DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW

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DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW

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DEDICATION

To my parents and sister
The reason for what I become today.
Thanks for your great support and continuous care.

To my true friends
I am really grateful to you.
You have been my inspiration.

To my respected guide
Who is the continuous Source of
Inspiration and constant encouragement for me.

Pranay...

DEPARTMENT OF RENEWABLE ENERGY ENGINEERING

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DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW

ABSTRACT

Key words*: *Farm rickshaw; performance evaluation; Solar power; BLDC motor; Electrical vehicle.

Rickshaws are small, three-wheeled vehicles which are used extensively in many Asian countries for transportation of people and goods. Rickshaws run on fossil fuels, which are non-conventional source of energy which creates huge problem of environmental pollution. The automobile industry in India is currently rapidly growing, the demand of energy is increasing day by day, comparatively to the discovery and production of fossil fuels. India is among the highest CO_2 emitting countries. To deal with these problems of fossil fuels, we need to look at the non-conventional sources of energy, which is available in inexhaustible and eco-friendly form in nature. The most significant source of renewable energy is sun, which is an infinite resource of energy to fulfil all energy requirements forever. The solar radiation incident over India is equal to 4–7 kWh per square meter per day with an average of 250–300 clear sunny days. Therefore, solar powered farm rickshaw was developed which gets charged through solar power. The solar panels were attached on roof of the vehicle, to harvest the light energy easily and convert it into electrical energy. The main components of developed solar powered farm rickshaw are solar panel, MPPT solar charge controller, lithium-ion battery, electronic motor controller and BLDC motor.

The performance evaluation of solar powered farm rickshaw in terms of solar charging, battery discharge in idle condition, voltage drop and time required per km, backup time and distance covered per charge, comparative analysis with and without solar power during transport and cost of operation was carried out. The developed model was tested on three different applied loads i.e., 100 kg, 200 kg and 300 kg on two types of road i.e., pakka and kachcha road. Statistical analysis using factorial completely randomized design was carried out to study the effect of independent parameters individually and their combined effect on dependent parameters. The results of univariate analysis indicated that the effect of applied loads on voltage drop per km and effect of applied load and roads on time required per km were all significant. The distance covered per charge was 18.44 km for 100 kg applied load. Comparative analysis shows that with connection of solar power, distance covered and backup time of rickshaw were 4.01 km and 32 min, respectively more as compared to without connection of solar power. The developed model was useful to carry the applied load of 300 kg to a distance of 20 km, per charge. The payback period of developed machine is 2.01 years. Thus, the developed rickshaw fulfils our motive of pollution free and low cost ride.

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CERTIFICATE – I

This is to certify that the thesis entitled **“DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW”** submitted by **Mr. LANJEKAR PRANAY RAJENDRA (Reg. No. 2050219010)** in partial fulfilment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in the subject of **RENEWABLE ENERGY ENGINEERING** to the Junagadh Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. He has successfully completed the comprehensive/preliminary examination held on **July 23, 2021** as required under the regulation for Post-graduate studies. He has submitted *Kachcha* bound thesis on **August 31, 2021.**

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Date: 12/10/2021

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LIST OF ABBREVIATIONS AND SYMBOLS

A	:	Ampere
Agril. Engg.	:	Agricultural Engineering
Ah	:	Ampere hours
Anon.	:	Anonymous
ANOVA	:	Analysis of Variance
AC	:	Alternating Current
BCR	:	Benefits Cost Ratio
BLDC	:	Brushless Direct Current
B. Tech	:	Bachelor of Technology
CAET	:	College of Agricultural Engineering and Technology
CD	:	Critical Difference
Ch.	:	Chapter
cm	:	Centimetre
cm^3	:	Centimetre cube
CNG	:	Compressed Natural Gas
CO_2	:	Carbon dioxide
CV	:	Coefficient of Variation
DC	:	Direct current
Dept.	:	Department
DF	:	Degree of Freedom
DOD	:	Deapth Of Discharge
Dr.	:	Doctor
et al.	:	et alia (and other)
etc.	:	Etcetera (and the rest)
E_a	:	Array efficiency
E_{SC}	:	Efficiency of solar charge controller
E_b	:	Efficiency of battery
E_{mc}	:	Efficiency of BLDC motor controller
F	:	Force
Fig.	:	Figure
FMPE	:	Farm Machinery and Power Engineering

g	:	Specific gravity
GDP	:	Gross Domestic Product
GI	:	Galvanized Iron
GW	:	Gigawatt
hrs.	:	Hour
hp	:	Horse power
i.e.	:	That is
ICAR	:	Indian Council of Agricultural Research
I_{sc}	:	Solar Intensity
JAU	:	Junagadh Agricultural University
JNNSM	:	Jawaharlal Nehru National Solar Mission
kg/m^3	:	Kilogram per meter cube
kWh	:	Kilowatt-hours
kWh/m^2	:	Kilowatt-hours per square meter
$kWh/m^2/day$	:	Kilowatt-hours per square meter per day
kWp	:	Kilowatt peak
LPG	:	Liquified Petroleum Gas
LPT	:	Large Plot Technique
m	:	Meter
mm	:	Millimetre
min	:	Minute
m^2	:	Meter square
m^2/s	:	Meter square per second
m^3/sec	:	Meter cube per second
m^3/kWp	:	Meter cube per kilowatt peak
MPPT	:	Maximum Power Point Tracking
MS	:	Mild Steel
M. Tech	:	Master of Technology
N	:	Newton
No.	:	Number
NS	:	Non-significant
P	:	Power
pp.	:	Page number

PV	:	Photovoltaic
PWM	:	Pulse Width Modulation
Q	:	Discharge
REE	:	Renewable Energy Engineering
Reg. No.	:	Registration number
RPM	:	Revolutions Per Minute
s	:	Second
Sr. No.	:	Serial number
UTs	:	Union Territories
USA	:	United States of America
V	:	Voltage
Vmp	:	Volts at maximum power
viz.	:	Namely
W	:	Watt
yr.	:	Year (s)
°	:	Degree
°C	:	Degree celsius
%	:	Per Cent
/	:	Per
+	:	Plus
-	:	Minus
x	:	Multiolication
ρ	:	Density
₹	:	Rupees
₹/h	:	Rupees per hour
€	:	Euro
$	:	Dollar
:	:	Colon
τ	:	Torque

CHAPTER - I

INTRODUCTION

1.1 GENERAL

The quests for a constant, safe, clean, environmental-friendly fuel is never-ending. Carbon-based fuels, such as fossil fuels are unsustainable and hazardous to our environment. Best alternatives are renewable energy sources, such as the sun, wind, biomass, tides and hydropower. Amongst these elements, solar energy is preferred since it could provide the cleanest sustainable energy almost everywhere for the longest duration of time. Solar photovoltaic (PV) is widely used technology which converts solar radiation directly in to electrical power. PV production becomes double every two years, increasing by an average of 48 percent each year since 2002 (Sani *et al.* 2014). The production of solar modules worldwide reached approximately 140 gigawatts in 2019, a significant increase from 238 megawatts in 2000 (Madhumitha Jaganmohan, 2021). Different countries in the world are using the solar power as an alternative to the other power. Countries that installed highest number of solar power are: Germany 9,785 MW, Spain 3,386 MW, Japan 2,633 MW, United States 1,650 MW, Italy 1,167 MW, Czech Republic 465 MW, Belgium 363 MW, China 305 MW, France 272 MW, India 120 MW. So, it has become very clear that the solar power is growing more eagerness among the people to use solar power as their alternative power system (Siddique *et al.* 2014). Due to its innumerable benefits in environmental, economic and social aspects PV systems have becomes the world's fastest growing energy technology. It can arguably be said that the only limitation to solar power as an energy source is our understanding of developing efficient and cost effective technology which can implement it.

1.2 HISTORY OF RICKSHAW

A rickshaw originally denoted a two or three-wheeled passenger cart, now known as a pulled rickshaw, which is generally pulled by one man carrying one passenger. The first known use of the term was in 1879. Over time, cycle rickshaws (also known as pedicabs or trishaws), auto rickshaws, and electric rickshaws were invented, and have replaced the original pulled rickshaws, with a few exceptions for their use in tourism.

Types of rickshaws include:

a) A pulled rickshaw; a two-wheeled passenger cart pulled by a human runner.
b) A cycle rickshaw, also called a pedicab.
c) An auto rickshaw, also called a tuk-tuk, auto, mototaxi, or baby taxi.
d) An electric rickshaw, also called e-rickshaw.

Electric rickshaws also known as electric tuk-tuks or e-rickshaws or toto or e-tricycles have been becoming more popular in some cities since 2008 as an alternative to auto rickshaws and pulled rickshaws because of their low fuel cost, and less human effort compared to pulled rickshaws. They are being widely accepted as an alternative to petrol/diesel/CNG auto rickshaws. They are three-wheelers powered by an electric motor ranging from 650 to 1400 Watts. They are mostly manufactured in India and China, only a few other countries manufacture these vehicles (Anon., 2016).

The first model solar car invented was a tiny 15-inch vehicle created by General Motors employee, William G. Cobb. Designated the sun mobile, he displayed it in 1955 at the Chicago, Powerama convention. It was made up of 12 selenium photovoltaic cells and a small electric motor. The first combination of photovoltaic devices and electric vehicles happened in the late 1970's (Chaturvedi *et al.* 2015).

Fig. 1.1 First Solar Car

1.3 SOLAR POWERED FARM RICKSHAW

Solar farm rickshaw can be categorized as a 'green vehicle' which is powered by renewable energy with zero carbon emission. Indeed, it would be delightful if our rickshaw could continue to run without us having to spend billions on fossil fuels every year and to deal with natural hazards that their combustion leave behind. If we could drive a solar-powered farm rickshaw, that auto dream would come true. Solar powered farm rickshaw would harness energy from the sun via solar panels. A solar panel is a packaged, connected assembly of solar cells, also called photovoltaic cells which are solid state devices that can convert solar energy directly into electrical energy through quantum mechanical transitions. They are noiseless and pollution-free with no rotating parts and need minimum maintenance. The electricity thus generated would then fuel the battery that would run the rickshaws motors. Therefore, we would obtain an electrically driven vehicle that would travel on "free" energy with no harmful emissions, that can utilize its full power at all speeds, and would have very little maintenance cost.

1.4 MOTIVATION

1.4.1 Energy Crisis

Energy crisis are a main issue in all over the world but it is also important to know about the available reserves of conventional energy resources like fossil fuels and uranium. Three fossil fuels are the main sources of world energy which are petroleum, coal, and natural gas. The demand of energy is rapidly increasing day by day comparatively to the discovery and production of fossil fuels. Fossil fuels formed from decomposition of buried dead organisms in millions of years, and sometimes exceed hundreds million years. Fossil fuels vehicle are using fossil fuels like petrol, LPG and CNG which are harmful for environment. Mostly in Asian Country, auto rickshaws are commonly used which are very inexpensive to operate.

1.4.2 Pollution

The earth is suffering as a result of the destruction wreaked upon it by humanity. Whether it is the pesticides contaminating the rivers, chemicals from factories polluting the seas or the exhaust fumes from vehicles and industries polluting the air, the systematic destruction of different ecosystems all over the world has led to a dreadful mess. Main focus is on the transportation industry which is the second largest source of pollution and health hazards. Thousands of people are becoming victims of heart and lung problems, depression, memory loss, asthma and even premature deaths. Despite the apparent advantages in the vehicle design auto rickshaws present a huge pollution problem. This is due to the use of an inefficient engine, in general a 2 or 4 stroke, with almost no pollution control.

1.4.3 Global Warming and Temperature

Fossil fuels when combusted forms a number of gaseous by-products, consisting mainly of carbon dioxide, but also containing traces of other gases such as carbon monoxide. The potency and increasing levels of these gases are causing gradual damage to the ozone layer in the Earth’s atmosphere and enhances global warming.

India is among the highest CO_2 emitting countries. The global warming resulting from this causes global temperatures to increase and consequently raises the sea levels as well. World economy would double in size in the next 20 years, resulting in demand for energy rising by almost 40%. Two-thirds of this demand would be met from fossil fuels, oil, gas and coal and that would lead to a 25% increase in carbon emissions as per world bank report on climate change (Anon., 2019).

1.4.4 Fuel Prices

Fuel-based cars not only threaten the very air we breathe in but also the cost of running and maintaining them are huge and overbearing, and as the fossil fuels are gradually being depleted, the cost of these limited scare resources, the existing fuels prices are continuously rising.

1.5 PRACTICAL UTILITY (JUSTIFICATION)

Rickshaws are small, three-wheeled vehicles which are used extensively in many Asian countries for transport of people and goods. Despite the apparent advantages in the vehicle design, auto rickshaws present a huge pollution problem in major Indian cities. After combustion of fossil fuel create toxic gases such as carbon monoxide (13.06 g/km), hydrocarbon (1.75 g/km), nitrogen oxide (0.87 g/km) and carbon dioxide (285 g/km). In the motivation showed that a different problem of engine operated vehicle such as pollution, energy crisis, global warming and fuel prices. In India mostly tractor is used for the farm works such as labour transportation, selling of farm products, etc. Tractor consumes more fuel for this small farm works. With the help of the solar powered farm rickshaw we can do this small farm work efficiently without fuel cost and environmental freely.

Public transport is the primary mode of road transport for most of the Indian citizens, and India's public transport systems are among the most heavily used in the world. India's road network is the second-largest and one of the busiest in the world, transporting 8.225 billion passengers and over 980 million tonnes of cargo annually, as of 2015. In total, about 21 percent of households have two wheelers whereas 4.7 percent of households in India have cars or vans as per the 2011 Census. The automobile industry in India is currently rapidly growing with an annual production of over 4.6 million vehicles, with an annual growth rate of 10.5% and vehicle volume is expected to rise greatly in the future (Anon., 2015). Companies have come out with alternative models such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) rickshaws to mitigate the pollution problem caused by traditional petrol models. But the reality is that fuels like CNG and LPG are non-renewable and will be exhausted in future. In all over the world the energy crisis is a main issue. Fossils that create the fossil fuels take millions of years to generate. Once we burn them or use them, they take another million years to get recreated and as every fossil is finite, eventually they will have diminished ultimately. Fossil fuels are harmful for the environment. So, in order to prevent disastrous environmental changes, it is essential to stop the extraction of the increasing demand of fossil fuels. For this purpose, it is quite necessary to make a new exploration of natural resources of energy.

