A Project Report on

Implementation of a Solar Power System with Home Automation

Submitted in partial fulfillment of the requirement of

University of Mumbai

For the degree of

Bachelor of Engineering

(Electronics and telecommunication)

by

Maniar Saad(14ET29)
Rais Umar(14ET34)
Naik Ramjan(14ET32)
Siddiqui Hasan(13ET10)

under the guidance of

Asst. Prof. Awab Fakih

Department of Electronics and Telecommunication
School of Engineering and Technology
Anjuman-I-Islam's Kalselar Technical Campus
Plot No.2 3 Sectot 16,Near Thana Naka,Khanda Gaon,
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This is to certify that the project entitled ***Implementation of a Solar Power System with Home Automation*** is a bonafide work of **Maniar Saad(14ET29), Rais Umar(14ET34), Naik Ramjan(14ET32), Siddiqui Hasan(13ET10)** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **Bachelor of Engineering** in**Department of Electronics and Telecommunication Engineering.**

Guide	Head of Department	Principal

Project I Approval for Bachelor of Engineering.

This project entitled ***Implementation of a Solar Power System with Home Automation*** by ***Maniar Saad(14ET29), Rais Umar(14ET34), Naik Ramjan(14ET32), Siddiqui Hasan(13ET10)*** are approved for the degree of ***Bachelor of Engineering in Department of Electronics and Telecommunication Engineering.***

Examiners:

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Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Maniar Saad ________________

Rais Umar ________________

Naik Ramjan ________________

Siddiqui Hasan ________________

Date:

Acknowledgments

All the authors of this work are obliged to thank, Director Dr. Abdul Razak Honnutagi of Anjuman-I-Islam Kalsekar Technical Campus. We are highly grateful Asst. Prof. Afzal Shaikh, HOD, Department of Electronics and Telecommunication Engineering, AIKTC, School of Engineering, Panvel for providing this opportunity to carry out the project. We are also grateful to our Project Co-ordinator, Asst. Prof. Shaheen Athvani.

We would like to take this opportunity to express our sincere thanks to our guide Awab Fakih, Assistant Professor, Department of Electronics and Telecommunication Engineering, AIKTC, School of Engineering, Panvel for his invaluable support and guidance throughout our project research work. We are grateful to him for his timely feedback which helped our track and schedule the process effectively.

We also extend our sincere thanks to all the faculty members for providing advice and valuable guidance.This work woudnt have been possible without the non-teaching staff, we whole heartedly thank them for their cooperation and we extend a special thanks to Mr. Sameer Salunke for his helping hand.

We also extend our love and gratitude towards our parents, namely, Mr. Imran Maniar, Mr. Moiz Rais, Mr. Naik Rasulsaheb, Mr. Mukhtar Hasan Siddiqui and Mr. Imran Yunus Chowdhary, and other family members who supported our work even when the times were tough.

Last but not the least, We are thankful to our sponsor Mr. Arif Naseem Khan (Ex-MLA) for his constant support and encouragement in every aspect which helped us to complete our project.

Maniar Saad
(14ET29)

Rais Umar
(14ET34)

Naik Ramjan
(14ET32)

Siddiqui Hasan
(13ET10)

Abstract

This book aims to cover all the topics that are relevant for getting an overview on the aspects of Solar Energy, with a focus on Photovoltaics, which allows the conversion of light energy or solar radiation into electrical energy, along with a brief introduction to Automation, with a focus on embedded devices such as Arduino, which is the technology that enables us to develop solutions for our automation needs.

In total, this book contains six modules. In the introductory Module I, we provide the reader with some general facts on energy in Chapter 1, summarize the current status & prospects of PV in the world in Chapter 2 and provide a first short explanation on how solar cells work in Chapter 3. Chapter 4 provides a basic understanding of any Automated Infrastructure and Chapter 5 describes the worldwide adoption of automated technologies.

Module 2 aims to cover all the physical fundamentals that are required for understanding PV Systems & Automated Infrastructures in general and the different technologies in particular. We discuss some basics from electrodynamics, solar radiation & solar cell parameters in Chapter 6. In Chapter 7 we look over some fundamentals of an automated infrastructure such as Microcontrollers, Integrated Development Environment(IDE), security intersects and capabilities.

In Module 3, at the beginning of Chapter 8, we elaborate on the different generation and recombination mechanisms and types of systems in the Solar energy domain. Likewise, a broad understanding of the ontology of Automation systems and its technological exposures is summarized in Chapter 9.

The different implementation scenarios are discussed in Module 4. We go through an in-depth explanation on the design and simulation of PV systems in a number of scenarios in Chapter 10, followed by a detailed overview on designing automation systems for a number of scenarios in Chapter 11. We conclude Module 4 with

a discussion on an analytical approach for choosing the best combination of a PV system and an Automation system for a said scenario in Chapter 12.

Next, we present a detailed description of the economics involved in setting up the combined PV and Automation system in Chapter 13 of Module 5, which also includes the economics of running the system & its benefits in monetary terms overtime in Chapter 14. Lastly, Module 6 consists of an epilogue which gives a conclusion in Chapter 15.

***Keyword*:Blynk, IoT, AC system, Solar power, PV module, On grid.**

Contents

List of Figures

Module 1

Introduction

Chapter 1

1 Energy

As this book is on alternative energy, it's smart to begin the discussion with some general thoughts on Energy. We will begin with a quote from The Richard Feynman Lectures on Physics. There is a truth, a law, governing all natural phenomenon. There is no exception to this law, it is precise thus far as we know. The law is termed conservation of energy. It states that theres a precise amount, that we tend to call energy, that doesnt amend with the manifold changes which nature undergoes. Its a mathematical principle; it says that there is a numerical figure that doesnt amend when anything happens in nature. It's not an outline of a mechanism, or something concrete; it's simply an odd fact that we are able to calculate some range and once we end looking at nature bear her tricks and calculate the amount once more, it's the same.
Energy contains a large number of various forms, and there is a formula for every form. These are: gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy. If we go ahead and add up all the formulas for each of those forms of energy, itll not amend except for energy moving into and out.

1.1 Some Definitions

We can now state some basic physical connections between the three most crucial physical quantities of energy, force, and power. These connections are derived from Newtonian mechanics however they are typically valid. We start with force F. Force is the effect on an object which changes its motion. Newtons second law states the relation between force and acceleration of a body via

$$F = ma,$$

Where, m is the mass of the body, the vectors F and a denotes the force and acceleration respectively.
In Newtonian mechanics, energy E, is defined as the product of force and distance,

$$E = F(s)\ ds,$$

Where, s is the distance.
Another crucial physical quantity is power P, which is defined by the amount of energy consumed per unit time,

$$E = P(t)\,dt,$$

Where, t is the time. Its unit is called Watt (W). 1 Watt is defined as one Joule per second. 1 Joule is a small amount of energy with respect to human consumption. Therefore, we use kilowatt hour (kWh) in the energy market; whereas, the amounts energy in the branch of physics that we will use to explain the working of solar cells are miniscule. Hence, we resort to use the electron volt, as our unit of energy while explaining the inner workings of a solar cell.

1.2 Energy Consumption

In todays society, humans dont solely need energy to keep their body running, but we tend to consume energy for a plethora of purposes. Us humans require energy for heating or cooling our houses, transportation of individuals and merchandise by vehicles and basically for every aspect of our life. At this instant you are using energy if you read this book on a laptop or a tablet, even if you read a printed copy, you implicitly utilized the energy that was needed to print it and to deliver it to your place. Our society survives on the ability to convert energy from one

Country	Energy Consumption (kWh/capita)
U.S.A	81642
Netherlands	53963
Germany	44310
China	23608
India	6987

Figure 1: Total primary energy consumption per capita of some countries in 2011 [2].

form to the other. Those nations that are using the most energy per individual are in fact the most prosperous and technologically developed. In the near future the tables will turn in favor of the nations that are most efficient in their use of energy. Hence, it is rightly believed that solving the energy problem is one of the biggest milestones of the 21st century. This energy problem has risen mainly due to two challenges: The first is a Supply-Demand problem. The world population remains quickly growing, and some studies predict a world population of nine billion around 2040 in distinction to the seven billion folks living on the world today. This increases the energy demand globally. The second challenge is that fossil fuels like oil, coal and gas dominate our energy infrastructure. These fossil fuels are in fact millions of years of solar power stored as chemical energy within the earth. The matter is that humans exhaust these fossil fuels quicker than they are generated through the chemical processes in nature. Thus, fossil fuels arent going to last very long as they are not sustainable. Burning of these fossil fuels also produce a number of green house gases. The International Panel on Climate Change (IPCC) states that carbon dioxide levels in the atmosphere are at the highest in at least 800,000 years.

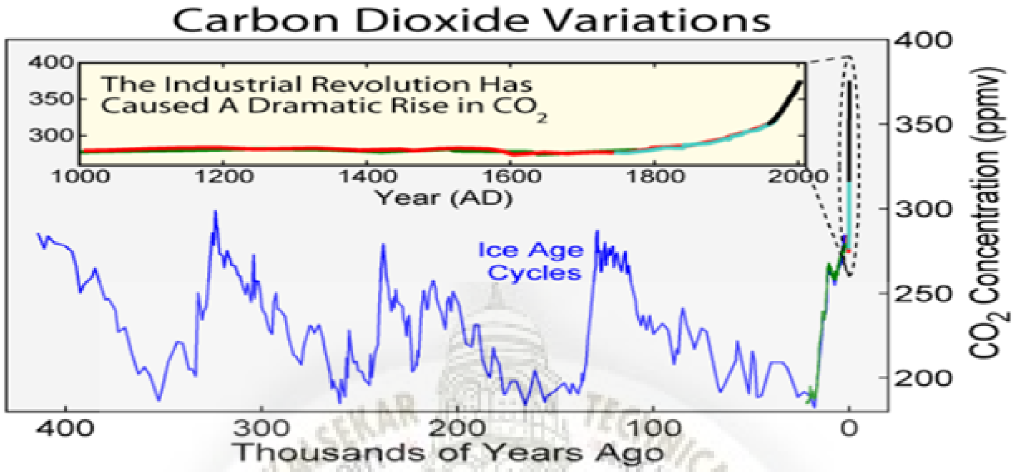


Figure 2: The atmospheric CO2 content in the last 400 000 years [6].

1.3 Renewable energy carriers

As we discussed above, the energy carrier known as fossil fuels are non-renewable as they cannot be replenished by nature in a practical amount of time. On the other hand, renewable energy carriers can be refilled by natural processes at a quicker rate compared to our consumption.
Some examples of this energy that is not generated by burning fossil fuels or nuclear fuels are: Hydroelectricity, which utilizes the potential energy stored in the rain falling in the mountains or the potential energy stored in tides. This potential energy can be converted into voltage by using a water turbine. Likewise, the kinetic energy of the wind can also be converted into electrical energy with the use of turbines.
Finally, the energy received via solar radiation, known as solar energy, can be transformed into electrical energy as well. If solar energy is directly converted into electrical energy through semiconductor materials, then it is called as photovoltaics (PV). Solar energy can also be converted into heat energy, we call it solar thermal energy. Apart from these, solar energy can also be converted into chemical energy. These solar fuels are produced by combining photovoltaics and regenerative fuel cells. Thus, we see that solar energy can be turned into electrical, heat as well as chemical energy. There is no doubt that the sun is the primary source of all power on earth and hence we need to work towards efficiently using

the energy provided by the sun directly to satisfy our needs. This book aims to make the reader learned in the science of utilizing this solar energy.

Chapter 2

2 Status and prospects of PV technology

In this Chapter we are going to provide a concise summary on the current standing of the PV technology and discuss its prospects.

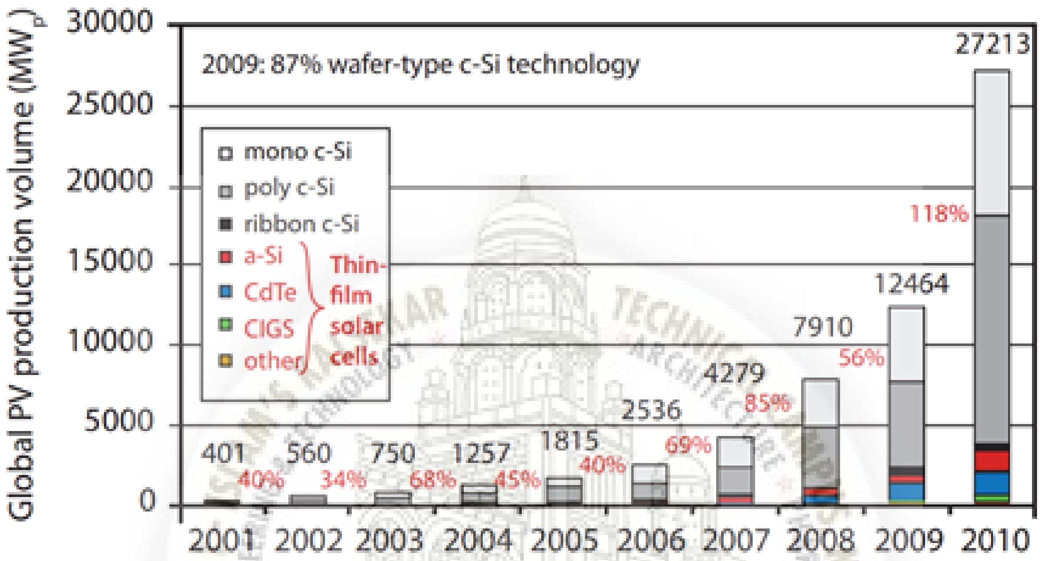


Figure 3: The global PV production volume in recent years.

In Fig. 3 the overall production of PV modules in recent years is shown. The vertical axis represents the annual production expressed within the total produced power capacity in MWp. The letter p denotes peak power, this means the utmost power a PV module will deliver if it's well-lighted with the standardized AM1.5 solar spectrum. On the horizontal axis is the time. we tend to see that the solar cell production is growing by more than 40% each year, which is an exponential growth.

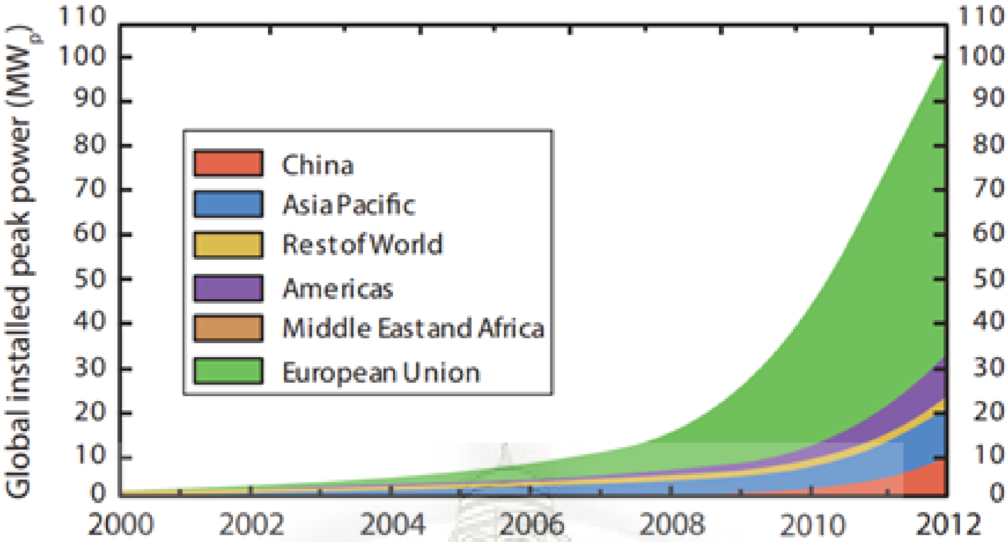


Figure 4: The global installed PV capacity (Data from [13]).

Figure 4 shows the worldwide additive installed PV power, that is rampantly increasing in time. The biggest share is set up in Europe, followed by the Asia Pacific Region, where most of the PV power is set up in Japan. For China there seems a robust increase in installed PV power since 2010. By the end of 2012 the a 100 GWp threshold was passed for the first time [13]. By the end of 2013, already 140 GWp was set up round the globe [14]. Of all the installed PV power at the end of 2013, almost one third was set up in 2013 alone!

In Fig.5 the PV power in many countries at the end of 2012 is shown. Around 31% of the PV capacity is set up in Germany. This is due to the German governments progressive feed-in-tariff policy that was introduced in 2000 [15]. Considering that Germany lies in a neighborhood with a comparatively low radiation level that's similar to that of Alaska [16], the large contribution of solar power to Germanys electricity production indicates the promising potential of solar energy for the sunnier areas of the planet.

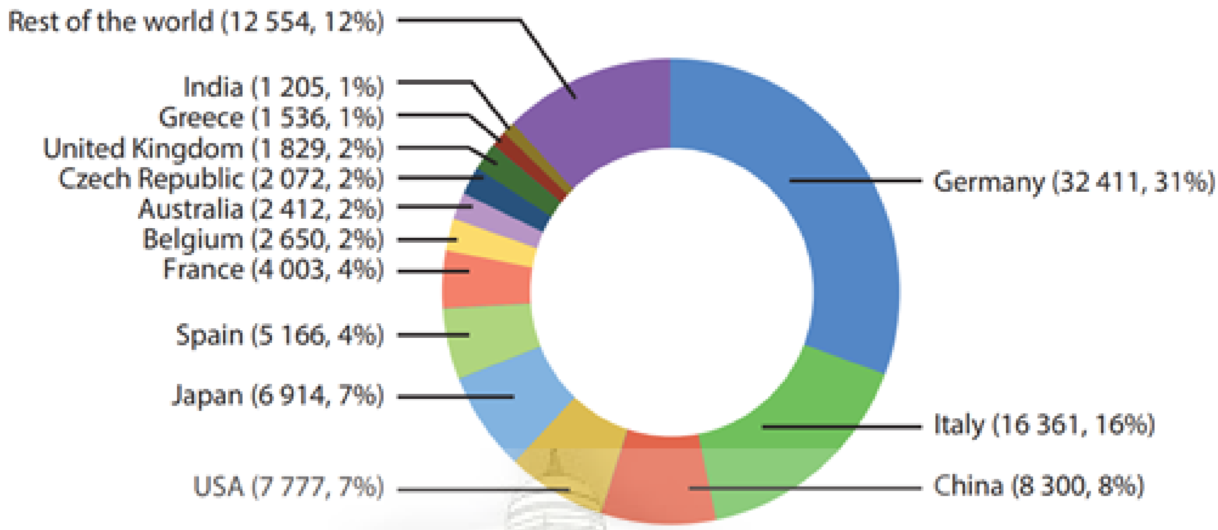


Figure 5: Fraction of PV installations for different countries by the end of 2012 (Data from [13]).

It is interesting to see that PV systems arent solely a European affair. The native demand and supply has been dramatically changing within the last thirteen years and is shown in Fig.6. This figure illustrates the evolution of the world-wide supply and demand of PV modules in the numerous regions round the world. In the year 2000, the largest market was Japan with a share of 40%. Germany then introduced the Renewable energy act that induced a strong growth of the German PV market. Around 2008, Europe had a market share of upwards of 80%. From 2009, PV markets in China and Asia Pacific started growing rapidly and catching up with Europe. The Chinese government made huge investments so as to scale up manufacturing in China. In 2012, about 60% of all PV modules were developed in China. Due to this, no local balance between supply and demand was in existence. While the majority of the demand is in Europe, Bulk of the production is in China.

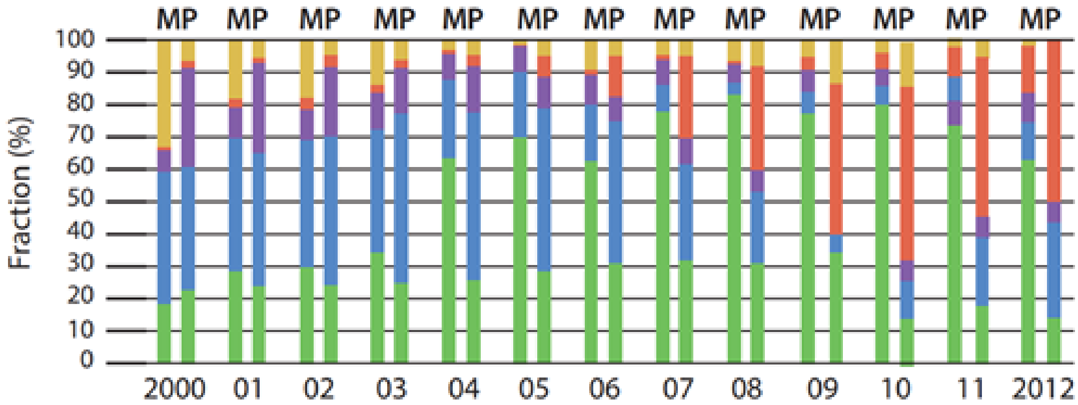


Figure 6: Development of the market and production shares of different PV markets since 2000 (Data from [13]).

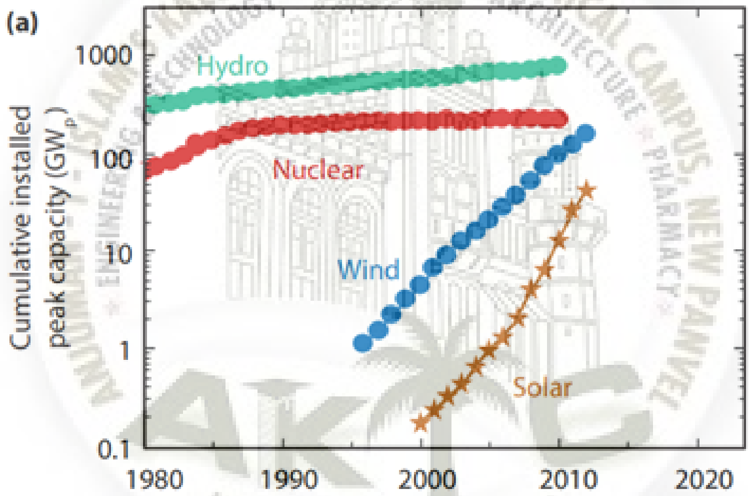


Figure 7: Cumulative installed capacity.

