used in power electronic circuit converts DC to AC . The term "Converter" used means either the rectifier or the inverter. The DC input to inverter may be from any of the following:

(a) DC output of the battery used in the wind or photovoltaic power system.
(b) Rectified DC output of the variable seed wind power system.
(c) DC output of the photovoltaic power module.

Figure 2.24 shows the DC to three phase AC inverter circuit diagram. The fundamental frequency (50 Hz) phase to neutral voltage is as follows:

$$V_{ph} = \frac{2*1.414}{\pi} \cos\left(\frac{\pi}{6}\right) . V_{dc} \tag{2.20}$$

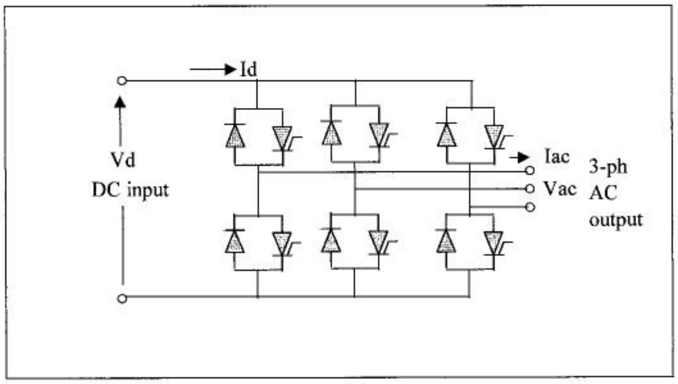


Figure 2.24: DC to three-phase AC inverter circuit.

As in the case of BJT, MOSFET, IGBT, the thyristor current, once switched on, must be forcefully OFF (commutated) to cease conduction. If thyristor is used as switching device, the circuit requires additional commutating circuit to perform the function. The commutating circuit is a significant part of the inverter circuit.

CHAPTER 3

PROBLEM FORMULATION

3.1 System Layout

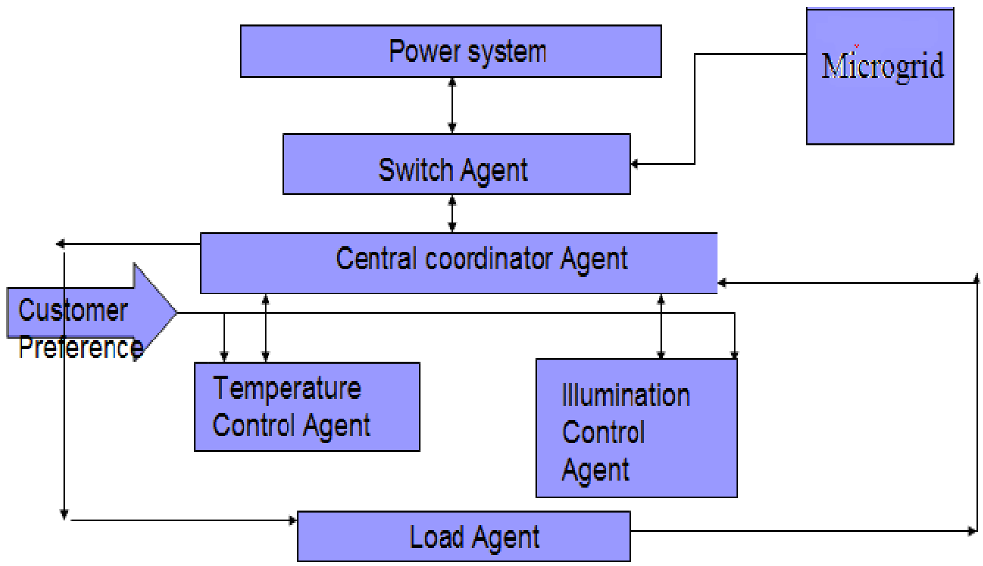


FIGURE 3.1: System layout with intelligent control for energy management

There is an increasing demand of energy in the power system and that could not be met by utility grid alone. It is due to the limited amount of conventional sources (coal, oil) available. In order to overcome the increasing demand of energy, Micro grid could be an alternative which uses renewable sources of energy. It includes photovoltaic arrays and wind turbines. Also, these renewable sources of energy have an additional advantage of being eco-friendly.

A control system is designed in the manner that if there would be an availability of both renewable and conventional sources. The higher priority would be given to the renewable sources as compared to conventional sources.

Moreover, the excess amount of energy, if available, could be stored using battery energy storage system which is present with micro-grid system. The system had a provision that the micro grid could be connected and disconnected from the utility grid by means of switch agent.

The control system for the smart building utilizes the intelligent multi-agent system technology. The factors that were under considerations were the comfort factors which includes visual and thermal factors.

A smart commercial building under consideration have critical and non-critical loads. Critical loads needs continuous supply, consists of lightning and air conditioners, which provides visual and thermal comforts.

Non-critical loads include swimming pool pumps, decoration lamps and fountain pumps. These loads can be properly managed using developed control system in such a way that the total energy consumption reduces and the saved energy is stored. The saved energy will be used by critical loads when required maintaining the visual and thermal comforts.

In power saving mode, the choice between the connection and disconnection of the non-critical loads would be dependent upon the priority set up using intelligent control system, or could be a Matlab program.

3.2 Microgrid: A Micro grid consists of renewable energy sources which are used as a primary energy sources and utility grid provides the backup.

The control system developed uses renewable energy sources, such as photovoltaic arrays, wind generation and battery energy storage system.

(a) **Solar Energy:** For tapping the solar energy photovoltaic arrays were used which have an advantage that they have no moving parts and requires less maintenance.
(b) **Battery Energy Storage System:** For storing surplus amount of energy battery energy storage system are used which stores energy during off peak hours and further used up during necessary requirements.

3.3 Intelligent Control System: The intelligent control system is an energy management system of the commercial building which aims to improve the environment within the building thereby reducing the energy consumption without sacrificing customer’s comfort. The agents used in the control system could be seen in the system layout. They are:

(a) Switch Agent: It connects or disconnects the micro-grid from the utility grid.

(b) Central Control Agent: It could be an intelligent control system or a Matlab program which combines all critical loads, non-critical loads, micro-grid thereby reducing power consumption.

(c) Load Control Agents: The load controller agents are fuzzy controllers for controlling comfort factors like visual and thermal comforts.

(d) Load Agent: They connect or disconnect the non-critical loads based on their priority thereby reducing the power consumption. The saved energy could be used by critical loads for maintaining overall comfort.

3.4 Control Scheme: The renewable sources of energy supply energy to the loads within the building which makes it self-reliant. For making best available use of energy the critical loads, lightning and air conditioners, are properly selected which selects the illumination level and temperature level according to the set values. For this fuzzy logic controllers are used. So, it reduces the energy consumption thereby maintaining customer's comfort.

If the energy consumption is not met by micro grid then the non-critical loads are managed in such a way that they are set up according to the priorities.

