GRID INTEGRATION OF LARGE-CAPACITY RENEWABLE ENERGY SOURCES

DISSERTATION

Submitted in partial fulfilment of the

Requirement for the award of

Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

By

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Under the guidance of

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CANDIDATE DECLARATION

I, SYED MOHD ADNAAN student of MASTER OF TECHNOLOGY (ELECTRICAL ENGINEERING) under school of ELECTRONICS AND ELECTRICAL ENGINEERING of LOVELY PROFESSIONAL UNIVERSITY, Punjab, hereby declare that all the information furnished in this dissertation report is an authentic record of my own work carried out under the supervision of Mr. Mukul Chankaya, Assistant Professor, School of Electronics and Electrical Engineering. The matter presented in this dissertation has not been submitted to Lovely Professional University or to any other university or institute for award of any degree.

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CERTIFICATE

This is to certify that the thesis title "GRID INTEGRATION OF LARGE-CAPACITY RENEWABLE ENERGY SOURCES" that is being submitted by "Syed Mohd Adnaan" is in partial fulfilment of the requirements for the award of MASTER OF TECHNOLOGY DEGREE (ELECTRICAL ENGINEERING), is a record of work done under my guidance. The content of this thesis in full or in parts, has neither taken from any other any sources nor have been submitted to any other university for the award of degree and the same is certified.

Mr Mukul Chanakya

Assistance professor

(Lovely Professional University)

Objective of thesis is satisfactory/unsatisfactory

Examiner

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This is to certify that Syed Mohd Adnaan bearing registration number 11511278 has completed objective formulation of thesis title "GRID INTEGRATION OF LARGE-CAPACITY RENEWABLE ENERGY SOURCES" under my guidance and supervision to the best of my knowledge, the present work is the result his original investigation and study. No part of thesis has ever been submitted for any other degree at any university.

The thesis is fit for submission and the partial fulfilment of the conditions for the award of MASTER OF TECHNOLOGY (ELECTRICAL ENGINEERING).

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

BJT- Bi-Polar Junction Transistor

CCM- Continuous Conduction Mode

CLMI-Cascaded Multilevel Inverter

DCM-Discontinuous Conduction Mode

FACTS- Flexible AC Transmission System

IGBT- Insulated-Gate Bipolar Transistor

KCL-Kirchhoff's Current Law

MMC-Modified Multilevel Connection

MOSFET- Metal–Oxide–Semiconductor Field-Effect Transistor

MPP-Maximum Power Point

MPPT- Maximum Power Point Tracker

PWM-Pulse Width Modulation

PV-Photovoltaic

SCR- Silicon-Controlled Rectifier

STATCOM- The Static Synchronous Compensator

LLP- Loss of load probability

ATLCC- Annualized total life cycle cost

ABSTRACT

The current scenario explains that power demand in the world is increasing at very fast rate day by day. The World Energy Council has calculated that overall energy consumption of electric energy is going to surpass 40000TWh in 2040. To meet this demand at economically and ecologically renewable energy is proving out to be the best alternative.

In order to meet demand renewable energy is injected into electric power grid. As the demand increases more power is to be injected in grid from renewable energy plant , this creates some issue in power quality and parameters of electric grid fall below the standard values.

The power generated by renewable energy sources usually has substandard power quality. The main reason behind this substandard quality is that that the energy produced by any renewable sources is not constant, it varies with time depending upon various factors, for example solar power depends upon solar radiation or wind power depends on wind velocity and these factors are not constant with time. So various quality issue like variable frequency output, change in active and reactive power are major concern.

This substandard power quality introduces voltage fluctuation, flickering, harmonics and transients into the system. Now in order to mitigate these problems various compensation devices and techniques are used which allow better integration of renewable energy to the grid system.

CHAPTER 1

INTRODUCTION

1.1 BASIC OVERVIEW

Electric energy is indispensable component of economic development, and this goes for all countries. It is relatively very important with increases in connection to technical progress, industrialisation and requirement of modern vantage. Increase in its production translates into better quality of life and the formation of wealth. Electric energy is most versatile form of energy it can be converted to any form and vice-versa. Electric energy can be stored also. The generation of electric is mainly from fossil fuels which are depleting at very fast rate. In 2013 net electricity generation across the globe was 23,322 TWh out which 41% was generated by coal, 5% by oil, 21% by natural gas, 19% by renewable sources 10% by nuclear [1].

Over past years renewable energy for electric power generation has gained focus of research as the available conventional energy resources are near to their depletion. Renewable contribution 19.2 percent to omnibus power utilization and 23 percent to their production of electrical energy in 2012 and 2013, respectively [2]. This power utilization is split as 9 percent accounting for biomass, 3.8 percent hydro-electric power, 4.2 percent as energy in form of heat, and 2 percent is coming from photovoltaics and CSP. Global funding for renewable energy production totals to more than US$214 billion in year of 2013, U.S and China have extensively invested in solar, hydro, wind. Renewable power is presumptive from resource's which are naturally refill on a human timescale, such as geothermal heat, tidal waves, wind, biomass and solar energy [3].

Renewable energy is often used for primary applications as electric power production, heating/cooling of water and air, in means of transportation, and rural energy services [4]. Non-conventional resources are available over vast topographical surface in respect to other conventional resources which are confined to particular area in few nations. As renewable energy and energy efficiency are deployed at very fast rate which are resulting in considerable climate quelling, energy security and financial benefits [5].

In latest review of literature [6] it is final that greenhouse gas emitters are accounted for damages to environment. Surveys show that in an international opinion there is a tremendous support for promotion of renewable springs like solar power, wind energy, tidal energy. In terms of national level around 30 nations across the globe have more than 20% energy supply from renewable sources. It is observed that national renewable market is growing at very fast rate and expected to increase tremendously in approaching decagon of years. Few places and two nations Norway and Iceland are have 100% energy generation from renewable sources and many other countries have set benchmark of achieving 100% renewable energy like ways Denmark Government has decide to go for 100 % switching to renewable energy for energy supply (electricity ,mobility and heating /cooling) by year 2050[7].

As many renewable energy projects are built for large scale energy production, this technology is also suited for various remote and rural areas and also for developing countries where energy provides a vital support in all round enhancement of human society . U.N Secretary-General Ban Ki-Mun has released a statement that non-conventional power has the proficiency to lift the indigent countries to new scale of success. Non-conventional is basically used for electricity generation which can be used in annexation with further electrifying in order to provide many benefits, for instance, electrical power can be transformed into thermic energy almost with negligible losses and higher temperature can be achieved with it in comparison to conventional fuels. It can also be transformed to mechanical energy for high productivity and it is clean at the point of utilization. It is also more efficient because most of the renewable system do not have the steam cycle with high [8].

1.1.1 POWER GENERATION

Power from hydro-electric energy accounts for 16.3 percent of the world's electricity, when combined with another form natural energy, the overall energy production goes up to 21.7% of electric power generation globally.

Non-conventional alternators are protracted over many nations, and wind electric power generation solely supplies a considerable portion of electric power in few countries: for instance 14 percent in the U.S.A. The state of Iowa, 40 percent in the German state of Schleswig-Holstein, and 49 percent in Denmark. Few nations receive their energy from non-conventional, including Iceland (100 percent), Brazil (86 percent), Norway (98 percent), Austria (62 percent), Sweden (54 percent) and New Zealand (65 percent).

Recently India has designed world's largest single location solar plant named as KAMUTHI SOLAR POWER PROJECT in a state of Tamil Nadu 55.92 miles from Madurai, capable of generating 648 MW. The plant comprises of 25 lakh solar modules and structures of 27000 meters with 154 transformers, 576 inverters and 4660.28 miles of cable

1.1.2 HEATING

Solar water heating as seen the tremendous boost in China which has around 70% of the worldwide (180GW). Mainly these are installed for apartment buildings and cater hot water need of approximate of 60000 thousand homes in China. Across the globe, water heating by means of solar is providing hot water for 70000 thousand families. The utilization of biomass is also in trend. In the case of Sweden usage of biomass energy has excel the usage of petroleum [11]. The demand for geothermal heat pumps is also increasing which provide cooling and heating, also adequate of flattening the electric demand-curve.

1.1.3 TRANSPORTATION

A solar vehicle is class of electric vehicle which runs on electric power generated by solar energy. Usually solar panels containing photovoltaic cells are used to convert sun energy to electrical power.

The terminology ‘solar vehicle’ explains the utilization solar power propulsion of the vehicle. Communication and control technologies are indulging in the use of solar energy. Solar energy is now a day's used into power boats also.

The solar powered boat has not learned that much success because these are limited to the river and canals only. A 14meter catamaran, the Sun21 boat was chosen for the experimental purpose, being powered by solar energy this boat was made to sail across Atlantic ocean from Seville to Miami and then further to New York. The solar vehicle has witnessed emergence in cars and railways also.

The fastest speed achieved by solar car is 91.332 km/h by Sky Ace TIGA from the Ashiya University. This record was created on 20th of august 2014 at the Shimojisha Airport, Japan. [12] In railways many corridors are transformed into the green corridor by placing solar arrays across the line.

Indian railway has also made a test run by placing the solar array on the rooftop of non ac coaches of Rewari-Sitapur passenger train [13].

Solar powered plane IMPULSE 2 has travelled across the globe covering the distance of 35000 km with an average speed ranging between 50-100 km/h [14] thus showing a potential of solar energy in the aviation industry.

GENERATION TYPE	TOTAL INSTALLED CAPACITY IN MW	2022 TARGET IN MW
Solar Power	8513.23	100,000.00
Small Hydro Power	4323.35	5,000.00
Wind Power	28082.95	60,000.00
Waste-to-Power	115.08	10,000.00
Biomass Power	4882.33	
TOTAL GENERATION	**44783.33**	**175,000.00**

Table 1 Installed Grid Interactive Renewable Power Capacity in India as Of September 30, 2016

1.2 PHOTOVOLTAIC POWER PRODUCTION

1.2.1 BASICS OF PHOTOVOLTAIC POWER PRODUCTION

Fabricated from semiconductor substance, a photovoltaic cell is capable of converting solar energy directly into electrical current. When irradiance scours on a particular photovoltaic cell, then the cell ingest energy packets from the sunray which is further conveyed to electrons present inside atoms of substance. Then the active electrons become the segment of the electric current in the network, producing electrical power.

1.2.2 TYPES OF PHOTOVOLTAIC POWER GENERATION TECHNOLOGIES

In pursuance of the substances and layout, present photovoltaic power production methodologies are classified as crystalline silicon, thin-film and concentrating photovoltaic. Si based photovoltaic cell in present time is most mature methodology, with an energy transformation proficiency of up to 20 percent. Lately, thin-film photovoltaics, which are also incorporating non-Si substance, which are also gaining attention. Albeit thin-film photovoltaic usually is having less efficiency when compared to Si-based photovoltaic (around 11 percent), it is comparatively cheaper and minor power-profound to assemble and is comparatively more flexi for multilateral usage. Concentrating Photovoltaics, in which beam of light is focused and powered by an optical aid before it reaches to photovoltaic unit, is on the brim of expanding. Concentrating Photovoltaic is capable of achieving proficiency up to 40 percent. Other techniques, such as organic photovoltaic cells are still in under process.

1.2.3 CHARACTERISTICS OF PHOTOVOLTAIC POWER GENERATION

The basic part of photovoltaic setup is an inverter. The direct current from photovoltaic system as output is converted into alternating current by means inversion circuit. The conduct of the inverter is very much required for necessary for grid-linked photovoltaic power plants, since it precisely effects whether the photovoltaic unit can expedient the demand for proper functioning of grid. As there are parts which are capable of rotation, photovoltaic systems are unable to provide inertia and assist to the power system. When compared to CSP, photovoltaic electricity generation has the benefit that is capable of using the diffuse component of sunlight to produce electric power, which permits its superior stationing in various realms. In comparison to wind electricity generation, photovoltaic electricity offers less hassle in grid injection because sunlight is more foreseeable than the wind. The high production cost and low efficiency is major hurdle in mass and extensive deployment of PV system

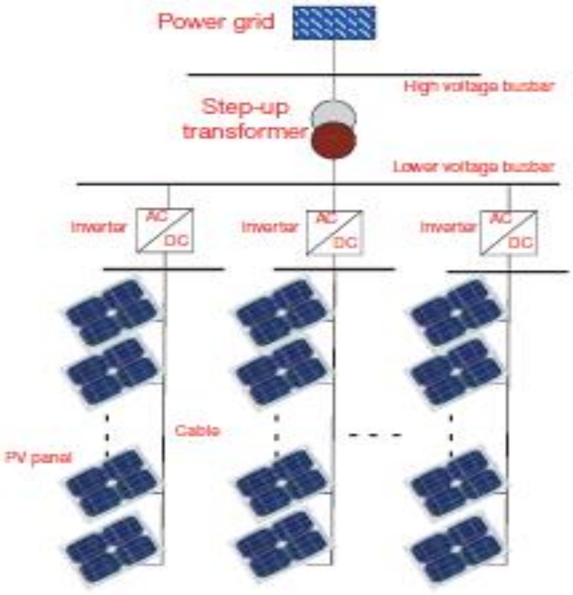

Figure 1 Solar plant connected to grid

Figure 2 Polycrystalline pave cell

1.3 CONCENTRATED SOLAR POWER GENERATION

1.3.1 BASICS OF CSP GENERATION

Concentrated Solar Power generation, is also called as the solar thermal power production, is very much homogeneous to a typical thermal power plant, which transforms the thermal energy into the electric power. A concentrated solar power plant employs are large number of mirrors in various layout (incorporated with a sun tracking system) for reflecting and concentrating the direct-beam sunrays to heat the working fluid in the collectors to very high temperatures, thus transforming the solar power into the thermal power.

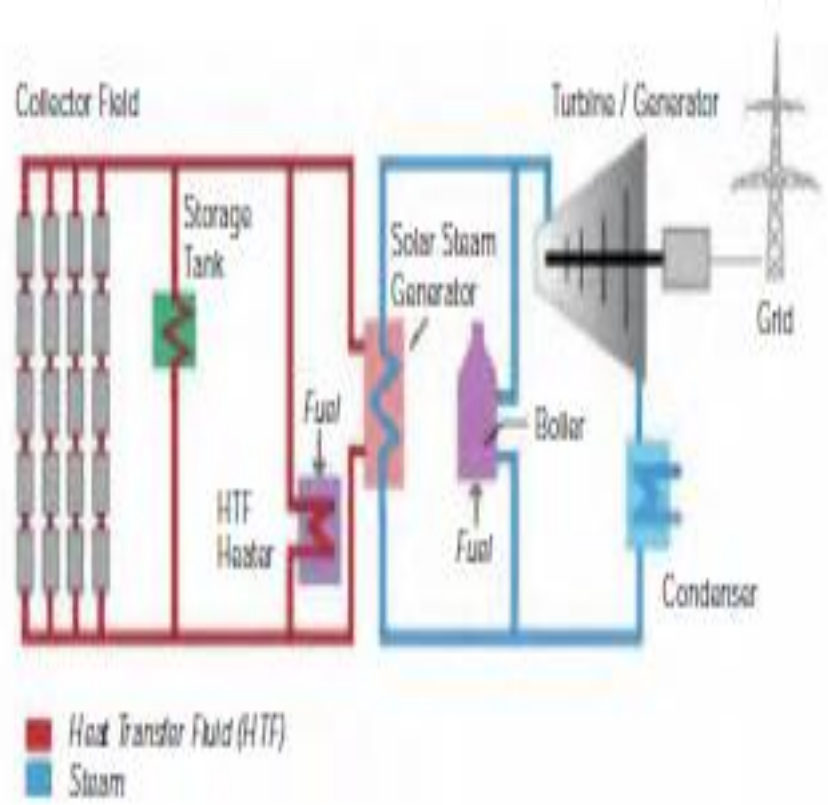

Figure 3 Grid connected concentrated solar plant

When by using a generator, which is driven by a heat engine, gas turbine and by a steam turbine, then electricity is received by converting the thermal energy into the electricity. A CSP plant may also be furnished with the energy storage system for its working during overcast or during night time. A normal off-grid concentrated solar power unit has a layout similar to shown in figure 3. A concentrated solar power system may also be structured as a hybrid system which utilize conventional resources to compensate the power output during the cloudy condition, by making the plants outputs more stable or dispatch able and. This can be combined with a traditional combined-cycle plant for the improvement of the energy efficiency.

Present CSP technology may have been classified into the four major types according to how the solar energy has been classified: Linear Fresnel reflector, solar tower and parabolic Dish system, parabolic trough.

Linear Fresnel reflector system uses slightly curved or lengthy chain of even mirrors to focus rays on a downward-facing linear receiver tube which has been settled in the gap in mirrors.

Solar tower system, which is called as central receiver system, uses abundant even mirrors to focus rays towards the top of tower where receiver is located.

Parabolic dish system, which is known as dish/engine system, concentrating rays onto the focal point of a sole dish, where the receiver and an engine/generator have been installed.

Parabolic trough system uses long row of the parabolic mirrors for reflecting and concentrating the sunlight beams on to a linear receiver tube which holds the working fluids

1.3.3 CHARACTERISTICS OF CSP GENERATION

Concentrated Solar Power is useful in which it is offering a service-scale, dispatch able and as an alternative to conventional energy resources. With the essential power storage potential in the mode of heat which may be utilized to produce electric power during later hours, concentrated solar power plant may carry on to generate constant electricity even when the sun is blocked by the clouds or during the dusk. So, it’s not much demanding to link concentrated solar power than wind energy system or photovoltaic production into the network. Even though concentrated solar power has superior working for grid injection, the comparatively premature technique and the huge investment are presently restraining its mass deployment.

The drawback of concentrated solar power is that it needs a substantial amount of solar energy. Thus, sufficient concentrated solar power resources are normally restricted to semi-arid, hot areas or deserts. Just like a typical conventional power plant, concentrated solar power demands water for condensation and cooling, which means a prodigious obstruction in utilizing concentrated solar power resource in the dry area. Cooling with air is also a competent option, but having huge investment and less operating

1.4 WIND ENERGY GENERATION

1.4.1 BASICS OF WIND POWER GENERATION

Wind turbine generators suck energy from wind movement and then transform it into electric energy by means of the rotor; the rotor is linked to electric generator then connected to a transmission network. A typical Wind Turbine Generators comprises of three blades which are capable of rotating on horizontal axis

Figure 4 A standards WTG with 3 blades and horizontal axis

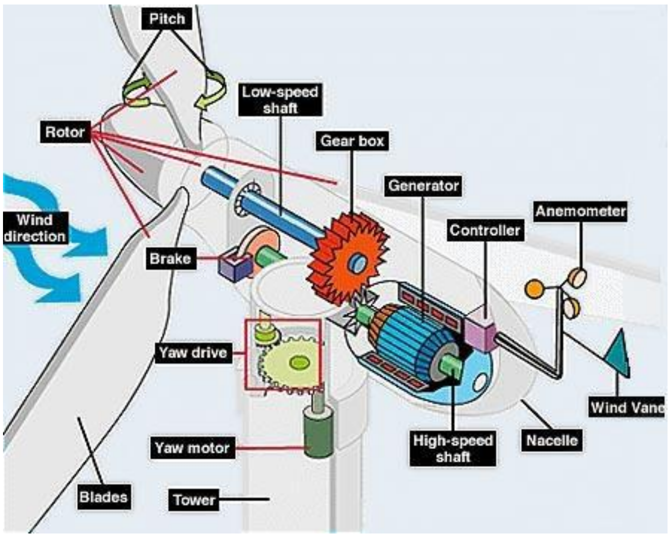

Figure 5 Parts of turbine

In general, wind turbine generators are capable of producing electric power from the wind at the nominal speed of 3 m/s and are capable of reaching its maximum output for speed range 10 m/s to 13 m/s. The resultant power from a wind turbine generator's projects increment by the three times with the increase in wind speed for instance if wind speed increases by 10% then output electrical energy may increase by 33%, this increment is also directly dependent upon rotor swept area. The output power can be supervised by both moving the nacelle in the horizontal direction (yawing) to revamp the alteration in direction of wind, and secondly turning the blades along the vertical axis (pitching) to adjust the variability in wind flow intensity. The potential of wind turbine generators is doubling itself every five years approx., but there is the decrement in this estimate for onshore utilization due to challenges in shipment, structure mass, and assembly. A usual commercial wind turbine generator at present have a capacity of 1.5 MW-3 MW and big ones can attain the capacity of 5 MW-6 MW, with a rotor having the radius of up to 207 feet. A sole wind turbine generators have a limitation on its space, which is comparatively less than a traditional generator, a wind power plant (WPP, usually called "wind farm") usually incorporates several wind turbine generator's connected together by underground cables or usually with overhead lines. The output from the turbine is collected and then transmitted to the electric grid by means of AC transmission line or DC transmission line depending upon the need. The generated output is step-up before transmission. Some wind power plant has generation capacity which can be compared to the capacity of typical conventional power plants.

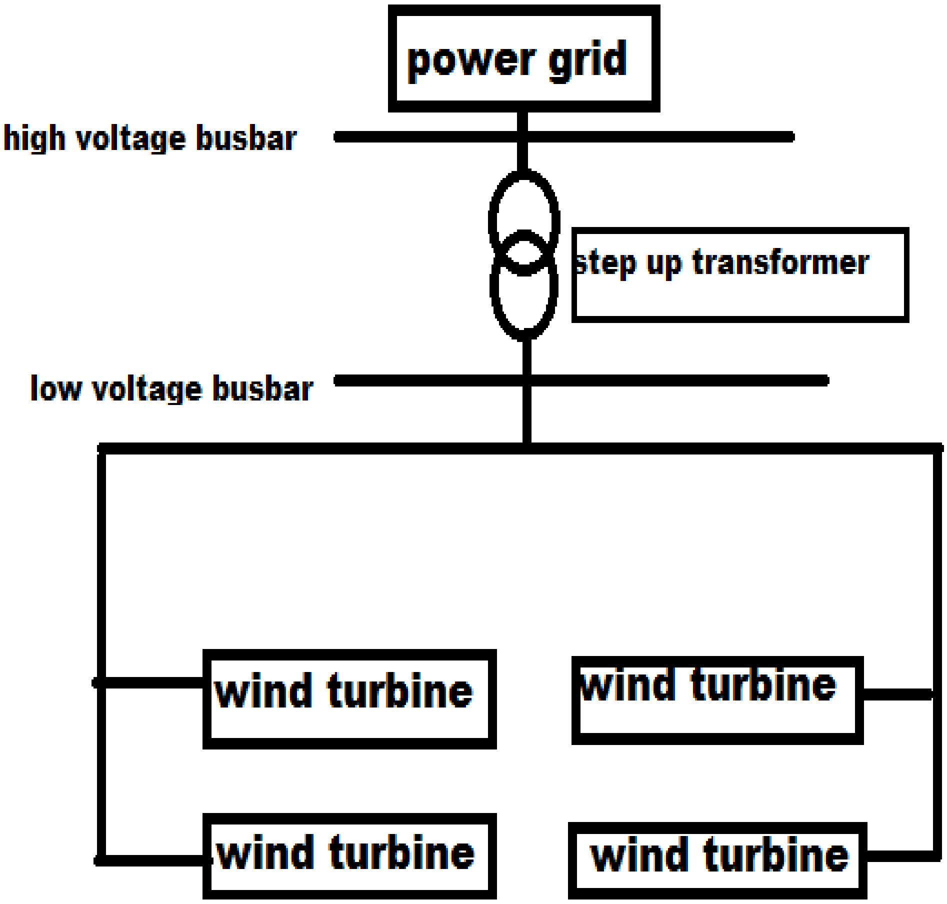

Figure 6 Layout of wind plant

1.4.2 DOUBLY FED INDUCTION GENERATOR

Doubly Fed Induction Generators are the most widely used wind turbine generators at present, it combines the benefit of foregoing wind turbine generator's designs with progressive changes in power electronics.

The Wound Rotor Induction Generator rotor is linked to the grid by means of a back to back Insulated Gate Bipolar Transistor power electronic converter capable of adjusting rotor current frequency and magnitude. Approximately 40 percent of the output electric power goes to a grid by means of the converter, and the remaining part goes straight to the grid.

This layout is capable of handling variation in wind speed and increasing the wind energy seize. The IGBT dispense decoupled control of reactive and active power, allowing pliable controlling for voltage control without any accessory need for compensation of reactive power.

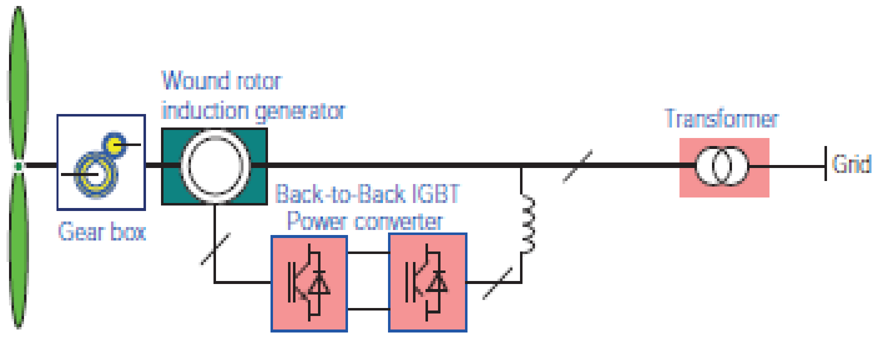

Figure 7 DFIG

CHAPTER 2
PROBLEM BACKGROUND

2.1 DEFINING PROBLEM

As mentioned earlier the generation of renewable is variable and have low power quality .this low power quality can result in losses which reduce the economics of the system. The various challenges are

2.1.1 VARIABILITY: Solar and wind power moves in such a way that operator cannot control generation as available solar radiation and wind speed can be vary from moment to moment impacting the output of torque and the fluctuation of power result in the necessity of further energy for balancing the supply and requirement on the grid on an immediate foundation, and auxiliary services such voltage support and frequency control.

On a second to minutes' scale, network operators have to cope with the fluctuations in voltage and frequency in the transmission system that if left without checking could harm the system and the devices at this. For doing this, the operator can order generator apply power to a network is not available for the sale to a consumer, but to satisfy the projected energy production, which is essential for maintaining voltage and frequency in a grid. The additional service goes specific descriptions and excess of names. Distinctive services impressionist survey includes:

2.1.2 FREQUENCY CONTROL: triggered by second to a minute, and is done by using (AGC) Automatic Generation Control signal to the generator.

Spinning reserve: generator power usable for over 10 minutes. When other generator system decreases, or disabled unexpectedly then these reserves are used.

Non-spinning reserves: The same function is served by these generators as by spinning reserve, but there is a gradual feedback time.

Support voltage: alternators have been used for the reactive power to increase the voltages if it is required

Black start capacity: alternators are available for the restart of the power system in case of total blackout.

2.1.3 PARTIAL UNPREDICTABILITY: Usability of solar radiation and wind is partly unpredictable. The Wind turbine can produce electricity only when the solar and wind photovoltaic system necessitates the presence of sunlight for work. Unpredictability can also be managed with the help of better weather conditions and forecast technologies which reserve holdings that are available to provide additional energy in generating renewable energy does not produce as much energy as we expect, and the availability of the dispatch able load "suck up" the excess energy when renewable energy (RE) generation produce more energy than it is expected.

2.1.4 UNIT COMMITMENT: is today mostly deterministic, which means that if once the generator has been decided to run, the full strength has been predicted to be usable for the use. It becomes more complicated in the case of the uncertain stochastic (stochastic) generation whose output committing time carry a certain degree of the uncertainty.

2.1.5 FORESIGHT TECHNOLOGY: aims to predict the weather, and therefore the energy output from the solar and wind sources in different time's frames accurately, and communicates all those predictions that network in a way which allows operators to efficiently dispatch and schedule resources.

2.1.6 LOCATION DEPENDENT: The renewable resources are site dependent and, unlike conventional resources can't be transported to the site of generation. The generating station should be must be placed at the site itself, Sometimes these sites are very far away from the point of consumption. A transmission line is occasionally necessary to link the wind and solar resources, to the remaining network. Transmission costs are particularly critical for wind power.

CHAPTER 3
LITERATURE SURVEY

Sharaf, M, et al (2007), the paper presents a model of the photovoltaic array designed for usage in MATLAB. The model was tested with dc load and then was connected to an inverter to test a load. For simulation of a model, a three-phase inverter was connected to the array; it was observed dc voltage generated by the model can be converted to ac.
This converted ac load can be interfaced with ac load as well as the utility grid. This also indicates that model presented in a paper can be treated as distributed generation system. [15]

Bansal, R, et al (2007), the paper discuss various technical challenges in integration of grid to renewable energy, giving more emphasis on stability issue.

The paper also views dynamic model for large scale PV system for stability analysis. The paper describes technical mitigation to the challenges in integration of PV to transmission and distribution level. [16]

Lu, M, (2008), various wind energy generation projects for large scale have been implemented across the globe. It is very economical to inject large block for wind-generated electricity in system. In contrast to other conventional generating unit, employing wind driven turbines shows difficulties in the generation of controllable and continuous electrical energy, incorporating an energy storage system with wind will result in decrement in fluctuations [17]

Lund, H, et al, (2008) in this paper integration of fluctuating renewable energy sources is discussed for Denmark model using EB, HFV, BEV ELT/CHP, HP, FLEX.[18]

Bialasiewicz, T, (2008) the PV array can operate in stand-alone or are connected to a grid. The current controlling is mainly used in applications related to a photovoltaic inverter. The main challenges offered by PV generation are efficiency and power quality. The maximum power point is a set of algorithms used to track maximum efficiency. The main goal of the paper is to reduce voltages of current ripple. [19]

Ton, D, (2008), in this paper the SEGIS is projecting to develop the advanced form of energy repository systems and components that will boost the overall working of PV based applications systems. [20]

Bialasiewicz, T, (2008), the paper focus on the modelling and operation a standalone PV power system in RPM-SIM. The inverter used for PV operation is operating in slave mode and also in master modes. It is noted that when the inverter is operated in the master mode for standalone applications then the setup give enhanced controlling of frequency and voltage of power system.

The study also discusses the cost effective operation and utilizations of renewable energy systems. The process is carried out with different values of temperature, varying insolation, irregular irradiance, dynamic wind speeds and uncertain load profile. The result discusses power quality of the system. [21]

Ram, S, et al (2009), this article presents a new development of fuzzy logic power system operated by wet UPFCs oscillations in fact based on a comprehensive system for the delivery of multi - machine containing the generator,3 Transformers, 9 buses, recorded 4 and 2 UPFCs.

Fluctuations in energy systems should be taken seriously into account from the time an error occurs in any part of the system, otherwise, it could lead to instability mode disconnected from the power system. This paper presents this hybrid combination of UPFC Fuzzy - control strategy POD wet electro - mechanical oscillations. Strengthening part of the normal controller regulates the coordination of fuzzy controller. [22]

Vergara, S, (2011), this work present the comparison of two types of solar energy sources: Photovoltaic (PV) plant and Concentrating Solar Power (CSP) plant. The key objective of work is to compare the economic aspect of both plants for generation of 40Mw plant .the paper discuss initial investment, maintenance, and production. [23]

Xue, Y, et al (2011), the paper presents the inspection of the passive and transient behaviour at the common coupling point for a PV system connected to the grid. Specifically, the study is done to understand the effects of system specifications such as solar irradiance, change in loading condition and temperature on the voltage stability. The brunt of small interruption in system specifications to the transient feedback is analysed. [24]

Gouda, K, P, et al (2012), this paper model and design and computer -aided electromagnetic switch direct current power system (PSCAD / EMTDC) in the unified power flow controller

(UPFC) is simulated. UPFC series converter line, real flow / UPFC reactive power and voltage deviation UPFC bus converter / DC link shunt capacitor voltage control and reactive power.