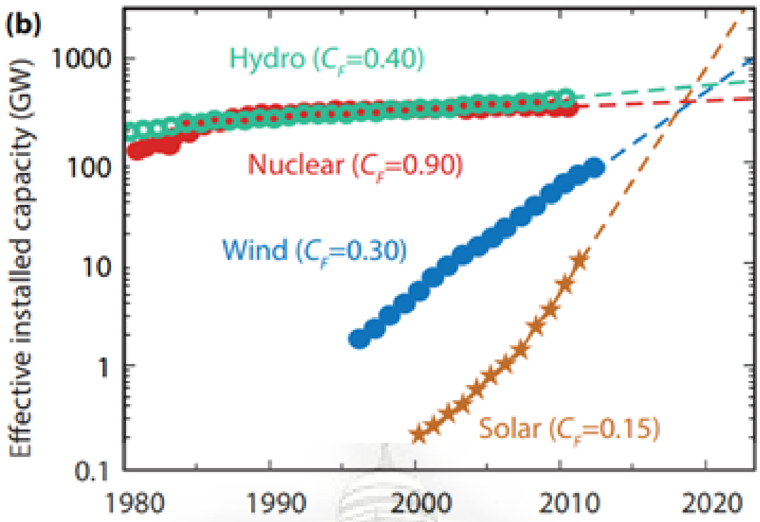


Figure 8: Effective installed capacity.

In Figure 8 we see the effective installed power corrected with the capacity factors until 2020. Presently, solar power generates an order of magnitude less electricity compared to wind energy and about two orders of magnitude less compared to hydro and nuclear electricity. But If we go ahead and extrapolate the trends of the last decade till 2020 we can see that the installed power output of solar energy can exceed nuclear, wind and hydro power. Its only a matter of time until Solar energy becomes the primary source of power generation for our society. Of course, we've got to justify why Solar Energy will grow a lot quicker than the other technologies shown in Fig. 7. First, radiation is obtainable all over the Earth and it's out there in great abundance. The amount of solar power incident on Earth is close to 10,000 times greater than the overall energy consumption of humans. If we consider hydroelectricity, it is generated by water which gets evaporated by the sun and falls down as rain, it is therefore a secondary form of solar power. In the same way, wind energy arises due to temperature and pressure variations in the atmosphere caused primarily by the sun, therefore, it can also be classified as a secondary type of solar power. Hence, solar power is by far the largest form of renewable energy source.

Chapter 3

3 Working Principle of a Solar Cell

In this chapter, we describe a simple model of a solar cell. Several notions bestowed during this chapter can be new, however, the core ideas of how a solar cell works will be clear. The aspects described in this chapter are discussed in greater detail within the chapters that will follow.

The working principle of a solar cell is predicated on the photovoltaic effect, which is the generation of a potential difference between the junction of two different materials caused by electromagnetic radiation. This effect is closely related to the photoelectric effect, in which electrons get emitted from a material which has absorbed light with a frequency higher than a material-dependent threshold frequency.

The photovoltaic effect can be divided into three basic processes:

3.1 Generation of charge carriers due to the absorption of photons in the materials that form a junction.

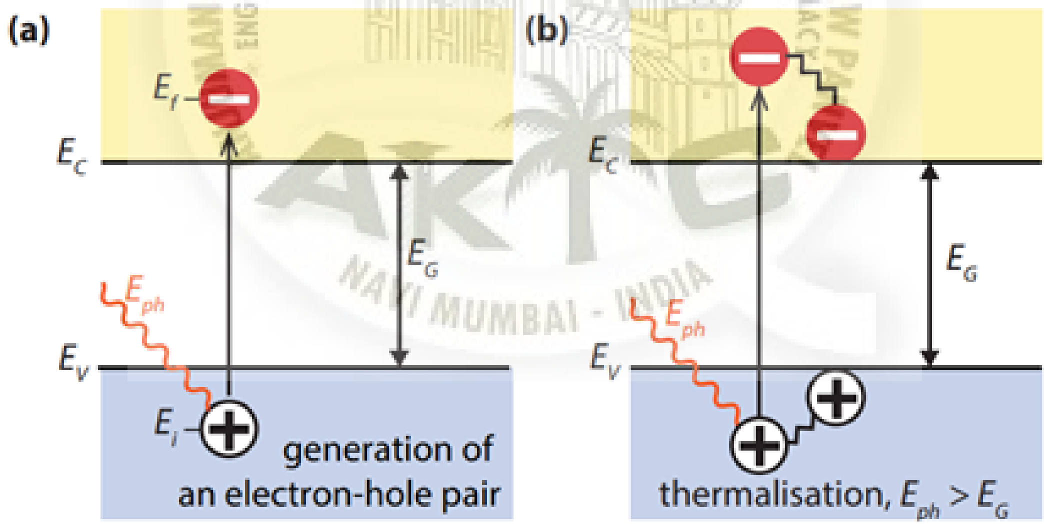


Figure 9: (a) Illustrating the absorption of a photon in a semiconductor with bandgap Eg. The photon with energy Eph = h excites an electron from Ei to Ef . At Ei a hole is created. (b) If Eph ¿ Eg, a part of the energy is thermalized.

When a photon gets absorbed in a material, it implies that the energy of that photon is gets used to excite an electron from an initial energy level Ei to a higher energy level Ef, from the fig.9a. we see that photons will solely be absorbed if the electron energy levels Ei and Ef exist such that their difference equals to the photon energy, h = Ef Ei. In a perfect semiconductor, electrons will populate energy levels below the valence band edge, Ev, and on top of the conductivity band edge, Ec. Between those 2 bands no allowed energy states exist, that can be populated by electrons. Hence, this energy distinction is called the bandgap, Eg. When an electron gets excited from Ei to Ef, a void is created at Ei. This void acts as a particle itself having a positive charge and it is called a hole. In this way, an electron-hole pair is created due to the absorption of a photon. In this process, the radiative energy from a photon gets converted into chemical energy of the electron-hole pair. The conversion efficiency is limited to around 67% to 86% due to the thermodynamic limit.

3.2 Subsequent separation of the photo-generated charge carriers in the junction.

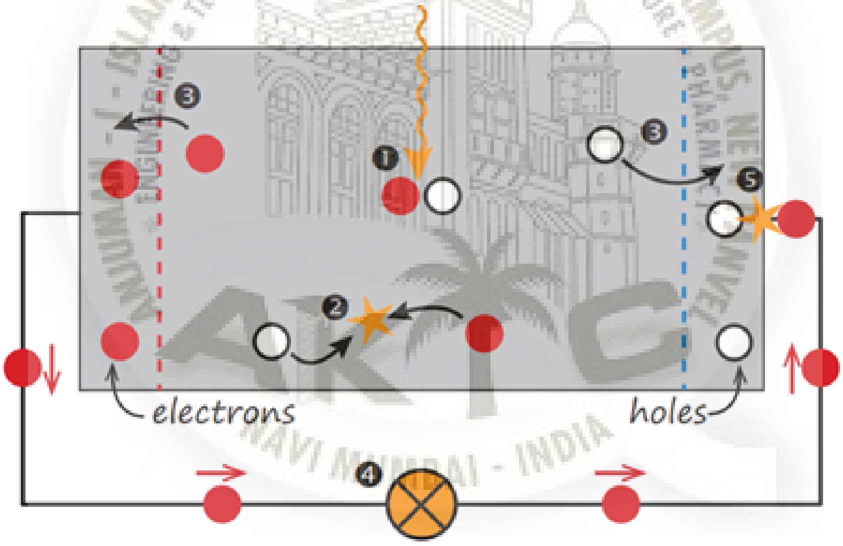


Figure 10: A very simple solar cell model.1) Absorption of a photon leads to the generation of an electron-hole pair. 2) Usually, the electrons and holes will combine. 3) With semipermeable membranes the electrons and the holes can be separated. 4) The separated electrons can be used to drive an electric circuit. 5) After the electrons passed through the circuit, they will recombine with holes.

As seen in fig.10, Usually, the electron-hole duo can recombine, i.e. the electron can fall back to the initial energy level Ei. The energy can then be free either as a photon or gets transferred to other electrons or holes. In order to use the energy within the electron-hole pair for external circuits, there has to be permeable membranes on either side of the absorbent material, so that electrons will effuse through one membrane and holes will effuse through the other. In most star cells, these membranes are fashioned by n- and p-type materials. A PV cell needs to be designed so that electrons and holes will reach the membranes before they recombine.

3.3 Collection of the photo-generated charge carriers at the terminals of the junction.

Lastly, the charge carriers can be extracted from the PV cell with electrical contacts so that these charge carriers can be used in external circuits. The chemical energy of the electron-hole pairs finally gets converted into electrical energy. After the electrons pass through the external circuit and the work is done, these charge carriers will recombine at a metal absorber interface, as shown in fig.10.

3.4 Loss Mechanisms.

The two most significant loss mechanisms in single bandgap PV cells are: The failure to convert photons with energies below the bandgap to electrical energy and thermalization of the photon energies surpassing the bandgap, as shown in fig.9(b). These two mechanisms alone result in the loss of close to half of the incident solar energy within the conversion process.

Chapter 4

4 Automated Infrastructures 101

In the past few chapters we have gone through the basic principles involved in the generation of electrical energy from incident solar radiation. As this book is aimed at providing the reader with in depth knowledge of a PV system as well as make the reader well versed in the domain of Automation, in this chapter we introduce the concept of an Automated infrastructure.

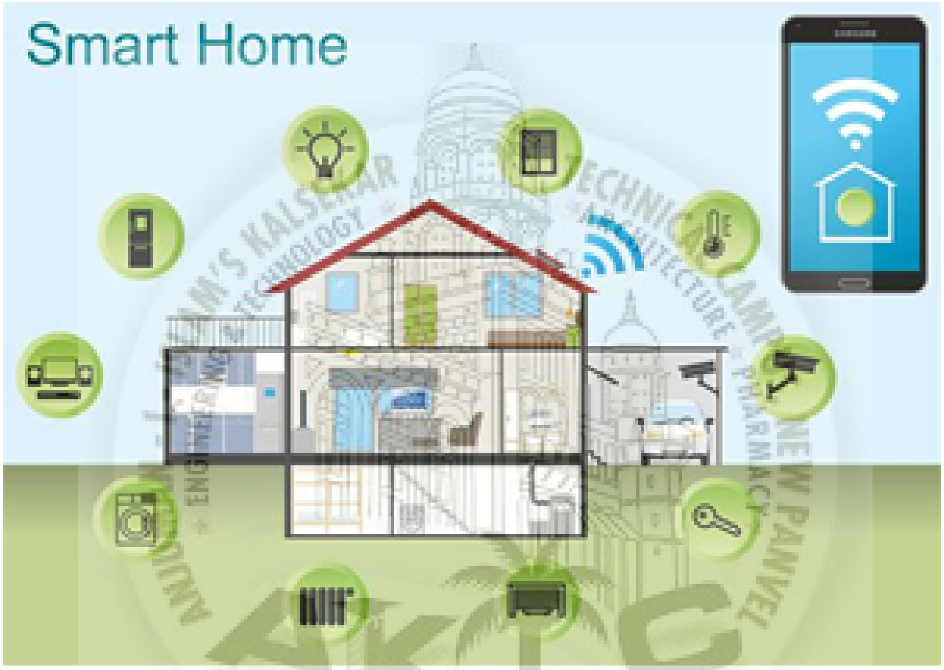


Figure 11: AutomatedInfrastructure.

4.1 Defining Automation

Automation technology is a crossover discipline that uses knowledge and scientific methods from numerous other technical sciences. An automatic machine is an artificial system that makes decisions based on the linking of inputs with the respective states of the system; these decisions then produce very specific desired outputs.

The lexicon defines automation as the technique of constructing an equipment or designing a process, or a system to operate automatically. Automation can also be described as The creation and application of technology to oversee and manage the assembly and delivery and of merchandise and services.

For the scope of this book we define automation as implementation of technologies which provide ease of access to individuals for monitoring and controlling various systems and equipment without the need to be locally present or physically interact with the system.

The best example of an Automated infrastructure that fits our definition is a Home Automation System (HAS). The idea of Home Automation has been around for many years. The concept of using network appliances and embedded devices in the house is termed as smart home or intelligent home. These systems mainly include a organized control of the appliances and the security equipment and they provide ease of access, energy efficiency and security at the same time.

Our aim throughout this chapter is to explain the reader things such as why automation is crucial in modern society and what can be achieved with it.

4.2 Working Principle of an Automation system

Understanding the fundamentals of control technology is the most important thing in understanding automation. Control systems are a central element in automation technology along with actuators and sensors. The term control system is frequently used in the broad sense to describe devices used for:
open-loop control, closed-loop control, monitoring, (process) data collection, communication, diagnostics.

In the narrower sense, control within automation technology refers to influencing an energy or material flow by means of one or more signals in an open control loop (DIN 19226). Control systems are frequently used for processes that are performed in steps. Examples of these include:
opening a door when there is someone standing in front of it, switching a traffic light to red after a specific time, switching on a corridor light after the light switch is pressed and automatically switching it off again after a specific time.

Control systems such as these are characterized by an open-loop process, i.e. the input variable (x) is not influenced by the controlled output variable (y). The control system cannot react to possible disturbance variables. In bullet-point three (above), this means that the open-loop time control system for the corridor lighting switches the light off after the specified time whether or not the person who pressed the light switch and thereby initiated the process has reached the apartment door. Figure 12 shows an open control loop.

Figure 12: Open control loop.

A closed-loop control system, on the other hand, continuously records the output variables (y) of the process, compares them with the input variables (x) and then automatically readjusts the process in the sense of an alignment of the output and input variables. It has a closed control loop and can react to disturbance variables. Closed-loop control processes are, for the most part, continuous processes where the output variable is to be maintained at a specific value. Examples of these include:
controlling the water temperature in an aquarium, controlling the speed in a vehicle (cruise control), controlling the rotational speed in an electric motor.

Figure 13: Closed control loop.

4.3 Benefitting from Automation

Us humans have always asked these two questions of ourselves and this has resulted in mankind to reach where it is today. The two simple questions are: what can we do to make life better? and how do we make time for the really important things in life?

Throughout history humans have worked very hard, and we have always put our resources towards finding ways to make our work easier by making improved tools and technologies to accomplish the task or to make others do it for us. For example, rather than digging the fields with our hands, we invented the plough and even started using cattle to do the work for us, then moved to tractors and now self-driven automated tractors. Rather than working harder on the task itself, we use our intellect to find out better ways to do the work or make the work easier.

Similarly, automation is a step towards making life better and ending the struggle of human labor. The main motivation to introduce automation into the market was to make us able to produce goods less expensively. This is achieved by automation in a number of ways: Fewer staff and labor is required in an automated production facility, the production machinery can run round the clock without human intervention and only needs interval periods for maintenance, the quality of production is consistent, processing times get faster and production can be scaled for large quantities and finally people can be relieved of physical human labor.

4.4 Less positive effects associated with Automation

- The loss of jobs, in particular those with a low skill level.
- The automation of production demands that employees occasionally make decisions, however the complexity of the system structure is such that they cannot fully decipher their consequences.
- The expenditure for an automated system of this type increases each individual's responsibility for the success of the company as a whole.

Chapter 5

5 Growing Adoption of Automation

5.1 History of Automation

These days when we hear "automation technology" we immediately think of industrial robots and computer controllers. In fact, automation technology in craft and industry began much earlier with the utilization of the steam engine by James Watt in 1769. For the first time, a machine could replace manpower or horsepower. The first steam engines were used to drain water from mines and to drive machine tools. In 1820 the Danish physicist Oersted discovered electromagnetism, in 1834 Thomas Davenport developed the first direct current motor with commutator (reverser) and received the patent for it one year later. The electric motor replaced the steam engine as a driving component.

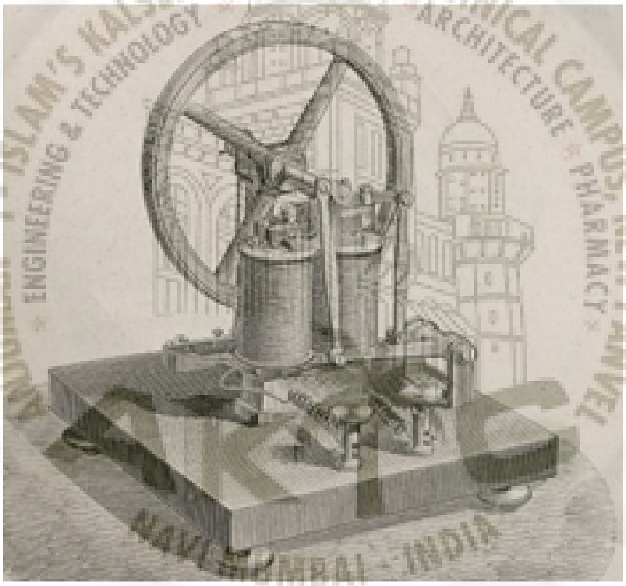


Figure 14: The first electric motor.

In 1873 a patent was granted for a fully automatic machine for manufacturing screws that used cam disks to store the individual program sequences.
In 1959 Joseph Engel Berger presented the prototype for an industrial robot that was used by General Motors in automobile production from 1961. This robot still had hydraulic drives; it was not until later that industrial robots were fitted exclusively with electric motors.

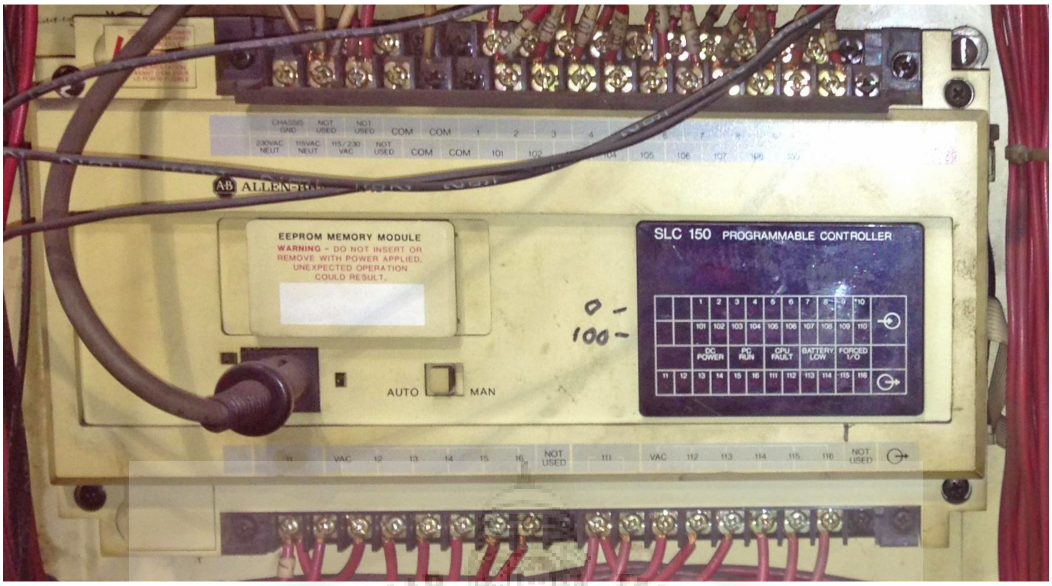


Figure 15: Early PLC.

In 1968 a team from the American company Allen Bradley under the leadership of Odo Struger developed the first programmable logic controller (PLC). Now it was possible to simply change a program without having to rewire lots of relays. Industrial robots became mainstream in modern industrial production in 1970 and remain so to this day. Modern production cannot manage without them for the moment at least. Quite the opposite in fact, their importance is continuously growing. In Germany alone, there are well over 100,000 robots, mostly in the automotive industry and its suppliers.

Figure 16: A Video On PLC

5.2 Market Research

Although we are just experiencing the hype about automation, the technology and idea behind it is not new. In fact, the concept of automation dates back even before the internet. The reason for it to grow so much in the past few years is because it is no longer cost prohibitive. As technologies become better and globalization increases we observe a decline in the prices of these tech.

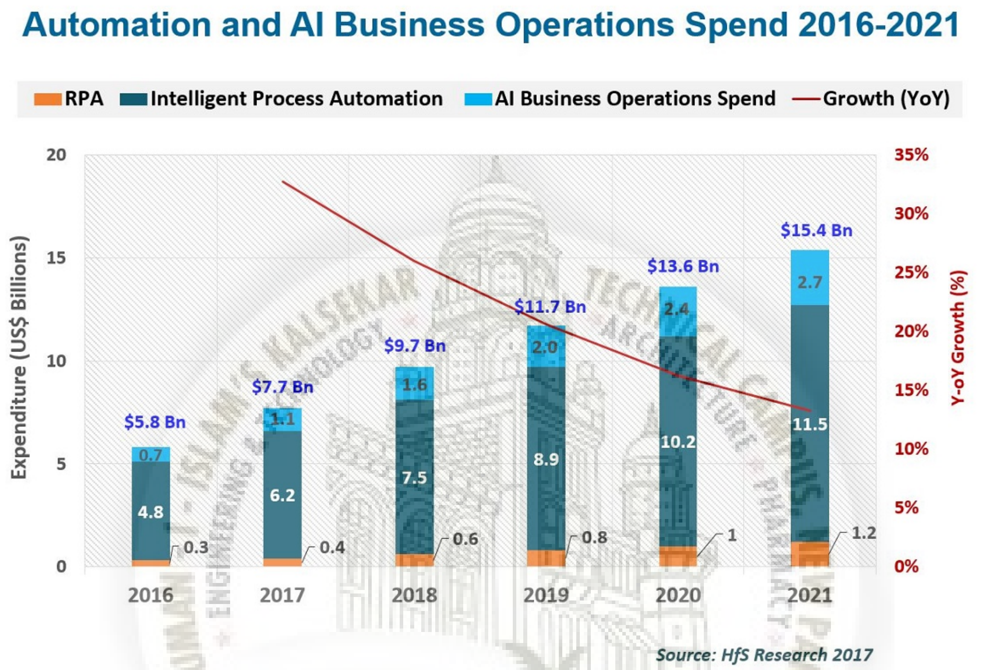


Figure 17: Global Automation Market.

- Home automation is expected to increase to 20 million installed units by 2017, up from 1.5 million in 2011. (ABI Research)
- 40-55% of U.S. broadband households are interested in IP-connected home controls and security solutions. (Parks & Associates)
- Home automation is expected to grow to a $35 million market in 2016, up from $16 million in 2011. (Markets & Markets)
- In the next few years, home automation installations will grow by double-digit rates. (Reuters)

It is expected that the global smart home market will expand at an annual growth rate of 15.1% and will reach a valuation of 130.1 Billion USD by the end of 2024.

Figure 18: Global Automation Market Share.

From fig.4.2, we can see that the majority of market share belongs to Europe. The real picture however, is that the majority of production is in China and Asia pacific while majority of demand is in European and western countries.