3.5Photovoltaic System: The components of the stand-alone pv power system is shown in the figure 3.2. the peak power tracker senses the current and voltage outputs of the array and continuously adjusts the operating point to extract the maximum power under the given climatic conditions. The output of the array goes to the inverter, which converts the DC into AC. The array output in excess to the load requirements is used to charge the battery the battery charger is usually a DC-DC buck converter. If excess power is still available after fully charging the battery, it is shunted in dump heaters, which may be space or room heaters in the stand alone system. When the sun is not available, the battery discharges to the inverter to power the loads. The battery discharge diode Db is to prevent the battery from being charged when the charger is opened after a full charge or for other reasons.

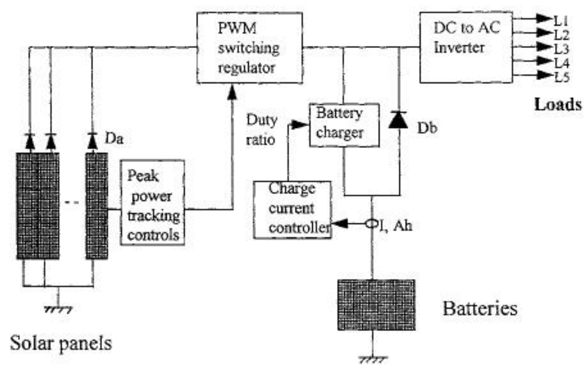


Figure 3.2: Peak power tracking photovoltaic power system showing major components

The array diode Da is to isolate the array from the battery, thus keeping the array from acting as load on the battery at night. The mode controller collects the system signals, such as the array the battery currents and the voltage, keep tracks of the battery state of charge by book keeping the charge/ discharge ampere- hours, and commands the charger, discharge converter, and dump heater ON and OFF as needed. The mode- controller is the central controller for the entire system.

Table 3.1: System Parameters

Serial Number	System Quantities	Parameters
1	Source	3 Phase,120 KV rms (phase-phase), 50 Hz, $2500e^6$ short circuit level(VA), 120 KV base voltage, X/R=7.
2	Converter	IGBT based , 3 arm, 6 pulse, $R_{on} = .2e^{-3}$
3	Transformer	Nominal Power $25e^3$VA, 50Hz, Y/Δ 2500/260 V, $(R_1/R_2, L_1/L_2)$ = (.001/.001 , .03/.03) .

4	PV Array	Open circuit voltage= 64.2 V, short circuit current= 5.96 A, maximum power current= 5.58 A, maximum power voltage= 54.7 V.
5	3-phase PI Section Line	Resistance (ohm/Km) $[r_1\ r_0]$ [.1153 .413], Inductance(H/Km) $[l_1\ l_0]$ $[1.05e^{-3}\ 3.32e^{-3}]$, Capacitance (F/Km) $[c_1\ c_0]$ $[11.33e^{-9}\ 5.01e^{-9}]$
6	STATCOM (Phasor Type)	Nominal voltage $25e^3$, 50 Hz, converter rating, converter impedence $[\ R_{pu}\ L_{pu}]$ =[.22/30, .22].
7	Induction Generator(Phasor type)	Output power $2*1.5e^6$ W, Base wind speed 9 m/sec, pitch angle controller gain $[K_p\ K_i]$ [5 25], maximum pitch angle 45 degree, Rate of change of pitch angle= 2 deg/sec.
8	Load	260 Vrms (phase to phase), 50 Hz, 100 W, voltage 10 KV.

SIMULATION STEUP:

The simulation diagram of the wind farm in phasor model generating 9MW power is shown in figure 3.3.

The wind farm is equipped with three wind turbine units. Each unit consists of two wind generators of 1.5MW rating. The three wind turbines are connected in parallel supplying power to the grid. The voltage generated by turbines is step-up to 25kv using step-up transformer. The voltage after stepping up is transmitted to the grid through a π connected transmission line. The photovoltaic system that is connected with the wind generation system to form an hybrid system is shown in figure 3.4.

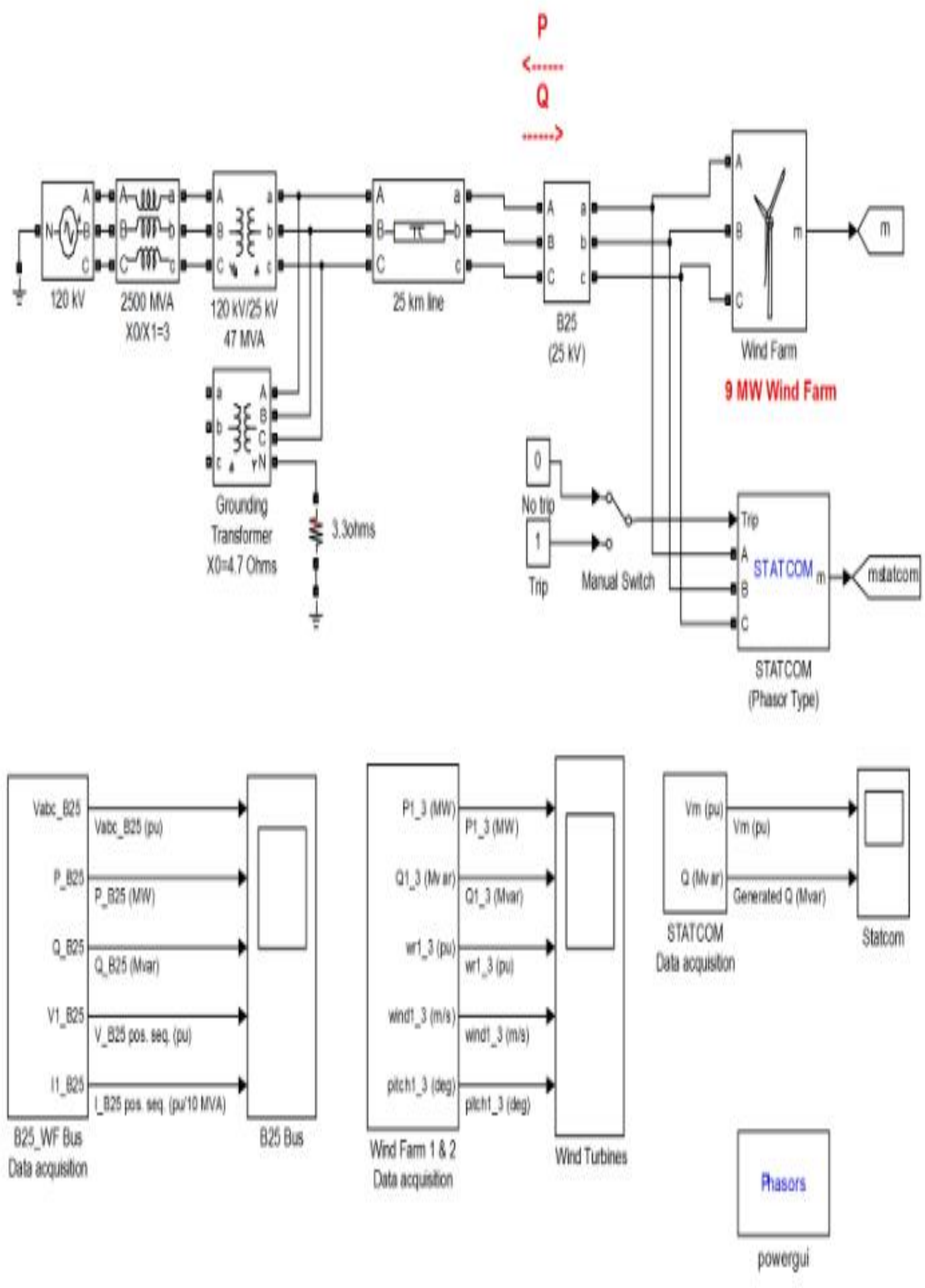


Figure 3.3: Phasor Model Of The Wind Energy Conversion System

The P.V. system is developed in Matlab/Simulink. The main parameters of the P.V. array is set according to Sunpower SPR-305-WHT. The irradiation values are varied in between 1000W/m^2 and 250W/m^2.

