DEVELOPMENT AND PERFORMANCE EVALUATION OF A SOLAR THREE-WHEELER FOR DISABLED PEOPLE

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BY

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CERTIFICATE OF APPROVAL

The thesis titled "**DEVELOPMENT AND PERFORMANCE EVALUATION OF A SOLAR THREE-WHEELER FOR DISABLED PEOPLE"** submitted by **Md. Shahidul Islam**, Student No. 0409082024P, Session-April 2009, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Industrial & Production Engineering on 16 June, 2012.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md. Shahidul Islam

This Work is Dedicated to My

Parents

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Abstract

The mobility of the physically disabled or crippled people is a great concern of the society. It is observed that physically disabled people in the country are basically using some assistive devices like, Crutch, artificial limbs or legs etc., manual wheel chair or three-wheeler for their day to day movements. But, these wheel chairs or three wheelers are crude or of inefficient design; not very much suitable for our terrain or outdoor use. More ever, this commonly found manual wheel chair/three wheeler has a basic problem that the occupant needs to use physical force to turn the chair's wheels. This action is physically stressful, can result in muscle and joint pain and degradation, torn rotor cuffs, repetitive stress injury, and carpal tunnel syndrome; which causes secondary injury or further disability.

This thesis presents research, development and performance evaluation of a solar powered three-wheeler for disabled people suitable for countries like Bangladesh which is an under developed country with huge disabled/crippled people from war, accidents and diseases. Solar three-wheeler is designed primarily focusing on the requirements of the disabled people who can't move in conventional transports comfortably. This three-wheeler is operated by solar power and suitable for outdoor use. Solar power option enables the disabled people to use it at any place, even in remote areas where there is no electricity. A general survey has been conducted on disabled people using wheel chairs and manual three-wheelers and the opinions of the experts working with the disabled people are also taken in to consideration to identify the needs and requirement for designing the solar three-wheeler. The developed solar three-wheeler exceeds the conventional three-wheeler's facilities with a more intelligent and efficient design. A solar panel to produce solar electricity, a battery system for preserving electric power, an efficient motor, cushion seat, all terrain tires are used for this solar three-wheeler. Due consideration and attention is given to better maneuverability, effective use of solar energy, biomechanics and comforts, increased suspensions, all terrain traffic ability, ease of use etc. while designing this solar three-wheeler for physically disabled people of the country.

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INTRODUCTION

1.1 Introduction

A lot of difficulties and hassles involved with the mobility of the physically disabled people in the society. It is really difficult to realize the problems/sorrows of a physically disabled/ crippled person who is partially or fully dependent on others or confining in a wheel chair with limited mobility. There is no exact data of disabled people in the country. Basing on some data collected by the prevailing NGOs and international organizations, it is commonly believed that almost 10% of the total populations of Bangladesh are disabled and 2.5% of which are crippled or physically disabled. Due to increasing rate of road accidents and other relevant diseases the number of disabled people is increasing rapidly.

It is observed that existing vehicles of the transportation sector in Bangladesh do not provide necessary facilities which are important for the disabled to move from one place to another without problems. Physically disabled people in the country are basically using manual wheel chairs, manual three-wheelers and some other assistive devices like, Crutch, artificial limbs or legs etc. for their day to day movements. Disabled people normally use wheel chairs for short distance and three-wheelers for comparatively long distance movement or rely on other person to use the conventional transport. Undoubtedly these manual wheel chairs or the three-wheelers are the blessings for crippled people but in the question of humanity, it is just “to add insult to injury” or “to pour water on a drowned mouse”. Because, commonly found manual wheel chair/three-wheeler has a basic problem that the occupant must use physical force to turn the chair’s wheels. This action is physically stressful, can result in muscle and joint pain and degradation, torn rotor cuffs, repetitive stress injury, and carpal tunnel syndrome, which causes secondary injury or further disability[3].

More so, these available wheel chairs or three-wheelers are crude or of inefficient in design; not very much suitable for outdoor use or common terrain in the country like Bangladesh. There are few electric wheel chairs found in some urban areas; again these wheel chairs are also not suitable for out door use or common terrain in the country and needs grid electric power which is also not available at all corners over the country. So a need emerges strongly for a specific vehicle which can overcome all these limitations and provide necessary facilities and comfort for the disabled people.
Again, the whole world is very much worried and looking for sustainable energy option, putting efforts to develop environment friendly machinery and equipments using renewable energy like solar power. Because, use of conventional energy sources and rapid development of the present world have some bad impacts on the surroundings and environment, like depleting limited energy resource, damage of ecosystem, environment pollution, global warming and so on. As a result, designing for environment (DFE) that is the environment friendly equipment and transports are the cry of the present time need of the world and it is very much necessary to develop environment friendly equipment or transport for better living, for better world.

Considering the overall prevailing situation, development of a solar three-wheeler for disabled people is a vital effort where solar energy and its advantages are taken into account. A solar three-wheeler is a "stand-alone system"; it is self-operated and independent in nature, using unending solar energy from the sun. It is powered by solar energy from attached solar panel at top, exposed to sunlight. It can take us off the grid; adding more mobility to an improved manual three-wheeler without worrying about running out of power, can be used in a place where there is no electricity.

Solar Powered three-wheeler is designed primarily focusing on the requirements of the disabled people who can't move in conventional transports comfortably. The transport idea concerned here is a solar power operated three-wheeler with light structure of moderate height-width and weight, which suits well to Bangladeshi terrain. Due emphasis is given to biomechanics, comforts, safety etc. while designing the seat for the solar three-wheeler. These features give greater stability, better maneuver ability, better mobility and comforts over the available manual three-wheelers. In a sense, a solar three-wheeler can be the complete solution for the transportation of physically disabled people of the country.

Use of available resources (for components such as pipes for chassis/body, wheels, bearing etc. from the local market) and simplicity in designing result cost economy. The battery used, motor and solar panels are also very much available in the markets. All these features make the solar three-wheeler a very cost effective/cost economy and pollution free or environment friendly transport for the daily use of the disabled people. From a survey result it is evident that most of the disabled people need traveling of a short distance of daily average range of maximum 15 ~ 20 km, neglecting pleasure rides at long distance. Investigation shows that 24V, 45 Ah battery with 100 W solar panel can provide all the power requirement of this solar three-wheeler for a speed of 6 km/hr in all over the country and round the year.

1.2 Objectives

The specific focuses of the project were to gather the knowledge of solar energy as well as solar system and study the data of solar radiation in Bangladesh round the year. A study on the traffic ability or terrain condition of the country and evaluation of the physical condition and capacity of the crippled or disabled person had been carried out. The needs and requirements of the disabled people were also investigated carefully. Finally, the desired solar three-wheeler had been designed and developed. After the development, the performance of the solar three-wheeler were evaluated and monitored in practical. Logically the outcome of project is the development of a comfortable and suitable solar three-wheeler for crippled/disabled people of Bangladesh.

1.3 Methodology

This project was based on literature study, field study, empirical investigation, innovative designing and performance monitoring. An empirical study was an investigation based on data, which had been collected through surveys or interviews. This research was conducted in consideration of the perimeter of Bangladesh.

The following sequences were followed to complete the total work of the project: Firstly, available data on solar radiation from different research centers/organizations, efficiency of solar module/panels, solar system and relevant technical data's on solar power were collected. Then a suitable questionnaire was prepared to interview different disabled people including those who are using wheel chairs, three-wheelers to know their problems and needs and translate those into technical needs/requirements. Survey and evaluation of the different roads, terrain conditions in deferent corners of the country was done and traffic ability justified. Different relevant articles from journal, thesis papers, news papers etc. were studied. Then a conceptual design was developed and prototype made. Finally, the solar three-wheeler was developed and testing completed. The performance was evaluated and necessary adjustments were carried out.

Some assumptions were made in considering the physical condition of a disabled person, over all terrain condition, safety etc. The speed of the solar three-wheeler was set to 6 km/hr or 100 m/min. This speed ensured better stability as well as comfort for the user.

1.4 Chapter Summery

In Chapter 2, the literature review including mobility and transportation of the disabled people are described. The drawbacks of the manual three-wheelers as well as the reasons for designing a solar three-wheeler are also discussed. Chapter 3 gives the clear picture of solar radiation, radiation in Bangladesh, solar photovoltaic system and the advantages of solar power. In Chapter 4, the overall designing of the solar three-wheeler which includes design phases, design requirements, considerations, designing of different parts/components, assembling, justifying the stability etc. are deliberately described. All types of calculations related to the designing of solar three-wheeler are gathered in Chapter 5. The finite element analysis and ergonomics analysis are shown in Chapter 6 and Chapter 7 respectively. The performances of the solar three-wheeler are evaluated in Chapter 8. Chapter 9 includes conclusion and recommendations for future work.

Chapter 2
LITERATURE REVIEW

2.1 Disability Concepts and Classifications

Disability is defined on the basis of International Classification of Impairments, Disabilities and Handicaps (WHO, 1991). Impairment is any loss or abnormality of psycho-logical, physiological or an anatomical structure or function. Impairment includes-Intellectual, Psychological, Language, Aural, Ocular, Visceral, Skeletal, Disfiguring and Sensory and Other impairment. Disability is any restriction or lack of ability to function any activity considered normal for a human. Disability includes-Behavior, Communication, Personal care, Loco motor, Body disposition, Dexterity, Situational, Particular skill, other restrictions. Handicap is a disadvantage resulting from impairment or disability. In survey operation, it is either an impairment or disability.

Classifications of Disability-Practice in Bangladesh are as below [13]:

1) **Decrepit-** A person who is deprived of the power of movement because of old age;
2) **Stammer**- A person who speaks haltingly;
3) **Mentally retarded-**Backwardness in physical or mental development or mentally out of balance;
4) **Deaf and dumb-** A person who cannot hear or utter word meaningfully;
5) **Night Blind-** Unable to see at night only;
6) **Blind-** Who has no visual capacity due to loss of eye-sight:
7) **Crippled**- A person who is incapable to use one or both hands or legs is called crippled.

2.2 Present Scenarios

Since the liberation war of Bangladesh in 1971, a large number of people have become disabled and vulnerable to the country. The prevalence of disability is believed to be high for basic reasons relating to over population, extreme poverty, mal-nutrition, illiteracy, social security, lack of awareness of traffic rules and above all lack of medical/health care and services. By latest, the numbers of disabled people are increasing rapidly due to increasing rate of road accidents and other relevant diseases [1].

The disable people are frequently neglected and do not have the opportunity to live with prestige and honor. Because of their physical problems, these people are also deprived and unable to obtain legal protection and opportunities in the field of education, employment, rehabilitation and other spheres of life. It is really difficult to realize the sorrows of a crippled or disabled person who is dependent on others or confining in a wheel chair with limited mobility. In the present social hardship, other family members often fail to pay proper attention and care to the disabled people. So, their lifestyle improvement and independency is very much important and urgent too.

The disability issue has been taken on by the United Nations with many organizations coming forward on behalf of Persons with Disabilities, but little has happened yet due to the lack of proper legislation, executive order and proper attention and awareness. Although the 1972 constitution legislated guarantees for the basic minimum needs of persons with disabilities, in practice these are not achieved due to the lack of proper initiatives and resources. In recent years, there have been some improvements and positive trends as a result of the efforts at both government and non-government levels; however the overall situation of Persons with Disabilities is still far from satisfactory level. In fact, they are still granted lowest priority in service provision in Bangladesh.

Government has limited program interventions in addressing the issues related to disabilities and the disabled; Women with disabilities constitute a large proportion of our population, but very little is known about their characteristics, the constraints they face in daily life and the quality of life they enjoy. This is equally true for men and children as well. In recent years some NGOs have come up with programs and projects for the benefits of the disabled. However, awareness of the needs and rights of persons with disabilities has gradually increased leading to expectations of special and comprehensive legislation on the right to live, work and obtain food, clothes, shelter, mobility aids and education; so that the persons with Disabilities can participate in public decision-making and contribute to the nation.

Although disability is a major social and economic phenomenon in Bangladesh, there is very little reliable data available on this issue, especially in the absence of a comprehensive national survey on persons with disabilities. The Government of Bangladesh (GOB) surveys in 1982, 1986 and 1998 estimated a national prevalence rate of disability at 0.64%, 0.5% and 1.60% respectively. Action Aid-Bangladesh and Social Assistance and Rehabilitation for the Physically Vulnerable (SARPV) put the disabled population at 8.8% of the total population. Bangladesh Protibandi Kalayan Samiti records 7.8%. Dr. Julian Francis, in a report prepared for the Aid Management Office (AMOD) of the Overseas Development Administration (ODA) of the British Government in 1995, estimated the Person with Disabilities population to be 9 million, of which no less than 7 million live in rural areas. Most of the estimates generally appear to be underrated, sometimes excessively. The WHO’s global estimate predicts approximately 10% of all people have a disability of one kind or another. This is also considered to be true in Bangladesh with some sources quoting a higher disability rate in rural Bangladesh.

The Government has not conducted a national study on issues till 2010, nor included questions on disability in its national census definitely. Although NGOs have conducted area- and field-specific studies, a national picture has not emerged from these studies. In National Census 2001, a little attention was given to the issue and some indefinite data were collected along with other issues. As a national survey or study on the actual situation of persons with disabilities in the country has not been conducted, NGOs have conducted their own surveys to design their projects for persons with disabilities. As the findings are limited to specific locations or programs and the prevalence of disability varies according to the socio-economic and geographic conditions of the country; these results cannot be represented as national findings.

Data on Disability are not collected in Bangladesh on regular basis and there is no exact figure of disabled peoples in the country. However such data have been collected through Census and Surveys since 1986 along with other issues. Basing on some data collected by the prevailing NGOs and international organizations, it is commonly believed that almost 10% of the total populations of Bangladesh are disabled and 2.5% of which are crippled or physically disabled [2].

By latest, Bangladesh Government has given special emphasis on disability issue. National Census conducted in 2011, disability issue is included and significant awareness and motivation works conducted among all to get the actual/exact figures of disable people in deferent verities in the country which is very much important for planning and development of the disability issue, for the development of the country. So, we really have to wait till the statistical result of National Census, 2011 to get the actual number of disability in the country.

However, some data are affixed in appendix 'A' and appendix 'B' to get some ideas on over all disability situations in various areas, different age group, sex etc. in different periods/times as collected by various non-government and government organizations**.**

2.3 Mobility and Transportation of the Disabled

Mobility (transportation and communication) of crippled or physically disabled is a great concern of the society. It is observed that existing vehicles of the transportation sector in Bangladesh do not provide necessary facilities for the disabled to move from (place to place) one place to another. Physically disabled people in the country are basically using manual wheel chair, manual three-wheeler and some other assistive devices like, Crutch, artificial limbs or legs etc. for their day to day movements. These wheel chairs are very light, actually suitable for indoor use or very short distance movement. Disabled people normally use three-wheelers for out door, for comparatively long distance movement or rely on other person to use the conventional transport. However, the commonly found mini private transports for the disabled peoples are: 1) Manual wheel chairs, 2) Manual three-wheelers and 3) Electric wheel-chairs (rarely found). Most of these available wheel chairs or three-wheelers are crude or of inefficient in design; having lot of technical drawbacks and three-wheelers are not very much suitable for outdoor use or common terrain in the country.

The numbers of crippled/ disabled people are quite alarming but the numbers of wheel chair or three-wheeler users are not big and mostly found them in hospitals and residents, especially in urban areas. It is revealed from the survey that the numbers of present wheel chair/three-wheeler users are negligible in all over the country. It happens because the presently available wheel chairs or three-wheelers are manual and not very suitable for outdoors use or for the roads around the country. The roads even in the cities are not very smooth or/and there is no lane for wheel chairs/ three-wheelers. Most of the cases the roads are very rough and narrows with some other limitations. Commonly Bangladesh has plain land and roads in the villages are of rough condition where peoples are moving with their bicycles, rickshaws etc. City roads are better where people move by rickshaws, auto- rickshaws, busses, taxi-cabs, cars etc.

There are few electric wheel chairs rarely found in some urban areas. However these are better than those of manuals, moved by electric motor power. Motor gets power from the battery which needs to be charged from electric line, the grid power. These wheel chairs are also not suitable for common roads in the country and needs grid electric power which is also not available at all corners over the country.

Studies have shown that manual wheel chair propulsion efficiency is between 5% and 18% depending upon the style of the wheel chair and the fit to the user. The low efficiency of manual wheel chair makes them ineffective for some individual to use during activities of daily living. A manual wheel chair user also experiences a high incidence of upper extremity pain and joint degeneration. Between 25% and 80% long term manual wheel chair users are reported to have injuries to the wrist, elbow, or shoulder. The risk of injury tends to increase with age, while cardio vascular fitness tends to decrease.

While propelling a wheel chair, user encounter obstacles such as bumps, curb descents and uneven driving surfaces. These obstacles causes vibrations on the wheel chairs and in turn, the wheel chair users, which through extended exposure can cause low back pain, disc degeneration and other harmful effects to the body. Typically seating systems are prescribed by clinicians based on the ability of the cushion to reduce pressure and provide proper positioning.

Basically the three-wheelers are made in the wayside workshops as ordered by the individuals and definitely the quality is not up to standard. There are some NGOs like, Centre for Disability Development (CDD), Centre for Rehabilitation of the Paralyzed (CRP) etc. working for the physically disabled people and producing some manual wheel chairs and three-wheelers, somehow suitable for outdoor use. But again the problems remain, as the users need to use the physical force to drive it.

So a need emerges strongly for a specific transport/vehicle which can overcome all these problems/limitations and provide necessary facilities and comfort for the disabled people. it is very important to come out of the problem and find out a suitable solution for the crippled people. Crippled or disabled people need to be helped not to use physical force; reducing their dependability, ensuring comforts, enhancing their mobility and moreover ensuring the use of echo-friendly /green energy for practical day to day life.

Wheel Chair and seating biomechanics research includes studies to prevent secondary conditions due to wheel chair and seating use (e.g. pressure ulcers, adverse changes in posture, repetitive strain injuries) and to reduce the incidence of accidental injuries(e.g. Injuries from wheel chair tips and falls, injuries from motor vehicle accidents). Solar Three-wheeler can be the specific solution for crippled or disabled people. If there is Solar Three-wheeler (solar wheel chair) then disabled people will no longer have use physical force or even wait for hours to charge batteries, depending on grid power or load shedding; even the people can use it where there is no electricity.

However, some photographs of the presently available wheelchairs and three-wheelers in Bangladesh are shown in Figure 2.1.

(a) Wheelchair (b) Three-wheeler (c) Three-wheeler

Figure 2.1: Different types of available wheelchair and three- wheelers

The common size and basic dimensions of the presently available wheel chairs and three-wheelers are shown in Table 2.1.

Table 2.1: Basic dimensions of the presently available wheel chairs and three-wheelers

Wheel chair	**Three-wheeler**
Length:97 cm	Length:145 cm
Width:56 cm	Width: 97 cm
Height:71 cm	Height: 86 cm
Rear Wheel Dia.:51 cm	Rear Wheel Dia.:68cm
Front wheel Dia.:15cm to 20cm	Front Wheel Dia.:68cm

2.4 Drawbacks of Available Wheel Chairs/Three-Wheelers

There are lots of technical drawbacks with the presently available three-wheelers. These are manual - needs physical force to drive that is the user to push the wheels to rotate it and this action causes secondary injury such as upper extremity repetitive strain injuries, vibration exposure injuries, pressure ulcers, accidental injuries etc.

Most of the three-wheelers are crude or of inefficient design, over weight, improper size, less stable, lack of safety measures etc. and not suitable for outdoor use or suitable for Bangladeshi terrain. Ergonomics or biomechanics are not well considered while making it. Less of mechanical safety observed and there is no shed for protection to the user against adverse environment like sunshine, rain etc.

2.5 Reasons for Designing a Solar Three-Wheeler

Humanity point of view and prevention of secondary injury/disability: Manual wheelchairs or three-wheelers have a basic problem that the occupant must use physical force to turn the wheels. This is just to add insult to injury. This action is physically stressful, can result in muscle and joint pain and degradation, torn rotor cuffs, repetitive stress injury, and carpal tunnel syndrome. So, crippled or physically disabled people need to be helped not to use physical force and prevent their secondary injury or further disability.

Use of eco-friendly renewable solar energy: Rapid development of the present world is undoubtedly the blessings of the modern science and technology; but in there are many bad impacts/affects of this development on the surroundings and environment as a whole, like depleting limited energy resource, damage of ecosystem, environment pollution, global warming and so on. The whole world is very much worried and looking for sustainable energy option, putting efforts to develop environment friendly machinery and equipments using renewable energy like solar power. So, Designing for Environment (DFE) and use of clean energy like solar energy is the cry of the time need and there is no way to avoid it for our existence, fighting global warming and climatic change. Development of a Solar Three-wheeler for disabled people would be such a vital effort where solar energy and its advantages are taken into account. A solar powered three-wheeler using solar panel to get required solar power for its movement and thereby ensuring the use of echo-friendly (green) energy for our practical day to day life.

Off-grid power system: If we use solar three-wheeler then we will no longer have to depend on grid power. Solar power is available at anywhere of the country. So, no need of grid-power/electricity and very much suitable for any location, for remote areas where there is no electricity.

Independency and wide mobility: As the solar three-wheeler has it's own power and durable storage; logically it is quite independent (stand alone system) and ensures better mobility.

Better maneuver ability and Turning balance: Solar power three-wheeler provides more maneuver ability as the design allows for a turning radius that is quite tighter - turning with a smaller radius than that of a wheel chair/transport having four wheels. So it is suitable for narrow roads. More so, low speed and better design ensures stability, turning balance as well.

All terrain traffic ability: The terrain conditions at urban or rural areas are not same. But there are physically disabled people everywhere. So, a solar three-wheeler is required which can move in all the places over the country or suitable for common roads around the country, the terrain in Bangladesh. For this, all terrain tires are considered for the three-wheeler.

Speed: Speed is a very important for our mobility. The speed of the manual wheel chairs is not continuous as it needs physical efforts. Again over/higher speed is not suitable for disabled person from biomechanics point of view. Higher speed causes jerks, instability and even accidents which are dangerous for the users. In consideration of the above, the designed maximum speed is 6 km per hour and can be controlled (lower down) by the speed control system.

Biomechanics: It is always considered and definitely better for designing a three-wheeler for disabled for better health. Because the seating style, comforts and some other factors are very much important for the disabled people as they need to sit some times for quite longer period. So, the existing problems with manual and electrical wheel chairs are identified and taken in to account while this solar three-wheeler is designed.

Protection from adverse environment: Solar panel at the top of the solar three-wheeler will protect the user from sun-shine and rain to some extent.

Cost effectiveness: Use of available resources (for components such as bearing, pipes for body, etc are available in the market) and simplicity in design results cost economy. The battery used, motor and solar panels are also very much available in our Bangladesh market. All these features make the three-wheeler a very cost effective.

Scarcity of energy is a common problem in all over the globe due to lack of conventional energy sources. So, Eco-friendly renewable energy (i.e. solar energy, wind energy etc.) can be the alternative and solve the power problem remarkably/to some extent. Solar energy is the most available and easiest source of renewable energy over other means. Availability of solar energy radiation is the most vital consideration for designing and development of a solar system or solar equipment at any location on the earth. Rated solar radiation power (global radiation flux) received by the earth surface is 1000 W/m^2 (AM 1.5, sun at about 48 ° from overhead position).

Availability of solar energy radiation in all over the country is very much encouraging for developing a solar three-wheeler for disabled people in Bangladesh. The geo-location of Bangladesh is in favor of receiving highest amount of solar radiation round the year. It is situated between 20.30-26.38 degrees north latitude and 88.04 - 92.44 degrees east, which is an ideal location for solar energy utilization. Solar radiation mapping shows that the daily average solar radiation varies between 4-6.5 kWh/m^2. Maximum amount of radiation is available on the month of March-April and minimum on December-January [5].

The researches have been going on producing solar car, solar plane and so on. In the transportation sector, the use of solar energy faces different problems, such as the limited space for panel, batteries, transmission problems etc. Many researchers in the world attempted to carry out the idea of a solar car, jointly forming as association and establishing a yearly race for solar powered cars, in different county each year. These works show the design parameters for a solar car only and no significant achievement yet for a suitable solar three-wheeler for disabled people.

Since the solar power system suits well with the minimal power consumption, the development of the solar three-wheeler was very much feasible as it as mini transport needs comparatively smaller power for the power system. It has been investigated and calculated/experienced that a 100 W solar panel is good enough to support the daily power requirement.

However, the most challenging part of the solar three-wheeler project was to use the limited solar energy effectively, maximize its efficiency and ensure suitability/traffic ability on our terrain. It is once again proved that successful implementation of the project depends on how successfully and exactly the problems are identified.

Considering the physical condition and comforts for crippled people, low speed, outdoor use, over all road condition, availability/crisis of electric power, better mobility; a solar three-wheeler can be the complete solution for crippled/disabled peoples of all over Bangladesh.

Chapter 3
SOLAR RADIATION AND PHOTO VOLTAIC SYSTEM

3.1 The Sun

Many people on the Earth are fascinated by the existence of the sun. There are several examples in human history that the sun became an object of worship and people believed that it possessed divine powers. No wonder, the sun is the source of all life and power on the Earth. The sun is an intensely hot, self-luminous body of gases (mainly hydrogen and helium) at the centre of the solar system. Figure 1.1 shows a photograph of the sun. The sun is a medium-size main sequence star. Here are some basic technical facts about the sun as bellow:

Mean distance from the earth: 149,600,000 km (the astronomic unit)

Diameter: 1,392, 000 km (109 × that of the earth)

Volume: 1,300,000 times that of the earth

Mass: 1,993 × 10^{27}kg (332, 000 times that of the earth)

Density (at its center): >100 × 10^{3} kg m-3 (over 100 times that of water)

Pressure (at its center): over 1 billion atmospheres

Temperature (at its center): about 15, 000, 000 degrees Kelvin

Temperature (at the surface): 6, 000 degrees Kelvin

Energy radiation: 380 × 10^{21} kW

The Earth receives: 170 × 10^{12} kW

3.2 Solar Radiation

All substances, solids, liquids and gases, at temperatures above absolute zero, emit energy in the form of electromagnetic waves. This energy is called radiation. The sun is an intensely hot, self-luminous body of gases (mainly hydrogen and helium) at the centre of the solar system and it is the prime source of energy into the atmosphere. Due to it's temperature, it continually (emits energy in the form of electromagnetic wave) sheds part of its mass by radiating waves of electromagnetic energy and high-energy particles into space which is called solar radiation or solar radiation energy.