Module 2

Fundamentals

Chapter 6

6 Photovoltaic Fundamentals

This chapter aims to cover all the physical fundamentals that are required for understanding PV Systems. We introduce the basics of electrodynamics that are required for solar cell physics.

6.1 Electrodynamics

Electrodynamics relates to the study of the electromagnetic theory and learning about the electromagnetic waves and their interaction in different mediums. Electricity and magnetism are well studied since old times but it was in the 19th century that we realized that they belong together as electromagnetism. As we know electric fields are generated by charges and magnetic fields are generated by currents which is nothing but flow of charges. Hence, we understand that electricity and magnetism are the two sides of the same coin. This was explained by James Maxwell in his theory of electromagnetic waves described by Maxwell equations.

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\mathbf{E}-\frac{n^2}{c_0^2}\left(\frac{\partial^2\mathbf{E}}{\partial t^2}\right)=0$$

for the electric field E(r, t), where c0 denotes the speed of light in vacuo and n is the refractive index of the material. In a similar manner we can derive the wave equation for the magnetic field,

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\mathbf{H}-\frac{n^2}{c_0^2}\left(\frac{\partial^2\mathbf{H}}{\partial t^2}\right)=0.$$

These equations predict the presence of electromagnetic waves and that the speed of these electromagnetic waves is the same as that of the speed of light. Therefore, Maxwell concluded that light is an electromagnetic wave. Therefore, all the physical laws of electromagnetic radiation related to optics in absorptive media apply to light as well.

6.2 Solar radiation

The sun is the central star in our solar system, it is mainly comprised of hydrogen and helium. Table below summarizes some facts about the sun

Mean distance from the Earth:	149 600 000 km (the astronomic unit, AU)
Diameter	1 392 000 km (109 × that of the Earth)
Volume	1 300 000 × that of the Earth
Mass	1.993×10^{27} kg (332 000 times that of the Earth)
Density	$>10^5$ kg $m-^3$ (over 100 times that of water)
Pressure	over 1 billion atmospheres
Temperature (at its center):	about 15 000 000 K
Temperature (at the surface):	6 000 K
Energy radiation:	3.8×10^{26} W
The Earth receives:	1.7×10^{18} W

As stated before in previous chapters, only the photons having appropriate energy will be absorbed to generate charge carriers in a PV cell. Hence, it is crucial to know about the spectral distribution of solar radiation, which is the number of photons of a particular energy as a function of the wavelength. The solar radiation spectrum is described by two quantities; the spectral irradiance and the spectral photon flux.

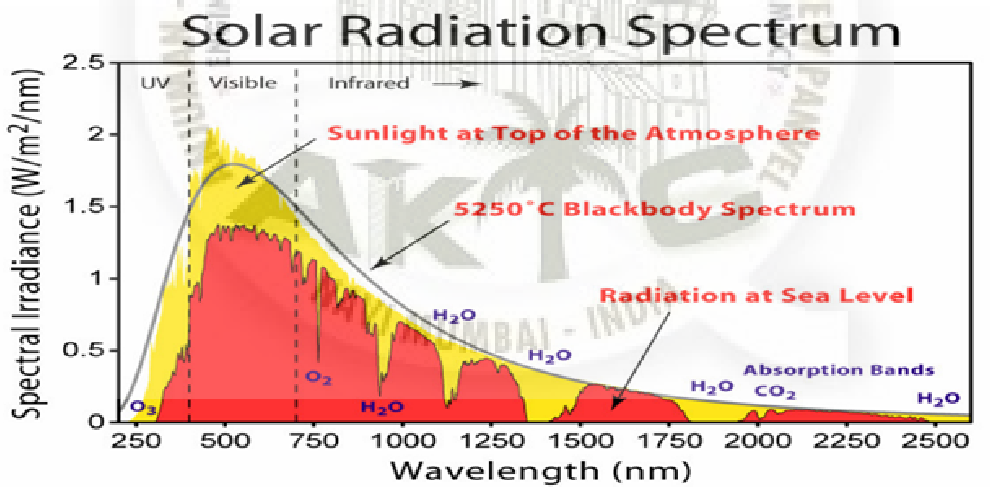


Figure 19: Different solar spectra.

As solar cells are manufactured by a number of companies and there are a number of technologies involved, it is therefore very important to define a reference solar spectrum in order for us to compare all the different technologies.

6.3 Solar Cell Parameters

The performance of a solar cell is characterized by the parameters such as the peak power Pmax, short-circuit current density JSC, the open-circuit voltage VOC, and the fill factor FF. The J-V characteristics in fig.6.2 help us determine these parameters

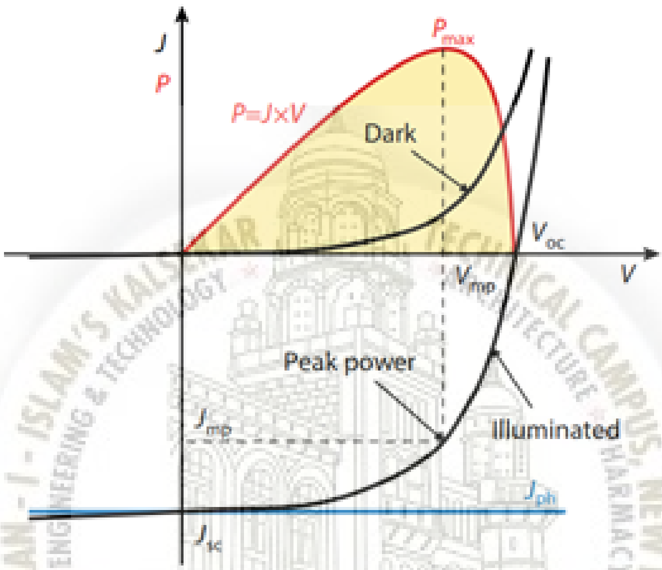


Figure 20: J-V characteristics of a p-n junction in the dark and under illumination.

6.3.1 Short-circuit current density

The current that flows through the external circuit when the electrodes of the PV cell are shorted is called as the short-circuit current ISC. This parameter depends on the density of the photon flux that is incident on the PV cell, this photon flux density is determined by the spectrum of incident light. The short circuit current also depends on the area of the PV cell. The ISC is actually the maximum current delivered by a solar cell. Realistically, we use the Short-circuit current density JSC to describe the maximum current as this parameter does not depend on the area of the solar cell. The short circuit current density mainly depends on the optical properties of the PV cell. Commercial PV modules have a JSC exceeding 35mA/cm2.

6.3.2 Open-circuit voltage

This is the voltage at which there is no current flowing through the external circuit. It is described as the maximum voltage that a PV module can deliver. It can be calculated using the following equation:

$$V_{oc} = \frac{kT}{e} \ln\left(\frac{J_{ph}}{J_0} + 1\right)$$

The Open-circuit voltage depends on the photo-generated current density and the saturation current. The saturation current basically depends on the amount of recombination of charge carriers in the PV cell. Therefore, VOC gives the measure of the recombination of charge carriers in the solar cell. Commercial PV modules have a VOC greater than 600mV.

6.3.3 Fill Factor

It is the ratio of the maximum power PMAX and the product of VOC with JSC. Where, PMAX = JmpVmp.

$$FF = \frac{J_{mp} V_{mp}}{J_{sc} V_{oc}}$$

It is basically a measure of quality of a solar cell.

6.3.4 Conversion efficiency

It is the ratio of the max generated power and the incident power.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{mp}\, V_{mp}}{P_{in}} = \frac{J_{sc}\, V_{oc}\, FF}{P_{in}}.$$

The conversion efficiency of commercially available PV modules lies in the range of 17 to 18%.

6.4 The equivalent circuit

The J-V characteristics of an ideal solar cell was seen before in the previous subtopic; that same J-V characteristics can be expressed by the equation:

$$J(V_a) = J_{\mathrm{rec}}(V_a) - J_{\mathrm{gen}}(V_a) - J_{\mathrm{ph}}$$
$$= J_0 \left[\exp\left(\frac{eV_a}{kT}\right) - 1\right] - J_{\mathrm{ph}}.$$

The first term denotes the dark diode current density and the second term denotes the photo-generated current density. This equation can be further expressed in the form of an equivalent circuit shown in fig.20. In which a diode and a current source are connected in parallel. The diode is formed by a p-n junction.

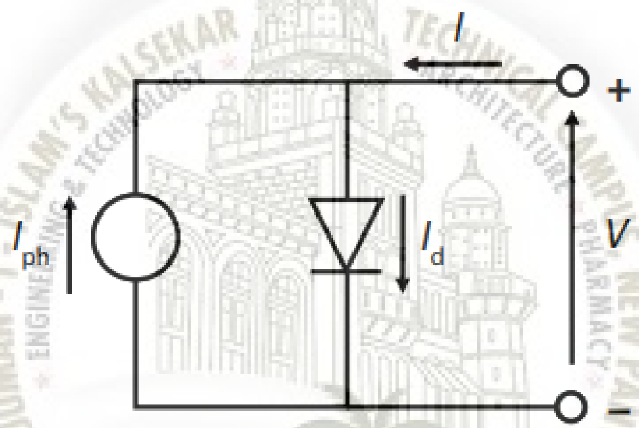


Figure 21: The equivalent circuit of an ideal solar cell.

Practically FF gets influenced by a series resistance Rs , and a shunt resistance Rp. The effect of these parameters on the J-V characteristics can be studied from the equivalent circuit in fig.21

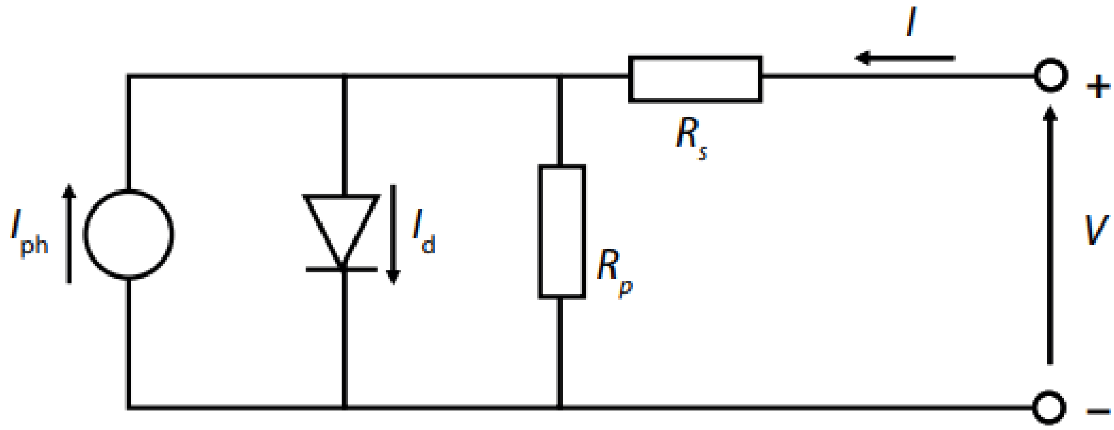


Figure 22: The equivalent circuit of a solar cell with a series resistance Rs and a shunt resistance Rp.

The J-V characteristics of this one diode equivalent circuit having a series and shunt resistance is given by,

$$J = J_0 \left\{ \exp \left[\frac{e\,(V - AJR_s)}{kT} \right] - 1 \right\} + \frac{V - AJR_s}{R_p} - J_{ph},$$

Where, the area of the solar cell is denoted by A.
The effect of these series and shunt resistances on the J-V characteristics is shown in the fig.22.

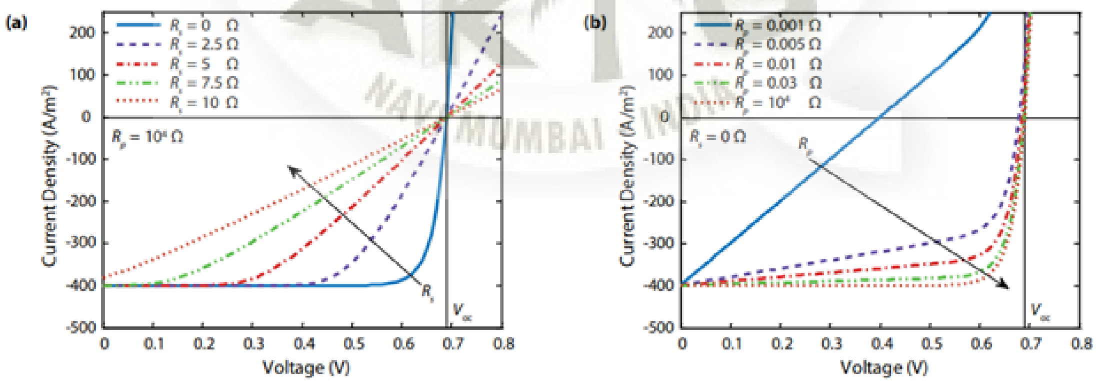


Figure 23: Effect of the (a) series resistance and (b) parallel resistance on the J-V characteristic of a solar cell.

In a practical Solar cell, the FF is additionally influenced by the recombination of the charge carriers in the p-n junction. A non-ideal diode in a practical Solar cell is represented by two diodes in the equivalent circuit of a practical Solar cell. It is shown in fig.23.

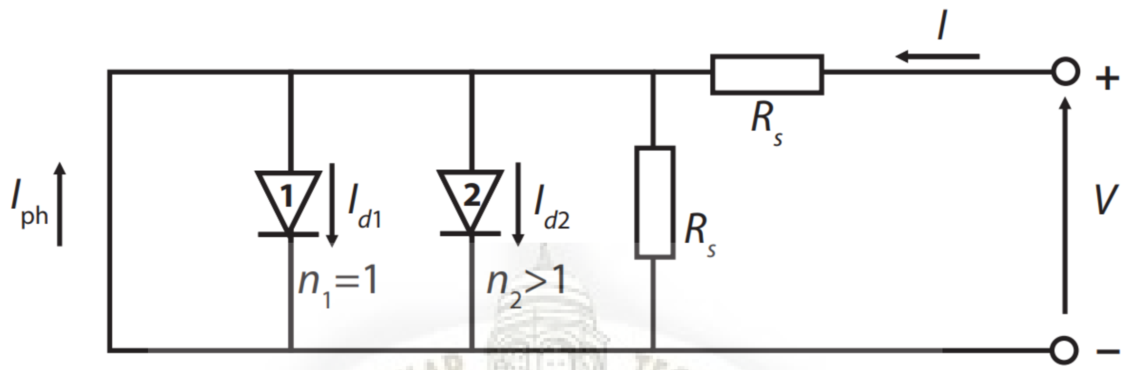


Figure 24: The equivalent circuit of a solar cell based on the two-diode model.

The J-V characteristic of the two-diode equivalent circuit of a practical solar cell is expressed as,

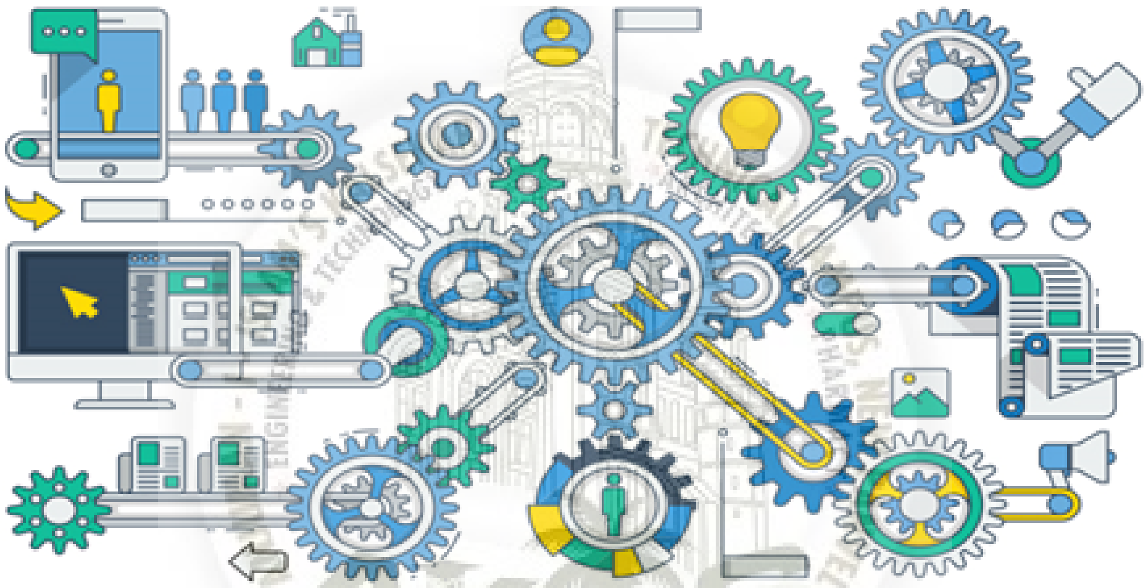
$$
\begin{aligned}
J = J_{01} & \left[\exp\left(\frac{e\,(V - AJR_s)}{n_1 kT}\right) - 1\right] \\
+ J_{02} & \left[\exp\left(\frac{e\,(V - AJR_s)}{n_2 kT}\right) - 1\right] \\
+ & \frac{V - AJR_s}{R_p} - J_{ph},
\end{aligned}
$$

Where the saturation current of the two diodes are denoted by J01 and J02 respectively.

Chapter 7

7 Automation Fundamentals

In this chapter we are going to take you through some basic fundamentals of embedded systems required for automation systems. With all the different technologies available today, it is increasingly confusing to decide over which way to go while designing your own automated infrastructure.
After reading this chapter the reader will hopefully be able to analyze his site and choose the appropriate technology as required by his/her use case.



There are a number of fundamental components which are required to successfully set up a reliable automation system, the most important of these components is probably the one which is the central processing unit of the system and provides a back bone for the system to be built upon. This component is called the Microcontroller.

7.1 Micro-controller

Figure 25: Two ATmega microcontrollers.

A microcontroller (or MCU for microcontroller unit) is a small computer on a single integrated circuit. In modern terminology, it is similar to, but less sophisticated than, a system on a chip or SoC; an SoC may include a microcontroller as one of its components. A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Program memory in the form of ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

Figure 26: A Video On MicroControllers

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

Some microcontrollers may use four-bit words and operate at frequencies as low as 4 kHz, for low power consumption (single-digit milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nanowatts, making many of them well suited for long lasting battery applications. Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP), with higher clock speeds and power consumption.

7.2 Integrated Development Environment (IDE)

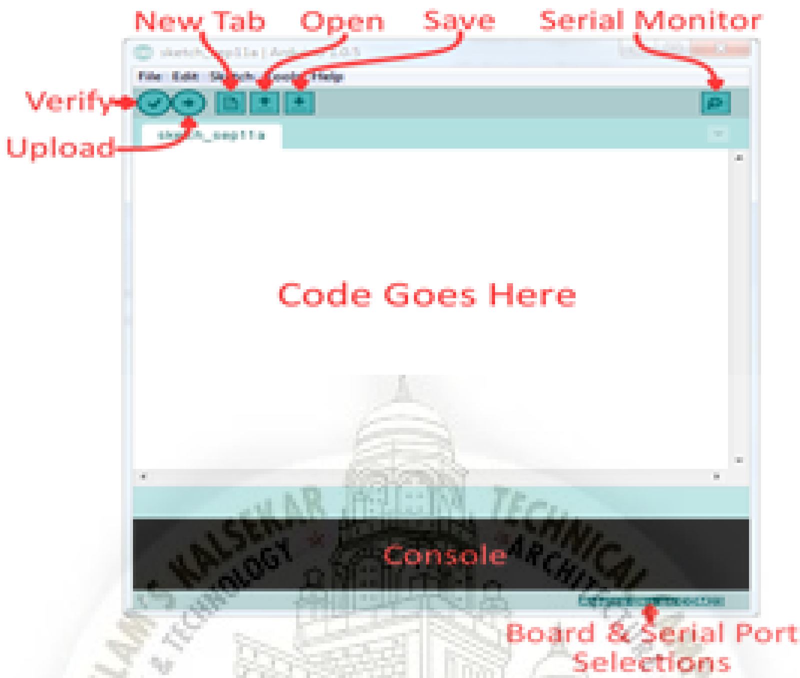


Figure 27: Arduino IDE.

An integrated development environment (IDE) is a software application that provides comprehensive facilities to computer programmers for software development. An IDE normally consists of a source code editor, build automation tools, and a debugger. Most modern IDEs have intelligent code completion. Some IDEs, such as NetBeans and Eclipse, contain a compiler, interpreter, or both; others, such as SharpDevelop and Lazarus, do not. The boundary between an integrated development environment and other parts of the broader software development environment is not well-defined. Sometimes a version control system, or various tools to simplify the construction of a Graphical User Interface (GUI), are integrated. Many modern IDEs also have a class browser, an object browser, and a class hierarchy diagram, for use in object-oriented software development.
The Arduino IDE is a multi-platform development platform for creating embedded programs that run on the many various Arduino microcontrollers. It is rather basic in its functionality when compared to many other modern IDEs. However, for small-scale hobbyist projects its relative lack of modern features, such as code auto-completion, is not an issue.
Deployment of the code to the microcontroller in the Arduino IDE is quite streamlined. One just needs to attach an USB cable to the to the USB port of the Arduino,

pick the right board model from the IDE and upload the code. The entire Arduino IDE with its many utility libraries is actually just a user-friendly wrapper around the AVR-GCC compiler, which handles compiling the source code to a format that the Arduinos on-board ATmega can understand. After the code has been checked for errors and compiled into binary, another utility program by the name of AVRDUDE (short for AVR Downloader/UploaDEr) handles the uploading and saving of the program to the Arduino itself. Many advanced users choose to bypass relative unwieldiness of the Arduino IDE by using their preferred text editor/IDE, and just use the AVR-GCC and AVRDUDE as stand-alone programs.
The Arduino project provides the Arduino integrated development environment (IDE), which is a cross-platform application written in the programming language Java. It originated from the IDE for the languages Processing and Wiring. It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching, and syntax highlighting, and provides simple one-click mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus.

A program written with the IDE for Arduino is called a sketch.[5] Sketches are saved on the development computer as text files with the file extension .ino. Arduino Software (IDE) pre-1.0 saved sketches with the extension .pde.
The Arduino IDE supports the languages C and C++ using special rules of code structuring. The Arduino IDE supplies a software library from the Wiring project, which provides many common input and output procedures. User-written code only requires two basic functions, for starting the sketch and the main program loop, that are compiled and linked with a program stub main() into an executable cyclic executive program with the GNU toolchain, also included with the IDE distribution. The Arduino IDE employs the program avrdude to convert the executable code into a text file in hexadecimal encoding that is loaded into the Arduino board by a loader program in the board's firmware.
The open-source nature of the Arduino project has facilitated the publication of many free software libraries that other developers use to augment their projects.