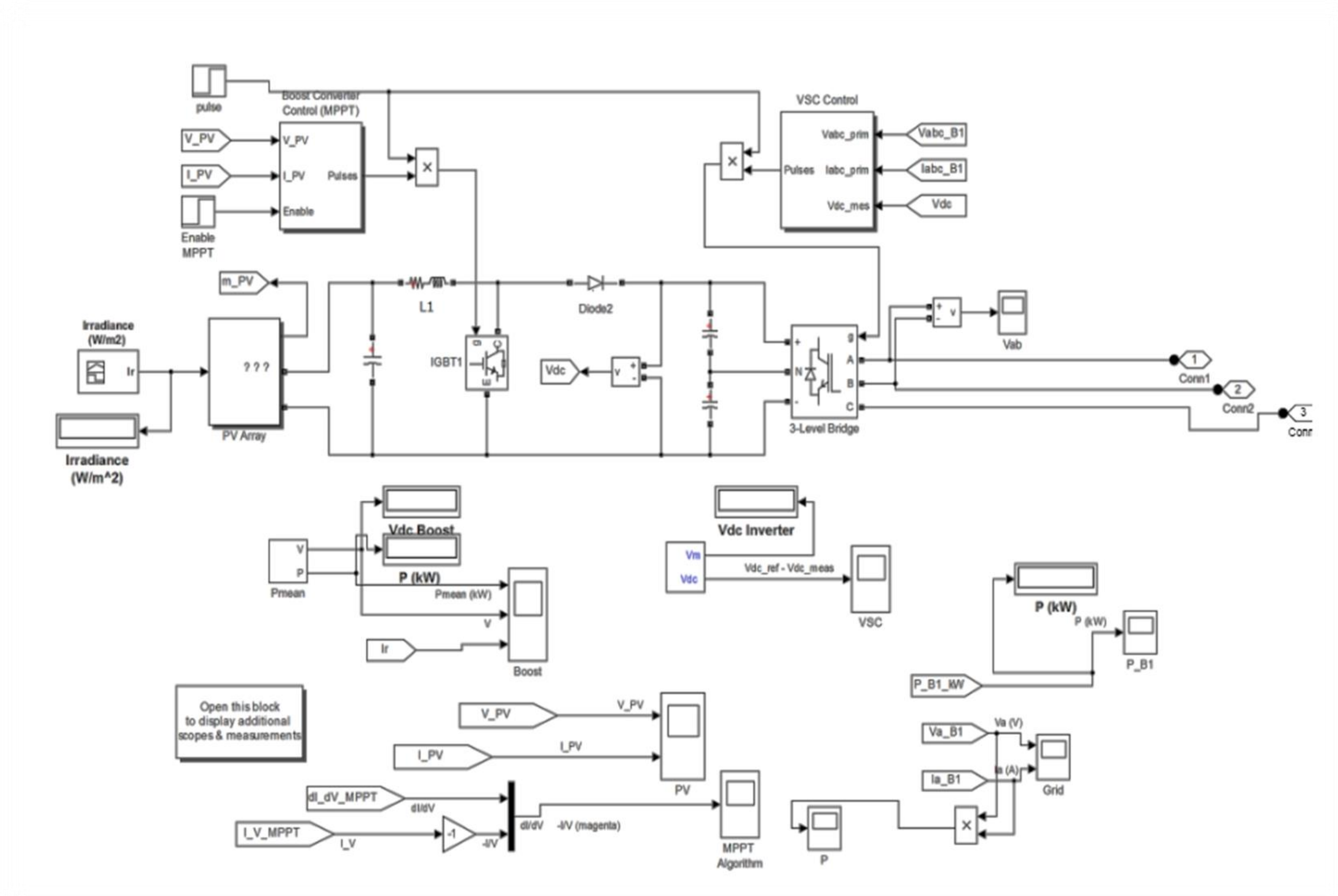


Figure 3.4: Discrete Model Of The Photovoltaic System

The current in the P.V. panel is calculated by equation:

$$Ipv = Iph - Ip\left[e^{\frac{q(Vpv+IpvRs)}{\eta.k.T}}\right] - \frac{Vpv + Ipv.Rs}{Rsh}$$

Where,

Ipv, Vpv: voltage and current at the output terminals of the photovoltaic cells,

Iph: photocurrent,

k: Boltzman constant

η: quality factor of n-p junction,

q: electron charge,

T: ambient temperature, K

The open circuit voltage(Voc), short circuit current(Isc), maximum power current(Ipm), maximum power voltage(Vpm) used in the PV system is given in the table:

Table 3.2: PV panel parameters

Open circuit voltage(Voc)	Short circuit current(Isc)	Maximum power current(Ipm)	Maximum power voltage(Vpm)
64.2	5.96	5.58	54.7

The three level voltage source converter (VSI) converts d.c. voltage into 3 phase a.c. voltage. A battery energy storage system is also connected with the P.V. system to store the excess amount of energy.

An hybrid system consisting of P.V. and wind plant could be connected/ disconnected from the grid by a change over switch to meet the load demand if the excess of energy available that could be stored in the battery storage system.