The energy from the sun is transferred to the earth in the form of photons (small packet of energy) moving at the speed of 3×10^8meter per second. This photon's energy can be converted into heat energy, chemical energy, electrical energy etc.

Many times there are misconceptions and people tend to believe that energy and power are the same and they use these two different terms for same meaning. Solar energy and the solar power are not same. Energy is defined as the capacity of a body to do the work. Energy neither be created nor destroyed. It has many forms, viz. chemical, mechanical, electrical etc. During application of energy, it changes from one form to another but total energy always remains constant. Power is not the same as energy. Power is the rate at which energy is used. Power (watts) = Energy (Joule)/Time (second).

The solar radiation spectrum: The electromagnetic radiation emitted by the sun shows a wide range of wavelengths. It can be divided into two major regions with respect to the capability of ionizing atoms in radiation-absorbing matter: ionizing radiation (X-rays and gamma-rays) and nonionizing radiation (UVR, visible light, and infrared radiation). Fortunately, the highly injurious ionizing radiation does not penetrate the earth's atmosphere.

Electromagnetic waves or photons are characterized either by their frequency (f) or their wavelengths (λ). Solar radiation is commonly divided into various regions or bands on the basis of wavelength. The wave length of solar radiation is given in micrometers (1 micrometer= 1× 10^{-6} meter) or nanometers (1 nanometer= 1×10^{-9}meters).A photon can also be described in terms of energy that it carries. The energy of the photon is given in the units of electron-volts or eV.

The sun emits energy in a wide range of wavelength, between 0.15 and 120 micrometers. The radiation of practical importance as far as solar energy applications are concerned is between 0.15 and 4.0 micrometers, which consists of about 99% of solar radiation. The radiation in this range consists of ultraviolet radiation, visible radiation and infrared radiation. About 48% of energy received on the earth is in the form of visible radiation and about 43% energy received in the form of infrared radiation, while about 7.5% is received in the form of ultraviolet radiation. The distribution in terms of web length and amount of energy carried is given in Table 3.1 as well as Figure 3.1

Table 3.1: The distribution in terms of web length and amount of energy carried[10]

Name	Range of web lengths(micrometers)	Energy carried (%)
Ultraviolet radiation	0.15 to 0.38	7.6
Visible radiation	0.38 to 0.72	48.4
Infrared radiation	0.72 to 4.0	43
Other radiation	>4.0	1

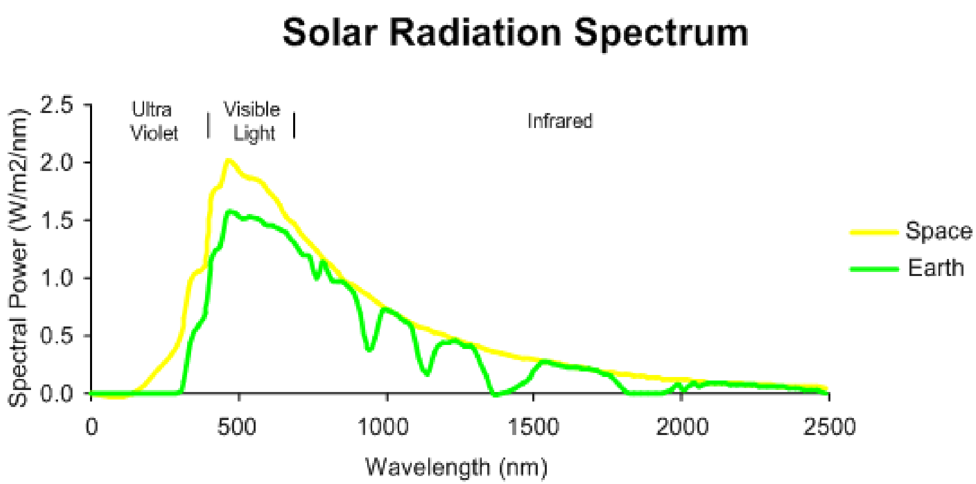


Figure 3.1: Solar radiation spectrums

Extraterrestrial radiation: The amount of solar radiation received by the planet depends on its distance from the sun. The earth is about 1.5 x 10^{11} meter away from the sun. The extra terrestrial radiation refers to the amount of radiation falling on the earth, outside its atmosphere. The extra terrestrial solar radiation received by the earth is essentially constant through the year as the medium, the vacuum, between the earth and the sun does not change with the time and the distance between the two remains nearly constant.

The extraterrestrial solar radiation is often given in terms of solar constant, which is defined as average radiation intensity received per unit area perpendicular to the earth surface at mean sun earth distance. The solar constant is taken as 1367 W/m^2.

Measurement indicate that the energy flux received from the sun out side the earth's atmosphere is essentially constant. The solar constant (I_{sc}) is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun. The value of the solar constant has been the subject of many experimental investigations. Based on measurement up to 1970, a standard value of 1353M/m^2 was adopted in 1971. However, based on subsequent measurement, a revised value of 1367 M/m^2 has been recommended.

Solar radiation on the Earth surface: Solar radiation assed through the earth's atmosphere before it reaches to the earth surface. The thickness of the earth atmosphere is referred to as Air Mass (AM). During the journey in the atmosphere, the radiation is subjected to absorption and scattering, which reduces the amount of solar radiation reaching the surface. Absorption and scattering occurs due to the presence of ozone, water vapour,CO_2, O_2, dust particles etc. in the atmosphere. The solar radiation intensity as a function of wavelength is given in the graph below.

The amount of attenuation of solar radiation depends on the distance that the solar radiation travels through earth's Air Mass. When radiation measured out side the earth's atmosphere (extraterretrial) then it is call AM 0 radiations; air mass traveled is zero. At earth surface, when the sun is exactly at overhead position, then it is called AM 1 radiation. But when sun is at some angle to the overhead position, rays need to travel more distance in earth's atmosphere to reach surface. If the distance traveled by radiation is 1.5 times the AM 1, then it is called AM 1.5. The amount of solar radiation reaching the earth surface through different air mass is tabulated in table 3.2

Table 3.2: Solar radiation reaching the earth surface through different air mass [10]

Distance traveled by sun rays to reach earth's surface or Air Mass	Solar radiation flux reaching the surface(W/m^2)
AM 0 (extraterrestrial)	1376
AM 1 (sun at overhead position)	1105
AM 1.5(sun at about 48° from overhead) position	1000
AM 2 (sun at about 60° from overhead)	894

Solar radiation suffers absorption and scattering before it reaches the earth surface. The term pertaining to solar radiation are now defined as below:

Short wave and long wave radiation: Incoming radiation from the sun is the short wave radiation. It has more energy. Whereas the reflection from the earth is the long wave radiation it has less energy. Only 0.4 – 0.7 μm wave length is visible to human eyes.

Extraterrestrial radiation: In space solar radiation is obviously unaffected by the earth's atmosphere and has a power density of approx. 1370 w/sq-m. This is called extraterrestrial radiation.

Direct or beam radiation: Radiation that is not reflected or scattered and reaches the earth's surface directly in line from the sun is called direct or beam radiation.

Diffuse radiation: The scattered radiation (scattered by aerosols and dust) which reaches the ground is called diffuse radiation.

Albedo: Part of radiation (nearly 30%) reflected back from the ground is called Albedo.

Sun at Zenith: It is the position of the sun directly overhead.

Air Mass (AM): It is the ratio of the path length of the beam radiation through the atmosphere, to the path length if the sun were at Zenith. At sea level AM=1, when the sun is at zenith or directly overhead. AM=2, when the angle subtended by Zenith and line of sight of the sun is 60°; AM=0 , just above the earth's atmosphere. At Zenith angle θz, the air mass is calculated as, Air Mass, AM= Sec θz.

Irradiance (W/m²): The rate of incident energy per unit area of a surface is termed as irradiance.

Total or Global radiation: Total or Global radiation = Beam radiation + Diffuse radiation.

Radiation of solar energy to and from the earth: The following figure shows the Radiation of solar energy to and from the earth.

The following figure 3.2 and figure 3.3 shows different radiations and solar spectrums from the sun.

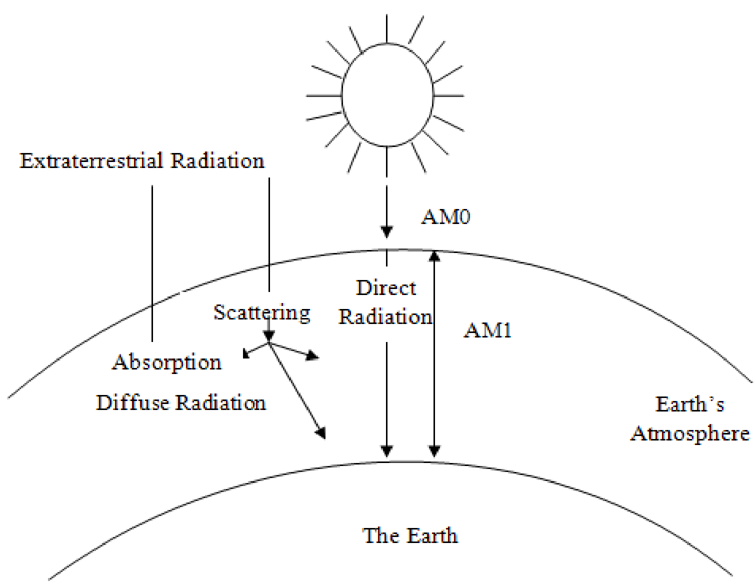


Figure 3.2: Different types of solar radiation [10]

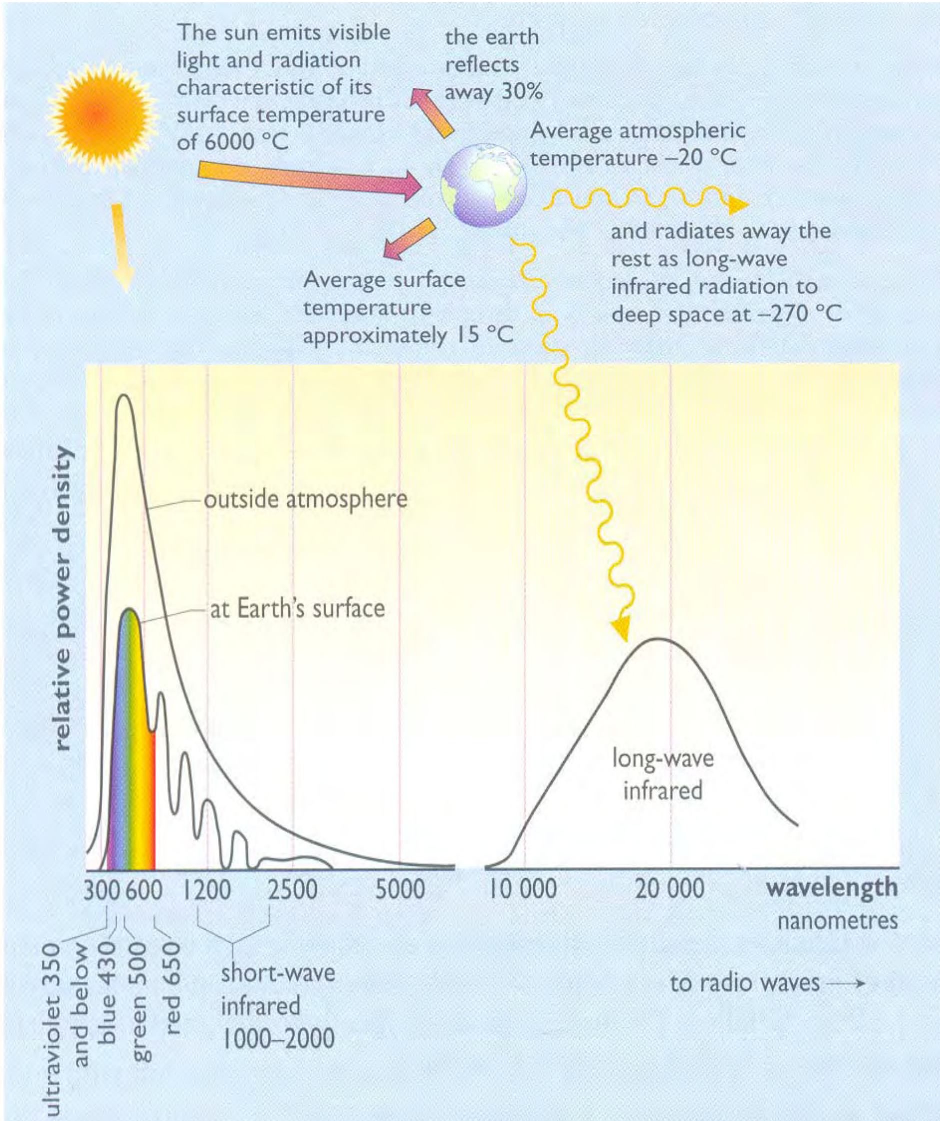


Figure 3.3: Spectral power distribution of solar radiation

Solar radiation at a given location: In order to design devices that use solar radiation, it is important to know the amount of solar radiation available at that location, at a given time. Knowledge of solar radiation requires information about many parameters which includes latitude and longitude of the location, time of the day, day of the year, surrounding weathers, temperature etc. These data are actually the fundamentals to the calculation of sun's position and finally to calculate solar radiation.

Daily radiation pattern: The sun rises in the east and sets in the west. Early in the morning the Zenith angle (the angle between sun rays and line perpendicular to the horizontal plane at any location) of the sun is high. The zenith angle of the sun decreases as the time approaches noon. At noon zenith angle is smallest and amount of solar radiation (Global) received by a location is the highest at that given day. Again the zenith angle increases in the evening and solar radiation declines. A typical daily pattern of global and diffuse solar radiation at a location given in Figure 3.4.

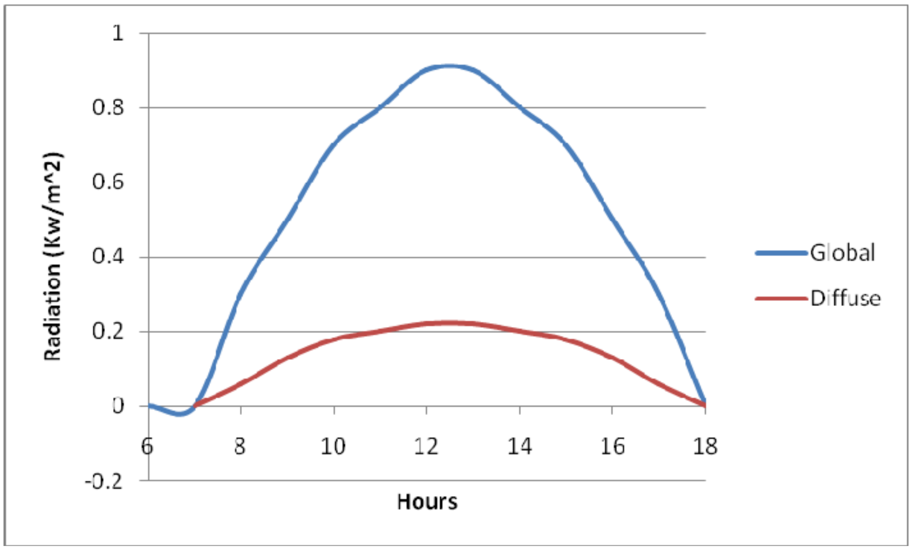


Figure 3.4: Daily pattern of global and diffuse solar radiation [10]

Annual variation in solar radiation: The motion of the earth and it's relation ship with the sun shows that the earth revolves around the sun and also rotates around it's own axis. The earth's own axis of rotation is inclined (by an angle of 23.5 °) with respect to the perpendicular to the plane of it's rotation around the sun as shown in figure 3.5.

The inclination of the earth axis and it's rotation around the sun is the fundamental to the change in seasons during the year.

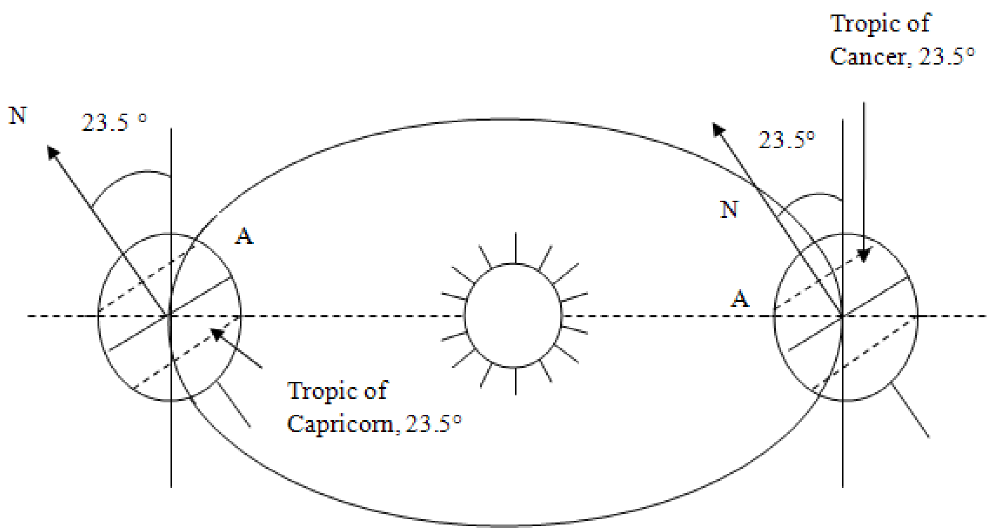


Figure 3.5: Rotation of the earth with respect to sun, demonstrating point 'A' on the earth going through summer and winter season[10]

The equator, the tropic of cancer and tropic of Capricorn are shown in the figure 2.5;It can be seen from the figure that on 21st June (known as summer solstice) location, point 'A', at tropic of cancer(latitude of 23.5° north)will become directly over head to the sun at noon. Therefore, location at tropic of cancer will get maximum radiation on 21st June. Similarly on 21st December (known as winter solstice), tropic of Capricorn (latitude of 23.5° south) will become directly over head to the sun at noon. The location, point 'A', in December will be making an angle of about 23.5° + 23.5° = 46° with the line joining the sun and the earth. Due to this angle, the amount of radiation reaching the point 'A' will be less than the case when point 'A' was on June 21st . However, the seasons on the earth are the result of inclination of earth axis by 23.5° to the plane n which it rotates.

Optimal tilt for solar equipment/panel: Let us consider a point 'A' (latitude 23½° north) on the tropic of cancer as shown in figure 3.7. Solar conversion equipment is installed at point 'A'. It can be seen from the figure that the location 'A' will get maximum sun light during the summer, that is June when the sun is at overhead position at noon.

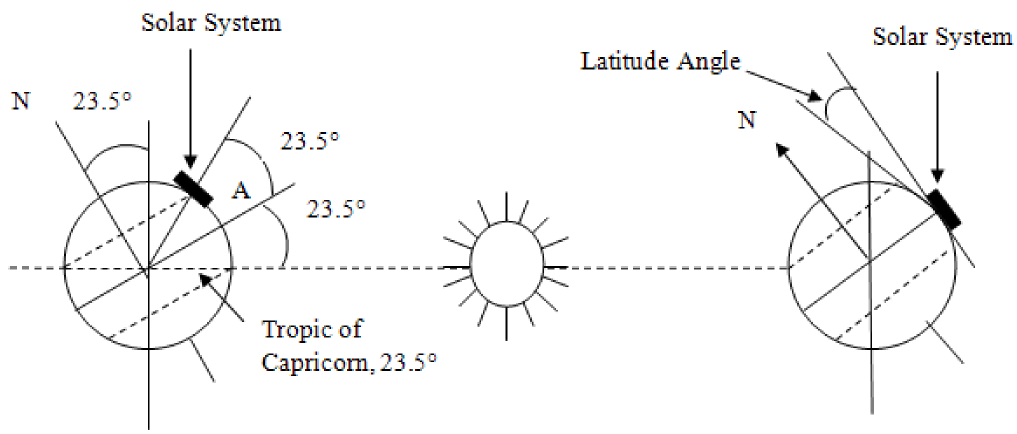


Figure 3.6: Optimal tilt for a solar panel/equipment[6]

The same point 'A' will get very small radiation during the month of December or in winter as the horizontal surface at point 'A' in December will receive the radiation at angle equal to latitude + inclination of earth axis(23½° + 23½°= 47°)

But many times it may be needed that a solar system should collect nearly same amount of radiation through out the year. In order to achieve that it is best to incline the solar system (panel) at an angle equal to the latitude angle. Due to the adjustment the value of maximum angle between sunrays at noon and a solar system will be the equal to angle of earth's axis inclination angle only. Therefore, the solar system inclined at latitude angle will get more radiation in winter as compared to flat surface at same location. From the figure, it can also be noticed that a solar system located in the northern hemisphere should be faced towards south and a solar system that is located in the southern hemisphere should be faced to wards north.

There are systems which track the sun, i.e. the systems adjust themselves in a position perpendicular to the sunrays. If sun tracking is being done, there is no need to install a system at an angle equal to the latitude angle of the location. A solar system should be installed at an angle equal to the latitude angle of the location in order to receive homogeneous solar radiation through out the year.

Latitude (φ): The latitude φ of a place is the angle subtended by the radial line joining the place to the center of the earth with the projection of the line on the equatorial plane. Conventionally, the latitude of northern hemisphere is measured positive.

Declination (δ): The declination δ is the angle subtended by the line centers of the earth and the sun with it's projection on the earth's equatorial plane. Declination occurs as the axis of the earth is inclined to the plane of it's orbit.

The declination angle changes from a maximum value of +23.5° on 21st June to a minimum of -23.5° on 22nd December. The declination is zero on two equinox days, i.e. March 22 and September 22. However the angle of declination may be calculated as suggested by Copper (1969); δ (in degrees)= 23.45 Sin [(360/365)(284+n)], where n is the total number of days counted from 1st January till the date of calculation[6].

Standard test condition of a PV:

Standard test condition of a PV module is as follows:

- Air mass is 1.5 [AM 1.5]
- Temperature is 25°C
- Irradiance is 1000 w/sq-m

3.3 Availability of Solar Energy Radiation in Bangladesh

Amount of solar radiation available at a given location varies from location to location and season to season, its knowledge is important for designing and estimating the output from a solar energy system.

The geo-location of Bangladesh is in favor of receiving highest amount of solar radiation round the year. It is situated between 20.30 - 26.38 degrees north latitude and 88.04 - 92.44 degrees east which is an ideal location for solar energy utilization. Daily average solar radiation varies between 4 to 6.5 kWh per square meter.

Solar irradiation map in Bangladesh was jointly prepared by Renewable Energy Research Centre (RERC), Dhaka, Bangladesh and National Renewable Energy Laboratory (NREL), USA .Maximum irradiation all over the country was observed in the month of May and minimum was observed in December. In general, maximum amount of radiation is available on the month of March-April and minimum on December-January [5].

Solar Mapping (Solar irradiation map of Bangladesh): Solar radiations of different intencity in different parts all over the country are shown by the solar mapping. Variations of solar intencity are shown by the different color sheddings as shown in figure 3.7 and 3.8. The total solar radiations are expressed in kWh/m²/day.

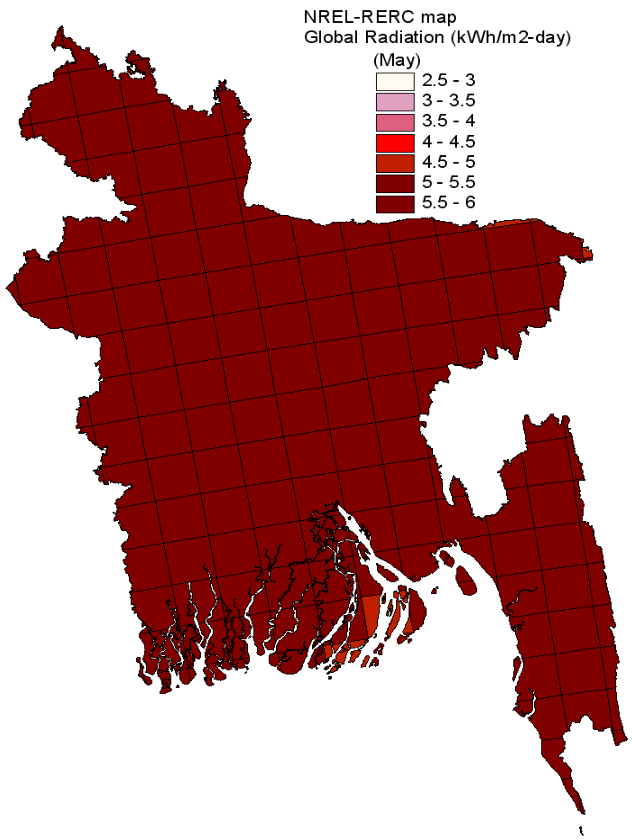


Figure 3.7: Solar radiation map for the month of May [5]

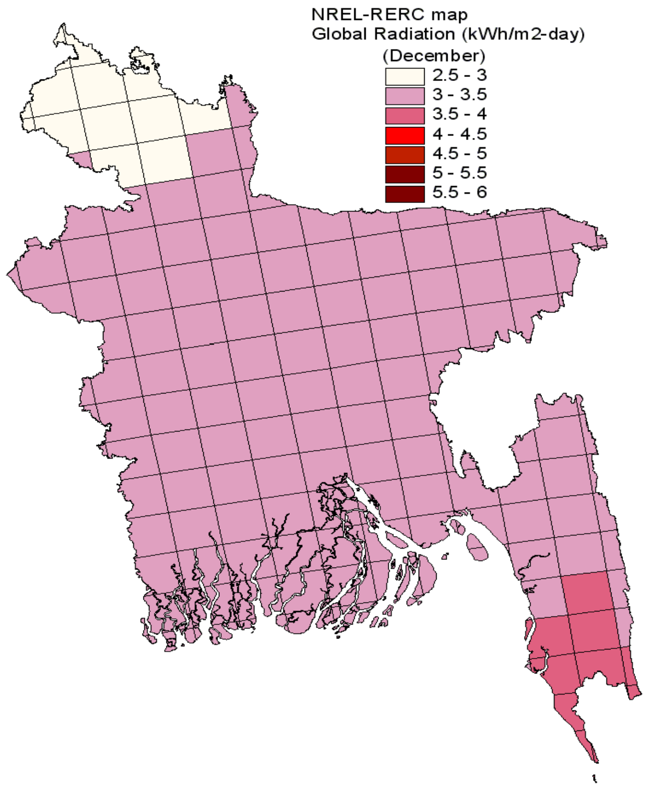


Figure 3.8: Solar radiation map for the month of December [5]

3.4 Solar Technology

In general, solar technology is the technique of converting sunlight (solar energy) to any other form of energy using some equipment. There are varieties types of technologies associated with solar power. These technologies can be basically divided into two groups.