7.3 Sensors

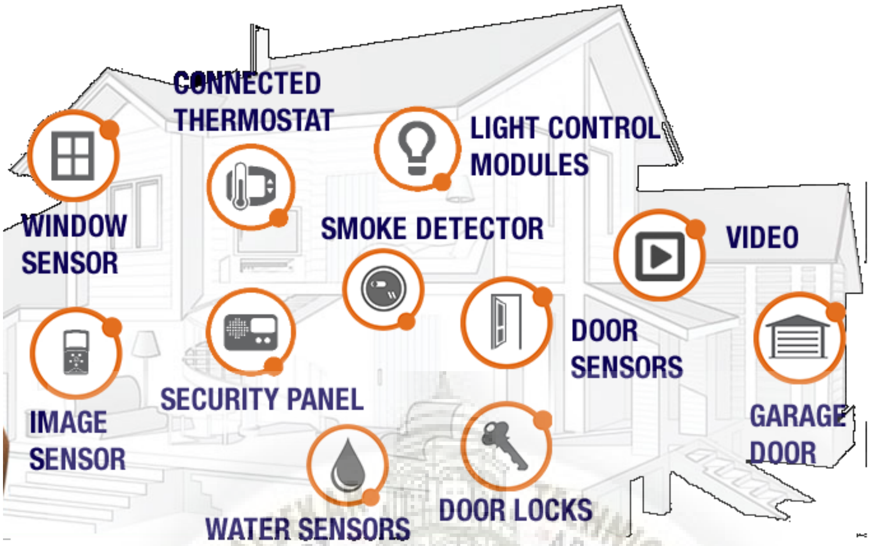


Figure 28: Sensors used for Automation

A sensor is defined as a device, module, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics, whether as simple as a light or as complex as a computer. A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes.

The sensors used most frequently in automation technology are those with digital outputs as they are much more immune to interference than those with analogue outputs. Digital controllers can also use the signals from these sensors directly without first having to convert them into digital signals by means of so-called analogue-digital converters as is the case with analogue signals.

7.4 Actuators

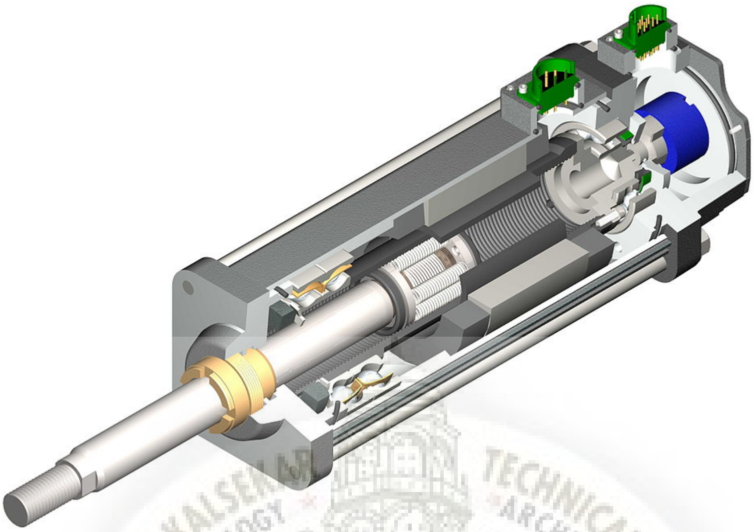


Figure 29: Actuators used in an Automated infrastructure

An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover".

An actuator requires a control signal and a source of energy. The control signal is relatively low energy and may be electric voltage or current, pneumatic or hydraulic pressure, or even human power. Its main energy source may be an electric current, hydraulic fluid pressure, or pneumatic pressure. When it receives a control signal, an actuator responds by converting the signal's energy into mechanical motion.

An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.

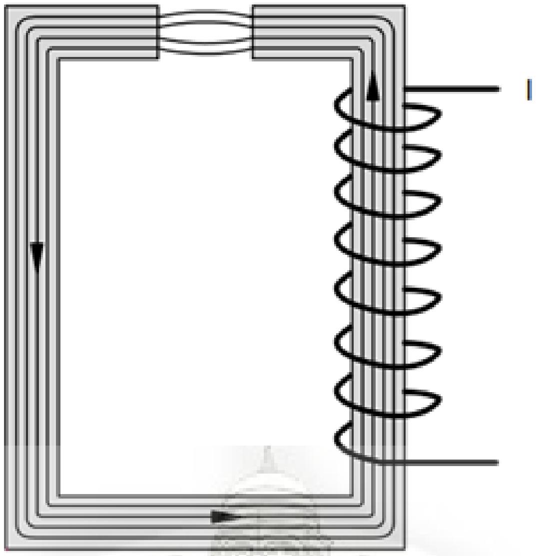


Figure 30: Coil with iron core and air gap

The current-carrying conductor is wound in the shape of a coil (air-cored coil). The overlaying of the magnetic field lines of all the coil windings (see Figure) amplifies the magnetic field. An iron core is placed in the coil. When an electric current flows, the iron is additionally magnetized. This enables a much stronger magnetic field to be generated at the same current intensity than with an air-cored coil.

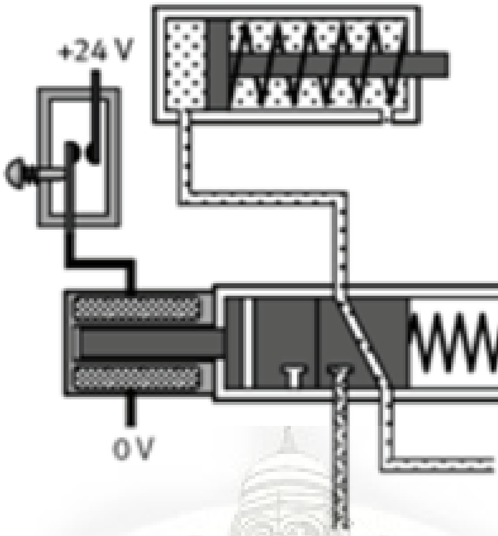


Figure 31: How a solenoid valve works

In electro pneumatic control systems, solenoids are primarily used to influence the switching position of valves, relays or contactors. To explain how this happens, we will use the example of a spring-return directional control valve:
When an electric current flows through the solenoid coil, the valve piston is actuated.
When the current flow is interrupted, a spring pushes the valve piston back into its initial position.

7.5 Switches

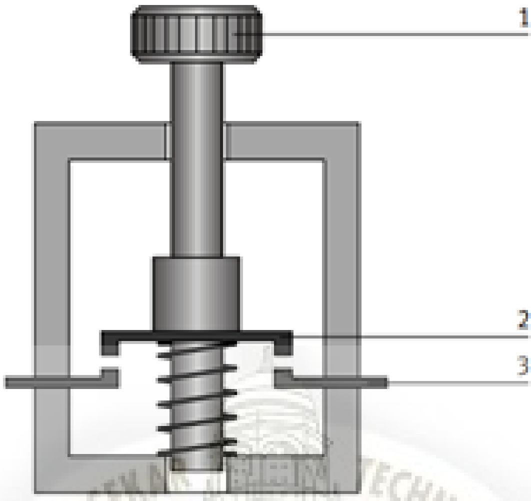


Figure 32: Sectional view for an N/O contact

Switches are used to facilitate or to interrupt a current flow in an electrical circuit. Depending on their design, these switches can either be pushbuttons or detenting switches.
In the case of a pushbutton, the chosen switching position is only maintained for as long as the pushbutton is actuated. Pushbuttons are used in doorbells, for example.
In the case of a detenting switch, both switching positions (ON/OFF) are mechanically latched. Each switching position is maintained until the switch is actuated again. Light switches in houses are an example of a latching switch in use.

7.6 Relays

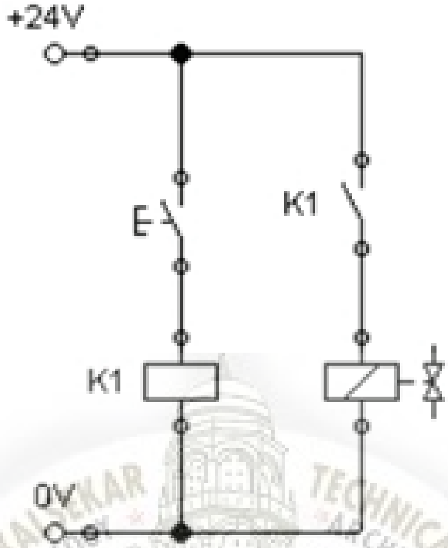


Figure 33: Circuit diagram for a basic relay circuit

Relays are used in electro pneumatic control systems to:
multiply signals, delay and convert signals, link information, separate the control and main circuits. They are also used in purely electrical control systems to separate the DC and AC circuits.

7.7 Security and Automation intersect

Automation is very closely intertwined with security, and the increasing integration of these two achieves a greater level of automation adoption.

On their own, standalone home automation and security systems are not that consumer friendly due to their cost and complexity; but it becomes more seamless and affordable for the consumer to acquire when the automation functionality is integrated in an overall security package.

The intersect of these technologies results in a dynamic system that lets us live safely, conveniently and most importantly affordably.

7.8 Automation Capabilities

Lets take a look at what we can achieve with a simple Home Automation system example. Although there are plenty of opportunities available with home automation, the best way to implementation is to figure out your unique needs and come up with the best plan and sensor layout for your home.

7.8.1 Lighting and Air Conditioning

Figure 34: Automated Lighting system

Timer based lighting is the simplest way to go; setting up the lighting system so that it turns on and off automatically according to the time you leave the house or enter it. You can also step it up by making a remote access system so that the lighting and air conditioning can be controlled remotely using your smart phone so you never leave your light ON when you leave or you can be welcomed to your home with your lights ON when you return.

7.8.2 Security and Locks

Figure 35: Automated security system

Set up an alarm system and remotely log in to arm or disarm it when you leave or enter, trigger an automatic email or text message alert if any sensors are tripped or remotely control the security cameras to adjust views and record, etc.
Receive security reminders straight to your mobile device if you travel beyond a predefined distance, but didnt lock your doors. Lock them remotely. Use your smartphone to unlock doors to let a caretaker, or an un expected visitor into the home.
All these prospects will be discussed in details in the upcoming chapters when we discuss the process of designing a complete system.

Module 3

System Architecture

Chapter 8

8 Photovoltaic System Architecture

In this chapter we take a look at the different types of PV systems and all hardware components that are required in order to implement such a system in the real world. Until now, we have studied the basic principles and fundamentals of generating electricity using solar energy. However, we have yet to discuss the design and implementation for real world scenarios; for that we must learn about all the different components involved in successfully setting up a solar power system.

First lets take a look at the different types of systems that can be implemented using todays technology.

8.1 Types of Photovoltaic Systems

Photovoltaic Systems are differentiated based on the components they use and also on their principle of operation. PV systems can be designed to provide DC and/or AC power supply, can operate interconnected with or independent of the power grid, and can be connected with other energy sources and energy storage systems. Keeping these things in mind, Photovoltaic System can be broadly classified as: Grid-connected Photovoltaic System and Stand-alone Photovoltaic System.

8.1.1 Grid-connected Photovoltaic System

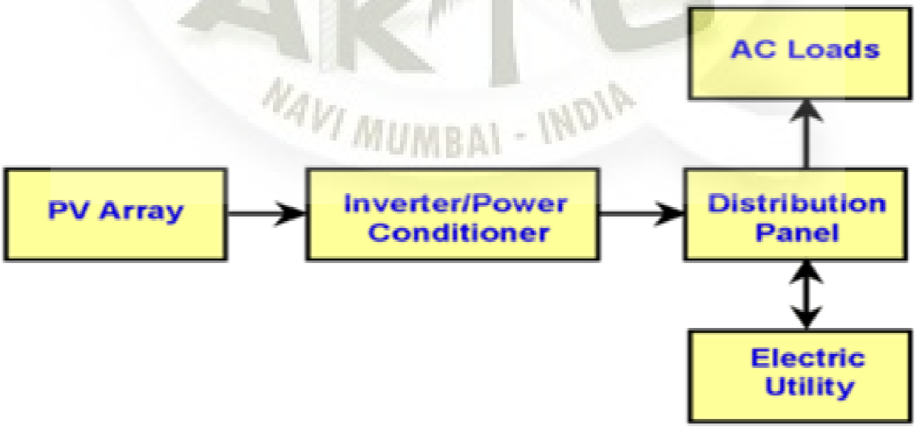


Figure 36: Diagram of grid-connected photovoltaic system.

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in this type of PV system is the inverter or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid. A bi-directional meter is used between the PV system AC output circuit and the grid via a distribution panel. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back-feed the grid when the PV system output is greater than the on-site load demand.

8.1.2 Stand-alone Photovoltaic System

Stand-alone PV systems are designed to operate independent of the electric grid, and can be designed to supply DC or AC power to the load directly. As these systems are not connected to the grid, the use of energy storage is required; for this, batteries are used. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing PV system; for this reason, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT) charge controller is used between supply and load.

In order to supply power to a DC load there is no need of an inverter, fig.35.

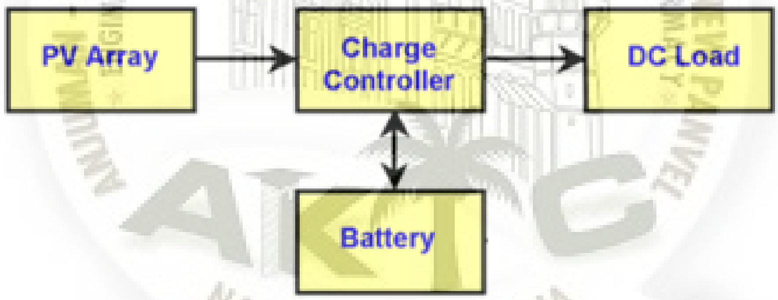


Figure 37: Standalone PV system for DC load.

To provide power to an AC load there is a need of an inverter as the panel output is in DC, fig.36.

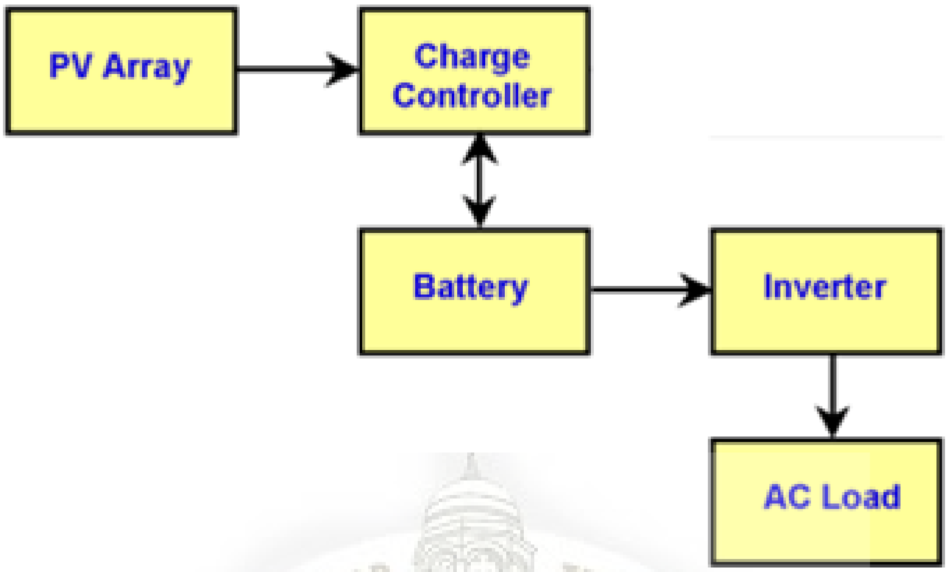


Figure 38: Standalone PV system for AC load.

8.2 Components of a PV system

Lets talk about the various components involved in setting up a PV system. We will look upon the most important ones without which a PV system cannot be implemented. There are a number of auxiliary components that add certain benefits to the setup but we will stick to the utmost important ones for a basic working setup. Irrespective of the type of system, it is crucial to learn about the following components:

8.2.1 Solar Panels

Figure 39: Monocrystalline panel.

Solar panel are manufactured by connecting solar cells in a combination of parallel and series connections, according to its output power requirement. Solar cells or PV modules deliver time varying output of electricity which is calculated by the angle and the intensity of solar radiation. Mainly there are three different types of PV modules or solar cells. Mono-crystalline silicon solar cells, polycrystalline silicon solar cells and thin-film solar cells. The mono-crystalline solar cells are produced out of high quality silicon ingots. They are easily distinguished from the other types by their dark blue colour and their shape which is tapered or rounded from all 4 edges. They provide the highest competence or efficiency of about 15% - 20%.

While the poly-crystalline cells have a lighter shade of blue colour than the mono-crystalline one and cut in a proper rectangle shape. Their efficiency is about 13%-15%. In thin-film solar cells a thin layer of PV material is placed substrate. Efficiency of these cells ranges from 7% to 13%. Different types of thin-film soar cells are, Amorphous silicon (a-Si) PV cells, Cadmium telluride (CdTe) PV cells and organic PV cells (OPC).

8.2.2 MPPT charge controller

Figure 40: Mppt Charge Controller.

Works on Maximum Power Point tracking algorithm which is used in DC to DC converter or so-called charge controller. By this algorithm, maximum available power based on I-V graph and P-V graph is drawn from the solar panels to charge the batteries in the most efficient way. The peak power voltage or maximum power fluctuates along with the changes in solar radiation and temperature. The MPPT charge controller converts the DC input from PV into AC and then it converts it back to DC but with stable voltage and current which is required by the battery, with the help of MPPT algorithm. An MPPT charge Controller provides at least 30% more efficiency in contrast with the PWM charge controller.

8.2.3 Batteries

Figure 41: Battery output.

There are different types of batteries Like Lithium-Ion, lead acid, tubular etc. Out of these Lithium-ion are the most expensive ones and they are mostly made on demand. Lead acid Batteries have good DOD and they are deep cycle batteries. They are readily available in different ratings. Although they have some disadvantages over lead-acid batteries, Tubular batteries can also be used as a replacement of lead acid batteries.

8.2.4 DC-AC inverter

Figure 42: DC-AC inverter.

In AC solar power system, the battery which stores DC provides AC to the load through a DC to AC inverter. These inverters consist of two stage converters. In the first stage, dc to dc converter, bucks or boosts the output and conditions the low voltage and fluctuating solar panel output, In the second stage the inverter inverts this Direct Current to a high-quality Alternating Current by producing pure sine wave as an output. To ensure there is no DC component in AC output, both the positive and the negative half cycles must be in symmetry. symmetrical operation obtained by buck boost principle provides two half cycles of the AC output.

Chapter 9

9 Automation System Architecture

In this chapter we take a look at the different types of Automation systems and all hardware components that are required in order to implement such a system in the real world. Until now, we have studied the basic principles and fundamentals of an Automated Infrastructure. However, we have yet to discuss the design and implementation for real world scenarios; for that we must learn about all the different components involved in successfully setting up an Automation system.

First lets take a look at the different types of systems that can be implemented using todays technology.

9.1 Types of Automation Systems

Automation Systems are differentiated based on the components they use and also on their principle of operation. For the scope of this book we define two types of Automation system: Offline/Locally operated and Online/Remotely operated Automation System.

9.1.1 Offline/Lan based Automation

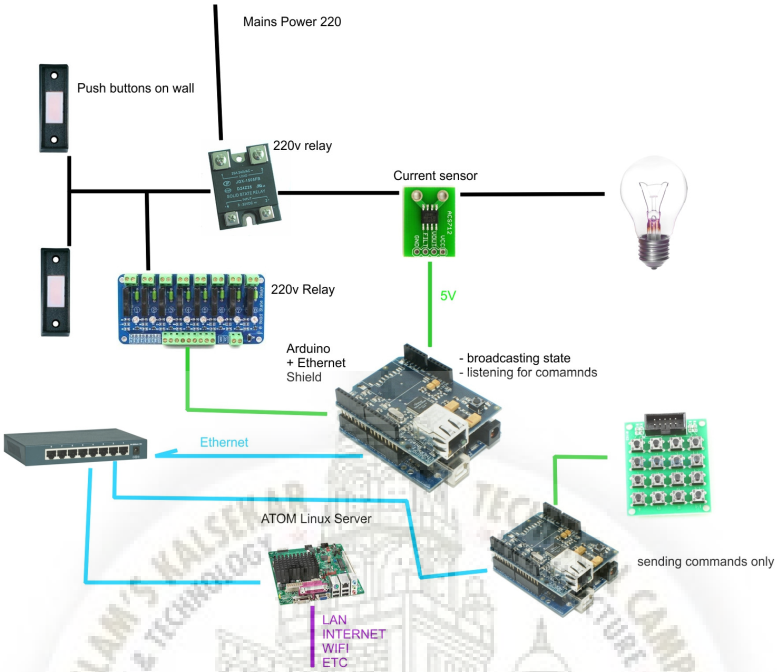


Figure 43: Offline/Lan based Automation

As the name suggests, this type of system is designed to provide automation solution to a closed local network of devices. In order to use or configure this system, one needs to be a part of the same local network. These systems permit automation and access control only in a Closed Connection or Local Area Network (LAN). It may consist of devices that have some sort of local processing ability. Some successful models of this type of system are: LAN based (Ethernet/Wi-Fi) systems in which the server and the client are enclosed in a local network.

Or Bluetooth Based Systems which makes use of a cell phone and Bluetooth technology. Bluetooth works at a speed of 3Mbps and has a range of 10 to 100 meters, it also has a bandwidth of 2.4GHz[4].
Another option to consider is a ZigBee Based System.