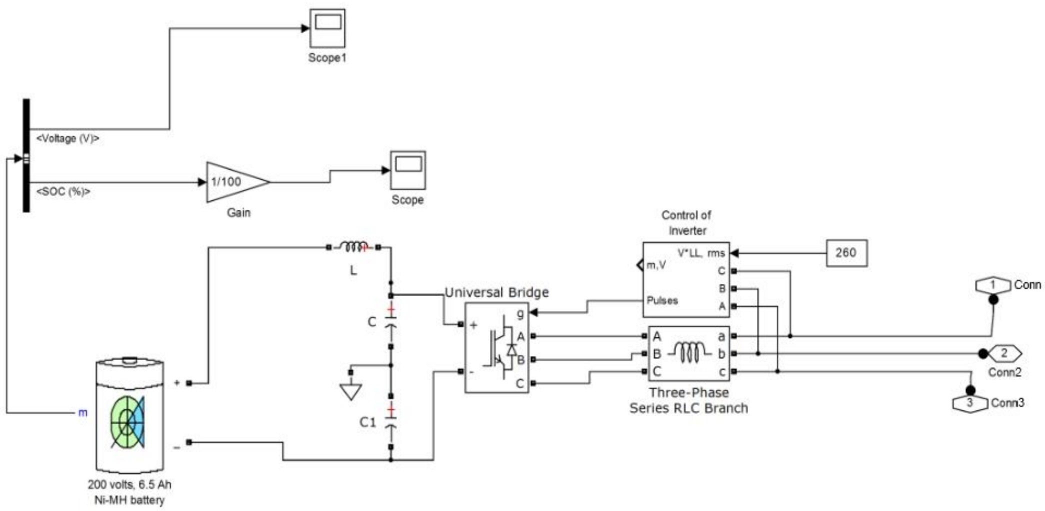
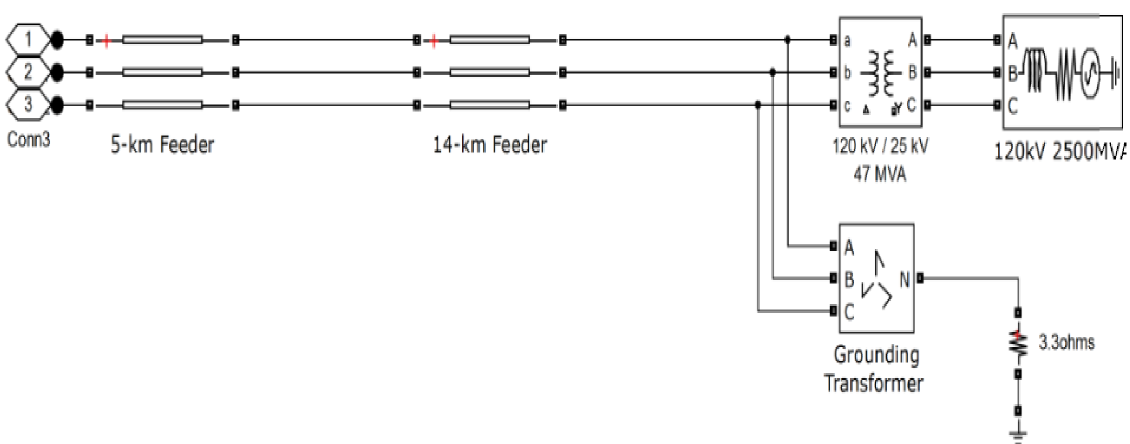


Figure 3.5: Simulation Model Of Battery Energy Storage System



FIigure 3.6: Simulation Model Of The Utility Grid

SIMULATION RESULTS AND DISCUSSIONS

The wind energy conversion system produces an output power of 9 MW at the wind speed of 11 m/sec.. The hybrid system is connected to the 50Hz grid. At starting the pitch angle of the turbine was at zero degree but when the generated power exceeds 3MW, the pitch angle increases from 0 degree to 8 degree in order to bring the power to the nominal value.

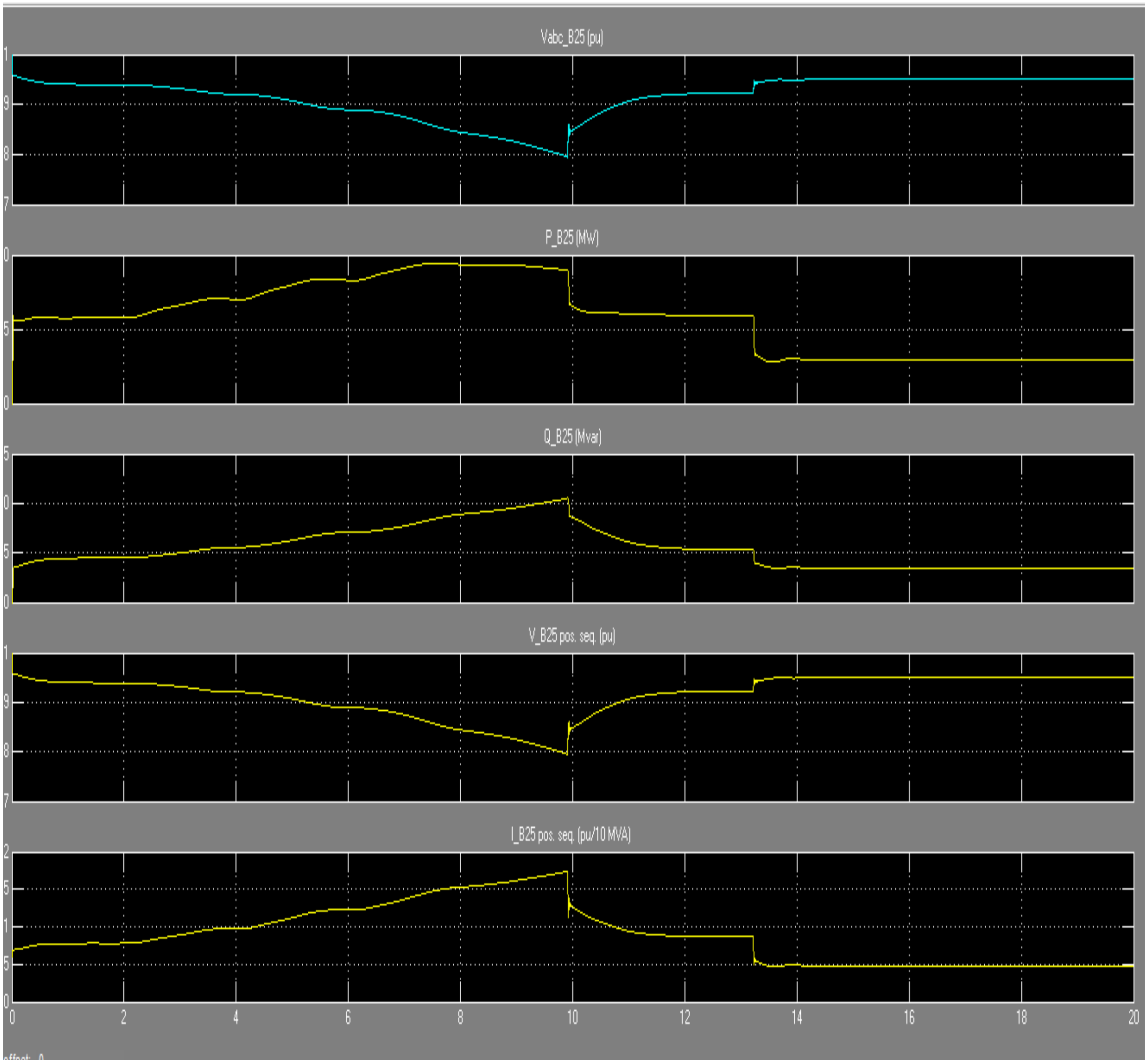


Figure 4.1: output voltage (V_abc), output power(MW), reactive power(Mvar), voltage (V_B25), and current(I_B25)