Researchers have shown that renewable energy sources are able to fully meet the global energy with almost no pollution and global warming emissions. In order to achieve the sustainable environment for all the living beings from the pollution caused by the combustion of petrol and diesel in automobiles, solar power should be used for the running of these vehicles. The most significant source of renewable energy is sun. Amazingly the sun provides enough energy to fulfil all energy requirements forever. Therefore, sunlight is now a day’s considered to be a source of energy which is implemented in various day to day applications. Transportation system based on auto rickshaws that operate in an environmentally friendly way is solar rickshaw. Solar energy is being used to produce electricity through sunlight. The main advantage of using solar powered rickshaw is low cost and pollution free ride.

However, studies on solar operated rickshaw are limited in India. In India many of research work in renewable energy sector is done on solar power operated, so this study is also helpful to achieve the sustainable environment for all the living beings. This study is exploring the use of solar powered rickshaw is low cost and pollution free ride. Looking to the above facts, the present research work is being undertaken with the following objectives.

1.6 OBJECTIVES

A study on “Development and performance evaluation of solar powered farm rickshaw” was taken with the following objectives:

1. To develop solar powered farm rickshaw.
2. To evaluate performance of the developed solar powered farm rickshaw.
3. To study economic benefits of the developed solar powered farm rickshaw.

CHAPTER - II

REVIEW OF LITERATURE

In this chapter, the comprehensive review of the research work done by various research workers relevant to the present study is presented and summarized under the following subheadings.

1. Solar Energy Status in India
2. Necessity of Solar Vehicles
3. Solar Powered Different Vehicles
   3.1 Solar E-Bicycle
   3.2 Solar tricycle
   3.3 Solar car
4. Solar Photovoltaic and Charge Controller
5. BLDC Motor
6. Performance Evaluation of Solar Rickshaw

2.1 SOLAR ENERGY STATUS IN INDIA

Sharma *et al.* (2012) Studied solar energy in India: strategies, policies, perspectives and future potential. The average intensity of solar radiation received on India is 200 MW/km square (megawatt per kilometre square) with 250–300 sunny days in a year. Solar energy intensity varies geographically with Western Rajasthan receiving the highest annual radiation energy and the north-eastern regions receiving the least. India has a good level of solar radiation, receiving the solar energy equivalent of more than 5000 trillion kWh/year. Depending on the location, the daily incidence ranges from 4 to 7 kWh/m^2, with the hours of sunshine ranging from 2300 to 3200 per year. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6000 million GWh of energy per year. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, and Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where development and deployment of solar technologies is maximum.

Pathak and Muller (2016) Studied on Gujarat state: pioneering and scaling up solar energy in India. Located in western India, Gujarat is one of India's most industrialized states. With a share of 7.5%, the state is the fourth largest contributor to national GDP. It has a population of around 60 million and is among India's most prosperous states with a per capita GDP higher than the national average. Since the 1960s, the state has witnessed rapid industrial growth and has established leadership in several industrial sectors. Gujarat also has abundant solar resource potential, receiving 5.5–6 kW/m^2 per day with over 300 days of sunshine.

Suman and Ahamad (2018) said that in India, there is a huge gap between the energy generation and energy consumption. India has a great potential for solar power and it is estimated so many times of the energy requirement which is about 5000 trillion kWh per year. The solar radiation incident over India is equal to 4–8 kWh per square meter per day with an annual radiation ranging from 1200–2300 kWh per square meter. It has an average of 250–300 clear sunny days and 2300–3200 hours of sunshine per year. India's electricity needs can be met on a total land area of 3000 km^2 which is equal to 0.1% of total land in the country.

2.2 NECESSITY OF SOLAR VEHICLES

Wamborikar and Sinha (2010) studied solar powered vehicle. Energy is one of the most vital needs for human survival on earth. We are dependent on one form of energy or the other for fulfilling our needs. One such form of energy is the energy from fossil fuels. We use energy from these sources for generating electricity, running automobiles etc. But the main disadvantages of these fossil fuels are that they are not environmental friendly and they are exhaustible. To deal with these problems of fossil fuels, we need to look at the non-conventional sources of energy. With regard to this idea we have designed an electrical vehicle that runs on solar energy.

Bharathi *et al.* (2015) studied car runs by solar energy. In Today's world global warming is being increased day by day. There are many reasons like pollution, deforestation, water contamination, etc. In coming years, the major problem is depletion of ozone layer which is caused by release of CFC's from vehicles. So the implementation of solar energy cars should be progressed. Solar energy car which plays a vital role for the upcoming energy crisis.

Sharma *et al.* (2016) said that in the current state of technological development, the future of vehicles seems to be with the hybridization of various energy sources. This sort of development in vehicles seeks to take the benefits from the best quality of each energy source and it is especially useful in urban driving vehicles. In cities of India one of the major medium of transportation is auto rickshaws, which is producing a huge amount of air pollution as well as greenhouse gases like CO_2. Fuel, which is used is a non-renewable source and also which costs high as a result of that transportation charges increases. It would also affect the economy as well as the users of the auto rickshaw. Thus they should go for a reliable source as know that current trend of using the reliable source like solar energy which is available in plenty in country like India.

Shukla *et al.* (2019) shows that need of solar powered vehicles. The air pollution that warming the earth as a result of pollutants from the automobiles, which is about 23% of the total air pollution. One of the great problems faced in urban areas throughout the world is the increase in vehicles due to an imbalance between the public transport and the increase in population which, finally results in a huge amount of air pollution. With the increasing rate of population, the number of vehicles is also increasing due to the imbalance between these two factors and finally the pollution rate is also increased. Over the last two decades, many experiments have been done to control emission from IC engine. So in this respect, this solar powered vehicle may be one of the solutions because of pollutant free property.

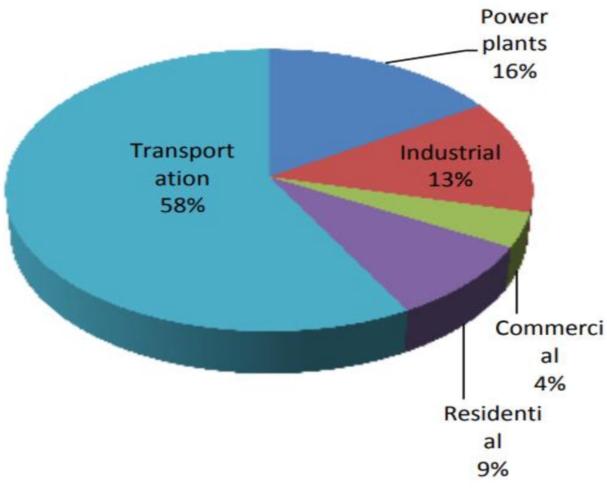


Fig. 2.1: CO_2 Emissions by different sectors

2.3 SOLAR POWERED DIFFERENT VEHICLES

2.3.1 Solar E-Bicycle

Mishra *et al.* (2016) said that a solar bicycle is an electric vehicle that provides that alternative by harnessing solar energy to charge the battery and thus provide required voltage to run the motor. Since India is blessed with nine months of sunny climate thus concept of solar bicycle is very friendly in India. Hybrid bicycle combines the use of solar energy as well as the dynamo that runs through pedal to charge the battery to run the bicycle. Thus solar hybrid bicycle can become a very vital alternative to the fueled automobile thus its manufacturing is essential.

Apostolou *et al.* (2018) studied an overview of existing experiences with solar-powered e-bikes. It presents research conducted so far on e-bikes and solar-powered e-bikes, as well as the main technical features of the solar e-bike. Finally, it analyses a sample of e-bikes' and solar-powered e-bikes' users, based on Dutch National Travel Survey data and an experimental field study conducted in 2017. Data showed that the main target group of (solar) e-bikes are commuters in the age group between 40 and 60 years old, commuting distances longer than 6 km, with a gross income higher than €2500. Electric bicycles (e-bikes) are considered a sustainable alternative to automobile transportation today. The electric bike includes all the benefits that conventional bicycles offer, plus faster, more comfortable and longer trips, as well as less effort for the user. Solar-powered e-bikes are concluded to have potential as a sustainable way of transportation in urban areas and cities, potentially replacing the conventional means of transport.

Nagwe *et al.* (2019) studied on the solar assisted bicycle developed is driven by DC motor fitted in front or rear axle housing & operated by solar energy. The solar panels mounted on the carriage will charge the battery & which in turn drive the hub motor. When the bicycle is idle, the solar panel will charge the battery. This arrangement will replace the petrol engine, the gear box & the fuel tank in case of a two wheeler or a chain sprocket, chain & gear shifting arrangement of a conventional bicycle being used by most common man. As a part of dissertation work, the solar assisted bicycle is fitted with a dc hub motor on front axle of a bicycle with power rating of 250W and with a travelling speed of around 25-30 kmph. It is provided with a pair of lead acid batteries of 35 Ah each, a photovoltaic solar panel with capacity of 20 watts, a voltage regulator of 24v 10 Amp, accelerator and motor controller of 24v 25Amp. There is also a provision for charging of the battery with 220-240V, AC wall outlet supply, in case of poor solar supply due to cloudy weather.

Shah *et al.* (2019) had experimented fabrication and testing of solar smart bicycle. The BLDC (Brushless DC) motor to convert the electrical energy into rotations of wheel and to convert and store the same rotation energy into electrical energy we have employed dynamos. By this paper, the solar smart bicycle speed is 19 km/hr at plain road and at incline road the speed is decrease to 17 km/hr. The actual time required to charge the battery by adapter 12 V 12Ah was 2hrs 15 mins which was more than the theoretical time by 12.5 % because of external factors like loose pin connection, air resistance, wire resistance factor etc. The actual time required to charge the battery by solar panel was 9.2 hrs which was more than theoretical time by 9.5% because of factors like inclination angle, soil factor, solar tracking etc.

2.3.2 Solar Tricycle

Waliullah *et al.* (2014) had experimented design a solar and pedalling powered rickshaw. The Indian subcontinent is a place where three wheeler rickshaws are driven by human power for transportation system. As a result, large portion of energy are wasted by human being through pedalling. Since pedalling is one kind of kinetic energy, so it can be converted into electric energy by using dynamo which produce 6 W electricity. As sun & pedal are the source of energy, so these energies can be stored into the battery which is used to supply power to the motor to drive the rickshaw automatically. The main purpose of this system is to use solar power through solar panel and to recharge the battery as solar power is available and costfree. Dynamo is used in rickshaw’s wheel to store some energy in an additional battery. The additional battery supplies power to the light and the horn. For this eco-friendly system around 6-7 hours are required to recharge the 48V 30Ah battery by solar power which can be used 4-5 hours. This eco-friendly solar and pedalling powered rickshaw will be more efficient after the improvement of solar cell, charging system and dynamo mechanism.

Masud *et al.* (2017) studied on design construction and performance study of a solar assisted tri-cycle. In this study, a cheaper solar tricycle with more capability of utilizing the solar energy is designed for developing countries. The main content of the tricycle is Solar PV panel, Brushless PMDC motor, controller, and battery. The power transmission of the solar tricycle is also simple. It can be said that, the tricycle construct with low cost and light weight, which can carry a 150 kg load with 26 km/h speed which is really a better one. It can also move a greater distance which is equivalent to 25 km with a full charged battery, but 31 km in the case of a battery which charging in the running time. So, when the solar system is active, the storage system can get back up about 24% which is equivalent to 6 km. Also, the total construction cost of the tricycle is only 240$ with near about zero impact on the environment.

2.3.3 Solar Car

Rattankumar and Gopinath (2012) studied on solar powered car using brushless dc hub motor with advanced pic microcontroller. Develop a prototype for a car run by solar energy using a special type of motor Brushless Permanent Magnet D.C. Motor (BLDC) and a microprocessor based controller to run the car. A solar powered car is an electric vehicle powered by solar energy obtained from sun and converted into usable form by solar panels on the roof of the vehicle. Photovoltaic (PV) cells in the solar panel convert the solar energy directly into electrical energy. The presently designed vehicle runs at a speed of 30Km/Hr for one charging which takes approx. 18 hours and successfully tested for 100Km per charge. Further work is in process to develop the vehicle with Reluctance motor as now it is run by BLDC. It is also proposing to use solar panels of higher efficiency with minimal size.

Mohammadi (2018) studied on design, analysis, and electrification of a solar-powered electric vehicle. electrification of an electric vehicle has been performed, in which the solar energy has been used along with the traditional plug-in energy to power the vehicle. The solar energy absorbed from the sun by the solar panel is converted into chemical energy, and stored in batteries. Therefore, the solar-powered electric car can work with an electric motor instead of an Internal Combustion Engine (ICE) to drive the car. Also, the motor can run on AC current which is converted by the inverter from DC current stored in batteries. To drive the car in electric mode, a 360 V Li-polymer battery pack with 100 kWh energy capacity has been proposed to install in the car. Thus, the approach of transforming solar energy into chemical energy, and converting chemical energy to mechanical energy have been applied in this solar-powered electric car. Utilizing solar panels to generate electricity for use in the SPEV not only acts as the range extender but also reduces the carbon footprint. Solely, relying on solar energy to power the electric vehicle has many limitations such as limited range and power capabilities. Thus, the ability to charge the vehicle from plug-in AC source has been also provided.

2.4 SOLAR PHOTOVOLTAIC AND CHARGE CONTROLLER

Wamborikar and Sinha (2010) stated that the main point that should be kept in mind while making a solar vehicle is the mounting of the solar panel. The panel should be mounted in such a way that it receives maximum sun rays so that it gives its maximum efficiency. For the vehicle designed, we have mounted the solar panel in SOUTH-EAST direction during the time 6 AM to 11.30 AM. After that the panel is changed to a SOUTH-WEST direction. The solar cell used in the vehicle is 140Wp (Watt Peak) multi-crystalline with 12 volts two batteries of 190 Ah, to store the power. The reason behind using the multi crystalline cell is that it is more efficient than the mono-crystalline cell and the rate of conversion of energy is faster in the former. The upper frame of this solar module is covered with thick glass to avoid breakage of the solar panel.