9.1.2 Online/IoT based Automation

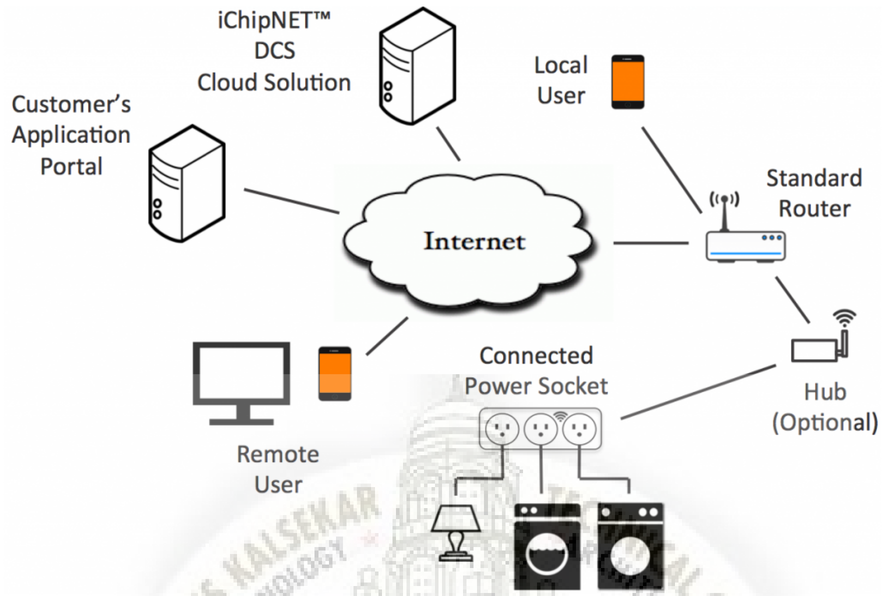


Figure 44: Online/IoT based Automation

These systems allow for us to attain remote access over our infrastructure. This may include models such as GSM based automation where GSM would be used as a communication medium to help establish connection. AT Commands are used by the server to communicate with the GSM modem. The system can also be controlled using SMS. Another model to consider for a remotely operable system would be the Iot model. Here the Internet is used as a communication medium and establish connection possibly from anywhere over the world. IoT allows objects to be sensed or controlled remotely across existing network infrastructure.

9.2 Components of an Automation System

Lets take a look at the various components required so implement an Automation system. The components discussed in this topic are the basic requirements of any automation system without which such a system cannot be implemented today. There are also many other possible ways to set up such a system and many other components that may be integrated into it, but as discussed earlier for the scope of this book we will consider offline/lan-based and online/iot-based home automation system. Keeping that in mind, these are the following components that we need to understand about.

9.2.1 User Interface/Command Console

A device that has enough processing power to display a GUI. This is the device that will provide the User Interface to attain control over the system. It is important to have a simple and easy to use graphical interface for smooth working of the system. This includes devices such as mobile phones, laptop/PCs, tablets, etc.

Android

Figure 45: Android OS

Android is a very popular Linux-based operating system, specifically tailored for smartphones and tablets. It is estimated there are currently over one billion devices running Android in the world (Android.com, 2015). Besides tablets and phones, Android is also found in TVs, wrist watches and cards, for instance. Being based on the Linux kernel, Android is open-source technology. Android was originally developed by Android Inc., however the company was acquired by Google in 2005, who is the current maintainer of Android. Even though Android is technically an open source technology, most manufacturers include at least some closed-source proprietary drivers, depending on the model. This has the unwanted side-effect of many Android devices being difficult to update, as Google cannot simply release a new version of the operating system. Because of this, Android has been criticized for having a lot of fragmentation with regards to its many different versions. This makes it difficult for Android developers, as they may have to develop for many wildly differing versions of Android.

Android App

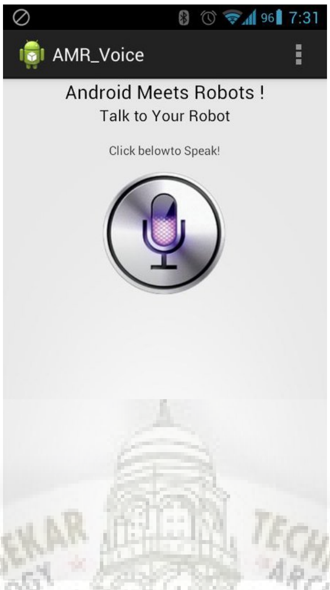


Figure 46: Android App

Uses android mobiles internal voice recognition to pass voice commands to your robot
Pairs with Bluetooth Serial Modules and sends in the recognized voice as a string for example if you say Hello the android phone will return a sting *Hello# to your bluetooth module *and # indicate the start and stop bits
Can Be used with any micro controller which can handle strings
Examples Platforms : Arduino , ARM , PICAXE , MSP430 , 8051 based and many other processors and controllers

9.2.2 Control Logic Device/Control interface

This device takes users request coming from the server and executes the specified task. Therefore, it must have enough processing power and the ability to interface with additional hardware components to perform operations such as switching the relays. As discussed earlier, our system will be based on the Arduino platform and will work with an Atmega 328 micro-controller.

Arduino

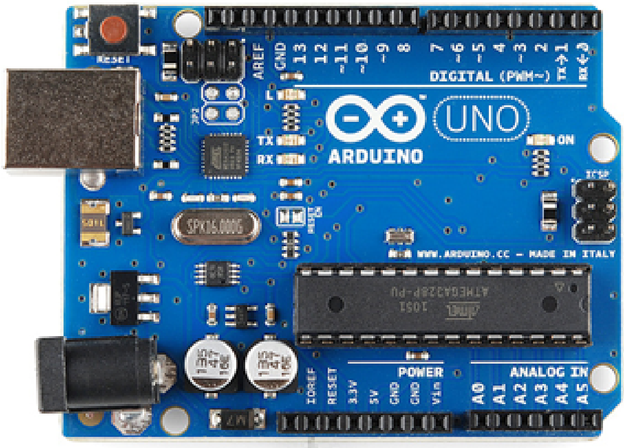


Figure 47: Arduino

Arduino is an open source computer hardware and software company, project, and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical and digital world. The project's products are distributed as open-source hardware and software, which are licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL),[1] permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are available commercially in preassembled form, or as do-it-yourself (DIY) kits.

Figure 48: A Video on Arduino

Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that

may be interfaced to various expansion boards or Breadboards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers. The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) based on the Processing language project.
The Arduino project started in 2003 as a program for students at the Interaction Design Institute Ivrea in Ivrea, Italy,[2] aiming to provide a low-cost and easy way for novices and professionals to create devices that interact with their environment using sensors and actuators. Common examples of such devices intended for beginner hobbyists include simple robots, thermostats, and motion detectors.
The name Arduino comes from a bar in Ivrea, Italy, where some of the founders of the project used to meet. The bar was named after Arduin of Ivrea, who was the margrave of the March of Ivrea and King of Italy from 1002 to 1014.[3]

Arduino is open-source hardware. The hardware reference designs are distributed under a Creative Commons Attribution Share-Alike 2.5 license and are available on the Arduino website. Layout and production files for some versions of the hardware are also available. The source code for the IDE is released under the GNU General Public License, version 2.[1] Nevertheless, an official Bill of Materials of Arduino boards has never been released by Arduino staff.
Although the hardware and software designs are freely available under copyleft licenses, the developers have requested the name Arduino to be exclusive to the official product and not be used for derived works without permission. The official policy document on use of the Arduino name emphasizes that the project is open to incorporating work by others into the official product.[2] Several Arduino-compatible products commercially released have avoided the project name by using various names ending in -duino.[3] Most Arduino boards consist of an Atmel 8-bit AVR microcontroller (ATmega8[2], ATmega168, ATmega328, ATmega1280, ATmega2560) with varying amounts of flash memory, pins, and features.[2] The 32-bit Arduino Due, based on the Atmel SAM3X8E was introduced in 2012.[2] The boards use single or double-row pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed shields. Multiple and possibly stacked shields may be individually addressable via an IC serial bus. Most boards include a 5 V linear regulator and a 16 MHz crystal oscillator or ceramic resonator. Some designs, such as the LilyPad, run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.
Arduino microcontrollers are pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory. The default bootloader of the Arduino UNO is the optiboot bootloader.[28] Boards are loaded with program code

via a serial connection to another computer. Some serial Arduino boards contain a level shifter circuit to convert between RS-232 logic levels and transistortransistor logic (TTL) level signals. Current Arduino boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Some boards, such as later-model Uno boards, substitute the FTDI chip with a separate AVR chip containing USB-to-serial firmware, which is reprogrammable via its own ICSP header. Other variants, such as the Arduino Mini and the unofficial Boarduino, use a detachable USB-to-serial adapter board or cable, Bluetooth or other methods. When used with traditional microcontroller tools, instead of the Arduino IDE, standard AVR in-system programming (ISP) programming is used.

Atmega328

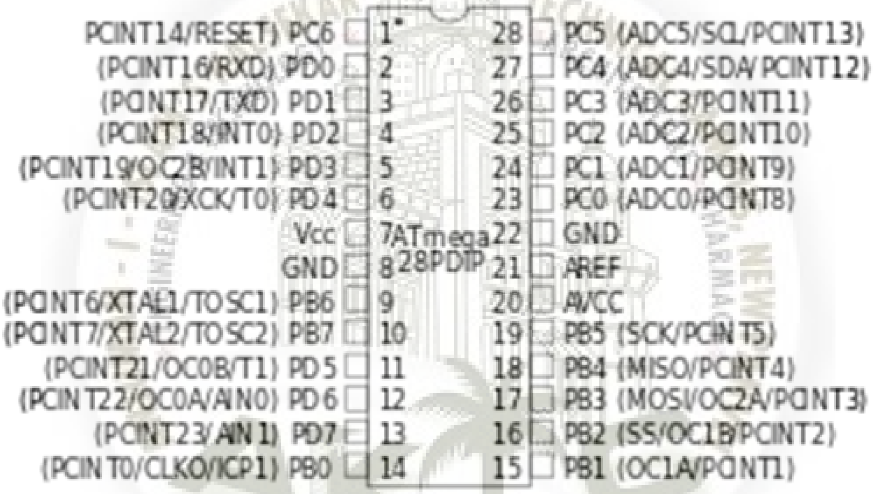


Figure 49: Atmega328

The ATmega328 is a single-chip microcontroller created by Atmel in the megaAVR family. The Atmel 8-bit AVR RISC-based microcontroller combines 32 kB ISP flash memory with read-while-write capabilities, 1 kB EEPROM, 2 kB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts. The device achieves throughput approaching 1 MIPS per MHz.[1]. As of 2013 the ATmega328 is commonly used in many projects and autonomous systems where a simple, low-powered, low-cost micro-controller is needed[citation needed]. Perhaps the most common implementation of this chip is on the popular Arduino development platform, namely the Arduino Uno and Arduino Nano models. Reliability qualification shows that the projected data retention failure rate is much less than 1 PPM over 20 years at 85 C or 100 years at 25 C.[4]

Features	ATmega328/P
Pin Count	28/32
Flash (Bytes)	32K
SRAM (Bytes)	2K
EEPROM (Bytes)	1K
General Purpose I/O Lines	23
SPI	2
TWI (I^2C)	1
USART	1
ADC	10-bit 15kSPS
ADC Channels	8
8-bit Timer/Counters	2
16-bit Timer/Counters	1

9.2.3 Data transmission Medium or Interconnectivity device

The user request data packets can be transferred through Wifi, Ethernet, Infrared, Radio, Bluetooth, etc. based on the type of system designed. There are a number of devices that can be interfaced to the Arduino that provide connectivity.

HC-05 Bluetooth Module

Figure 50: HC-05

HC05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. The HC-05 Bluetooth Module can be used in a Master or Slave configuration, making it a great solution for wireless communication. This serial port bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature).
The Bluetooth module HC-05 is a MASTER/SLAVE module. By default the factory setting is SLAVE. The Role of the module (Master or Slave) can be configured only by AT COMMANDS. The slave modules cannot initiate a connection to another Bluetooth device, but can accept connections. Master module can initiate a connection to other devices. The user can use it simply for a serial port replacement to establish connection between MCU and GPS, PC to your embedded project, etc.

Hardware Features

- Typical 80dBm sensitivity.
- Up to +4dBm RF transmit power
- 3.3 to 5 V I/O.
- PIO(Programmable Input/Output) control.
- UART interface with programmable baud rate.

- With integrated antenna.
- With edge connector.

Software Features

- Slave default Baud rate: 9600, Data bits:8, Stop bit:1,Parity:No parity.
- Autoconnect to the last device on power as default.
- Permit pairing device to connect as default.
- Autopairing PINCODE:1234 as default.

The HC-05 Bluetooth Module has 6pins. They are as follows:

ENABLE:

When enable is pulled LOW, the module is disabled which means the module will not turn on and it fails to communicate. When enable is left open or connected to 3.3V, the module is enabled i.e the module remains on and communication also takes place.

Vcc:

Supply Voltage 3.3V to 5V

GND:

Ground pin

TXD & RXD:

These two pins acts as an UART interface for communication

STATE:

It acts as a status indicator. When the module is not connected to / paired with any other bluetooth device, signal goes Low. At this low state, the led flashes continuously which denotes that the module is not paired with other device. When this module is connected to/paired with any other bluetooth device, the signal goes High. At this high state, the led blinks with a constant delay say for example 2s delay which indicates that the module is paired.

BUTTON SWITCH:

This is used to switch the module into AT command mode. To enable AT command mode, press the button switch for a second. With the help of AT commands, the user can change the parameters of this module but only when the module is not paired with any other BT device. If the module is connected to any other bluetooth device, it starts to communicate with that device and fails to work in AT command mode.

Module 4

Implementation of Scenarios

Chapter 10

10 PV system design

In this chapter we will understand different combinations of solar power system and Home Automation system. Until now we have seen what to use in these systems, now we will see how to use these technologies in the best possible manner. We will see the basic steps of how to do a simulation for designing a solar power system. And we will discuss about the difference between AC and DC solar power systems along with offline and online home automation system.

10.1 Basics steps for PV system design and simulation

These are the few easy and basic steps to learn how to do a simple simulation for Solar power system
MindMap Here

10.2 Grid-Tied or On Grid AC solar power system

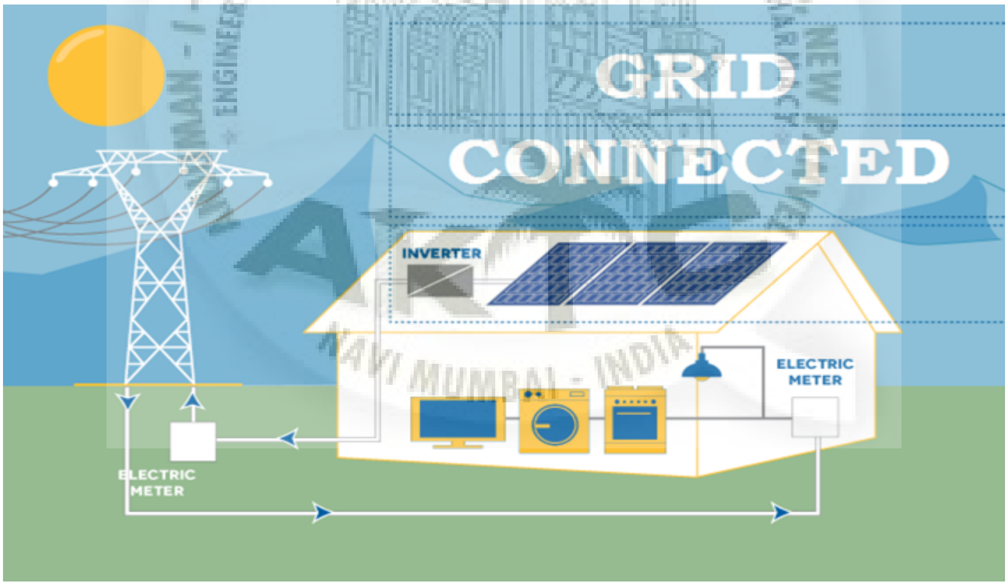


Figure 51: On Grid AC solar power system

The grid tied, or On-Grid AC solar power system is the most convenient and its components are readily available in urban areas. The AC grid tied solar power system has some advantages for the urban and industrial sectors over the DC stand-alone system.AC solar power system basically means a solar power system through which AC appliances are used. And Grid-Tied system means the appliances can run on both power sources solar as well as grid electricity.

10.3 Off Grid or Stand-alone DC solar power system

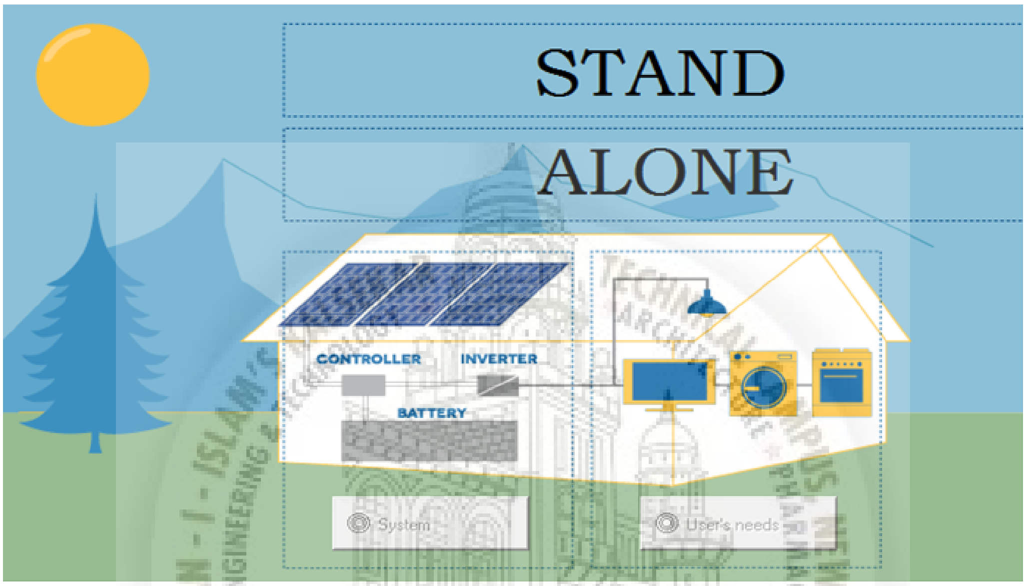


Figure 52: Off Grid or Stand-alone DC solar power system

The Off Grid or Stand-alone DC solar power system is the most suitable for rural areas. The Off Grid or Stand-alone DC solar power system has some advantages for remote rural areas where Grid Electricity is barely available or completely not available. Solar power system basically means a solar power system through which DC appliances are used. And OFF-Grid system means the appliances will have only one power source that is solar panels.

10.4 Example: Size determination of Solar Power System

P = V x I
1bulb = 12Wh power
Total running load = 10 bulb x 12Wh =120Wh
Battery Capacity for day = Load in (kWh) X number of operational hours of appliance.

Batterie capacity for day = 120Wh x 6hrs = 720W
Using Full charge batterie capacity 2592
And we use a 320W solar panel or 4 x 80watt panels.
Two sets of two 12V panels are connected in series to obtain 24V. Arrange these two sets in parallel to obtain 24V and 320W solar power output.
Present tub light is 36W,
Total running load per hrs = 36W x 8 tub light = 288W
Running for day = 288W x 6 = 1,728W
From above calculation the main system takes 1,008W more energy as compare to ac solar system.

Chapter 11

11 Automation system design

11.1 Offline Home Automation system

Figure 53: Lan Based Automation Web Page

The Offline home automation system basically works without internet connection. It works on a LAN based offline network, in which there is host server which hosts an HTML control page. This system is more suitable for areas where internet is not readily available. The first step is to develop a simple web page which contains the buttons to send switching signals.
Now to host our webpage onto our server we embed our html code into the Arduino's native code. Finally, we write some functions to read the string received via the URL FRAGMENT and control the pin status accordingly.

11.2 Online Home Automation system

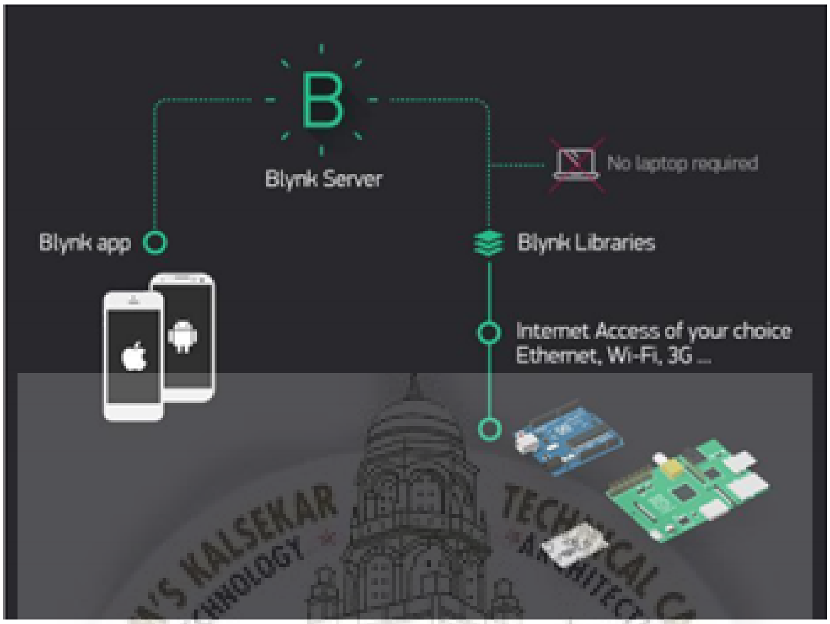


Figure 54: IoT Based Automation Web Page

The Online home automation system basically works with internet connection. To best implement the proposed system, there are a lot of options regarding the different technologies that can be used to obtain the desired result. In this research we opt for the most stable and easily implementable approach for our system which includes: Arduino, Ethernet shield, Blynk app.
The command console is the mobile phone which has a Blynk app running connected to the Blynk Server, The Control Logic
Device in this case an Arduino coupled with an Ethernet Shield is connected to the relays which control the Appliances. The Arduino is running The Blynk libraries which enable it to connect to the Blynk Server.

Chapter 12

12 Simulations

In this chapter we will do multiple simulations for different scenarios for solar power system on the software named PVSyst. Both types of solar power systems (AC and DC) along with both types of Automation systems (Online and Offline) will be discussed.

Here we will take 3 scenarios for better understanding and will perform 2 simulations for every scenario.
1) A collage Laboratory
2) A basic Urban house hold
3) A small rural house

Note: In the simulation Report we must see the tilt of solar panels, battery requirement, solar panel requirement, average daily power consumption, yearly power consumption, nominal power production from graph and detailed losses.