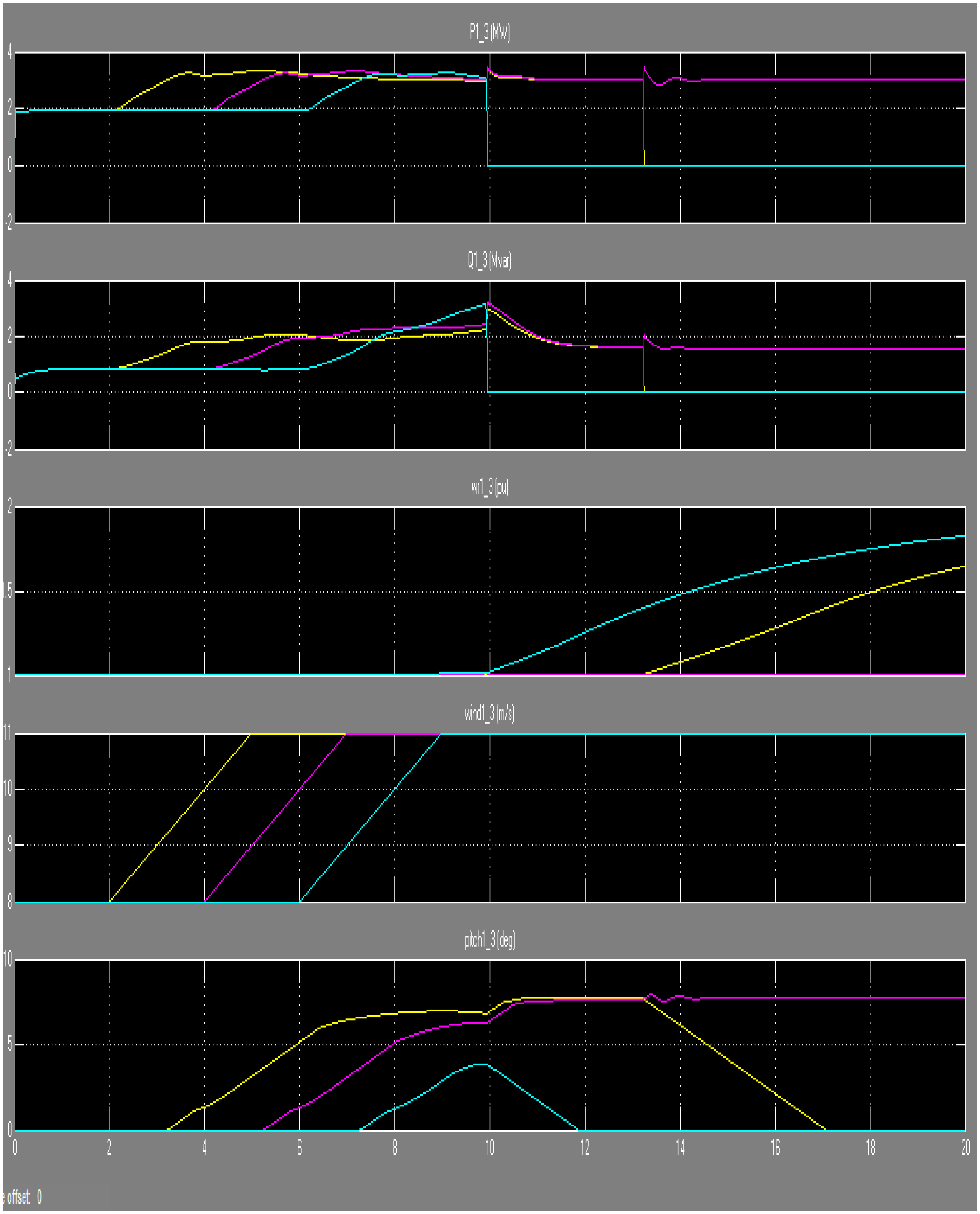


Figure 4.2 : output power (MW) ,reactive power (Mvar), Wind Speed (pu), Wind Speed (m/sec), and Pitch (degree) of the Wind Turbine.

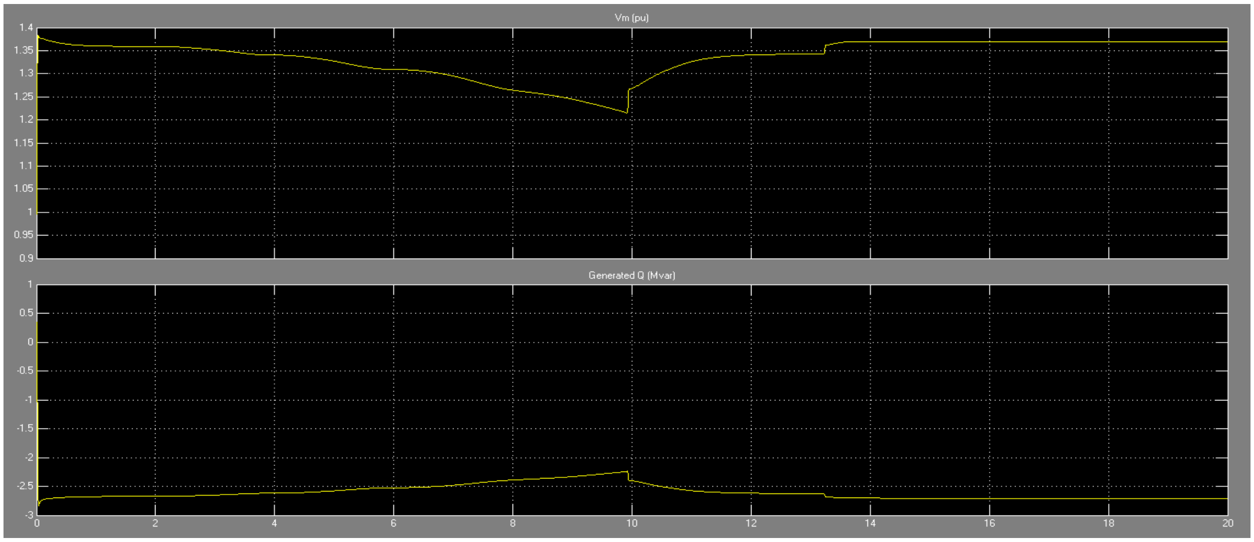


Figure 4.3 : Voltage (pu), and Reactive Power (Mvar) supplied by the STATCOM

In the simulation, the PV plant produces a power output of 100KW at an irradiance of 1000W/m^2.