UPFC through the DC link capacitor series converter requires real power converter is equipped with a ramp. UPFC bus voltage lines to control the flow of reactive power leads to excessive voltage excursion. [25]

Austria, R, et al (2012), in this paper analysis of harmonics issue that is limiting solar PV power generation in 12.47 KV distribution network, major capacitor are located at the substation. Inverter depended PV units introduce the harmonic current which excites resonant frequencies developed by the capacitor.

To increase the injection of PV power various measures like the repurposing of capacitor and installation of filters are taken. The paper also points out that PV penetration is also significantly influenced by tolerable limit endorsed by the utility. [26]

Manohar, K, et al (2012), the paper presents a dynamic model of solar PV system connected to utility grid designed in MATLAB. The model has D & Q axis coordinates which are rotating in phase with grid voltages and reflecting systems characteristic precisely .the system comprises of a PV solar array, a controlling mechanism, distributed structure and a load.

The control mechanism offers two ways to control, firstly at common coupling point current is regulated which in turn regulates dc link voltage by achieving power factor control, while second is to attain closed-loop controlling by voltage control mechanism of PV output voltage, this offers smooth tracking of MPP.

Perturb and observe is used for MPP tracking. For fault analysis, LLLG is introduced the proposed system is simulated with and without fault during simulation of both the cases various power quality event are observed. [27]

Raut, B, et al (2013), the paper talks about variable nature of solar PV generation which doesn't allow solar PV system to supply constant power. So in order to supply constant power to customer solar plant are synchronized with the grid, but again variable nature of solar PV generation can affect the grid parameter and Detroit power profile in a grid.so analyse this a 1kwp solar PV system is designed and connected to a grid . It is observed that on using Perturb and Observe the power output in enhanced by 23% than the system having no MPPT.

The power electronic setup of converter and inverter introduce harmonics in the system which is dependent on solar irradiance.

It is observed that voltage THD is less responsive to a fluctuation of solar irradiance as compared to current THD which is highly receptive to change of solar irradiance. [28]

Belfiore, F, (2013), the maintenance and operation of large-scale photovoltaic plants requires a management system that has to integrate and also has to be implemented throughout the entire life cycle. The problem related to the connection to the grid can often be critical, both in aspects convenience and continuity of the energy delivery. Breakage caused by either major interruptions downstream in the utility area or faults on the transmission line to the interconnection switchyard or should be identified and communicated quickly. [29]

Dris, M, et al (2013), the work views the theoretical study of various MPPT topologies like Perturb & Observe, Fractional open circuit voltage,, and Incremental conductance, using real-time irradiance data for different weather conditions. It is observed that for a cloudy situation the incremental conductance offers higher efficiency. For low cost system Perturb and Observation technique is preferred as it requires only one sensor compared to IC using four sensors for same task. [30]

Tyagi, P, et al (2013), the paper illustrates DC-DC converters as interfacing device between photovoltaic array and the applied load. The MPPT is applied to draw maximum power. The converter should be designed in such manner that there is the direct connection between PV array and MPPT. MPPT along with converters are used together to reduce the losses. The BUCK-BOOST converter is capable of following MPPT irrespective of irradiance, connected load and temperature. This topology serves higher efficiency but at the higher price. [31]

Uttam, B, et al (2013), the paper lays emphasis on boosting the efficiency of photovoltaic plant by using the incremental conductance. A solar PV model was designed in MATLAB to carry out the simulation to analyse the efficiency of with and without MPPT. The incremental conductance offers higher efficiency over various other techniques like PERTURB & OBSERVE. [32]

Kumar, V, et al (2013), the main objective the paper is to use incremental conductance for MPPT topology for developing a grid connected PV model for simulation in MATLAB. Initially, a PV model is designed then connected to MPPT followed by the DC-DC converter.

Then DC-AC converter is connected so that PV setup can be integrated into the grid, in result various waveforms for output currents and voltage for PV model, Ac voltage real power and current to the system are presented. [33]

Sharma, m, et al, (2014), as a need for power is increasing day by day the more alternative energy sources are hunted. The wind generated electricity has also revived a mass attention. The power generated by the wind is injected to grid. The paper discusses various challenges faced in grid integration. [34]

Pilo, F, et al, (2014), the paper talks about renewable energy utilization in Sardinia. It explains the usage of Hydro pumping storage. The hydro pumping storage is used for integration of various renewable energy to grid with better output characteristics. [35]

Costina et al (2014), as wind power plant are growing at the very fast rate, there WPP which have the single turbine and some have several hundred of turbine operating. The paper tells about maintenance issue and economics WPP in Romania. [36]

Arifur, R, et al (2014), the major hindrance is connecting renewable to grid lack of proper transmission techniques .this paper present control of a grid connected photovoltaic solar farm to improve transient stability. [37]

Sharma, G, et al (2014), the paper discuss the analysis of one MW PV solar plant designed on MATLAB. The key points of paper are designing of solar plant, estimating the power production depending on these estimation cost optimization of a plant is discussed. [38]

Hussain, I, et al (2014), the paper accord the grid synchronization of double stage solar PV system employed 2-level eighteen pulses double bridge voltage source converter with controlling based on PLL. Incremental Conductance serves the purpose for tracking maximum power point. Each VSC is connected to phase shift transformer to mitigate harmonics between various converter modules. The robust integration of PV solar system grid, the controller responses are enhanced and faster than earlier. The study has been carried out under various varying conditions. [39]

Sengar, S, (2014), the paper explains the various characteristics of nonlinear V-I relationship, a dependence of output power on environmental conditions like temperature and irradiation. The paper defines maximum power point as a point which lies on P-V, I-V characteristic curve. Maximum power is obtained at this point. The MPPT tries to derive maximum power for varying environmental condition. The main focus is given to Incremental Conductance. [40]

Alexander, A, et al (2014), the paper talks about the designing of the control circuit for PV fed CLMI resulting in the reduction in the number of semiconductor switches, the topologies suited for changing input from photovoltaic are MMC, Ternary, and Binary. The output voltage level 2Ns+1-1 are obtained for binary mode, where Ns are a number of individual and similarly 3Ns level is achieved for the ternary mode. Modified multilevel connection is proposed to provide output voltage level for both power and control circuits with an appropriate number of switches. For designing a 15 level output inverter conventional method uses 28 switches whereas binary uses 12, MMC uses 7 switches and ternary uses 12 switches for 27 levels. These reduced number of switches result in the decrease in harmonic content. [41]

Bharti, N, et al (2014), this paper discusses the modelling of a PV solar model then carrying out its simulation in MATLAB. The boost converter is being used to step up generated PV panel voltage. The MPPT is employed to track down maximum power generation. Perturb & Observe serve as the mechanism to supervise the duty cycle of Boost converter for varying loading conditions with respect to MPPT. The applied setup results in enhanced efficiency than a model without MPPT. [42]

Patil, R, et al (2014), the paper presents the modelling of 500KW PV system connected to a utility grid having the radial 2-bus system in MATLAB. This is done to understand the effects of varying irradiance on PV layout connected to a grid. The PV solar model is connected to a 3 level inverter. Incremental conductance serves as maximum power point tracking methodology and also for controlling of Boost converter. For varying environmental conditions like varying nature of solar irradiance and alter in a cell, a temperature is also taken into account to study the harmonics and overall efficiency of the designed model. [43]

Dash, R, et al (2015), this work projects a technical inspection of power quality enhancement using facts devices associated with the distributed system based on renewable. For the selection of the facts device the IEEE and IEC standards for grid connected renewable system is considered. This paper includes the integration of PV and wind energy system. [44]

Shaik, G, et al (2015), various methods for localization and detection for power quality events related to grid synchronization of solar plant and outage of a solar plant are being presented in the paper. A 100Kw solar plant is connected to distribution network having a standard IEEE 13 bus system.
Voltages signals recorded at the node of designed system during simulation are used for power quality analysis. To calculate harmonics in system Fourier analysis is done and for voltage swell and sag wavelet analysis is carried out. To study various power quality events excelled sudden disturbance in solar insolation are taken into consideration. [45]

Gherbi, A, et al (2015), the paper presents the modelling and simulation PV plant connected to grid in MATLAB. Initially PV module is designed then connected to DC-DC boost converter having Perturb & Observe algorithm serving as the MPPT which helps in extracting maximum power from PV system.

The extracted power is now integrated to ac utility grid via DC-AC inverter. The designed model is simulated for various conditions and power quality events are discussed. [46]

Kim, I, et al (2015), the paper points the concern of reverse power flow Solar PV system. This reverse power flow can cause overvoltage across the feeder, this may rise up to 5% of the rated value. This problem is mitigated in modern power system as they can either absorb or inject reactive power by means of Volt/Var controller.

The study also inspects the time series steady state characteristics for a solar PV system injecting or absorbing reactive power connected to a distribution network. It is observed that grid connected PV solar system can reduce peak effectively. [47]

Wadekar, N, et al (2016), the paper discus about the efficiency of solar cell and maximum output generated by it .There is also elaborated comparison for various DC-DC converter along with use of Perturb & Observes.
Quick tracking of maximum power point in case of sudden in environmental condition by is not possible. So P&O is used with different DC-DC converter to study the overall efficiency of system. [48]

Patel, J, et al (2016), the paper presents real-time application of 100 kW rooftop Solar PV grid connected plant. performance ratio ,system loss, collection loss, performance ratio , produced energy, ambient temperature system efficiency, global irradiation , energy feed to grid and final yield are the performance indices that are used to study power quality events .The paper explains that for complete year performance ratio is 78.80% collection loss and system loss remains constant throughout the year. For the months June to August energy output form inverter is less than compared to rest of the year. [49]

Anwar, B, et al (2016), the paper talks about the forecasting of wind speed and solar irradiance in order to harness the renewable electric energy from them. Since variability in output is the major concern for both as it can effect system stability and voltage profile? Various forecasting technique use artificial intelligence, hybrid, statistical and physical procedures. The confidence interval and hybrid procedures have gained more attention than other techniques. For dealing with typical data and long term forecasting Pre-Processing methodology is preferred. [50]

CHAPTER 4

PROPOSED RESEARCH OBJECTIVE

Lots of research are being carried, on renewable sources because after the depletion of the sources like coal and oil, off the track sources like wind and solar attract everybody towards it. It is also important because firstly it is free source and lots of new things can be done in this field.

The basic objectives of the works are:

a) Modelling of a photovoltaic solar energy system

b) Interconnection of photovoltaics system with grid

c) Optimization of photovoltaic system

CHAPTER 5

PROPOSED RESEARCH METHODLOGY

As mentioned earlier the objective of this study is to analyse the various power quality events during integration large renewable energy to grid and to enhance the quality profile of various power quality events. Since major focus of study is on solar energy, so methodologies are discussed with respect to grid connected solar plant. Performance and reliability are essential to the PV system with a considerable power scale and voltage level. Therefore, proper modelling and control design allows for progress on hardware implementation. The whole PV system can be divided into several subsystems to facilitate the control individually. First of all, in our connected photovoltaic system connected to grid. Then maximum power point tracking control is put in action with boost converter to fortify the high efficiency of the distributed power generation. Then the inversion system transforms DC power to AC power to interface with distribution network. The following statements describe the proposed methodologies.

5.1 MODELLING OF PV SOURCE

As know a solar cell is fundamental unit of a photovoltaic system. It is designed as p-n junction possessing nonlinear attributes reflecting its electrical behaviour. To study these attributes a solar cell is model mathematically by equations. For ideal case the R_s is taken to zero and shunt resistance is taken to infinity. The resultant current equal to the difference between photo current I_l and diode current

$$I=I_l-I_o(e^{((q(V+IRs)/nkT)}-1))-((V+IR_s)/R_{sh}) \quad \ldots 1$$

The temperature T_1 and T_2 govern the photocurrent

$$I_l=I_l(T)+K_o(T-T1) \quad \ldots 2$$

$$I_L(T_1)=I_{SCT1}(G/G_{nom}) \quad \ldots 3$$

$$K_o=(I_{SCT2}-I_{SCT1})/(T_2-T_1) \quad \ldots 4$$

G_{nom} is reference solar radiation and G in present solar radiation.

The very fundamental solar cell can be modelled by connecting a diode in parallel to a current source, this is easiest equivalent circuit. The current at output terminal is directly proportional to the irradiance received by cell.

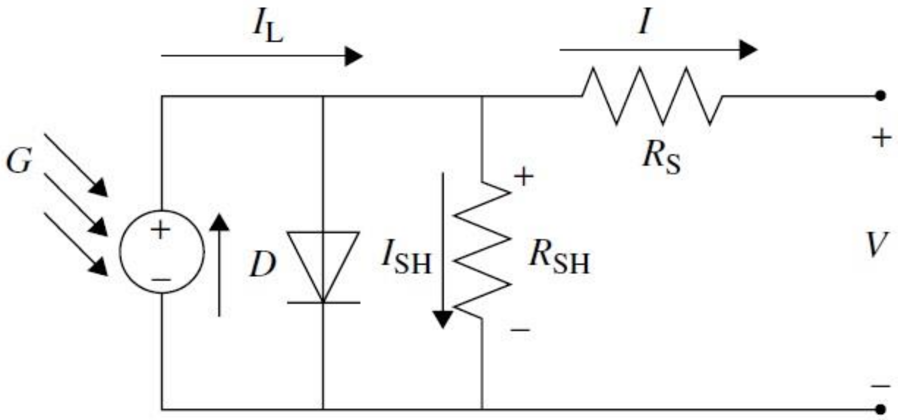

Figure 8 Equivalent circuit for solar cell

During absence of light cell is not active anymore and behaves like a diode. It is not generating voltage or current at that moment. In presence of light diode current is generated and the V-I characteristics of the solar cell are governed by diode. The shunt resistance offered is denoted by R_{sh} and internal resistance of cell is represented by R_s generally due to its large value R_{sh} is neglected.

A normal I-V attributes for a solar cell a presented in figure above for certain ambient temperature and irradiation G. For resistive nature load the characteristics observed are linear with slope I/V= 1/R. The power at output terminal is depend upon the value of R. For smaller load value the cell functions as constant current source and its operation lies in M-N region , it behaves as constant voltage source for region P-S when large load is available.

During M-N region the generated current is almost equal to the short circuit current and for P-S region the voltage is equal to open circuit voltage. The short circuit current I_{SC} is the maximum current that can be generated by solar cell, it is produced during the condition when V=0 , i.e. short circuit and V_{oc} is obtained across the terminal when I_{SC} is equal to zero i.e. is open circuit condition

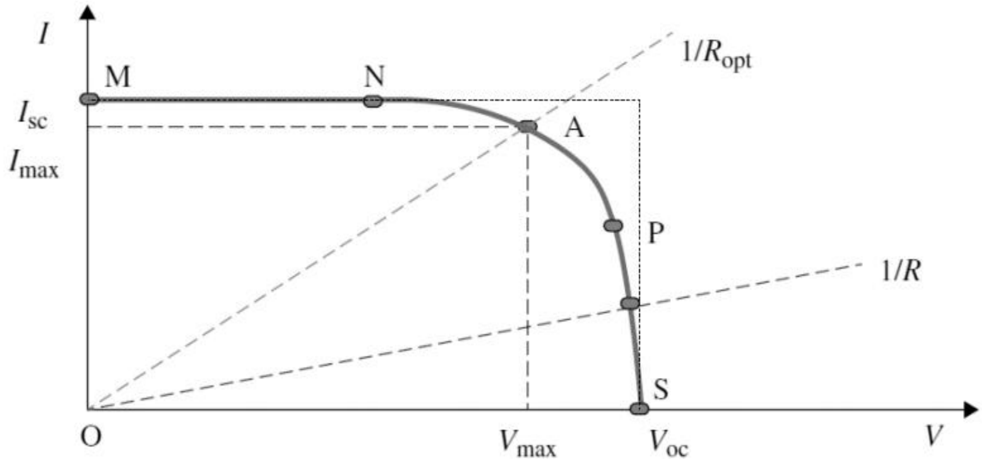

Figure 9 V-I characteristics for solar cell

For given resistive load the point A is maximum power point what which max amount of power is dissipated

$$P_{max}=V_{max}I_{max} \quad \ldots\ldots 5$$

The efficiency for solar cell is given by the ratio of power generated to irradiance received

$$\eta= P_{max}/P_{in} =(I_{max}V_{max})/(AG) \quad \ldots\ldots 6$$

here A is the area of the module and G is irradiance.

Fill Factor (FF) is the ,measure of the quality of solar cell. It is obtained by making comparison between maximum powers to the theoretical power. It should be more than 0.7, with increase in cell temperature the value of FF decreases

$$FF=(I_{sc}V_{oc})/(I_{max}V_{max}) \quad \ldots\ldots 7$$

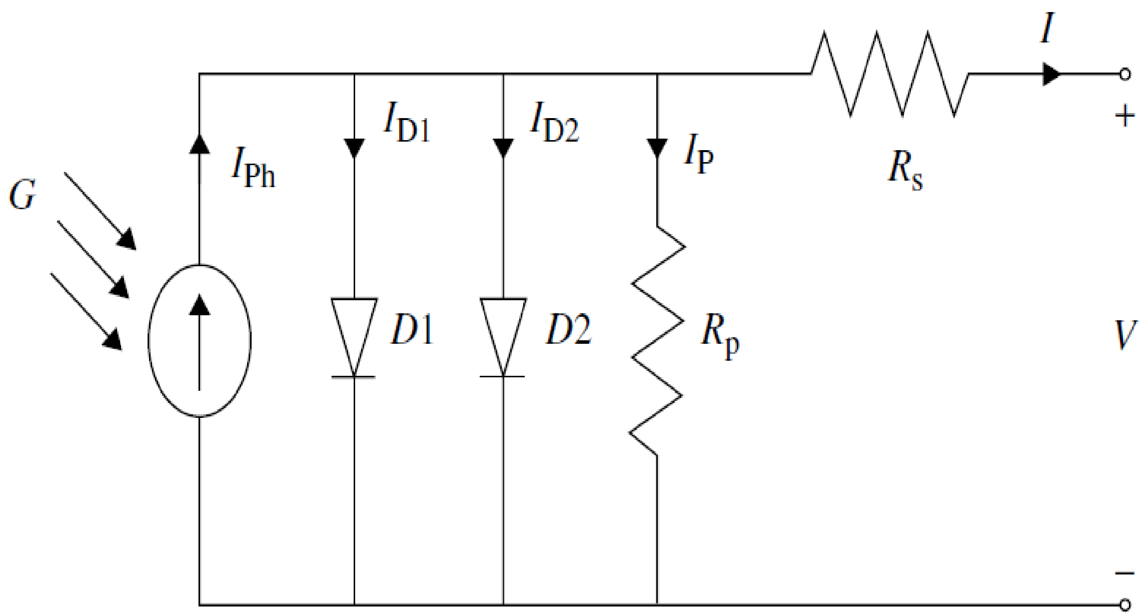

Figure 10 Double diode solar cell

The solar comprising single diode is sufficient for typical ambient condition but it fails to provide satisfactory output during less irradiance , to cope this loss of power another diode is added parallel to the existing diode and this configuration is known as double diode photovoltaic cell . The net current is given as

$$I=I_l-I_{D1}(e^{((q(V+IRs\ )/V1t)}-1))- I_{D2}(e^{((q(V+IRs\ )/V2t)}-1))\ ((V+IR_s)/R_{sh}) \quad \ldots\ldots 8$$

I_{D1} and I_{D2} are saturation current for each diode whereas V_{1t} and V_{2t} are thermal voltages for both diodes

$$V_{1t}=(a_1KT_C)/q \quad \ldots\ldots 9$$

$$V_{2t}=(a_2KT_C)/q \quad \ldots\ldots 10$$

Here a_1 a_2 are diode ideality factor that depicting the segments of recombination and diffusion. Double diode configuration has higher efficiency than single diode but with increased complexity. The half volt for every volt produced by solar cell is not usable for nearly all practical usage. So cells are connected in series to form string which result in increased voltage and then many strings are connected in parallel to increase over all current.

Then these cells are placed between a top layer of glass and bottom layer of metal/plastic long with their electric connection. For increased mechanical strength an outer frame is provided, this complete unit is known as Photovoltaic Panel/Module.

The correlation between panel voltage (V_P) and panel current (I_P) and cell current (I_C) and cell voltage (V_C) is given by

$$I_P = N_{PP} I_C \quad \text{...11}$$

$$V_P = N_{SP} V_C \quad \text{...12}$$

$$R_{SP} = (N_{SP}/N_{PP}) R_{SC} \quad \text{...13}$$

N_{SP} is the number cell connected in series to increase voltage, R_{SP} denotes the equivalent series resistance and N_{PP} is the number of cell connected in parallel to increase overall current. The performance of photovoltaic panel strongly relies upon the light conditions or to say intensity of solar radiation. The average standard value for bright clear day is taken to be 1000 W of solar energy/meter^2. This average value is also known as “one sun” or “peak”. If the radiation is less than one peak then output will be decreased in that proportion.

For half sun i.e. 500 watts per meter square the output will be reduced to half value. Temperature also affects the working of panel after a certain value (depending upon the semiconductor material used in fabrication of cell) for rise of 1^{o}C the voltage can reduced by 0.04-0.1 V. the figure shows the effects of sunlight and temperature on working of PV panel.

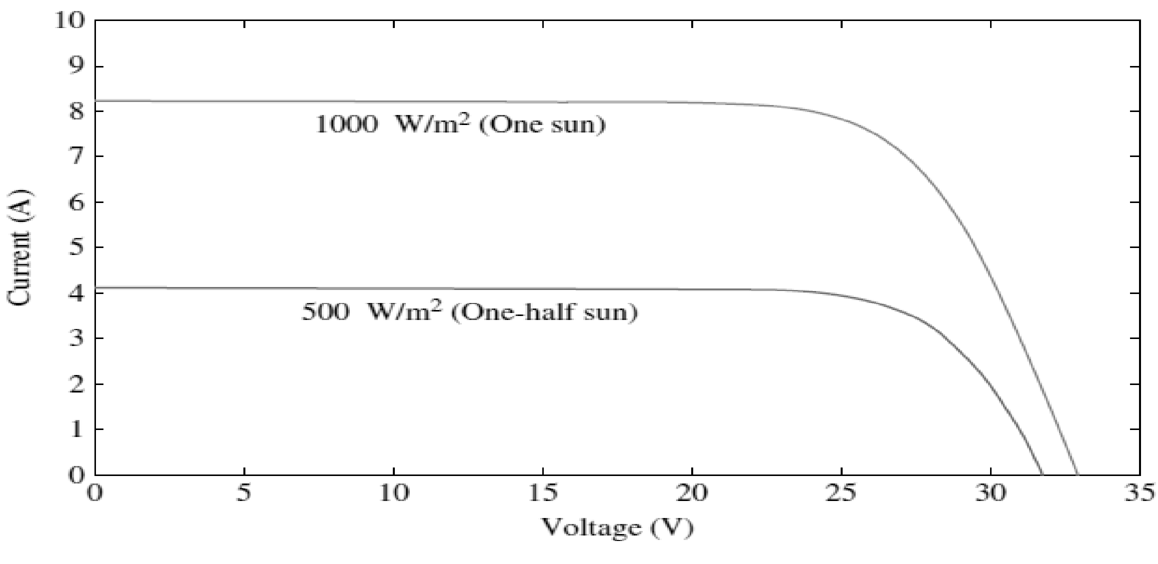

Figure 11 V-I characteristics for varying solar radiation

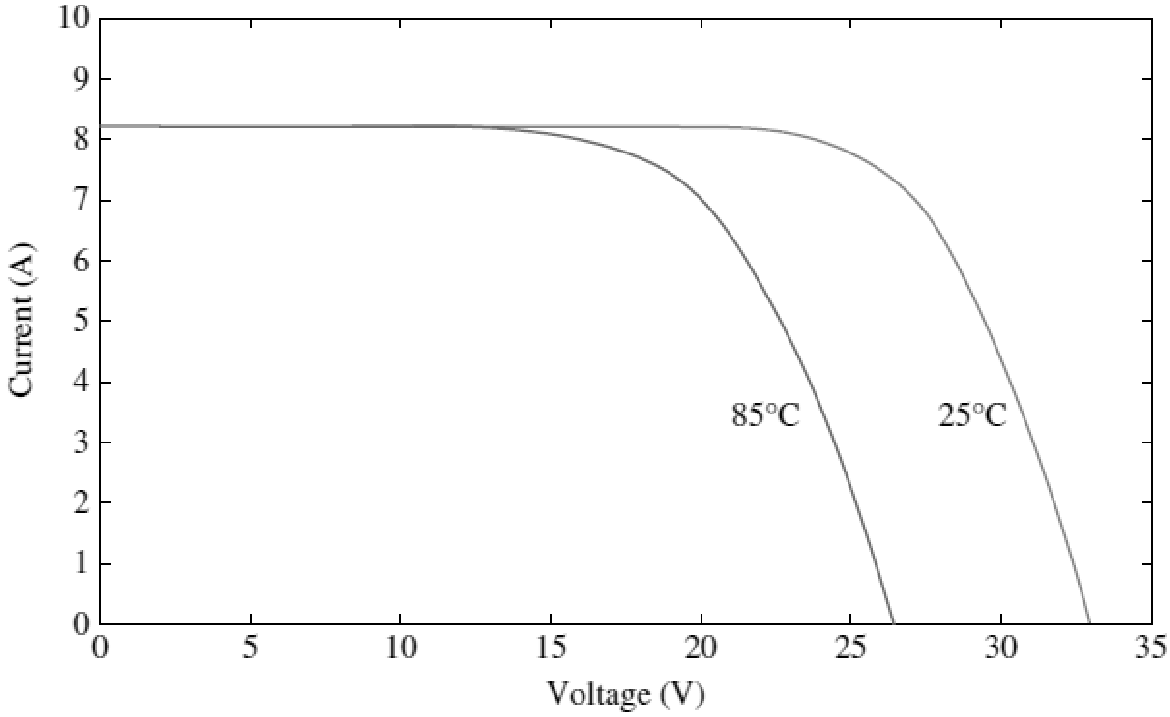

Figure 12 V-I characteristics for varying temperature

As known sometimes power generated by cell is inadequate similarly for some applications the power generated by module is not sufficient, so a number of panels are connected in similar manner again series and parallel to increase the voltage and current.

For instance 4 panel connected in parallel each panel having rating of 20 V and 4 A then the output generated will be 20 V and 16 A and when this configuration connected in series will give 80 V thus the overall production will be 80 V and 16 A.

Generally photovoltaics are connected with any energy storage like battery. So during night there will be no generation of power and this can result in reverse flow of power from battery to panel. This reverse flow will drain out battery and overheat the panels, in order to curb this reverse flow a diode is used.

The harm of using diode is that it can create voltage drop, so some sophisticated system have automatic controller which disconnect system from battery instead of a diode. If any panel fails during the operation then it will offer such high resistance that other module in string wont perform satisfactorily, for elimination of this a bypass track is used, the bypass diode permits the flow of current through in the “right” course from other panels.

5.2 DESIGNING OF MPPT

A conventional solar array is capable of converting 30 to 40 percentage of the incident sunlight into useful electrical energy. Maximum power point tracker serves as the medium to enhance the productivity of the solar array. In accordance to Maximum Power Transfer theorem, the output power is maximum for a circuit when the load impedance is equal to Thevenin's impedance .Thus challenge for tracking maximum power point is now just reduced to case of impedance matching. By altering the duty cycle of the converter accordingly, load impedance can be matched with source or for say Thevenin's impedance.

The choice of algorithm for selection of tracking techniques depends upon various factors like computation time, complexity level, cost and effectiveness. In practical use there are various MPPT techniques few of them are listed below:

Perturb and Observe

Incremental Conductance

Fractional short circuit current

Fractional open circuit voltage

Neural Networks

5.2.1 PERTURB & OBSERVE

The simplest method for MPPT is Perturb & Observe (P&O). The very first step of tracking algorithm is to measure the initial sample of the working voltage **Vpv** at time instance **T1** and current **Ipv** also at time instance **T1**. After taking the initial sample a second set of values for the working voltage **Vpv** (*t*2) and current **Ipv** (*t*2) is calculated. Considering the sedate data for current and voltage, the derivative of power is calculated **Δ*P*pv**. If the value for **Δ*P*pv** is coming positive, then the working voltage has to be altered in the course similar to the perturbation. If **Δ*P*pv** is anti-positive, the working voltage of the system has moved away from the maximum power point and it should be moved in direction opposite to the perturbation. Constant C is the value by which the operating voltage has to be perturbed. The value of C is taken to be as 0.1V as a suitable perturbation step value in the programming. If the photovoltaic output shows increment, then working voltage should also show increment, but with decrease in output power, the voltage should project decrement.

The advantage of this method is that a previous knowledge of PV generator characteristics is not required, and it is a relatively simple method. The P&O employs only one sensor, which is the voltage sensor, to detect the photovoltaic output voltage, thus the cost of device is reduced and it is relatively easy to assemble.

The duration taken by this algorithm is less but it has one drawback that on reaching in vicinity of MPP the iteration doesn't stop rather it continues perturbation in both directions. In this situation when algorithm has reached very close to the MPP at that instance a suitable error limit can be set.

Case	Δ***P***	Δ***V***	Δ***P/*** Δ***V***	Direction of Tracking	Control action for Voltage
1	-	-	+	Bad direction	Increase voltage **V by ΔV**
2	+	+	+	Good direction	Increase voltage **V by ΔV**
3	+	-	-	Bad direction	Decrease voltage **V by ΔV**
4	-	+	-	Good direction	Decrease voltage **V by ΔV**

Table 2 Control Actions for Various Operating Points in the P&O Method

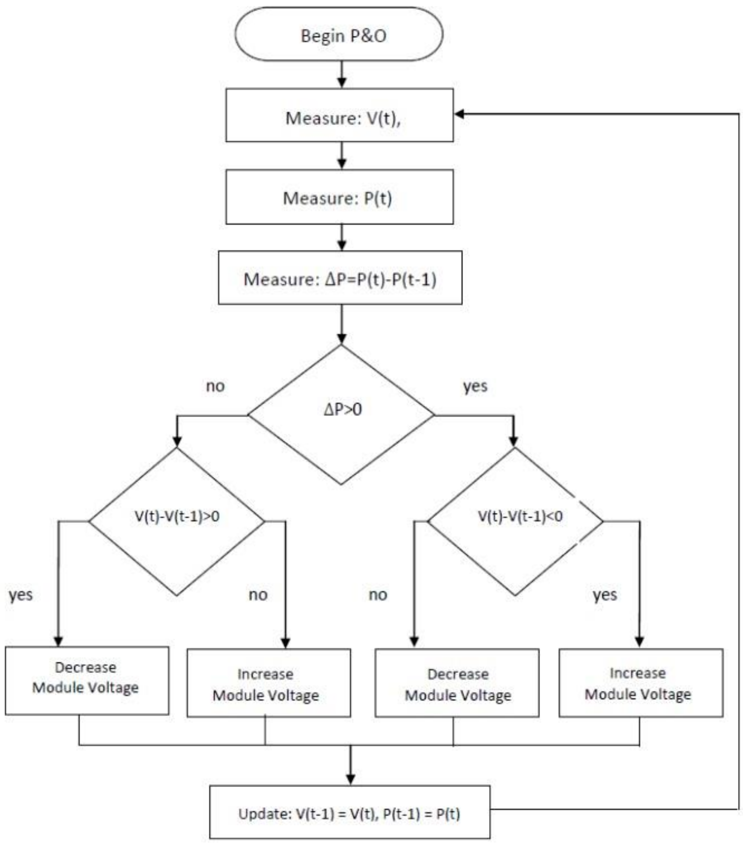

Figure 13 Algorithms for PERTURB and OBSERVE

5.2.1 INCREMENTAL CONDUCTANCE

This is another drastically adopted method for locating the maximum power point. Incremental Conductance is calculated by differentiating the photovoltaic output with respect to operating voltage and then setting the results equivalent to zero. The con of the perturb and observe of tracking the apex output under fast changing weather condition is overpowered by incremental conductance method.