Figure 55: A Video On PVSyst

12.1 Simulation report for Collage Laboratory with AC solar power system

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Grid Connected: Simulation parameters

Project :	**Solar AC LAb**			
Geographical Site	**Mumbai**		Country	**India**
Situation	Latitude	19.12° N	Longitude	72.85° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	18 m
	Albedo	0.20		
Meteo data:	**Mumbai**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**New simulation variant**	
	Simulation date	14/02/18 10h00

Simulation parameters				
Collector Plane Orientation	Tilt	23°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics				
PV module Si-poly	Model	**LNSP-150**		
Original PVsyst database	Manufacturer	Linuo		
Number of PV modules	In series	1 modules	In parallel	12 strings
Total number of PV modules	Nb. modules	12	Unit Nom. Power	150 Wp
Array global power	Nominal (STC)	**1800 Wp**	At operating cond.	1628 Wp (50°C)
Array operating characteristics (50°C)	U mpp	30 V	I mpp	55 A
Total area	Module area	**15.5 m²**		
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	9.3 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	2.1 % at STC
Module Quality Loss			Loss Fraction	5.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter	System type	**Grid Connected**		
Battery	Model	**12-CS-11PS**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Voltage	24 V	Nominal Capacity	1776 Ah
	Nb. of units	2 in series x 6 in parallel		
	Temperature	Fixed (20°C)		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	26.6 / 25.1 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	23.5 / 24.4 V
User's needs :	Daily household consumers	Constant over the year		
	average	6.8 kWh/Day		

PVsyst Evaluation mode

Figure 56: Grid Connected Lab Simulation Parameters

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Gird Connected : Detailed User's needs

Project : **Solar AC LAb**

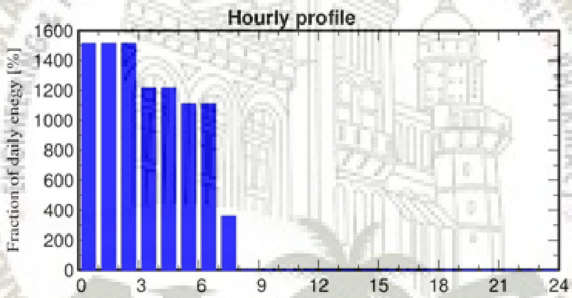
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	LNSP-150	Pnom	150 Wp
PV Array	Nb. of modules	12	Pnom total	**1800 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**24 V / 1776 Ah**
User's needs	Daily household consumers	Constant over the year	global	2494 kWh/year

Daily household consumers, Constant over the year, average = 6.8 kWh/day

Annual values

Use 5 days a week	Number	Power	Use	Energy
Tube light	10	36 W/lamp	8 h/day	2880 Wh/day
Fan	10	75 W/app	7 h/day	5250 Wh/day
PC	1	105 W/app	5 h/day	525 Wh/day
Projector	1	300 W tot	3 h/day	900 Wh/day
Total daily energy				9555 Wh/day



PVsyst Evaluation mode

Figure 57: Grid Connected Lab Detailed User's need

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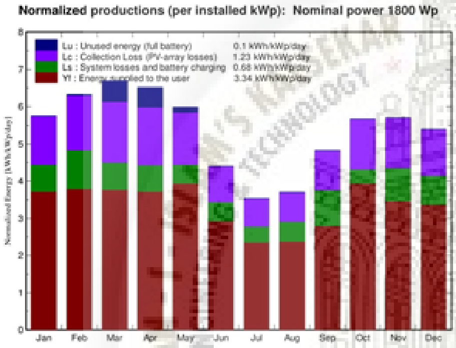
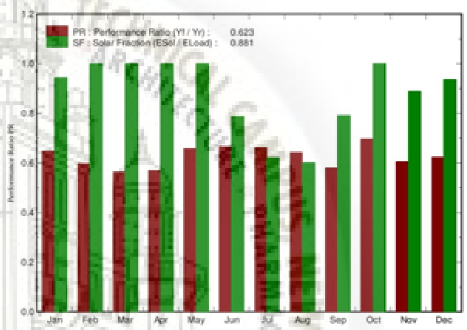
Grid Connected : Main results

Project : **Solar AC LAb**
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	LNSP-150	Pnom	150 Wp
PV Array	Nb. of modules	12	Pnom total	**1800 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**24 V / 1776 Ah**
User's needs	Daily household consumers	Constant over the year	global	2494 kWh/year

Main simulation results				
System Production	**Available Energy**	**2548 kWh/year**	Specific prod.	1415 kWh/kWp/year
	Used Energy	2196 kWh/year	Excess (unused)	69 kWh/year
	Performance Ratio PR	62.33 %	Solar Fraction SF	88.07 %
Loss of Load	Time Fraction	14.5 %	Missing Energy	297 kWh/year





New simulation variant
Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	173.6	232.266	0.04	12.408	207.4	219.8	0.944
February	151.2	173.0	229.124	1.43	0.000	191.1	191.1	1.000
March	191.9	201.9	266.256	31.16	0.000	210.2	210.2	1.000
April	198.0	189.8	252.544	28.41	0.000	200.7	200.7	1.000
May	201.6	179.5	240.252	7.59	0.000	219.8	219.8	1.000
June	146.0	127.1	174.392	0.01	42.489	158.2	200.7	0.788
July	119.0	105.5	146.494	0.03	79.153	131.1	210.2	0.623
August	120.9	110.3	153.047	0.02	87.428	132.3	219.8	0.602
September	141.1	140.0	190.419	0.00	40.033	151.1	191.1	0.791
October	157.0	170.4	225.636	0.00	0.000	219.8	219.8	1.000
November	138.9	166.5	220.289	0.00	23.361	186.8	210.2	0.889
December	131.7	163.3	217.035	0.02	12.531	188.1	200.7	0.938
Year	1839.4	1900.8	2547.756	68.71	297.403	2196.5	2493.9	0.881

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 58: Grid Connected Lab Main Results

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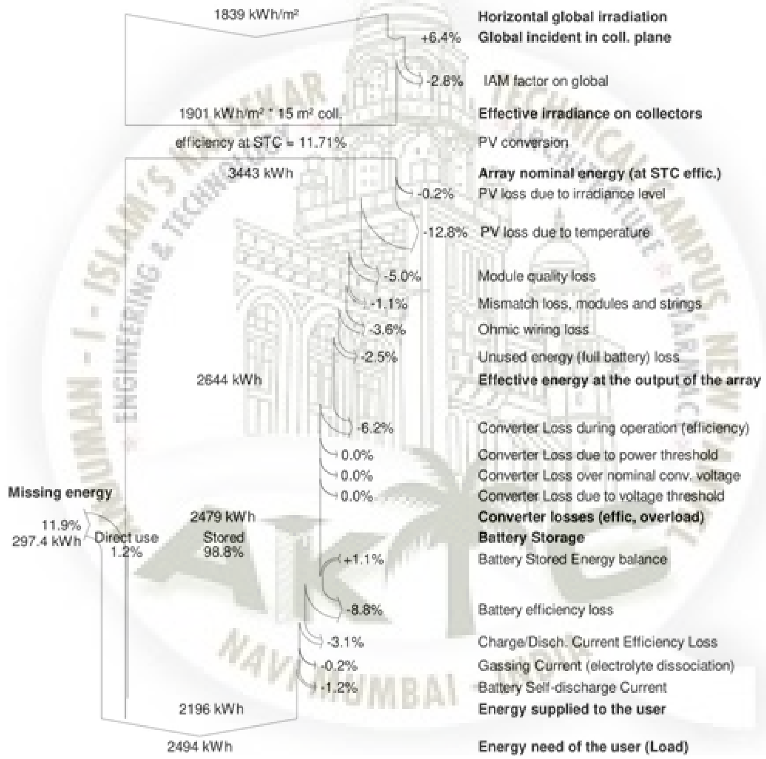
Grid Connected : Loss diagram

Project : **Solar AC LAb**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	LNSP-150	Pnom	150 Wp
PV Array	Nb. of modules	12	Pnom total	**1800 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**24 V / 1776 Ah**
User's needs	Daily household consumers	Constant over the year	global	2494 kWh/year

Loss diagram over the whole year



PVsyst Evaluation mode

Figure 59: Grid Connected Lab Loss Diagram

12.2 Simulation report for Collage Laboratory with DC solar power system

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Stand Alone System: Simulation parameters

Project :	**Solar Lab DC**				
Geographical Site		**Mumbai**		Country	**India**
Situation		Latitude	19.12° N	Longitude	72.85° E
Time defined as		Legal Time	Time zone UT+5.5	Altitude	18 m
		Albedo	0.20		
Meteo data:		**Mumbai**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**New simulation variant**				
		Simulation date	14/02/18 10h38		

Simulation parameters					
Collector Plane Orientation		Tilt	24°	Azimuth	0°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics					
PV module	Si-mono	Model	**ZT 80S**		
Original PVsyst database		Manufacturer	Zytech		
Number of PV modules		In series	2 modules	In parallel	3 strings
Total number of PV modules		Nb. modules	6	Unit Nom. Power	80 Wp
Array global power		Nominal (STC)	**480 Wp**	At operating cond.	435 Wp (50°C)
Array operating characteristics (50°C)		U mpp	31 V	I mpp	14 A
Total area		Module area	**3.9 m²**	Cell area	3.3 m²
PV Array loss factors					
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	38 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss		Voltage Drop	0.7 V	Loss Fraction	2.0 % at STC
Module Quality Loss				Loss Fraction	2.5 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter		System type	**Stand Alone System**		
Battery		Model	**12-CS-11PS**		
		Manufacturer	Rolls		
Battery Pack Characteristics		Voltage	24 V	Nominal Capacity	592 Ah
		Nb. of units	2 in series x 2 in parallel		
		Temperature	Fixed (20°C)		
Controller		Model	Universal controller with MPPT converter		
		Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter		Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control		Treshold commands as	SOC calculation		
		Charging	SOC = 0.90 / 0.75	i.e. approx.	26.5 / 25.1 V
		Discharging	SOC = 0.20 / 0.45	i.e. approx.	23.5 / 24.4 V
User's needs :		Daily household consumers	Constant over the year		
		average	1.9 kWh/Day		

PVsyst Evaluation mode

Figure 60: Stand Alone Lab Simulation Parameters

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Stand Alone System: Detailed User's needs

Project : **Solar Lab DC**

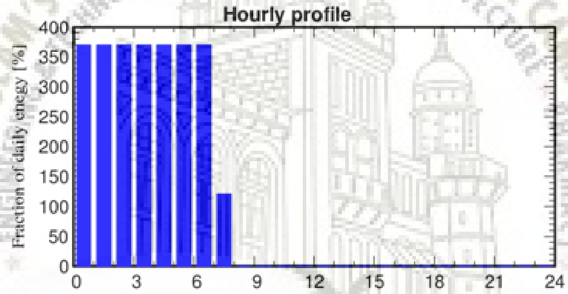
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	ZT 80S	Pnom	80 Wp
PV Array	Nb. of modules	6	Pnom total	**480 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	707 kWh/year

Daily household consumers, Constant over the year, average = 1.9 kWh/day

Annual values

Use 5 days a week	Number	Power	Use	Energy
DC LED Bulb	10	12 W/lamp	8 h/day	960 Wh/day
DC Fan	10	25 W/app	7 h/day	1750 Wh/day
Total daily energy				2710 Wh/day



PVsyst Evaluation mode

Figure 61: Stand Alone Lab Detailed User's need

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Stand Alone System: Main results

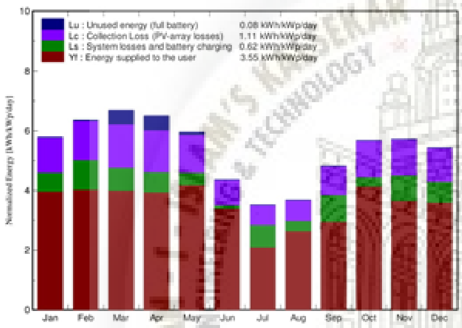
Project : **Solar Lab DC**

Simulation variant : **New simulation variant**

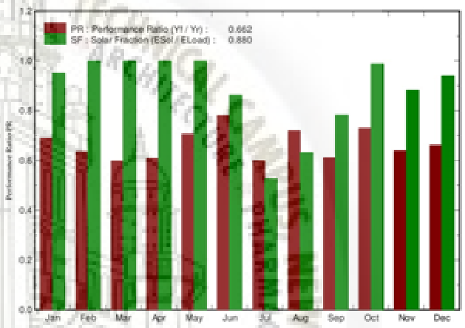
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	ZT 80S	Pnom	80 Wp
PV Array	Nb. of modules	6	Pnom total	**480 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	707 kWh/year

Main simulation results				
System Production	**Available Energy**	**707.2 kWh/year**	Specific prod.	1473 kWh/kWp/year
	Used Energy	622.3 kWh/year	Excess (unused)	14.9 kWh/year
	Performance Ratio PR	66.23 %	Solar Fraction SF	87.98 %
Loss of Load	Time Fraction	17.0 %	Missing Energy	85.0 kWh/year

Normalized productions (per installed kWp): Nominal power 480 Wp



Performance Ratio PR and Solar Fraction SF



New simulation variant

Balances and main results

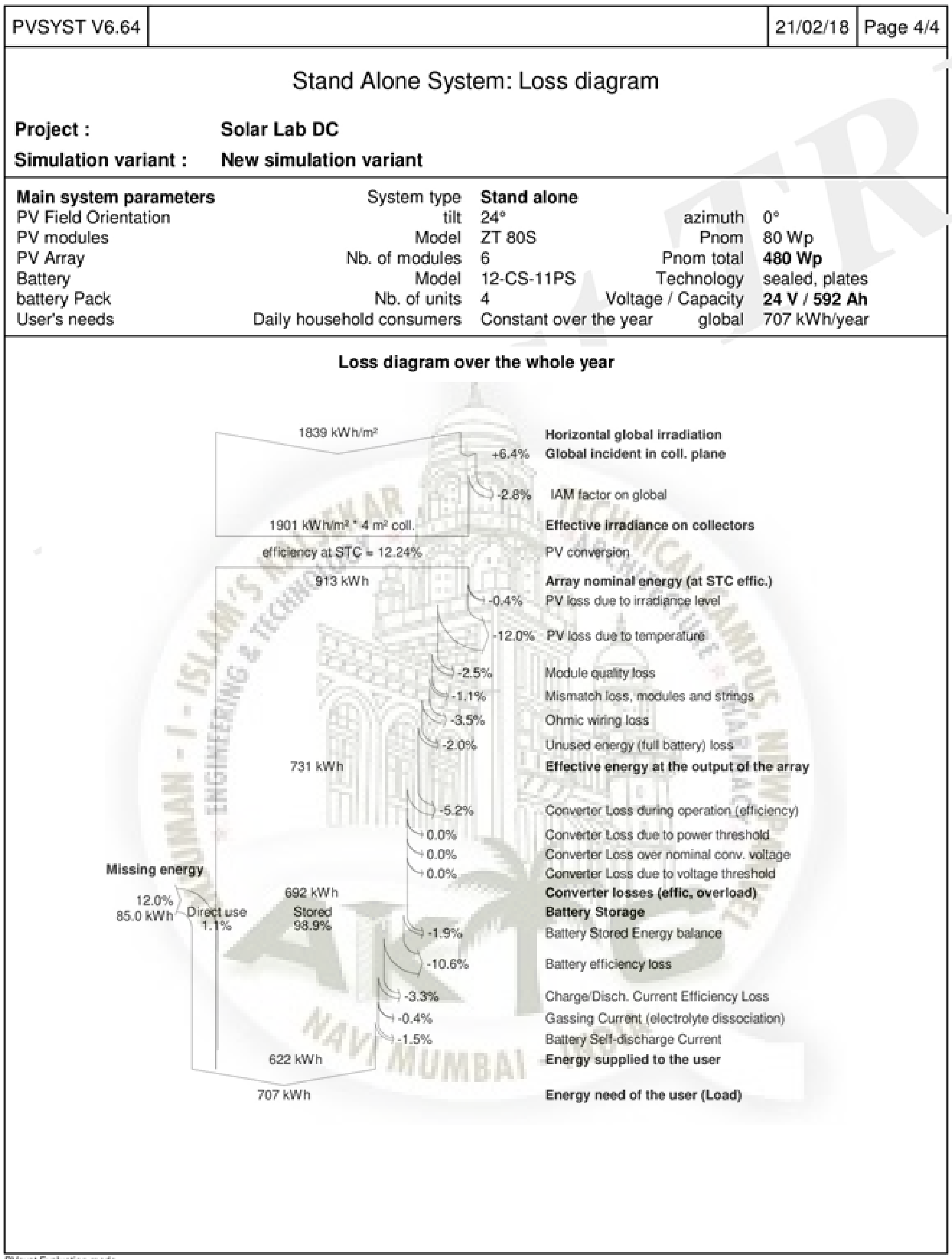
	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	174.7	65.127	0.024	3.056	59.27	62.33	0.951
February	151.2	173.6	64.165	0.015	0.000	54.20	54.20	1.000
March	191.9	202.0	74.123	6.717	0.000	59.62	59.62	1.000
April	198.0	189.1	70.012	6.818	0.000	56.91	56.91	1.000
May	201.6	178.3	66.326	1.257	0.000	62.33	62.33	1.000
June	146.0	126.2	47.772	0.003	7.822	49.09	56.91	0.863
July	119.0	104.8	39.851	0.012	28.206	31.41	59.62	0.527
August	120.9	109.7	41.823	0.012	22.992	39.34	62.33	0.631
September	141.1	139.8	52.684	0.000	11.742	42.46	54.20	0.783
October	157.0	170.8	62.925	0.000	0.800	61.53	62.33	0.987
November	138.9	167.4	61.656	0.000	7.006	52.61	59.62	0.882
December	131.7	164.4	60.781	0.006	3.394	53.52	56.91	0.940
Year	1839.4	1900.8	707.225	14.864	85.017	622.30	707.31	0.880

Legends:

GlobHor	Horizontal global irradiation	E Miss	Missing energy
GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 62: Stand Alone Lab Main Results



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Stand Alone System: Loss diagram

Project : **Solar Lab DC**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	ZT 80S	Pnom	80 Wp
PV Array	Nb. of modules	6	Pnom total	**480 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	707 kWh/year

Loss diagram over the whole year

PVsyst Evaluation mode

Figure 63: Stand Alone Lab Loss Diagram

Simulation Summary:

From these 2 simulations we get that using AC power system will make much difference as there is grid connection is available so using DC appliance along with preinstalled AC appliance is Will just add up to the costing of the system and make it more complex and non-viable

12.3 Simulation report for basic Urban house hold AC solar power system

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Gird Connected : Simulation parameters

Project :	**Urban homes AC**				
Geographical Site		**Mumbai**		Country	**India**
Situation		Latitude	19.12° N	Longitude	72.85° E
Time defined as		Legal Time	Time zone UT+5.5	Altitude	18 m
		Albedo	0.20		
Meteo data:		**Mumbai**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**AC home U**				
		Simulation date	15/02/18 11h07		

Simulation parameters					
Collector Plane Orientation		Tilt	24°	Azimuth	0°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics					
PV module	Si-mono	Model	**SCM-300**		
Original PVsyst database		Manufacturer	Sunny Call		
Number of PV modules		In series	2 modules	In parallel	5 strings
Total number of PV modules		Nb. modules	10	Unit Nom. Power	300 Wp
Array global power		Nominal (STC)	**3000 Wp**	At operating cond.	2724 Wp (50°C)
Array operating characteristics (50°C)		U mpp	58 V	I mpp	47 A
Total area		Module area	**16.3 m²**	Cell area	14.2 m²
PV Array loss factors					
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	20 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss		Voltage Drop	0.7 V	Loss Fraction	1.1 % at STC
Module Quality Loss				Loss Fraction	-0.8 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter		System type	**Grid Connected**		
Battery		Model	**12-CS-11PS**		
		Manufacturer	Rolls		
Battery Pack Characteristics		Voltage	48 V	Nominal Capacity	888 Ah
		Nb. of units	4 in series x 3 in parallel		
		Temperature	Fixed (20°C)		
Controller		Model	Universal controller with MPPT converter		
		Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter		Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control		Treshold commands as	SOC calculation		
		Charging	SOC = 0.90 / 0.75	i.e. approx.	53.9 / 50.1 V
		Discharging	SOC = 0.20 / 0.45	i.e. approx.	47.0 / 48.9 V
User's needs :		Daily household consumers	Constant over the year		
		average	9.6 kWh/Day		

PVsyst Evaluation mode

Figure 64: Grid Connected Urban Simulation Parameters

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Grid Connected : Detailed User's needs

Project : **Urban homes AC**

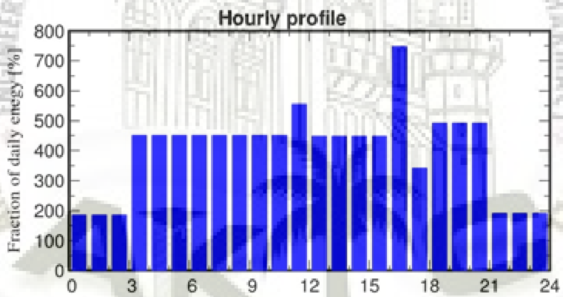
Simulation variant : **AC home U**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	SCM-300	Pnom	300 Wp
PV Array	Nb. of modules	10	Pnom total	**3000 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 888 Ah**
User's needs	Daily household consumers	Constant over the year	global	3517 kWh/year

Daily household consumers, Constant over the year, average = 9.6 kWh/day

Annual values

	Number	Power	Use	Energy
Tube Light	3	36 W/lamp	12 h/day	1296 Wh/day
Fan	4	75 W/app	18 h/day	5400 Wh/day
LED Lights	3	12 W/app	3 h/day	108 Wh/day
Fridge / Deep-freeze	1		24 Wh/day	1001 Wh/day
Dish- & Cloth-washers	1		1 Wh/day	300 Wh/day
Tv	1	150 W tot	6 h/day	900 Wh/day
Pc	1	105 W tot	6 h/day	630 Wh/day
Total daily energy				9635 Wh/day



PVsyst Evaluation mode

Figure 65: Grid Connected Urban Detailed User's need

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Grid Connected : Main results

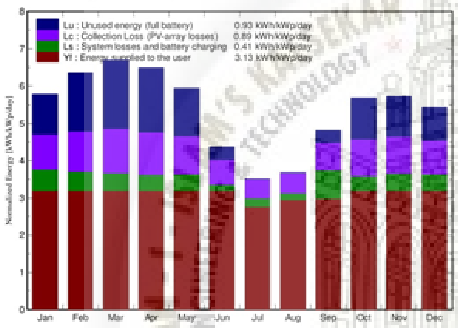
Project : **Urban homes AC**

Simulation variant : **AC home U**

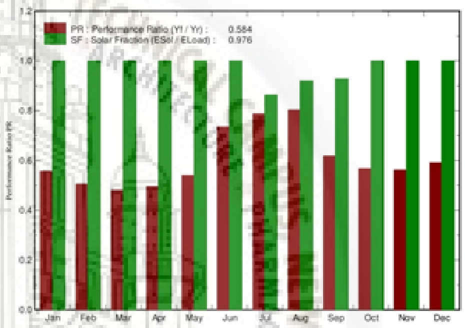
Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	SCM-300	Pnom	300 Wp
PV Array	Nb. of modules	10	Pnom total	**3000 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 888 Ah**
User's needs	Daily household consumers	Constant over the year	global	3517 kWh/year