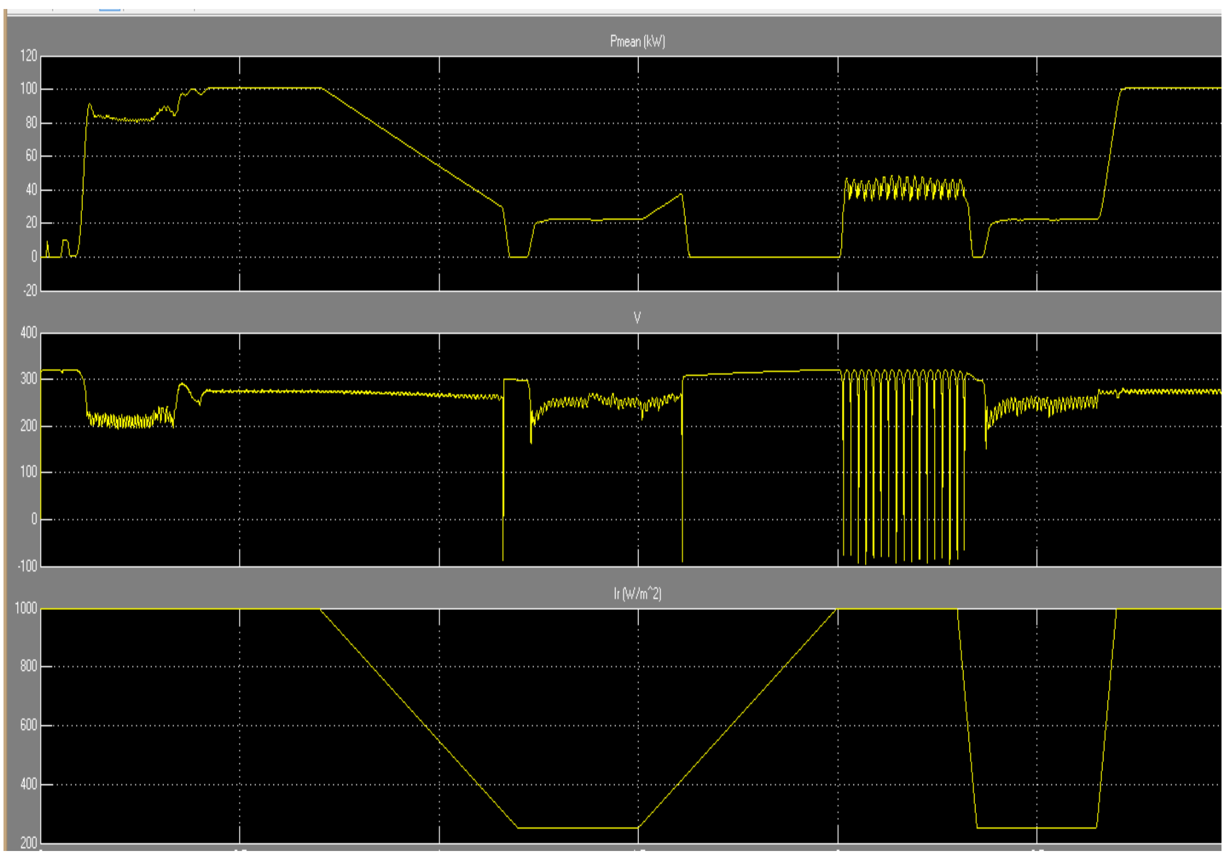


Figure 4.4 : output power (KW), voltage (V), and Irradiance (W/m^2) of the photovoltaic plant

The DC output voltage and DC output current of the photovoltaic array panel.

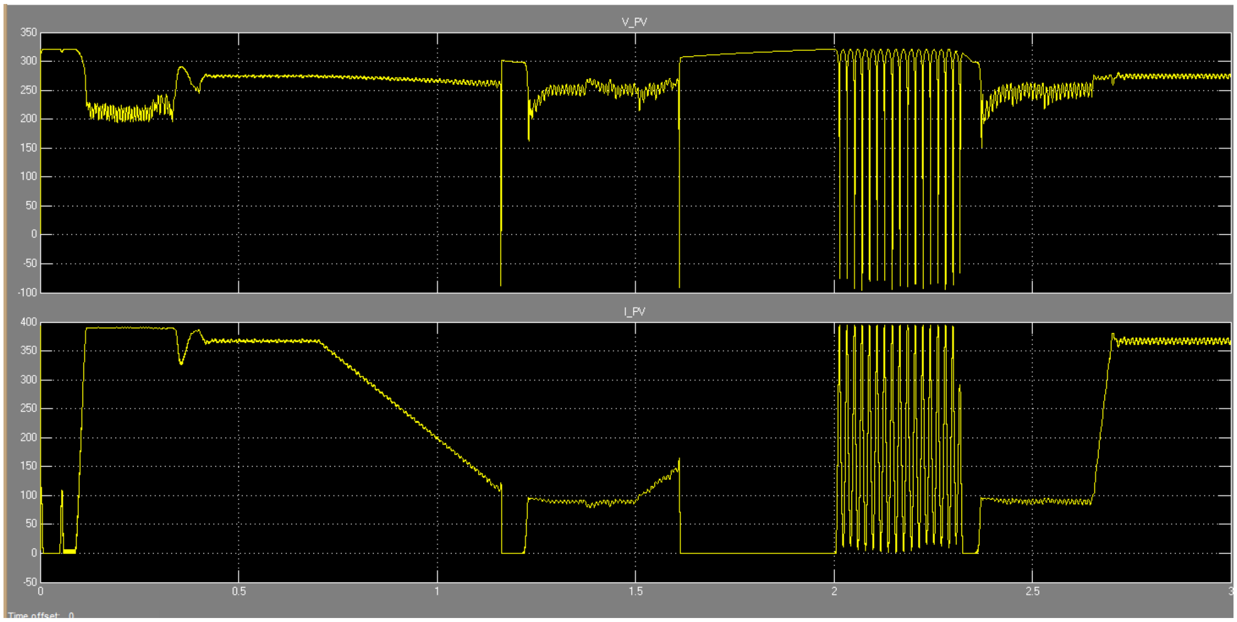


Figure 4.5 : output D.C. voltage(V) and output D.C. current(A) of the photovoltaic array

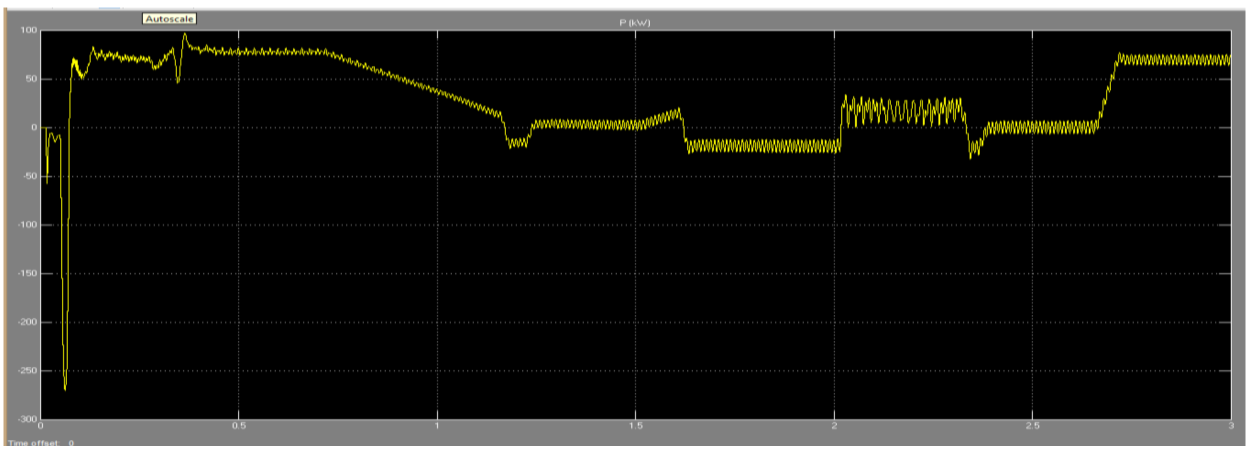


Figure 4.6 : Output Power of the Photovoltaic Plant.