The incremental conductance is capable of locating that the maximum power point tracker has reached the maximum power point and stop perturbing the operating point. If this argument is not met, then course for which the operating point should be perturbed can be determined by using the link between dl/dV and –I/V.

This co-relation is obtain from the factor that dP/dV is positive when it is to the left of the maximum power point and negative when the maximum power point tracker is to the right of the maximum power point.

This computation has pro over Perturb & Observe, in incremental conductance it can determine when the maximum power point tracker has reached the maximum power point, where Perturb & Observe swings around the maximum power point.

Also, incremental conductance can also quickly record irradiance with either increment or decrement conditions more accurately than P and O. The IC involves the usage of two voltages and two current sensors to determine the output voltage and current of photovoltaic panel.

(dP/dV)MPP=d (VI)/dV ……………………………………………………………………14

0=I+VdI/dVMPP…...………………………………………………………………….15

dI/dVMPP = - I/V…………………………………………………………...………16

The instantaneous conductance for the photovoltaic panel is projected on left hand side. When conductance of the PV panel is equal to this instantaneous conductance then MPP is reached. The current and voltage both are sensed simultaneously. Thus any error due to irradiance change is exempted. The usage of two sensors each for

At maximum power point the slope of the P-V curve is 0.

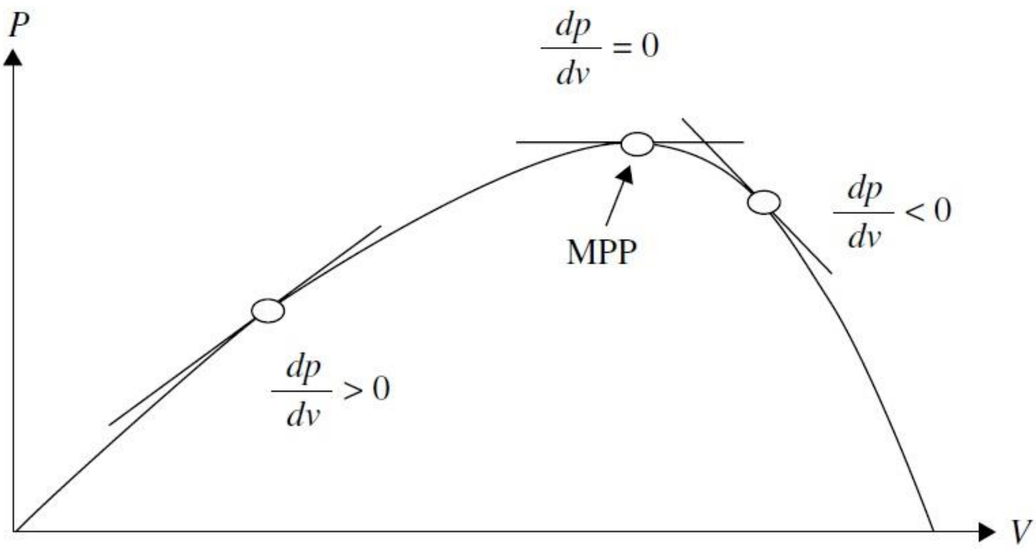

Figure 14 The basis of the IC method

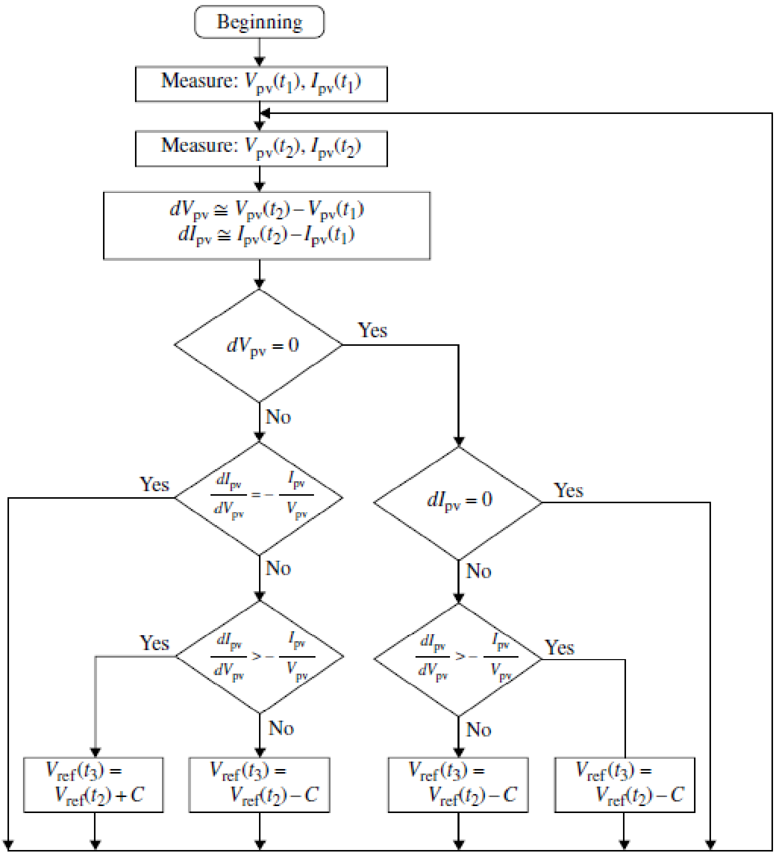

Figure 15 Incremental conductance method

MPPT TECHNIQUE	CONVERGENCE SPEED	IMPLEMENTATION COMPLEXITY	PERIODIC TUNING	SENSED PARAMETERS
Perturb & observe	**Varies**	**Low**	**No**	**Voltage**
Incremental conductance	**Varies**	**Medium**	**Yes**	**Voltage, Current**
Fractional Voc	**Medium**	**Low**	**Yes**	**Voltage**
Fractional Isc	**Medium**	**Medium**	**Yes**	**Current**
Fuzzy logic control	**Fast**	**High**	**Yes**	**Varies**
Neural network	**Fast**	**High**	**Yes**	**Varies**

Table 3 Characteristics of different MPPT techniques [51]

5.3 SELECTION OF INVERTER

The primary goal of static converter is to produce a regulated AC supply from unregulated DC input. For AC output to be sinusoidal, frequency, the output magnitude and phase should be tractable.

Depending upon the kind of output AC waveform, this design can be treated as voltage source inverter, voltage waveform is independently tractable ac output where the independently controlled ac output is a voltage waveform or as current source inverter, current waveform is independently tractable ac output.

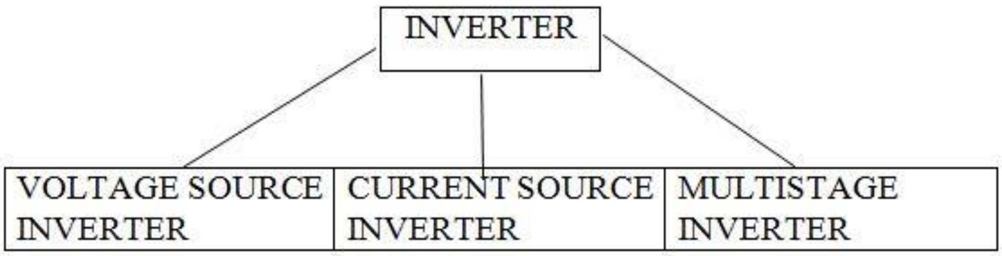

Figure 16 Classification of inverter

5.3.1 VOLTAGE SOURCE INVERTERS

A single phase voltage source inverter includes low energy applications and three phase voltage source inverter include medium range to high energy operations. As in single phase voltage source inverter, switching on of any leg simultaneously is not possible as it can lead to short circuit supply providing dc link voltage. Similarly, switches of nay leg on inverter can’t be turn off as it leads to voltage generation which depends upon polarity of each line current .This is done to prevent any undefined states in voltage source inverter

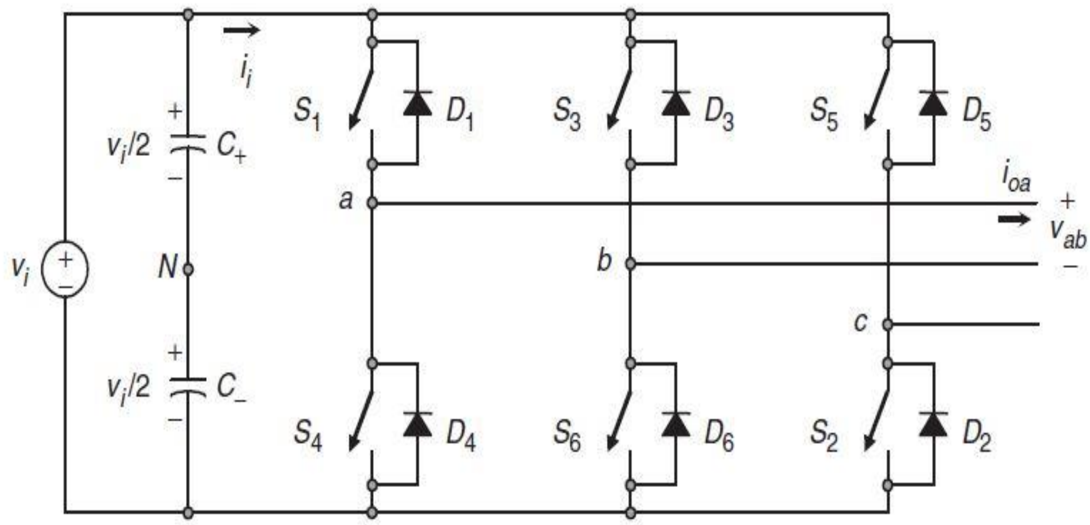

Figure 17 Three-phase VSI topology.

The various modulation techniques used in VSI are as following

- Pulse Width Modulation
- Sinusoidal Pulse Width Modulation
- Modified Sinusoidal Pulse Width Modulation
- Space Vector Modulation

5.4 DRAFTING OF ENERGY STORAGE

The battery is most commonly used means for energy storage in photovoltaic plant The battery incorporates a series and parallel combination of electrochemical cells. The series combination provides the desired voltage and parallel combination provides desired current The energy is stored in cell at low potential of few volts. C is the cell capacity which is gauged in Aretha average voltage during the discharge period and capacity C defines the rating of battery. An equivalent circuit for battery is shown in figure 30. V1 and R1 represent the internal voltage and internal resistance respectively.

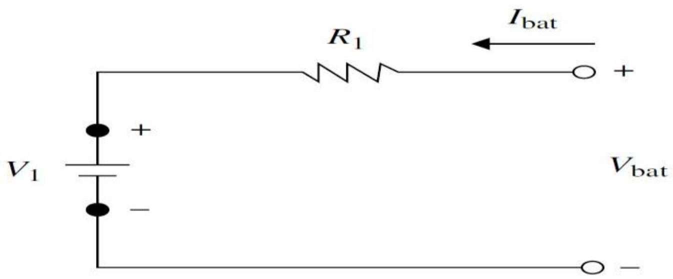

Figure 19 Equivalent circuit of battery

Ibatt, is discharging or charging current relying on voltage level of system. If the system voltage applied is greater than battery voltage Vbatt then the current Ibatt will flow towards battery as in charging mode .Similarly if the system voltage applied is smaller than battery voltage Vbatt then the current Ibatt will flow away from battery as in dis-charging mode.

For charging a battery of 800Ah at C/20 explains that battery should be charged at 40 A for 20hr. Likewise discharging at rate of C/4depicts to drain out battery current by 100 A for 4 hr continuously.

State of Charge= Remaining Ahr capacity /Rated Ahr capacity……………..…………17

Lead-acid ,Nickel metal hydride and Nickel Cadmium batteries are most commonly utilized batteries for hybrid system of solar and wind. The most commonly rechargeable batteries are of Lead-acid type as the technology highly matured and very cost effective irrespective of its low energy density .In Pb-acid battery during discharging **PbSO4** and water is created.

The water serves the dilution of **H2SO4** acid ,thus with decrement with state of charge the electrolyte specific gravity also decreases he water dilutes the sulphuric acid electrolyte and the specific gravity of the electrolyte decreases with decreasing SOC.

The reverse chemical reaction is carried during charging process. Battery is brought back to initial charge level by formation Lead-di-oxide on both negative and positive plate. Shallow cycle and deep cycle are two variant in which Pb-acid battery is available.

For repeatedly full charging and full discharging the deep cycle variant is well suited. A 'gel-cell' with add-ons version is also available for Pb-acid battery . This is quite expensive and serves purpose in army and warfare.

In this electrolyte is form of non-spill able gel. Pb-acid battery is twice as heavy as Ni-Cd battery. Ni-Cd battery have longer life ,longer deep cycle and more temp permissive than Pb-acid batteries. Ni-Cd battery has memory effect which downgrades the battery life if not used for longer time.

Radioactivity is possessed by Cadmium thus it is relatively not safe, so NiMH is replacing NiCad batteries. As known no electric appliance can work for varying level of voltage or frequency, so the dynamic current and voltage from hybrid system can't be supplied to any appliance .

So the power output from wind plant or solar is initially stored in batteries then from batteries a constant supply is provided to load. A battery having Pb-acid cells having value of 2V are widely used for storing large blocks of energy and they suit the economical factor also.

5.5 MOTOR PUMP MODEL IN PHOTOVOLTAIC PUMPING SYSTEM

For low power applications, hindrance offered by a regular DC motor is overcome by Brushless permanent magnet DC motor. The back EMF of DC motor is related to output current and voltage of photovoltaic panel at maximum power point.

$$V=IR_A+E_B \quad \ldots 18$$

Where armature current and armature voltage of a conventional DC are denoted by I and V. The back electromotive force voltage of motor is denoted by E_B and R_A represents the armature resistance. The electromagnetic torque(unit Nm) for DC motor is given

$$T_M=K_T\, I \quad \ldots 19$$

T_M represents the electromagnetic torque whereas K_T torque constant (unit Nm/A). The efficiency (ŋ)and power (P_{MO}) neglecting frictional and rotational losses can be given as

$$P_{MO}=I*E_B \quad \ldots 20$$

$$\eta_M = P_{MO}/VI \quad \ldots 21$$

The torque is also dependent upon rotational speed ω(radian/second)

$$T_p = K_P\, \omega^2 \quad \ldots 22$$

K_P is constant and is calculation is dependent upon dimensions of pump impeller

$$K_P=2\,\pi\rho h_1 r_1^2 \tan(\beta_1)[r_2^2 - \{ r_2^2 h_1 \tan(\beta_1)/h_2 \tan(\beta_2)\}] \quad \ldots 23$$

where ρ is the water density given as kg/m^3, h_1 h_2 are height of impeller blades in millimetres , r_1 r_2 are impeller radius also given in millimetres and β_1 β_2 are the inclination angles in degrees.

Thus having all the parameters the ω can be computed as below

$$\omega= \sqrt{(K_T\, /Kp)} * I \quad \ldots 24$$

When neglecting the various losses then in that case input power(P_{PI}) for pump is equal to the mechanical output . The power at output (P_{PO}) and the efficiency can be given as

$$P_{PO}=T_p\, \omega \quad \ldots 25$$

$$\eta = P_{PO}/P_{PI} \quad \ldots 26$$

the inclusive efficiency and subsystem efficiency is given as

$$\eta_{sub} = \eta_M\, \eta_P \quad \ldots 27$$

$$\eta_{SYS} = \eta_{PV}\, \eta_M\, \eta_P \quad \ldots 28$$

5.6 MODELLING OF PHOTOVOLTAIC SYSTEM ENERGY FLOW

The operation and extent of a photovoltaic system relies upon various climatic factors like solar radiation ,wind velocity and surrounding temperature. So in order to amend and govern photovoltaic system, strict modelling must be designed.

Photovoltaic system configurations can be grouped in two categories current based layout and energy flow layout . To project photovoltaic structure controlling scheme current based configuration are preferred and for structure sizing energy based configuration are chosen.

A photovoltaic system consist of photovoltaic panels/array , power conditioner (this include charge controller or MPPT), energy storage ,inversion circuit and load (utility grid). Normally the solar radiation is collected by photovoltaic module and DC is produced ,then this current goes to inverter through power conditioner. In inverter DC is converted to AC. Now this AC is injected to grid at zero point of grid

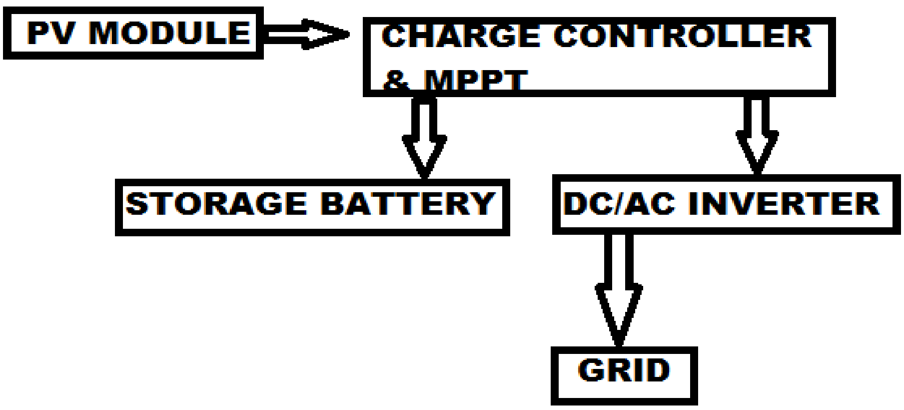

Figure 20 Energy flow for PV system

The energy produced by photovoltaic array E_{pv} is dependent upon the time slot for which meteorological data is used for instance if time slot is hourly then power generated by photovoltaic P_{pv} is equal to the energy produced

$$E_{pv}(t)=P_{pv}(t)D \quad \text{.....29}$$

Where D is the day length and given as

$$D=\frac{2}{15}\cos^{-1}(-\tan L*\tan\delta) \quad \text{.....30}$$

Lis the latitude of location and δ is angle of declination

The energy at the load side is by $E_{sum}(t)$

$$\mathbf{E_{sum}(t)=\sum_{i=1}^{366}(Epv(t) - E_L(t))} \quad \ldots\ldots\ldots 31$$

E_L is the load demand, if ($E_{PV}>E_L$) i.e. positive then there is abundance in energy (EE) or ($E_{PV}<E_L$) negative then there is shortage of energy (ED). The extra energy is stored in energy storage device like batteries to supply during the shortage of energy. The energy shortage or energy deficit can be narrated as the infirmity of photovoltaic system to supply the required power to the demand at a particular time .

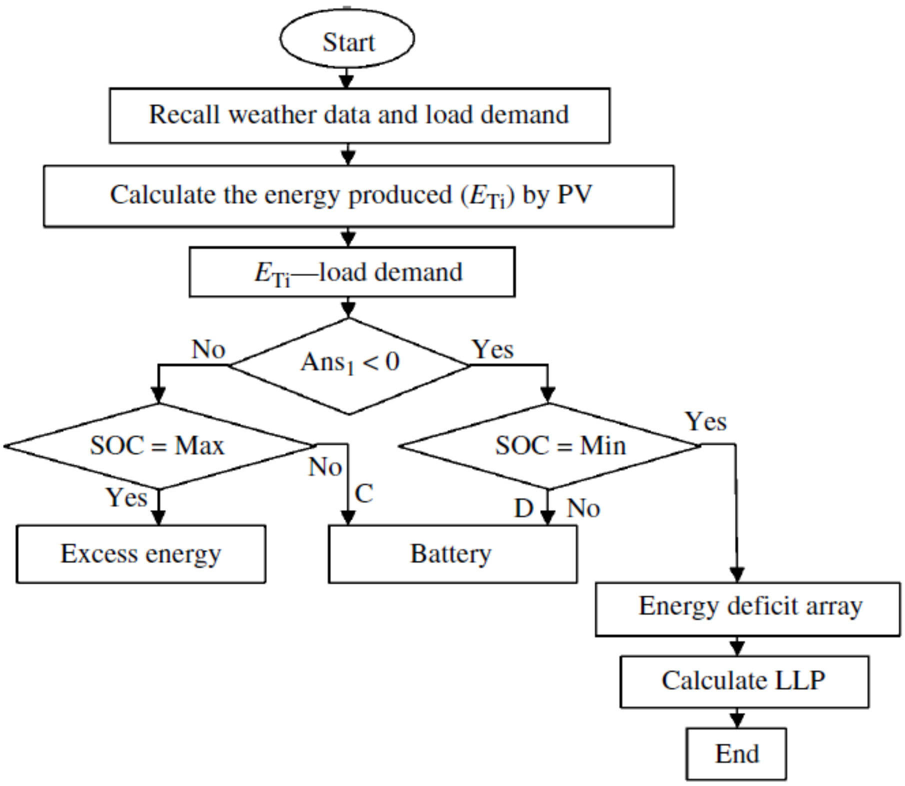

Figure 20 Flowchart for modelling of SAPV system

5.6 ENERGY FLOW MODELLING FOR HYBRID (DIESEL/PHOTOVOLTAIC) POWER SYSTEM

As mentioned earlier that photovoltaic system is not capable of supplying the load completely around the clock, to cope this deficit of energy photovoltaic system are connected to an energy storing battery.

At times there is very low generation form panels due heavy overcasting of clouds or due to foggy surroundings that batteries connected are not able to compensate for deficit so for this photovoltaic system is also connected to diesel generator to provide requisite demand of power.

So for this hybrid layout the deficit time can be stated as the instance for which the generated from the photovoltaic module and energy from battery is sufficient to meet the load requirement.

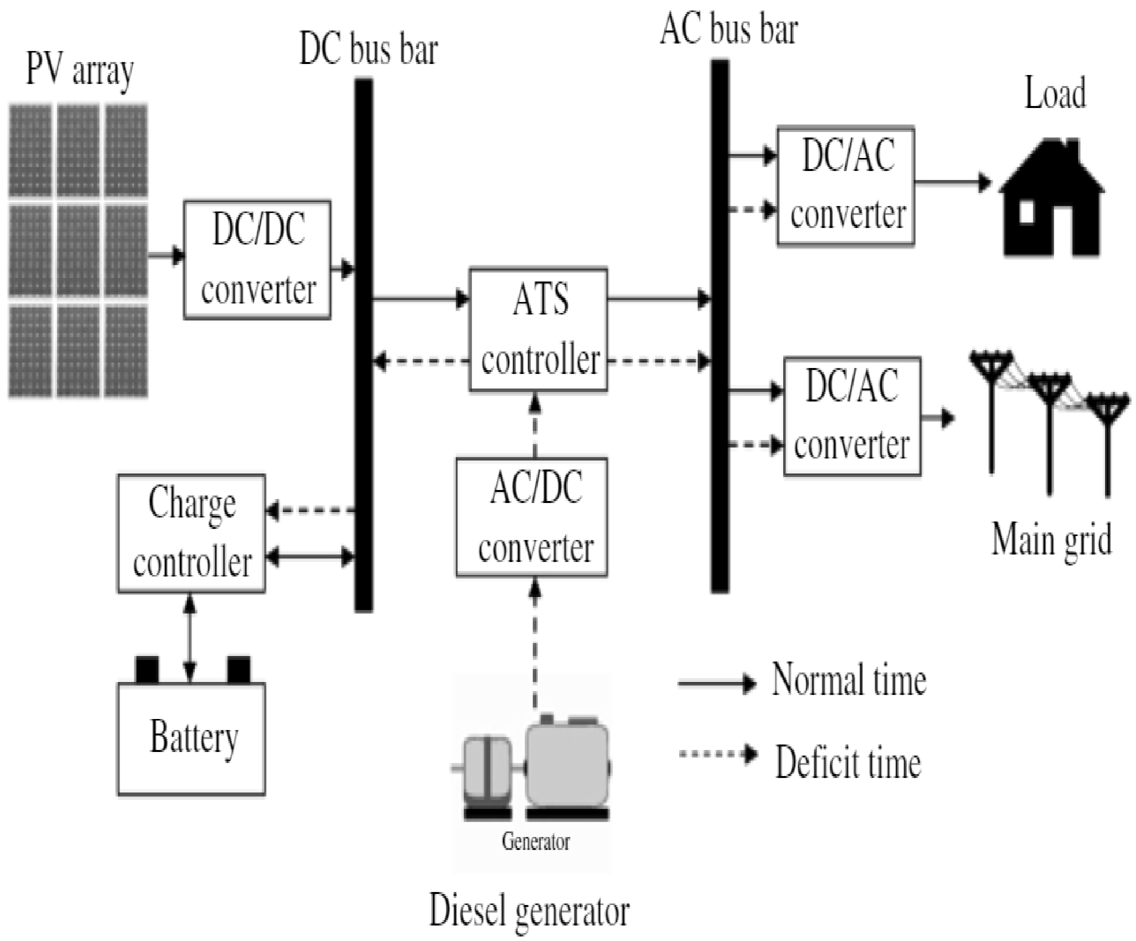

Figure 21Layout for PV/Diesel hybrid system

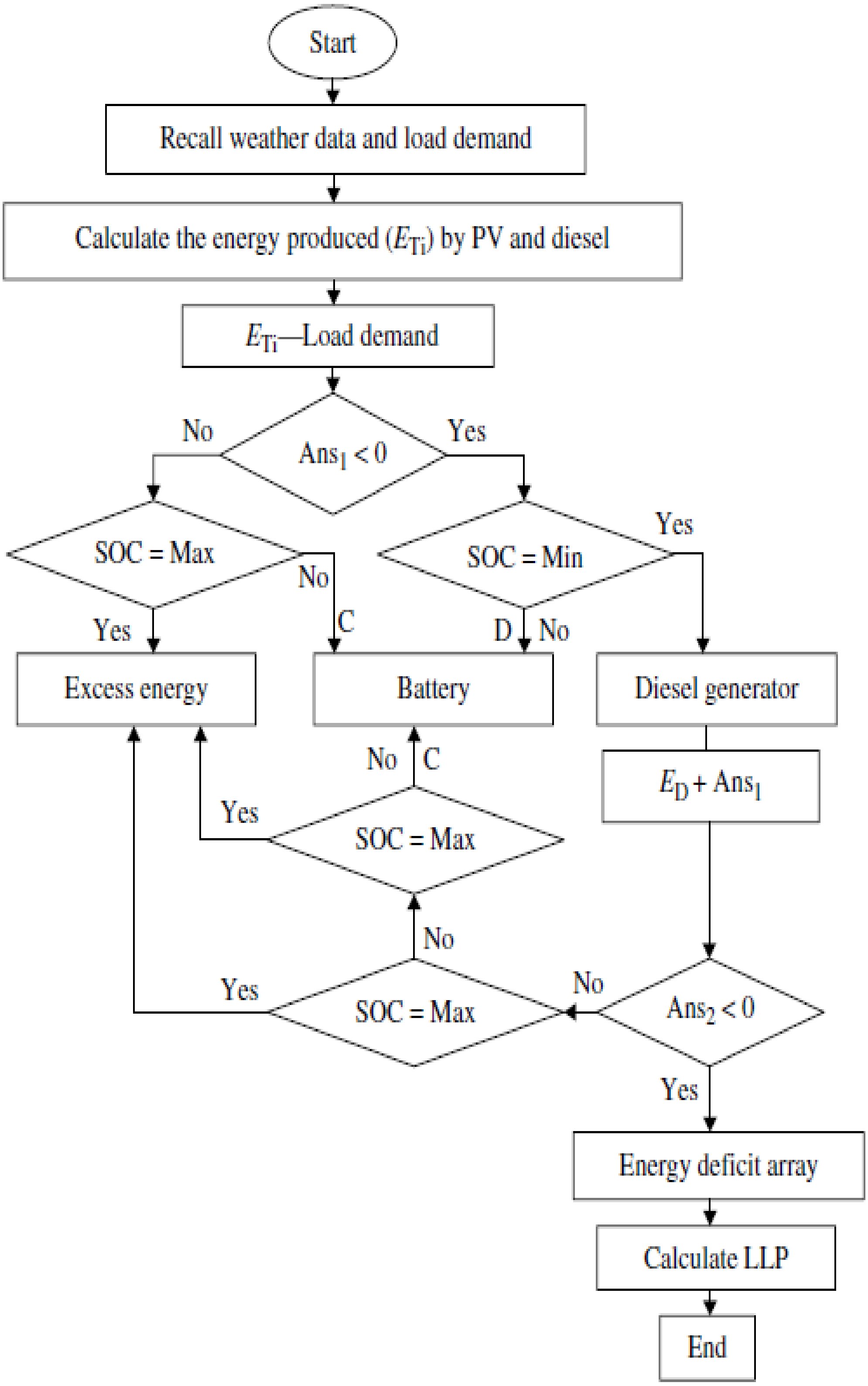

Figure 22 Flowchart for simulation of hybrid system

5.7 CURRENT BASED MODELLING OF HYBRID/BATTERY SYSTEM

In this type of layout the flow of current is to depicted correctly such that to have exact operating conduct of photovoltaic system. This helps in proper sizing and governing of system.

Broadly there are to governing schemes for hybrid/battery system, these include load following scheme and cycle charging scheme

5.7.1 LOAD FLOW SCHEME

Initially the data set for various parameters like insolation and temperature are procured. The specifications for system and its various components are described. Then current generated by photovoltaic module (I_{PV}) is compared to load current (I_L). The flowchart for the simulation process is as following

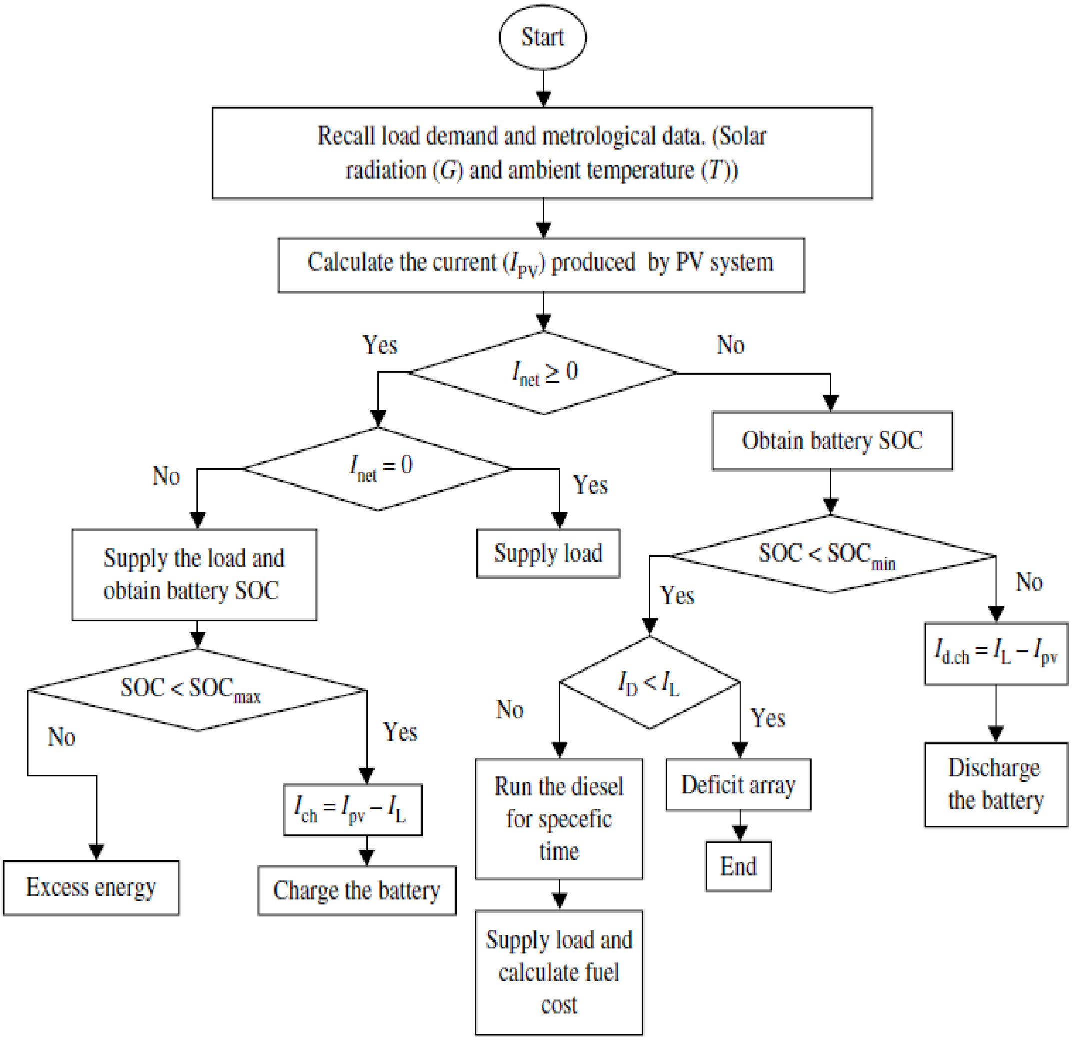

Figure 23 Flowchart for simulation of hybrid system following load cycle

5.7.2 CYCLE CHARGING SCHEME

This scheme is more like similar to load flow scheme, but the difference occurs when battery is not capable to meet energy demanded by load. (**STATE OF CHARGE < STATE OF CHARGE$_{MIN}$**) . For this situation there is the case

Firstly, when diesel generator current is more than load current(I_L). So the diesel generator will be running at its rated power and will be supplying to load , if there is any excess of energy it will charge the until state of charge ≤ state of charge$_{MAX}$.