Main simulation results				
System Production	**Available Energy**	**4639 kWh/year**	Specific prod.	1546 kWh/kWp/year
	Used Energy	3430 kWh/year	Excess (unused)	1015 kWh/year
	Performance Ratio PR	58.41 %	Solar Fraction SF	97.55 %
Loss of Load	Time Fraction	2.3 %	Missing Energy	86 kWh/year

Normalized productions (per installed kWp): Nominal power 3000 Wp



Performance Ratio PR and Solar Fraction SF



AC home U

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	174.7	426.522	100.1	0.000	298.7	298.7	1.000
February	151.2	173.6	422.618	132.1	0.000	269.8	269.8	1.000
March	191.9	202.0	488.088	168.9	0.000	298.7	298.7	1.000
April	198.0	189.1	460.074	155.5	0.000	289.0	289.0	1.000
May	201.6	178.3	435.902	119.5	0.000	298.7	298.7	1.000
June	146.0	126.2	312.435	30.1	0.000	289.0	289.0	1.000
July	119.0	104.8	261.034	0.1	41.056	257.6	298.7	0.863
August	120.9	109.7	273.021	0.0	24.167	274.5	298.7	0.919
September	141.1	139.8	343.057	28.4	20.889	268.1	289.0	0.928
October	157.0	170.8	412.881	100.8	0.000	298.7	298.7	1.000
November	138.9	167.4	404.710	97.3	0.000	289.0	289.0	1.000
December	131.7	164.4	398.253	82.4	0.000	298.7	298.7	1.000
Year	1839.4	1900.8	4638.594	1015.1	86.111	3430.4	3516.5	0.976

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 66: Grid Connected Urban Main Results

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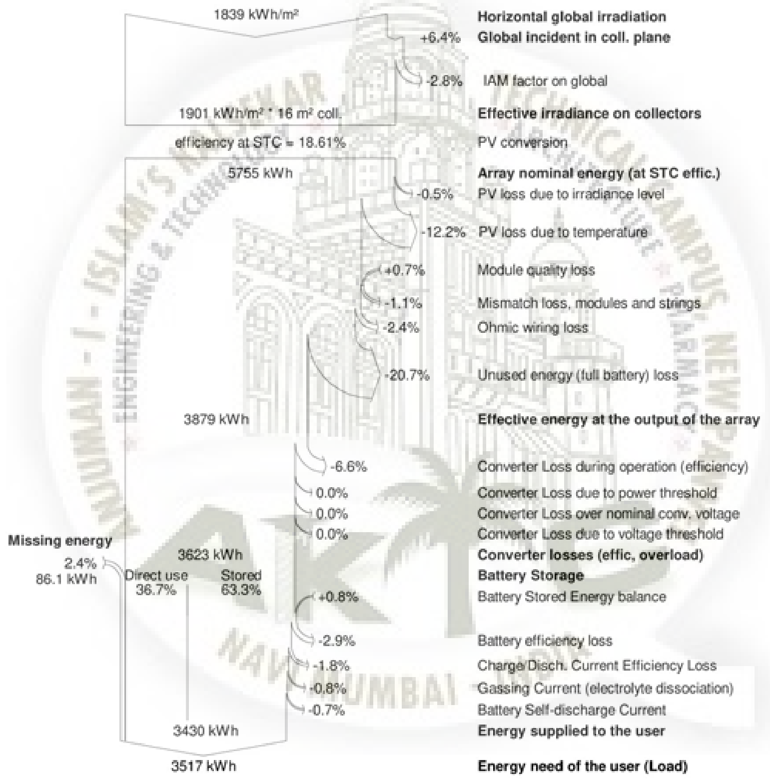
Grid Connected : Loss diagram

Project : **Urban homes AC**

Simulation variant : **AC home U**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	SCM-300	Pnom	300 Wp
PV Array	Nb. of modules	10	Pnom total	**3000 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 888 Ah**
User's needs	Daily household consumers	Constant over the year	global	3517 kWh/year

Loss diagram over the whole year



PVsyst Evaluation mode

Figure 67: Grid Connected Urban Loss Diagram

12.4 Simulation report for basic Urban house hold with DC solar power system

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Stand Alone System: Simulation parameters

Project :	**Urban Home DC**			
Geographical Site	**Mumbai**		Country	**India**
Situation	Latitude	19.12° N	Longitude	72.85° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	18 m
	Albedo	0.20		
Meteo data:	**Mumbai**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**New simulation variant**			
	Simulation date	21/02/18 15h21		

Simulation parameters				
Collector Plane Orientation	Tilt	24°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics				
PV module Si-mono	Model	**BE 150 S24**		
Original PVsyst database	Manufacturer	Bharat Electronics		
Number of PV modules	In series	1 modules	In parallel	5 strings
Total number of PV modules	Nb. modules	5	Unit Nom. Power	150 Wp
Array global power	Nominal (STC)	**750 Wp**	At operating cond.	663 Wp (50°C)
Array operating characteristics (50°C)	U mpp	29 V	I mpp	23 A
Total area	Module area	**6.3 m²**		
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	22 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	2.1 % at STC
Module Quality Loss			Loss Fraction	1.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter	System type	**Stand Alone System**		
Battery	Model	**12-CS-11PS**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Voltage	24 V	Nominal Capacity	592 Ah
	Nb. of units	2 in series x 2 in parallel		
	Temperature	Fixed (20°C)		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	26.7 / 25.1 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	23.5 / 24.4 V
User's needs :	Daily household consumers	Constant over the year		
	average	2.4 kWh/Day		

PVsyst Evaluation mode

Figure 68: Stand Alone Urban Simulation Parameters

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Stand Alone System: Detailed User's needs

Project : **Urban Home DC**

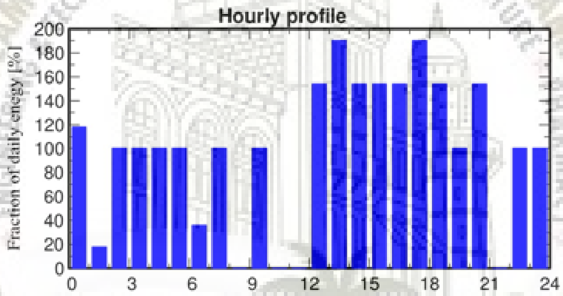
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	5	Pnom total	**750 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	867 kWh/year

Daily household consumers, Constant over the year, average = 2.4 kWh/day

Annual values

	Number	Power	Use	Energy
Lamps (LED)	3	18 W/lamp	8 h/day	432 Wh/day
DC Fan	4	25 W/app	18 h/day	1800 Wh/day
DC LED Bulb	3	12 W/app	4 h/day	144 Wh/day
Total daily energy				2376 Wh/day



PVsyst Evaluation mode

Figure 69: Stand Alone Urban Detailed User's need

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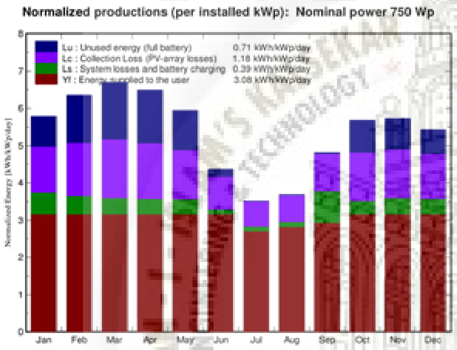
Stand Alone System: Main results

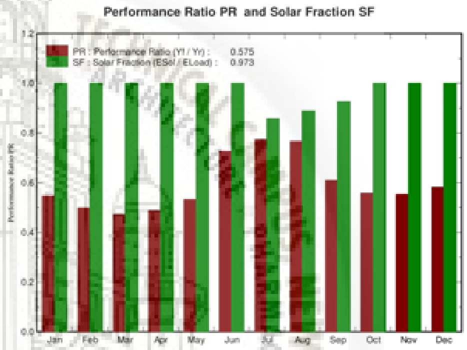
Project : **Urban Home DC**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	5	Pnom total	**750 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	867 kWh/year

Main simulation results				
System Production	**Available Energy**	**1094 kWh/year**	Specific prod.	1459 kWh/kWp/year
	Used Energy	843 kWh/year	Excess (unused)	195 kWh/year
	Performance Ratio PR	57.45 %	Solar Fraction SF	97.26 %
Loss of Load	Time Fraction	2.8 %	Missing Energy	24 kWh/year





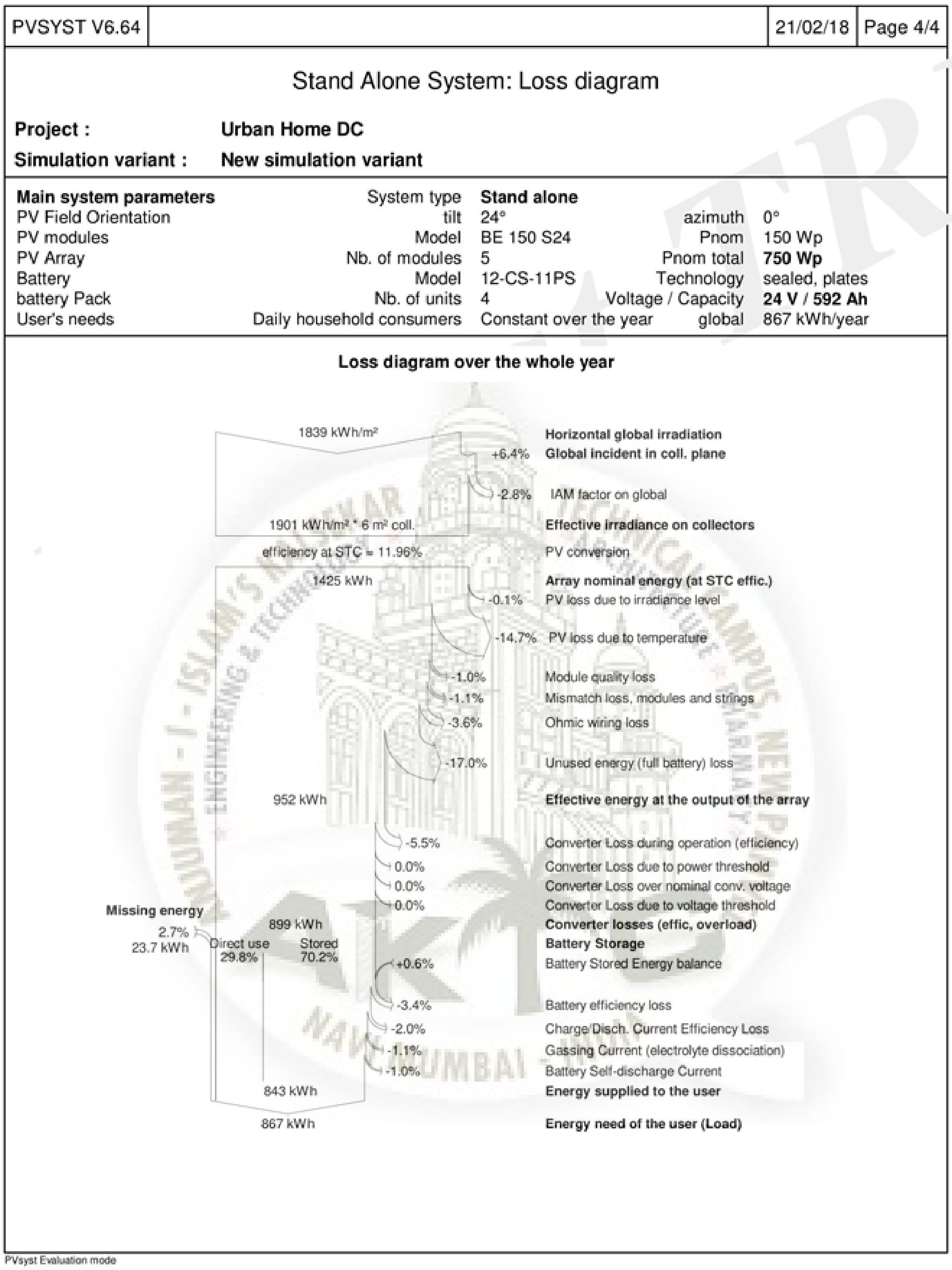
New simulation variant
Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	174.7	100.6	18.42	0.00	73.66	73.66	1.000
February	151.2	173.6	99.3	26.69	0.00	66.53	66.53	1.000
March	191.9	202.0	114.3	35.20	0.00	73.66	73.66	1.000
April	198.0	189.1	108.1	31.89	0.00	71.28	71.28	1.000
May	201.6	178.3	102.9	24.44	0.00	73.66	73.66	1.000
June	146.0	126.2	74.2	4.21	0.00	71.28	71.28	1.000
July	119.0	104.8	62.1	0.01	10.44	63.22	73.66	0.858
August	120.9	109.7	65.1	0.01	8.09	65.56	73.66	0.890
September	141.1	139.8	81.2	0.67	5.22	66.06	71.28	0.927
October	157.0	170.8	97.2	19.72	0.00	73.66	73.66	1.000
November	138.9	167.4	95.2	18.52	0.00	71.28	71.28	1.000
December	131.7	164.4	93.8	15.04	0.00	73.66	73.66	1.000
Year	1839.4	1900.8	1094.0	194.81	23.75	843.49	867.24	0.973

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 70: Stand Alone Urban Main Results



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Stand Alone System: Loss diagram

Project : **Urban Home DC**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	24°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	5	Pnom total	**750 Wp**
Battery	Model	12-CS-11PS	Technology	sealed, plates
battery Pack	Nb. of units	4	Voltage / Capacity	**24 V / 592 Ah**
User's needs	Daily household consumers	Constant over the year	global	867 kWh/year

Loss diagram over the whole year

PVsyst Evaluation mode

Figure 71: Stand Alone Urban Loss Diagram

Simulation Summary:

From these 2 simulations we get that using AC power system will make much difference as there is grid connection is available so using DC appliance along with preinstalled AC appliance is Will just add up to the costing of the system and make it more complex and non-viable, and also as it is a household more appliances wont be available in DC configuration.

12.5 Simulation report for small rural house with AC solar power system

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Grid Connected: Simulation parameters

Project :	**Rural Home AC**			
Geographical Site	**Mumbai**		Country	**India**
Situation	Latitude	19.12° N	Longitude	72.85° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	18 m
	Albedo	0.20		
Meteo data:	**Mumbai**	MeteoNorm 7.1 station - Synthetic		
Simulation variant :	**New simulation variant**			
	Simulation date	06/03/18 14h27		
Simulation parameters				
Collector Plane Orientation	Tilt	23°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics				
PV module Si-mono	Model	**BE 150 S24**		
Original PVsyst database	Manufacturer	Bharat Electronics		
Number of PV modules	In series	1 modules	In parallel	3 strings
Total number of PV modules	Nb. modules	3	Unit Nom. Power	150 Wp
Array global power	Nominal (STC)	**450 Wp**	At operating cond.	398 Wp (50°C)
Array operating characteristics (50°C)	U mpp	29 V	I mpp	14 A
Total area	Module area	**3.8 m²**		
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	36 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	2.1 % at STC
Module Quality Loss			Loss Fraction	1.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter	System type	**Grid Connected**		
Battery	Model	**PVX-2580L**		
	Manufacturer	Concorde		
Battery Pack Characteristics	Voltage	24 V	Nominal Capacity	239 Ah
	Nb. of units	2 in series		
	Temperature	Fixed (20°C)		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	27.1 / 25.1 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	23.3 / 24.4 V

PVsyst Evaluation mode

Figure 72: Grid Connected Rural Simulation Parameters

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Grid Connected : Detailed User's needs

Project : **Rural Home AC**

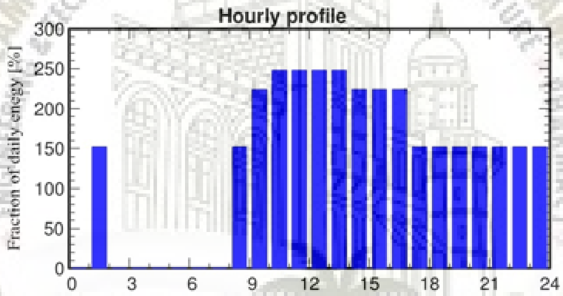
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	3	Pnom total	**450 Wp**
Battery	Model	PVX-2580L	Technology	sealed, AGM
battery Pack	Nb. of units	2	Voltage / Capacity	**24 V / 239 Ah**
User's needs	Daily household consumers	Constant over the year	global	1188 kWh/year

Daily household consumers, Constant over the year, average = 3.3 kWh/day

Annual values

	Number	Power	Use	Energy
Tube Light AC	2	36 W/lamp	8 h/day	576 Wh/day
Fan AC	2	76 W/app	17 h/day	2584 Wh/day
LED Light	2	12 W/app	4 h/day	96 Wh/day
Total daily energy				3256 Wh/day



PVsyst Evaluation mode

Figure 73: Grid Connected Rural Detailed User's need

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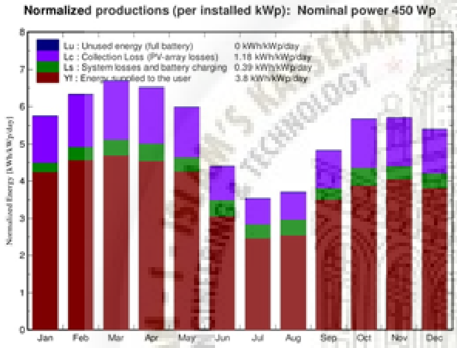
Grid Connected: Main results

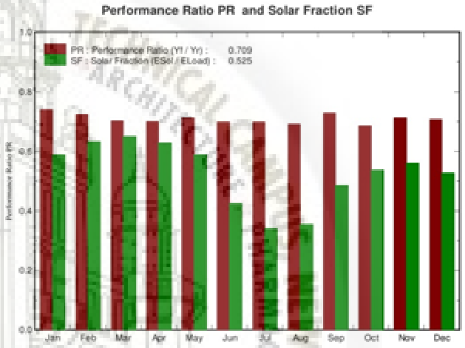
Project : **Rural Home AC**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid Connected**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	3	Pnom total	**450 Wp**
Battery	Model	PVX-2580L	Technology	sealed, AGM
battery Pack	Nb. of units	2	Voltage / Capacity	**24 V / 239 Ah**
User's needs	Daily household consumers	Constant over the year	global	1188 kWh/year

Main simulation results				
System Production	**Available Energy**	**652.2 kWh/year**	Specific prod.	1449 kWh/kWp/year
	Used Energy	624.3 kWh/year	Excess (unused)	0.1 kWh/year
	Performance Ratio PR	70.86 %	Solar Fraction SF	52.53 %
Loss of Load	Time Fraction	49.8 %	Missing Energy	564.2 kWh/year





New simulation variant

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	173.6	59.81	0.012	41.62	59.32	100.9	0.588
February	151.2	173.0	58.95	0.007	33.47	57.70	91.2	0.633
March	191.9	201.9	67.80	0.002	35.42	65.51	100.9	0.649
April	198.0	189.8	64.37	0.000	36.20	61.48	97.7	0.629
May	201.6	179.5	61.54	0.007	41.53	59.40	100.9	0.589
June	146.0	127.1	44.59	0.002	56.32	41.36	97.7	0.423
July	119.0	105.5	37.22	0.009	66.50	34.43	100.9	0.341
August	120.9	110.3	39.02	0.007	65.28	35.66	100.9	0.353
September	141.1	140.0	48.82	0.000	50.31	47.37	97.7	0.485
October	157.0	170.4	57.86	0.000	46.79	54.15	100.9	0.536
November	138.9	166.5	56.52	0.000	42.95	54.73	97.7	0.560
December	131.7	163.3	55.73	0.005	47.77	53.17	100.9	0.527
Year	1839.4	1900.8	652.24	0.051	564.15	624.29	1188.4	0.525

Legends:

GlobHor	Horizontal global irradiation	E Miss	Missing energy
GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 74: Grid Connected Rural Main Results

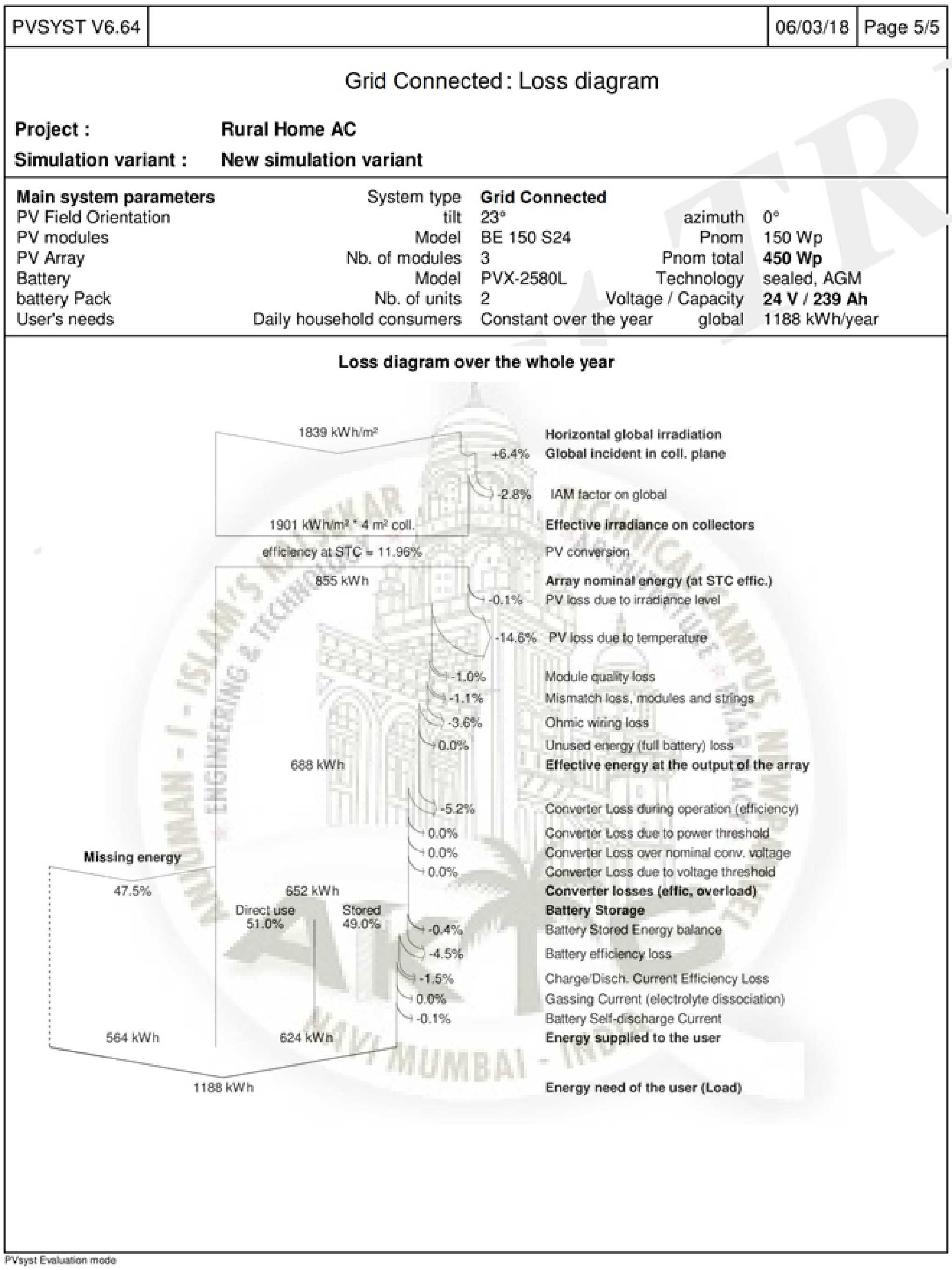


Figure 75: Grid Connected Rural Loss Diagram

12.6 Simulation report for small rural house with DC solar power system

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Stand Alone System: Simulation parameters