- The first group is those that use the sun light to generate heat, called solar thermal technology. Solar thermal technologies include solar concentrator power systems, flat plate solar collectors, and passive solar heating.
- The other group directly converts the sun light directly into electricity through the photoelectric effect (with out going through a thermal process) by using photovoltaic technology.

The following diagram (Figure 3.9) gives an idea about solar photovoltaic technology and system as well:

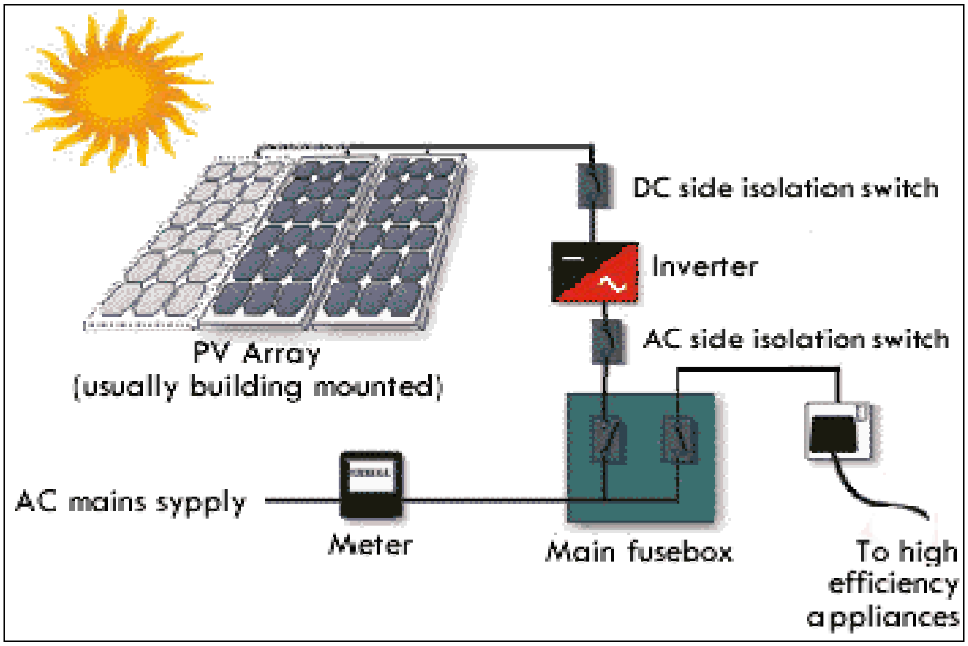


Figure 3.9: Solar photovoltaic system

3.4.1 Solar Photovoltaic Technology

Photovoltaic is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Photovoltaic (PV) technology is the technique of direct conversion of light into electricity at the atomic level. Some materials (semi-conductors) exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured an “electric current” result that can be used as electricity.

3.5 Solar Cell

A basic photovoltaic cell is commonly known as solar cell. A solar cell is a solid state device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Semiconductor materials like Silicon, Gallium Arsenide, Indium Phosphide, Cadmium Tellurium etc. are used in the microelectronics industry to make solar cells. It is to be mentioned that for solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. PV cells consist of a junction between two thin layers of dissimilar semi conducting materials. One is the positive type semiconductors or ‘p’ type and the other is the negative type semiconductors or ‘n’ type. The components of a solar cell are shown in Figure 3.10.

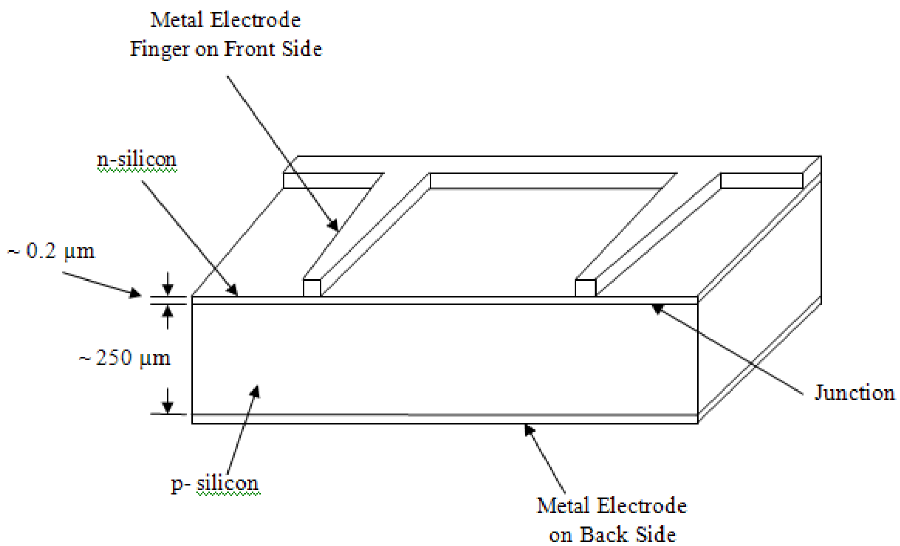


Figure 3.10: Solar cell components [6]

When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

Most of the cases, the cells are of Si solar cells as shown in figure 3.11. The junction is made between p-type and n-type silicon. When light falls on p-n junction, the voltage generated is about 0.5 to 0.6 volts. This generated voltage is then capable of supplying current in the circuit, which can be used for any electrical application. The voltage across a solar cell is generated as long as light is falling on it. As soon as there is no sunlight (for instance, during night) voltage generated across the solar cell is zero. Thus under sunlight, a solar cell acts like a charged battery.

Figure 3.11: Silicon solar cell

Theory of Solar Cell: The solar cell works in three steps:

1) Photons in sunlight hit the solar panel and are absorbed by semi conducting materials, such as silicon.
2) Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
3) An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

There are different types of solar cell such as:

1) Mono-crystalline silicon cells
2) Multi or Poly-crystalline silicon cells
3) Thin film solar cells (Amorphous)
4) Triple Junction cells

3.5.1 Power Output of Solar Cell

Power out put of a solar cell depends on cell efficiency, it's size, intensity of light and surrounding temperature to some extent. Different types of cells having different efficiencies.

Basically, the amount of power a cell can produce depends on cell efficiency and solar cell area.

- A 15% efficient solar cell can convert 15% of light (falling on to it) in to electricity.
- Larger the cell area, the larger will be the power out put. Because, in case of larger solar cell, we are collecting light from larger area.
-

Typically solar cells are characterized by 1000 watts per meter squire(W/m^2) falling on the solar cell at 25°C temperature, which is a world standard. Thus 10 cm by 10 cm solar cell having area of 100 cm^2 or 0.001 m^2 with 15% efficiency under 1000 W/m^2 solar condition will give following power output; Power = 15%(cell efficiency) x 0.01 m^2(cell area) x1000 W/m^2(solar radiation) = (15/100) x 0.01 m^2 x 1000 W/m^2 = 1.5 W.

Most commonly found solar cells are silicon solar cells and mono-crystalline silicon cells are having better efficiency than that of other types. Normally, a commercially available solar cell having the dimension of 3 inches by 6 inches. A 3 x 6 solar cell's electricity output is likely rated at 0.5 volts with 3.2 to 3.5 amps. If we break that solar cell into two equal halves, we would get two solar cells that rate at .5 volts and 1.5 amps each. So volts stay the same, but amps changes with solar cell size. As we know, Watts equals to Volts multiplied by Amps; a (3 x 6) solar cell put out .5 volts and has 3.3 amps in general. A Cell power out put is equal to 1.65 watts.

3.6 Solar Panel/Module

A Solar cell is the basic unit of a solar module/panel. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. The current produced is directly dependent on how much light strikes the module.

A module can be described as:

- Solar cells are often electrically connected and encapsulated as a module.
- Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from the elements (rain, hail, etc.).
- Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current.
- There are generally 30 to 36 solar cells per module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. Typical small PV systems use a single panel to charge a 12 volt battery.
- The energy generated from these solar modules, referred to as solar power, is an example of solar energy.
- Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak DC voltage and current.

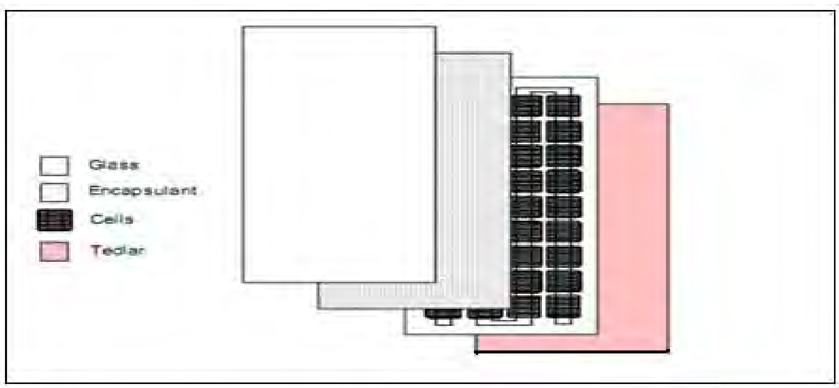


Figure 3.12: Module assembly

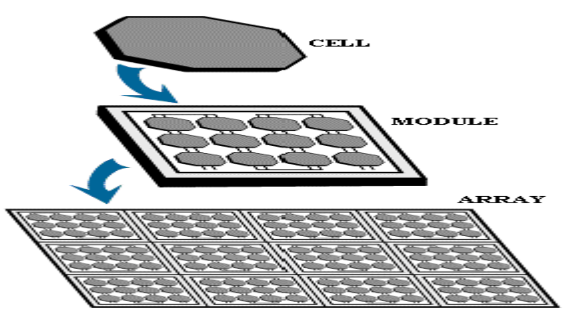


Figure 3.13: Solar cells,Modules and Arrys

3.6.1 Types of Solar Panels

Solar panels are special devices that harvest the sun's light and turn it into energy that can be used for a lots of things. They are also referred to as active solar power producers. The solar panel is made of a lot of solar cells. These solar cells, also known as photovoltaic cells are arranged on the panel's surface in a grid like pattern. During the day if exposed to sunlight these solar cells will collect the energy that comer from the sun and transform it into electrical power that is stored in special batteries attached to the solar panel.

Solar panels are usually made of crystalline silicon that is used for the microprocessor industry and of gallium arsenide which is used only for making the solar cells. Modern solar cells are recently made of amorphous silicon alloy and this is why you might find them under the name of A-Si. Using the amorphous silicon technology in building up a solar panel will make the new product be more durable, thinner than the older ones and more efficient.

Solar panels are not used only by regular people for day to day activities; they are also used in space for the solar projects. These solar panels are made up of gallium arsenide through the molecular beam epitaxy process. P-n junction diodes are implemented to the solar cells included in those solar panels making the whole system working at higher standards that we could ever imagine. Due to the high costs that are involved for building such a great solar panel they are not rentable for the everyday activities. Different types of solar panels are as follows:

1) Mono crystalline solar panels

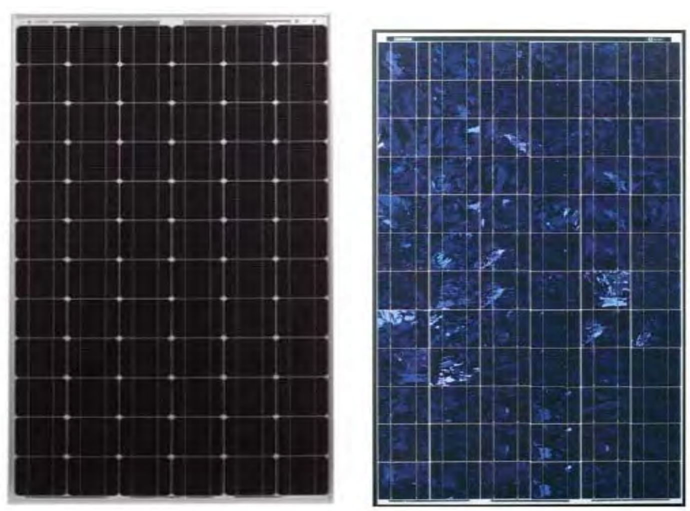
The most efficient and expensive solar panels are made with Mono crystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Long silicon rods are produced which are cut into slices of .2 to .4 mm thick discs or wafers which are then processed into individual cells that are wired together in the solar panel.

2) Poly crystalline solar panels

Often called Multi-crystalline, solar panels made with Polycrystalline cells are a little less expensive and slightly less efficient than Mono crystalline cells because the cells are not grown in single crystals but in a large block of many crystals. This is what gives them that striking shattered glass appearance. Like Mono crystalline cells, those are also then sliced into wafers to produce the individual cells that make up the solar panel.

3) Amorphous solar panels

These are not really crystals, but a thin layer of silicon deposited on a base material such as metal or glass to create the solar panel. These Amorphous solar panels are much cheaper, but their energy efficiency is also much lower. So, more square footage is required to produce the same amount of power as the Mono crystalline or Polycrystalline type of solar panel. Amorphous solar panels can even be made into long sheets of roofing material to cover large areas of a south facing roof surface.



Mono Crystalline Module Poly Crystalline Module

Figure 3.14: Mono and Poly Crystalline Module

Series of Panel/Module: Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Figure 3.15: Solar array (series of modules)

3.6.2 The Rated and Actual Power from a Module

Normally for PV module, the rated power is measured under sunlight condition corresponding to 1000 W/m² and at 25°C Temperature. The rated power is the peak powers that can be achieved from a PV module. The manufacturers always specify rated power and we buy solar module from the market based on the rated power.
However, in reality the amount of solar radiation varies throughout the day. The solar radiation can be as low as 100 W/m² during the morning hours. During noon, it will typically be in the range of 600 W/m² to 800 W/m² and it is lower than the standard condition (rated power).Also power output decreases due to higher operating temperature. As the operating temperature increases above characterization temperature (25°C), solar cell efficiency decreases and reduced cell efficiency means reduced power output. Typically the actual power output from a PV panel is 20 to 40% lower than rated power value depending on the module temperature.

3.6.3 Modern Trends in Designing PV Module

Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used.

3.7 Solar Power System

It is a system for collecting solar energy for effective use to run any electric equipment or machinery. A solar system effectively harvest solar energy in the form of electricity and make an effective use of it to run different loads or machinery/equipments. There are three broad categories of PV power system: Stand alone system, grid connected and solar power satellite. Stand alone system are virtually self sufficient, are not hooked in to electricity grid, have some backup system and require no maintenance or regular fuel.

3.7.1 System Components

The solar power system normally comprise of some elements like solar module/panel, charge controller, battery, inverter (if necessary) and load/ the equipments etc. are commonly known as system components. The components used in a solar photovoltaic (PV) system other than the panels are referred to as the balance-of-the system (BOS). These are necessary part of the total photovoltaic system. Theses components are divided in to three categories:

- Structure and installation
- Power conditioning and control
- Storage batteries

The following figure 3.16 gives an idea about the solar power system and the system components in general:

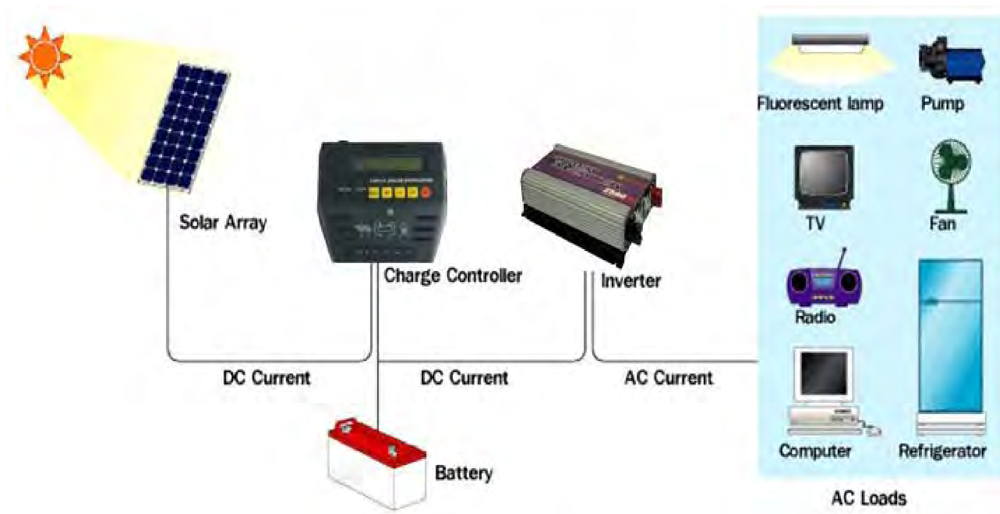


Figure 3.16: Solar system components

3.7.1.1 Solar Panel

The panels are referred to as active solar power producers and deliberately described previously. So, these panels are nothing but the power generator from the sun-light. Solar P V modules (panels) are rated in terms of peak wattage (or watt-peak) and it's symbol is Wp. Watt-peak is the maximum power output a solar panel can provide under Standard Test Condition (STC). Solar PV modules of various power ratings are available in the market. Typical power ratings of solar PV modules are: 3Wp, 5 Wp, 7 Wp, 12 Wp, 20 Wp, 40 Wp, 50Wp, 75 Wp, 90 Wp, 100 Wp,120 Wp, 300 Wp. etc

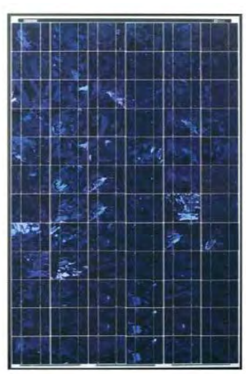


Figure 3.17: A 100 Wp solar panel

Apart from power, solar PV modules are also rated for current and voltage it can supply. Most of the PV modules are designed to give more than 15 volt output voltage in working condition, which is suitable for charging a 12 volt battery. A smaller rating PV module is designed to be used for charging 6 volt battery. Higher output voltage like 24 volt, 48 volt, etc. can also be obtained by connecting the PV modules in series. Current from a PV module directly depends on its size; larger the module, higher the current generated.

There are different types of panels in the market and it's efficiencies also differs. For single crystal silicon, an efficiency value as high as 24.7 per cent has been obtained under laboratory condition. However, for commercially available modules, efficiency ranges between 12 and 16 per cent. The highest value reported is 22.7 per cent. The cost of the PV module depends on its size as well as it's efficiency. Module specifications includes module size, weight, cell size, number of cells, nominal out put, nominal voltage, maximum voltage, open circuit voltage, short circuit current, conversion efficiency etc.

3.7.1.2 Charge Controllers

PV Solar charge controller collects charges from solar panels and charge the battery. It regulates the power from the solar panels and controls the charge of the batteries that means, Solar PV charge controllers take the uncertain voltage from a solar panel and condition it to safely charge lead acid batteries.

These solar PV charge controllers use pulse width modulation (PWM), and a 3 stage charging method, bulk, absorption, and float (maintenance) charge. They also protect the panels from the batteries after the sun goes down. Solar charge controllers are necessary to protect your PV investment. It also cuts out the batteries from the load when the lead acid batteries are depleted to prevent damage to the battery. Sometimes it has LED bar readout to show the status of the solar charging system and batteries.

Figure 3.18: Solar charge controller

3.7.1.3 MPPT Solar Charge Controllers

A basic charge controller simply performs the necessary function of ensuring that batteries cannot be damaged by over-charging, effectively cutting off the current from the PV panels (or reducing it to a pulse) when the battery voltage reaches a certain level. A Maximum Power Point Tracker (MPPT) controller performs an extra function to improve system efficiency. The efficiency loss in a basic system is due to a miss-match between voltage produced by the PV panels and that required to charge the batteries under certain conditions.

A MPPT charge controller extracts maximum power from the solar PV module throughout the day. A MPPT device tries to match the impedance of the module with that of load/battery, which is required for extracting maximum power. With the help of this device about 20 to 40% more energy can be generated.

3.7.1.3.1 Advantages of MPPT Charge Controller

An MPPT controller, in addition to performing the function of a basic controller, also includes a DC voltage converter, converting the voltage of the panels to that required by the batteries, with practically no loss of power. In other words, they attempt to keep the panel voltage at their Maximum Power Point, while supplying the varying voltage requirements of the battery. Furthermore, a 24 volt system with an MPPT charge controller may have the panels wired in series to produce 48 volts, maintaining the ability to provide some charging current in dull conditions, when a standard system would not provide any charge. Manufacturers claim up to 40% power increase from your panels using MPPT, which is most likely to be achieved when battery levels are low and/or light levels are low.

3.7.1.3.2 Inverter

A inverter is a device for converting DC from the array or battery to single or three-phase AC suitable for AC loads. The out put must meet the necessary requirements of the electricity authority in terms of voltage, frequency and the harmonic of the waveform for the grid interactive systems. These are done by the additional transformer and special filtering respectively. BUT this leads to additional losses and increase the cost. In stand-alone systems however, the requirements are much less stringent. An inverter for PV system should have the following in-built features:

- Automatic switch-off it the array/panel output voltage is too high or too low.
- Automatic restart when the array/panel output voltage is within the desired range.
- Protection against short-circuit or overloading.

3.7.1.4 Batteries

Batteries are nothing but the energy storage device. A battery stores energy in chemical forms, which can be converted in to electrical form. To make practical use of the solar energy generated from solar panels, batteries are used to store the energy that is not needed immediately or use it at night time if needed. A battery is rated for it’s voltage output and current capacity. There are many types of batteries such as lead-acid battery, lithium-cadmium battery etc. Special solar type battery or lithium battery can also be used to reduce weight.

Figure 3.19: A lead acid battery

Typically rechargeable batteries are available in 6 volt and 12 volt output. The capacity of a battery is determined by the amount of energy it can store. It's current capacity is given in terms of ampere-hour (Ah) which tells us how much current and for how long can the current be extracted from a fully charged battery. A 10 Ah battery can provide us 10 A current for 1 hour or 1 A current for 10 hours. As the battery size increases, battery's Ah capacity also increases. I most stand alone PV power system, storage batteries with charge regulators have to be incorporated to provide a stable back-up power source during periods of low solar irradiance or at night.

Several types of storage battery are available in the market for use in PV power systems. Each type has it's own particular characteristics. The main requirements to be met by a storage battery for solar power system are:

- Ability to withstand several charge/discharge cycle
- A low self discharge rate
- Little or no need for maintenance.

The capacity of battery is the total amount of electricity(current x time) that can be drawn from a fully charged battery at a fixed discharged rate and electrolyte temperature until the voltage falls to a specified minimum. It is expressed in ampere-hour (Ah).The capacity of battery depends on several factors including it's age and temperature; below 25°C it is reduced by about 0.6% per °C. The depth of discharge should not exceed 80% and battery should not be left uncharged for long. The depth of discharge is the main factor affecting the chare/discharge cycle life. The expected life of batteries varies from 3500 cycles to 1000 cycles for a charge in the depth of discharge from 40% to 80%.

The batteries in most PV systems are of lead-acid type consisting of one or more 2 V cells. Each cell has a positive plate of lead peroxide and a negative plate of sponge lead. The electrolyte is dilute sulphuric acid. During discharging, when current is drawn from it, the material of both plates changes to lead sulphate and water content in the electrolyte increases thereby reduces specific gravity. When battery is charged by passing electric current through it in the opposite direction, the reverse chemical reaction takes place. The cell voltage is typically 2, V and 1.9 V for fully charged and deeply discharged battery respectively. Lead-acid battery self discharge slowly when not in use.

Nickel-cadmium batteries though expensive are ideally more suited to PV system than the lead-acid batteries. The Ni-Cd cells consist of positive plate of Nickel packed with nickel hydroxide while the negative plate is of cadmium immersed in aqueous solution of potassium hydroxide. Ni-Cd batteries have the following advantages over the lead-acid batteries:

- No problems of electrolyte depletion and stratifications
- Less sensitive to temperature
- Less sensitive to rate of discharge
- No problems of electrolyte freezing, and
- No damage if the battery remains fully discharged for long periods.

Battery Voltage: The nominal voltage of a lead-acid battery depends on the number of cells that have been wired in series. As mentioned above, each battery cell contributes a nominal voltage of 2 Volts, so a 12 Volt battery usually consists of 6 cells wired in series.

State of Charge: The State of Charge describes how full a battery is. The exact voltage to battery charge correlation is dependent on the temperature of the battery. Cold batteries will show a lower voltage when full than hot batteries. This is one of the reasons why quality alternator regulators or high-powered charging systems use temperature probes on batteries.

Depth of Discharge (DOD): The Depth of Discharge (DOD) is a measure of how deeply a battery is discharged. When a battery is 100% full, then the DOD is 0%. Conversely, when a battery is 100% empty, the DOD is 100%. The deeper batteries are discharged on average, the shorter their so-called *cycle life*. For example, starter batteries are not designed to be discharged deeply (no more than 20% DOD). Indeed, if used as designed, they hardly discharge at all: Engine starts are very energy-intensive but the duration is very short. Most battery manufacturers advocate not discharging their batteries more than 50% before re-charging them.

Battery Storage Capacity: The Amp-hour (Ah) Capacity of a battery tries to quantify the amount of usable energy it can store at a nominal voltage. All things equal, the greater the physical volume of a battery, the larger its total storage capacity. Storage capacity is additive when batteries are wired in parallel but not if they are wired in series.

Lead- Acid Battery: A lead-acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again. Battery Cells are the most basic individual component of a battery. They consist of a container in which the electrolyte and the lead plates can interact. Each lead-acid cell fluctuates in voltage from about 2.12 Volts when full to about 1.75 volts when empty. Note the small voltage difference between a full and an empty cell (is another advantage of lead-acid batteries over rival chemistries).