Secondly, when battery is fully charged state of charge > state of charge$_{MIN}$ and load current(I_L) is greater than maximum diesel generator current($I_{D\ MAX}$).So for this scenario generator and battery both will supply to load.

Thirdly, when battery state of charge < state of charge$_{MIN}$ and load current(I_L) is greater than maximum diesel generator current($I_{D\ MAX}$) ,then diesel generator wont able to supply the load and also won't able to charge battery.

The flow depicting the simulation process for cycle charging scheme is following

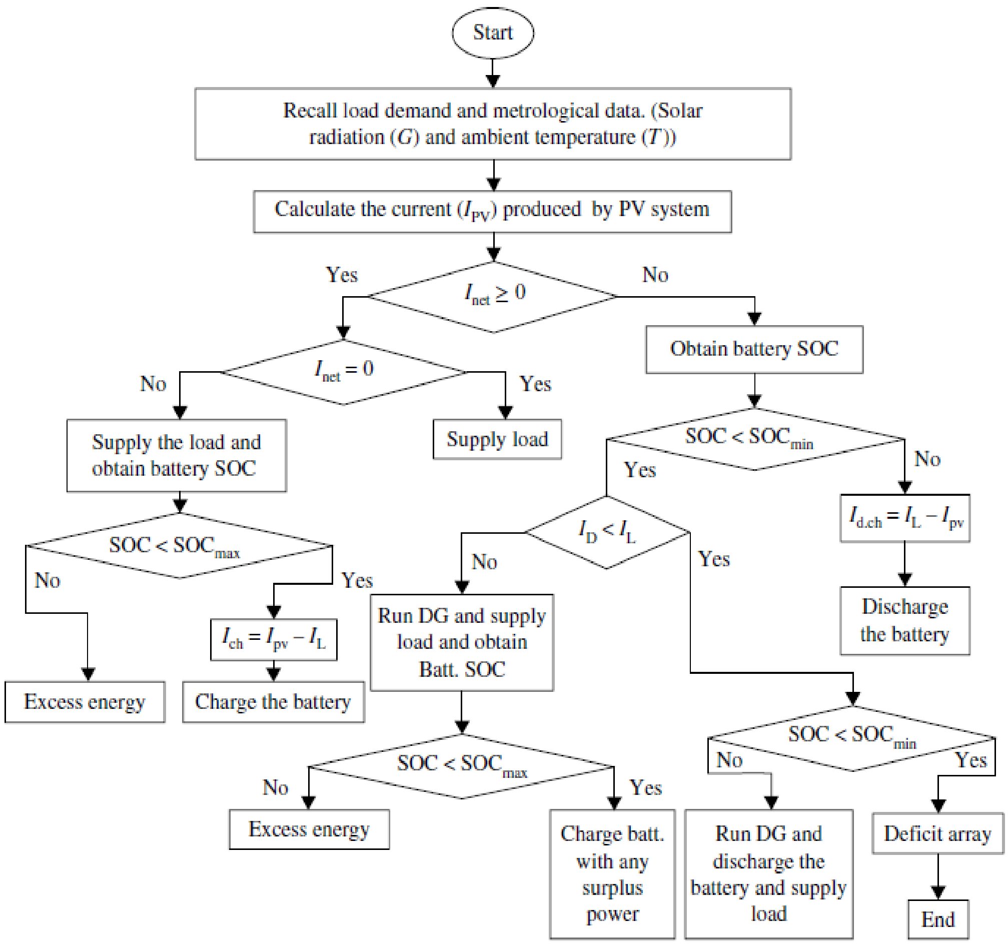

Figure 24 Flowchart for simulation of hybrid system following charging cycle

5.8 INTEGRATION OF PHOTOVOLTAICS SYSTEM INTO POWER SYSTEM

The ever increasing demand for power has pushed electrical energy generation to its brim. Yet power providers have sufficient amount of backup. Presently transmission systems have reached to maximum of their capacity due massive power movement. So all this increasing the burden on existing system, thus service provider doing lot of investment to ensure continuous and healthy power supply.

Thus with advent of photovoltaics has led to many advantages like voltage backing, enhanced quality of power, reduction in loss, delaying the need of new generating unit and revamp security. The photovoltaics distributed generation can be located near to consumer and also linked to grid thus meeting the power demand and reducing the congestion on transmission line.

When photovoltaics distributed generation is integrated to grid it can have either positive effects or negative effects relying on the characteristics of distribution network working and photovoltaics distributed generation. If photovoltaics distributed generation is capable of meeting the fundamental needs of the network the it can be termed as beneficial.

The interference of photovoltaics distributed generation with utility network , the rating of diesel generator, and the overall rating of photovoltaics distributed generation effects the power quality of system. The following figure shows the layout of grid integrated photovoltaics distributed generation.

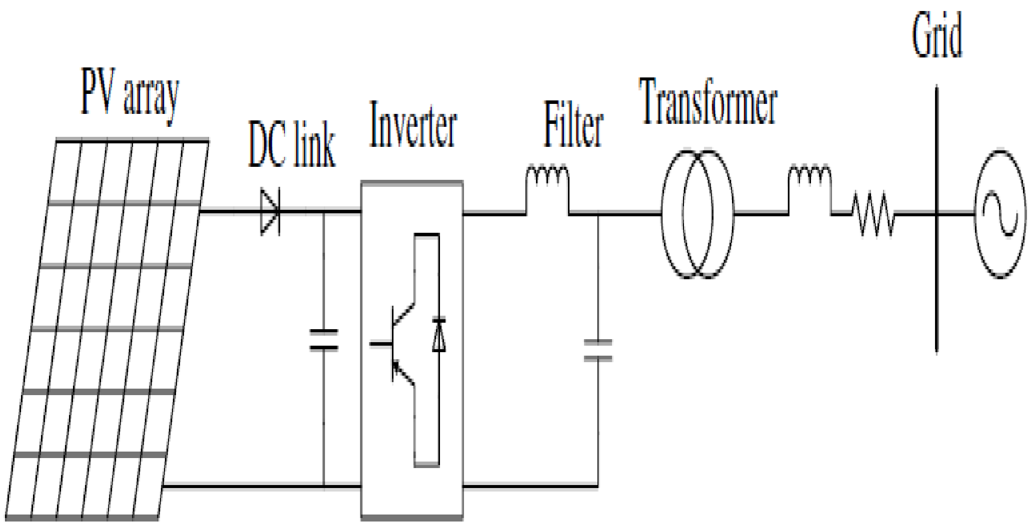

Figure 25 Integration of photovoltaics with grid

The harmonics are major power quality issue that downgrades the working of power system. The root cause of harmonics are increment in power electronic appliances, nonlinearity of device also triggers harmonics.

The harmonics created have negative effect on devices and system both like derating of appliance, protection equipment may malfunction and overheating of transformer and neutral conductors.

When photovoltaics distributed generation is linked to grid, harmonic resonance is another issue effecting power quality. When inductive element is equalling to the capacitive component then for this resonant frequency harmonics resonance will happen.

The number of photovoltaics distributed generation units effects the harmonic resonance. The connection of photovoltaics distributed generation can reduce the transmission line congestion, can result in peak shaving and provide strength to grid requirement.

5.9 OPTIMAL SIZING AND PLACEMENT OF PHOTOVOLTAICS DISTRIBUTED GENERATION

Harmonic distortion and voltage fluctuation are primary interference in distribution system. Growing electric power need is resulting in voltage drop, there by advising to enhance the infrastructure of distributed system.

Various analysis and studies have pointed out that 13% of produced electric power is wasted as losses in distribution network. To avert the voltage variation and harmonics disturbances various schemes were deployed like using custom power controllers to avert voltage fluctuation problem and for harmonics active and passive filter are used and these scheme require initial investment.

So in order to curb fluctuations in voltage and distortion due to harmonics in distributed network by photovoltaics distributed generation to have a proper groundwork for photovoltaics distributed generation units and deciding optimal location and sizing of photovoltaics distributed generation units.

Photovoltaics distributed generation unit installation effects the power system operations, so before installation the feasibility analysis has to be performed.

Therefore permissible photovoltaics distributed generation injection to the grid must adhere to harmonic boundary. To implement the optimization strategy for resolving the challenge of optimal location and sizing of photovoltaics distributed generation is shown in following flow chart.

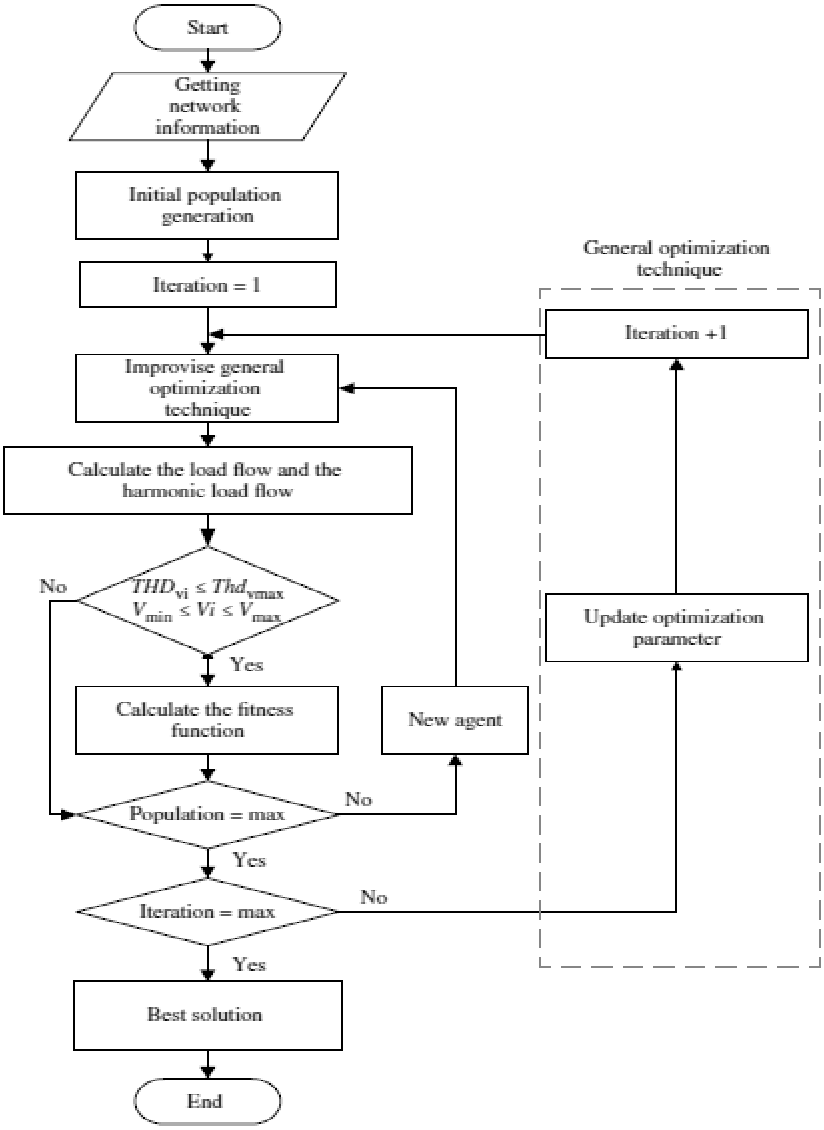

Figure 26 Optimal sizing and placement of photovoltaics distributed generation

5.10 OPTIMIZATION FOR PHOTOVOLTAIC SIZING

The operation and extent of a photovoltaic system relies upon various climatic factors like solar radiation ,wind velocity and surrounding temperature. So in order to amend and govern photovoltaic system, strict modelling must be designed.

Normally widely employed optimization technique begins by laying the size for the particular system and then data with respect to time for solar radiation, surrounding temperature and wind velocity is collected .

Depending upon the type of photovoltaic system i.e. standalone or grid connected , the computation of system energy for optimum capacity is done depending upon availability index of system

5.10.1 OPTIMIZATION OF PHOTOVOLTAIC SIZING IN STAND-ALONE SYSTEM

Standalone photovoltaic systems are generally used in remote area where there is no connection to electric grid. Standalone photovoltaic system must be architect to fulfil load requirement at a particular reliability value. The three main procedures for sizing of standalone photovoltaic system they are simulation(numerical), intuitive and analytical method.

In intuitive approach computation for the size of system is carried out without forming any co-relation between various subsystems or taking the varying behaviour of solar irradiation. The main drawback of this approach is that result in over/under sizing of standalone photovoltaic system ,thus affecting the cost on investment and reliability of system .On the basis of this approach the required photovoltaic panel and capacity of battery can be formulated

$$P_{PV}=(E_{DL}/\eta_{SY}\,\eta_{INV}\,PS)*S_F \qquad \ldots 32$$

E_{DL} is energy utilization on daily basis, η_{SY} η_{INV} are system components efficiency, PS is the peak solar hour and S_F is the safety factor showing the indemnity of losses due cell temperature and due to resistance. The battery capacity can be given as

$$B_{WH}= (E_{DL}*D_{AUTONOMOUS})/(V_B*DOD*\eta_B) \qquad \ldots 33$$

Battery block’s voltage and efficiency are given by V_B and η_B respectively and DOD cell’s rate of depth of discharge. For system designed by these equations the loss of load probability is 8% which quite much.

For numerical approach a simulation of system is used for a definite time period taken in consideration , normally an hour or a day , the system’s energy balance and load state of battery are computed.

This approach has benefits such as the approach is more accurate, energy reliability concept can be enforced in a perceptible way. The reliability of system can be expressed as the percentage load caters by the photovoltaics for a longer duration. The economical costing of system and energy both can be optimized by this approach

Lastly the analytical approach, equations defining the photovoltaics size as the function of reliability is designed.

The primary benefit of this approach is computation for photovoltaics size is very easy and the drawback of this approach is that is tedious to find coefficients of the equations as they rely on factors which depend upon a particular location.

Loss of load probability (LLP) can be explained as the situation when system is not able to cater the load demand. If LLP is 1 (100%), it means that power from system is sufficient to meet the load completely without any discontinuity.

For the case when LLP is 0,this means that source in unable to supply load for given particular time at all. So LLP can be expressed as the ratio of the overall energy deficit to the overall demand by the load for given time.

$$\mathbf{LLP} = \frac{\sum_t^T \mathrm{DE(t)}}{\sum_t^T \mathrm{P_{LOAD}(t)\Delta t}} \qquad \dots 34$$

DE(t) is the energy deficit, which can be interpreted as defect in system such that it can't provide power to the load at given time, the power demand at that time is given by P_{LOAD}(t)and time period for both is given by Δt.The annual total life cycle cost (ATLCC) is used to compute the estimated value of annual cost for the parts of system. It can depicted as the total amount of operation and maintenance cost annually(C_O), annual cost of replacement(C_R) and annual capital cost(C_C).This total amount is then deducted from annual savings(C_S).

$$\mathbf{ATLCC} = \sum_{device} C_C + C_O + C_R + C_S \qquad \dots 35$$

The levelled cost of energy (LCE) is described as the ratio of the annual costing of the components of system to annual generation of energy through the system(E_T).

$$\mathbf{LCE} = \frac{\mathrm{ATLCC}}{\mathrm{E_T}} \qquad \dots 36$$

The algorithm used for numerical approach for optimal sizing of photovoltaics has two stages in first stage begins by stating the spec for components and system, in stage two current flow approach for hourly basis is used to calculate the Loss of Load Probability for each layout using the indirect models, following flowchart shows the algorithm.

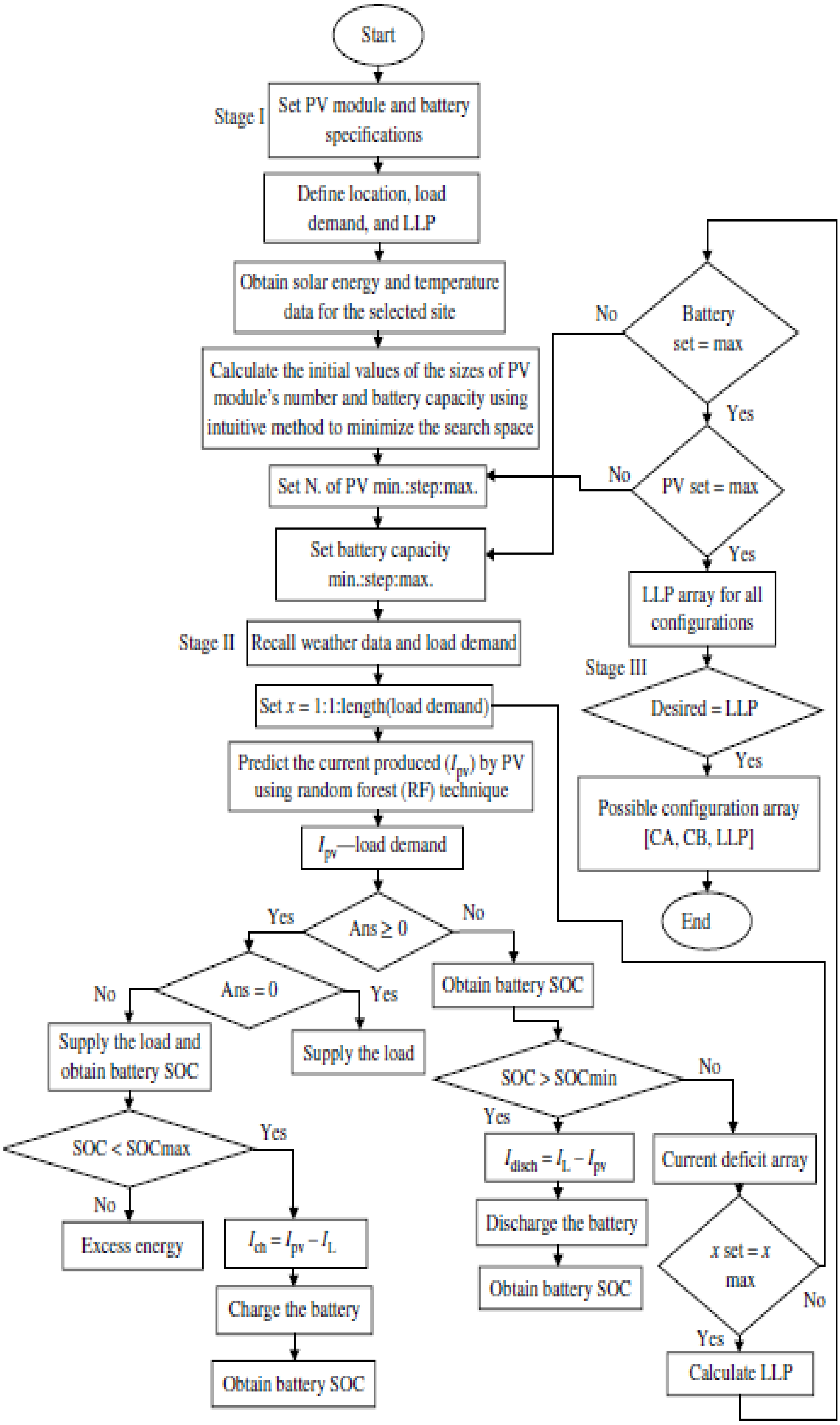

Figure 27 Flowchart for optimization of photovoltaic sizing in stand-alone system

When designed space is determined in such manner that it equals to the favourable LLP then the ATLCC for every layout in designed space is computed. The layout having the least value for ATLCC is then chosen for optimal size of system. The following flowchart describes the computation of ATLCC

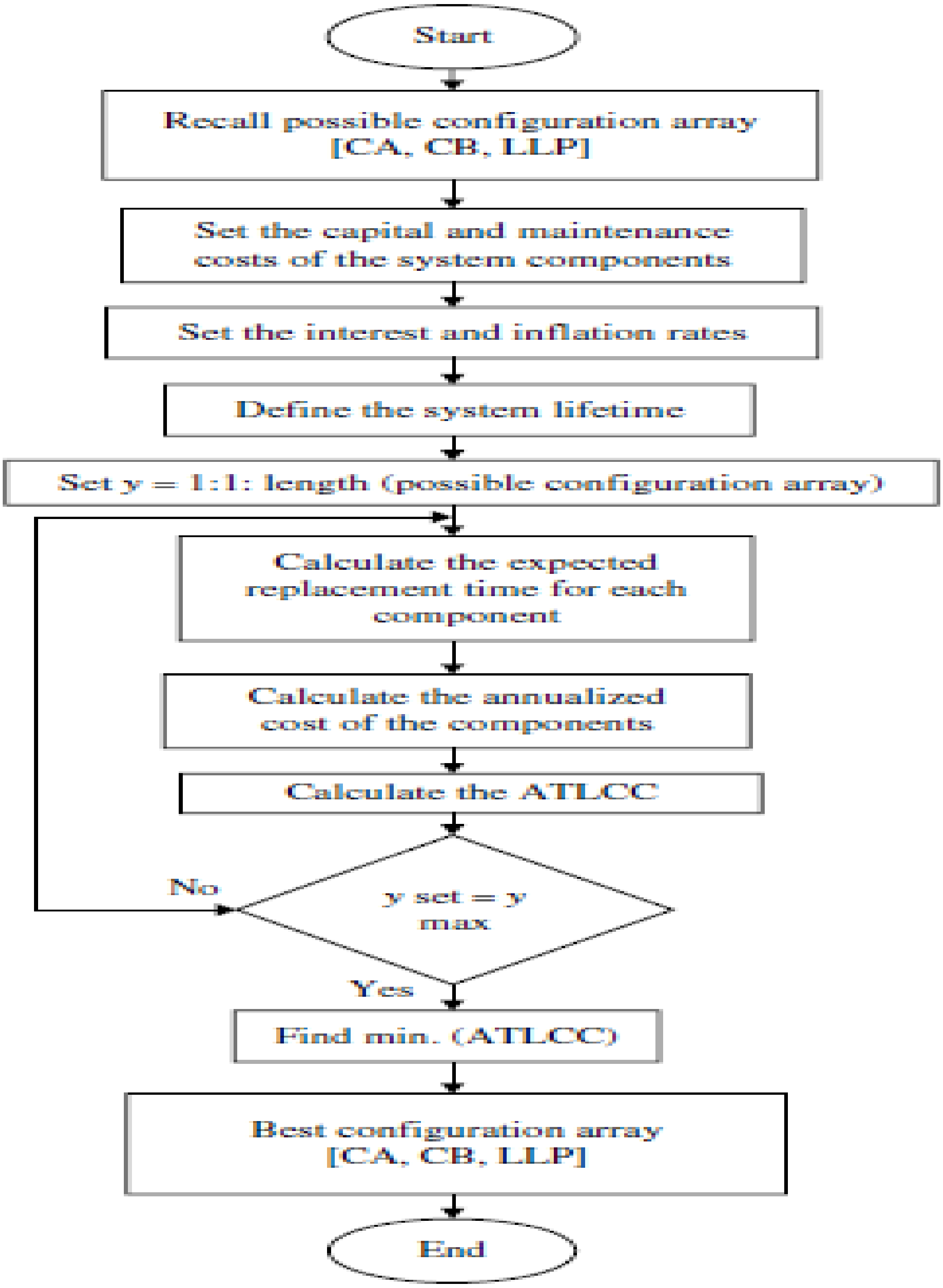

Figure 28 Flowchart for ATLCC

5.10.2 OPTIMAL SIZING FOR HYBRID PHOTOVOLTAIC SYSTEM

Like standalone photovoltaic system, optimal sizing is needed for hybrid photovoltaic system. In order to get accurate value of result modelling is done. Here a hybrid system incorporating photovoltaic array, wind turbine, battery for energy storage and a diesel generator.

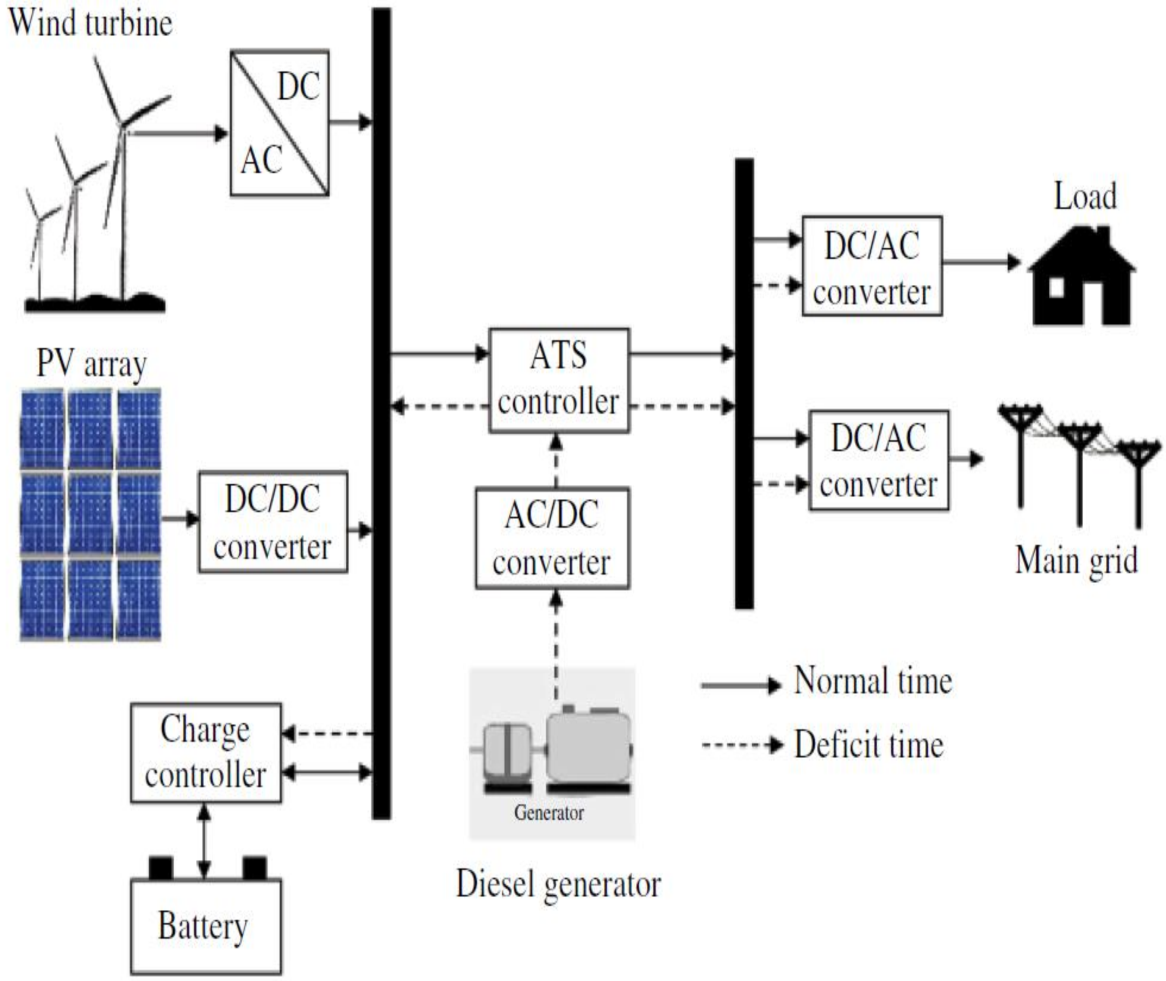

Figure 29 Layout for wind/battery/photovoltaics/ diesel generator hybrid system

The system is catering a load and excess of energy will be penetrated into grid, the photovoltaic system and wind energy system both are supplying to the load. For the scenario when the power produced by photovoltaic system and wind system is not capable of meeting the load demand, the deficit will be compensated by batteries.

The generator comes in operation when power demanded is more than combined power supplied by photovoltaic system, wind energy system and batteries.