Sasikumar and Jayasubramaniam (2013) studied on “solar energy system in India.” Conventional energy sources like coal, oil, natural gas, etc., are limited in quantity and if these continue to be depleted at the present rate, these will be exhausted in the coming decades. Energy demand is resulting in the creation of fossil fuel based power plants leading to substantial greenhouse gas emissions having an adverse impact on global warming and climate change solar energy offers a clean, climate-friendly, abundant and inexhaustible energy resource to mankind. The costs of solar energy have been falling rapidly and are entering new areas of competitiveness. Solar Thermal Electricity (STE) and Solar Photo Voltaic Electricity (SPV) are becoming competitive against conventional electricity generation in tropical countries. Solar Photovoltaic (SPV) cells convert solar radiation (sunlight) into electricity. A solar cell is a semi-conducting device made of silicon materials, which, when exposed to sunlight, generates electricity. Solar cells are connected in series and parallel combinations to form modules that provide the required power.

Desai *et al.* (2016) studied on design and fabrication of solar tri cycle. As the title suggests, the tricycle is operated by solar energy. The batteries are charged with solar energy with the help of a solar cell. Solar cells convert the energy of sunlight directly into electricity through the use of the photovoltaic effect. The photovoltaic effect involves the creation of a voltage into an electro-magnetic radiation. The photoelectric and photovoltaic effects are related to sunlight, but are different in that electrons are ejected from a material's surface upon exposure to radiation of sufficient energy in photoelectric, and generated electrons are transferred to different bands of valence to conduction within the material, resulting in the build-up of voltage between two electrodes in photovoltaic. Solar cells are electrically connected and fabricated as a module with a sheet of glass on top to allow light to pass and protect the semiconductor from the weather. To obtain a desired peak DC voltage we will add solar cells in series, and to obtain a desired peak current, the solar cells are put in parallel position.

Reddy *et al.* (2017) carried a research on techno-economic investigation of solar powered electric auto-rickshaw for a sustainable transport system. The idea of incorporating solar PV modules into passenger vehicles has been prototyped by some of the top automobile companies as it lessens gasoline dependence and significantly cuts down fuel expenses, while also reducing carbon emission levels. The Japanese companies Mazda and Toyota are the front runners in transforming this concept into reality. In the early 2000s Mazda's 929 luxury sedan came up with an optional solar roof to power their air-conditioning system. Toyota redesigned its model Prius Prime to accommodate a 180 W solar panel to charge the batteries and power the rickshaw accessories. Ford Motor Company developed a product "C-MAX Solar Energy" with an off-vehicle solar concentrator made up of a special Fresnel lens to direct sunlight to the rooftop solar cells while enhancing the solar radiation to harness more power from highly efficient solar cells.

Nagwe *et al.* (2019) stated that solar power charge controller is essential to regulate the voltage output from the solar panel before it is supplied to the battery. A voltage regulator is a power converter with an output DC voltage greater than the input DC voltage. This is used to regulate an input voltage to a higher regulated voltage. The output of the solar panel is not always being stable due to fluctuations in intensity of sunlight, angular changes with respect to the direction of sunlight, as well as other environmental factors. The output of the solar panel is the input of the boost converter, which then outputs into the battery for charging. Because the output of the solar panel will be varying constantly, we need a voltage regulator/boost converter that will take an input from a wide range of voltages and output a specific, constant voltage value. A voltage regulator/boost converter is a power converter that will take in a DC voltage and output a higher value DC voltage.

Shukla *et al.* (2019) stated that A standard solar panel consists of a layer of silicon cells, a metal frame, a glass casing and various wiring to allow current to flow from the silicon cells. Silicon (atomic -14 on the periodic table) is a non-metal with conductive properties that allow it to absorb and convert sunlight into electricity. When light interacts with a silicon cell, it causes electrons to be set into motion, which initiates a flow of electric current. This is known as the “photovoltaic effect,” and it describes the general functionality of solar panel technology.

Asrori *et al.* (2020) The study was conducted to compare the use of Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) of the Battery Charging Controller (BCC) from the flexible solar panels to work optimally as a battery charging system on electric bicycles. The independent variables in this experiment are BCC type and solar irradiation. Meanwhile, the dependent variable consists of voltage and current output of the solar panel. The flexible solar panel used is the monocrystalline type and has a capacity of 100 Wp. In this study, the devices to the optimization of the battery charging system consist of; BCC PWM, BCC MPPT, flexy solar cell, data logger, and battery. The results showed that PWM Solar charger can be producing the average power output of 29.92 Watt, while the MPPT type is 38.89 Watts. The use of MPPT will increase performance by about 10% compared to PWM. This study concludes that the solar charger controller with MPPT type is successful in optimizing the battery charging system compared to the PWM type.

2.5 BLDC MOTOR

Beedu (2015) studied on design, development and performance evaluation of solar power assisted tricycle. Selection of motor depends on the power requirement and the mode of driving. Two types of motors are available, mechanically commuted DC motor and Brushless electronically commuted DC motor (BLDC motor). Among these two types, BLDC motor is preferred because it provides noiseless operation, more efficient, gives under voltage and over voltage protection and waterproof.

Desai *et al.* (2016) studied on design and fabrication of solar tri cycle. The hub motor is a conventional DC motor. The rotor is outside the stator with the permanent magnets mounted on inside. The stator is mounted and fixed onto the axle and the hub will be made to rotate by alternating currents supplied through batteries. Hub motor generates high torque at low speed, which is highly efficient and which doesn't need sprockets, brackets and drive chains. This means they are very reliable and have a long life. The main characteristic of Brushless DC Machines is that they may be controlled to give wide constant power speed ranges.

Joy *et al.* (2018) studied on BLDC motor drive for electric vehicle. BLDC Motor of high power rating is not available easily. When compared with other motor, cost of BLDC motor is really high. BLDC Motor and its controller should be matched to each other. Coupling the motor with the gear box of the existing vehicle was tiresome and time consuming. Thus by providing BLDC drive we can achieve smooth operation with high efficiency, high torque and easy speed regulation. As per the weight and required torque of the vehicle we can convert the conventional vehicles to pollutant free, highly efficient electric vehicles.

Shah (2018) opined that a simple BLDC motor transmit the power by gear attachment to the differential. From differential half shaft would carry the transmission to the wheels. Here advantage is reduced sensors as the mechanical differential does the job. Only extra gear attachment is needed to be used.

Meshram *et al.* (2019) stated that the powered BLDC prototype of the vehicle was designed with just forward and backward movement which was able to achieve a speed of 23Kmph.The rear axle of the vehicle is connected to the driving shaft of the BLDC motor through the fly wheel. With the exchange in motor, which has high Torque, the automobile would be successful of been driven with heavy load. The operation of a BLDC is based on the force interaction between the permanent magnet and the electromagnet. For robotics, auto motive and small actuating application, 48V or less voltage BLDC motors are preferred and for industrial application and automation system, 100V or higher rating motors are used.

2.6 PERFORMANCE EVALUATION OF SOLAR OPERATED RICKSHAW

Prabhu and Manigandan (2010) carried out research on design and fabrication of solar transport vehicle. In the current state of technological development, the future of vehicles seems to be with the hybridization of various energy sources. This sort of development in vehicles seeks to take the benefits from the best quality of each energy source and it is especially useful in urban driving vehicles. In cities of India one of the major medium of transportation is auto rickshaws, which is producing a huge amount of air pollution as well as greenhouse gases like CO_2. Fuel, which is used is a non-renewable source and also which costs high as a result of that transportation charges increases. It would also affect the economy as well as the users of the auto rickshaw. Thus they should go for a reliable source as know that current trend of using the reliable source like solar which is available in plenty in country like India. Adopted solar energy as the additional sources in addition to the conventional IC engines. they using the solar panel, controller and DC motor setup to convert the light energy as an electrical energy which is fed to the DC motor to obtain mechanical motion. The mechanical motion was transferred to wheels through chain drive in the propeller shaft which leads to cheap and effective transmission. Finally, fabricated a concept auto rickshaw with the help of modified transmission system and energized with solar energy to run it.

Sheikh *et al.* (2014) carried out research work on design a solar and pedaling powered rickshaw. The Indian subcontinent is a place where three wheeler rickshaws are driven by human power for transportation system. As a result, large portion of energy are wasted by human being through pedaling. Since pedaling is one kind of kinetic energy, so it can be converted into electric energy by using dynamo which produce 6 W electricity. As sun and pedal are the source of energy, so these energies can be stored into the battery which is used to supply power to the motor to drive the rickshaw automatically. The main purpose of this system is to use solar power through solar panel and to recharge the battery as solar power is available and cost-free. Dynamo is used in rickshaw's wheel to store some energy in an additional battery. The additional battery supplies power to the light and the horn. For this eco-friendly system around 6-7 hours are required to recharge the 48 V 30 Ah battery by solar power which can be used 4-5 hours. The implementation of this system would be beneficial and efficient, because these are not only depending on the availability of sun.

Shaik *et al.* (2015) carried out a research work on solar rickshaw for sustainable energy future. In order to achieve the sustainable environment for all the living beings from the pollution caused by the combustion of petrol and diesel in automobiles solar power should be used for the running of these vehicles. An electric rickshaw fitted with a solar panel and which run up to 40 km per charge has a potential to replace the petrol consuming public transport vehicles. At our staggering consumption levels, the world's petroleum reserves will be exhausted in the next 30 to 40 years. Also the petroleum powered transportation network is responsible for a large amount of the hazardous emissions causing global warming and air pollution problems worldwide. Public transport vehicles with renewable fuels like solar panels can rule the coming markets as these vehicles need very less maintenance and no need to spend any extra amount of fuel. Hence a vehicle which runs using solar energy and having an average speed of around 25 kmps and running around 40 km per charge can save our environment from the pollution caused due to exhaust gases which are formed due to un burnt fuel in engine and also due to use of adulterer fuel can be reduced. High import duty on the fuels can be reduced. The average income of the people who earn money by running transport vehicles will increase to around 40%. The transportation cost for the public decrease. Hence with these many benefits the use of solar panels in the public transport vehicles will be a boon to human kind. This rickshaw is being able to work continuously with a good mechanical efficiency and also it needed no fuel for its working as it can directly charge its batteries using a solar panel fixed at its roof. The maximum speed of the rickshaw found to be around 15 to 25 kmph at a load of 250 kgs (load of 3 persons in rickshaw) and weigh of the body is 150 kg (including all items). Full charging time of the batteries is around 3.5 to 4 hrs. Rickshaw is running around 35 to 45 km per charge.

Saleh *et al.* (2016) studied on design and performance analysis of a solar powered hybrid rickshaw for commercial use in Pakistan. The energy sector of Pakistan is not well developed and it is also inadequately managed. Due to this fact currently the country is facing severe energy crisis and large share of the energy sources are consumed by automobiles. In order to contribute in solving energy crisis problem, there is a need to increase awareness of using alternate fuel for automobiles and also to propose an alternate solution for conventional rickshaw which is the most famous mean of transport for local public in Pakistan. The main issue with conventional rickshaw is high fuel cost, high noise pollution, high maintenance cost, less mileage and high smoke pollution. The solar powered hybrid rickshaw (S-rickshaw) product is designed and fabricated to overcome these issues. The product efficiency is enhanced to make it feasible as compared to fuel prices and cartridge battery system is introduced to enhance its availability. The concept of solar charging stations for Karachi, Pakistan is proposed to make the product commercially viable. The four prototypes for passenger type rickshaws and one prototype for cargo loading type are fabricated to check the results. The performance of solar powered hybrid rickshaw is tested through average speed analysis test i.e., 40 kmph, mileage per charge i.e., 40 km per charge, charging time for batteries is 8 h, tyre load index is 71 and stopping distance at maximum speed of 50 kmph is 14 m. The breakeven time period of S-rickshaw is higher than the E-rickshaw because of higher initial investment but this is compensated by lower operational cost per year. As resultant the user gets higher annual savings from the product. Annual saving difference for S-rickshaw will be US $468 higher than E-rickshaw and US $1350 higher than the conventional rickshaw (C-rickshaw).

Bhatia *et al.* (2017) studied on design of solar powered e-rickshaw. There has been a growing concern regarding the use of fossil fuel, generally petroleum products, as the main source to drive our vehicles, two, three and four wheelers, resulting in making them one of the major sources of CO_2 and other gases that have contributed to the growing scrouge of global warming and greenhouse effect. Thus, it is high time that we start searching for an alternative source of fuel this is renewable, replenish able and non-polluting. Thus, taking this in view, the objective of the paper is to design a solar powered rickshaw by modifying the old model of manual rickshaw. This paper will also describe the working principle, design calculation and assembly of the rick. The solar powered rickshaw can be a good alternative for a diesel run or a CNG run rickshaw. These rickshaws have the capability to work with a consistent speed and this will also result in less fatigue of the driver. Not only it will contribute nil to air pollution, they will not contribute to the raging noise pollution, which has become another big problem off lately. They will also usher in more green jobs and help a country become less and less dependent on foreign fuel.

Reddy *et al.* (2017) studied on techno-economic investigation of solar powered electric auto-rickshaw for a sustainable transport system. Technologies influencing alternative means of transportation have been expanding in recent years due to increasing urbanization and motorization. In this paper, a solar powered electric auto-rickshaw (SPEA) is designed and developed for Indian conditions. The vehicle developed is comprehensively analysed techno-economically for its viability in the Indian market. The performance analysis of SPEA results in an optimal charging rate of 2 kWh per day with an average solar irradiance of 325 W/m^2 on a typical sunny day. The discharging characteristics are studied based on different loading conditions. The vehicle achieved a maximum speed of 21.69 kmph with battery discharge rate of 296 W at 90 kg load and also reached a maximum discharge rate of 540 W at 390 kg loading with a maximum speed of 12.11 kmph. Environmental analysis of SPEA indicated that the yearly CO_2 emissions of 1777 kg, 1987 kg and 1938 kg from using Compressed Natural Gas, Liquefied Petroleum Gas and gasoline engines respectively can be mitigated using SPEA. The financial analysis of SPEA concluded that the investor's payback duration is 24.44 % less compared to a gasoline-run vehicle. Socio-Economic analysis of SPEA discussed its significant advantages and showed 15.74 % and 0.85 % increase in yearly income over gasoline driven and battery driven vehicles.