Advantages of lead acid battery:

1) Low cost.
2) Reliable. Over 140 years of development.
3) Robust. Tolerant to abuse.
4) Tolerant to overcharging.
5) Low internal impedance.
6) Can deliver very high currents.
7) Indefinite shelf life if stored without electrolyte.
8) Can be left on trickle or float charge for prolonged periods.
9) Wide range of sizes and capacities available.
10) Availability-Many suppliers worldwide.

11) The world's most recycled product.

Shortcomings of lead acid battery:

1) Very heavy and bulky.
2) Typical columbic charge efficiency only 70% but can be as high as 85% to 90% for special designs.
3) Danger of overheating during charging
4) Not suitable for fast charging
5) Typical cycle life, 300 to 500 cycles.
6) Must be stored in a charged state once the electrolyte has been introduced to avoid deterioration of the active chemicals.
7) Gassing is the production and release of bubbles of hydrogen and oxygen due to the breakdown of water in the electrolyte during the charging process, particularly due to excessive charging, causing loss of electrolyte. In large battery installations this can cause an explosive atmosphere in the battery room. Because of the loss of electrolyte, Lead acid batteries need regular topping up with water. Sealed batteries however are designed to retain and recombine these gases.
8) Sulphation may occur if a battery is stored for prolonged periods in a completely discharged state or very low state of charge, or if it is never fully charged, or if electrolyte has become abnormally low due to excessive water loss from overcharging and/or evaporation. Sulphation is the increase in internal resistance of the battery due to the formation of large lead sulphate crystals which are not readily reconverted back to lead, lead dioxide and sulphuric acid during re-charging. In extreme cases the large crystals may cause distortion and shorting of the plates. Sometimes sulphation can be corrected by charging very slowly (at low current) at a higher than normal voltage.
9) Completely discharging the battery may cause irreparable damage.
10) Shedding or loss of material from the plates may occur due to excessive charge rates or excessive cycling. The result is chunks of lead on the bottom of the cell, and actual holes in the plates for which there is no cure. This is more likely to occur in SLI batteries whose plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. This gives a very large surface area

enabling high power handling, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells.

11) Toxic chemicals
12) Very heavy and bulky
13) Lead acid batteries can work down to temperatures below -45 °C, however, like all batteries the discharge rate and effective capacity are reduced at low temperatures. In the case of Lead acid batteries the capacity falls by about 1% per degree for temperatures below +20 °C so that at the lowest temperatures cranking capacity is seriously impaired.

3.7.1.5 Motor Controller

The motor controller controls the overall functioning of the motor as driving unit. It is directly connected with battery, on/off switch, speed regulator/controller etc. In actual sense, it controls electric supply to different units, primly to the motor.

3.7.1.6 Motor

In solar system, load means the machine or equipment which consumes the power. The load may be a light (bulb) or fan or motor or any equipment like TV, refrigerator, radio etc.

The prime mover to be used in this solar three-wheeler is a permanent magnet D.C. motor. The main reason for using this motor is that it is highly efficient and the flux density does not decrease with time. It’s performance characteristics suite very well to the requirement of our solar three-wheeler. At standard load condition, the motor needs 149Watts. This power will cover the required power needed to run the solar three-wheeler at a speed of 6 km/hr. If the load increases or the three-wheeler climbs up-ward slope, then the current will also increase and power output of the motor will also increase. However, considering standard power requirement and the safety, the designed motor power capacity is set to 200 W.

3.8 Advantages and Opportunities of Solar Power

Solar power having lot of advantages and opportunities and human being can easily avail it at any time.

3.8.1 Advantages

Cost Efficient

1) After the initial investment has been recovered, the energy from the sun is practically free.
2) The recovery/ payback period for this investment can be very short depending on how much electricity is required.
3) Financial incentives are available from the government that will reduce cost. It will save money on electricity bill.
4) Solar energy does not require any fuel.
5) It's not affected by the supply and demand of fuel and is therefore not subjected to the ever-increasing price of gasoline.
6) The savings are immediate and for many years to come.
7) The use of solar energy indirectly reduces health costs.

Environmentally friendly

1) Environment friendly and sustainable energy option that is, Solar Energy is clean, renewable (unlike gas, oil and coal) and sustainable, helping to protect our environment.
2) It does not pollute air by releasing carbon dioxide, nitrogen oxide, sulphur dioxide or mercury into the atmosphere like many traditional forms of electrical generation does.
3) Therefore Solar Energy does not contribute to global warming, acid rain or smog.
4) It actively contributes to the decrease of harmful green house gas emissions.
5) It's generated where it is needed.

6) By not using any fuel, Solar Energy does not contribute to the cost and problems of the recovery and transportation of fuel or the storage of radioactive waste.

Independent/ semi-independent

1) Solar Energy can be utilized to offset utility-supplied energy consumption. It does not only reduce your electricity bill, but will also continue to supply your home/ business with electricity in the event of a power outage.
2) A Solar Energy system can operate entirely independently, not requiring a connection to a power or gas grid at all. Systems can therefore be installed in remote locations (like holiday log cabins), making it more practical and cost-effective than the supply of utility electricity to a new site.
3) The use of Solar Energy reduces our dependence on foreign and/or centralized sources of energy, influenced by natural disasters or international events and so contributes to a sustainable future.
4) Storable, can be used at any time as per requirement.
5) Work well for remote location and package of diff. size can be made for diff. power requirement.
6) Solar Energy supports local job and wealth creation, fuelling local economies.

Low/ no maintenance

1) PV solar system users pay only the initial investment and not for the energy they consume.
2) Initial cost is higher but long lasting(20 to 25 years)
3) Solar Energy systems are virtually maintenance free or Least maintenance
4) Once installed, no recurring costs involved.
5) They operate silently, have no moving parts, do not release offensive smells and do not require you to add any fuel.
6) More solar panels can easily be added in the future when your family's needs grow.

3.8.2 Opportunities

1) Off-grid PV solar systems can be affordable.
2) Sizing and estimating cost of a PV system is easy
3) Portable small system can be made for any power requirement.
4) Work even in diffused light
5) Suitable for minimal power consumers
6) In PV solar system load management is more important than power production.
7) Unlimited supply and untapped market.

Chapter 4

DESIGNING OF SOLAR THREE-WHEELER

4.1 Designing of the Solar Three-wheeler

Designing of the solar three-wheeler has two major parts/aspects. Firstly, Designing the three-wheeler and it's components from mechanical and biomechanics point of view and secondly, incorporation of solar power system to the improved manual three-wheeler to achieve automation. Drawbacks of the available manual three-wheelers as well as needs and requirements from the disabled people (users) are seriously considered while making definite improvement in designing. Effective use of limited solar energy (due to limited space/module), energy storage and power requirement (load) are also seriously considered to balance and optimize the solar power system of the solar three-wheeler.

4.2 Design Phases

The overall designing of the solar three-wheeler is done through different phases as: recognition of the needs, definition of problem, synthesis, analysis and optimization, evaluation and presentation as shown in the following diagram (Figure 4.1)

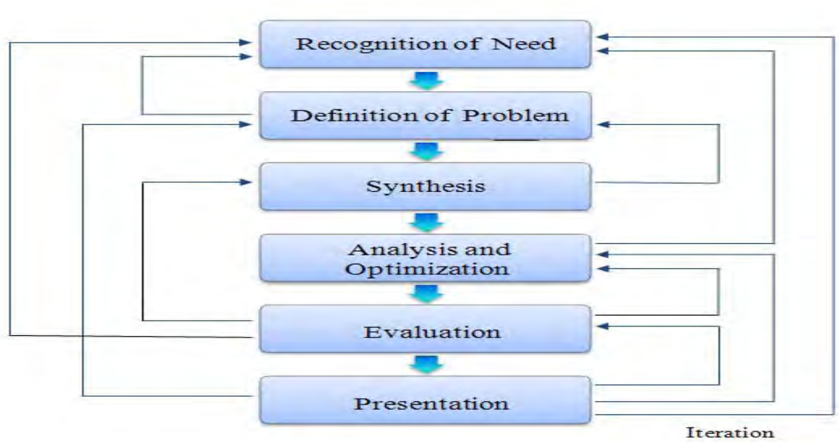


Figure 4.1: Design phases

1) **Recognition of the need:** To design a solar (pollution free) three-wheeler which is efficient, comfortable, economical and suitable for Bangladeshi terrain. Here the disadvantages of the conventional wheel chair, manual three-wheeler or electric wheel chair are tried to eliminate. Demand or requirements from the disabled people are identified and due consideration is given to practical requirements.

2) **Definition of Problem:** The human requirements are translated to technical requirements. This includes all the specifications for the solar three-wheeler to be designed. The specification is the characteristics. The dimension of the space it must occupy. All the limitations on these quantities. The main dimensions are width, length height of the floor from the ground. Weight, fatigue strength, factor of safety, speed, source of power etc.

3) **Synthesis:** The system under design must be analyzed to whether it complies with specifications. The analysis may reveal that the system is not an optimum one. If the design fails either or both these tests, the Synthesis procedure must begin again.

4) **Evaluation:** It is a significant phase of the total design process. Evaluation in the final proof of a successful design and usually involves testing of a prototype in the laboratory. Here I wish to discover if it is the design really satisfies the need or needs. I should consider if it is reliable, will complete successfully with similar products, economical to manufacture and to use. Easily maintained and adjusted, beneficial to disabled or profit can be made from its sale or use.

5) **Presentation:** Communicating the design to other is the final and vital steps in the design process. Undoubtedly many great designs, inventions and creative works have been lost to mankind simply because the originators were unable or unwilling to explain their accomplishments to others.

4.3 Requirements from the Disabled People

A general survey had been conducted among significant numbers of disabled people who are using wheel chairs and manual three-wheelers. They had been interviewed on some specific questions and their problems/needs had been investigated and identified. They came out with their problems, requirements, opinions as well. Basically these are the requirements from the physically disabled persons using manual wheel chair/three-wheelers. The opinions and advices of the experts working with the disabled people are also taken in to consideration. Their overall needs and requirements can be pointed out as below:

1) The three-wheeler should be automatic (power driven) to avoid physical force.
2) Easy to control (steering as well as speed) and better maneuverability in case of narrow space/roads.
3) Comfortable
4) Lighter weight with better safety and stability
5) All terrain traffic ability/mobility and suitable for outdoor use.
6) Available solar power to drive the three-wheeler in average15~20 km distance per day
7) It can be used at any time either in day or night
8) Able to protect the user from the adverse environment like sunshine, rain etc.
9) Having availability of spares
10) Easy maintenance.
11) Cheaper price (lower cost).

4.4 Design Requirements

Basically these are the requirements from the Wheel chair users/ physically disabled persons and experts working with the disabled people. Their requirements can be pointed out follows:

1) Automatic, to avoid physical force.
2) Any time/all time use, either in day or night.

3) Light weight with better safety and stability.
4) Easy to control (steering as well as speed) and better maneuverability in case of narrow space/roads.
5) Comfortable and no occurrence of secondary injury.
6) All terrain traffic ability/mobility and suitable for indoor as well as outdoor use.
7) Available solar power to drive the three-wheeler in average 20 km distance per day.
8) Able to protect the user from the sun or rain.
9) Availability of spares.
10) Easy maintenance.
11) Simple and Economic (lower cost).

4.5 Design Considerations

Design considerations refer to some characteristic which influences the design of the element or, perhaps, the entire system. When one of them becomes critical and it is satisfied, the others no longer need to be considered. The strength of each element, its dimension and geometry are important design consideration from the mechanical point of view. As a transport for the physically disabled people the overall safety, stability, reliability, control, comforts etc are a very much important and must be taken in to consideration while designing it. However, the following general points had been considered in general while designed the solar three-wheeler:

1) Simplicity
2) Strength
3) Reliability
4) Stability
5) Safety
6) Corrosion
7) Wear
8) Cost

9) Weight(light-weight)
10) Noise: higher motor power than the requirement to avoid noise.
11) Style
12) Size
13) Flexibility
14) Control
15) Modularity
16) Effective use of Solar energy
17) Energy storage
18) All terrain tires for all terrain traffic ability/mobility.
19) Comforts
20) Biomechanics
21) DFE principles.

In considering the physical condition of a disabled person, over all terrain condition, safety etc., the speed of the solar three-wheeler is set to 6 km/hr or 100 m/min. This speed will ensure better stability as well as comfort for the user. Power loss due to chain drive is considered as 10% of the power requirement.

4.6 Different Parts/Components of the Solar Three-Wheeler

The main components of the solar three-wheeler are: Chassis, Fork, Rear Axel, Wheels, Body, Seat, Solar panel mounting frame, Solar Panel, Charge controller, Battery, Control panel/motor controller, Motor, Chain and sprockets, Steering System, Speed Controller, Break System, lights, horns etc.

Chassis: Chassis is the main frame of the transport solar three-wheeler. The front part of the chassis is connected/attached with the fork (through bearings) which holds the front wheel and rear axel is jointed with rear side of the chassis. The engine/motor, body frame etc. are normally directly mounted on or attached with the chassis. The chassis can withstand necessary loads as well as absorbs shocks. The solar three-wheeler chassis is designed by using rectangular steel pipes (Steel ASTM-A36) commonly known as box pipes reinforced with angle bars where necessary. The overall length and width are also reduced to some extent.

Fork and Steering: The fork is a very important part of the three-wheeler. The name it self indicates that it holds the front wheel like a fork/clip through its axel with nuts. A normal handle bar decorated with brake lever, accelerator, horn, switches etc. and attached with fork/front wheel is used here as steering. Steering actually steer or guide the front wheel of the three-wheeler to a particular direction as per the driver's desire. A commonly found rickshaw fork and a motor cycle handle are used here in the three-wheeler.

Rear Axel: Normal rickshaw axel (standard size-6) is used here in the three-wheeler with some modifications. The axel is simply made of mild steel solid rod having 1 inch diameter and 34 inches length. The rear axel is attached with the chassis through bearing and bears the rear-side load. One wheel is fixed (jammed) at one end with nuts and anther wheel is attached through bearings at other end of the axel. There is a sprocket at almost middle to receive rotational power from the motor through chain-drive and ultimately the axel rotates the wheels of the tree-wheeler.

Wheels: Commonly found three bicycle wheels of same size (50 cm. diameter each) are used in this three-wheeler; one in front and two in the rear. The wheel rims are of stainless steel and hubs are modified to match the rear axel. Right wheel is fixed (jammed) with the rear axel and left wheel is free to rotate as attached through bearings. Actually the power is transferred on right wheel that is the axel rotates the right wheel and left wheel works as a support only. There are tubes inside the wheel-tires. All terrain tires are used for better traffic ability. The total load of the three-wheeler exerted on ground through the wheels and three-wheeler moves on wheels.

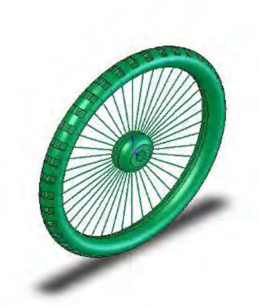


Figure 4.2: Wheel

Body: The body of the solar three-wheeler is made of pipes, steel sheets of minimum possible thick-ness and woods for lighter weight. While modeling; sharp edges, bends, nails are avoided to avoid accidents and ensure better safety. The basic size and dimensions of the solar three-wheeler are set to: Length: 168 cm, Width: 86 cm, Height: 152 cm with the ground clearance of 20 cm.

Seat: A water proof cushioned seat is used for comfortable sitting. This is adjustable in nature, set on a seat-frame fixed with the chassis almost in middle. There is a groove or slide-way on seat frame over which the seat can slide over to front or rear direction as necessary and then locked with the screws and nuts. Overall shape and sizes of the seat matches with seating ergonomics or biomechanical theories.

Solar Panel Mounting Frame: It is a mild steel (high strength and light weight) rectangular-pipe (box-pipe) frame fitted/based on the Chassis in four points. The roof-structure of the frame supports the two solar panels and holds it firmly. Used pipe's dimension is 19.05×19.05 mm with the thickness of 1 mm approximately. The length, width and height of the panel mounting frame are 1402.50 mm, 520.50 mm and 1340 mm respectively.

Solar Panel: Two polycrystalline solar panels (50 watts each) are used in three-wheeler. The panels are connected parallel and mounted/set on the top (over head) with the panel mounting frame/structure and exposed to sun light. The solar panels harvest the solar energy and generate electricity. Panels are connected to the battery through MPPT charge controller.

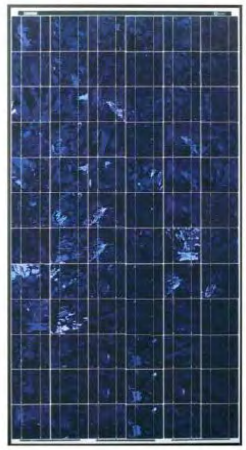


Figure 4.3: Polycrystalline panel

Charge Controller: PV Solar charge controller collects charges from solar panels and charge the battery. Solar PV charge controllers take the uncertain voltage from a solar panel and condition it to safely charge lead acid batteries. A basic charge controller simply performs the necessary function of ensuring that batteries cannot be damaged by over-charging, effectively cutting off the current from the PV panels (or reducing it to a pulse) when the battery voltage reaches a certain level. It also protects the panels from the batteries after the sun goes down. It also cuts out the batteries from the load when the lead acid batteries are depleted to prevent damage to the battery. It has LED bar readout to show the status of the solar charging system and batteries.

A MPPT (Maximum Power Point Tracker) controller performs an extra function to improve system efficiency. The efficiency loss in a basic system is due to a miss-match between voltage produced by the PV panels and that required to charge the batteries under certain conditions. MPPT controller attempts to keep the panel voltage at their Maximum Power Point, while supplying the varying voltage requirements of the battery. Manufacturers claim up to 40% power increase from your panels using MPPT, which is most likely to be achieved when battery levels are low and/or light levels are low.

Figure 4.4: MPPT Charge controller

Battery: Two 12 volt (45 Ah each) lead-acid batteries connected in series are used here in this solar three-wheeler power system as used in most of the PV systems. The solar three-wheeler is the stand-alone system**.** To make practical use of the solar energy generated from solar panels and for required steady power supply to the motor, the lead-acid batteries are used to store the energy that is not needed immediately or use it at night time if needed. Each battery having dimensions of 240mm x 120mm x 255mm. The total weight of a battery is (14.5 kg each x 2) 29 kg. The batteries are placed in a battery casing under the seat to protect it from any damage.

Figure 4.5: Lead acid battery

Motor Controller: The motor controller controls the overall functioning of the motor as driving unit. It is directly connected with battery, on/off switch, speed regulator/controller etc. In actual sense, it controls electric supply to different units, primly to the motor.

Motor: This is an important part of the solar three-wheeler. A 250 watt D.C. motor (permanent magnet, brush less) is used in this solar three-wheeler as the prime mover. This power will cover the required power needed to run the solar three-wheeler at a speed of 6 km/hr. The main reason for using this motor is that it is highly efficient and the flux density does not decrease with time. T motor is placed at the rear and fixed in a adjustable platform on the chassis. The motor gets power from the battery through controller. Once the motor shaft rotates, the power is transferred to the wheel shaft through the chain drive which ultimately rotates the wheels. The driving unit is shown in the figure 4.6.

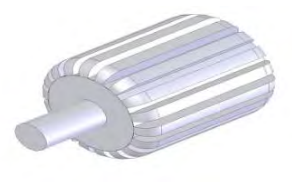


Figure 4.6: DC motor

Chain and Sprockets: Standard rickshaw chain and sprocket are used in the solar three-wheeler. However, the chain is shortened to adjust with the motor and sprocket on axel. The motor power is directly transferred to axel through the sprocket and chain.

Speed Controller: The speed controller which we normally call accelerator (a twist throttle). The speed of the solar three-wheeler is controlled by continuous change in voltage by the twist throttle. Due to voltage change the motor power also changes and there by speed is controlled by increasing the voltage from 0 to 12 and vice versa. If the voltage increases the speed also increases and if decreases then speed also decreases.

Break System: Normal friction type braking systems (used in bi-cycle or rickshaw) are used in this solar three-wheeler in front as well as in rear-left wheel for better safety. A hand liver attached with handle/steering is used to actuate the brake.

Lights: One headlight, indicator lights and backlights are attached to the solar three-wheeler, which get power from the battery.

Horns: A red push button attached to the handle (steering) acts as horn-switch and connected to the horn (attached to Chassis-fork joint). The horn makes continuous pip sound till the switch pushed in and stops once released.

4.7 Design Process

Before the age of computers, drawings and blueprints were drafted by hand. CAD is more efficient because the software records lines as *vectors* based on mathematical equations. Portions of a drawing can be twisted, stretched, or moved. The picture as a whole will automatically adjust.

CAD Software will let the designer

1) Switch between two-dimensional (2D) and three-dimensional (3D) views.
2) Zoom in and out for close-up and distant views.
3) Rotate images to view them from different perspectives.
4) Change the scale of images: When one value changes, related values are automatically adjusted.
5) Manipulate the shape of images: Changing one portion of an image automatically changes the entire picture.

Using 3D design modeling greatly improves design quality because it is a more complete process than 2D design. As a result, many human errors that can occur with traditional 2D design methods are avoided. In the past problems such as component collisions, incorrect quantities or parts that don't fit, would happen because a designer who works in only 2D is forced to hold much of the information mentally. It is this point that gives rise to errors because the brain can’t visualize to exact scale. Reducing human error by using the 3D modeling design methods minimizes the need for re-work because the design quality is greatly improved.

Communication of design intent is vastly improved by using CAD 3D modeling. In the past, non technical people interested in a 2D design often had to wait for a prototype before they could truly understand a design. Since cad 3D modeling can be used to generate pictorial views, as well as traditional projections, the design intent can clearly be seen by anyone willing to look. Consequently, it is possible to communicate a 3D modeling design and promote inter departmental understanding earlier in the project cycle, thus creating a time saving.

The possibilities for concurrent engineering take a real step forward with CAD 3D design because the sheer quality of 3D design modeling data can be instinctively understood and acted on by other departments.

A very impressive and up-to-date approach can be achieved by using 3D AutoCAD modeling - particularly in the eyes of customers. This also applies to individuals because their skills as employees need to be up dated in order to remain competitive in the jobs market.

4.7.1 Advantages

3d design software – Solid Works CAD helps design teams around the world bring their ideas to life. Solid Works is easy to learn, easy to use, and easy to navigate, letting users concentrate on their designs, not their CAD software.

Design validation – Solid Works Simulation allows design teams to simulate how designs will perform in the real world without having to build costly prototypes, helping to reduce costs and time to market.

Product data management – Solid Works Enterprise PDM helps design teams manage product data, share design information, automate workflows, and improve collaboration. Lost and overwritten files become a thing of the past.

Sustainability software – Solid Works Sustainability helps design teams reduce the carbon footprint of products and reduce pollution. By conducting life cycle assessment (LCA) directly within Solid Works, designers can see how region-specific material sourcing, manufacturing, use, and disposal will affect their product’s life cycle—before manufacturing begins.

4.8 Designing Different Parts/Components of the Solar Three-Wheeler

Solar three-wheeler is designed using Solid Works 2003. This Three-wheeler is designed into multiple parts and the parts are finally assembled into a single product. The various parts are,

1) Chassis
2) Fork
3) Axel
4) Wheel
5) Roof structure
6) Chair support
7) Chair
8) Motor
9) Sprocket and Chain
10) Battery and Controller
11) Solar panel,
12) Charge Controller (MPPT type)

4.8.1 Chassis

It is known that chassis is nothing but the main frame of the three-wheeler which must withstand the overall loads of the three-wheeler. It supports self weight, the weight of the seat and occupant/driver, battery weight, motor weight, panels, panel mounting frame etc. Keeping in mind that the weight of the solar three-wheeler should be as low as possible and must have required strength; the solar three-wheeler chassis is designed by using rectangular iron pipe (box-pipe, Steel ASTM-A36) reinforced with angle where necessary. The chassis not only withstand necessary load but also absorbs shocks to some extent. The front side is connected to the fork which holds the front wheel and rear is pointed with the axel.

Inconsideration of the space requirement, stability etc., it's length is set to almost 1500 mm and width is 550 mm. Two types of mild steel rectangular iron pipe (box-pipe) is used in its construction. These pipes are actually hollow and of rectangular cross-sections, available in the market in some particular sizes such as 19mm x 19 mm, 25mm x 25mm etc. with the thickness of 1mm, 1.5mm etc. respectively.

As welding of thin pipes (thinner than 1.5 mm) is not possible, the chosen pipe dimensions are 40mm ×40 mm and 25mm×25 mm with the thickness of 2mm and 1.5 mm respectively. It is been calculated that above thickness of the chassis pipes is good enough to bear the load of the three-wheeler and deliberately discussed in calculation and finite element analysis chapter.

Actually two (25×25 mm) pipes are used as main frame and one (40×40 mm) pipe is used to support the bend in front and hold the fork. The design parameters/dimensions of the chassis are shown in the bellow.