The algorithm used for optimal sizing of hybrid system is having three parts. In first portion system's design space is developed as shown in following flowchart

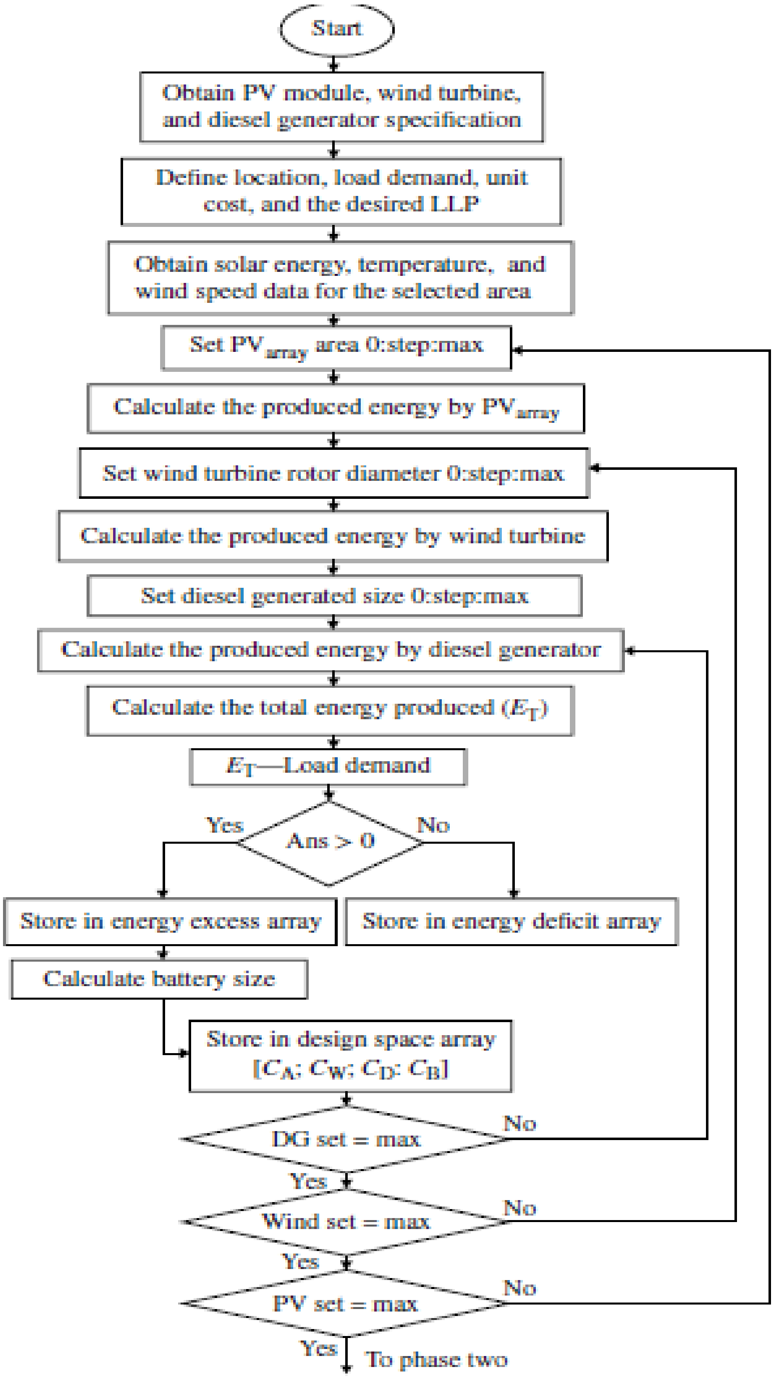

Figure 30 Flowchart for first portion of optimization for wind/battery/photovoltaics/ diesel generator hybrid system

In second portion the need to compute the system's availability the developed design space is utilized for performing the simulation for system. The following diagram explains the algorithm

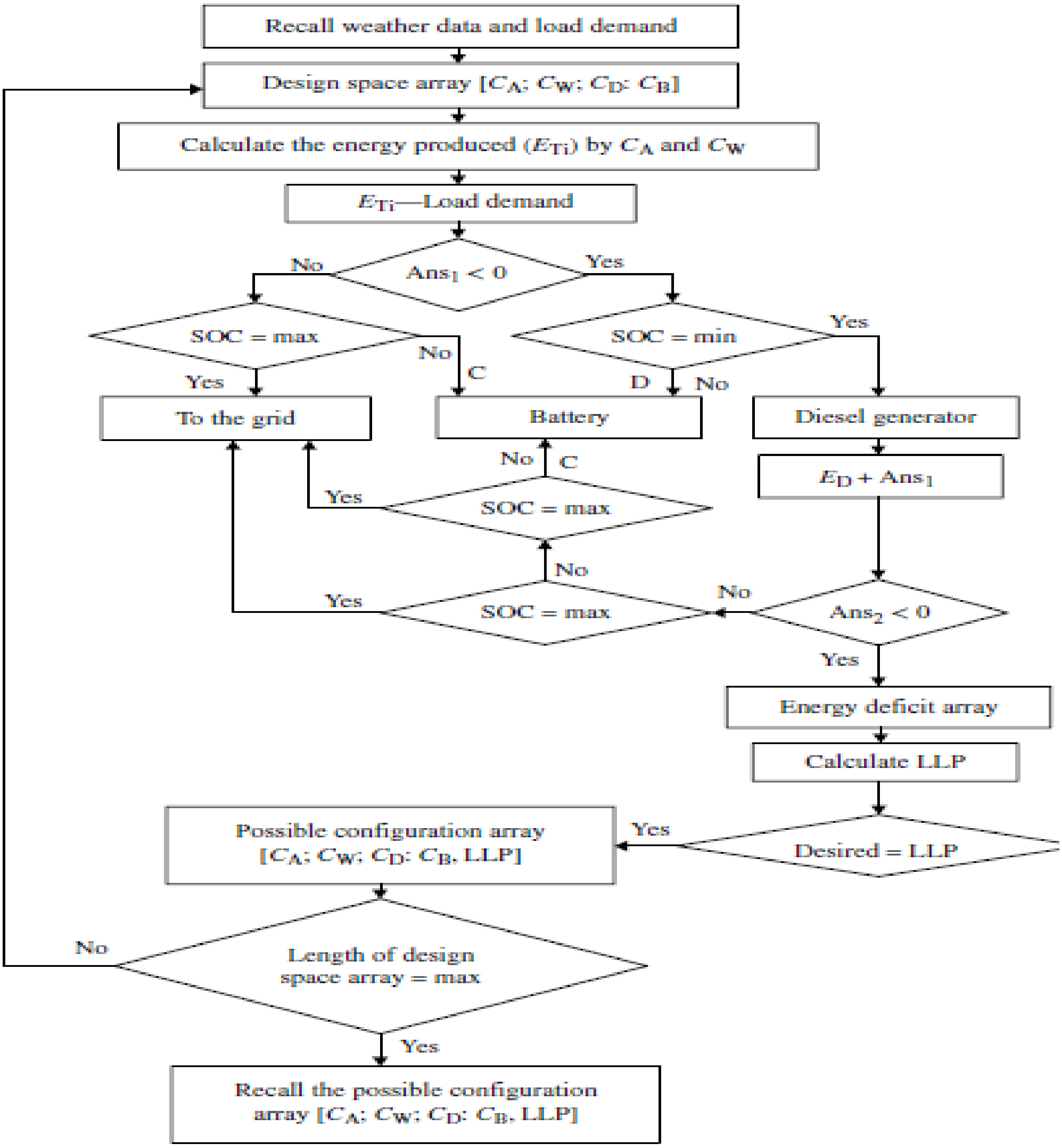

Figure 31 Flowchart for second portion of optimization for wind/battery/photovoltaics/ diesel generator hybrid system

In third portion for every component of system and for the system itself the unit cost are determined. The system cost includes the cost of running , cost of replacement and capital cost. Thus the system having minimum cost is treated as optimal system.

5.10.3 OPTIMIZATION OF PHOTOVOLTAIC PUMPING SYSTEM

The configuration of system plays vital role in effecting the operational behaviour of photovoltaic pumping system, the optimum layout is preferred in order to meet the water demanded. For this numerical approach is used to decide the optimum layout for photovoltaic array and for storage tank also.

The optimum layout is stated on two points, technicality for reliability and economics for system cost. The following flow chart explains the algorithm for optimum sizing of photovoltaic pumping system

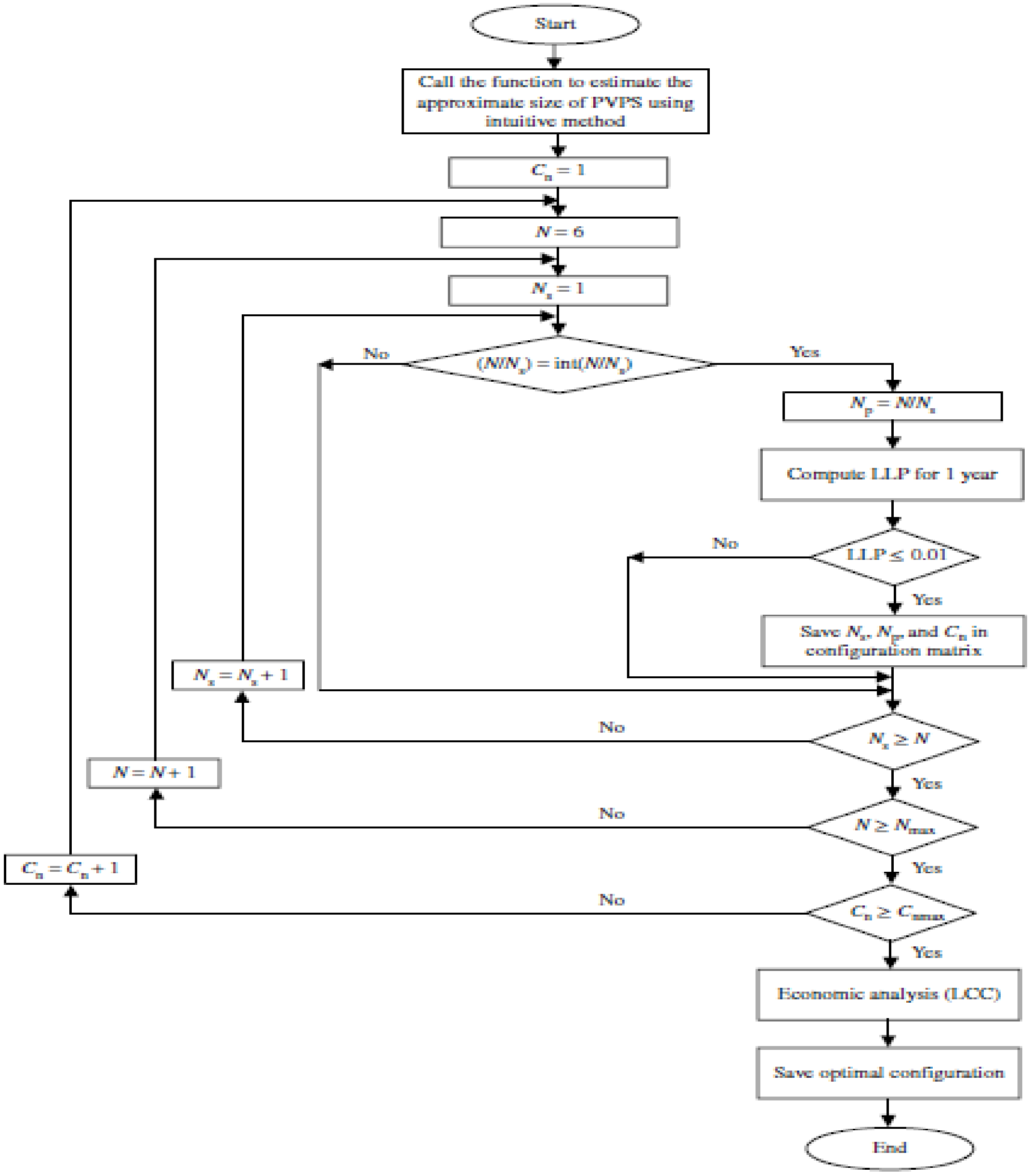

Figure 32 Flowchart for optimized sizing of photovoltaics pump system

The optimum layout selects a photovoltaic pumping system with higher reliability and minimum cost. The technicality deals with achieving the desired LLP whereas the economical objective is find out minimum cost for configuration between set of various layout, which are also capable to deliver zero load rejection. If the LLP of system is less than 0.01 then it is zero load rejection. To evaluate the cost of photovoltaic pumping system and then to choose optimal layout the key parameter is Life cycle cost (LCC) .The life cycle cost of photovoltaic pumping system includes, initial investment(IC), present maintenance cost(MC) , current replacement cost(RC).

LCC=IC+MC+RC…………………………………………………………………………..37

CHAPTER 6

RESULT AND DISCUSSION

6.1 MODELLING OF SOLAR SOURCE

The first step was to develop a solar cell. The solar cell used in work is double diode model offering better result than single diode model.

The PV characteristics for MSX-60 module are presented in work. The PV characteristics for module are affected by the change in solar radiation and change in temperature. The effect of both is presented in work, the typical electrical characteristics of module are

Maximum Power -	60 W
Voltage at maximum power -	17.1 V
Current at maximum power -	3.5 A
Minimum guaranteed maximum power -	58 W
Short-circuit current (I_{SC}) -	3.8 A
Open-circuit voltage (V_{OC}) -	21.1 V
Temperature coefficient of open circuit voltage –	-(80$\pm$10)mV/C^o
Temperature coefficient of short circuit current –	(0.065$\pm$0.015)%/C^o
Module weight –	15.9 pounds

The module consists of 36 polycrystalline cell connected in two series string, each string having 18 cells. A bypass diode is also installed at 18 cell strings.

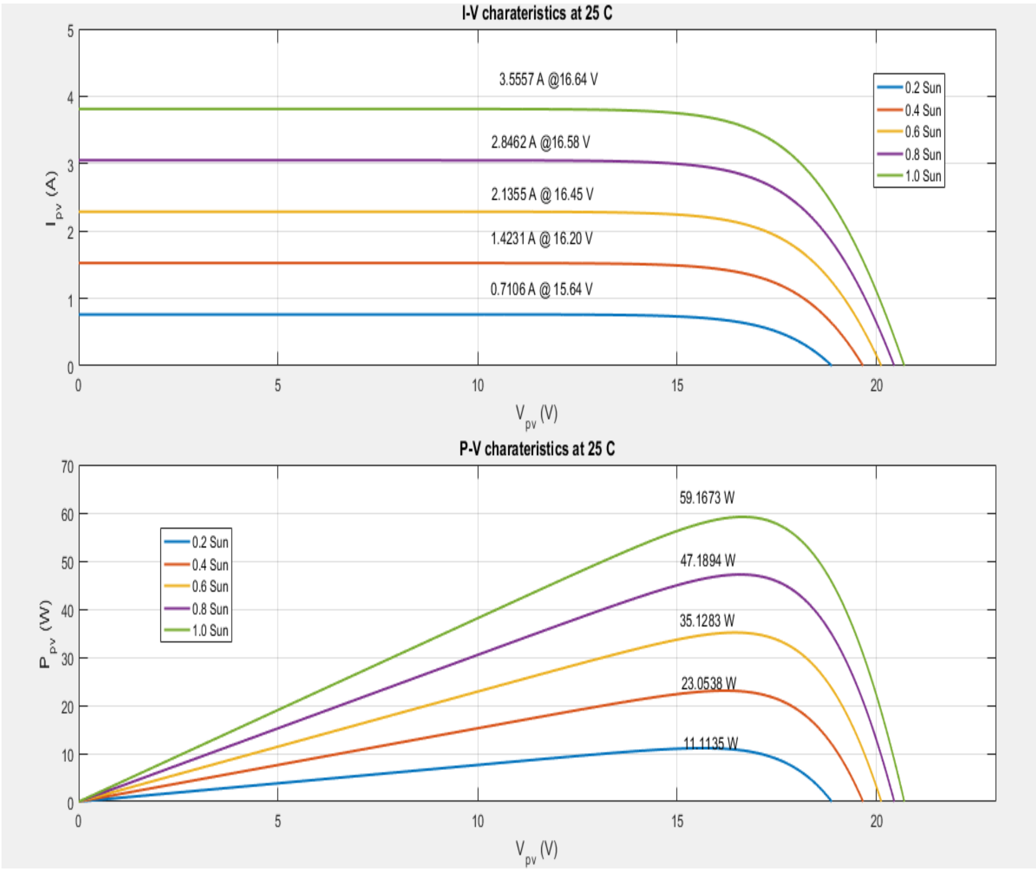

Figure 33 Plot showing V-P and V-I characteristic for varied insolation

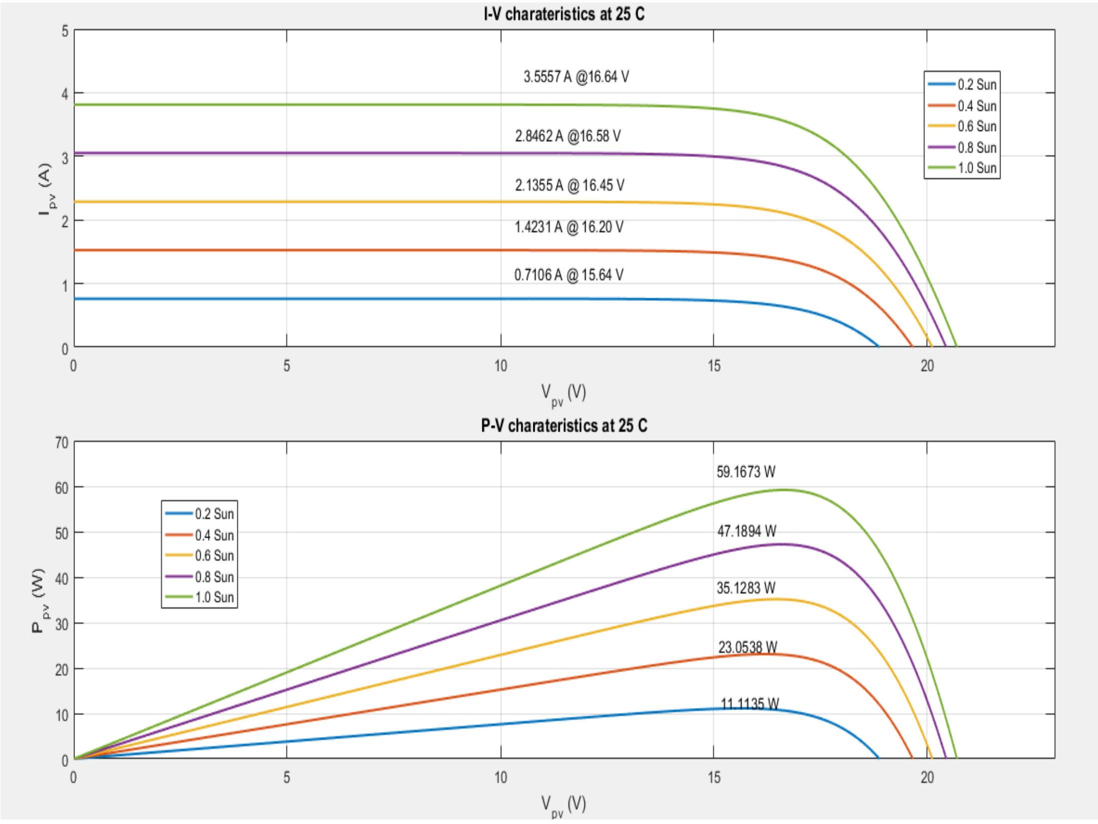

Figure 34 Plot showing V-P and V-I characteristic for varied temperature

6.2 DESIGNING OF MAXIMUM POWER POINT TRACKER

After the modelling of solar source the next step is to design a maximum power point , the maximum power depending upon the generated voltage and current tries to locate an optimum position in V-I curve so that the output power from module is maximum for given temperature and solar radiation.

PERTURB & OBSERVE

The first designed MPPT is Perturb & Observe. In this the initial value for voltage and current is taken at time instance T1 then again new set of values is taken for time instance T2, depending upon the values taken the derivative of power is taken and if derivative of power is coming positive then working voltage should be carried in the direction of perturbation and if derivative of power is coming negative then the direction of working voltage should be changed in opposite to the perturbation direction.

So in modelled MPPT using P&O the derivative of power is coming negative, so the working voltage is changed in the reverse of perturbation direction

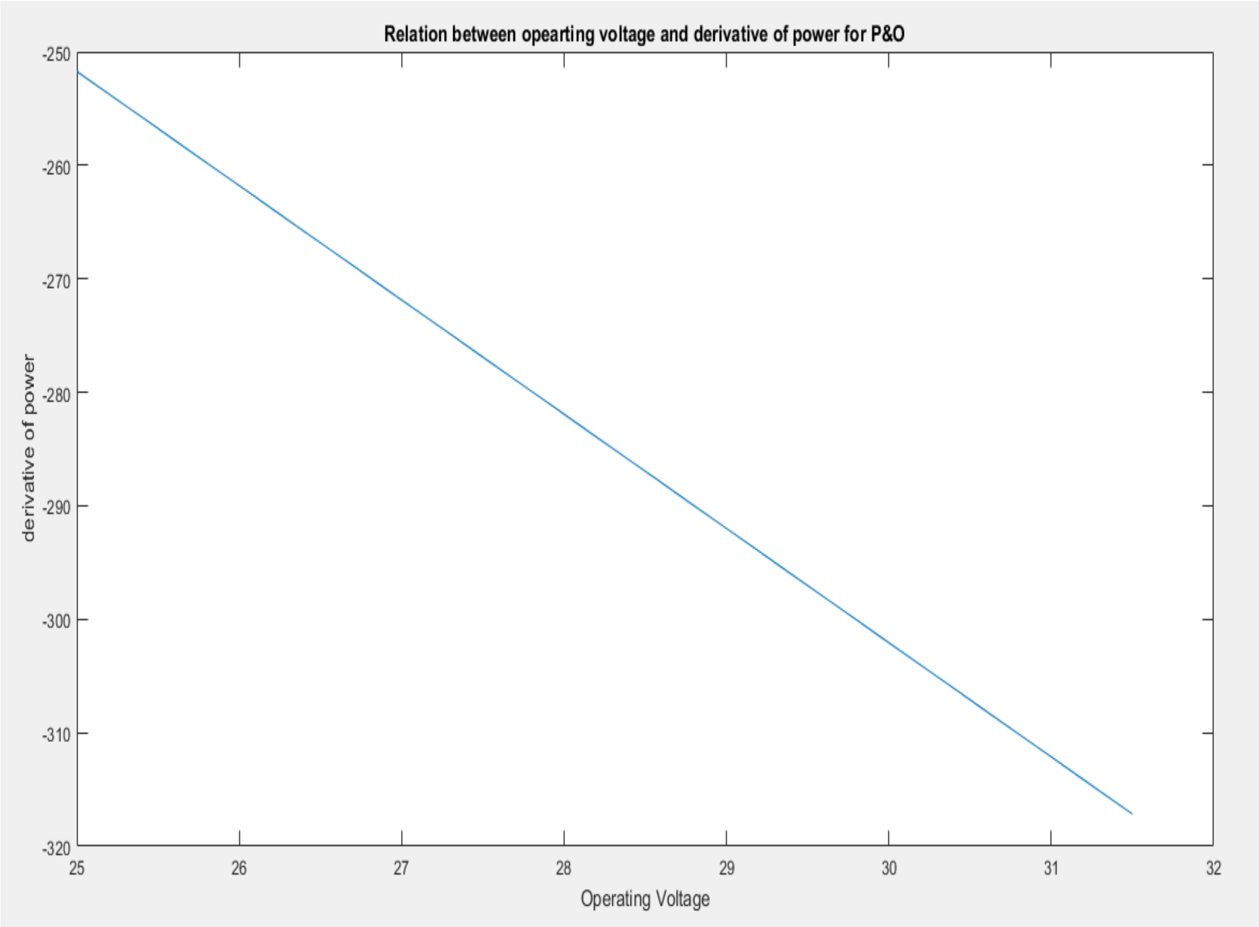

Figure 35 Plot for relation between operating voltage and derivative of power

INCREMENTAL CONDUCTANCE

This is another drastically adopted method for locating the maximum power point. Incremental Conductance is calculated by differentiating the photovoltaic output with respect to working voltage and then placing the results equivalent to zero. The incremental conductance is capable of locating that the maximum power point tracker has reached the maximum power point and stop perturbing the operating point. If this argument is not met, then course for which the operating point should be perturbed can be determined by using the link between dl/dV and –I/V. This co-relation is obtain from the factor that dP/dV is positive when it is to the left of the maximum power point and negative when the maximum power point tracker is to the right of the maximum power point.

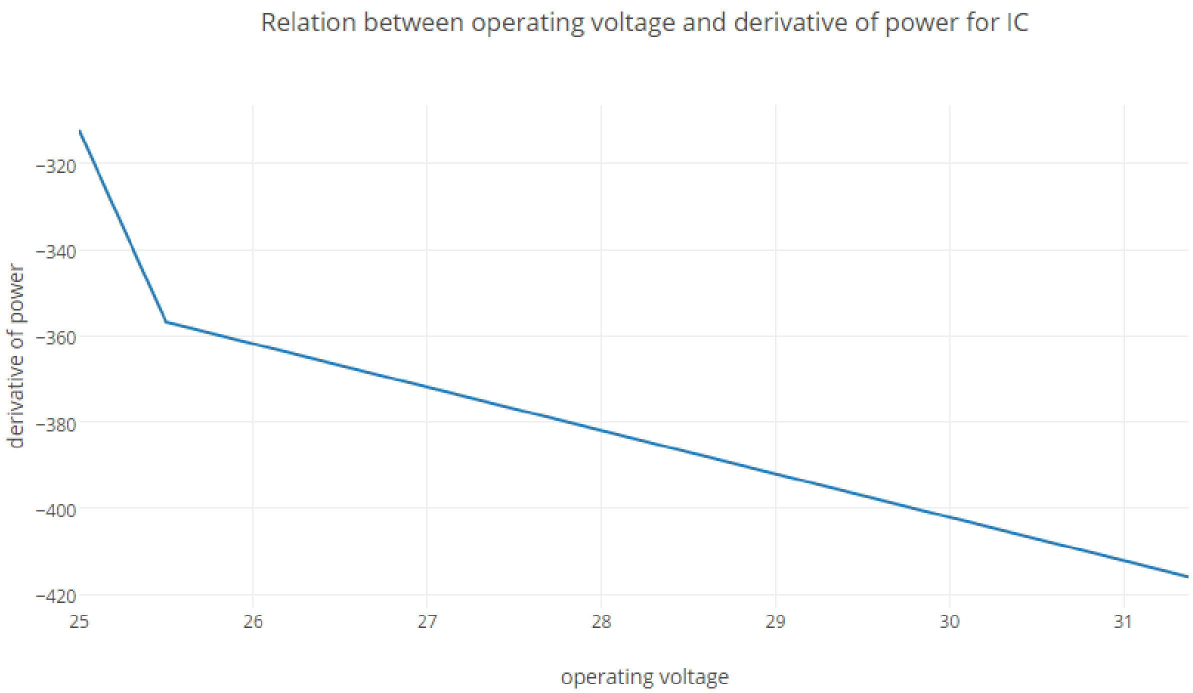

Figure 36 Plot for relation between operating voltage and derivative of power

From the obtained curves it is observable that result for IC are more accurate than P&O, thus IC has higher efficiency but computation time for IC is more than P&O. The P&O employs only single sensor whereas IC employs two sensor, thus making it more expensive.

6.3 MODELLING OF SUN-TRACKER

If photovoltaic system is capable of tracking the varying position of Sun by moving the panels in orientation with Suns position, then the energy production increases. On brighter days when there high insolation so direct radiation is available in abundant, thus with help of Sun tracking device energy production can be increased many folds. A photovoltaic system having sun tracker can increase its yield by 50 % on bright clear day during summer and for winter this yield can increase up to 300% when compared to photovoltaic system without tracker.

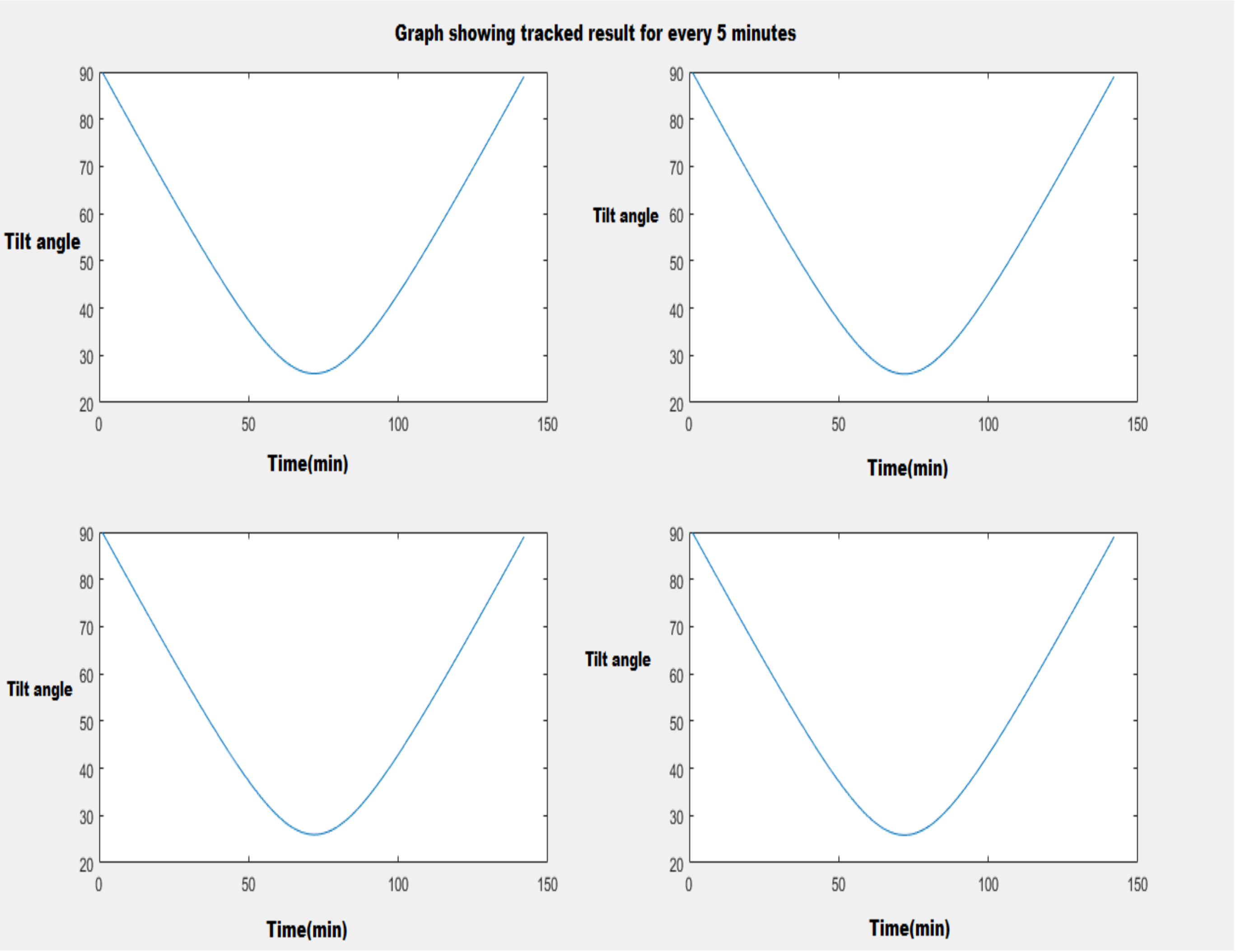

Figure 37 Graph showing the sun tracking for every 5 minute

6.4 MODELLING OF INVERTER

The primary goal of static converter is to produce a regulated AC supply from unregulated DC input. For AC output to be sinusoidal, frequency, the output magnitude and phase should be tractable. Depending upon the kind of output AC waveform, this design can be treated as voltage source inverter, voltage waveform is independently tractable ac output where the freely governed ac output is a voltage waveform or as current source inverter, current waveform is independently tractable ac output. The performance of inverter depends a lot on the performance of photovoltaic system so the real time data various of parameters like solar radiation, wind velocity, humidity and temperature is collected for the span of 10 years (January 1995- December 2005), the latitude and longitude for test location are 18^o,12^o.

The efficiency curve for the inverter can be given as

$$\eta = C_1\left(\frac{P_{PV}}{P_{INV}}\right)^{C_2} + C_3\frac{P_{PV}}{P_{INV}} > 0 \quad \text{……38}$$

$$\eta = 0\frac{P_{PV}}{P_{INV}} = 0 \quad \text{……39}$$

Here P_{PV} and P_{INV} rated power output from module and inverter, while C_1 C_2 C_3 is coefficients of model.