2.7 REVIEW SUMMARY

1. In cities of India one of the major medium of transportation is auto rickshaws, which is producing a huge amount of air pollution as well as greenhouse gases like CO_2.
2. Fuel, which is used is a non-renewable source and also which costs high as a result of that transportation charges increases.
3. Thus should go for a reliable source as know that current trend of using the reliable source like solar energy which is available in plenty in country like India. solar energy car which plays a vital role for the upcoming energy crisis.
4. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, and Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world.
5. The solar radiation incident over India is equal to 4–8 kWh per square meter per day with an annual radiation ranging from 1200–2300 kWh per square meter. It has an average of 250–300 clear sunny days and 2300–3200 hours of sunshine per year.
6. Solar powered different vehicle contains; solar e-bicycle, solar tricycle, solar car.
7. The solar assisted vehicle is fitted with a DC motor, batteries, a photovoltaic solar panel, accelerator and motor controller and there is also a AC charging.
8. A solar powered car is an electric vehicle powered by solar energy obtained from sun and converted into usable form by solar panels on the roof of the vehicle.

9. The poly crystalline solar cells are used in solar powered vehicle, because it is more efficient than the mono-crystalline cell and the rate of conversion of energy is faster in the former.
10. The batteries are charged with solar energy with the help of a solar cell. Solar cells convert the energy of sunlight directly into electricity through the use of the photovoltaic effect.
11. The actual time required to charge the battery by solar panel was more than theoretical time, because of factors like inclination angle, soil factor, solar tracking etc.
12. Solar vehicle can also move a greater distance with a full charged battery as well as it can give more time backup in the case of a battery which charging in the running time.
13. BLDC motor is preferred because it provides noiseless operation, more efficient, gives under voltage and over voltage protection and waterproof.
14. The solar charger controller with MPPT type is successful in optimizing the battery charging system compared to the PWM type.
15. For eco-friendly system around 6-7 hours are required to recharge the 48 V 30 Ah battery by solar power.
16. A vehicle which runs using solar energy and having an average speed of around 25 kmph and running around 40 km per charge.
17. The discharging characteristics are studied based on different loading conditions.

CHAPTER - III

MATERIALS AND METHODS

This chapter deals with the design and development of solar powered farm rickshaw. It also includes the methods of design specification of various components, its fabrications, performance evaluation of developed solar powered farm rickshaw in terms of solar charging, battery discharge measurement in idle condition, battery discharge measurement on different load and road conditions and cost of operation. Details of materials and methods adopted and instruments used in study are also described here under.

3.1 LOCATION OF EXPERIMENT

To fulfill objectives, solar powered farm rickshaw was developed at the Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh. The field experiments were conducted in the farm of Junagadh Agricultural University, Junagadh.

3.2 YEAR OF EXPERIMENT

The experiment was conducted during the academic year of 2020-21.

3.3 SPECIFICATIONS OF NORMAL AUTO RICKSHAW

An auto rickshaw is a motorized version of the pulled rickshaw or cycle rickshaw. Most have three wheels and do not tilt. The auto rickshaw is a common form of urban transport, both as a vehicle for hire and for private use, in many countries around the world. They are especially common in countries with tropical or subtropical climate, since they usually are not fully enclosed. Specification of the normal auto rickshaw are given below:

Table 3.1: Specifications of the normal auto rickshaw

Sr. No.	Items	Specifications
1.	Wheel Track	1070 to 1160 mm
2.	Total length	2150 to 2900 mm
3.	Total width	1200 to 1300 mm
4.	Maximum height	1650 to 1950 mm
5.	Engine	2 stoke, 4 stroke, CNG kit
6.	Brake	Hydraulic / Mechanical
7.	Piston displacement	Less than 100 cc
8.	Fuels	Petrol, CNG, LPG

3.4 PRINCIPLE AND WORKING OF SOLAR POWERED VEHICLE

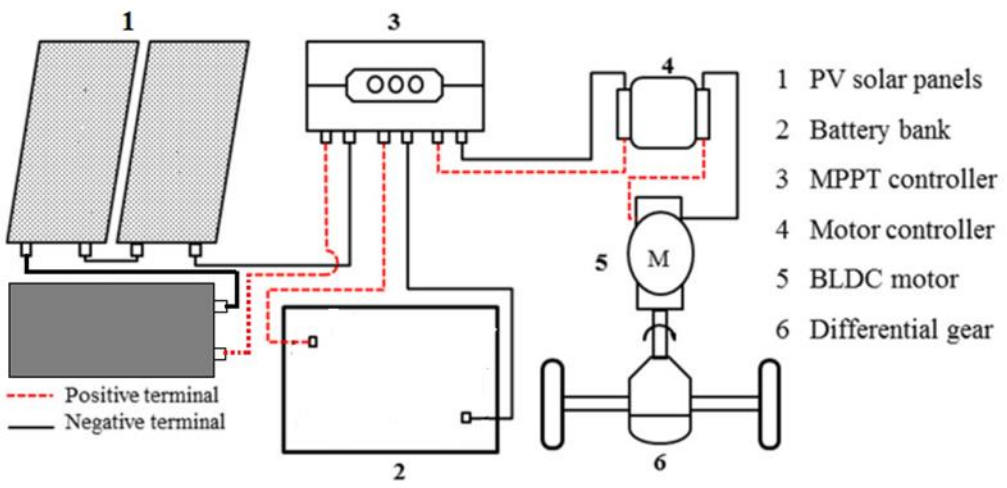


Fig. 3.1: The operating principle of the developed solar powered farm rickshaw

The working principle of the proposed solar vehicle is briefly explained in Fig. 3.1. Solar PV panels are fixed on the vehicle roof, which convert the sun's energy directly into electrical energy. The maximum power point tracking (MPPT) controller is incorporated to extract the maximum power out of solar panels for charging the lithium ion automotive batteries. The Brushless Direct Current (BLDC) electric motor is employed to convert the battery power into mechanical drive energy. BLDC motors are reliable, safe to handle and operate with minimum noise with less frictional losses. The motor controller provided along with the motor senses the position of the stator and energizes the rotor accordingly using the Hall Effect sensor. Power from the motor is transmitted to the wheels through differential gears.

3.5 DESIGN CONSIDERATION OF SOLAR POWERED FARM RICKSHAW

While designing solar powered farm rickshaw, following parameters were considered for its efficient utilization:

i. While designing solar powered farm rickshaw the initial parameters such as weight of rickshaw including load, maximum speed, types of road, slope etc. were considered.

ii. For the power calculations of BLDC motor three different methods were used.

iii. For the calculations of battery backup time, depth of discharge of battery and battery efficiency were used to calculate the required battery power.

iv. In the solar photovoltaic calculations, array load and array size were calculated to provide required solar power to charge the lithium ion battery.

v. In the solar powered farm rickshaw, a trolley like structure was provided to transport the load. Load on various parts of the rickshaw were uniformly distributed. Unbalancing of the parts during operation may cause sudden or impact load which may cause failure of the vehicle parts.

vi. Motion of the moving parts of the rickshaw was smooth without any undesired constraints.

vii. The power transmission unit used was properly lubricated to avoid frictional resistance. There is always a loss of power due to frictional resistance.

viii. Safety of operator was considered while development of farm rickshaw. Parts of rickshaw were free from sharp edges to avoid any accidental damage.

ix. The operational cost and maintenance cost of the farm rickshaw was negligible. It was also aimed to design at lowest possible cost so that it could be affordable for small and marginal farmers.

x. The farm rickshaw was aimed to be light in weight so that there will be minimum power consumption for operation.

xi. The developed farm rickshaw was aimed to require least maintenance time so that operator can utilize those time for other productive work.

xii. Farm rickshaw was fabricated with good quality material surface and finish.

xiii. Environmental factor such as harmful emissions were considered while development of solar powered farm rickshaw.

3.5.1 Brushless Direct Current Motor (BLDC)

Motor is the heart of an electric vehicle, motor's capacity and efficiency is a great deal, an e-vehicle used BLDC motor powered with controller that controls the movement of the motor. Choosing the best motor was critical for the electric vehicle, the capacity of the motor was decided to generate high enough torque to enhance the user experience without wasting too much energy to ensure longer mileage is delivered by the battery. Key considerations while determining motor capacity were to get more mileage and sufficient power to ply with maximum 5 passengers. There were other factors to be considered for optimal performance along with the motor, most important being the integration of motor, controller and the batteries.

The principle behind the internal working of both a brushless DC motor and a brushed DC motor are essentially the same. When the motor windings become energized, a temporary magnetic field is created that repels (and/or attracts) against permanent magnets. This force is converted into shaft rotation, which allows the motor to do work. As the shaft rotates, electric current is routed to different sets of windings, maintaining electromotive repulsion/attraction, forcing the rotor to continually turn. Brushes inside electric motors are used to deliver current to the motor windings through commutator contacts. Brushless motors have none of these current carrying commutators. The field inside a brushless motor is switched via an amplifier triggered by a commutating device, such as an optical encoder. Windings are on the rotor (Rotating part of motor) for brushed motors and on the stator (stationary part of motor) for brushless motors. Brushless motors alleviate some of the issues associated with the more common brushed motors (short life span for high use applications) and are mechanically much simpler in design (not having brushes). The motor controller uses Hall Effect sensors to detect the rotors position and using this, the controller can accurately control the motor via current in the rotor coils to regulate the speed. The advantages of this technology is the long life, less noisy, little maintenance and high efficiency (85-90%). These types of motors are generally used in speed and positional control with applications such as electric vehicle, fans, pumps and compressors where reliability and ruggedness are required.

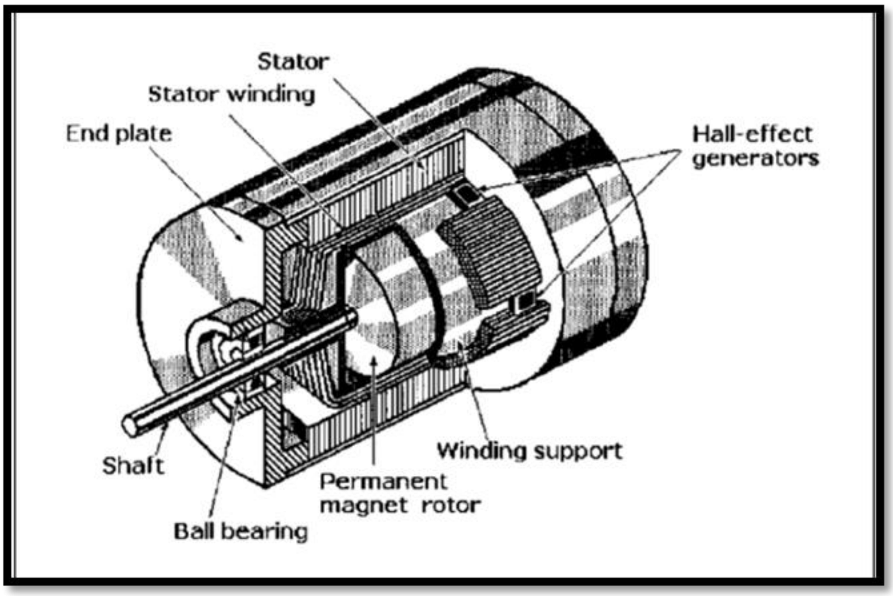


Fig. 3.2: Cutaway view of a brushless DC motor

3.5.2 BLDC Motor Power Calculations

Method: 1

The power needed to propel a vehicle can be determined by combining the forces that needs to be applied to the vehicle to move it with the vehicle speed at which this propelling force must be sustained. The drive torque generated by the motor for the wheels produces a drive force at the tire/road contact. At the design stage it's easier to frame the calculation around this drive force rather than the drive torque. Thus the calculations in this section started by determining the size of this drive force, and given a set of speed at which the vehicle should move, the drive power was found. The total drive force that has to act on the vehicle to make it move (or keep it moving) was estimated by adding together individual force components that arose from different physical effects. These were force to overcome the rolling resistance of the wheels on the drive surface, force to overcome aerodynamic drag and force to accelerate the vehicle's mass. There might be other effects but these were usually the main ones. These opposing forces were accounted for as follows:

A. Rolling resistance

The rolling resistance force is the force resisting the rolling motion of the tires as they roll over the road surface. Factors that contribute to rolling resistance are the (amount of) deformation of the wheels, the deformation of the roadbed surface, and movement below the surface. Additional contributing factors include wheel diameter, speed, load on wheels etc.

The least resistance is offered by concrete with a rolling friction factor of 0.02 and the highest is offered by dune sand which resists with a rolling resistance coefficient of 0.3. When it comes to sandy surfaces, the rickshaw puller is ideally supposed to prevent these types of surfaces. Even though such condition occurs, the passengers would be debarred and the rickshaw pulled manually. Next comes grass which offers the second highest rolling resistance, just next to dune sand with a factor of 0.075. Still the rickshaw is not meant to be ridden on grass surfaces. Now next important surface comes mud, this surface cannot be overlooked because it is very commonly found and seen in India, typically during the monsoon seasons and sometimes even the entire year. A muddy surface at its highest offers a resistance coefficient of 0.15. The rolling resistance force can be expressed as,

$$\mathbf{F_{ROLLING} = \mu_R \times W} \quad \text{.... (1)}$$

where,

W = The weight of the rickshaw in kg

μ_R = Coefficient of rolling resistance

Thicker tires having wider treads, although good for adhesion, however produce more rolling resistance. To conserve power solar rickshaw, need to use thinner tires. Also harder surfaces offer lower rolling resistance force than softer ones. Some standard values are shown in table 3.2.

Table 3.2: Coefficient of rolling resistance (μ_R) of different wheels/surface

Sr. No.	**Description**	**μ_R**
1	"Pure rolling resistance" Railroad steel wheel on steel rail	0.0003 to 0.0004
2	Railroad steel wheel on steel rail. Passenger rail car.	0.0010 to 0.0024
3	Hardened steel ball bearings on steel	0.001 to 0.0015
4	Production bicycle tires at 120 psi (8.3 bar) and 50 km/h (31 mph), measured on rollers	0.0022 to 0.005
5	Large truck (Semi) tires	0.0045 to 0.008

6	Ordinary car tires on concrete	0.010 to 0.020
7	Stage coach (19th century) on dirt road. Soft snow on road for worst case.	0.0385 to 0.073
8	Ordinary car tires on sand	0.3

B. Aerodynamic drag force

The aerodynamic drag force is simply the force exerted by the air to prevent the vehicle from moving through it. The aerodynamic drag force can be expressed as,

$$\mathbf{F_{DRAG} = [(1/2) \times C_d \times A \times \rho \times (V)^2]} \quad \text{…. (2)}$$

where,

C_d = The coefficient of drag of the vehicle

A = frontal area in square feet

ρ = A constant that accounts for the air mass density

V = The vehicle's speed.