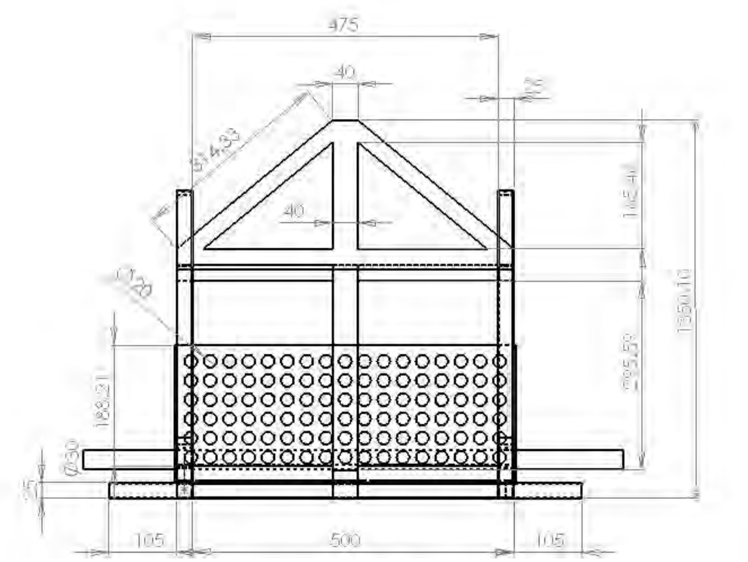


Figure 4.7: Front View of Chassis

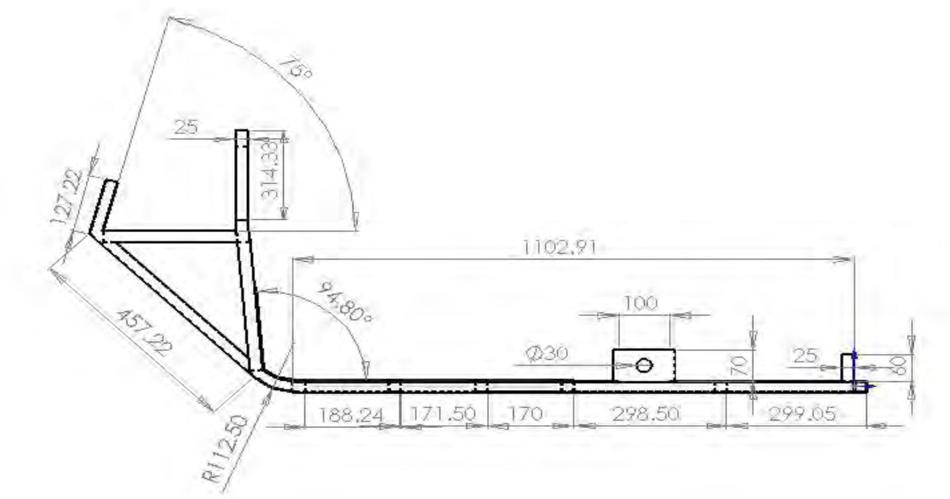


Figure 4.8: Side View of Chassis

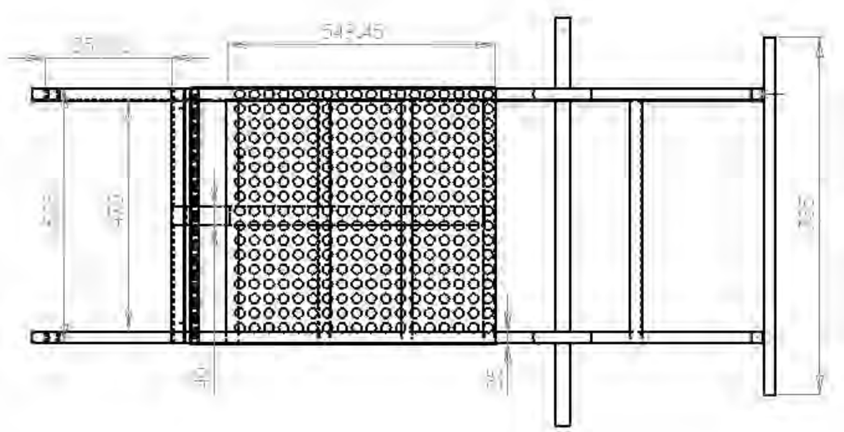


Figure 4.9: Top View of Chassis

Figure 4.10: Three Dimensional Views of Chassis

4.8.2 Fork

The fork used in the Solar Powered Three-wheeler is a conventional fork commonly used in bicycles or rickshaw. This fork holds the front wheel and takes the load generated in the front part of the chassis.

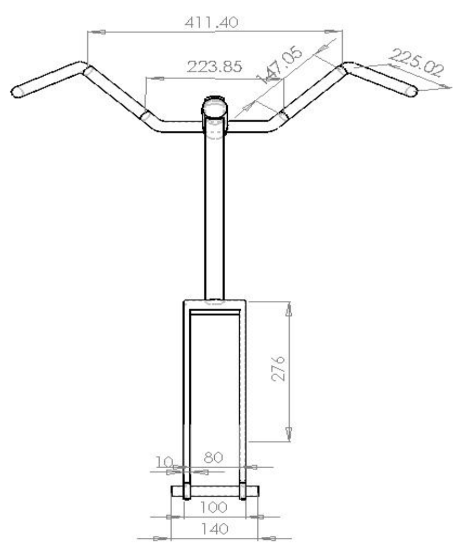


Figure 4.11: Front View of Fork

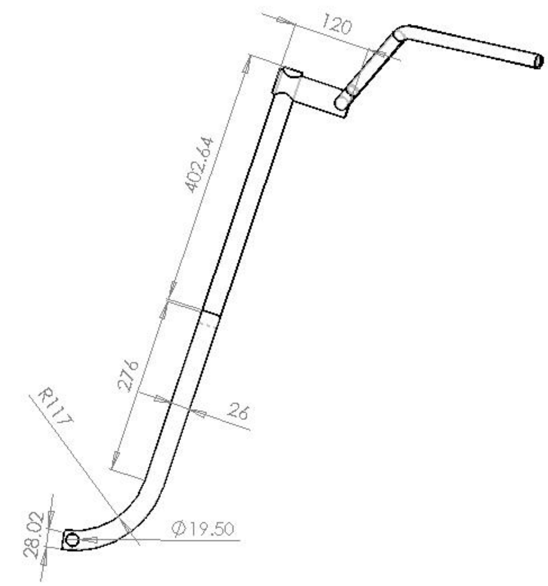


Figure 4.12 Side View of Fork

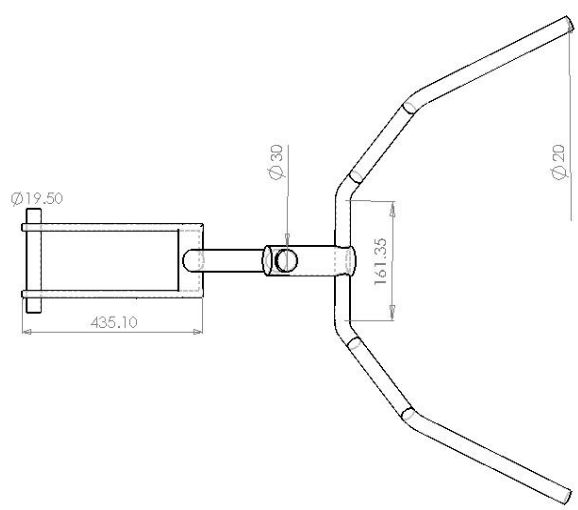


Figure 4.13: Top View of Fork

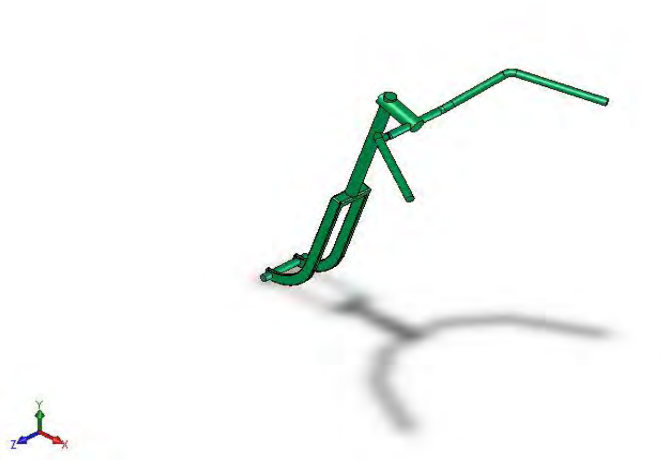


Figure 4.14: Three Dimensional View of Fork

4.8.3 Axel

A commonly found rickshaw axel (standard size-6) is used in this three-wheeler with some modifications in it; that is the length of the axel is reduced to some extent to match the width (550 mm) of the three-wheeler. The axel is simply made of mild steel solid rod having 25.4 mm (1 inch) diameter and 861 mm (34 inches) length. This dimension is well suited to with stand the required load. The axel is attached with the chassis through bearing and bolts and bears the rear-side load. Practically it is experienced that the selected fork and axel is very much suitable and strong enough to bear the load of the three-wheeler.

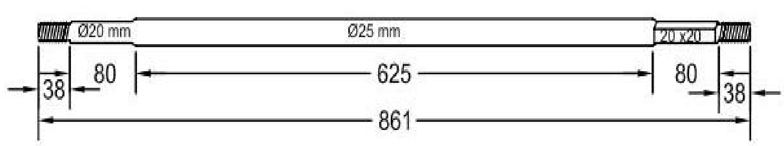


Figure 4.15: Rear axel

4.8.4 Wheels

Common bi-cycle wheels are used here in the three-wheeler. Comparatively smaller wheels (50 mm dia.) are selected; keeping in mind that the weight of the solar three-wheeler should be as low as possible and must have required strength to bear the total load. Overall terrain /road condition including bumps, pot-holes etc. around the country is duly considered while choosing the wheel as well as it's size. All terrain tires are used for better traffic ability. All the three wheels are of equal size having the diameter of 50 cm each. The wheel rim is of very good quality and standard rickshaw hubs are a bit modified to match well. The bearings used are also having standard quality.

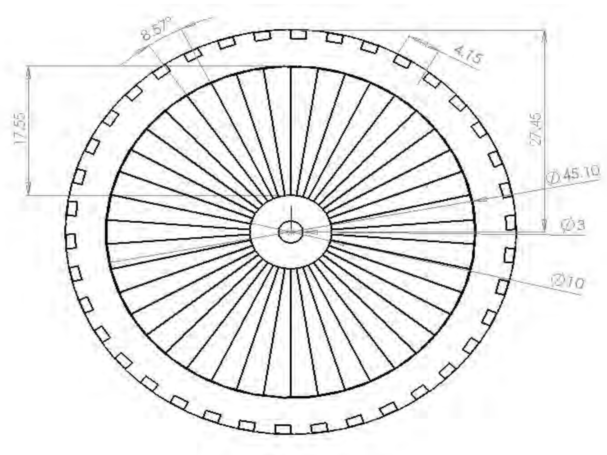


Figure 4.16: Side View of Wheel.

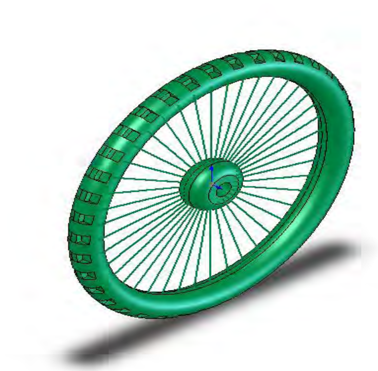


Figure 4.17: Three Dimensional View of Wheel.

4.8.5 Panel Mounting/ Roof Structure

Roof structure supports two solar panels over head, on top of the three-wheeler. Mild steel rectangular iron pipe (box-pipe) is used to construct the panel mounting structure. Pipe dimension is 17.5×17.5 mm with thickness of 1 mm approximately. It is supported by the chassis at four points. Its length is 1402.50 mm, width is 520.50 mm and height is 1420 mm. However the structure is strong enough to hold the panels.

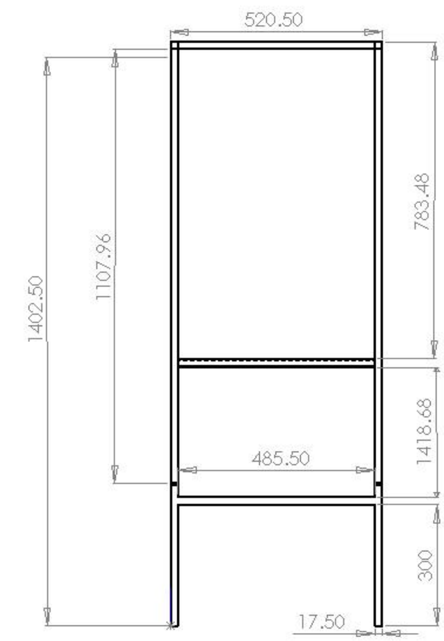


Figure 4.18: Front View of Roof Structure

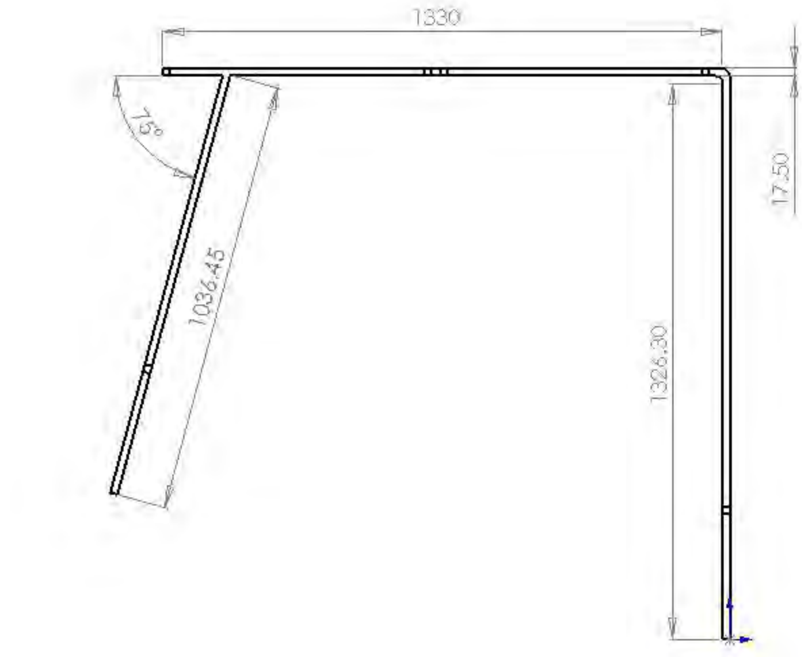


Figure 4.19: Side View of Roof Structure

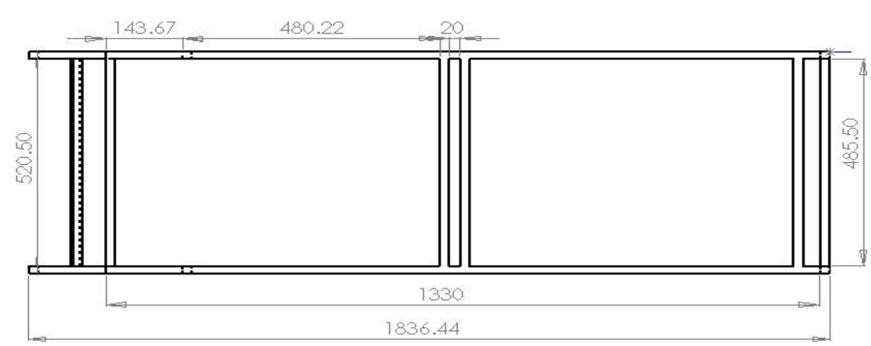


Figure 4.20: Top View of Roof Structure.

Figure 4.21: Three Dimensional View of Roof Structure.

4.8.6 Chair/Seat Support

The purpose of this structure is to support the chair/seat. It is fixed on the chassis by screws and the seat/chair is placed on it's grove on top. Its length is 521 mm, height is 405 mm and width is 457 mm. Mild steel rectangular pipe having sizes 25×25 mm with 1.5 mm thickness are used in its construction.

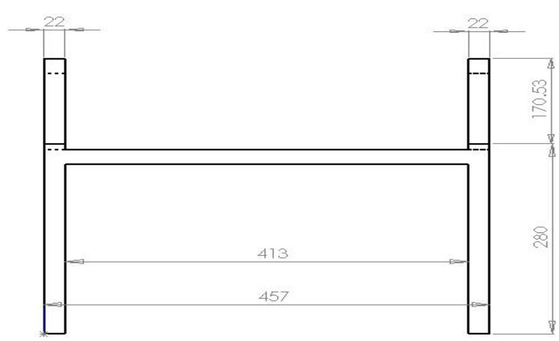


Figure 4.22: Front View of Chair Support

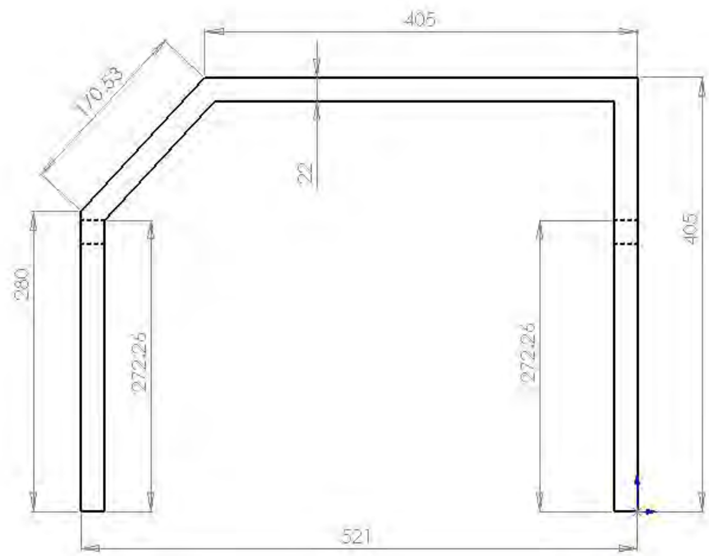


Figure 4.23: Side View of Chair Support

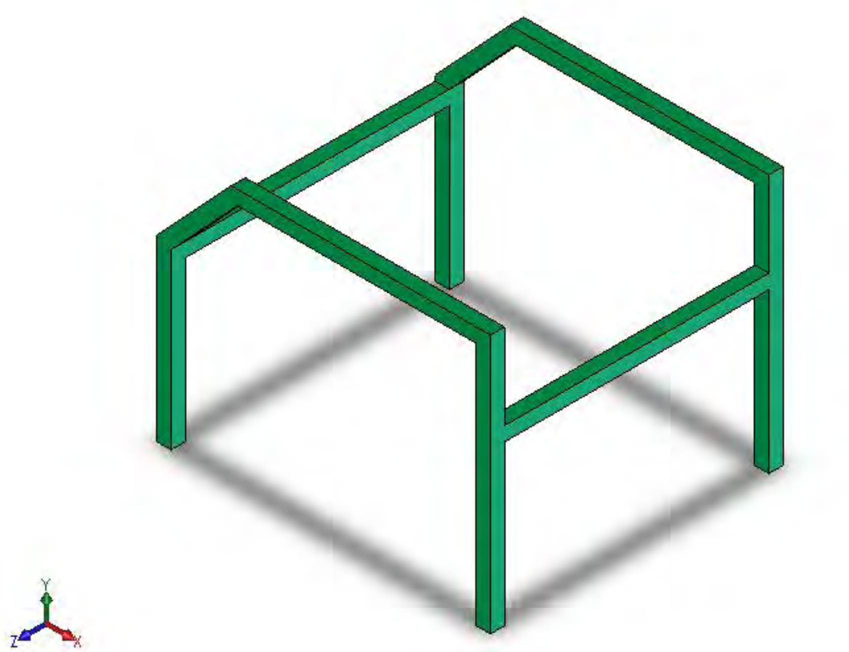


Figure 4.24: Three Dimensional View of Chair Support.

4.8.7 Chair

Seat is made of steel pipes (0.75 inch dia.), wood, foam, rexin etc. Length of the chair used in the Solar Powered Three-wheeler is 460 mm, width is 400 mm and height is 520 mm. Backrest angle is 90°. Basic ergonomic points are seriously considered while designing the seat.

Figure 4.25: Three Dimensional View of Chair.

4.8.8 Motor

Motor, the prime mover to be used in this solar three-wheeler is a permanent magnet D.C. motor. The main reason for using this motor is that it is highly efficient and the flux density does not decrease with time. It's performance characteristics suite very well to the requirement of our solar three-wheeler.

The motor size has been designed or selected based on the power requirement to drive the three-wheeler. It has been calculated that at standard load condition, the motor needs 149Watts. This power will cover the required power needed to run the solar three-wheeler at a speed of 6 ~ 7 km/hr. Motor power is transferred to the shaft to rotate the wheel through sprockets and chain drive. There is a power loss due to power transmission through chain drive and it approximately 10% of the required power. If the load increases or the three-wheeler climbs up-ward slope, then the current will also increase and power output of the motor will also increase.

However, considering standard power requirement and the safety, the designed motor power capacity is set to 250 W and it is higher than the driving power requirement. This higher motor power will make less of noise and meet the higher power if needed.

General specification of the motor can be summarized as bellow:

Power: 250 watts

R.P.M.: 200 rpm

Control Voltage: 1.5 to 24 volt,

Low voltage protection: 21 V

Amp: not specified

Power angle: 120

Sprocket diameter: 60 mm

Weight: 6 kg.

Figure 4.26: DC Motor (250 W).

4.8.9 Sprockets and Chain

The components of chain-drive system of the solar three-wheeler are motor-shaft sprocket, axel-sprocket and the ordinary rickshaw chain. Motor shaft-sprocket diameter is 60 mm (D_1) and axel- sprocket diameter is 120 (D_2) mm. Motor shafts and the axel is connected by the chain through sprockets. The motor shaft rpm and axel rpm is considered as N_1 and N_2 respectively. For power transmission in chain drive, $N_1 /N_2 = D_2/ D_1$. So, $N_1 /N_2 = 120/60 = 2$; that is $N_1 = 2N_2$. Finally the axel will have just half rotation than that of motor.

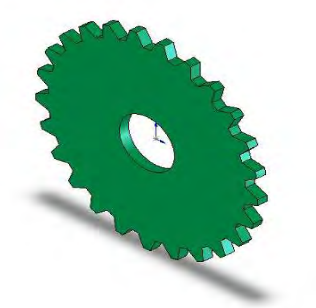


Figure 4.27: Three Dimensional View of Sprocket.

4.8.10 Battery and Controller

Two 12 volt (45 Ah each) lead-acid batteries connected in series are used in the solar three-wheeler. Basic considerations for designing the battery for the solar three-wheeler are: daily motor power requirement, the depth of discharge and suitable discharging rate of the battery, charging capacity, suitability for the solar three-wheeler as a transport and it's cost. Main reason of using such lead acid battery are, it's availability, suitable for transport use and comparatively cheaper cost.

As per the calculation, an average 2 x 12 volt (45 Ah) lead-acid battery should supply about 1080 Wh, provided that the energy withdrawal is at low level current. For the speed of 6 km/hr, the solar three-wheeler requires 149 watts in full load condition. Thus battery (2 x 12 volt ,45 Ah) has to supply amps approximately 6.2 amps, which is a very reasonable rate of withdrawal from a lead-acid battery of intermediate range for meeting normal playing load. The solar three-wheeler requires 149 W for running a distance of 6 km. Therefore, with 2 x 12 volt (45 Ah) lead-acid battery, it can cover a distance of 43 km in full charge. It is experienced from the survey report that a disabled person normally travels maximum 15~20 km per day and thereby daily average power requirement is 450 watts. Now, 2 x 12 volt (45 Ah) lead-acid battery once fully charged can run for more tan 2 days easily that means we can easily run a day by using half charge only. So, the daily depth of discharge (DOD) is 50%, which is quite healthy for battery it self. Again, as per the charging capacity calculation, we can charge in average 50% of the batteries by 100 Wh solar panel used for this three-wheeler.

To charge a battery, the charging voltage must be higher than the battery voltage or at least equal. As per the motor power requirement, a 12 V- 80 A-hr. lead acid battery is very much feasible for the solar three-wheeler. “Trickle charging” that is charging in low amps (2 to 10 amps) is always better for any battery charging; it increases battery life and decreases electricity pilferage. Here, 100 W solar panel through charge controller will charge the battery at around 29 volts and 2~3 amps. A full day of sunlight (6~7 hours) will charge it fully if it’s not fully discharged when hooked up.

Finally, each battery voltage is 12 volt (45 Ah) and combined voltage is 24 volt as connected in series. Each battery having dimensions of 240mm x 120mm x 255mm. The total weight of a battery is (14.5 kg each x 2) 29 kg.

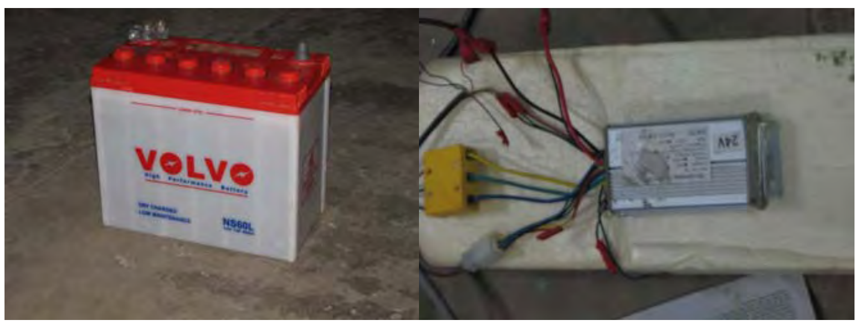


Figure 4.28: 12 V (45 A) Lead-acid Battery and controller

A suitable motor controller is used to match with 24 volt (45 Ah) battery and 250 W D.C. motor having 200 rpm. Controller control the total power supply from battery to motor, horn, lights etc smoothly.

Controller specifications:

Brushless controller

Voltage : 24 V

Power : 250 W

Throttle voltage: 1.5 to 24 V

Low voltage protection: 22.2

Protection current:

Angle : 120°

4.8.11 Solar Panel

In consideration of the efficiency, durability, availability and the cost, polycrystalline solar panel has been used for this solar three-wheeler. The basic target while designing the solar panel is get required voltage to charge the 24 volt (2 x 12 volts in series) battery in safe mode. As per requirement of charging a battery, the battery charging voltage must be higher than the battery voltage or at least equal. Again "Trickle charging" (charging in low amps, 2 to 10 amps) is always better for any battery charging; it increases battery life and decreases electricity pilferage. So, more than 24 volts and 2 to 10 ampere current is required to charge the battery.

Considering the limited space availability for solar panels on top of the three-wheeler, 2 x 50 W panels can be suitably set for solar power to charge the battery. A single 50W panel (consists of 36 cells) will have 18 volt rated output. If operating factor considered as 0.9, then the actual (practical) output voltage 16.2 V. If, 2 x 50 W panels are connected together in series, then total output voltage becomes 32.4 V. However, this 32.4 V output in practical field matches and good enough to meet up the requirements of charging 24 V lead-acid batteries. Here, the charge controller will charge the battery at around 32.4 volts and 2~3 amps under suitable sunlight.
Now, The size of the single panel = (794 mm x 660 mm) = 0.524 sq-m with thickness 35 mm. in general. So, total area needed for 2 panels = (0.524 ×2) sq-m = 1.04 sq-m, which fits well in the space available at the roof of the solar three-wheeler.