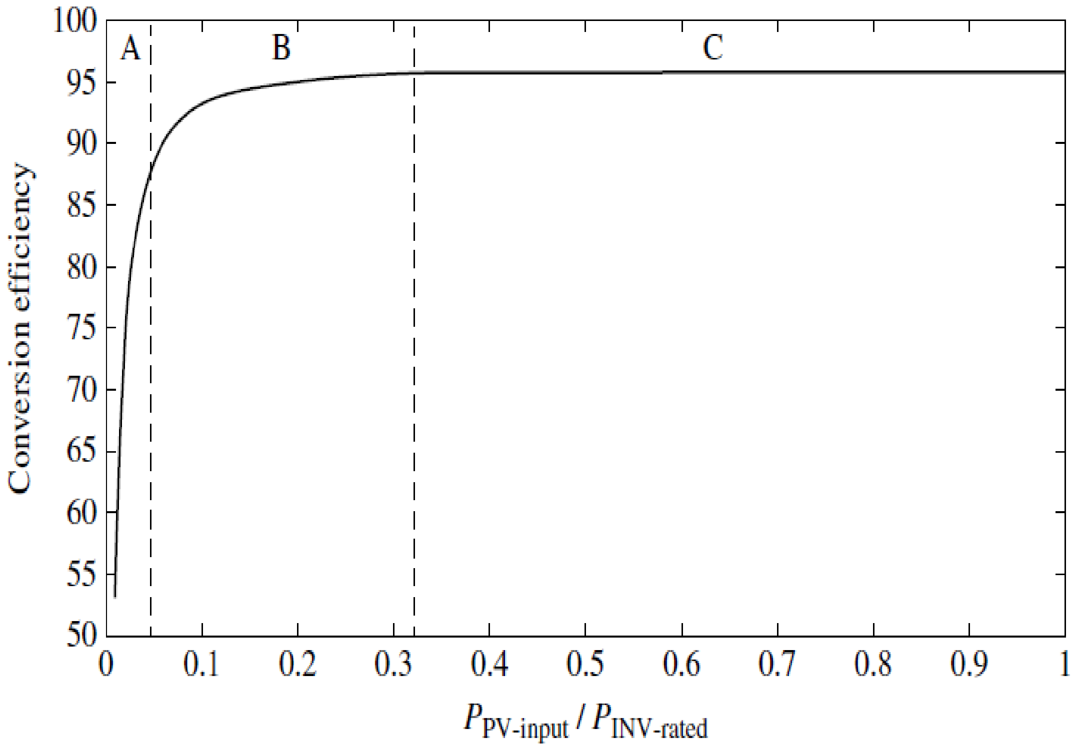

Figure 38 Efficiency curve for inverter

Output voltage frequency , f=50 Hz

Modulation index, ma = .2

Load's phase angle = 25

Carrier Signal frequency = 200

Output voltage RMS value

V_{ORMS} = 0.3742

Output voltage fundamental component RMS

V_{FRMS} = 0.1408

Load current RMS value

I_{LRMS} = 0.1859

Supply current RMS value

I_{SRMS}= 0.0906

Supply current average value

I_{AVG} = 0.0295

Performance parameters are

THDVo = 2.4618

THDIo = 0.8624

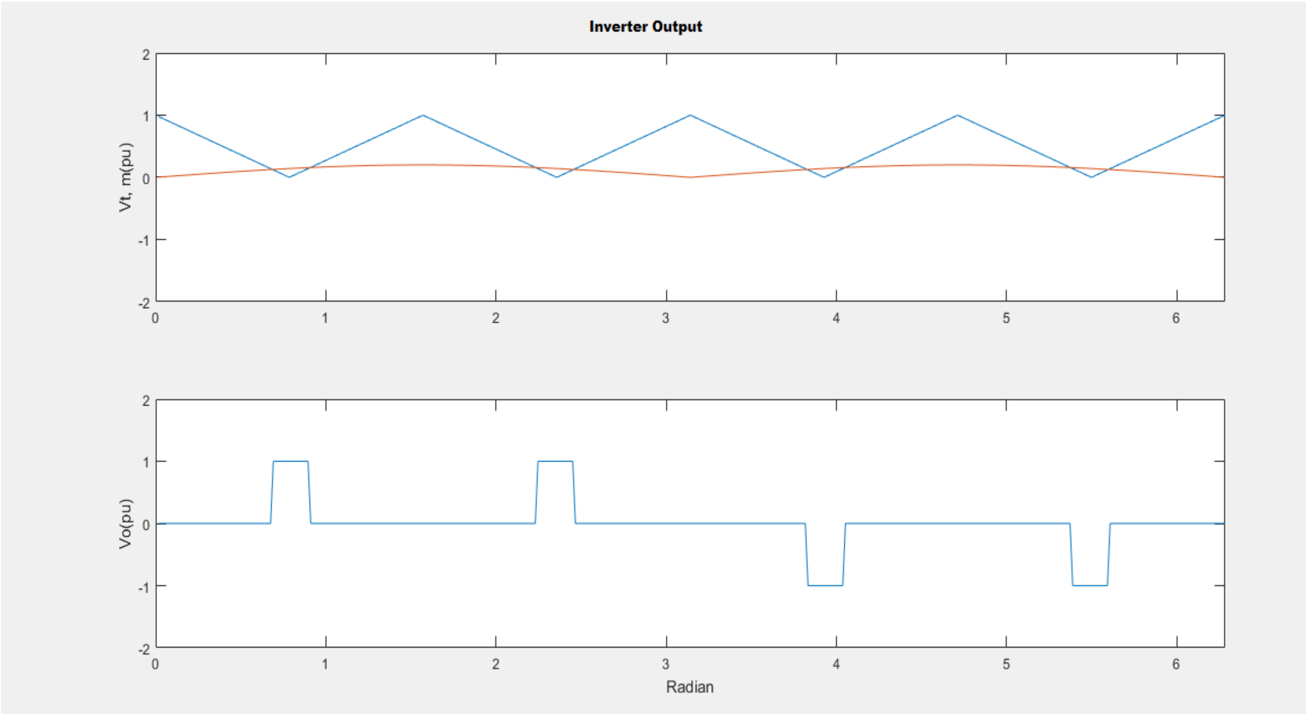

Figure 39 Inverter output 1

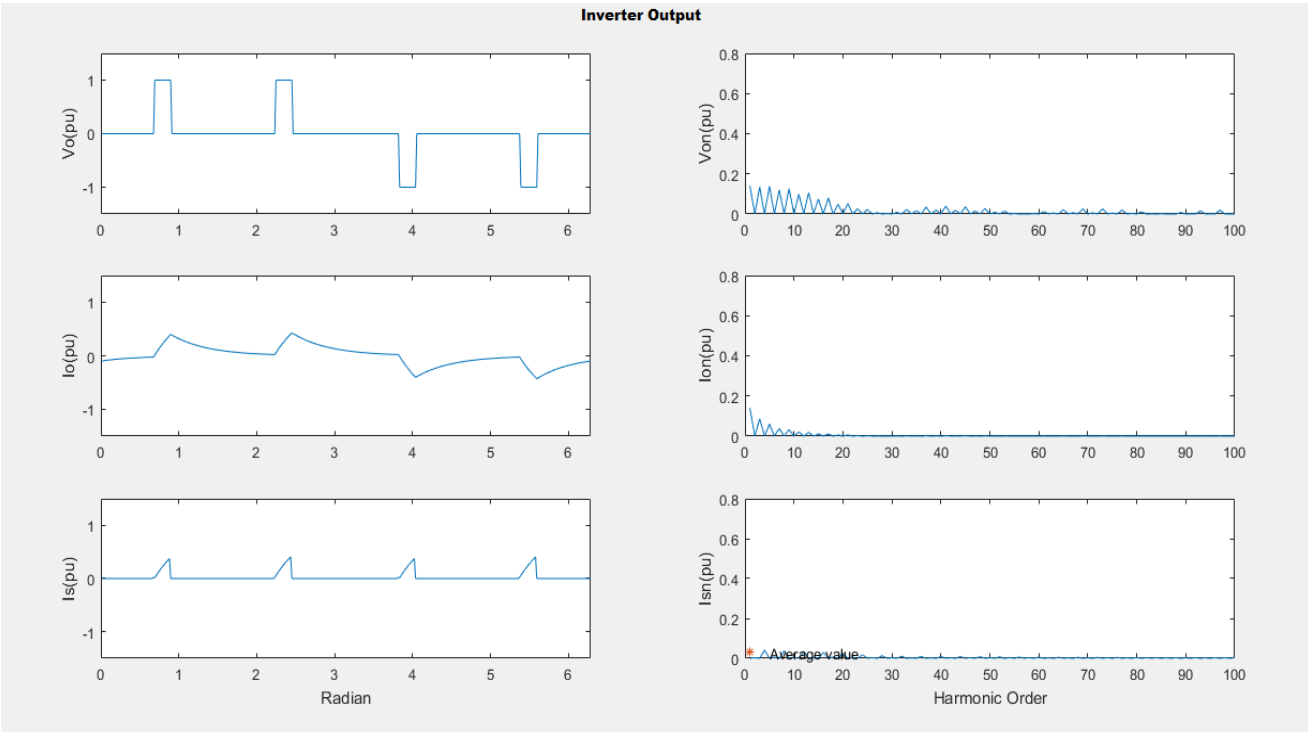

Figure 40 Inverter output 2

6.5 MODELLING OF BATTERY

The battery is most widely adopted means for storing energy in photovoltaic plant The battery incorporates a combination of series and parallel electrochemical cells. The series combination provides the desired voltage and parallel combination provides desired current The energy is stored in cell at low potential of few volts. C is the cell capacity which is gauged in Aretha average voltage during the discharge period and capacity C defines the rating of battery.

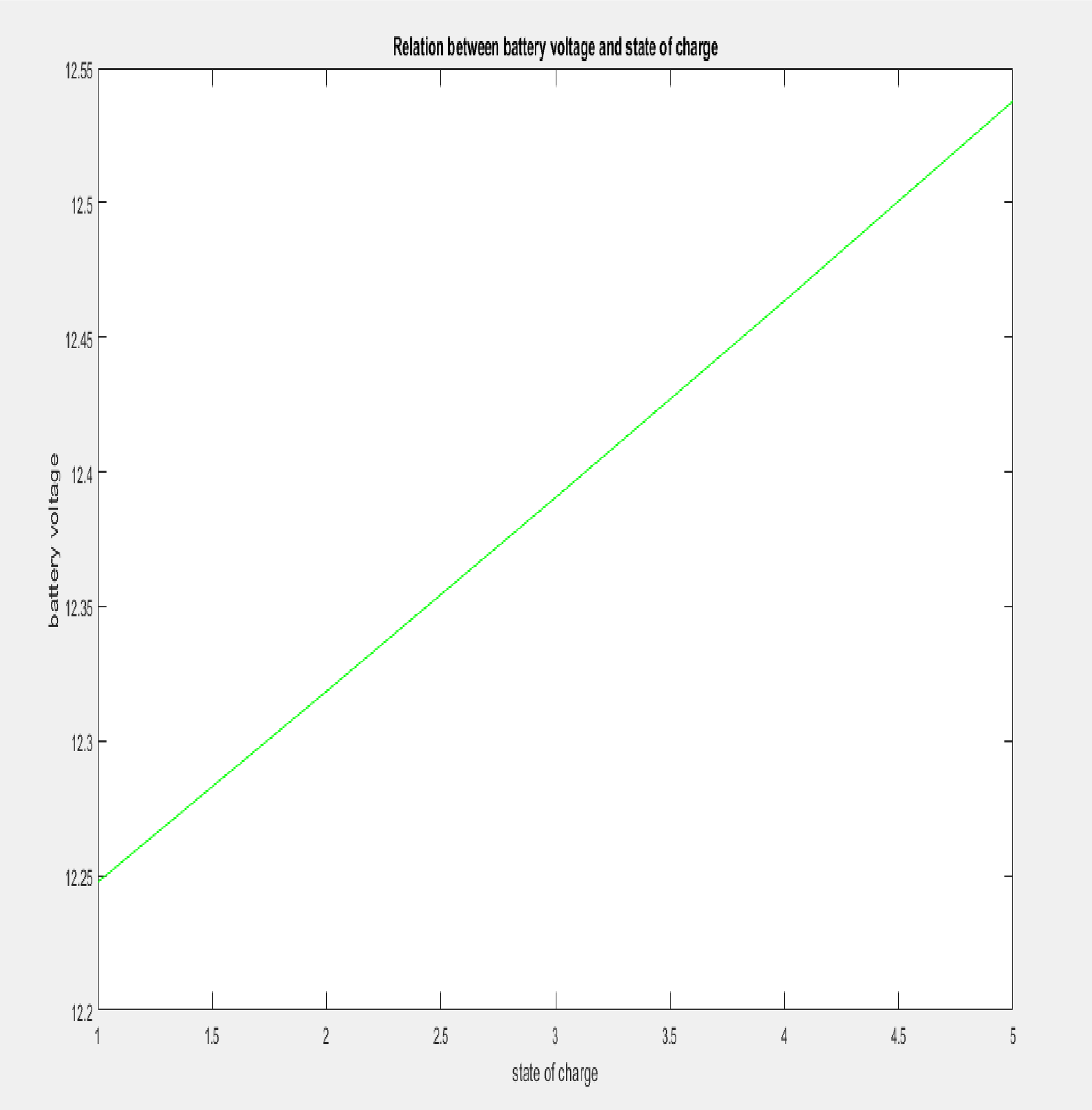

Figure 41 Relation between battery voltage and state of charge

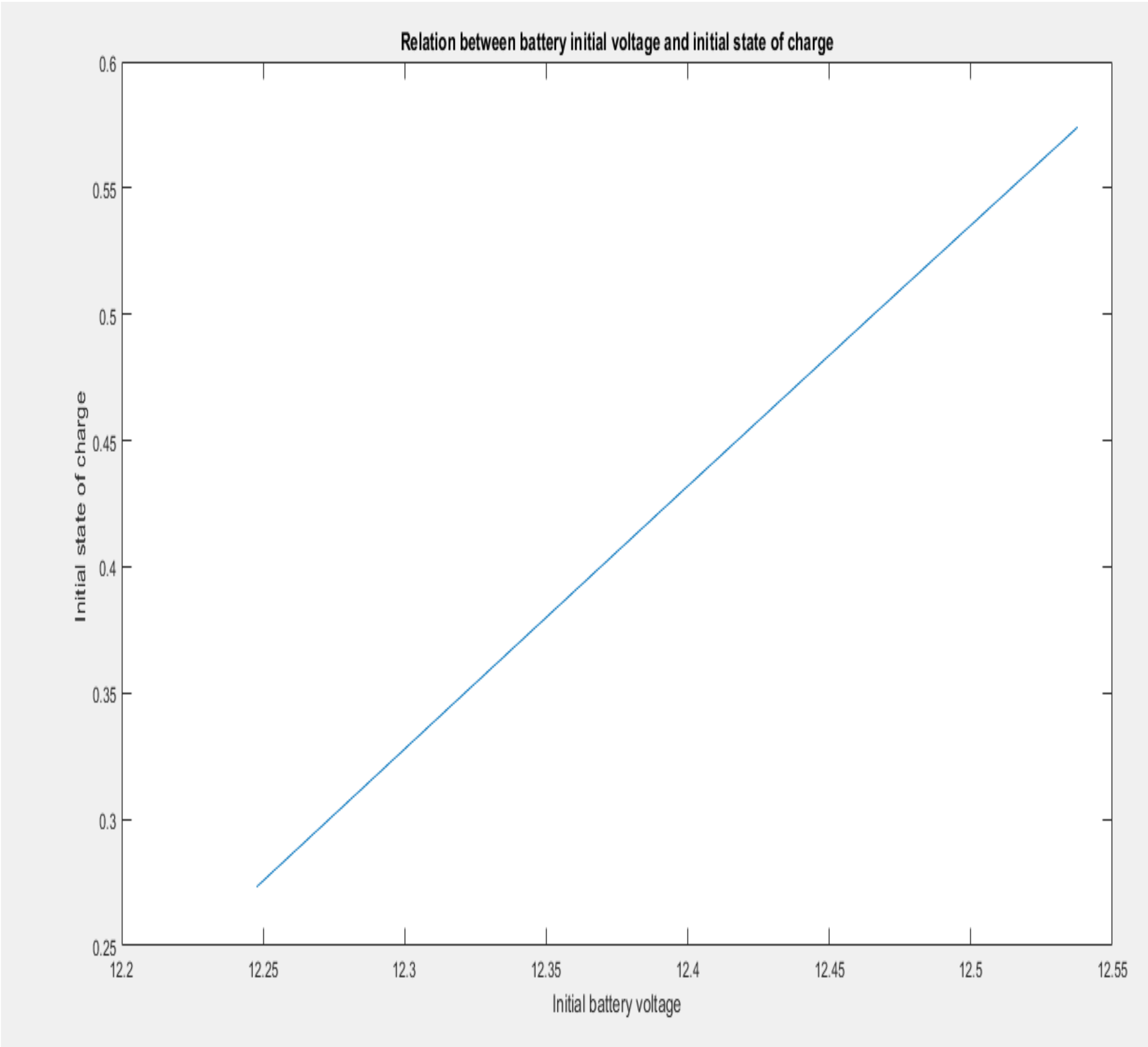

Figure 42 Relation between battery initial voltage and initial state of charge

6.6 OPTIMIZATION OF TILT ANGLE

The optimize tilt angle is computed for a test location using equation

$$G_{TILT}=(G_G-D_G)[\{\cos(Lattitude-Tilt_{ANGLE})\ \cos D\ \sin\omega_{SS}\ +\ \omega_{SS}\ \sin(Lattitude-Tilt_{ANGLE})\ \sin D\}/\{\cos Lattitude\ \cos D\ \sin\omega_{SS}\ +\ \omega_{SS}\ \sin Lattitude\ \sin D\}]+[D_G(1+\cos Tilt_{ANGLE}/2)]+[G_\rho(1-\cos Tilt_{ANGLE}/2)\ \ldots\ldots 40$$

G_{TILT} is optimize tilt $_{angle}$

G_G is global solar emission and D_G is diffused solar emission

Latitude is locations latitude

$Tilt_{ANGLE}$ is the locations tilt angle

D is declination angle

ω_{SS} is the sunshine angle

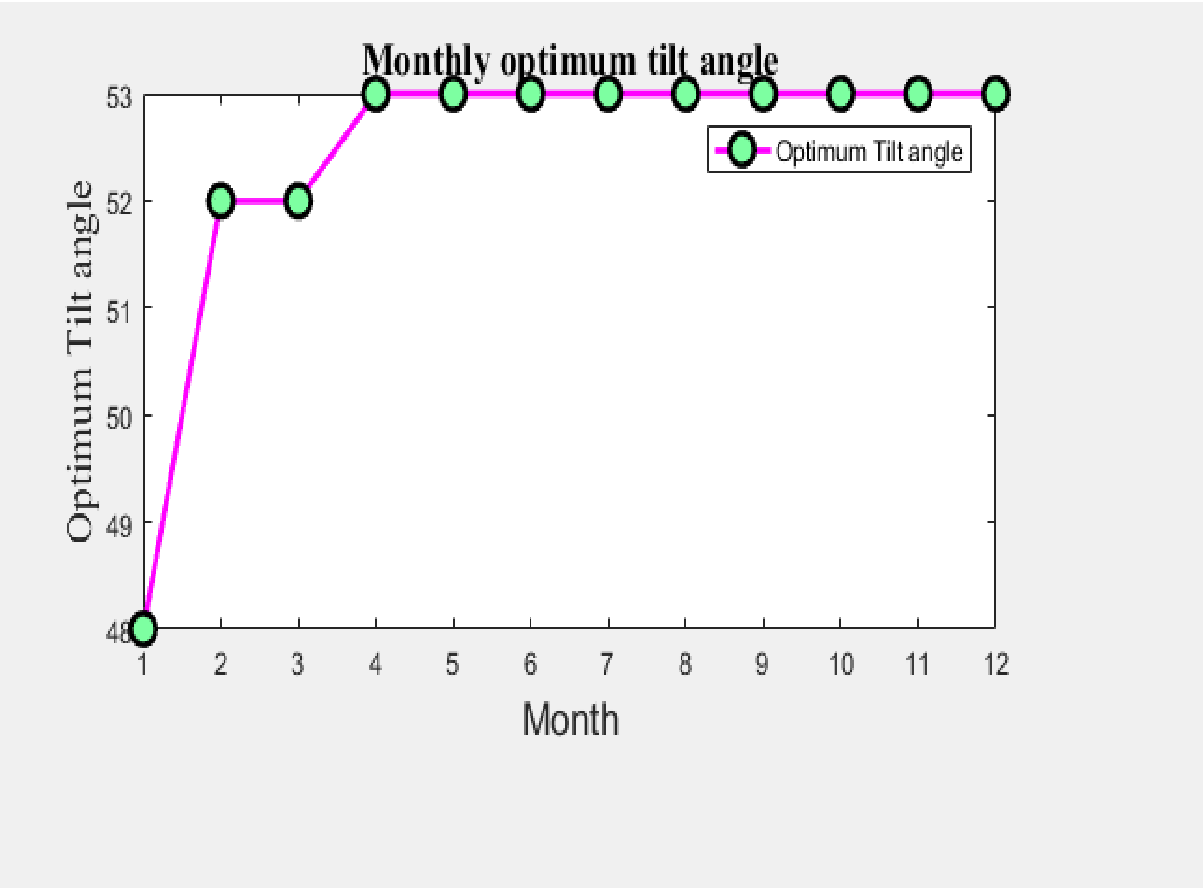

Figure 43 optimum Tilt angle

6.7 MODELLING OF MOTOR PUMP IN PHOTOVOLTAIC SYSTEMS

The pump operates for its H-Q characteristics. A program is developed to implement photovoltaic pumping system, the specification for brushless permanent magnet motor and for pump is given

For motor

Attribute	Value
Rated armature current (I)	16.5 A
Rated armature voltage (V)	60 V
Armature resistance (R_a)	0.8 Ω
Rated motor speed (ω)	272.3 rad/s
Motor constant (K_T)	0.175 V/(rad/s)

For pump

Characteristics	Value
Pumping capacity (Q)	4.8 m3/h
Maximum pumping head (H)	33 m
Nominal speed (ω)	298.5 rad/s
Nominal required power (P_{pi})	750 W
Inlet impeller radius (R_1)	16.75 mm
Outlet impeller radius (R_2)	80 mm
Inclination angle of impeller blade at impeller inlet (β_1)	38°
Inclination angle of impeller blade at impeller outlet (β_2)	33°
Height of impeller blade at impeller inlet (b_1)	5.4 mm
Height of impeller blade at impeller outlet (b_2)	2.2 mm

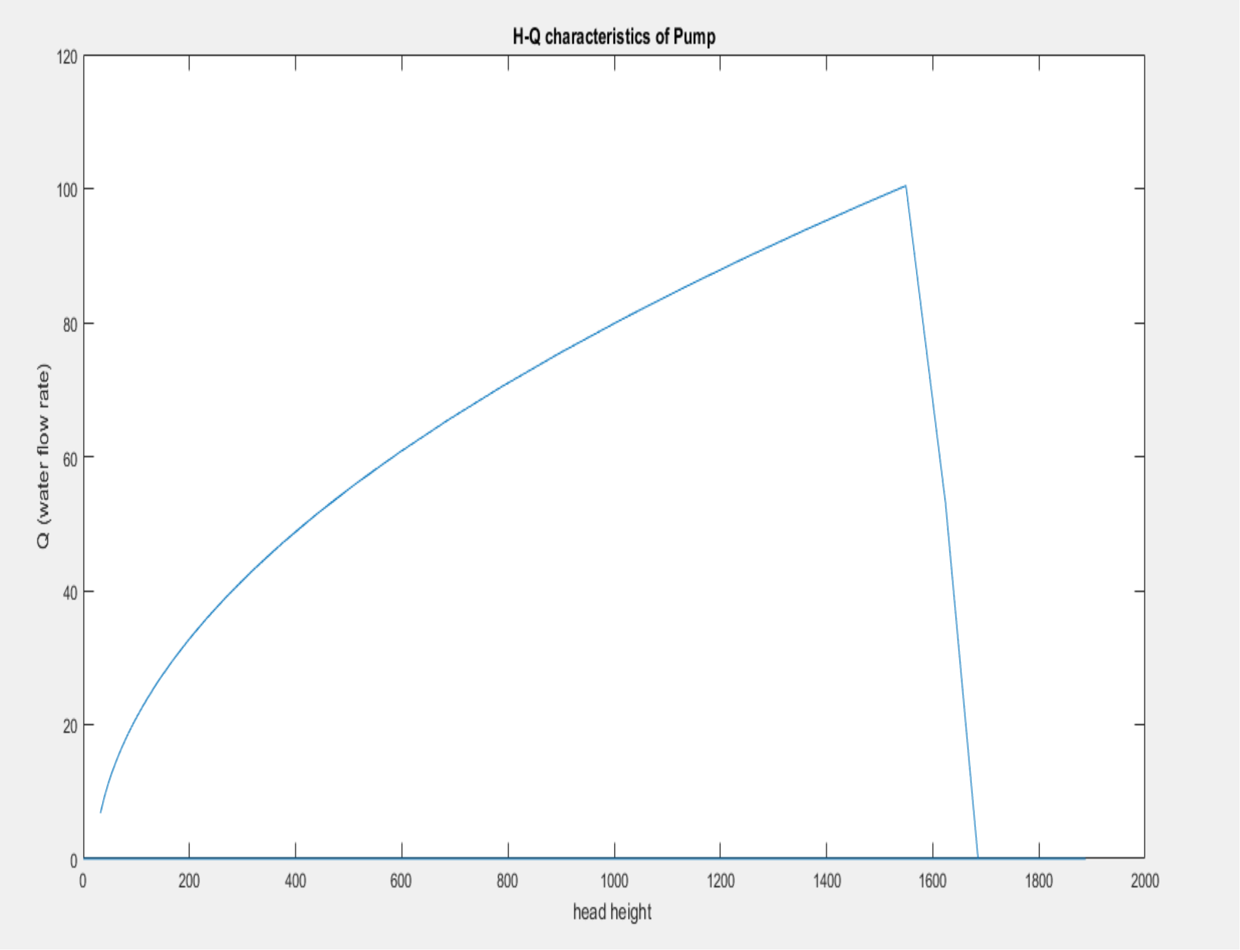

Figure 44 H-Q characteristics of Pump

The value of Loss of load probability is 0.0247

6.8 MODELLING OF PHOTOVOLTAICS/DIESEL/BATTERY

The operation and extent of a photovoltaic system relies upon various climatic factors like solar radiation , wind velocity and surrounding temperature. So in order to amend and govern photovoltaic system, strict modelling must be designed.

Photovoltaic system configurations can be grouped in two categories current based layout and energy flow layout. A program is executed to model a photovoltaics/diesel/battery system having specification 1.4kW,1KVA,83 Ah/12 V

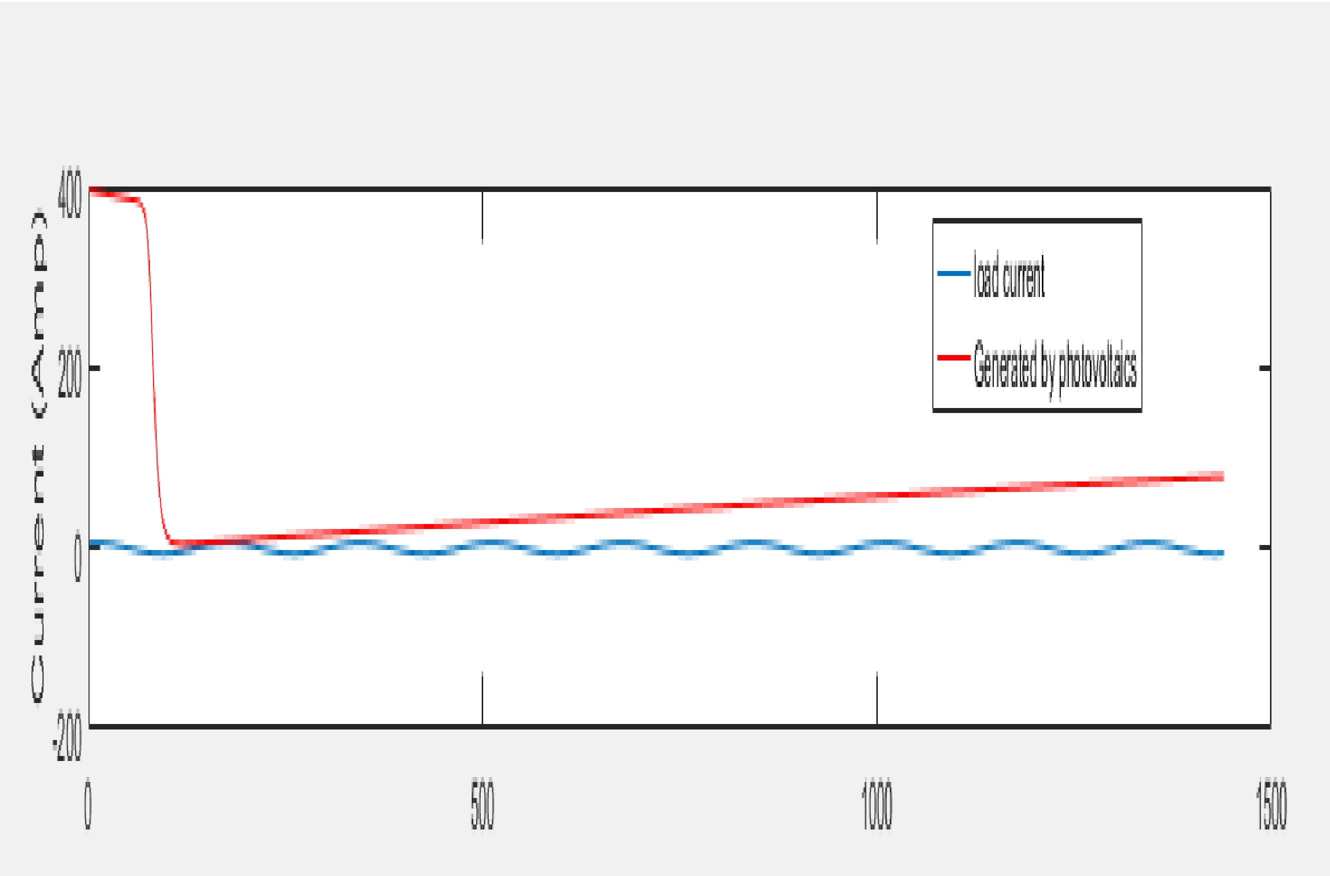

Figure 45 Relation between energy generated photovoltaic and load demand

6.9 MODELLING FOR INVERTER OPTIMIZATION

The rated power of photovoltaic system should be equal to the rated power of inverter for enhanced efficiency. The optimum size of inverter is defined by a ratio I_S

$$I_s = \frac{P_{PVR}}{P_{INR}} \quad \textbf{41}$$

Where P_{PVR} is photovoltaic system rated power and P_{INR} is the rated power for inverter. A program is executed to optimize inverter size three PV system's for 5 KW each.

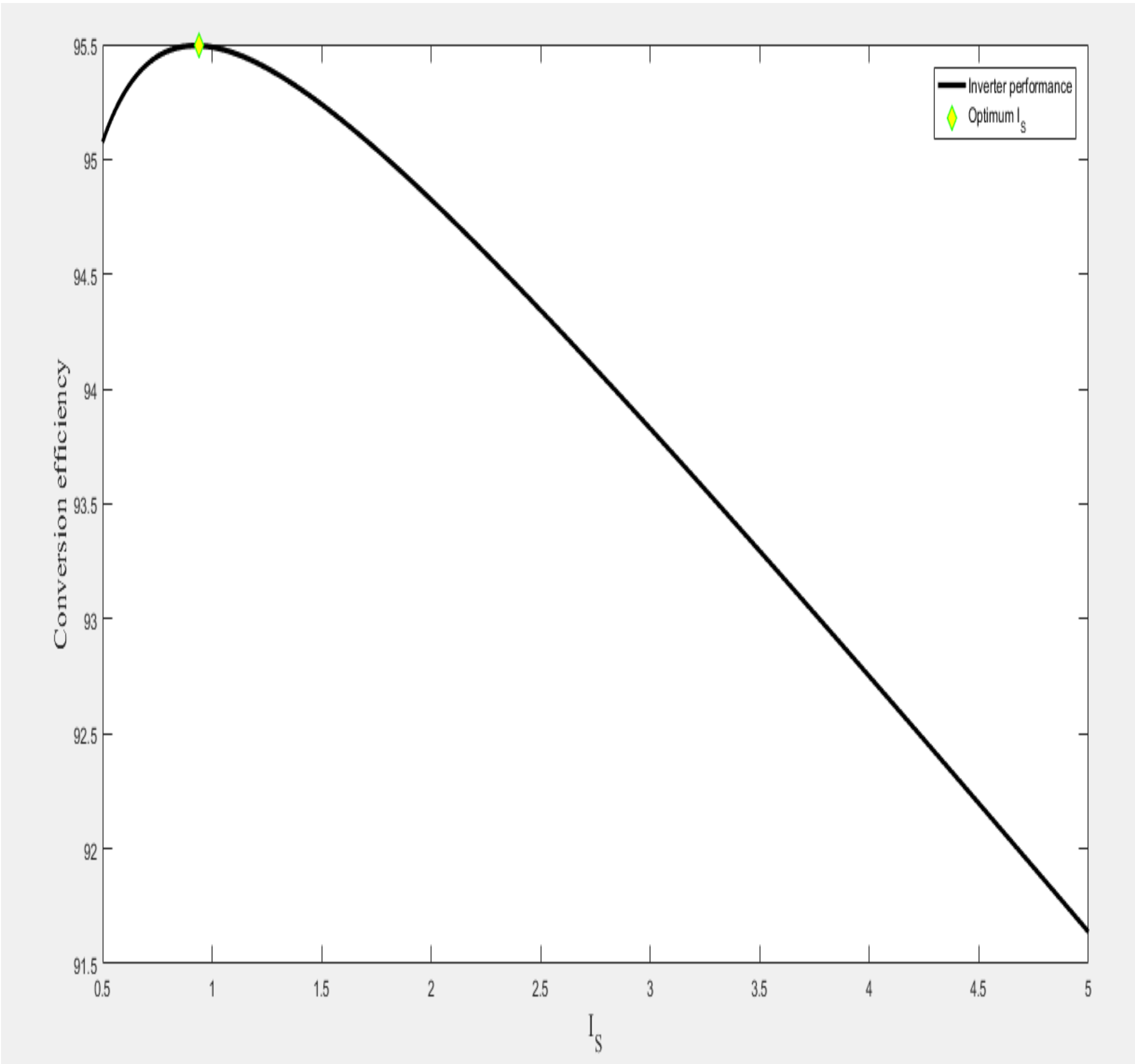

Figure 46 optimized inverter performance

6.10 MODELLING FOR OPTIMIZATION OF HYBRID PHOTOVOLTAIC /WIND /DIESEL SYSTEM

Like standalone photovoltaic system, optimal sizing is needed for hybrid photovoltaic system. In order to get accurate value of result modelling is done. Here a hybrid system incorporating photovoltaic array, wind turbine, battery for energy storage and a diesel generator.