To minimize drag force for any vehicle, the coefficient of drag (C_d), and its frontal area (Across), must be minimized. Fig. 3.2 shows that the more streamlined the shape of the rickshaw the lower is C_d.

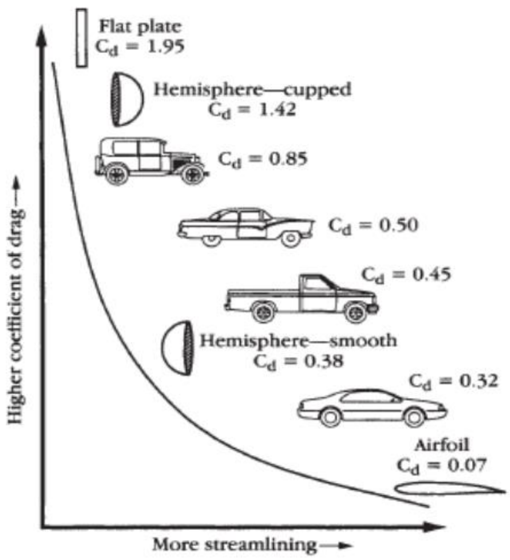


Fig. 3.3: Coefficient of drag of different vehicle shape

C. The Acceleration Force

Acceleration force is the force that helps the vehicle to reach a predefined speed form rest in a specified period of time. The motor torque bears a direct relationship with the acceleration force. Better the torque, lesser the time required by the vehicle to reach a given speed. The acceleration force is a function of the mass of the vehicle. The force of acceleration should be only accounted for when the rickshaw is accelerating and is given by newton's second law of motion.

$$\mathbf{F_A = M \times A} \qquad \text{.... (3)}$$

where,

M = Mass of the rickshaw

A = Acceleration

D. Total tractive force

It is the total force required to be generated by the power train/ power supply mechanism in order to accelerate the vehicle at the required units. Now as obvious the upper three forces all finally act towards retarding the vehicle so, the total tractive effort has to be the sum total of all the three above forces and thus,

$$\mathbf{F_D = F_{ROLLING} + F_{DRAG} + F_A}$$

$$\mathbf{= [\mu_R \times W] + [(1/2) \times C_d \times A \times \rho \times (V)^2] + [M \times A]}$$

At the design stage the following necessary assumptions of what the most probable values of the above parameters might be was made as given below in Table 3.3

Table 3.3: Details of physical quantity for sizing of electric motor

Sr. No.	Physical quantity	Value considered
1	Weight, W	600 kg
2	Top speed, V_{MAX}	30 km/h = 8.33 ms^{-1}
3	Coefficient of rolling resistance (μ_R)	0.010
4	Coefficient of drag (C_d)	0.32
5	Frontal area, A	1 m × 1.3 m
6	Mass density of air (ρ)	1.2 kgm^{-3}

The power needed to be supplied by the motor in order to provide the current speed and acceleration will therefore be,

$$\mathbf{P_T = F_D \times V} \qquad \text{……. (4)}$$

where,

P_T = Maximum power of BLDC motor

F_D = Drive force

V = Max. allowable speed of the rickshaw

Method:2

Selection of BLDC motor will be also carried out based on following formula,

$$\mathbf{P(Watt) = W \times g \times V \times S} \qquad \text{……. (5)}$$

where,

P = Power of BLDC motor in watt,

W = Total weight of rickshaw including load,

g = acceleration due to gravity (9.81 ms^{-2}),

V = Top speed of rickshaw,

S = Assumed Slope 1.5 to 2%.

Method: 3

From the resulting force and the rickshaw tire radius r,

$$\mathbf{Torque\ (\tau) = r \times F} \qquad \text{……... (6)}$$

$$P(Watt) = (\tau \times RPM)/9.55$$

where,

τ = Torque

r = radius of wheel

F = Total tractive forces

Table 3.4 Specification of brushless direct current motor

List of parameters	Specification
Motor Type	Brushless Direct Current
Frame Material	Steel
Power	1200 W
Voltage Rating	48 V DC
Full load Current	26.2/21.10 A
No load current	4.50/4.0 A
Rated speed	3000 RPM
Speed after reduction	555 RPM
Speed Type	Variable Speed
Efficiency	85 %
Transmission mode	Differential
Shaft	Yes
Gear on Shaft	Yes
Length	250
Height	150
Weight	5.2
Application	Small and medium size E- Tricycle

Plate 3.1: Brushless Direct Current (BLDC) Motor

3.5.3 Electronic Motor Controller

A motor controller is a device or a group of devices that serves to govern in some predetermined manner the performance of the electric motor. The controller includes an automatic switch turning the motor on/off., selecting forward or reverse rotation, selecting and regulating speed, regulating or limiting torque and protecting against overloads. The motor controller is connected to the battery pack and the controller feeds the input to the motor, lamp, AC/DC convertor and speedometer /indicator.

Table 3.5: Specification of electronic motor controller

List of parameters	Specification
Rated voltage	48 V DC
Power	1200 W
Working Efficiency	95%
Dimension	180 X 85 X 50 mm
Weight	1.3 kg
Control method	Accelerator
Casing Material	Aluminium

Plate 3.2: Electronic motor controller

3.5.4 Battery Capacity

The battery is the primary “source” of electrical energy. It stores chemicals, not electricity. Two different types of lead in an acid mixture react to produce an electrical pressure. This electrochemical reaction changes chemical energy to electrical energy (David and Thomas, 2002). Battery bank capacity has been selected based on the total power needed for the required duration in a day and the battery efficiency. Battery bank is act as a secondary or backup power source for the vehicle during cloudy or rainy days. The weight of battery also concerns the traveling performance of the vehicle. Thus choosing the capacity of the battery bank is a critical part of designing a solar powered system. Battery bank capacity were selected using the following relation:

$$\textbf{Battery Capacity }(\textbf{Ah}) = \frac{(\textbf{Rated Wattage of BLDC Motor} \times \textbf{Operating Hours})}{(\textbf{Nominal Voltage} \times \textbf{Maximum Allowable Discharg})} \quad \ldots (7)$$

Rechargeable lithium-ion batteries were developed and introduced in the 1990 to the world with a significant weight advantage over other battery systems. Lithium-ion battery, known as one of the most outstanding quality in the new electrochemical industry. It is one of the most used and widespread batteries used by electric vehicles today. The Lithium-ion battery's weight advantages make it competitive with other battery systems. Because of its high specific energy, the lithium-ion battery has a relatively greater travel distance, which is about three times greater than the mileage of the lead acid battery (Chian *et al.* 2019).

In the automotive industry, the Lithium-ion battery has obvious advantages as it has a long cycle life, high energy capacity and high efficiency. Lithium-ion batteries are extremely likely to contribute more to the current markets and the lives of people as the development of new products, innovations and strategies continues to advance

(Nitta *et al.* 2015). As per that, 48 volts 30 Ah lithium-ion battery is used. Battery is select based on power requirement of BLDC motor. More specification of battery is given below table.

Table 3.6: Specifications of battery

List of parameters	Specification
Battery types	Lithium–ion
No. of battery	1
Voltage	48 V
Current	30 Ah
Size (l*b*h) mm	300 x 200 x 200
Weight of Battery	14.28 kg
Discharge rate	80 %

Plate 3.3: Lithium-ion battery

3.5.5 Photovoltaic (PV) Panel

Solar panel works on the principle of photovoltaic effect which converts light energy into electrical energy. Solar panel comprises of many smaller units called photovoltaic cell. When the photons of sunlight fall on these cells, they release free electrons to form electron-hole pair. The movement of these electrons and holes is the principle behind the conversion of light energy into electrical energy.

$$\textbf{Total PV panels energy needed} = \frac{\textbf{Total power consumption}}{(\textbf{efficiency of all the auxiliary unit})} \quad \ldots\ldots (8)$$

$$\textbf{Size of the panel} = \frac{\textbf{Total power required for motor}}{(\textbf{Esc} \times \textbf{Eb} \times \textbf{Emc})} \quad \ldots\ldots (9)$$

Where,

E_{sc} = Efficiency of solar charge controller

E_b = Efficiency of battery

E_{mc} = Efficiency of BLDC motor controller

Poly crystalline silicon cell type solar photovoltaic (PV) modules were mounted on top of the rickshaw. Solar cells are basic building block of solar module which convert solar radiation directly into electrical power. They're made up of silicon semiconductors. Silicon in its extrinsic form produce flow of electrons when exposed to bright sunlight, which generates electricity that charges the battery which in turn power electric motor to run solar farm rickshaw.

3.5.5.1 Types of solar panels

Solar panels of different types are available in the market, they are mainly mono crystalline silicon, polycrystalline silicon, and amorphous Silicon or 'thin film' modules.

(a) (b) (c)

Plate 3.4: Types of solar panels (a) mono crystalline (b) polycrystalline (c) amorphous (thin film)

3.5.5.2 Selection of solar module

Since solar rickshaw needs much less energy to drive as compared to energy provided by internal combustion engines, it is important that this small energy is as efficiently utilized as possible. Also the lesser the space the solar panels take up over the body of the rickshaw the better it is. Therefore, judging from the characteristics of the three types of solar panels as described above it was most prudent to go with the poly crystalline type of solar panels. Considering solar panel cost, durability, longevity, warranty, size and wattage, a string of three polycrystalline 150 watt solar panels were placed on the roof of the solar powered farm rickshaw. Specifications of the solar panel selected for the project was as follows:

Table 3.7: Specifications of solar panel

Sr. No.	Specification	Value
1	Module	LE12P150
2	Type	Polycrystalline
3	Rated maximum power (P_{max})	150 W ± 3 % 8.13 A
4	Rated operating voltage (V_{max})	18.55 V
5	Rated operating current (I_{max})	8.13 A
6	Open circuit voltage (V_{oc})	22.54 V
7	short circuit current (Isc)	8.59 A
8	Maximum system voltage	1000 V
9	Module dimensions (L×W×T)	1480 mm × 675 mm × 35 mm
10	Module weight	10.52 kg

3.5.6 Solar Charge Controller

The objective of the charge controller was to act as a battery management system (BMS) where it regulates the charging and discharging of the battery to ensure trouble free operation and longer life of the battery system. A solar charge controller manages the power going into the battery bank from the solar array. It also ensures the power doesn't run backwards to the solar panels overnight and drain the batteries (Alphonse *et al.* 2012). The solar charge controller is available in two different technologies, PWM and MPPT. How they perform in a system is very different from each other. An MPPT charge controller is more expensive than a PWM charge controller, and it is often worth it to pay the extra money. The solar charge controller is typically rated against Ampere and Voltage capacities. Therefore, solar charge controller was selected as per the following formula,

Solar charge controller rating = Total short circuit current of PV array x 1.3

3.5.6.1 PWM solar charge controller

A PWM solar charge controller stands for "Pulse Width Modulation". Pulse Width Modulation is a technique that manipulates the width of the pulse duration based on controlling information to deliver specific amounts of power to a device. These operate by making a connection directly from the solar array to the battery bank. During bulk charging, when there is a continuous connection from the array to the battery bank, the array output voltage is 'pulled down' to the battery voltage. As the battery charges, the voltage of the battery rises, so the voltage output of the solar panel rises as well, using more of the solar power as it charges. As a result, it need to make sure to match the nominal voltage of the solar array with the voltage of the battery bank. The actual voltage of a 12V solar panel, when connected to a load, is close to 18 Vmp (Volts at maximum power). This is because a higher voltage source is required to charge a battery. If the battery and solar panel both started at the same voltage, the battery would not charge.

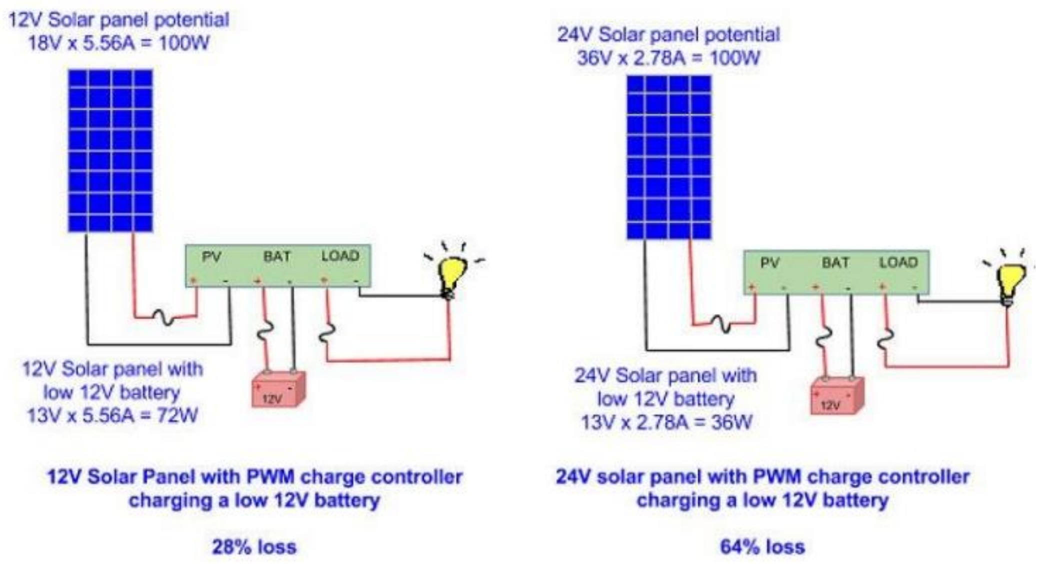


Fig. 3.4: Performance of PWM charge controller

3.5.6.2 MPPT solar charge controller

An MPPT solar charge controller stands for “Maximum Power Point Tracking”. It will measure the Vmp voltage of the panel, and down-converts the PV voltage to the battery voltage. Because power into the charge controller equals power out of the charge controller, when the voltage is dropped to match the battery bank, the current is raised, so using more of the available power from the panel. Such charge controller is cheaper and more suitable for automobile application.