Panel specifications:

Model	HS-M-50
Rated power at STC(Wp)	50 W
Power tolerance	:±3%
Module size	:794 mm x 660 mm x 35 mm
Module weight	:6.3 kg
Cell size	:10 cm x 10 cm
Number of cells	:36
Voltage at max. power(Vmp)	:17.5 V

Current at max. power(Imp)	2.90 A
Open circuit voltage(Voc)	:22 V
Short circuit current(Isc)	:3.10 A
Conversion efficiency	:14.5 %
Standard test condition(STC)	1000 W/m², AM = 1.5, 25°C

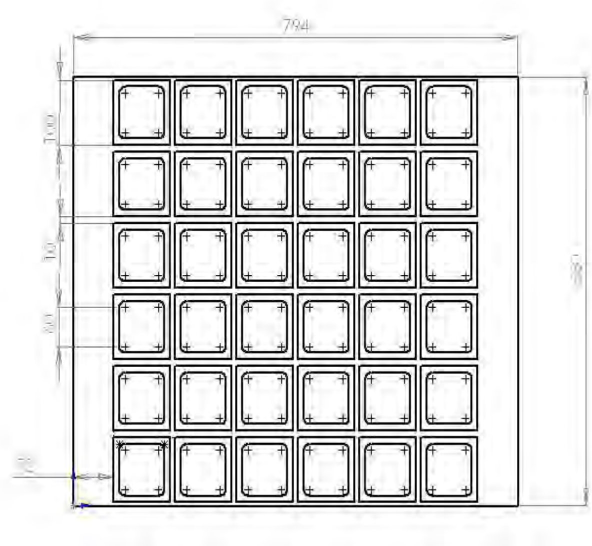


Figure 4.29: Front View of Solar Panel.

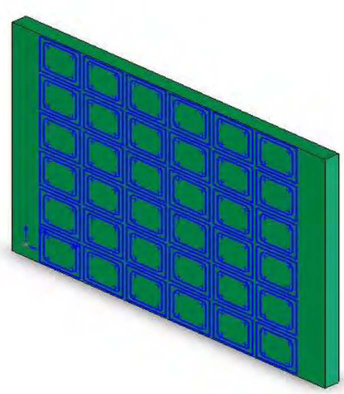


Figure 4.30: Three Dimensional View of Solar Panel

4.8.12 Charge Controller (MPPT type)

Normally charge controller regulates the power from the solar panels and controls the charge of the batteries. Solar PV charge controllers take the uncertain voltage from a solar panel and condition it to safely charge lead acid batteries. A MPPT (Maximum Power Point Tracker) controller performs an extra function to improve system efficiency. It is been experienced that a MPPT charge controller increases the system efficiency up to maximum 40% in adverse situation like defused sunlight or in cloudy days.

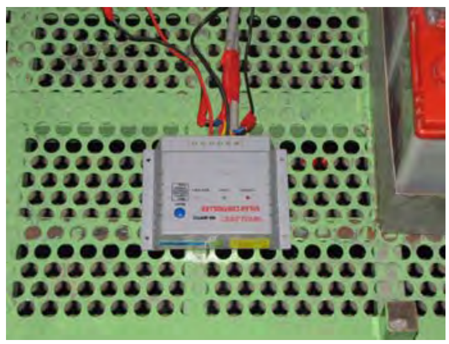


Figure 4.31: MPPT controller

MPPT Controller specifications:

1) Rated voltage : 12/24 V
2) Max load current :10 A
3) Input voltage range :24 ~ 40 V
4) Full charge cut : 27.4~28.8 V
5) Low voltage cut :21~22V
6) No load loss <10 mA
7) Efficiency 95~97%
8) Ambient temp. -25~55°C

4.9 Power/Electrical Circuit Diagram of Solar Powered Three-Wheeler

Solar panels are the main source of power and this power is stored in the battery for suitable use. Motor gets power from the battery through controller. Actually, the controller controls the necessary power supply to all the electrical components like, motor, light, horns etc for it's smooth functioning. High-grade wires are used to make necessary circuits/wirings for electrical system of the solar three-wheeler. High-grade wires reduces the resistance, ensures smooth electricity functioning, reduces system loss and ultimately results efficient system.

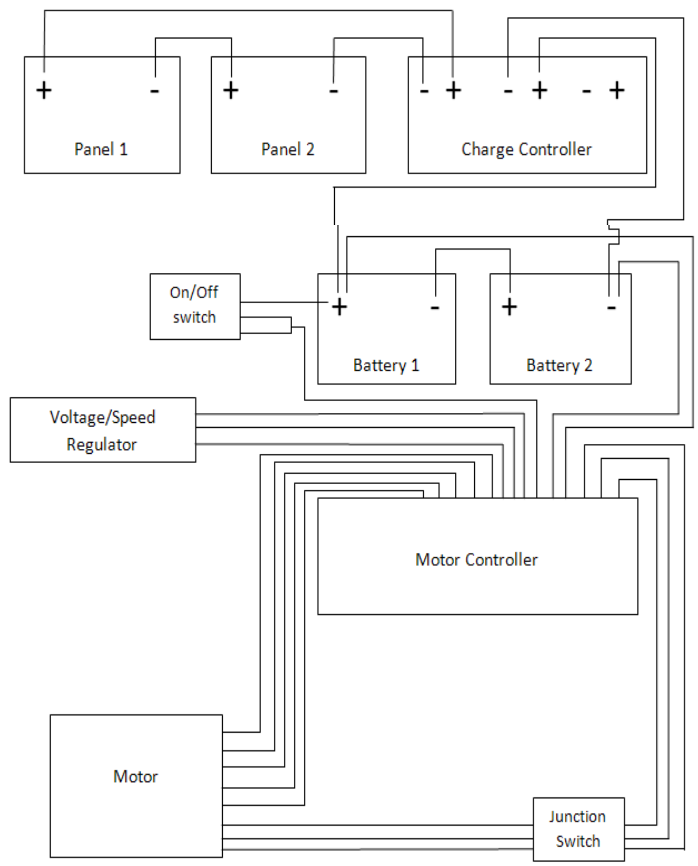


Figure 4.32: Power/Electrical Circuit Diagram of Solar Powered Three-wheeler

4.10 Final Assembly

All the modules/components are finally assembled together to reach to the target-the development of the solar three-wheeler. It had been observed that the components are well matched and functioning very smooth. Very little modifications were brought to some components/parts to have better performance of the three-wheeler. The figure 4.33(a) and figure 4.33(b) shows the Battery system with controller and completely assembled solar three-wheeler respectively.

Figure 4.33(a): Battery system with controller.

Figure 4.33(b): Finally assembled solar three-wheeler

4.11 Stability, Turning Balance and Safety Measures

Stability and the safety are the most important issues for designing a solar three-wheeler for disabled people. When a vehicle travels around a bend (on horizontal surface), it is subject to centrifugal force. This force always acts in a radial direction. If the bend is in a horizontal plane then the force always acts horizontally through the centre of gravity. The weight of the vehicle is a force that always acts vertically down through the centre of gravity. The following diagram shows these two forces.

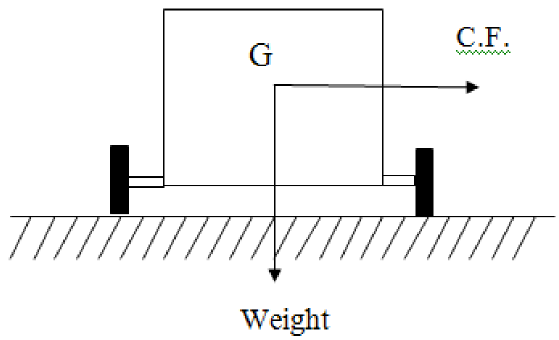


Figure 4.34: Weight and centrifugal force

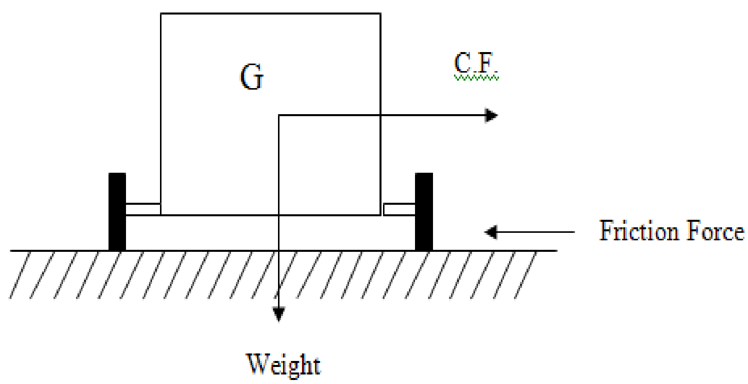


Figure 4.35: Friction force

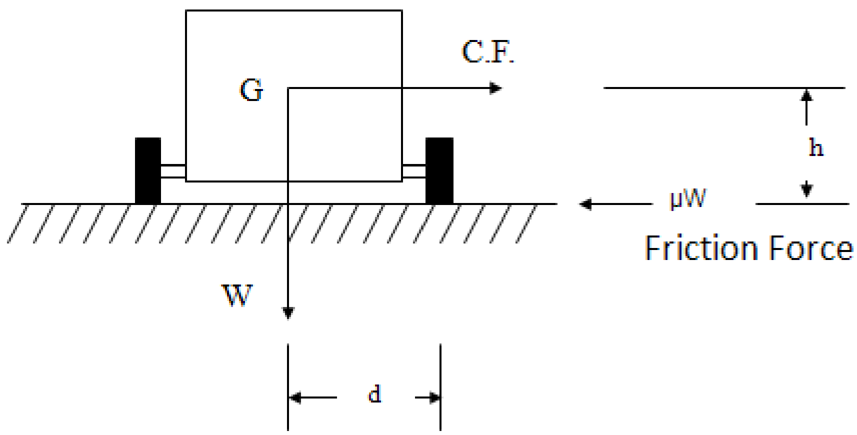


Figure 4.36: Height of CG and distance between wheels

The centrifugal force tends to make the vehicle slide out wards. This is opposed by the friction of the wheels. If the wheels were about to slide, the friction force would be μW, where μ is the coefficient of friction between wheels and the road. The tendency would be vehicle to overturn. If we consider the turning moment involves, we may solve the velocity which makes it overturn. If the vehicle mass is M, its weight is Mg. The radius of bend is R.

Consider the turning moments about point O.

The moment of force due to weight is Wd = Mgd, where d is half of the distance between rear wheels.The moment due to centrifugal force is C.F x h, where h is the height of CG from ground.

From the formula for centrifugal force C.F = (Mv^2/R)

The moment due to centrifugal force is C.F x h = (Mv^2/R) x h

When the vehicle is about to overturn the moments are equal to opposite.

Equating the moments about point O, it is found, $(Mv^2/R) \times h = Mgd$.

That is $\mathbf{v = (gdR/h)}^{1/2}$

If the vehicle was about to slide sideways without overturning then the centrifugal force would be equal and opposite to the friction force. In this case, $\mu W = Mv^2/R$

Or, $\mu Mg = Mv^2/R$

That is $v = (\mu gR)^{1/2}$

Comparing these two equation it is apparent that it skids if $\mu < d/h$ and overturn $\mu > d/h$.

Jones and Childers report coefficients of friction of about 0.7 for dry roads and 0.4 for wet roads. The tread design represents an "all weather" compromise. If you were an Indianapolis race driver, you would use "slick" racing tires with no tread. On dry surfaces you might get as high as 0.9 as a coefficient of friction, but driving them on wet roads would be dangerous since the wet road coefficient might be as low as 0.1.

To justify the stability, the turn over and slide way velocity are measured for different turning radius. It is practically seen that most of the narrow roads are having radius of more than 4 meters though the developed solar three-wheeler can take a turn in 3 meters of radius. However, the following table shows the turn over and slide way velocity for different turning radius.

Table 4.1: Turn over and slide way velocity for different turning radius

Turning radius(m)	Over turning Velocity (Km/hr)	Skidding Velocity (Km/hr)
1	9.07299891	7.13127197
2	12.83115812	10.08514155
3	15.71489510	12.35172539
4	18.14599783	14.26254395
5	20.28784234	15.94600891
6	22.22421778	17.46797756
7	24.00489878	18.86757218

From the above table 4.1 it is very much clear that the solar three-wheeler will not slide way or turn over as it’s velocity is lower than that of slide way or turn over velocity at lowest possible turning radius(3 km/hr).

Canadian Motor Vehicle Safety Regulations: The ratio of the center of gravity height (red) to this half-track (green) thus plays a crucial role in determining the stability against rollover of three-wheelers.

These new Canadian Motor Vehicle Safety Regulations of 2003 stipulate in Standard 505 that:

"............ the height of the center of mass, shown in Figure 4.37, of a motor tricycle or a three-wheeled vehicle shall not exceed one and a half times the horizontal distance from the center of mass to the nearest roll axis".

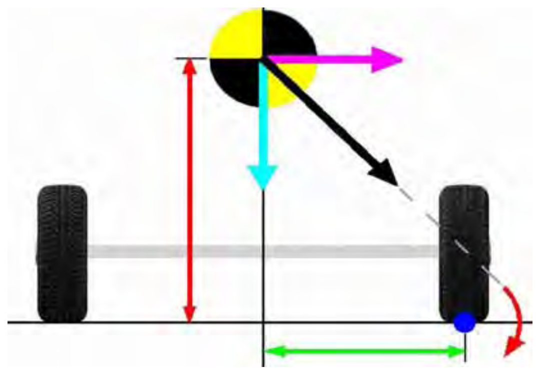


Figure 4.37: Center of mass and distance between wheels

So according to this regulation, the center of gravity height (in red) may thus be one and a half times the green line between the center of gravity and the rollover line, as illustrated at the right. The resulting force (black) may thus be aligned over the imaginary point (deep blue) and roll the vehicle over in a curve. Obviously, this regulation is very large if not too large; since it lets certain insufficiently stable vehicles circulate on public roads.

However, the center distance between two rear wheels is 72 cm; thereby the distance between a wheel and rollover axis “d” is 36 cm. The center of gravity (CG) of the three-wheeler is located 55 cm above the base/ground. So, CG is located with in the height around one and half times of “d” and as per regulation the three-wheeler is very much stable and safe.

Safety Measures

1) User's (driver) Training: Though it is not very difficult to drive this mini three-wheeler, but a very good training is mandatory for driving it.
2) Three-wheeler‘s front wheel has a tendency to go straight on plane and to right or left on slope, that is the slope ward movement. So, the driver must be aware of such tendency while driving it.
3) The user must put on safety wears like helmet etc. while driving solar three-wheeler.

4.12 Testing of the Solar Three-Wheeler

After assembling, the solar three-wheeler had been tested through driving it in practical field. All the components functions very smoothly and overall performances are quite satisfactory. There observed some difference between theoretical and results in practical field. However, the testing of the solar three-wheeler was successfully done and found no major abnormality.

4.13 General Specifications

- Size:168 x 86 x152 cm
- Height: 152 cm
- Weight with batteries: 29 kg
- Speed: 6 km per hour
- Distance per charge: 40 plus km
- Standard weight capacity: 75 kg
- Tire size: 127 x 6 cm
- Controller: Weather Proof
- Drive system: Handle Bar
- Speed control : Continuous (Voltage Regulation)
- Braking system: Friction Type
- Shock absorber: Flexible Pipe Frame
- Seat: Cushioned and Water proof.

- Tool kit : Standard
- Career: Attached at the back.

4.14 Power (Solar Panel/Battery/Motor) Specifications

- Panel:
  1) Watts: 100 W
  2) Amps: 2.90 amp
  3) Volts: 35 V
- Motor power: 250 W
- Batteries: lead acid battery, 24 V- 45 amps.
- Charger/Charge controller: Solar based(MPPT type)

4.15 Advantages of Solar Three-Wheeler

1) Avoiding of physical force/labor by occupants and there by no secondary injury to the physically disabled persons.
2) Use of echo-friendly solar power for clean environment- for better world which is available in everywhere of the country
3) Avoiding hassles of charging battery (for electric wheel chair) from grid power and thereby enhancing mobility, saving time as well.
4) Independent as a "stand alone system" - can be used at remote area where there is no electricity.
5) Suitable for outdoor use; all terrain mobility.
6) Solar panel as roof will protect the user from sun-shine and rain to some extent.
7) Lower maintenance cost, no power cost and long term solution for power as the panels having long life (20 to 25 years).

Chapter 5
CALCULATIONS

5.1 Load Calculations

Load includes the self weight of the complete solar three-wheeler and the weight of the user/driver. To calculate the total load of the solar three-wheeler chassis, the weights of each component are measured individually and then the weights of all the components are added together as bellow:

Weight of the three-wheeler chassis/frame (including 3 wheels): 25 Kg

Weight of the seat and other accessories: 5 kg. Weight of the Battery: 29 kg.

Weight of the motor: 6 kg. Weight of the solar panel including mounting: 15 kg.

Weight of a person: 75 kg.

Total weight of the solar three -wheeler (with a person): (25+5+29+6+15+75) kg. = 155 kg. So, total equivalent Load: (155 X 9.81) N = 1520 N

5.2 Load Distributions

Assume that, loads are equally distributed on each rear wheel.

Centre distance between front and rear wheel: 100 cm.

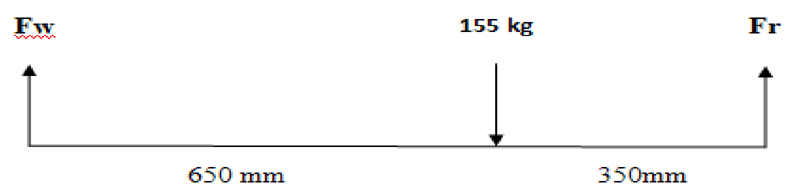
Distance between rear wheels = 72 cm

Centre of gravity of the load is at 35 cm distance from rear wheel.

So, Load on front wheel (F_w) = 35/(100) x 155 x 9.81= 532 N

Load on rear wheel (F_r) = 65/(100) x 155 x 9.81= 988 N

Load on each rear wheel: 988/2 N = 494 N



5.3 Desired Speed

If we consider the physical condition, over all terrain condition, safety etc. then the speed of the Solar three- wheeler should be as low as possible. Our desired speed of the three- wheeler is 6 Km/hr or 100 m/min. This speed will ensure better stability as well as comfort for the user.

5.4 Energy/Power Requirement

Practically it is experienced and measured that the total force required moving the fully loaded solar three-wheeler on common smooth road (concrete road) is almost 6 kg. and speed is assumed as 6 km/hr.

Now, let us calculate the power requirement for the three- wheeler basing on the following data;

Required pulling force, F_p = 6 kg. = (6 x 9.81) N = 58.86 N

Wheel diameter, D_w = 0.5 m

Speed of the tricycle, V_c = 6 km/hr = 100 m/min

Wheel RPM, $W_{rpm} = V_c/\pi D_w$ = 63.67

Torque, T_w = Force x Distance (wheel radius) = (58.86 x 0.25) N-m = 14.72 N-m

Required power, P_x = (Torque x rpm)/5252 = (14.72 x 63.67)/5252 hp. = 0.1784 hp = 133.12 W

There is a power loss due to chain drive and it max. 10% of the total input power (Pt).

Now, Pt = (0.1 x Pt) + P_x = (0.1 x Pt) + 133.12 W

Or, Pt = 147.91 W

So, Total power requirement for driving the solar three-wheeler P_t = 147.91 W ≈148 W.

5.5 D.C. Motor Power Requirement

It is to be mentioned that the prime-mover to be used in this Solar three-wheeler is a permanent magnet D.C. motor. The main reason for using this motor is that it is highly efficient and the flux density does not decrease with time. It's performance characteristics suite very well to the requirement of our solar three- wheeler.

At standard load condition (as calculated), the motor needs 148 Watts, that is 148 W/24 V =6.17 amps. If the load increased or the three-wheeler climbs up-ward slope, then the current will also increase and power output of the motor will also increase. This power will cover the required power needed to run the Solar three-wheeler at a speed of 6 km/hr.

5.6 Energy/Power Available from a Lead-Acid Battery

An average 12 volts 45 amp-hr capacity Lead-acid battery (Car battery) should supply about $12 \times 45 \times 3600/1000$ kj =1944 kj = 0.54 kWh = 540 Wh. So 2 x12 volt (45 Ah) Lead-acid battery will supply 2 x 540 Wh = 1080 Wh = 1.08 kWh , provided that the energy withdrawal is at low level current.

For a speed of 6 km/hr. the Solar three-wheeler requires 145 watts in full load condition.Thus a 2 x12 volt battery (in series) has to supply 145/24amps = 6.04 amps, which is a very reasonable rate of withdrawal for a lead-acid battery (car battery) of intermediate range for meeting normal playing load.

Our proposed Solar three-wheeler requires 148 W for running a distance of 6 km. Therefore, with 2 x12 volt lead-acid battery (Car battery) it can cover a distance of (1080/148) x 6 km = 43.78 km ≈ 44 km in full charge. It is to be mentioned that a lead-acid battery must not be discharged fully. It should be recharged before it lefts with one-third of full charges.

From the survey, it is experienced that a disabled person normally needs to travel maximum 15~20 km per day, then from the above calculation we can say that 2 x12 volt (45 Ah) Lead-acid battery with a single full charging can run for at least 2 days or we can run 40 ~ 45 km without recharging the battery.

5.7 Battery Charging Voltages and Currents

Our main aim is to store the solar energy in a battery and for this; we need to charge/recharge the battery by solar power/electricity from the solar panel through a charge controller to the battery. As per our requirement, 2 x12 V, 45 Ah batteries (in series) is very much feasible for our solar three-wheeler.

Most flooded batteries (i.e. lead-acid battery) should be charged at no more than the "C/8" rate for any sustained period. "C/8" is the battery capacity at Ah rate divided by 8. For a 45 Ah battery, this would equal 5.63 Amps. Slow charging which is commonly known as “trickle charge” (charging in low amps) is always better for any battery charging, it increases battery life and decreases electricity pilferage. A good battery charger will have 2amps to 10 amps charging. At 2 ~ 3 amps this will charge the battery fully depending on if it’s fully discharged. A full day of sunlight (8 hours) will charge it fully if it’s not fully discharged when hooked up.

In order to charge a battery, the recharging voltage must be greater than or equal to the voltage of the battery to be charged. The lead-acid batteries in our solar three-wheeler systems is charged from the solar panels having rated out put of 36 volts and 3 amps through charge controller. This charge controller will protect the battery from over charging.

Charging at 31 volts will give us a 100% charge on Lead-Acid batteries. Once the charging voltage reaches 2.583 volts per cell, charging should be stopped or be reduced to a trickle charge. Note that flooded batteries must bubble (gas) some what to ensure a full charge, and to mix the electrolyte. Float voltage for Lead-Acid batteries should be about 2.15 to 2.23 volts per cell, or about 12.9-13.4 volts for a 12 volt battery. At higher temperatures (over 85 degrees F) this should be reduced to about 2.10 volts per cell. However, in case of our solar three-wheeler, the MPPT charge controller controls every details of charging automatically.

5.8 Solar Power (panel output power) for Charging the Battery

Power needed to run the three-wheeler is solar energy which will be supplied from solar panels on it’s top. This solar energy (solar electricity) will be stored in a battery and will be used as and when required. Basically this solar panel when exposed to the sun light produces D.C. current/electricity which can be stored in the battery.

Solar cells are nothing but the semi-conducting materials like silicon and it is the basic unit of a solar panel. A commercially available solar cell having the dimension of 3 inches by 6 inches or 10 cm by 10 cm. A 10 cm x 10 cm solar cell's electricity output is likely rated at 0.5 volts with 3.2 to 3.5 amps. If we break the solar cell into two equal halves, we would get two solar cells that rate at 0 .5 volts and 1.5 amps each. So volts remain the same, but amps changes with solar cell size.

As we know, each panel normally having 36 cells and watts equals to Volts multiplied by Amps; A (10 cm x 10 cm) solar cells put out 0.5 volts and have 3 amps in general. So panel rated output voltage = 18 V and current 3 A. But in practical, to get 50 W solar panel voltage ; 50 watts divided by 3 amps equals' to 16.67 volts. So, our overall solar panel voltage 33.33 volts (as 2 x 50 W panels are in series).

We can select our required voltage or current (amps) by connecting the solar panels/modules in series or parallel. For our Solar three-wheeler, we need 2X 50 watts solar panel/module in parallel connection which will give us 100 watts with 33.33 volts and 3amps.In any DC generating device such as a battery or solar module, you will always have a negative (-) terminal and a positive (+). Electrons or (current) flows from the negative terminal through a load to the positive terminal.

5.9 Box-Pipe Dimensions, Deflection

We know the deflection,

$Ymax = \frac{FL^3}{192EI}$ (For both end fixed beam), Here deflection= $Ymax$

Total Load on rear wheel, Fr = 100.71 Kg

So, Load on each pipe=50.35 Kg, as there are 2 pipes to bear the load as frame/chassis.

Pipe Length, L=26.38 inch. × 25.4= 670 mm

Modulus of elasticity, E=200 GPa

Area moment of inertia = I

Therefore, $I = \frac{FL^3}{192 Ymax E} = \frac{50.35 \times 9.81 \times (670)^3}{192 \times Ymax \times 200 \times 10^3} = \frac{3868.67}{Ymax}$

Again, we know

I= $\frac{1}{12}(b_0 {h_0}^3 - bihi^3)mm = \frac{1}{12}(416231.42 - 299821.95)mm = 9700.79\ mm = \frac{3868.67}{Ymax}$

Here, b_0= Outer width = 1 inch = 25.4 mm, h_0 = Outer height= 1 inch = 25.4 mm

bi = Inner width = 0.92 inch = 23.4 mm, hi = Inner height = 0.92 inch = 23.4 mm

Therefore, $Ymax = \frac{3060.67}{9700.79}$ = 0.3987 mm

This is the static deflection of the pipes and this value is acceptable. Due to shock, these pipes will also deflect more and act as a shock absorber.

5.10 Height of the Center of Gravity

Height of the Center of gravity of the solar three-wheeler calculated by taking moments of the weight elements around the base/ground line. If 'h' be the height of CG, then;

155 kg x h = (25 kg x 0.203m) + (29 kg x 0.254m) + (5kg x o.406m) + (6kg x o.254m) + (15kg x 1.52m) + (75kg xo. 635m)

Or, 155 h = 5.075 +7.25 +2.03 +1.524 + 22.8 + 47.625

Or, 155 h = 86.304

Or, h = 0.556

So, height (h) of the center of gravity (CG) is 55 cm.