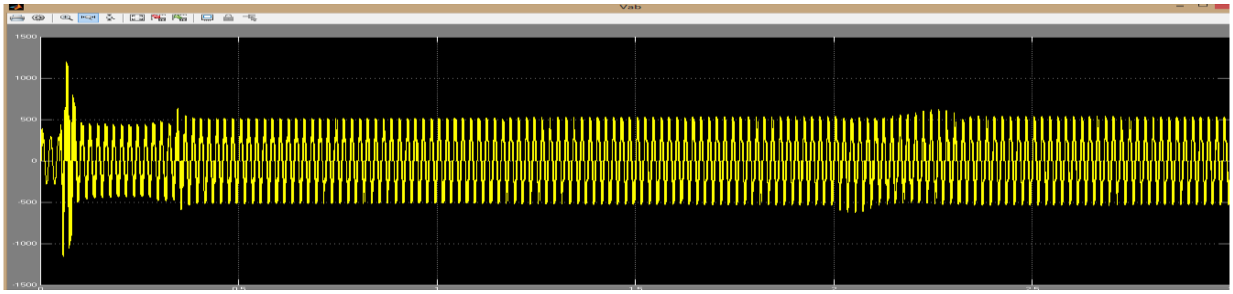


Figure 4.7 : Line to Line voltage (V_{ab}) of the photovoltaic plant.

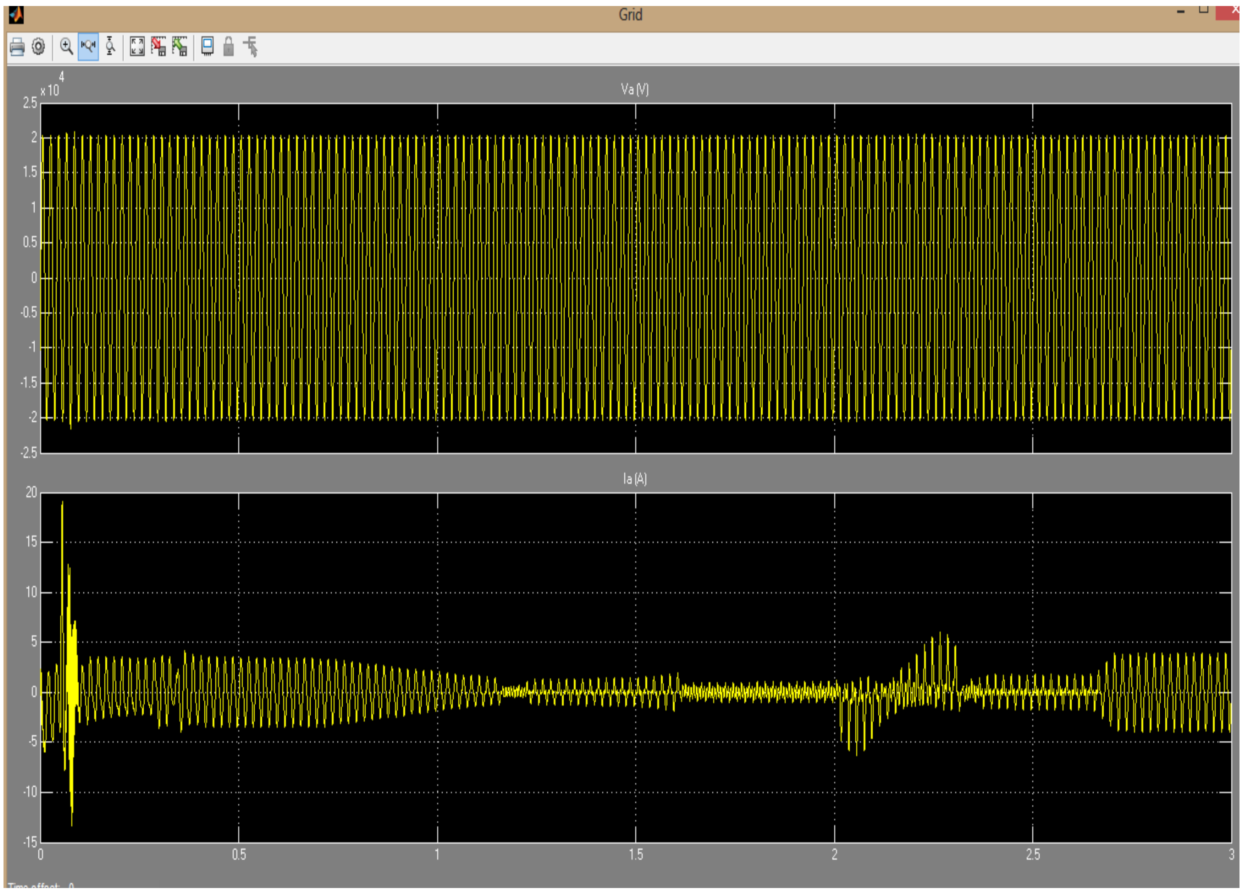


Figure 4.8 : Output voltage (V) and Output Current (A) of the grid connected to the photovoltaic plant.