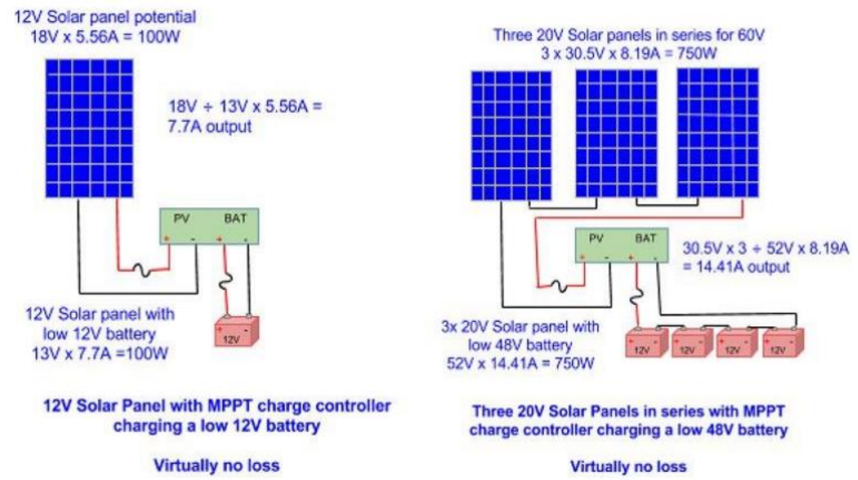


Fig. 3.5: Performance of MPPT charge controller

MPPT solar charge controller allows higher voltage solar array than battery, as it is more efficient and smarter than PWM charge controller. This opens up a whole wide range of solar panels that now can be used for your off-grid solar system.

Plate 3.5: MPPT solar charge controller

3.5.7 Battery Charger

The solar system suffers a limitation of day charging only, that too when sun shines clearly. To charge batteries during overcast periods and night time one needs main AC supply and AC adapter. This makes the charging system hybrid and provides autonomy to the system, allows user to charge batteries either by solar or AC mains.

Electric vehicle Charger is designed to fulfil charging needs of electric vehicle. This intelligent charger is capable of operating at wide Input AC voltage range of 170-300 VAC. It has been designed to withstand the adverse Indian power conditions. Efficient, compact in size, 4 stage battery charging algorithm are some of its salient features when compared to the linear chargers (bulky transformer based chargers). Its high efficiency and battery life extension features are its USP.

Plate 3.6: Battery charger

3.5.8 Height of Center of Gravity

The height of center of gravity determines the stability of the vehicle considering its total weight and wheelbase distance. It is significant to determine the load transfer between the front and rear wheels. Height of center of gravity (h_{CG}) is found out by,

$$= \frac{\text{wheelbase distance} \times \text{difference in vehicle weight}}{\text{Total weight of vehicle x tan of slope of track}}$$

3.5.9 Speed controller system

Electronically throttle control system provides excellent throttle control in all the operating ranges. Its working principle is based on Hall Effect sensor. When we actuate the throttle body electromagnetic line of force generates inside the body and since magnates are placed inside the throttle body voltage is generated. The amount of voltage depends upon controller which varies the speed of the BLDC motor. In the developed solar powered farm rickshaw, we provided three different speed which is adjusted through speed controller. In the initial starting stage we start the rickshaw on first speed and then after that increases speed one by one.

Plate 3.7: Throttle controller system

3.5.10 Axle, differential and gears

Axles are an integral component of most practical wheeled vehicles. The axles serve to transmit driving torque to the wheel, as well as to maintain the position of the wheels relative to each other and to the vehicle body. The axle part in solar rickshaw which supports the differential and motor, it should be sturdy enough for safety and life of the vehicle. On solar rickshaw, the axle was fixed to the wheels, rotating with them. Bearings or bushings were provided at the mounting points where the axle is supported. The axle was protected by enclosing the length of the axle in a housing. Split-axle design was followed where in each rear wheel was mounted on separate shaft.

A differential is a mechanical device made up of several gears. It is used in almost all mechanized vehicles. In solar rickshaw it was used to transmit the motor power from the driveshaft to the drive wheels. Its main function is to allow the drive wheels to turn at different rpms allowing the wheels to go around corners while still receiving power from the BLDC motor.

Electric rickshaw, driven mainly by electric motors makes use of modest transmission because of the flat torque output from an electric motor at all speeds. So, a high speed, low speed and reverse gear were arranged to match physical road speeds.

3.5.11 Drum Brakes

Conventional drum brake was taken into consideration to control the speed of the wheels. The drum brakes are a simple arrangement which consists of a drum made out of metal alloy and a pair of shoes connected to two retractable springs and a tension wire made out of tensile steel. The brakes were mounted on the chassis (Pedal-Brakes), so on pressing the pedal the brakes will engage stopping the rear wheels.

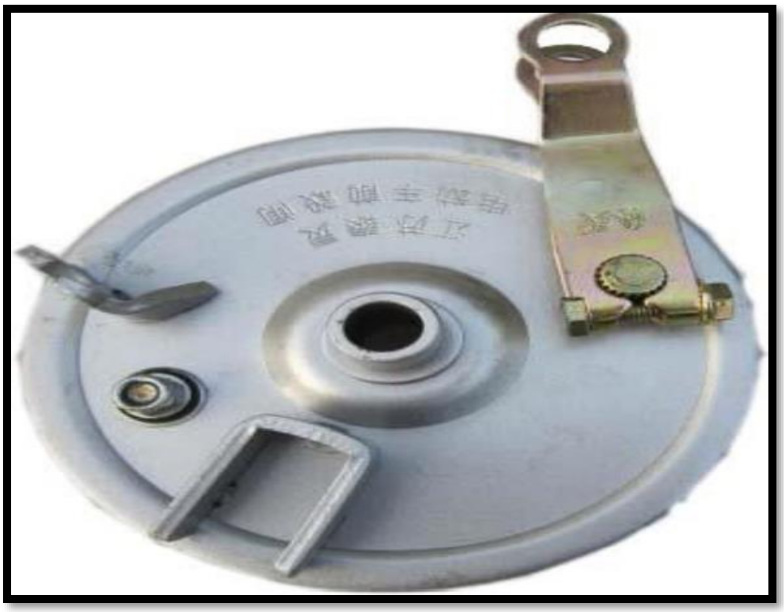


Plate 3.8: Drum brake

3.6 SPECIFICATION OF DEVELOPED SOLAR POWERED FARM RICKSHAW

Solar farm rickshaw was fabricated on the basis of normal auto rickshaw. Trolley type structure is provided by removing the passenger seats, so it can helpful to loading the farm products transport or labour transportation. Solar panels frame structure is provided on the roof of solar farm rickshaw. In that frame solar panels are attach, it can provide shadow over the driver. The specifications of developed solar rickshaw are given below:

Table 3.8: Detailed specifications of the developed solar powered farm rickshaw

S. No.	Particulars	Specifications
1	**Name of the equipment**	**Solar powered farm rickshaw**
2	**Type of action and its detail**	
	Action	Self-propelled
	Power source	Solar power
3	**Overall dimensions**	
	Length (mm)	2450
	Width (mm)	1250
	Height (mm)	1800
	Ground clearance (mm)	250
	Weight (kg)	295
4	**Solar panels**	
	Solar panels type	Polycrystalline
	Module dimensions (L×W×T)	1480 mm × 675 mm × 35 mm
	Module weight	10.52 kg
	No. of solar panels are used	3
	Rated maximum power (P_{max})	150 W ± 3 % 8.13 A
5	**Solar panel frame**	
	Material used for frame	G.I. square pipe
	Length (mm)	2155
	Width (mm)	675
	Height of supporting pipe	1000
	No. of supporting pipe	4
6	**Trolley**	
	Material of construction	M.S. plate
	Length (mm)	1160
	Width (mm)	1250
	Height (mm)	1320
	Height from ground (mm)	560
7	**Wheel unit**	
	Wheel type	Pneumatic
	No. of wheel	3

	Material of rim	Steel
	Width of wheel, mm	110
	Rim diameter, mm	254
	Overall diameter, mm	300
8	**BLDC motor**	
	Material of casing	Aluminum
	Power	1200 W
	Voltage	48
	Current	25 A
	Dimensions of motor	250 × 200 ×150
	No. of teeth on shaft	14
9	**Battery**	
	Type	Lithium ion
	Voltage V	48 V
	Current capacity Ah	30 Ah
	Length (mm)	300
	Width (mm)	200
	Height (mm)	200
	Max. voltage at full charged	50.3
	Min. voltage at discharge	47
	Weight (kg)	14.28 kg
10	**Solar charge controller**	
	Type	MPPT
	Voltage	48 V
	Current	15 A

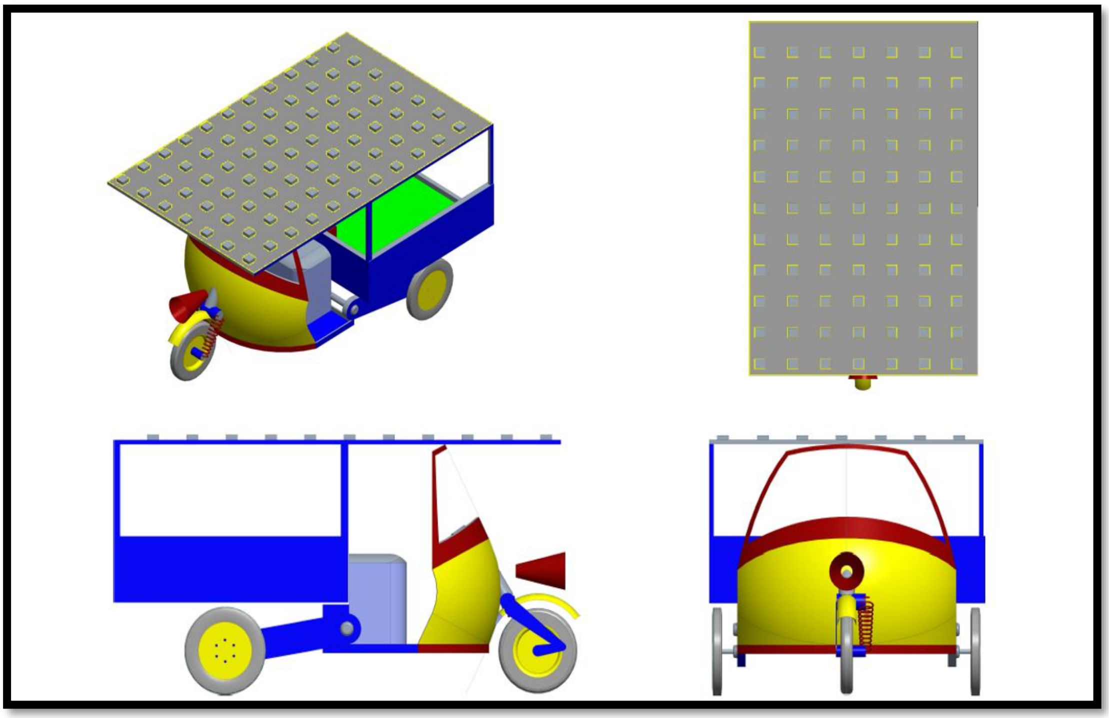


Fig. 3.6 Different views of developed solar powered farm rickshaw

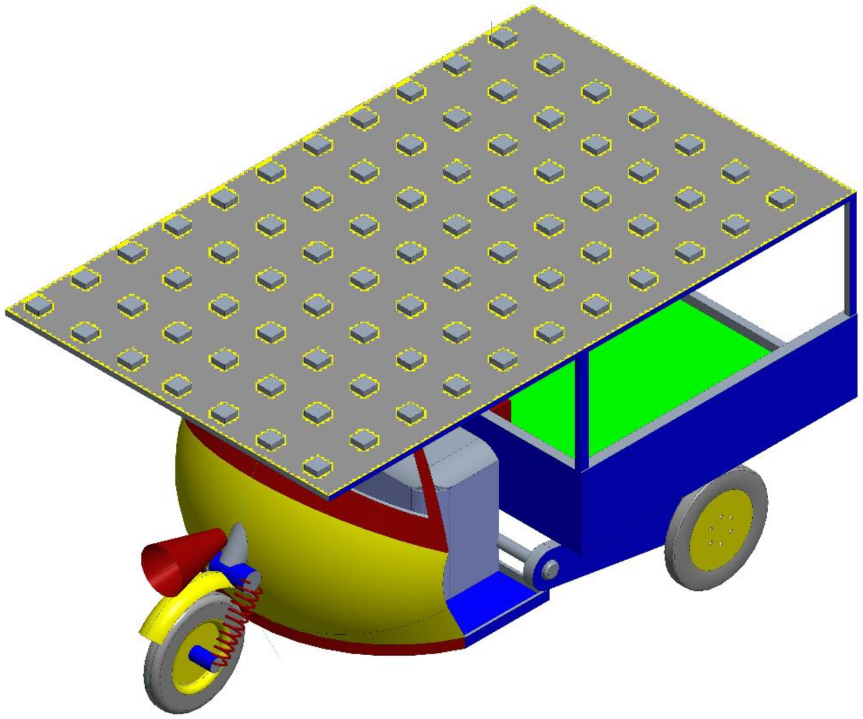


Fig. 3.7 Isometric view of developed solar powered farm rickshaw

Plate 3.9: Isometric view of developed solar powered farm rickshaw

Plate 3.10: Front view of developed solar powered farm rickshaw

Plate 3.11 (a): Top view

Plate 3.11 (b): Side view

3.7 Instrumentation

To study the development and performance of solar powered farm rickshaw the following instruments and equipment were used.

3.7.1 Luxmeter

To measure solar radiation at the solar charging time, luxmeter was used. Luxmeter was placed on the surface of the solar panel in such way that complete solar radiation falls on the luxmeter. The observation was taken in lux/m^2 and then converted it into watt/m^2.

The standard conversion of is 1 lux/m^2 = 0.0079 w/m^2.

3.7.2 Measuring Tape

The measuring tape (A metallic tape of 30 m and steel tape of 3 m) is a basic tool to design mounting structure and for measuring dimensions during project development.

3.7.3 DC Multi-Meter

A DC multi-meter is an electronic measuring instrument that combines several measurement functions in one unit. It is used for measuring current, voltage, open circuit voltage, short circuit current and resistance. Its range is up to 10 A for D.C current and voltage up to 600V.

3.7.4 Weight Balance

An electric weight balance was used for measuring the weight of solar powered farm rickshaw.

3.8 STATISTICAL ANALYSIS

Statistical analysis was carried out by Factorial Completely Randomized Design method, in which the effect of various treatments on various parameters was analyzed (Panse and Sukhatme, 1967).