5.11 Stability for the Solar Three-Wheeler

To calculate the stability whether it over turns or slides away, Let us consider the following data as we get from the solar three-wheeler:

Assume that in case of turning in bends, the minimum circular track radius, R = 5 meters.

Distance between rare wheels = 0.72 meters, that is half distance, d = 0.72/2 = 0.36 m

Height of the center of gravity (CG), h = 0.55 meters

The coefficient of friction, μ = 0.4 (lowest as in wet road)

Now for over turning, v = (gdR/h) ½

Or, v = (9.81 x 0.36 x 5/0.55) ½

= 5.63 m/s = 20.28 km/hr.

For slide ways, v = (μgR) ½

Or, v = (0.4 x 9.81 x 5)½

= 4.42 m/s = 15.94 km/hr.

So, it follows that the three-wheeler will over turn when velocity exceeds 20.28 km/hr or will slide when velocity exceeds 15.94 km/hr. in a circular track. In fact, it is quite impossible as our maximum speed is only 6 km/hr.

Turn over and slide way velocities are measured for different turning radiuses are as bellow:

Radius(m)	Turning Velocity (Km/hr)	Skidding Velocity (Km/hr)
1	9.072998917	7.131271976
2	12.83115812	10.08514155
3	15.7148951	12.35172539
4	18.14599783	14.26254395
5	20.28784234	15.94600891
6	22.22421778	17.46797756
7	24.00489878	18.86757218

Chapter 6
FINITE ELEMENT ANALYSIS

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition. There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

6.1 Working Method

FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. Points of interest may consist of: fracture point of previously tested material, fillets, corners, complex detail, and high stress areas. The mesh acts like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes. This web of vectors is what carries the material properties to the object, creating many elements

A wide range of objective functions (variables within the system) are available for minimization or maximization:

- Mass, volume, temperature
- Strain energy, stress strain
- Force, displacement, velocity, acceleration
- Synthetic (User defined)

There are multiple loading conditions which may be applied to a system.

- Point, pressure, thermal, gravity, and centrifugal static loads
- Thermal loads from solution of heat transfer analysis
- Enforced displacements
- Heat flux and convection
- Point, pressure and gravity dynamic loads

Each FEA program may come with an element library, or one is constructed over time. Some sample elements are:

- Rod elements
- Beam elements
- Plate/Shell/Composite elements
- Shear panel
- Solid elements
- Spring elements
- Mass elements
- Rigid elements
- Viscous damping elements

Many FEA programs also are equipped with the capability to use multiple materials within the structure such as:

- Isotropic, identical throughout
- Orthotropic, identical at 90 degrees
- General anisotropic, different throughout

6.1.1 Types of Engineering Analysis

Structural analysis consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation.

Vibrational analysis is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibration frequency of the material which, in turn, may cause resonance and subsequent failure.
Here, the Structural analysis was followed to find the elastic deformation of various components of the solar three-wheeler.

6.2 ANSYS (Finite Element Analysis Software)

ANSYS includes a great number of advanced features that make it easier, faster and cheaper for customers to bring new products to market, with a high degree of confidence in the ultimate results they will achieve. The product suite delivers new benefits in three major areas:

- Greater accuracy and fidelity: As engineering requirements and design complexity increase, simulation software must produce more accurate results that reflect changing operating conditions over time.
- Higher productivity: ANSYS 13.0 includes dozens of features that minimize the time and effort product development teams invest in simulation.
- More computational power: For some engineering simulations, ANSYS can provide speedup ratios that are five to 10 times greater than previous software releases. Even complex multiphysics simulations can be accomplished more quickly and efficiently, speeding up product development and market launch initiatives.

ANSYS builds on the foundation of previous ANSYS releases, taking product development to the next level by continuing the evolution of Smart Engineering Simulation. By compressing design cycles, optimizing product performance across multiple physics, maximizing the accuracy of virtual prototypes, and automating the simulation process, ANSYS is making it easier and faster than ever to bring innovative new products to market — which has become imperative in today's difficult economy.

6.3 Finite Element Analysis of Solar Three-wheeler

ANSYS 10 is used for the finite element analysis of Solar Powered Three-wheeler. In this analysis three critical components of the Solar Powered Three-wheeler are analyzed. They are,

1) Beam in chassis
2) Joint between chassis and fork
3) Beam in roof structure

6.3.1 Finite Element Analysis of Beam in the Chassis

This analysis of beam is performed using ANSYS 10. Material used in the model is mild steel. In this analysis Modulus of elasticity and Poisson's ratio are assumed to be 210 Gpa and 0.3 respectively. Elements used in the chassis having rectangular cross-sections are hollow and have thickness of 1.5 mm. Amount of load applied on the beam are 360 N, 460 N, 560 N, 660 N,760 N.

Figure 6.1: Beam in the chassis

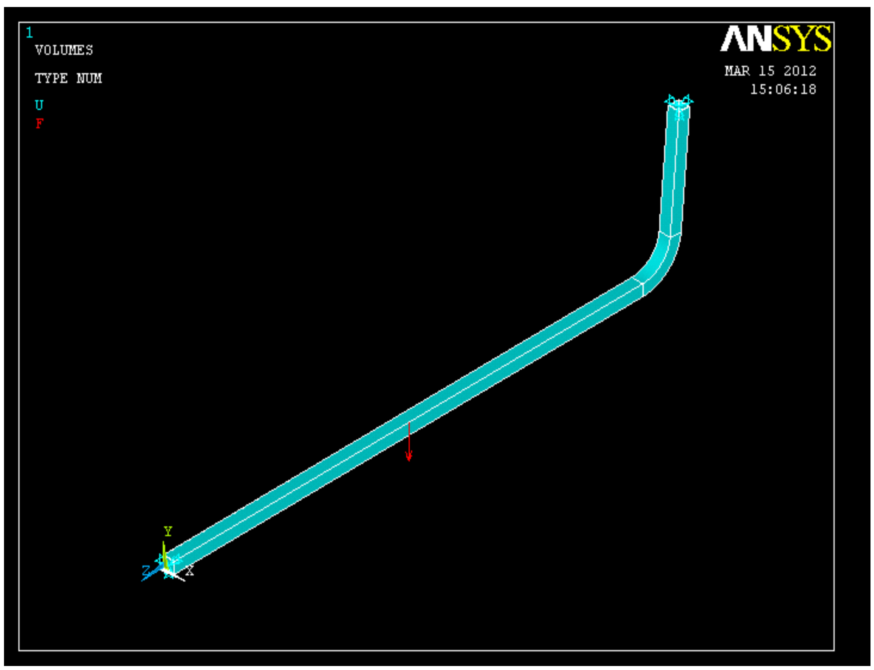


Figure 6.2: Application of load and constraint on the beam

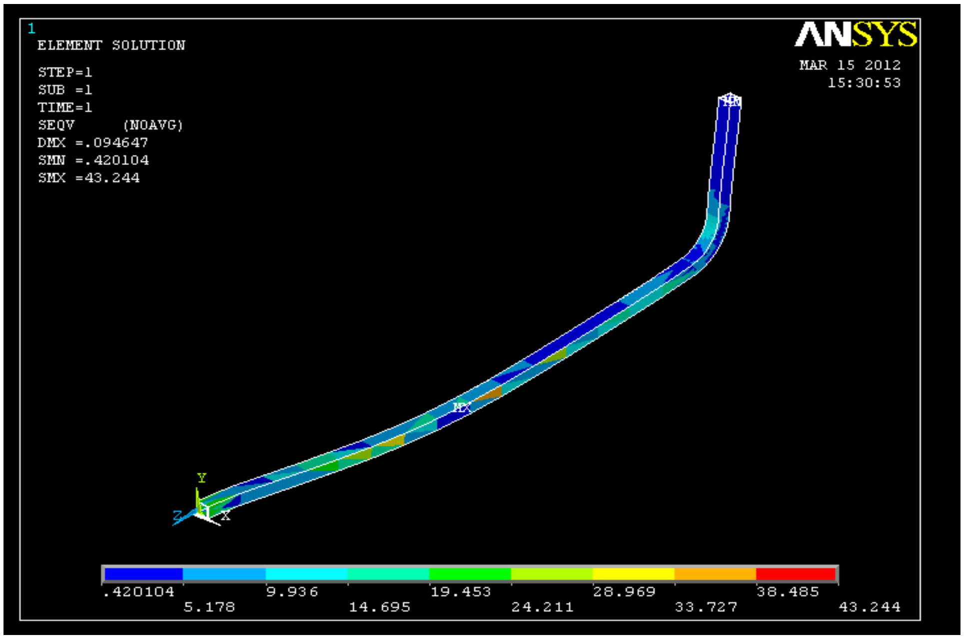


Figure 6.3: Stress and deflection diagram of the beam. (Applying 760 N)

Data Table and Chart: Deflection and stress values for various loads are given in the following table 6.1.

Table 6.1: Deflections and stresses for different loads

Load (N)	Deflection (mm)	Stress (Mpa)
360	0.044833	20.484
460	0.057286	26.174
560	0.06974	31.864
660	0.082193	37.554
760	0.094647	43.244

6.3.2Finite Element Analysis of Joint between Fork and Chassis

This analysis of joint is performed using ANSYS 10. Material used in the model is mild steel. In this analysis Modulus of elasticity and Poisson's ratio are assumed to be 210 Gpa and 0.3 respectively. Elements used in the chassis having rectangular cross-sections are hollow and have thickness of 1.5 mm. Amount of loads applied on the top of the joint are 360 N, 460 N, 560 N, 660 N, 760 N.

Figure 6.4: Chassis and fork joint

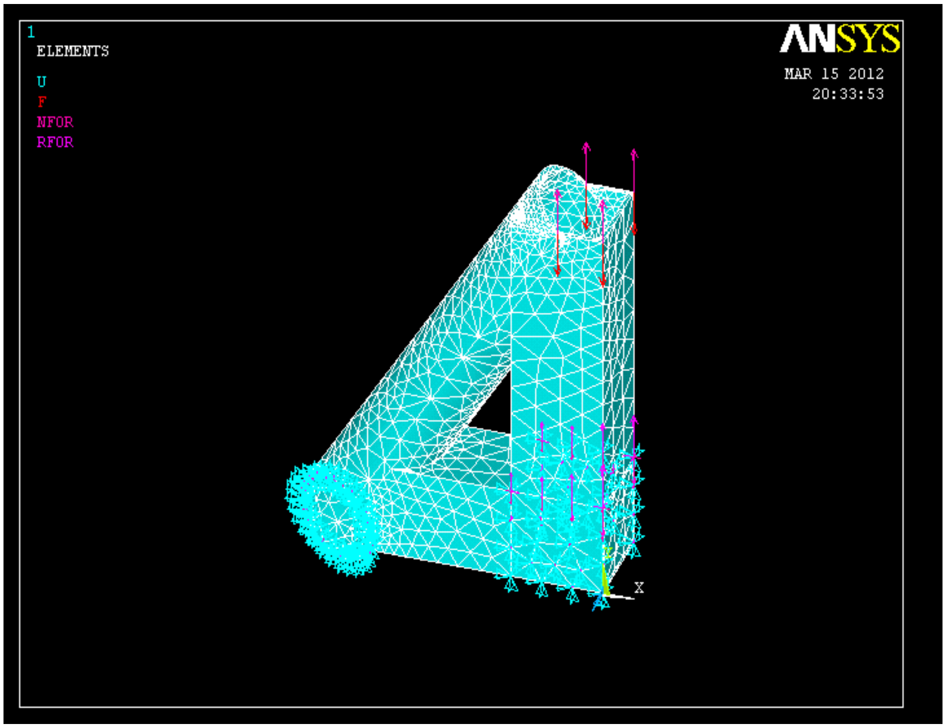


Figure 6.5: Application of load and constraint on the joint

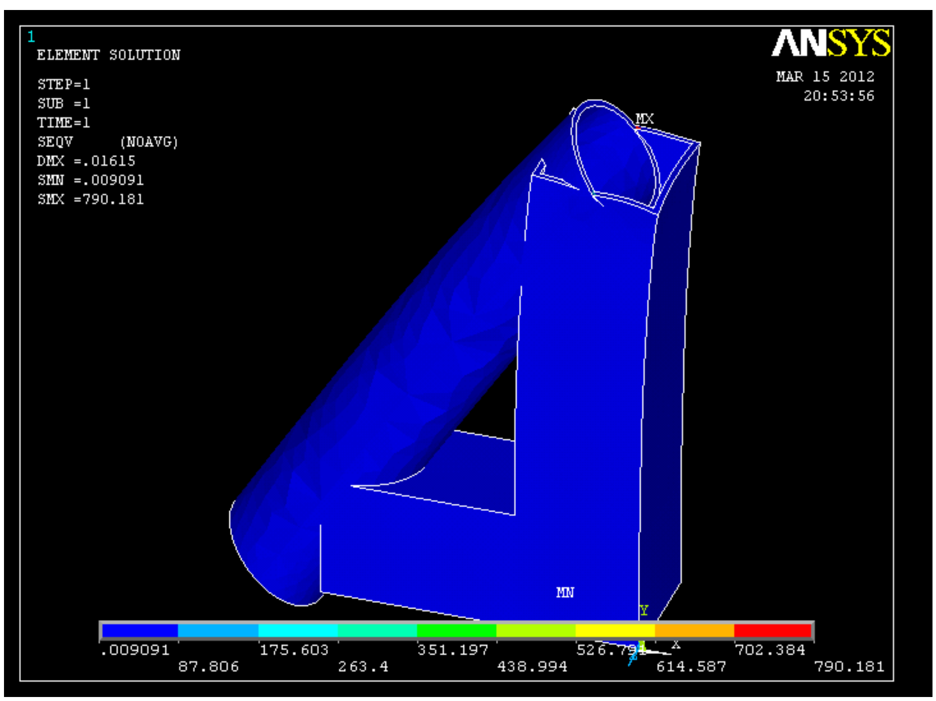


Figure 6.6: Stress and deflection diagram of the joint. (Applying 760 N)

Data Table and Chart: Deflection and stress values for various loads are given in the following table 6.2.

Table 6.2 Deflections and stresses for different loads

Load (N)	Deflection (mm)	Stress (MPa)
360	0.007686	372.662
460	0.009783	478.261
560	0.011933	579.791
660	0.014064	683.326
760	0.01615	790.181

6.3.3 Finite Element Analysis of Beam in the Roof Structure

This analysis of beam is performed using ANSYS 10. Material used in the model is mild steel. In this analysis Modulus of elasticity and Poisson's ratio are assumed to be 210 Gpa and 0.3 respectively. Elements used in the roof structure having rectangular cross-sections are hollow and have thickness of 1.5 mm. In this analysis uniform pressure of 0.12 N/mm, 0.24 N/mm, 0.36 N/mm, 0.48 N/mm, 0.60 N/mm are applied on the top surface of the beam.

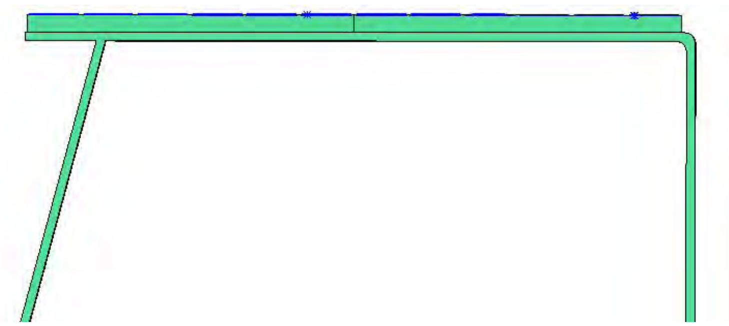


Figure 6.7: Beam in the roof structure

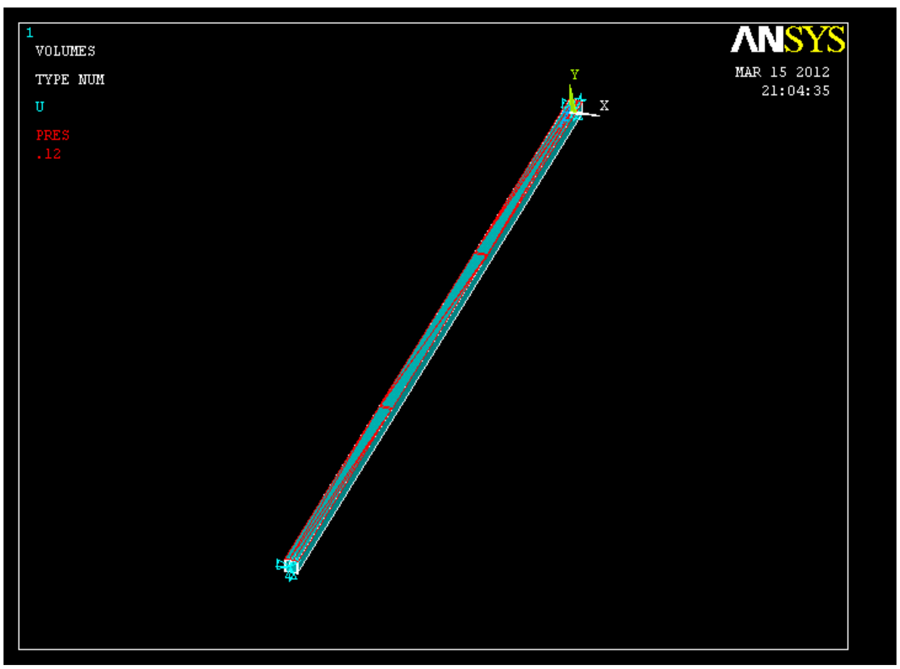


Figure 6.8: Application of pressure and constraint on the roof beam.

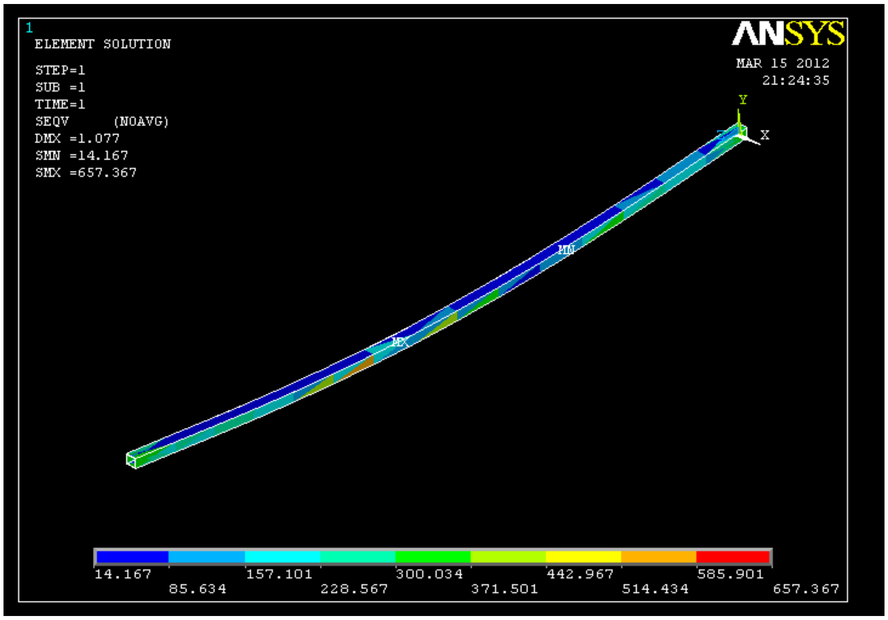


Figure 6.9: Stress and deflection diagram of the roof beam. (Applying 0.60 N/mm)

Data Table and Chart: Deflection and stress values for various loads are given in the following table 6.3.

Table 6.3 Deflection and stresses for different loads

Load (N/mm)	Deflection (mm)	Stress (Mpa)
0.12	0.215401	131.473
0.24	0.430802	262.947
0.36	0.646203	394.42
0.48	0.861604	525.894
0.60	1.077	657.367

Chapter 7
ERGONOMIC ANALYSIS

7.1 Ergonomics

The word ergonomics comes from two Greek words 'Ergo' meaning work and 'Nomos' meaning laws. Ergonomics is a science focused on the study of human fit, and decreased fatigue and discomfort through product design. Ergonomics applied to office furniture design requires that we take into consideration how the products we design fit the people that are using them. At work, at school, or at home, when products fit the user, the result can be more comfort, higher productivity, and less stress. Ergonomics can be an integral part of design, manufacturing, and use.

7.1.1 Common terms Regarding Ergonomics

Anthropometric Measurements: Anthropometry is the science that measures the range of body sizes in a population. When designing products it is important to remember that people come in many sizes and shapes. Anthropometric data varies considerably between regional populations. For example, Scandinavian populations tend to be taller, while Asian and Italian populations tend to be shorter.

Percentile Humans: Anthropometric dimensions for each population are ranked by size and described as percentiles. It is common practice to design for the 5th percentile (5th %) female to the 95th percentile (95th %) male. The 5th% female value for a particular dimension (e.g. sitting height) usually represents the smallest measurement for design in a population. Conversely, a 95th% male value may represent the largest dimension for which one is designing. The 5th% to 95th% range accommodates approximately 90% of the population.

7.2 BIFMA

BIFMA is the Business and Institutional Furniture Manufacturers Association. It was founded in 1973 with a mission to lead, advocate, inform and develop standards for the North American office and institutional furniture industry. It serves businesses that are primarily engaged in design, development, marketing and fulfillment of office and institutional furniture products. It is a not-for-profit organization that provides an effective forum for members to cooperate and collaborate on appropriate industry issues. It develops voluntary product and industry standards that support safe, healthy and sustainable environments; publish key industry statistics; advocate for legislation and government regulation that has a direct impact on the health of the industry; and facilitate meaningful dialog and education to support our core services and the industry we serve.

7.3 Sitting Parameters

Knowing what parameters to design for while the user is seated can help increase the comfort of the user. Common seated Anthropometric measurements can be seen in the following figure.

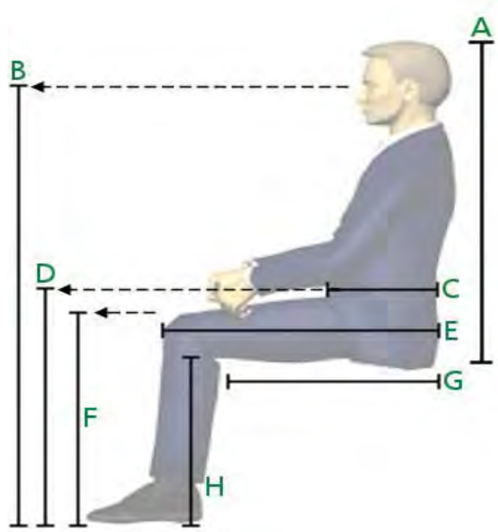


Figure 7.1: Common Anthropometric measurements for the seated position.

Table 7.1: Values for 5th to 95th percentile males and females in the seated position used in designing seating (Using figure 7.1 for visualization. Data from BIFMA Ergonomics Guidelines, 2002. All measurements are in inches).

Measurement	Letter	Female 5th – 95th%	Male 5th – 95th%	Overall Range 5th – 95th%
Sitting Height	A	31.3” – 35.8”	33.6” – 38.3”	31.3” – 38.3”
Sitting Eye Height	B	42.6” – 48.8”	46.3” – 52.6”	42.6” – 52.6”
Waist Depth	C	7.3” – 10.7”	7.8” – 11.4”	7.3” – 11.4”
Thigh Clearance	D	21.0” – 24.5”	23.0” – 26.8”	21.0” – 26.8”
Buttock-to-Knee	E	21.3” – 25.2”	22.4” – 26.3”	21.3 – 26.3”
Knee Height	F	19.8” – 23.2”	21.4” – 25.0”	19.8” – 28.0”
Seat Length/Depth	G	16.9” – 20.4”	17.7” – 21.1”	16.9” – 21.1”
Popliteal Height	H	15.0” – 18.1”	16.7” – 19.9”	15.0” – 19.9”
Seat Width	Not Shown	14.5” – 18.0”	13.9” – 17.2”	13.9” – 18.0”

7.3.1 Evaluation of Sitting Parameters in Solar Three-wheeler

Measurements of the sitting parameters described above are taken for the Solar Powered Three-wheeler and evaluated against the given ones.

Table 7.2: Sitting parameters evaluation

Measurement	Letter	Overall Range 5th – 95th%	Measured Value	Evaluation
Sitting Height	A	31.3” – 38.3”	34.25”	Passed
Sitting Eye Height	B	42.6” – 52.6”	48.03”	Passed
Waist Depth	C	7.3” – 11.4”	11.02”	Passed

Thigh Clearance	D	21.0” – 26.8”	23.62”	Passed
Buttock-to-Knee	E	21.3 – 26.3”	22.83”	Passed
Knee Height	F	19.8” – 28.0”	22.44”	Passed
Seat Length/Depth	G	16.9” – 21.1”	18.50”	Passed
Popliteal Height	H	15.0” – 19.9”	19.68”	Passed
Seat Width	Not Shown	13.9” – 18.0”	15.75”	Passed

So existing seat design meet the given parameters required to ensure user comfort.

7.4 Specific Design Recommendation for Chair

1) Seat Height and Slope:

Fixed Height- 18 to 19 inch (ANSI)

Adjustable Height- Minimum range of 16 to 20.5 inch

- 5° to 15° forward tilt to 5° backward tilt (Lueder, 1986)

2) Seat Depth and Width:

-Chairs depth should not exceed 16.8” and the width of the seat surface should not be less than 15.7” (Grandjean et al, 1973)

-Seat depth: 15 to 17 inch (ANSI) Seat width: 18.2 inch (ANSI)

3) Contouring and Cushioning:

Disadvantages of Contouring-

a. Restricting movement
b. Promoting postural fixity

Disadvantages of Cushioning-

a. Posture is restricted
b. Blood circulation is reduced
c. Skin temperature increase
d. Pain may results

4) Seat Back Parameters:

- Seat back angle: a minimum range of 90° to 105° with the seat pan
- Up to 120° (ANSI)
- Seat back width: at least 12” in the lumber region.
- Seat back height: a minimum of 19.5”

7.4.1 Evaluation of Chair

Since it is a low velocity transport, only static ergonomics are considered. However the dynamic ergonomics can also be considered for better justifications of the sitting parameters in future.