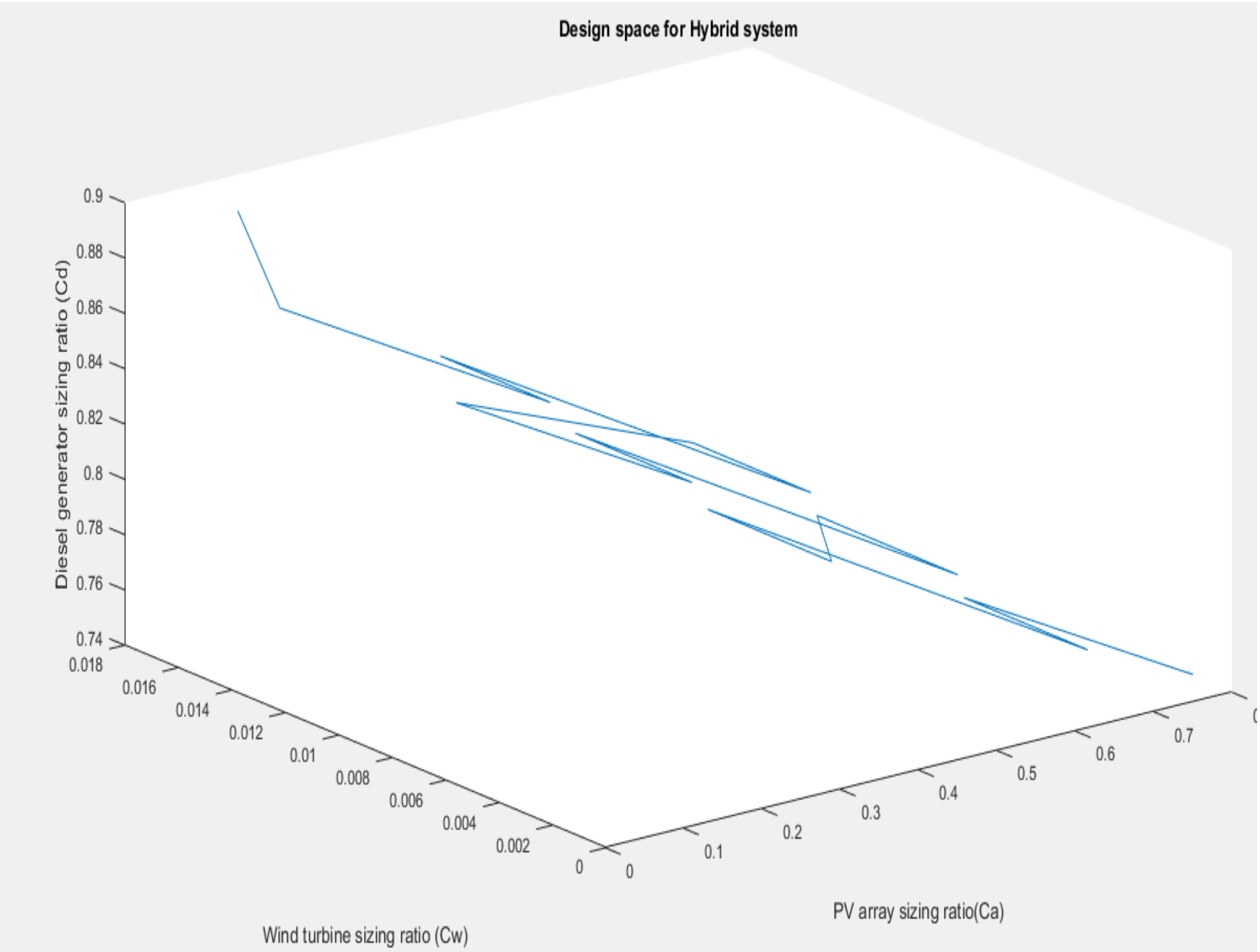

Figure 47 Design space for hybrid system

CHAPTER 7

CONCLUSION & FUTURE SCOPE

The various methodologies have been implemented in formation grid connected PV system. Double diode Solar Cell modelling is done and discussed in this thesis. Developed PV system is a sustainable and reliable option for growing energy demands, as it is designed with battery backup, in consideration with varying climatic condition and meteorological factors like temperature and solar radiation variation. Grid connection of PV system employing Diesel Generator and Pumped Storage plant with VSC Inverter to create a Micro Grid is also modelled and discussed in this research work. Optimization is done to find the optimal sizing of generation system to cater the dynamic demand of Micro Grid.

The efficiency of solar cell is still very low and an effort is done to enhance it by using MPPT. So a lot of work can be done to enhance the efficiency of cell like using nano-technology in fabrication of thin films, the packaging and casing of module can be altered to boost generation. The grid connected PV system can be designed such that handle the failure on both DC and AC side. Further research can be done on having faster response for dynamic changes like loss of load or sudden voltage drop. For protection of system the research can be extended to deploy islanding in grid connected PV system for personal security and for better power quality events. More work can be done to have high efficiency energy storage system for reasonable pricing. Finally research can be focused on reducing the overall installation cost PV system.

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APPENDIX

WRITE A CODE THAT PRESENT THE I–V AND P–V CHARACTERISTIC OF THE SOLAREX MSX-60 FOR VARIATION IN SOLAR RADIATION IN MATLAB.

```
V_a=0:.01:25;
G=.2:.2:1;
TC=30;
Ipv=zeros(size(V_a));
Ppv=zeros(size(V_a));
for s=1:1:length(G)
for i=1:1:length(V_a)
k=1.38e-23;
q=1.6e-19;
A=1.2;
V_g=1.12;
N_s=36;

T_1=273+25;
Voc_T_1=21.06/N_s;
Isc_T_1=3.80;

T_2=273+75;
Voc_T_2=17.05/N_s;
Isc_T_2=3.92;

Tar_K=273+TaC;
Tref=273+25;
%{Va=0;Iph_T1=Isc_T1;%}
Iph_T_1=Isc_T_1*G(s);
a=(Isc_T_2-Isc_T_1)/Isc_T_1*1/(T2-T_1);
I_ph=Iph_T_1*(1+a*(Tar_K-T_1));

Vt_T_1=k*T_1/q;
I_r_T_1=Isc_T_1/(exp(Voc_T_1/(A*Vt_T_1))-1);
Ir_T_2=Isc_T_2/(exp(Voc_T_2/(A*Vt_T_1))-1);
b=V_g*q/(A*k);
I_r=I_r_T_1*(Tar_K/T_1).^(3/A).*exp(-b.*(1./Tar_K-1/T_1));
X2v=I_r_T_1/(A*Vt_T_1)*exp(Voc_T_1/(A*Vt_T_1));
dVdI_V_oc=-1.15/N_s/2;
R_s=-dVdI_V_oc-1/X2v;
%Ia=1:0.01:Iph;
Vt_Ta=A*k*Tar_K/q;
Vc=V_a(i)/N_s;
Ia=zeros(size(Vc));
%Iav=Ia
for j=1:1:10
Ia=Ia-(I_ph-Ia-I_r*(exp((Vc+Ia*R_s)/Vt_Ta)-1))./(-1-I_r*(exp((Vc+Ia*R_s)/Vt_Ta)-
1).*R_s/Vt_Ta);
end
```

```
Ipv(s,i)=Ia;
Ppv(s,i)=V_a(i)*Ipv(s,i);
end
end
```

WRITE A CODE THAT PRESENT THE I–V AND P–V CHARACTERISTIC OF THE SOLAREX MSX-60 FOR VARIATION IN AMBIENT TEMPERATURE.

```
V_a=0:.01:22;
G=1;
% TeC=30;
TeC=25:10:65;
l_va=length(V_a);
%lG=length(G);
l_T=length(TeC);

I_pv=zeros(size(V_a));
% for s=1:1:lsuns
for s=1:1:l_T
for i=1:1:l_va
k=1.38e-23;
q=1.6e-19;
A=1.2;
V_g=1.12;
N_s=36;
T_1=273+25;
V_oc_T1=21.06/N_s;
I_sc_T1=3.80;
T_2=273+75;
V_oc_T2=17.05/N_s;
I_sc_T2=3.92;
Tar_K=273+TeC(s);
T_ref=273+25;
I_ph_T1=I_sc_T1*G;
a=(I_sc_T2-I_sc_T1)/I_sc_T1*1/(T_2-T_1);
I_ph=I_ph_T1*(1+a*(Tar_K-T_1));
Vt_T1=k*T_1/q;
Ir_T1=I_sc_T1/(exp(V_oc_T1/(A*Vt_T1))-1);
Ir_T2=I_sc_T2/(exp(V_oc_T2/(A*Vt_T1))-1);
b=V_g*q/(A*k);
I_r=Ir_T1*(Tar_K/T_1).^(3/A).*exp(-b.*(1./Tar_K-1/T_1));
X2_v=Ir_T1/(A*Vt_T1)*exp(V_oc_T1/(A*Vt_T1));
dVdI_V_oc=-1.15/N_s/2;
Rs=-dVdI_V_oc-1/X2_v;
Vt_Ta=A*k*Tar_K/q;
V_c=V_a(i)/N_s;
I_a=zeros(size(V_c));
for j=1:1:100
```

```
I_a=I_a-(I_ph-I_a-I_r*(exp((V_c+I_a*Rs)/Vt_Ta)-1))./(-1-I_r*(exp((V_c+I_a*Rs)/Vt_Ta)-
1).*Rs/Vt_Ta);
end
I_pv(s,i)=I_a;
P_pv(s,i)=V_a(i)*I_a;
end
end
```

DESIGN A SUN TRACKER BASED ON SINGLE AXIS TRACKING THE FOR EVERY 5 MINUTES IN MATLAB

```
%--------------------------------------------------------
%Date 01.01 to 4.01 2015 (four days)
%Location Kuala Lumpur, Malaysia, L =(3.12), LOD = (101.7)
Latt=3.12; % latitude of kuala lumpur
Longi=101.7; %(A1.2)longitude of kuala lumpur
Beta_T=[];
for DN=1:1:4 %Day number
T_GM_T=8; %ahead of gmt
StepS=5; % step size
D_s=23.45*sin((360*(DN-81)/365)*(pi/180)); % declination angle
B_=(360*(DN-81))/364; %(A3.1)
EqT=(9.87*sin(2*B_*pi/180))- (7.53*cos(B_*pi/180))-(1.5*sin(B_*pi/180)); %(equation of
time)
Lz_t= 15* T_GM_T; %(lst)
if Longi>=0
T_s_correction= (-4*(Lzt-Longi))+EqT;% corrction for solar time
else
T_s_correction= (4*(Lzt-Longi))+EqT; %corrction for solar time
end
W_sr_ssi=- tan(D_s*pi/180)*tan(Latt*pi/180);
W_srsr_ss=acosd(W_sr_ssi);
AST_sr=abs((((W_srsr_ss/15)-12)*60));
AST_ss=(((W_srsr_ss/15)+12)*60);
T_sr=AST_sr+abs(T_s_correction);
T_ss=AST_ss+abs(T_s_correction);
A_lpha=[];
T_heta=[];
for LM_T=T_sr:StepS:T_ss
T_s= LM_T + T_s_correction; % solar time
H_s=(15 *(T_s - (12*60)))/60; % Hour angle degree
sin_A_lpha = ( sin ( Latt * pi / 180 ) * sin ( D_s * pi / 180 ) ) +
(cos(Latt*pi/180)*cos(D_s*pi/180)* cos(H_s*pi/180));
%(A5.1)
A_lpha_i=asind(sin_A_lpha) ; %altitude angle (A5.1)
A_lpha=[A_lpha;A_lpha_i];
end
A_lpha;
```

```
B_eta=[];
for i=1:1:length(A_lpha)
Beta_i=90-A_lpha(i);
B_eta=[B_eta;Beta_i];
end
B_eta;
Beta_T=[Beta_T,B_eta];
end
Beta_T
Beta_1=[];
Beta_2=[];
Beta_3=[];
Beta_4=[];
for i=1:1:142;
Beta_1=[Beta_1;Beta_T(i,1)];
Beta_2=[Beta_2;Beta_T(i,2)];
Beta_3=[Beta_3;Beta_T(i,3)];
Beta_4=[Beta_4;Beta_T(i,4)];
end
Beta_1;
Beta_2;
Beta_3;
Beta_4;
subplot(2,2,1)
plot(Beta_1)
subplot(2,2,2)
plot(Beta_2)
subplot(2,2,3)
plot(Beta_3)
subplot(2,2,4)
plot(Beta_4)
```

DEVELOP A MATLAB PROGRAM IMPLEMENTING A P&O-BASED MAXIMUM POWER POINT TRACKER ALGORITHM

```
function [Ia,Va]=ponew
TaC=25; %cell temperature
C=0.5; %step size
Suns=0.028; %(1 G=1000 W/m^2)
Va=31; %PV voltage
Ia=doublediodesolarex(Va,Suns,TaC);
Pa=Ia.*Va;% PV output power
Vref_new= Va+C %new reference voltage
Va_array=[];
Pa_array=[];
Suns=[0 0.1 ; 1 0.2; 2 0.3; 3 0.3; 4 0.5; 5 0.6; 6 0.7; 7 0.8; 8 0.9; 9 1; 10 1.1; 11 1.2; 12 1.3;
13 1.4;];
x= Suns(:,1)'; %read time data
y= Suns(:,2)'; %read solar radiation data
```

```
xi=1:200; % set points for interpolation
yi=interp1(x,y,xi,'cubic'); %Do cubic interpolation
for i=1:14
%read solar radiation value
Suns=yi(i);
%taking another set of values
Va_new=Vref_new
Ia_new= doublediodesolarex(Va,Suns,TaC);
Pa_new=Va_new*Ia_new
deltaPa=Pa_new-Pa
if deltaPa>0;
if Va_new>Va;
Vref_new=Va_new+C; %refrence increment
else
Vref_new=Va_new-C; %refrence decrement
end
elseif deltaPa<0
if Va_new>Va
Vref_new=Va_new-C;
else
Vref_new=Va_new+C;
end
else
V_ref= Va_new;
end
Va=Va_new
Pa=Pa_new
Va_array= [Va_array Va];
Pa_array= [Pa_array Pa];
plot(Va_array,Pa_array)

end
```

DEVELOP A MATLAB CODE FOR IMPLEMENTING AN IC-BASED MAXIMUM POWER POINT TRACKER ALGORITHM

```
TaC=25
C=.5
E=0.5

Suns=0.045
Va=31;
Ia= doublediodesolarex(Va,Suns,TaC);
Pa= Va* Ia
Vref_new= Va+C
Va_array=[]
Pa_array=[]
Pmax_array=[]
```

```
Suns=[0 0.1 ; 1 0.2; 2 0.3; 3 0.3; 4 0.5; 5 0.6; 6 0.7; 7 0.8; 8 0.9; 9 1; 10 1.1; 11 1.2; 12 1.3;
13 1.4;]
x= Suns(:,1)';
y= Suns(:,2)';
xi=1:200;
yi=interp1(x,y,xi,'cubic')
for z=1:14
Suns=yi(z)

Va_new=Vref_new;
Ia_new= doublediodesolarex(Va,Suns,TaC)+C;

deltaVa=Va_new-Va
deltaIa=Ia_new-Ia
if deltaVa==0
if deltaIa==0
Vref_new=Va_new
elseif deltaIa>0
Vref_new=Va_new+C
else
Vref_new=Va_new-C
end
else
if abs(deltaIa/deltaVa+Ia_new/Va_new)<E
Vref_new=Va_new;
else
if deltaIa/deltaVa>-Ia_new/Va_new +E
Vref_new=Va_new+C
Vref_new= Va_new-C
end
end
end

end
```

DEVELOP A MATLAB CODE FOR A PWM-BASED INVERTER MODEL WITH A SIGNAL OF 50 HZ OUTPUT, 20% MODULATION INDEX, 200 HZ CARRIER FREQUENCY, AND A PHASE ANGLE OF THE LOAD OF 25°.

```
% PART I (preparation)

disp('Voltage-source inverter with Sinusoidal-Pulse Width Modulated output')

disp('')

% PART II
```

```
Vrin=1;
% f is the frequency of the output voltage waveform.
f=input('The frequency of the output voltage, f = ');
% Z is the load impedance in per unit.
Z=1;
% ma is the modulation index
ma=input('the modulation index,ma, (0<ma<1), ma = ');
% phi is load-phase-angle
phi=input('the phase angle of the load in degrees = ');
% fc is frequency of the carrier signal.
fc=input('The frequency of the carrier signal= ');
%
% PART III
% Calculating load parameters.
%
phi=phi*pi/180;
% R and L are the load resistance and inductance respectively.
R=Z*cos(phi);
L=(Z*sin(phi))/(2*pi*f);

% PART IV
% Calculating the number of pulses per period,N
N=fc/f;

%PART V
% Building the Sawtooth signal,Vt, the output voltage waveform, Vout,

for k=1:2*N
for j=1:50

i=j+(k-1)*50;

wt(i)=i*pi/(N*50);

if(sin(wt(i)))>0
hpf=1;
else
hpf=-1;
end

ma1(i)=ma*abs(sin(wt(i)));

if rem(k,2)==0
Vt(i)=0.02*j;
if abs(Vt(i)-ma*abs(sin(wt(i))))<=0.011
m=j;
beta(fix(k/2)+1)=3.6*((k-1)*50+m)/N;
else
j=j;
end
```

```
else
Vt(i)=1-0.02*j;
if abs(Vt(i)-ma*abs(sin(wt(i))))<0.011
l=j;
alpha(fix(k/2)+1)=3.6*((k-1)*50+l)/N;
else
j=j;
end
end

if Vt(i)>ma*abs(sin(wt(i)))
Vout(i)=0;
else
Vout(i)=hpf*Vrin;
end
end
end
beta(1)=[];
% PART VI
% Displaying the beginning (alpha), the end (beta) and the width of each of the output voltage pulses.
disp(' ')
disp('............................................... ....................')
disp('alpha beta width')
[alpha' beta' (beta-alpha)']
% PART VII
% Plotting the , the triangular carrier signal, Vt,% the modulating signal and the output voltage waveform, Vout.
a=0;
subplot(2,1,1)
plot(wt,Vt,wt,ma1,wt,a)
axis([0,2*pi,-2,2])
ylabel('Vt, m(pu)');
subplot(2,1,2)
plot(wt,Vout,wt,a)
axis([0,2*pi,-2,2])
ylabel('Vo(pu)');
xlabel('Radian');
% PART VIII
% Analyzing the output voltage waveform and finding the rms value of the output voltage
Vo =sqrt(1/(length(Vout))*sum(Vout.^2));
disp('The rms Value of the output Voltage = ')
y=fft(Vout);
y(1)=[];
x=abs(y);
x=(sqrt(2)/(length(Vout)))*x;
disp('The rms Value of the output voltage fundamental component = ')
x(1)
THDVo = sqrt(Vo^2 -x(1)^2)/x(1);
% PART IX
```

```
% calculating the output current waveform
m=R/(2*pi*f*L);
DT=pi/(N*50);
C(1)=-10;

i=100*N+1:2000*N;
Vout(i)=Vout(i-100*N*fix(i/(100*N))+1);

for i=2:2000*N;
C(i)=C(i-1)*exp(-m*DT)+Vout(i-1)/R*(1-exp(-m*DT));
end
% PART X
% Analyzing the output current waveform and finding the harmonic contents of the output
current waveform
for j4=1:100*N
CO(j4)=C(j4+1900*N);
CO2= fft(CO);
CO2(1)=[];
COX=abs(CO2);
COX=(sqrt(2)/(100*N))*COX;
end

CORMS = sqrt(sum(CO.^2)/(length(CO)));
disp(' The RMS value of the load current =')
CORMS

THDIo = sqrt(CORMS^2-COX(1)^2)/COX(1);
% PART XI
% Finding the supply current waveform
for j2=1900*N+1:2000*N
if Vout(j2)~=0
CS(j2)=abs(C(j2));
else
CS(j2)=0;
end
end
% PART XII
% Analyzing the supply current waveform

for j3=1:100*N
CS1(j3)=abs(CS(j3+1900*N));
end
CSRMS= sqrt(sum(CS1.^2)/(length(CS1)));
disp('The RMS value of the supply current is')
CSRMS
CSAV= (sum(CS1)/(length(CS1)));
disp('The Average value of the supply current is')
CSAV

CS2= fft(CS1);
```

```
CS2(1)=[];
CSX=abs(CS2);
CSX=(sqrt(2)/(100*N))*CSX;
% PART XIII
% Displaying the calculated parameters.
disp(' Performance parameters are')
THDVo
THDIo
a=0;
%PART XIV
% Opening a new figure window for plotting of the output voltage, output current, supply current and the harmonic
figure(2)
subplot(3,2,1)
plot(wt,Vout(1:100*N),wt,a);
title('');
axis([0,2*pi,-1.5,1.5]);
ylabel('Vo(pu)');
subplot(3,2,2)
plot(x(1:100))
title('');
axis([0,100,0,0.8]);
ylabel('Von(pu)');
subplot(3,2,3)
plot(wt,C(1900*N+1:2000*N),wt,a);
title('');
axis([0,2*pi,-1.5,1.5]);
ylabel('Io(pu)');
subplot(3,2,4)
plot(COX(1:100))
title('');
axis([0,100,0,0.8]);
ylabel('Ion(pu)');
subplot(3,2,5)
plot(wt,CS(1900*N+1:2000*N),wt,a);
axis([0,2*pi,-1.5,1.5]);
ylabel('Is(pu)');
xlabel('Radian');
subplot(3,2,6)
plot(CSX(1:100))
hold
plot(CSAV,'*')
text(5,CSAV,'Average value')
title('');
axis([0,100,0,0.8]);
ylabel('Isn(pu)');
xlabel('Harmonic Order');
```

DEVELOP A MATLAB CODE FOR CHARGING AND DISCHARGING A BATTERY.

```
Vbati=[];
SOCi=[];
for I1=1:1:5;
t1=7;
SOC1=.2;
K=.8;
D=1e-5;
SOCm=936;
ns=6;
SOC2=SOC1;
for t=0:.1:t1;
B=SOC2;
if (I1<=0);
V1=(1.926+.124*B)*ns;
R1=(.19+.1037/(B-.14))*ns/SOCm;
elseif (I1>0);
V1= (2+.148*B)*ns;
R1=(.758+.1309/(1.06-B))*ns/SOCm;
R1=double(R1);
end
syms v;
f1=K*V1*I1-D*SOC2*SOCm;
ee= int ((K*V1*I1-D*SOC2*SOCm),v,0,t);
SOC=SOC1+SOCm^-1*ee;
SOC2=SOC;
end
Vbat=V1+I1*R1;
Vbat=double(Vbat);
Vbati=[Vbati; Vbat];
SOC=double(SOC);
SOCi=[SOCi;SOC];
end
Vbati
SOCi
plot(Vbati,'green')
figure
plot(SOCi,'red')
plot(Vbati,SOCi)
```

WRITE A MATLAB PROGRAM THAT OPTIMIZES THE TILT ANGLE.

```
filename = 'combined data.xlsx';
G_T= xlsread(filename,'B5:B540')
G_D= xlsread(filename,'C5:C540')
daynumber= xlsread(filename, 'A5:A540');
```

```
N=daynumber;
G=G_T;
D=G_D;
L=18;
OptimumB_M=[];
for k=1:30:360
G_M=[];
D_M=[];
N_M=[];
for j=0+k:1:29+k
G_M=[G_M;G(j)];
D_M=[D_M;D(j)];
N_M=[N_M;N(j)];
end
G_M;
D_M;
N_M;
days=30;
GBAns=[];
for B=0:1:90;

Ds=23.45*sin((360*(284+N_M)/365)*(pi/180));
W=acosd(-1*tan((L)*(pi/180))*tan(Ds*(pi/180)));
Rb=((cos((L-B).*(pi/180)).*cos(Ds.*(pi/180)).*    sin(W.*(pi/180))+    (W.*(pi/180)).*sin((L-
B).*(pi/180)).*sin(Ds.*(pi/180))))/((
(cos(L*(pi/180)).*cos(Ds.*(pi/180)).*sin(W.*(pi/180)))+((
W.*(pi/180)).*sin(L*(pi/180)).*sin(Ds.*(pi/180)))));
Rd=(1+cos(B*(pi/180)))./2;
Rr= (0.3*(1-cos(B*(pi/180))))./2;
P=G_M-D_M;
F=transpose(Rb)
BB=(F*P);

DB=(D_M.*Rd);
RB=(G_M.*Rr);
GB=BB+DB+RB;

x_GB=GB;
AV_GB=[];
for i=1:days:round(length(x_GB)/days)*days
AV_GB=[AV_GB;sum(x_GB(i:i+days-1))/days];
end
AV_GB;
GBAns=[GBAns; AV_GB];
end
GBAns;
[MAX, MAX_INDEX]=max(GBAns);
maximum_Solar_Radiation=MAX;
optimumB1=MAX_INDEX-1;
OptimumB_M=[OptimumB_M; optimumB1];
```

```
end
OptimumB_M;
Year_Months=[1 2 3 4 5 6 7 8 9 10 11 12];
figure
subplot(2,2,1)
plot(Year_Months, OptimumB_M,'-mo','LineWidth',2,'MarkerEdgeColor','k','MarkerFaceColor',[.49 1 .63],'MarkerSize',10)
grid on;
xlim([1 12])
legend('Optimum Tilt angle','FontSize',4,'FontName','Times new roman')
xlabel('Month','FontSize',14,'FontName','Times newroman')
ylabel('Optimum Tilt angle','FontSize',14,'FontName','Times new roman')

title('Monthly optimum tilt angle','FontSize',14,'FontName','Times new roman')
```