Table 3.9: Experimental details

<table>
<tr><td rowspan="5">Independent variables</td><td rowspan="3">Applied load</td><td>100 kg (A_1)</td></tr>
<tr><td>200 kg (A_2)</td></tr>
<tr><td>300 kg (A_3)</td></tr>
<tr><td rowspan="2">Road</td><td>Pakka (B_1)</td></tr>
<tr><td>Kachcha (B_2)</td></tr>
<tr><td>Dependent variables</td><td colspan="2">Voltage drop per km</td></tr>
</table>

	Time required to covered per km
Treatments	Six
Replications	Four
Statistical design	Factorial completely randomized design

3.9 FUNCTIONAL PERFORMANCE OF THE SOLAR POWERED FARM RICKSHAW

The solar powered farm rickshaw was tested in the farm of Junagadh Agricultural University, Junagadh. During its performance evaluation, its solar panel performance for battery charging, battery discharging performance on idle and different loading conditions on different roads and cost of operation etc. were determined. All the parameters are described as below:

3.9.1 Solar Charging

Solar radiation was measured on panel surface with the help of digital solarimeter in watt/m^2. Battery charging status was constantly monitored digital battery voltage display unit. Solar radiation readings were recorded at regular interval of 1 h and were measure time required to charge the system.

Plate 3.12: Measurement of Solar Charging Status

3.9.2 Battery Discharging under Idle Condition

The battery test was carried out by charging it with an electrical vehicle charger. During charging mode voltage and time were measured at different state of charging. Battery performance under discharging mode, the same reading was taken under full throttle condition (rated power of BLDC motor) by putting the rickshaw on jack stands, allowing rear wheels to rotate freely. The test was carried out on fully charged battery until exhausted.

Plate 3.13: Measurement of battery discharge in idle condition

3.9.3 Battery Discharging During Transportation

Discharging of fully charged battery was studied during transportation for three different loads as follows 100 kg, 200 kg and 300 kg on two types of road (pakka and kachcha road). After covering 1 km distance, the dropped voltage and time required to covered the distance were measured. In this evaluation the effect of different loads and types of road on voltage drop and time required to covered per km was studied by following the procedure given below:

a. For this evaluation taken the fully charge battery, which is already fully charge with the solar power or AC power.
b. The load was applied as per the specified treatment.
c. The solar powered farm rickshaw was made to travel on road as per treatment.

d. In this evaluation, the battery discharge and time required to covered the specified distance were recorded.
e. The discharge was measured using the voltmeter connected to the battery and time required to covered the specific distance measured using the stopwatch.

Plate 3.14: Battery discharging during transportation

3.9.4 Backup Time and Distance Covered During Transportation

Performance evaluation of fully charge battery was carried under transport mode for three different loads as follows 100kg, 200kg and 300 kg on two types of road (pakka and kachcha road). After fully discharging of battery, the covered distance and backup time of battery were measured. In this evaluation the effect of different loads and types of road on total covering distance and backup time was studied by following the procedure given below:

a. For this evaluation taken the fully charge battery, which is already charge with the solar power or AC power.

b. The load was applied as per the specified treatment in the solar powered farm rickshaw.
c. The solar powered farm rickshaw was run on path as per treatment up to the battery can fully discharge.
d. In this evaluation recorded the dropped voltage and distance covered after each 15 min interval up to the battery can fully discharge.
e. The dropped voltage was measured using the voltmeter connected to the battery and covered distance measured using the odometer.

Plate 3.15: Measuring backup time and distance covered

3.9.5 Comparative Analysis of with and without Solar Power for Battery Backup Time and Distance Covered During Transport

The comparative analysis between with and without solar power to measure the battery backup time and distance covered were carried out. In first condition fully charged battery was taken then it was discharged without connection of solar power in transportation and the total travelled distance and backup time in such condition were measured. In the second condition fully charged battery was taken then it was discharged with connection of solar power in transportation and total travelled distance and backup time in such condition were measured. Both the conditions are compared with each other and shows that which one is better.

3.10 ECONOMIC BENEFITS OF SOLAR POWERED FARM RICKSHAW

The total cost of operation of the solar powered farm rickshaw in ₹/h was calculate by considering the fixed cost and variable cost of the vehicle by making few assumptions. The cost of all operation is calculate based on the current inputs and manufacturing prices of the tools, the machinery and rental wages of the operators and workers. The total cost of a solar powered farm rickshaw is divide into two parts, fixed cost and variable cost, where fixed cost is independent of operational use and variable cost is proportional to usage (Kamboj *et al.*, 2012).

3.10.1 Fixed cost

Fixed cost includes depreciation, interest, housing, insurance and taxes.

3.10.1.1 Depreciation

It is a measure of the amount by which the value of the machine decreases over time. The annual depreciation is calculated as follows (Kepner *et al*., 1978):

$$D = \frac{C - S}{L \times H} \quad \text{........ (10)}$$

where,

C = Capital cost, ₹,

D = Depreciation, ₹/h,

S = Salvage value, 10 per cent of capital cost,

H = Number of working hours per year,

L = Life of machine, year.

3.10.1.2 Interest

Interest is calculated based on the average investment of the machine, taking into account the machine value of the first year and last year. These are usually calculated on an annual basis. The annual interest on the investment can be calculated as (Kepner *et al*., 1978).

$$I = \frac{C + S}{2} \times \frac{r}{H} \quad \text{......(11)}$$

where,

I = interest per year

r= interest rate per year, per cent

C = capital cost, ₹

3.10.2 Variable cost

Variable cost includes repairs, maintenance and other costs.

3.10.2.1 Repair and maintenance

The repair and maintenance cost is a product of machine's cost price and repair and maintenance percentage factor (Kepner *et al.,* 1978) and (Kamboj *et al.,* 2012).

RM = 3 per cent × annual purchase price or capital investment … (12)

3.10.3 Total operating cost

Total cost of operation is a summation of total fixed cost and total variable cost

Total cost of operation per hour = Total fixed cost + Total variable cost

3.10.4 Payback period

The payback period of solar powered farm rickshaw in years has been worked out based on the relationship of annual use of working hours, total benefits, total cost, net benefits and initial investment of the machine (Shukla, 2018). The payback period is expressed by the relation given below:

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benefit}} \quad \text{…. (14)}$$

where,

Average net annual benefit (₹) = (Custom fee, ₹/h – Total operating cost, ₹/h) × Annual utility

Custom fee, ₹/km = ₹ 8/km

3.10.5 Benefit: cost ratio

The benefit: cost ratio is calculated by using the following formula

$$\text{Benefit: cost ratio} = \frac{\text{Total benefit}}{\text{Total cost of investment}} \quad \text{…. (15)}$$

where,

Total benefit = Average annual net benefit (₹) × Life of machine (L) in years

Total cost of investment = Initial cost of machine.

3.10.6 Breakeven point

The benefit: cost ratio is calculated by using the following formula

$$BEP = \frac{\text{TFC}}{\text{CHC} - \text{TOC}} \qquad \text{.... (16)}$$

where,

TFC = Total fixed cost

CHC = Custom hiring charge

TOC = Total operating cost

CHAPTER - IV

RESULTS AND DISCUSSION

This chapter deals with the performance evaluation of developed solar powered farm rickshaw in terms of its solar array, voltage drop and required time to covered per km distance, total backup time and total distance covered per charge with three different loads of operation and different road conditions. A comparative analysis was also undertaken to compare the performance of solar powered farm rickshaw with only on fully charged battery power and attachment of solar power on travelling. The field observations and results obtained at different independent parameters were analysed statistically and discussed in detail.

During preliminary trials it was observed that the solar powered farm rickshaw was very easy to operate without any risk of worker getting injured and all the precautions are also taken during the driving.

The material used for construction of the solar powered farm rickshaw is easily available and its cost is also affordable to small and marginal farmer. It was observed that the vehicle is having an almost no maintenance cost and there was no break down were observed during field operation and testing.

The developed solar powered farm rickshaw was tested in the main campus of Junagadh Agricultural University on two types of road. The details of treatment and replication were discussed in previous chapter.

4.1 LOCATION OF THE FIELD

The field testing was done on two types of road i.e. pakka road and kachcha road in the main campus of JAU, Junagadh.

4.2 PERFORMANCE PARAMETERS

The performance parameters include solar array, battery discharging in idle conditions, battery discharging mode during transport for 1 km distance to measure the dropped voltage and required time, battery discharging mode during transport to measure the covered distance and backup time and comparative analysis of battery connected with solar and disconnected with solar power during transport.

4.3 SOLAR CHARGING

In the performance evaluation of solar charging, measure the solar radiation and battery voltage for 1 hr time interval. The solar radiations were measured on solar panel with the help of the luxmeter and voltage change was measured with the help of digital multimeter. The following graphical representation shows the performance of solar power charging,

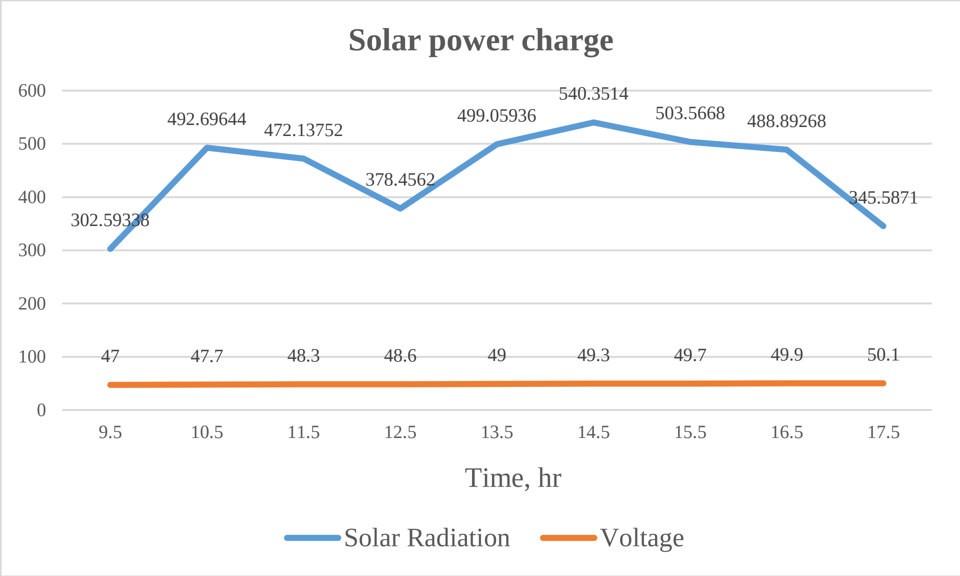


Fig. 4.1: Solar charging of solar powered farm rickshaw

Graphical representation of solar charging of solar powered farm rickshaw at is shown in the fig. 4.1. It is shows that the solar radiation and voltage with respect to the time. The solar radiation data is mostly fluctuating due to cloudy atmosphere. Therefore, required time to charge the solar powered farm rickshaw was around 8 hr, which is more than theoretical required time. The graphical representation shows that voltage status with respect to time. At the initial stage or discharge stage, battery voltage was 47 V. The voltage was going up to the 50.1 V in fully charged condition.

4.4 BATTERY DISCHARGING UNDER IDLE CONDITION

In the performance evaluation of solar powered farm rickshaw under battery discharging mode in idle condition (laboratory test), measure the voltage drop on full throttle speed in the 15 min interval. In this evaluation got the backup time of battery in laboratory test condition. The following table shows the performance of solar powered farm rickshaw on idle conditions,

Table 4.1: Idle condition battery discharge with respect to time

Sr. No.	Time (min)	Voltage (V)
1	0	50.2
2	15	49.8
3	30	49.7
4	45	49.6
5	60	49.6
6	75	49.5
7	90	49.4
8	105	49.2
9	120	49.1
10	135	49
11	150	49
12	165	48.9
13	180	48.7
14	195	48.4
15	201	47

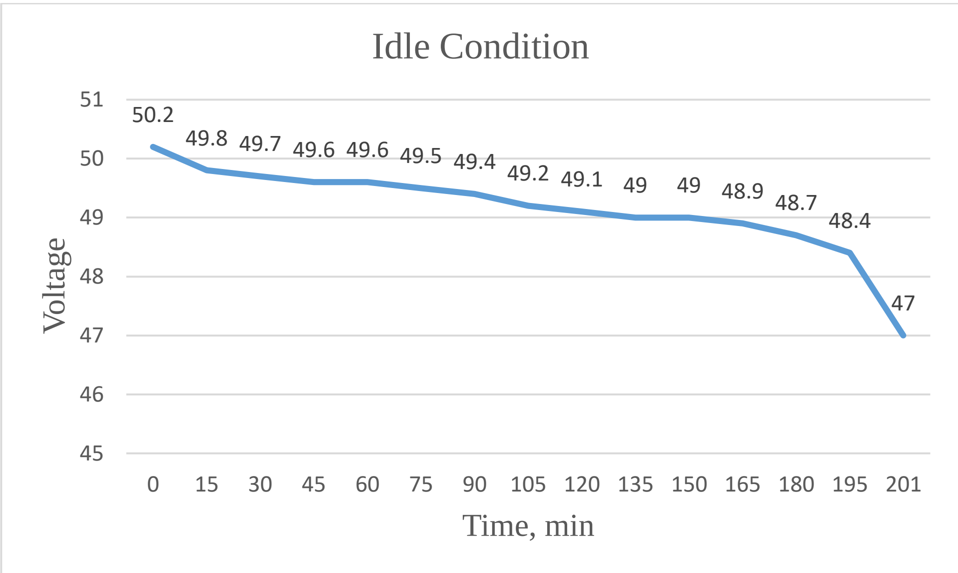


Fig. 4.2: Idle condition battery discharge

Table 4.1 and fig. 4.2 show the performance of solar powered farm rickshaw battery discharging mode under idle condition (lab condition). In fully charged condition battery voltage was going up to 50.2 V. It revealed that top speed of solar powered farm rickshaw was achieved at 50.2 V. The voltage of the battery was gradually decreased with increase in time. The total backup time was 3hr 21min. At the last stage of the battery backup, voltage was drop suddenly from 48.4 V to 47 V. In the idle condition battery performance was found better as compared to the road transport condition because of the resistance to the drive wheel was less as compare to transport on road.

4.5 BATTERY DISCHARGING DURING TRANSPORT

4.5.1 Voltage drop per km

The voltage drop indicates how many volts are drop after the specified distance in the specific treatment. The voltage drop value was shown in the digital multimeter directly when it attaches to the battery. Higher the value of voltage drops reveals that more resistance or load in the solar powered farm rickshaw.

The voltage drops of battery after drive the solar powered farm rickshaw was calculated and evaluated on the basis of statistical analysis. ANOVA showing the effects of load, roads and their interactions on voltage drops is given in table 4.2.