In the solar three-wheeler, seat height is 18 inch with no forward or backward tilt. Seat depth is 18 inch and width is 15.75 inch. It has not too much contouring and its cushion thickness is almost 1.5 inch thick. Seat back angle is 90°.Seat back height is 20.5 inch. All the design parameters meet the design recommendations except the seat width which is appropriate for Gradjean et al, 1973 but not suitable according to ANSI. So seat width may cause little problem for the user.

Chapter 8
PERFORMANCE EVALUATION

8.1 Scope

Performance evaluation of the solar three-wheeler includes testing of the three-wheeler in practical field, monitoring the overall performance of different parts and components whether it function properly or not, Justify the efficiency of different components through different data's, finding the gaps/difference between theoretical and practical out puts and finding reasons behind, and finally overall evaluation of the three-wheeler.

8.2 Solar Panel Performance

There are different types of panels in the market and their efficiencies also differ. For single crystal silicon, an efficiency value as high as 24.7% has been obtained under laboratory condition. However, for commercially available modules, efficiency ranges between 12% and 16%. The highest value reported is 22.7%. The cost of the PV module depends on its size as well as it's efficiency. Module specifications includes module size, weight, cell size, number of cells, nominal out put, nominal voltage, maximum voltage, open circuit voltage, short circuit current, conversion efficiency etc.

Normally for PV module, the rated power is measured under sunlight condition corresponding to 1000 W/m², AM- 1.5 and at 25°C temperature. The rated power is the peak power that can be achieved from a PV module. The manufacturers always specify rated power and we buy solar module from the market based on the rated power. However, in reality the amount of solar radiation varies throughout the day. The solar radiation can be as low as 100 W/m² during the morning hours. During noon, it will typically be in the range of 600 to 800 W/m² and it is lower than the standard condition (rated power). Also power output decreases due to higher operating temperature. As the operating temperature increases above characterization temperature (25°C), solar cell efficiency decreases and reduced cell efficiency means reduced power output. Typically the actual power output from a PV panel is 20 to 40% lower than rated power value depending on the module temperature.

As per our per our panel specifications, the rated power (at STC) is 50 W x 2 = 100 W, maximum voltage = 35 V and maximum current = 2.90 A.

However, practically we achieved the panel output at BUET campus as shown in table 8.1.

Table 8.1: Solar panel voltage and current output.

Date	**Time**		**Solar Panel**	
	Hour	Min.	Voltage (V)	Current(A)
11 May, 2012	12	05	29	1.7
	12	30	29.5	1.8
	12	40	29.3	1.75
18 May, 2012	12	40	29.3	1.7
	12	45	27.8	1.2
	12	50	28.3	1.29
13 June, 2012	10	30	29.5	1.9
	10	35	29.7	1.94
	10	50	29.5	1.85

Now if we summarize the above data then we find that the panel voltage ranges from 27.8 V to 29.7V and the average voltage is 28.8 V. Regarding current, it ranges from 1.2 A to 1.94 A and the average current is 1.65.Maximum voltage 29.7 V and current 1.94 A had been noted .

So, the average power out put of the panel = (28.8 x 1.45) W = 41.76 W

Daily power out put = 41.76 W x 7 hr. = 292.32 Wh

Now, the practical solar panel power out put is far bellow the rated power even after using the MPPT controller.

As per solar mapping, the daily radiation in the month of May at any place of Bangladesh ranges 5kWh/m² to 5.5 kWh/m². A 100 W solar panel having area of 1 m² with 14.5% efficiency. So, daily power output of the panel (100 W) = 5000 x (14.5/100) kWh/m² = 725 Wh.

The causes of this big difference between the theoretical and practical result of daily panel power output may be as follows:

1) Increased temperatures (34°C as recorded) which decreases panel efficiency.
2) The overall environment was hot, but there had been clouds in the sky to interrupt sun light.
3) Quality of the panel might not be good enough as mentioned in panel specification.

However, a solar three-wheeler with all limitations can be run at-least 2.5 hours (15 km) with the total power harvested by the panel/day.

8.3 Speed Test

The solar three-wheeler had been tested on roads practically to see whether it runs as per desired /designed speed or not. To find the speed and power consumption rate, the solar three-wheeler were tested for different road conditions. As already mentioned earlier the designed speed of the three-wheeler is 6 km/hr.

To test the solar three-wheeler, two types of places/roads had been selected. Firstly, it had been tested in the laboratory, on it's smooth floor. Secondly, on the BUET Campus concrete road. However, the road test data are furnished in table 8.2 as below:

Table 8.2: Average power consumptions at different speed and road conditions

Road condition	Speed(v) in Km/hr	Acceleration (a) in m/s²	Voltage (V)	Current (I)	Power (W)	Power ($P_{avg.}$) (W)
Lab.	0 – 7	0.39	24	13	312	312
	0 – 7	0.39	24	13	312	
	0 – 7	0.39	24	13	312	
	7	0	24	5	120	120
	7	0	24	5	120	
	7	0	24	5	120	
Concrete road	0 – 6	0.33	24	15 – 5	360	360
	0 - 5.5	0.30	24	15 – 5	360	
	0 – 6.5	0.36	24	15 – 5	360	
	6	0	24	5	120	120
	5.5	0	24	5	120	
	6.5	0	24	6	120	

Now, from the table 8.2, we see that in laboratory it takes 5 sec to attain maximum speed of 7 km/hr. In the initial moment while starting, the ammeter shows the maximum current supply of 13 A . So, the initial power consumption to start the solar three-wheeler and reaching to maximum speed (7 km/hr) is 312 W. After attaining the maximum speed of 7 km/hr, it moves in the uniform speed (as7 km) and the average power consumption is120 W.

Similarly, the solar three-wheeler was also tested on concrete road of BUET campus, where the highest speed achievement was average 6 km/hr. It needed 360 W to start and achieved the maximum speed of 6 km/hr. Subsequently it need average 120 W to run the solar three-wheeler at the average speed of 6 km/hr.

8.4 Motor Performance (Rated capacity Vs. Actual capacity)

Performance of motor is quite appreciable as it practically satisfies the motor specifications. It is run by 24 V battery and it's RPM in full load condition is 150 which is little lower than the rated RPM. More so It runs very smooth with almost no sound.

8.5 Overall Performance

The overall performance is satisfactory as it runs well and all components especially the solar system works properly as per designed specifications. The desired speed (6 km) has been achieved and solar panel/system harvest necessary power for required running. Though there are some differences in various outputs between theoretical calculation and practical findings, but there is no abnormality.

8.6 Feedback from the Users

It is practically used/driven by a disabled person and he expressed his feelings. However, he put his opinions as was comfortable to drive it and the speed of the solar three-wheeler is okay. He also added that it would have back gear, more cushioned seat and also protection from the sides.

8.7 Manufacturing Cost

Manufacturing cost may include designing cost, raw material and component cost, labor cost, assembling cost, over heads and so on. However, raw material, ready components and assembling costs are the major cost components of manufacturing cost. The cost components are shown in table 8.3.

Table 8.3: Major components and their cost

Serial No.	Parts/components	Unit cost/price (in Taka)	Quantity	Total price (in Taka)
1	Pipes for chassis and Roof structure	@35 , @48 and @100	80 feet,20 feet and 5 feet	4260
2	Fork	240	01	240
3	Axel	300	01	300
4	Wheels and bearings	650	3 sets	1950
5	Chair/Chair support	1800	01	1800
6	Motor	8000	01	8000
7	Sprocket and chain	300	01	300
8	Battery	4750	02	9500
9	Controller	4500	01	4500
10	Solar panel	5500	02	11000
11	MPPT controller	5000	01	5000
12	Throttle(voltage regulator) Electrical wires, brake, horn, light etc	1600	1 set	1600
	TOTAL			48450

Chapter 9

CONCLUSION AND FUTURE WORKS

The solar three-wheeler is a automatic (solar powered) and environment friendly mini transport. As a 'standalone system'- can be used at remote places where there is no electricity. Biomechanical benefits; comfortable and suitable for the health of the disabled is the most important issue. Better safety, stability, maneuverability and modularity in design are also remarkable features. It is suitable for Bangladeshi-terrain and having protection from sunshine, rain etc. It is economic as no running power cost and easy maintenance

The essential energy requirement of the solar three-wheeler is equal to the drag force caused by air resistance while it is in motion at full load condition. To reduce the frictional energy loss in wheel, bearings, the loss in braking and also the in vibration, the weight of the transport body was maintained as low as possible. For this mild steel rectangular pipes and sheets used for constructing the frame were of minimum possible thickness/size. To reduce the losses for power transmission the wheel are rotated by a D.C motor through Chain drive. A lot of energy is lost in clutches, gears and different shafting in conventional power transmission. High efficient solar panel is used as there is limited space on the hood of the three-wheeler. However, the solar panel (panel size used) is capable to support the energy requirement. The overall body size (dimensions), shape, wheel size etc. are maintained as smaller as possible and in consideration of the road condition. The main attraction of the solar three-wheeler is the modular design. The front wheel system, the braking system, rear wheel system, Seat, hood, height of the chassis etc. can be modified or readjusted as per requirement. The main problem faced is to manage required capacity D.C motor and controller as D.C motor and controller of different capacity are not available in market.

However the initial cost is the main disadvantage of installing a solar energy system, largely because of the high cost of the semi-conducting materials used for it. Solar panels require quite a large area for installation and production of solar energy is influenced by the presence of clouds or pollution in the air. Similarly, no solar energy will be produced during night.

9.1 Recommendations for Future Work

The volume/size of the solar panels can be increased or solar tracker can be used with the panel for increased energy demand. Instead of lead-acid battery, the lithium battery can be used; as a result the overall weight of the three-wheeler will be reduced to some extent. The braking system can be improved by designing an energy saving gadget which will store the kinetic energy during braking and release the energy after braking. This system can also deliver the energy for starting when high torque is required. Energy loss will be reduced if the gadget attached. Leaf spring can be used for increased suspension. Overall size of the three-wheeler can be made smaller or bigger as per the demand.

9.2 Conclusion

Development of the solar three-wheeler is a blessing for the disabled people and will have significant change in their mobility as well as life style. The overall designing of the solar three-wheeler is done with a view to provide maximum possible facilities to it's user - the disabled people. Automation by solar power, biomechanics, comforts and safety get maximum priority in designing. Other attractions of this solar three-wheeler are flexible and modular designing. Because of flexibility and modularity in design, desired modification (change of wheels, seat, height of the chassis etc.) if needed, can easily be done to meet up any individual requirement. Though it is solar operated but it can also be charged with grid electricity if desired. Long distance (over 35 km/day) traveling is not possible by this solar three-wheeler due to limited energy storage and it may not perform well during consecutive cloudy/rainy days. Again, the volume/size of the solar panel cannot be increased easily for increased energy demand due to limited space over head (roof). However, more efficient solar panel or solar power tracker can be used to extract more (maximum possible) energy from the sun to meet up increased energy demand. Nickel-cadmium batteries though expensive are ideally more suited to PV system than the lead-acid battery and can be used for better performance; it also has less of weight and no damage if the battery remains fully discharged for long periods.

As a “stand alone system”- all the disabled people at any corner of the country can enjoy the benefits or advantages of this solar three-wheeler for their daily use. Though the solar three-wheeler has been designed and developed in consideration of the disabled people of Bangladesh but disabled people at different corners of the world can use it provided that there is sufficient amount of solar radiation. Finally it is important to mention that the solar three-wheeler is not only environment friendly transport for disabled people but also prevent the secondary disability as auto power transport. So, it is a complete solution for mobility of the disabled people of the society.

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Appendix A: Disability-specific data (Indicators on Disability)

Types of Persons with disabilities in Bangladesh in 1999

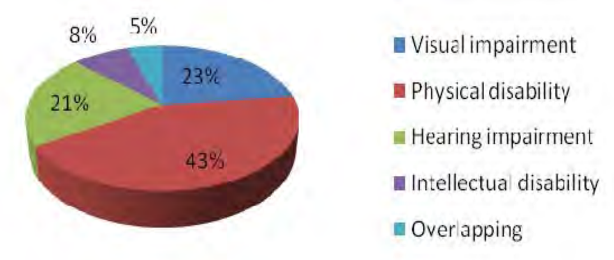
Visual impairment23%

Physical disability43%

Hearing impairment21%

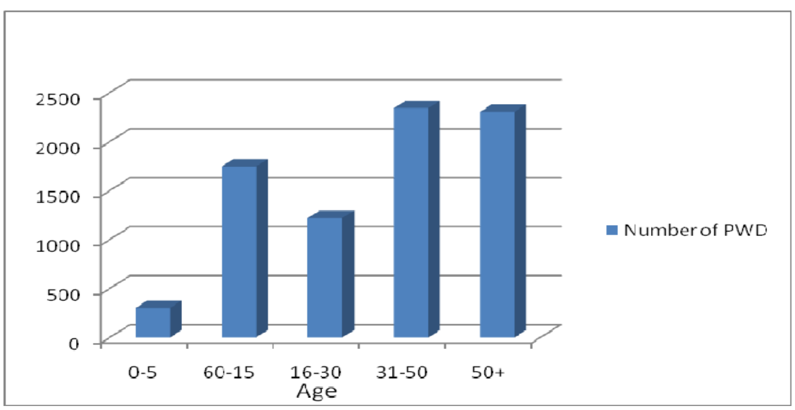
Intellectual disability8%

Overlapping5%



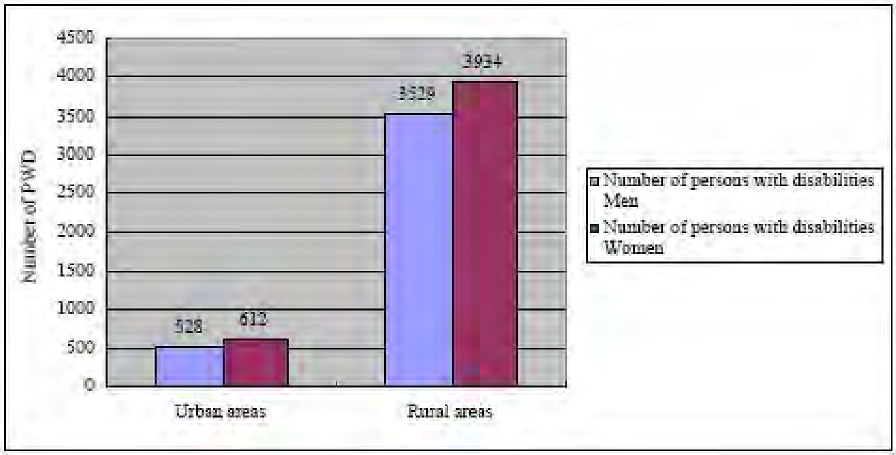
Source: Impact Foundation Bangladesh (IFB), Center for Services and Information on Disability (CSID), 1999

Number of Person with Disabilities in Each Age Category (age-specific data)



Source: Voluntary Health Services Society (VHSS), Action Bangladesh, Center for Services and Information on Disability (CSID), Impact Foundation Bangladesh

<u>Distribution of Persons with Disabilities in Urban and Rural Areas (Area-specific Data)</u>



Source: VHSS Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

<u>Types of Persons with Disabilities in Urban Areas in 1999</u>

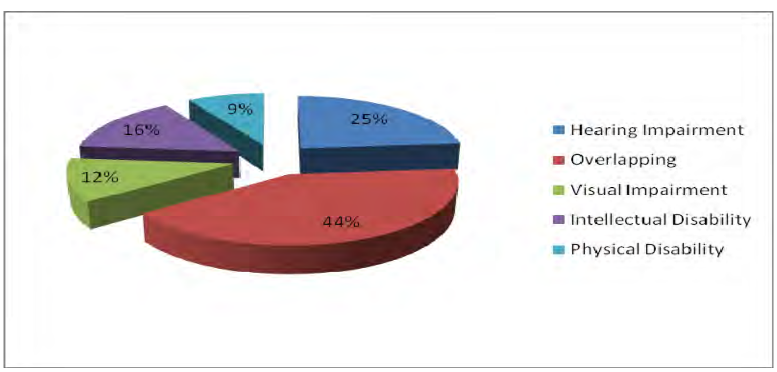
Hearing impairment 25%

Overlapping 44%

Visual impairment 12%

Intellectual disability 16%

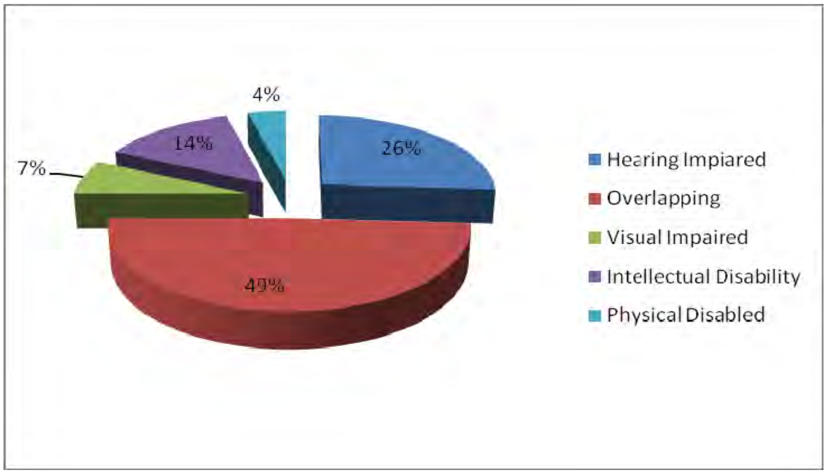
Physical disability 3%



Source: VHSS. Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

Types of Persons with Disabilities in Rural Areas in 1994-1999

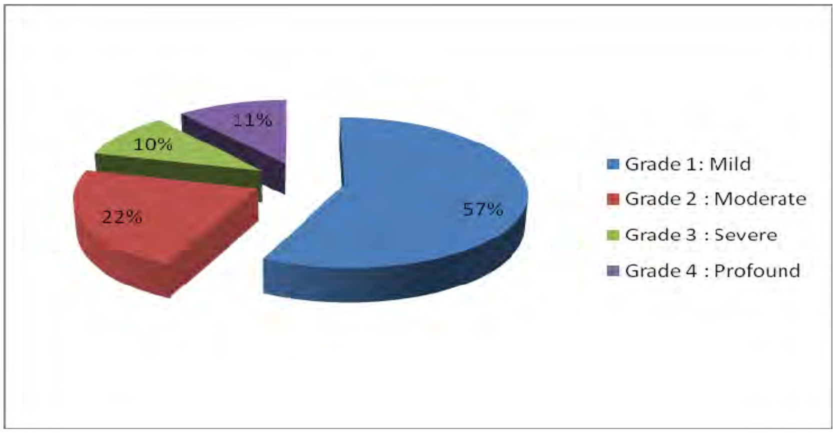
Hearing impaired	26%
Overlapping	49%
Visually impaired	7%
Intellectual disability	14%
Physically disabled	4%



Source: VHSS. Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

Persons with Physical Disability in Each Grade (Grade-specific data)

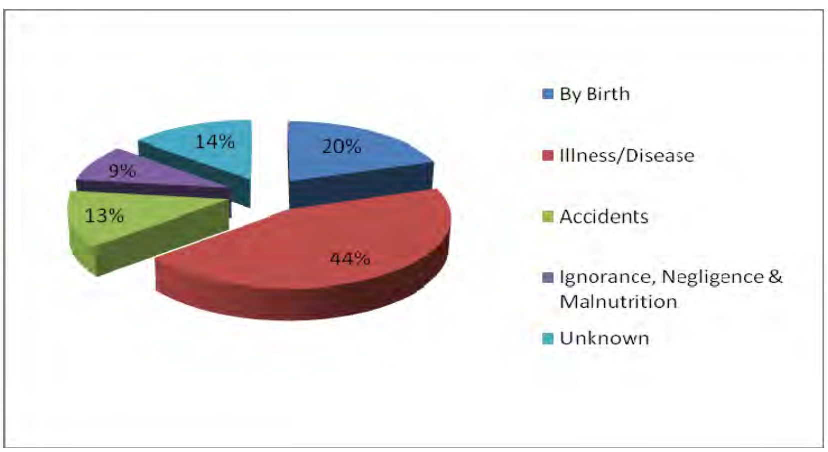
Grade 1: Mild	57%
Grade 2: Moderate	22%
Grade 3: Severe	10%
Grade 4: Profound	11%



Source: VHSS. Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

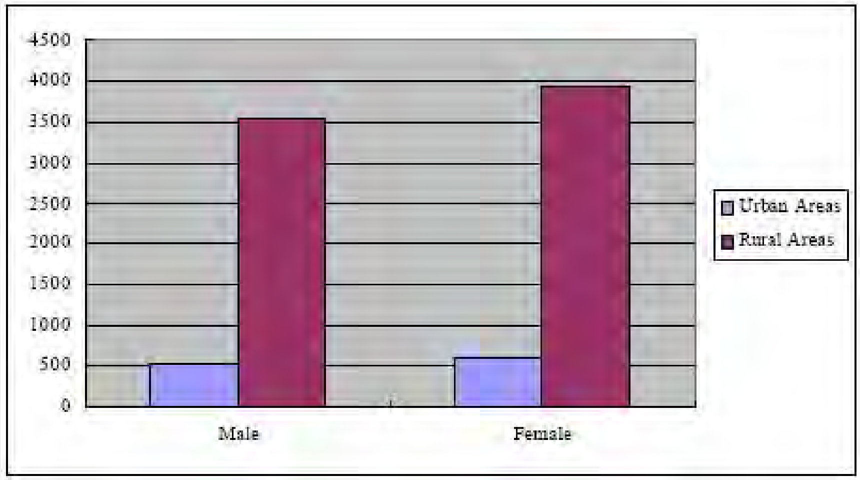
<u>Causes of Disabilities in 1994-1999 (Cause-specific Data)</u>

By Birth	20%
Illness/Disease	44%
Accidents	13%
Ignorance, Negligence & Malnutrition	9%
Unknown	14%



Source: VHSS. Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

Number of Male or Female Persons with Disabilities (Gender-specific Data)



Source: VHSS. Country Profile Study on Persons with Disabilities in Bangladesh. 2000.

Appendix B: Quantitative National Data on Disability

Prevalence of Disability by Type (per'000')

Type of Disability	2004		1991		1986	
	Male	Female	Male	Female	Male	Female
Night Blind	0.40	0.3	NA	NA	NA	NA
Blind	1.50	1.3	0.9	0.7	1.6	1.2
Deaf and Dumb	1.7	1.4	1.1	0.9	0.9	0.7
Lack of Intelligence	0.0	0.5	NA	NA	NA	NA
Mentally Retarded	0.6	0.4	0.9	0.6	0.7	0.5
Leprosy	0.1	0.0	0.1	0.1	0.2	0.1
Crippled	2.5	1.5	2.5	1.6	2.0	0.9
Old Age	0.9	0.9	NA	NA	NA	NA
Stammering	0.6	0.3	NA	NA	NA	NA
All type	9.1	6.7	5.5	3.9	6.2	4.1

Prevalence of disability at household and individual Level, Census-2001

Disability Type	Prevalence of disability in Household level	Prevalence of disability at individual level
All	21.7	4.87
Blind	4.4	1.01

Deaf and Dumb	4.6	1.06
Crippled	7.4	1.60
Mentally Retarded	5.3	1.19

Source: Population Census 2001

<u>Prevalence of disability in some specific area</u>

Type of Disability	Baseline Survey [4 locations with 46874 people]	Baseline Survey [5 locations with 94260 people]	Micro study of disables in disaster prone and iodine deficient-Jamalpur district[11782 people]
Loco motor	4.9%	4.2%	11.9%
Visual	53.5	48.8	34.2
Hearing and speech	24.5	25.4	35.0
Cognitive/ mental retardation	3.8	3.7	4.6
Epilepsy/ Other	2.3	2.2	2.0
Multiple	11.0	15.7	12.2
Any type	14.4%	13.3%	8.78%

Source: Action Aid and a Micro Study of Disability in Jamalpur during 1995-1997

Prevalence of Disability by Type (per'000')

Type of Disability	Prevalence of Disability HDS,2005	Prevalence of Disability ,2008		
		Both Sex	Male	Female
Any type	10.62	8.96	9.98	7.94
Blind	2.81	8.44	8.01	8.99
Night Blind	NA	5.22	4.73	5.83
Dumb/Deaf	3.45	16.79	16.12	17.65
Mental Retarded	0.50	12.76	13.32	13.33
Kushtah	0.12	1.00	1.15	0.80
Lame	1.17	22.54	26.26	17.79
Othorbo	1.42	5.58	5.71	5.40
Dhabal	NA	1.89	1.52	2.36
Memory loss	0.23	10.05	9.60	10.62
Goitre	0.45	1.40	0.81	2.15
others	16.02	14.34	13.78	15.08

Source: Sample Vital Registration System, 2008. BBS

Disability Rate by Gender

Year	Both Sexes	Male	Female
2008	8.96	9.98	7.94
2007	9.11	8.04	10.16
2006	10.31	8.38	9.36

Source: Sample Vital Registration System, BBS

Age Specific disability rate per 1000 by sex, 2008, Bangladesh

Age Group	Both Sex	Male	Female
00-04	2.02	2.06	1.97
05-09	4.96	5.61	4.29
10-14	5.74	6.03	5.42
15-59	7.83	9.30	6.39
60+	46.54	45.89	47.25
All Age	8.96	9.98	7.94

Source: Sample Vital Registration System, BBS

Age-Specific disability rate per 1000 by sex and locality, 2007

Age Group (Year)	National		Rural		Urban	
	Women	Men	Women	Men	Women	Men
00-04	2.17	2.57	2.21	2.67	1.98	2.22
05-09	4.42	5.81	4.75	6.15	3.35	4.67
10-14	5.39	6.42	5.54	6.40	4.90	6.49
15-59	6.75	9.56	7.21	10.73	5.79	6.27
60+	46.40	46.05	48.92	49.61	36.36	31.91
Total	8.04	10.16	8.63	11.20	6.24	6.98

Source: SVRS, BBS, 2007