DEVELOP A MODEL OF A PV WATER PUMPING SYSTEM AND IMPLEMENT IT IN MATLAB.

```
t=cputime;
%%%%%%%% Reading the Solar radiation, Cell temperature,Module voltage and Module current data %%%%%%%%
fileName = 'combined data.xlsx';

Vm=xlsread(fileName,'L3:L3000'); %///&&&Readingthe experimental voltage///&&&%
Im=xlsread(fileName,'M3:M3000');
G=xlsread(fileName,'C3:C3000');
Tc=xlsread(fileName,'E3:E3000');

save ('input_variable', 'G','Tc','Im','Vm');%Save G, Tc, Im & Vm data in MAT file
%%%%%%%%%%%%%%%%%% h1 and h2 are changed according topumping head %%%%%%%%%%%%%%%%%%
%%h1=20, 30, 40, 50 and 60, respectively.
%%h2=0.1444, 0.1907, 0.2371, 0.2835 and 0.3298,respectively
h1=20;
%%%&&&Factors of head equation we have got it from headcalculations
h2=0.1444;
%%%&&&Factors of head equation we have got it from headcalculations
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PV ARRAY %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Ns=5;%%%&&&Number of modules are connected in series
Np=4;%%%&&&Number of modules are connected in parallel

Cn=50;%%Size of storage tank (m^3), (for two days)
Va=Ns.*Vm;%Computing the hourly voltage of PV array (V)
Ia=Np.*Im;%Computing the hourly current of PV array (A)
Vpv=Va;%Output voltage of PV array for storing purpose
Ipv=Ia;%Output current of PV array for storing purpose
Pao=Va.*Ia;%Computing the hourly output power of PV array (W)
Am=0.9291;%The area of PV module (m^2)
A=Ns*Np*Am;%Computing the area of PV array (m^2)
```

```
Pai=A.*G;%Computing the hourly input power of PV array (W)
effa=Pao./Pai;%Computing the hourly efficiency of PV array
save ('output_variable_PV_array', 'Ia','Va','Pao','Pai','effa','A');
%Save Ia,Va,Pao,Pai,effa & A data of PV array in MAT
file%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% MOTOR
%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%
Va=0.95.*Va;%The output voltage of DC-DC converter
Ia=0.9.*Ia;%The output current of DC-DC converter
Ra=0.8;%Armature resistance of DC motor (Ohm)
Km=0.175%Torque and back emf constant (V/(rad/sec))
TC=0.08;%Torque constant for rotational losses
VT=0.01;%Viscous torque constant for rotational losses
Ebb=Va-(Ra.*Ia);%Computing the hourly back emf voltage of motor (V)
%%%%%%%%%% The case of overcurrent supplied to motor byPV array %%%%%%%%
Eb=(Ebb>=0).*Ebb;%Set Eb=0 when Ebb<0 (overcurrent)/turn off motor
Ia=(Ebb>=0).*Ia;%Set Ia=0 when Ebb<0 (overcurrent)/turn off motor
Va=(Ebb>=0).*Va;%Set Va=0 when Ebb<0 (overcurrent)/turn off motor
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Tm=Km.*Ia;%Computing the hourly torque of DC motor
Tmm=(Tm==0).*1;
Tm1=Tmm+Tm;
Rou=1000;%Density of water (Kg/m^3)
g=9.81;%Acceleration due to gravity (m/Sec^2)
d1=33.5*0.001;%Inlet impeller diameter (mm)
d2=160*0.001;%outlet impeller diameter (mm)
beta1=38*2*pi/360;%Inclination angle of impeller blade at impeller inlet (degree)
beta2=33*2*pi/360;%Inclination angle of impeller blade at impeller outlet (degree)
b1=5.4*0.001;%Height of impeller blade at impeller inlet (mm)
b2=2.2*0.001;%Height of impeller blade at impeller outlet (mm)
Kp=Rou*2*pi*b1*(d1/2)^2*tan(beta1)*((d2/2)^2-
((b1*(d1/2)^2*tan(beta1))/(b2*tan(beta2))))%Computingthe hourly output power of DC
motor (W)
Pdev=Eb.*Ia;
Omega=abs(sqrt((Km.*Ia)./Kp));
%Computing the hourly angular speed of motor (rad/sec)
%Pmo=Tm.*Omega
%Computing the hourly output mechanical power of motor (W)
% Omega=Pdev./Tm1;
Pmo=Pdev;
Pmi=Pao.*0.9;%Computing the hourly input power of DC motor (W)
PMI1=(Pmi==0).*1;%To overcome divided by zero
PMI2=Pmi+PMI1;%To overcome divided by zero
effm=Pmo./PMI2;%Computing the hourly efficiency of DC motor
save ('output_variable_Motor', 'Ia','Va','Pmo','Pmi','effm','Tm','Omega');
%Save Ia,Va,Pmo,Pmi,effm, Tm & Omega data of DC motor inMAT file
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PUMP
%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%
```

```
% Tp=Kp.*Omega.^2;
%Computing the hourly torque of pump
Tp=Tm;%-TC-0.1.*VT.*Omega;
%The produced torque by motor is equal the torque requiredfor k= pump (Nm)
Eh=Tp.*Omega;%Computing the hydraulic energy (W)
Ppo=Eh;%Computing the hourly output power of pump (W)
Ppo=(Ebb>=0).*Ppo;
Ppi=Pmo;%Computing the hourly input power of pump (W)
PPI1=(Ppi==0).*1;%To overcome divided by zero
PPI2=Ppi+PPI1;%To overcome divided by zero
effpp=Ppo./PPI2;%Computing the hourly efficiency of pump
effp=(effpp<=0.95).*effpp;

Q=zeros(length(Eh),1);
for ii=1:length(Eh)
r1 =h2*2.725;%Computing the flow rate of water
r2 =0;%Computing the flow rate of water
r3 =h1*2.725;%Computing the flow rate of water
r4 =-Eh(ii);%Computing the flow rate of water
r= roots([r1 r2 r3 r4]);%Computing the flow rate of water
if (imag(r(1))==0 && real(r(1))>0)%Choosing the real value of the flow rate of water
QQQ=real(r(1));
elseif (imag(r(2))==0 && real(r(2))>0)%Choosing the real value of the flow rate of water
QQQ=real(r(2));
elseif (imag(r(3))==0 && real(r(3))>0)%Choosing the real value of the flow rate of water
QQQ=real(r(3));
else
QQQ=0;
%If all the roots are complex and/or the real part is negative number or zero
end
QQ(ii,1)=QQQ;%Hourly flow rate (m^3/h)
end
Q1=(QQ==0).*1;%To overcome divided by zero
Q2=QQ+Q1;%To overcome divided by zero
H=Eh./(2.725.*Q2);
%Computing the head of pumping water (m)
%%%%%%%%%%%%       OVERALL       SYSTEM
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%
effsub=effm.*effp;%Computing hourly subsystem efficiency
effoverall=effa.*effm.*effp;%Computing hourly overall efficiency
QQ=(Ebb>=0).*QQ;
QQ=(effpp<=0.95).*QQ;
Q=[0;QQ];%To add initial case Q=0 for programming purposes
d=2.5;%Hourly demand water (m^3/h)
Cr=zeros(length(Q),1);%To specify the size of current resident matrix of storagetank
Qexcess_pv=zeros(length(Q),1);%To specify the size of excess water matrix
Qexcess_s=zeros(length(Q),1);
SOC=zeros(length(Q),1);
Qdef_pv=zeros(length(Q),1);
```

```
%To specify the size of deficit water matrix (before tank)
Qdeficit_s=zeros(length(Q),1);%To specify the size of deficit water matrix (after tank)
X=Q(2:end,1)-d;%Difference between the hourly production and demandwater
%%%%%%%%%%%%%%********** Before Tank **********%%%%%%%%
%%%%%%%
Qdef_pv(2:end,1)=(X<0).*abs(X);
%Computing hourly deficit water before tank (m^3)
%%%%%%%%%%%%%%********** After Tank **********%%%%%%%%%
%%%%%%
C=length(Q)-1;
Qexcess_pv(2:end,1)=(X>=0).*abs(X);%Computing hourly excess water before and after tank(m^3)
for i=1:C
Cr(i+1,1)=((Cr(i,1)+X(i,1))>=0).*abs(Cr(i,1)+X(i,1));
%T o compute the hourly current resident water in the tank (m^3)
SOC(i+1,1)=Cr(i+1,1)/Cn;
%Computing the hourly state of charge of storage tank
if SOC(i+1,1)>=1
SOC(i+1,1)=1;
Qexcess_s(i+1,1)=Cr(i+1,1)-Cn;
Cr(i+1,1)=Cn;
else
Qexcess_s(i+1,1)=0;
end
Qdeficit_s(i+1,1)=((Cr(i,1)+X(i,1))<0).*abs(Cr(i,1)+X(i,1));
%To compute the hourly deficit water (m^3/h) (after tank)
end
Q=Q(2:end,1);
%Final computing of hourly flow rate of water (m^3)
Qexcess_pv=Qexcess_pv(2:end,1);
%Final computing of hourly excess water before and after tank (m^3)
Qexcess_s=Qexcess_s(2:end,1)
%Final computing of hourly excess water after the tank is filled (m^3)
Qdeficit_s=Qdeficit_s(2:end,1)
%Final computing of hourly deficit water after tank (m^3)
Qdef_pv=Qdef_pv(2:end,1);
%Final computing of hourly deficit water before tank (m^3)
Cres=Cr(2:end,1);
%Final computing of hourly current resident water in tank (m^3)
SOC=SOC(2:end,1);
%Final computing of hourly state of charge (SOC)
D=zeros(length(Q),1)+d;
%Constructing the matrix of hourly demand water (m^3)
LLPh=Qdeficit_s(1:end,1)./D(1:end,1);
%Computing the hourly LLP
%disp([Q D X Cres Qexcess_s Qdeficit_s Qexcess_pv LLPh]);
LLP=sum(Qdeficit_s(1:end,1))/sum(D(1:end,1))
%Computing the LLP of one year
for i=1:C
Cr(i+1,1)=((Cr(i,1)+X(i,1))>=0).*abs(Cr(i,1)+X(i,1));
```

```
%To compute the hourly current resident water in the tank(m^3)
SOC(i+1,1)=Cr(i+1,1)/Cn;
%Computing the hourly state of charge of storage tank
if SOC(i+1,1)>=1
SOC(i+1,1)=1;
Qexcess_s(i+1,1)=Cr(i+1,1)-Cn;
Cr(i+1,1)=Cn;
else
Qexcess_s(i+1,1)=0;
end
Qdeficit_s(i+1,1)=((Cr(i,1)+X(i,1))<0).*abs(Cr(i,1)+X(i,1));
%To compute the hourly deficit water (m^3/h) (after tank)
end
Q=Q(2:end,1);
%Final computing of hourly flow rate of water (m^3)
Qexcess_pv=Qexcess_pv(2:end,1);
%Final computing of hourly excess water before and after tank (m^3)
Qexcess_s=Qexcess_s(2:end,1);
%Final computing of hourly excess water after the tank is filled (m^3)
Qdeficit_s=Qdeficit_s(2:end,1);
%Final computing of hourly deficit water after tank (m^3)
Qdef_pv=Qdef_pv(2:end,1);
%Final computing of hourly deficit water before tank (m^3)
Cres=Cr(2:end,1);
%Final computing of hourly current resident water in tank (m^3)
SOC=SOC(2:end,1);
%Final computing of hourly state of charge (SOC)
D=zeros(length(Q),1)+d;
%Constructing the matrix of hourly demand water (m^3)
LLPh=Qdeficit_s(2:end,1)./D(1:end,1);
%Computing the hourly LLP
%disp([Q D X Cres Qexcess_s Qdeficit_s Qexcess_pv LLPh]);
LLP=sum(Qdeficit_s(1:end,1))/sum(D(1:end,1))
%Computing the LLP of one year
plot(H,Qexcess_s)
```

DEVELOP A MATLAB MODEL FOR A 2.5 KW, 117 AH/12 SAPV SYSTEM.

```
function E_net=standalone


fileName = 'combined data.xlsx';
G=xlsread(fileName,'L3140:L3141');
G_T=xlsread(fileName,'C5:C1800');%Global solar radiation
L_T=xlsread(fileName,'Q5:Q1800');%load demand
Temp=xlsread(fileName,'E5:E1800');%ambient temperature
E_Capacity=117;

PV_Wp=2500;
```

```
Battery_SOCmax= 1400; % battery capacity Wh/day
PV_eff=0.16; % efficiency of the PV module
V_B=12; % voltage of the used battery
Inv_RP=2500; %inverter rated power
DOD=0.8; %allowed depth of charge
Charge_eff=0.8; % charging eff
Alpha= .05; % alpha
Wire_eff= 0.98;
SOCmin=Battery_SOCmax*(1-DOD);
%%(3.1) Simulation of the SAPV system
P_Ratio=(PV_Wp *(G_T/1000))/Inv_RP;
Inv_eff=97.644-(P_Ratio.*1.995)- (0.445./P_Ratio); %5KW
E_PV= ((PV_Wp.*(G_T/1000))-(Alpha.*(Temp-25))).*Wire_eff.*Inv_eff;
E_net=E_PV-L_T;
SOCi =Battery_SOCmax;
SOCf=[];
Deff=[];
Dampf=[];
%%(3.2)
ED=E_net-E_PV;
for i=1:length(E_net);
SOC= ED+SOCi;
if (SOC > Battery_SOCmax)
Dampi=SOC-Battery_SOCmax;
Defi=0;
SOCi=Battery_SOCmax;
%%(3.3)
else
end
if (SOC<SOCmin)
SOCi=SOCmin;
Defi=SOC-SOCmin;
Dampi=0;
%%(3.4)
else
SOCi=SOC;
Defi=0;
Dampi=0;
end
%%(3.5)
SOCf=[SOCf; SOCi];
Deff=[Deff; Defi];
Dampf=[Dampf; Dampi];
end
SOCf;
Deff;
Dampf;
SOC_per=SOCf./Battery_SOCmax;
LLP_calculated=abs(sum(Deff))/(sum (L_T));
LLP_calculated
```

DEVELOP A MATLAB CODE FOR A PV/DIESEL SYSTEM UTILIZING THE DATA IN (SOURCE) 2500 WP PV ARRAY, 3 KVA DIESEL GENERATOR, AND A 580 AH/12 V BATTERY AT 1% LOSS OF LOAD PROBABILITY.

```
fileName = 'combined data.xlsx';
G=xlsread(fileName,'L3140:L3141');
G_T=xlsread(fileName,'C5:C1800');%Global solar radiation
L_T=xlsread(fileName,'Q5:Q1800');%load demand
Temp=xlsread(fileName,'E5:E1800');%ambient temperatu
E_Capacity=117;
SOCmax=580;
E_net=standalone
for i=1:length(E_net);
SOC= E_net(i)+SOCi;

if (SOC > SOCmax)
Dumpi=SOC-SOCmax;
Defi=0;
SOCi=SOCmax;
E_Gen=0;
%%(2.1)
elseif (SOC<SOCmin)
Old_Defi=(SOC-SOCmin)+E_Capacity;
if (Old_Defi >=0)
SOCi=SOCmin+Old_Defi;
%%(2.2)
if (SOCi<=SOCmax)
    Defi=0;
Dumpi=0;
E_Gen= abs(Old_Defi)+ (SOCi-SOCmin);
SOCi=SOCmin+Old_Defi;
%%(2.3)
else
Defi=0;
Dumpi=0;
E_Gen= abs(Old_Defi)+ (SOCi-SOCmin)- (SOCi-SOCmax);
SOCi=SOCmax;
end
%%(2.4)

SOCi=SOCmin;
Defi=Old_Defi;
Dumpi=0;
E_Gen= E_Capacity;
end
%%(3)
else
SOCi=SOC+ E_Capacity;
```

```
if (SOCi <= SOCmax)
Defi=0;
Dumpi=0;
E_Gen=E_Capacity;
SOCi=SOC+ E_Capacity;
else
Defi=0;
Dumpi=0;
E_Gen=E_Capacity- (SOCi-SOCmax);
SOCi=SOCmax;
end
end
SOCf=[SOCf; SOCi];
Deff=[Deff; Defi];
Dumpf=[Dumpf; Dumpi];
E_Geni=[E_Geni; E_Gen];
E_PV=max(0,E_PV);
E_net=max(0,E_net);
Deff=max(0,Deff);
Dampf=max(0,Dampf);
ED=max(0,ED);
Inv_eff=max(0,Inv_eff);
P_Ratio=max(0,P_Ratio);
SOC_per=max(0,SOC_per);
SOCf=max(0,SOCf);
end
SOCf;
Deff;
Dumpf;
E_Geni;
SOC_per=SOCf./SOCmax;
LLP_calculated=abs(sum(Deff,1))/(Sum(L_T,1))
```

DEVELOP A MATLAB CODE THAT OPTIMIZES INVERTER SIZE FOR THREE PV SYSTEM SIZES OF 5 KW.

```
fileName = 'combined data.xlsx';

E_Solar=xlsread(fileName, 'C307:C672');
Solar_Rad=(E_Solar/12)*1000;
AV_InvEff=[];
Is=[];
for Rsi=.5:.01:5;
Is=[Is;Rsi];
Pm=2;
```

```
InvC=Pm/Rsi;
P_Ratio=(Pm*(Solar_Rad/1000))/InvC;
InvEffi=97.644-(P_Ratio.*1.995)- (0.445./P_Ratio); %5KW
N=[];
P=[];
for j=1:length(InvEffi)
if (InvEffi(j)<0);
N=[N;InvEffi(j)];
else
P=[P;InvEffi(j)];
end
end
N;
P;
Av=sum(P)/length(P);
AV_InvEff=[AV_InvEff;Av];
end
Is;
AV_InvEff;
plot(Is,AV_InvEff,'-k','LineWidth',2.5)
hold on
[MAX, MAX_INDEX]=max(AV_InvEff);
Maximum_EFF=MAX;
OPT_Rs=(MAX_INDEX*0.01)+.5;
plot(OPT_Rs,Maximum_EFF,'dred','MarkerFaceColor','yellow','MarkerEdgeColor','green',
'MarkerSize',8)
xlabel('I_S','FontSize',14,'FontName','Times new roman')
ylabel('Conversion efficiency','FontSize',14,'FontName','Times new roman')
legend('Inverter performance','Optimum I_S ,'FontSize',14,'FontName','Times new roman')
```

WRITE A PROGRAM TO OPTIMIZE THE SIZE OF HYBRID PV SYSTEM IN MATLAB

```
fileName = 'combined data.xlsx';
%Modeling of PV system using MATLAB
%Sizing PVPS for one year based on numerical iterative
%method. To compute LLP only Size of tank is changed from 1m^3 to 160m^3 with
%1m^3 as a step size. In the meanwhile, the PV array size is
%changed from 6 to 32 modules. For 20m as a head
%The computations are hourly for one year data
CNs=zeros(1,80000);
%Create a matrix for Ns values for each configuration realizes LLP<=0.01 over a year
CNp=zeros(1,80000);
%Create a matrix for Np values for each configuration realizes LLP<=0.01 over a year
CCn=zeros(1,80000);
%Create a matrix for Cn values for each configuration realizes LLP<=0.01 over a year
CLLP=ones(1,80000);
%Create a matrix for LLP values for each configuration realizes LLP<=0.01 over a year
CLLP=CLLP.*(-0.5);
CQexcess=ones(1,80000);
%Create a matrix for Qexcess values for each configuration realizes LLP<=0.01 over a year
```

```
CQexcess=CQexcess.*(-0.5);
CQdeficit=ones(1,80000);
%Create a matrix for Qexcess values for each configuration realizes LLP<=0.01 over a year
CQdeficit=CQdeficit.*(-0.5);
CQ=ones(1,80000);
%Create a matrix for Q values for each configuration realizes LLP<=0.01 over a year
CQ=CQ.*(-0.5);
q=0;
%Initialize the counter for indexing CNs, CNp, CCn & LLP matrices
G=xlsread(fileName,'C2:C3654'); %Reading the hourly solar radiation (W)
Tc=xlsread(fileName,'E2:E3654'); %Reading the hourly cell temperature (K)
Vm=xlsread(fileName,'L2:L3654'); %Reading the hourly voltage of one module (V)
Im=xlsread(fileName,'M2:M3654'); %Reading the hourly current ofone module (A)
for Cn=1:120
%Size of storage tank is increased by 1m^3
for N=6:32
%Number of modules are increased by one
for Ns=1:N
%Number of series modules are increased by one
if rem(N/Ns,1)==0
Np=N/Ns;
%To set the number of parallel modules
%%%%%% COMPUTE LLP %%%%%%%%%%
%%%%%%%%%%%%%%%%% h1 and h2 are changed according to pumping head %%%%%%%%%%%%%%%%%%
%%h1=20, 30, 40, 50 and 60, respectively.
%%h2=0.1444, 0.1907, 0.2371, 0.2835 and 0.3298, respectively
h1=20;
%%%&&&Factors of head equation we have got it from head calculations
h2=0.1444;
%%%&&&Factors of head equation we have got it from head calculations
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PV ARRAY %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Va=Ns.*Vm;
%Computing the hourly voltage of PV array (V)
Ia=Np.*Im;
%Computing the hourly current of PV array (A)
Vpv=Va;
%Output voltage of PV array for storing purpose
Ipv=Ia;
%Output current of PV array for storing purpose
Pao=Va.*Ia;
%Computing the hourly output power of PV array (W)
Am=0.9291;
%The area of PV module (m^2)
A=Ns*Np*Am;
%Computing the area of PV array (m^2)
Pai=A.*G;
%Computing the hourly input power of PV array (W)
effa=Pao./Pai;
```

```
%Computing the hourly efficiency of PV array
%%%%%%%%%%%%%%%%%%%%%%%%%%% MOTOR
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Va=0.95.*Va;
%The output voltage of DC-DC converter
Ia=0.90.*Ia;
%The output current of DC-DC converter
Ra=0.8;
%Armature resistance of DC motor (Ohm)
Km=0.175;
%Torque and back emf constant (V/(rad/sec))
Ebb=Va-(Ra.*Ia);
%Computing the hourly back emf voltage of motor (V)
%%%%%%%%% The case of overcurrent supplied to motor by PV array %%%%%%%
Eb=(Ebb>=0).*Ebb;
%Set Eb=0 when Ebb<0 (overcurrent)/turn off motor
Ia=(Ebb>=0).*Ia;
%Set Ia=0 when Ebb<0 (overcurrent)/turn off motor
Va=(Ebb>=0).*Va;
%Set Va=0 when Ebb<0 (overcurrent)/turn off motor
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Tm=Km.*Ia;
%Computing the hourly torque of DC motor
Tmm=(Tm==0).*1;
Tm1=Tmm+Tm;
Rou=1000;
%Density of water (Kg/m^3)
g=9.81;
%Acceleration due to gravity (m/Sec^2)
d1=33.5*0.001;
%Inlet impeller diameter (mm)
d2=160*0.001;
%outlet impeller diameter (mm)
beta1=38*2*pi/360;
%Inclination angle of impeller blade at impeller inlet (degree)
beta2=33*2*pi/360;
%Inclination angle of impeller blade at impeller outlet (degree)
b1=5.4*0.001;
%Height of impeller blade at impeller inlet (mm)
b2=2.2*0.001;
%Height of impeller blade at impeller outlet (mm)
Kp=Rou*2*pi*b1*(d1/2)^2*tan(beta1)*((d2/2)^2 -((b1*(d1/2)^2*tan(beta1
))/(b2*tan(beta2))));%Computing the hourly output power of DC motor (W)
Pdev=Eb.*Ia;
Omega=abs(sqrt((Km.*Ia)./Kp));
%Computing the hourly angular speed of motor (rad/sec)
Pmo=Pdev;
Pmi=Pao.*0.9;
%Computing the hourly input power of DC motor (W)
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```
PMI1=(Pmi==0).*1;
%To overcome divided by zero
PMI2=Pmi+PMI1;
%To overcome divided by zero
effm=Pmo./PMI2;
%Computing the hourly efficiency of DC motor
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PUMP
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Tp=Tm;
%The produced torque by motor is equal the torque required for pump (Nm)
Eh=Tp.*Omega;
%Computing the hydraulic energy (W)
Ppo=Eh;
%Computing the hourly output power of pump (W)
Ppo=(Ebb>=0).*Ppo;
Ppi=Pmo;
%Computing the hourly input power of pump (W)
PPI1=(Ppi==0).*1;
%To overcome divided by zero
PPI2=Ppi+PPI1;
%To overcome divided by zero
effpp=Ppo./PPI2;
%Computing the hourly efficiency of pump
effp=(effpp<=0.95).*effpp;
Q=zeros(length(Eh),1);
for ii=1:length(Eh)
r1=h2*2.725;
%Computing the flow rate of water
r2=0;
%Computing the flow rate of water
r3=h1*2.725;
%Computing the flow rate of water
r4=-Eh(ii);
%Computing the flow rate of water
r=roots([r1 r2 r3 r4]);
%Computing the flow rate of water
if (imag(r(1))==0 && real(r(1))>0)
%Choosing the real value of the flow rate of water
QQQ=real(r(1));
elseif (imag(r(2))==0 && real(r(2))>0)
%Choosing the real value of the flow rate of water
QQQ=real(r(2));
elseif (imag(r(3))==0 && real(r(3))>0)
%Choosing the real value of the flow rate of water
QQQ=real(r(3));
else
QQQ=0;
%If all the roots are complex and/or the real part is negative number or zero
end
QQ(ii,1)=QQQ;
```

```
%Hourly flow rate (m^3/h)
end
Q1=(QQ==0).*1;
%To overcome divided by zero
Q2=QQ+Q1;
%To overcome divided by zero
H=Eh./(2.725.*Q2);
%Computing the head of pumping water (m)
%%%%%%%%%%% OVERALL SYSTEM %%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
effsub=effm.*effp;
%Computing hourly subsystem efficiency
effoverall=effa.*effm.*effp;
%Computing hourly overall efficiency
QQ=(Ebb>=0).*QQ;
QQ=(effpp<=0.95).*QQ;
Q=[0;QQ];
%To add initial case Q=0 for programming purposes
d=2.5;
%Hourly demand water (m^3/h)
Cr=zeros(length(Q),1);
%To specify the size of current resident matrix of storage tank
Qexcess_pv=zeros(length(Q),1);
%To specify the size of excess water matrix
Qexcess_s=zeros(length(Q),1);
SOC=zeros(length(Q),1);
Qdef_pv=zeros(length(Q),1);
%To specify the size of deficit water matrix (before tank)
Qdeficit_s=zeros(length(Q),1);
%To specify the size of deficit water matrix (after tank)
X=Q(2:end,1)-d;
%Difference between the hourly production and demandwater
%%%%%%%%%%%%%%********** Before Tank
Qdef_pv(2:end,1)=(X<0).*abs(X);
%Computing hourly deficit water before tank (m^3)
After Tank**********%%%%%%%%%%%%%%
C=length(Q)-1;
Qexcess_pv(2:end,1)=(X>=0).*abs(X);
%Computing hourly excess water before and after tank (m^3)
for i=1:C
Cr(i+1,1)=((Cr(i,1)+X(i,1))>=0).*abs(Cr(i,1)+X(i,1));
%To compute the hourly current resident water in the tank (m^3)
SOC(i+1,1)=Cr(i+1,1)/Cn;
%Computing the hourly state of charge of storage tank
if SOC(i+1,1)>=1
SOC(i+1,1)=1;
Qexcess_s(i+1,1)=Cr(i+1,1)-Cn;
Cr(i+1,1)=Cn;
else
Qexcess_s(i+1,1)=0;
```

```
end
Qdeficit_s(i+1,1)=((Cr(i,1)+X(i,1))<0).*abs(Cr(i,1)+X(i,1)); %To compute the hourly deficit water (m^3/h) (after tank)
end
Q=Q(2:end,1);
%Final computing of hourly flow rate of water (m^3)
sumQ=sum(Q);
%To sum the hourly Q values over a year
Qexcess_pv=Qexcess_pv(2:end,1);
%Final computing of hourly excess water before and after tank (m^3)
Qexcess_s=Qexcess_s(2:end,1);
%Final computing of hourly excess water after the tank is filled (m^3)
Qexcess=sum(Qexcess_s);
Qdeficit_s=Qdeficit_s(2:end,1);
%Final computing of hourly deficit water after tank (m^3)
Qdeficit=sum(Qdeficit_s);
Qdef_pv=Qdef_pv(2:end,1);
%Final computing of hourly deficit water before tank (m^3)
Cres=Cr(2:end,1);
%Final computing of hourly current resident water in tank (m^3)
SOC=SOC(2:end,1);
%Final computing of hourly state of charge (SOC)
D=zeros(length(Q),1)+d;
%Constructing the matrix of hourly demand water (m^3)
LLPh=Qdeficit_s(1:end,1)./D(1:end,1);
%Computing the hourly LLP
LLP=sum(Qdeficit_s(1:end,1))/sum(D(1:end,1));
%Computing the LLP of one year
if LLP<=0.01
q=q+1;
%Increment the index of CNs, CNp, CCn & LLP matrices
CNs(1,q)=Ns;
%Store the value of Ns
CNp(1,q)=Np;
%Store the value of Np
CCn(1,q)=Cn;
%Store the value of Cn
CLLP(1,q)=LLP;
%Store the value of LLP
CQexcess(1,q)=Qexcess;
CQdeficit(1,q)=Qdeficit;
CQ(1,q)=sumQ;
%To store the value of Q over a year
end
end
end
end
end
C=[CNs; CNp; CCn];
%Matrix with all configurations
```

```
%%%%%% NEGLECTING THE SURPLUS COLUMNS IN MATRIX (C), THE COLUMNS WITH ZERO VALUES %%%%%
idx=C(1,:)==0;
%Index those columns which have a zero value in the first row
C=C(:,~idx);
%Take all rows, but only columns that do not have a zero value in the first columns
iidx=CLLP(1,:)==-0.5;
%Index those columns which have a -0.5 value
CLLP=CLLP(1,~iidx);
%Take all values, but only columns that do not have a -0.5 value
CQexcess=CQexcess(1,~iidx);
CQdeficit=CQdeficit(1,~iidx);
CQ=CQ(1,~iidx);
e=cputime-t;
%To compute the total time consumed for computing LLP program for all configurations
%%%%%% COST COMPUTATION FOR ALL CONFIGURATIONS THOSE SATISFY LLP<=0.01%%%%%%%%
CAc=800;
%Total capacity of converter required for system (W)
CAmp=840;
%Total capacity of motor-pump set required for system (W)
UCpv=1;
%%Unit cost of PV ($/Wp)
UCc=0.5;
%%Unit cost of converter ($/W)
UCmp=0.75;
%%Unit cost of motor-pump set ($/W)
UCt=20;
%%Unit cost of storage tank ($/m^3)
ICI=4000;
%%Civil and installation works cost ($)
FR=0.04;
%%Inflation rate
IR=0.08;
%%Interest rate
LP=20;
%%Life time of PVPS
Nr=1;
%%Number of replacement times for motor-pump set and converter
u=length(C);
%Speci fying the number of configurations those satisfy
LLP<=0.01;
LCC_cost=zeros(1,u);
%Creat ing matrix to store the cost of all configurations those satisfy LLP<=0.01
cost_Year=zeros(1,u);
%Creating matrix to store the yearly cost of all configurations
COU_vector=zeros(1,u);
%Creat ing matrix to store the water unit cost of all
configurations
for p=1:u
```

```
Ns=C(1,p);
%Taking each configuration to compute its cost
Np=C(2,p);
%Taking each configuration to compute its cost
Cn=C(3,p);
%Taking each configuration to compute its cost
N=Ns*Np;
%Total number of PV modules
%%%%%%%% COST SCRIPT %%%%%%%%%%%%%%%%%%%%%%
CApv=120*N;
%Total capacity of PV required for system (Wp)
CAt=Cn;
%Total capacity of storage tank required for system (m^3)
%%%%%%%%%%%%%%%%%%%% COMPUTING INITIAL COST OF PVPS
%%%%%%%%%%%%%%%%%%%%%%%
IC=(CApv*UCpv)+(CAc*UCc)+(CAmp*UCmp)+(CAt*UCt)+ICI;
%Initial cost of PVPS ($)
%%%%%%%%%%%%%%%%%%%% COMPUTING REPLACEMENT COST OF
PVPS %%%%%%%%%%%%%%%%%%%%
RCCmp=zeros(1,2);
%Array to accumalate the replacement cost for every replacement of motor-pump set
RCCc=zeros(1,2);
%Array to accumalate the replacement cost for every replacement of converter
for j=1:Nr
RRCmp=(CAmp*UCmp)*(((1+FR)/(1+IR))^((LP*j)/(Nr+1)));
%Replacement cost of motor-pump set ($)
RRCc=(CAc*UCc)*(((1+FR)/(1+IR))^((LP*j)/(Nr+1)));
%Replacement cost of motor-pump set ($)
RCCmp(1,j)=RRCmp;
%Accumalate the replacement costs for motor-pump set
RCCc(1,j)=RRCc;
%Accumalate the replacement costs for converter
end
RCmp=sum(RCCmp);
%Sum the replacement cost for L replacement motor-pump set ($)
RCc=sum(RCCc);
%Sum the replacement cost for L replacement converter ($)
RC=RCmp+RCc;
%Computing the replacement cost for PVPS ($)
%%%%%%%%%%%%%%%%%%% COMPUTING OPERATION AND MAINTENANCE
COST OF PVPS %%%%%%%%
MCpv0=0.01*(CApv*UCpv);
%Maintenance and operation cost of PV in the first year ($)
MCmp0=0.03*(CAmp*UCmp);
%Maintenance and operation cost of motor-pump set in the first year ($)
MCt0=0.01*(CAt*UCt);
%Maintenance and operation cost of storage tank in the first year ($)
MCpv=MCpv0*((1+FR)/(IR-FR))*(1-((1+FR)/(1+IR))^LP);
%Maintenance and operation cost of PV along life time of PVPS ($)
MCmp=MCmp0*((1+FR)/(IR-FR))*(1-((1+FR)/(1+IR))^LP);
```

```
%Maintenance and operation cost of motor-pump set along life time of PVPS ($)
MCt=MCt0*((1+FR)/(IR-FR))*(1-((1+FR)/(1+IR))^LP);
%Maintenance and operation cost of storage tank along life time of PVPS ($)
MC=MCpv+MCmp+MCt;
%Calculating the maintenance and operation costs of PVPS along life time of PVPS ($)
%%%%%%%%%%%%%%%%% COMPUTING LIFE CYCL COST OF PVPS
%%%%%%%%%%%%%%%%%%%%%%
LCC=IC+RC+MC; %Computing the LCC of PVPS ($)
%%%%%%%%%%%%%%%%% COMPUTING COST OF ENERGY
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
LCC_Year=LCC/LP;
%Computing the system cost for one year ($/year)
%Water_Volume_Year=10585
%Computing the volume of pumped water per year (m^3/year)
%COE=LCC_Year/Water_Volume_Year;
%Computing the cost of energy ($/m^3)
LCC_cost(1,p)=LCC;
%To store the LCC for each configuration
cost_Year(1,p)=LCC_Year;
%To store the yearly system cost for each configuration
COU=LCC_Year/(CQ(1,p)-CQexcess(1,p));
%Cost of water unit ($/m^3)
COU_vector(1,p)=COU;
end
% %%%%%%% SPECIFYING THE CONFIGURATION THAT SATISFY LLP<=0.01
WITH MINIMUM COST %%%%%%%
[n,i]=min(LCC_cost);
%To specify the minimum cost configuration (value and index)
cost_optimal=n;
%LCC for optimal configuration
cost_Year_optimal=n/LP;
%yearly system cost for optimal configuration
COU_optimal=COU_vector(1,i);
%Water unit cost value of optimal configuration
Ns_optimal=C(1,i);
%Optimal Ns value
Np_optimal=C(2,i);
%Optimal Np value
N_optimal =Ns_optimal*Np_optimal;
%To compute the total number of PV modules for optimal size
Cn_optimal=C(3,i);
%Optimal Cn value
LLP_optimal=CLLP(1,i);
%Optimal LLP value
Qexcess_optimal=CQexcess(1,i);
%Qexcess for one year of optimal PVPS configuration
Qdeficit_optimal=CQdeficit(1,i);
%Qdeficit for one year of optimal PVPS configuration
Q_optimal=CQ(1,i);
%Q for one year of optimal PVPS configuration
```