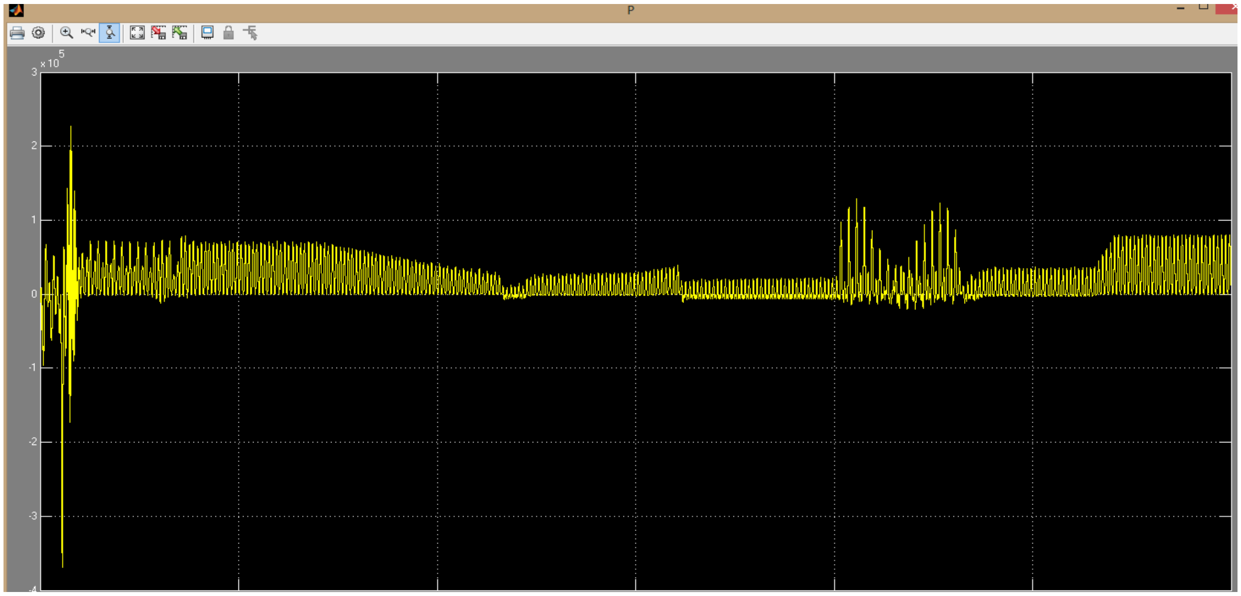


Figure 4.9 : Output Power(W) of the grid connected to the photovoltaic plant

BATTERY STORAGE SYSTEM

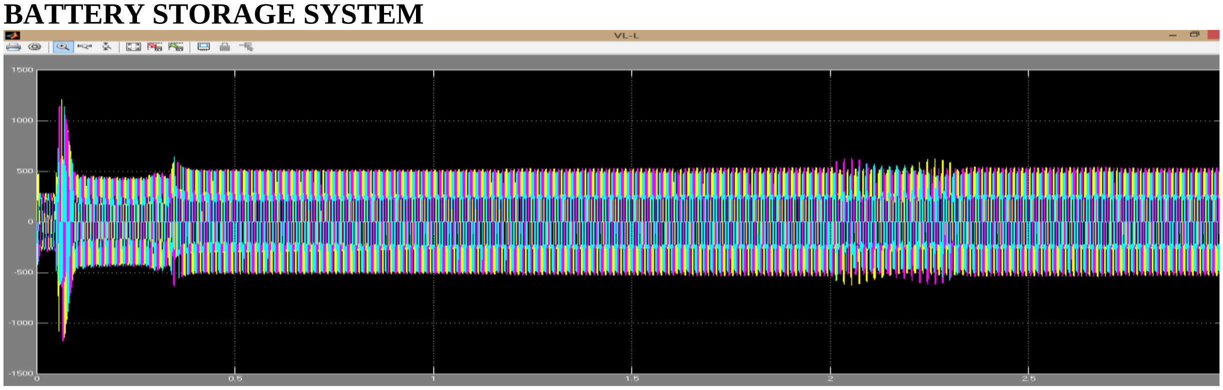


Figure 4.10: Line to Line voltage of the battery energy storage system.

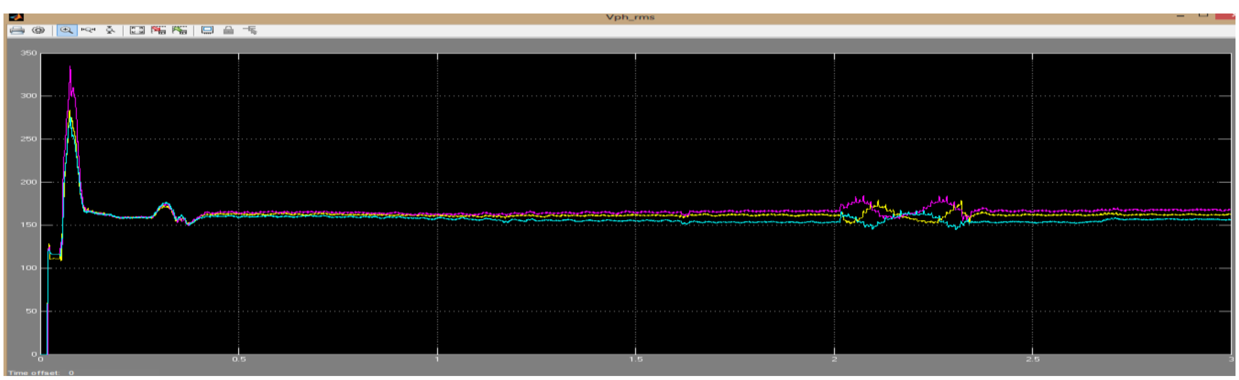


Figure 4.11: phase voltage (V_{ph_rms}) of the battery energy storage system.

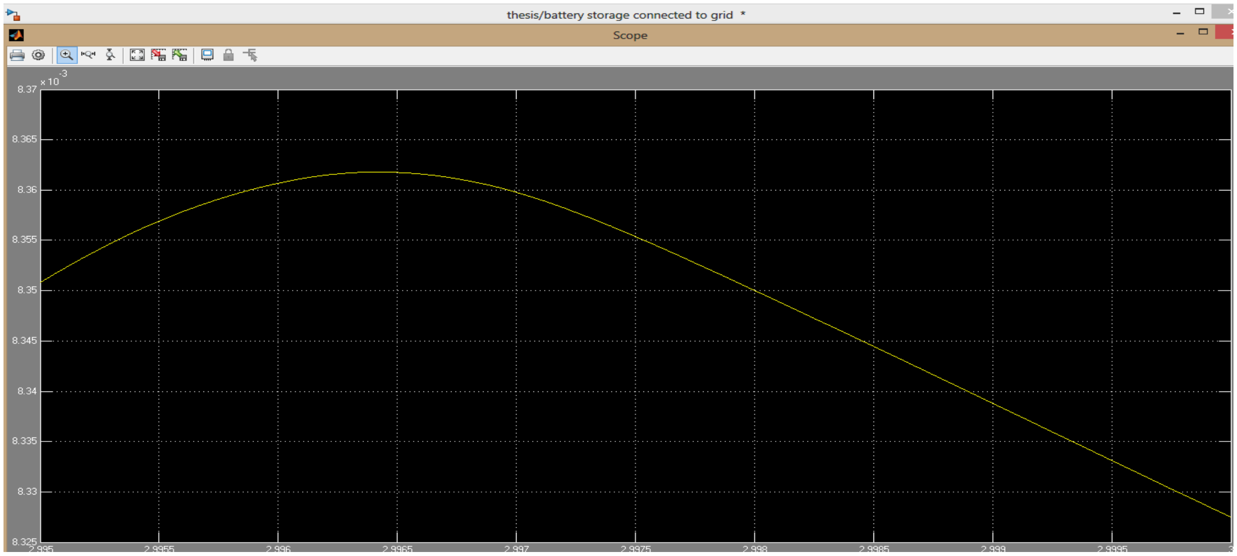


Figure 4.12: State Of Charge of the Battery in Battery Energy Storage System.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION:

In this dissertation a hybrid system model based on Photovoltaic and wind energy conversion system was proposed. The proposed system was simulated using Simulink block and modalism. The outputs of the PV system and the wind energy conversion system were studied. It was found that the proposed system was recovered from most of the faults as in the case of STATCOM. The transients were very less.

5.2 FUTURE SCOPE:

In this dissertation, the hybrid system is simulated which is used as a renewable energy source. The work could be expanded as follows:

Further work needs to be done in the hybrid system model as some controller could be connected in place of the manual change over switch for continuous supply to the loads. Additional work needs to be done in the hybrid model to replace the STATCOM to deliver the continuous supply to the grid even under faulty conditions.

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