Project :	**Rural Home DC**				
Geographical Site		**Mumbai**		Country	**India**
Situation		Latitude	19.12° N	Longitude	72.85° E
Time defined as		Legal Time	Time zone UT+5.5	Altitude	18 m
		Albedo	0.20		
Meteo data:		**Mumbai**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**New simulation variant**		
		Simulation date	21/02/18 15h13

Simulation parameters					
Collector Plane Orientation		Tilt	23°	Azimuth	0°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics					
PV module	Si-mono	Model	**BE 150 S24**		
Original PVsyst database		Manufacturer	Bharat Electronics		
Number of PV modules		In series	1 modules	In parallel	3 strings
Total number of PV modules		Nb. modules	3	Unit Nom. Power	150 Wp
Array global power		Nominal (STC)	**450 Wp**	At operating cond.	398 Wp (50°C)
Array operating characteristics (50°C)		U mpp	29 V	I mpp	14 A
Total area		Module area	**3.8 m²**		
PV Array loss factors					
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	36 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss		Voltage Drop	0.7 V	Loss Fraction	2.1 % at STC
Module Quality Loss				Loss Fraction	1.0 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter		System type	**Stand Alone System**		
Battery		Model	**PVX-2580L**		
		Manufacturer	Concorde		
Battery Pack Characteristics		Voltage	24 V	Nominal Capacity	239 Ah
		Nb. of units	2 in series		
		Temperature	Fixed (20°C)		
Controller		Model	Universal controller with MPPT converter		
		Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter		Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control		Treshold commands as	SOC calculation		
		Charging	SOC = 0.90 / 0.75	i.e. approx.	27.1 / 25.1 V
		Discharging	SOC = 0.20 / 0.45	i.e. approx.	23.5 / 24.4 V

PVsyst Evaluation mode

Figure 76: Stand Alone Rural Simulation Parameters

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Stand Alone System: Detailed User's needs

Project : **Rural Home DC**

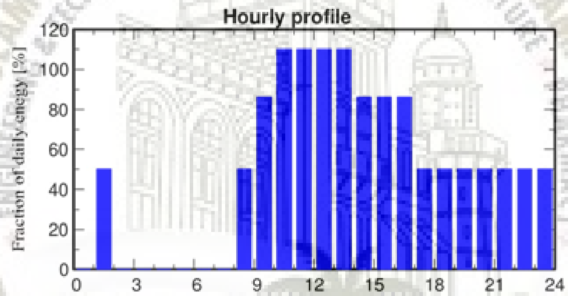
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	3	Pnom total	**450 Wp**
Battery	Model	PVX-2580L	Technology	sealed, AGM
battery Pack	Nb. of units	2	Voltage / Capacity	**24 V / 239 Ah**
User's needs	Daily household consumers	Constant over the year	global	450 kWh/year

Daily household consumers, Constant over the year, average = 1.2 kWh/day

Annual values

	Number	Power	Use	Energy
Tube Light DC	2	18 W/lamp	8 h/day	288 Wh/day
Fan DC	2	25 W/app	17 h/day	850 Wh/day
LED Light	2	12 W/app	4 h/day	96 Wh/day
Total daily energy				1234 Wh/day



PVsyst Evaluation mode

Figure 77: Stand Alone Rural Detailed User's need

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Stand Alone System: Main results

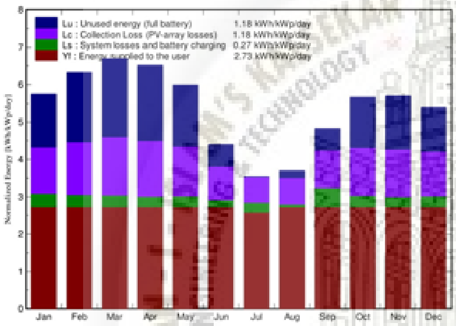
Project : **Rural Home DC**

Simulation variant : **New simulation variant**

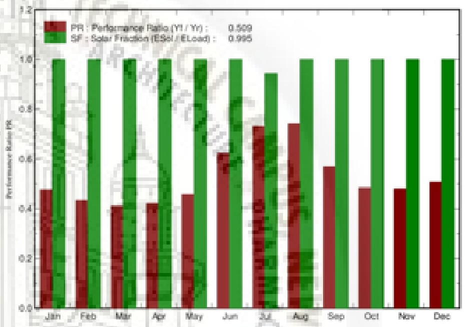
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	3	Pnom total	**450 Wp**
Battery	Model	PVX-2580L	Technology	sealed, AGM
battery Pack	Nb. of units	2	Voltage / Capacity	**24 V / 239 Ah**
User's needs	Daily household consumers	Constant over the year	global	450 kWh/year

Main simulation results				
System Production	**Available Energy**	**662.2 kWh/year**	Specific prod.	1471 kWh/kWp/year
	Used Energy	448.3 kWh/year	Excess (unused)	194.6 kWh/year
	Performance Ratio PR	50.88 %	Solar Fraction SF	99.53 %
Loss of Load	Time Fraction	0.5 %	Missing Energy	2.1 kWh/year

Normalized productions (per installed kWp): Nominal power 450 Wp



Performance Ratio PR and Solar Fraction SF



New simulation variant

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	142.1	173.6	60.782	19.78	0.000	38.25	38.25	1.000
February	151.2	173.0	60.087	23.45	0.000	34.55	34.55	1.000
March	191.9	201.9	69.248	28.91	0.000	38.25	38.25	1.000
April	198.0	189.8	65.768	27.19	0.000	37.02	37.02	1.000
May	201.6	179.5	62.767	22.79	0.000	38.25	38.25	1.000
June	146.0	127.1	45.028	7.86	0.000	37.02	37.02	1.000
July	119.0	105.5	37.216	0.01	2.119	36.13	38.25	0.945
August	120.9	110.3	39.155	2.50	0.000	38.25	38.25	1.000
September	141.1	140.0	49.197	7.69	0.000	37.02	37.02	1.000
October	157.0	170.4	58.801	18.67	0.000	38.25	38.25	1.000
November	138.9	166.5	57.515	19.13	0.000	37.02	37.02	1.000
December	131.7	163.3	56.589	16.60	0.000	38.25	38.25	1.000
Year	1839.4	1900.8	662.152	194.58	2.119	448.28	450.40	0.995

Legends:
- GlobHor: Horizontal global irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E Avail: Available Solar Energy
- EUnused: Unused energy (full battery) loss
- E Miss: Missing energy
- E User: Energy supplied to the user
- E Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

PVsyst Evaluation mode

Figure 78: Stand Alone Rural Main Results

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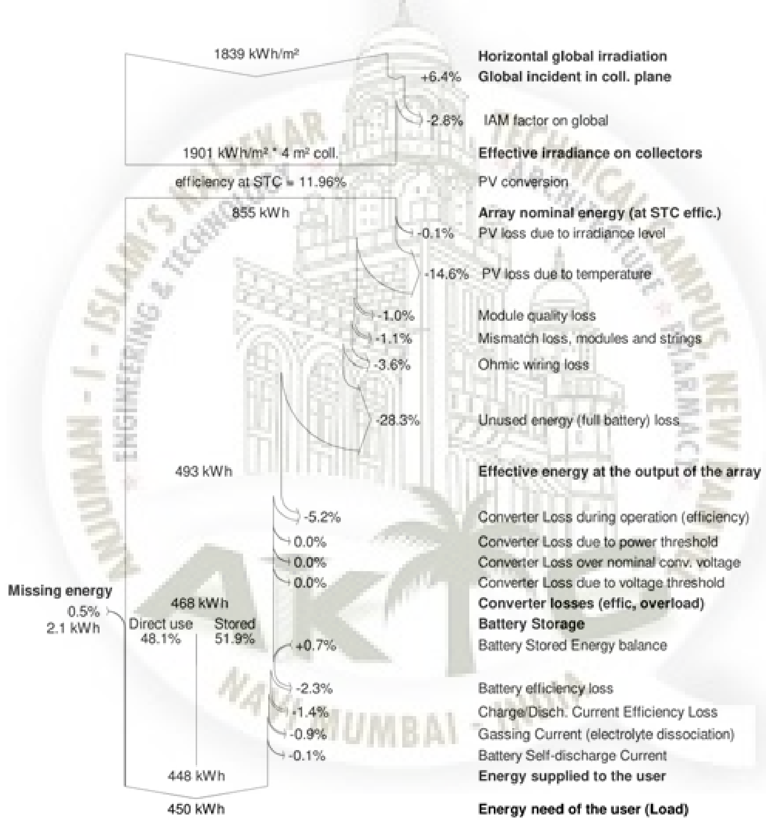
Stand Alone System: Loss diagram

Project : **Rural Home DC**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	23°	azimuth	0°
PV modules	Model	BE 150 S24	Pnom	150 Wp
PV Array	Nb. of modules	3	Pnom total	**450 Wp**
Battery	Model	PVX-2580L	Technology	sealed, AGM
battery Pack	Nb. of units	2	Voltage / Capacity	**24 V / 239 Ah**
User's needs	Daily household consumers	Constant over the year	global	450 kWh/year

Loss diagram over the whole year



PVsyst Evaluation mode

Figure 79: Stand Alone Rural Loss Diagram

Simulation Summary:

From these 2 simulations we get that using DC solar power supply will be much suitable for remote rural areas as grid supply is rarely available and using DC appliance will reduce power consumption and discarding the need of an inverter, which will largely affect the costing.

Module 5

System Economics and Ecology

Chapter 13

13 Costing of setup

In previous chapters we saw hoe to design a complete solar power system and home automation system. Now in this chapter we will make a costing report based on the components required for the setup. For all the scenarios the costing will differ according to the size of the system and requirement of components. And then we will make a savings report for every scenario to get a clear idea about the best combination of the systems required in different conditions.

13.0.1 Costing for Solar power and Automation for Laboratory:

Lets start with the easiest and the system requiring least number of components.

Laboratory with DC appliances

If we convert Our Laboratories Fans and Bulbs on DC solar power system along with the home Automation system installation, we will require following things.

Material	Specification	Amount	Cost(Rs.)
Solar Panels	300Watts	2	22000
MPPT	20A	1	5000
Battery	1.2kW	2	11000
Jumper Cables	1	1	1000
Screws, Nuts, etc.	1	1	1000
Wires	1mm&6mm	1/1	3500
Battery Cover	1	1	1000
Wire insulation	1	1	1500
Solar DC Fan	25Watts	10	20000
DC LED Bulbs	12Watts	10	2000
TOTAL			68000

Figure 80: Laboratory with DC appliances

Approx **Rs.68000** is required to setup a solar power system for 10 DC Fans and 10 Dc bulbs.
But this system will require additional appliances as this setup is DC power based and laboratory already has AC appliances.
Now we will see electric bill calculation and maintenance charges.

No of years	Electricity charges	Maintenance charges
1st	**10592.18**	1500 yearly
2nd	11651.40	
3rd	12816.54	
4th	14098.20	
5th	15508.02	
6th	17058.82	11000 (Battery)
7th	18763.88	
8th	20640.27	
9th	22704.29	
10th	24974.72	3500(wiring)
11th	27472.20	
12th	30219.42	11000 (Battery)
13th	33241.36	
14th	36565.49	
15th	40222.64	
Grand Total	**336528.93**	

Figure 81: Electricity charges for next 15 years

Maintenance charges for solar power system:
Rs.1500 yearly charges for cleaning solar array
Rs.11000 for battery pack after every 6 years
Rs.3500 for wiring after every 10 years

Now lets see the calculations in which we use AC appliances instead of DC so we can use more of them on solar energy.

Laboratory with AC appliances

Material	Specification	Amount	Cost(Rs.)
Solar Panels	320Watts	4	53000
MPPT	55A	1	8000
Battery	1.8kW	4	30000
Jumper Cables	-	1	1800
Screws, Nuts, etc.	-	1	1800
Wires	1mm&6mm	1/1	6500
Battery Cover	1	1	2500
Wire insulation	1	1	1500
Solar Inverter	24V	1	8500
TOTAL			**111000**

Figure 82: Laboratory with AC appliances

Maintenance charges for solar power system:
Rs.1500 yearly charges for cleaning solar array
Rs.30000 for battery pack after every 6 years
Rs.6500 for wiring after every 10 years

No of years	Electricity charges
1st	**28364.76**
2nd	31201.23
3rd	34321.35
4th	37753.49
5th	41528.84
6th	45681.72
7th	50249.90
8th	55274.89
9th	60802.38
10th	66882.62
11th	73570.88
12th	80927.97
13th	89020.76
14th	97922.84
15th	107715.12
Grand Total	**754218.75**

Figure 83: Electricity charges for next 15 years

As we see in this scenario as the Grid electricity is available and no extra appliance required AC solar power system is more feasible as more electricity is being saved in this system.

Now lets take the 2nd scenario which is a standard House hold in an urban area.

Urban Residence with AC appliances

Material	Specification	Amount	Cost(Rs.)
Solar Panels	300Watts	7	110000
MPPT	55A	1	8000
Battery	2.4kW	4	36000
Jumper Cables	-	1	2500
Screws, Nuts, etc.	-	1	2000
Wires	1mm&6mm	1/1	9500
Battery Cover	1	1	3000
Wire insulation	1	1	1800
Solar Inverter	24V	1	15000
TOTAL			**184000**

Figure 84: Urban Residence with AC appliances

Approx. **Rs.184000** is required to setup a solar power system a standard urban household.

No of years	On Grid Calculation
1st	**28364.76**
2nd	31201.23
3rd	34321.35
4th	37753.49
5th	41528.84
6th	45681.72
7th	50249.90
8th	55274.89
9th	60802.38
10th	66882.62
11th	73570.88
12th	80927.97
13th	89020.76
14th	97922.84
15th	107715.12
Grand Total	**754218.75**

Figure 85: Electricity charges for next 15 years

Maintenance charges for solar power system:
Rs.1500 yearly charges for cleaning solar array
Rs.36000 for battery pack after every 6 years
Rs.9500 for wiring after every 10 years

Urban Residence with DC appliances

Material	Specification	Amount	Cost(Rs.)
Solar Panels	300Watts	2	22000
MPPT	20A	1	5000
Battery	1.2kW	2	11000
Jumper Cables	1	1	1000
Screws, Nuts, etc.	1	1	1000
Wires	1mm&6mm	1/1	3500
Battery Cover	1	1	1000
Wire insulation	1	1	1500
Solar DC Fan	25Watts	4	8000
DC LED Bulbs	12Watts	3	600
DC Tube Lights	18Watts	3	1200
TOTAL			**55000**

Figure 86: Urban Residence with DC appliances

But this system will require additional appliances as this setup is DC power

based and an urban house already has AC appliances.
Only fans and lights can be used on solar if DC energy system is used.

Now we will see electric bill calculation and maintenance charges.

No of years	On Grid Calculation
1st	**10109.31**
2nd	11120.24
3rd	12232.27
4th	13455.49
5th	14801.14
6th	16281.15
7th	17909.26
8th	19700.19
9th	21670.21
10th	23837.23
11th	26220.95
12th	28843.05
13th	31727.35
14th	34900.09
15th	38390.09
Grand Total	**285487.82**

Figure 87: Electricity charges for next 15 years

As we see in this scenario as the Grid electricity is available in this region too, and more appliance can be used (Fridge, TV etc.) if AC solar power system is used in this condition.

Hence we can save more on electric bills in urban households if we use AC solar power.

Rural Residence with AC appliances

Material	Specification	Amount	Cost(Rs.)
Solar Panels	250Watts	3	26000
Inverter	20A	1	8000
Battery	1.8kW	2	15000
Jumper Cables	1	1	1000
Screws, Nuts, etc.	1	1	1000
Wires	1mm&6mm	1/1	3500
Battery Cover	1	1	1000
Wire insulation	1	1	1500
TOTAL			57000

Figure 88: Rural Residence with AC appliances

If we assume grid power supply is available in that region this will be the amount spent on electricity bill.

No of years	On Grid Calculation
1st	11372.55
2nd	12509.81
3rd	13766.79
4th	15142.87
5th	16657.16
6th	18322.87
7th	20155.16
8th	22170.53
9th	24387.58
10th	26826.34
11th	29508.97
12th	32459.87
13th	35705.86
14th	39276.45
15th	43204.09
Grand Total	361466.90

Figure 89: Electricity charges for next 15 years

Rural Residence with DC appliances

Material	Specification	Amount	Cost(Rs.)
Solar Panels	300Watts	1	11000
MPPT	20A	1	5000
Battery	1.2kW	1	6000
Jumper Cables	1	1	1000
Screws, Nuts, etc.	1	1	1000
Wires	1mm&6mm	1/1	3300
Battery Cover	1	1	1000
Wire insulation	1	1	1500
Solar DC Fan	25Watts	2	4000
DC LED Bulbs	12Watts	2	400
DC Tube Lights	18Watts	2	800
TOTAL			35000

Figure 90: Rural Residence with DC appliances

No of years	On Grid Calculation
1st	8469.33
2nd	9316.26
3rd	10247.89
4th	11272.68
5th	12399.95
6th	13639.95
7th	15003.94
8th	16504.34
9th	18154.77
10th	19970.25
11th	21967.27
12th	24164.005
13th	26580.40
14th	29238.44
15th	32162.29
Grand Total	269091.22

Figure 91: Electricity charges for next 15 years

In this scenario where the requirement is inly fans and lights, DC solar energy system will be more beneficial as energy consumption of the required Appliances reduce which will reduce the size and cost of solar power system and the requirement of inverter is eliminated.

Module 6

Epilogue

Chapter 14

14 Conclusion

This book concludes the design and working of a self-sustainable DC Solar power system and Offline Ethernet based home automation system to design a smart adobe or small infrastructure in remote areas without conventional grid power supply. A precise load calculation of load using PVSYST software is shown in this paper. This setup can be used in hospitals and schools or even in small scale business setups. Go green initiative along with the advancement in technology for even the remotest part of the world is the sole purpose of this document.

We have also introduced a home management system. Our prototypical system is applicable to real-time home security, automation, monitoring and controlling of remote systems. By pressing virtual button on the smartphone, the home appliances can be controlled from any remote location. One advantage of this app is that it can be shared within all the family members of the house. When one member switches ON or OFF an appliance, the action will be apparent to all other members sharing the app. Similarly, real-time as well as historical data of measurements of temperature, humidity, GPS location and distance-measure can be obtained from anywhere using the app. Further, this system can be employed in many places such as banks, hospitals, laboratories, traffic stations, residential apartments, house, streets, poultry farms, greenhouse etc. In a nutshell, this system can be used at multiple fields and areas in order to make them operate smartly

Looking at the prospect of combining an automation system with a P.V solar array system, it is rather beneficial to pair a DC solar system with a locally operatable automation system as these are more suitable for use in combination in rural areas where there is a high chance of the infrastructure being completely off grid and hence creating a self-contained and self-sustained system whereas for urban or developed areas an On grid AC system Paired with a remotely operatable automation system provides greater ease, this can be easily implemented in residential as well as commercial complexes. Although forming a combination the other way round would also be possible, the deciding factor would be the use case.

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Participations

- 4th National Level Technical Poster Presentation, 2016.
  Universal College of Engineering, Vasai
- Inter College Project Presentation, 2017.
  Kalsekar Technical Campus, Panvel
- "Technology-Innovation" Model Presentation, 2018.
  Poornima College of Engineering, Jaipur

Achievements

Bonafied Achievements of the Project This Project has been presented at a number of technical competitons and has been awarded numerous prizes.

- 2nd National Level Technical Poster Presentation, 2016.
  1st Prize*, Project Exhibition, Universal College of Engineering*
- 3rd National Level Technical Poster Presentation, 2017.
  1st Prize*, Project Exhibition, Universal College of Engineering*
- Inter College Technical Paper Presentation, 2017.
  1st Prize*, TECHNOZON 2K17, New Horizon institute of Technology*
- 4th National Level Technical Paper Presentation, 2017.
  1st Prize*, Technical Paper Presentation, Universal College of Engineering*

Papers Published

3 Research Papers based on the said project were submitted to be published at various National as well as International conferences. All the 3 papers were accepted and duly published at IEEE Explore.

- **"Implementation of a Self-Sustainable Infrastructure with remote power management",**International Conference on Smart City and Emerging Technologies (ICSCET),2018,
Universal College of Engineering, Vasai, 5th Jan 2018.

- **"A Green Energy System for Smart abode",**International Conference on Smart City and Emerging Technologies (ICSCET),2018,
Universal College of Engineering, Vasai, 5th Jan 2018.

- **"Ontalogy of DC solar system with locally automated power management in Contrast with AC solar system with remote power management",**International Conference on Electrical, Electronics, Computers, Communication, Mechanical and Computing (EECCMC),2018
Priyadarshini Engineering College, Tamil Nadu, 28th Jan 2018.