Table 4.2: ANOVA showing the effect of applied loads and roads and their interaction on voltage drop per km distance

<table>
<tr><th>SOURCE</th><th>DF</th><th>SS</th><th>MSS</th><th>CAL F</th><th>TAB F</th><th>TEST</th><th>SEM</th><th>CD</th></tr>
<tr><td>A</td><td>2</td><td>0.0408</td><td>0.020</td><td>5.444</td><td>3.554</td><td>*</td><td>0.021</td><td>0.064</td></tr>
<tr><td>B</td><td>1</td><td>0.0004</td><td>0.0004</td><td>0.111</td><td>4.413</td><td>NS</td><td>0.017</td><td>NS</td></tr>
<tr><td>A X B</td><td>2</td><td>0.0008</td><td>0.0004</td><td>0.111</td><td>3.554</td><td>NS</td><td>0.030</td><td>NS</td></tr>
<tr><td>ERROR</td><td>18</td><td>0.0675</td><td>0.003</td><td colspan="5" rowspan="2">CV= 29.99375</td></tr>
<tr><td>TOTAL</td><td>23</td><td>0.1095</td><td></td></tr>
</table>

*significant at 5 per cent level

It is shown that the effect of applied load in solar powered farm rickshaw on the voltage drops is significant i.e., A significant change was observed in the voltage drops per km on individually varying the applied different load. On varying the applied load on solar powered farm rickshaw, which in turn affects the required power to the pull the load is more as per load, so required voltage is also change as per the load.

It is revealed that from the table 4.2 the road conditions and interaction of load and road on voltage drop per km is non-significant i.e., there was no significant effect of road conditions and interaction on the battery voltage drop per km. The value of the drop voltage on both roads are around same. The coefficient of variation of voltage drop per km for different interactions of applied load and roads is 29.99%.

4.5.1.1 Interaction effect of applied load and roads on the voltage drop of battery

Analyzing four replications of each treatment and by evaluating the average, it is found from table 4.3 that combination of applied loads 100 kg on both road Pakka and Kachcha is giving the least voltage drop of 0.15 whereas the combination of applied load 300 kg on roads Pakka and Kachcha is giving the highest voltage drop of 0.25. Mean value of voltage drop with respect to different interactions of applied loads and roads is shown in table 4.3.

Table 4.3: Mean value of voltage drop with respect to different interactions of applied loads and roads

Load/Road	Pakka road	Kachcha road
100 kg	0.15	0.15
200 kg	0.2	0.23
300 kg	0.25	0.25

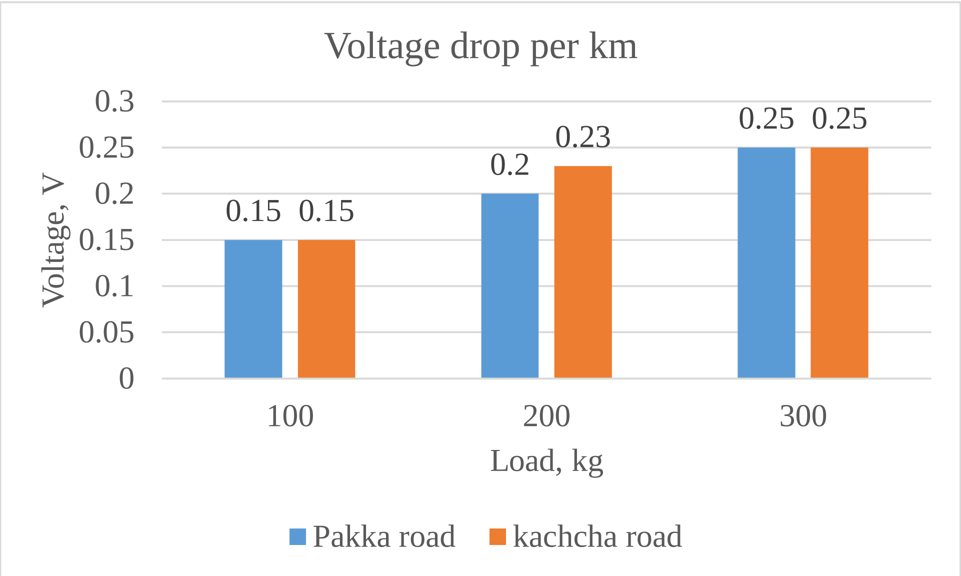


Fig. 4.3: Effect of different applied loads and roads on voltage drop

Graphical representation of voltage drop at various combinations of applied loads with roads is shown in the fig. 4.3. It is shown that the voltage drop is found to be highest for combination of applied load on the roads 300 kg pakka and 300 kg kachcha followed by 200 kg kachcha, 200 kg pakka, 100 kg kachcha and 100 kg pakka respectively. The maximum value of voltage drop is 0.25 for interaction of 300 kg pakka and kachcha road. The minimum value of voltage drop is 0.15 for interaction of 100 kg pakka and kachcha road.

4.5.2 Time Required to Covered Per Km Distance

The time required to cover per km distance shows how much time required to cover 1 km distance as per the specified treatment. The required time to cover 1 km distance is measured in minute with the help of stopwatch. Higher the value of time required to cover the distance reveals that applied load is more and road conditions is not good.

The time required to cover the distance per km evaluated on the basis of statistical analysis. ANOVA showing effect of applied loads, roads and their interactions on time required to cover per km is given in table 4.4.

Table 4.4: ANOVA showing the effect of applied load and roads and their interaction on time required to cover per km

SOURCE	DF	SS	MSS	CAL F	TAB F	TEST	SEM	CD
A	2	0.4501	0.2250	6.4698	3.5545	*	0.0659	0.19593
B	1	19.1173	19.1173	549.524	4.4138	*	0.0538	0.159976
A X B	2	0.1836	0.0918	2.6398	3.5545	NS	0.0932	NS
ERROR	18	0.6262	0.0347	CV= 3.582861				
TOTAL	23	20.3773						

*significant at 5 per cent level

It is shown that the effect of applied loads and roads on the time required to cover per 1 km distance is significant i.e., A significant change was observed in the time required to cover per 1 km distance on individually varying the applied loads and roads.

On increasing the applied loads in the solar powered farm rickshaw, the time required to cover per km distance is also increased because power required to pull is increase and speed of the vehicle is also decrease.

If road conditions are good, then required time to cover specified distance is less. In the farm road or kachcha road required time to cover per km distance is more as compare to pakka road because in the kachcha road resistance and required power to pull the load is more.

It is also given in the table 4.4 that the interaction of applied load and road is non-significant i.e., there was no significant effect of interaction of applied loads and roads on time required to cover per km distance. The coefficient of variation of time required to cover per km distance for different interactions of applied loads and roads is 3.58%.

4.5.2.1 Interaction Effect of Applied Loads and Roads On the Time Required to Cover Per Km Distance

The solar powered farm rickshaw was tested in the six different treatment. There were twenty-four experimental readings. Each treatment underwent four replications. Analyzing four replications of each treatment and by evaluating the average, it is found from table 4.5 that combination of applied load 100 kg on the pakka road is giving the less time required to cover per km distance is 4.1 min whereas the combination of applied load 300 kg on the kachcha road is giving the highest time required to cover per km distance of 6.33 min.

Mean value of time required to cover per km distance with respect to interactions of applied loads and roads is shown in table 4.5.

Table 4.5 Mean value of time required to cover per km distance with respect to interactions of applied loads and roads

Loads/Roads	Pakka road	Kachcha road
100 kg	4.1	6.04
200 kg	4.38	6.07
300 kg	4.46	6.33

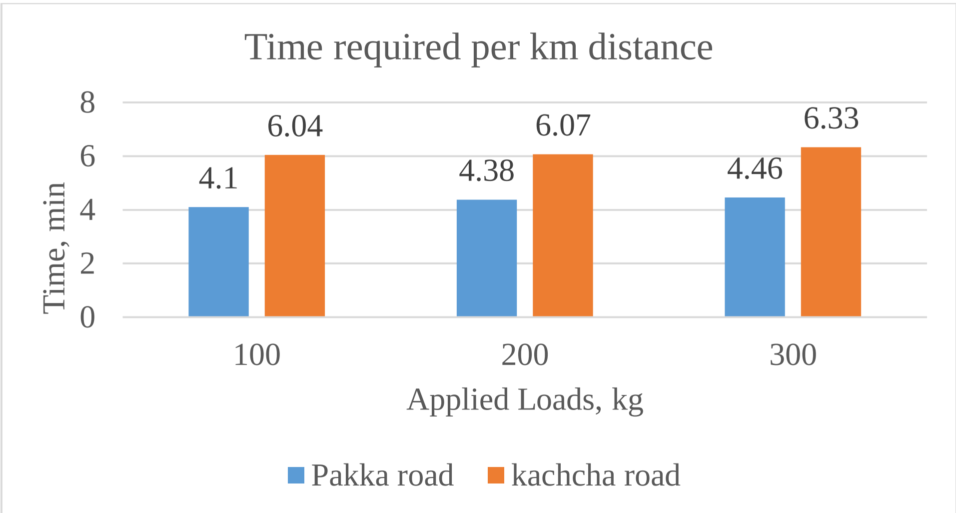


Fig. 4.4: Effect of different applied loads and roads on time required to cover per km distance

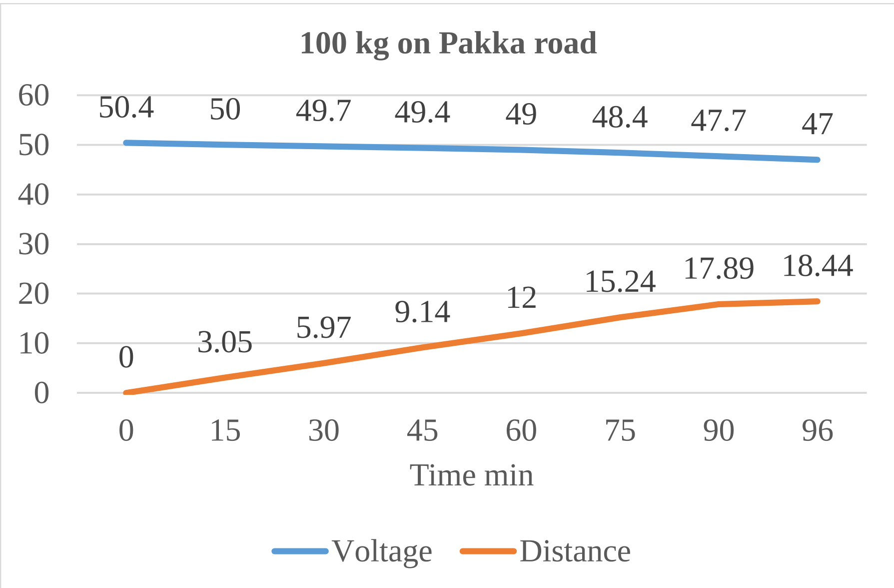
Graphical representation of time required to cover per km distance at various combinations of applied loads with roads is shown in the fig. 4.4. It is shown that the time required to cover per km distance is found to be highest for applied load and road combination 300 kg kachcha followed by 200 kg kachcha, 100 kg kachcha, 300 kg pakka, 200 kg pakka and 100 kg pakka, respectively. The maximum time required to cover per km distance is 6.33 min for interaction of 300 kg load on kachcha road. The minimum time required to covered per km distance is 4.1 min for interaction of 100 kg load on pakka road.

4.6 BACKUP TIME AND DISTANCE COVERED DURING TRANSPORTATION

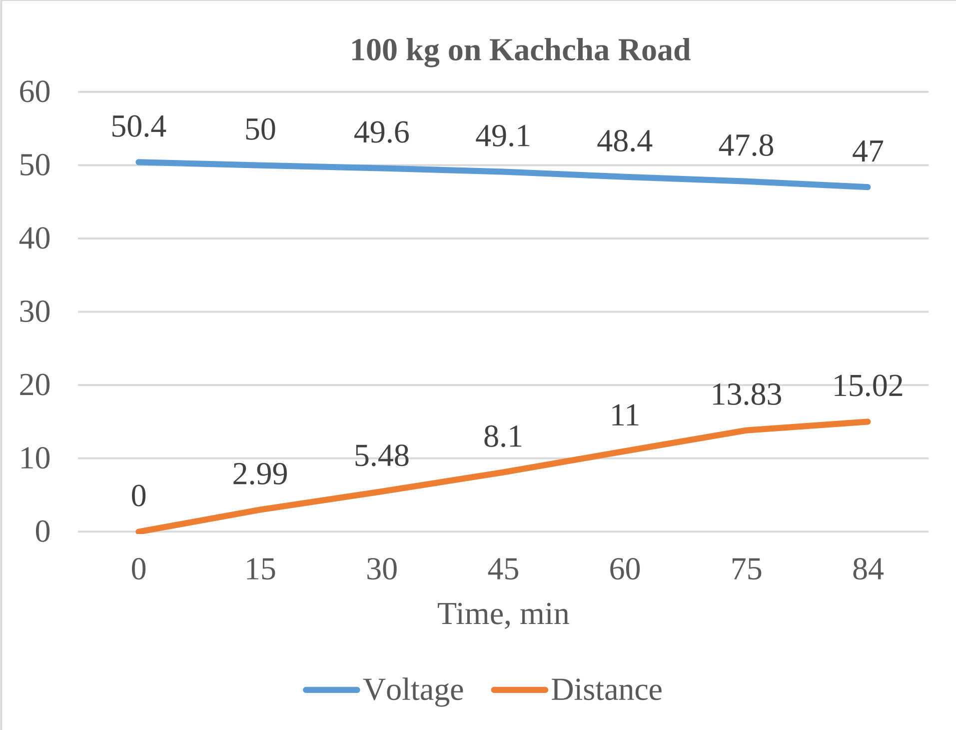
Performance evaluation of fully charge battery was carried under transport mode for three different loads as follows 100kg, 200kg and 300 kg on two types of road (pakka and kachcha road) after fully discharge of battery measure the covered distance and backup time of battery. In this evaluation the effect on total covering distance and backup time with different load was calculated.

4.6.1 Effect of A_1 (100 Kg) Applied Load On Distance Cover and Backup Time for Both Roads (B_1 and B_2)

The effect of 100 kg applied load on the distance cover and backup time per charge of battery on the both roads are shown in the following graphical representation. In the graphical representation the value of voltage drop is also shown.



(a)



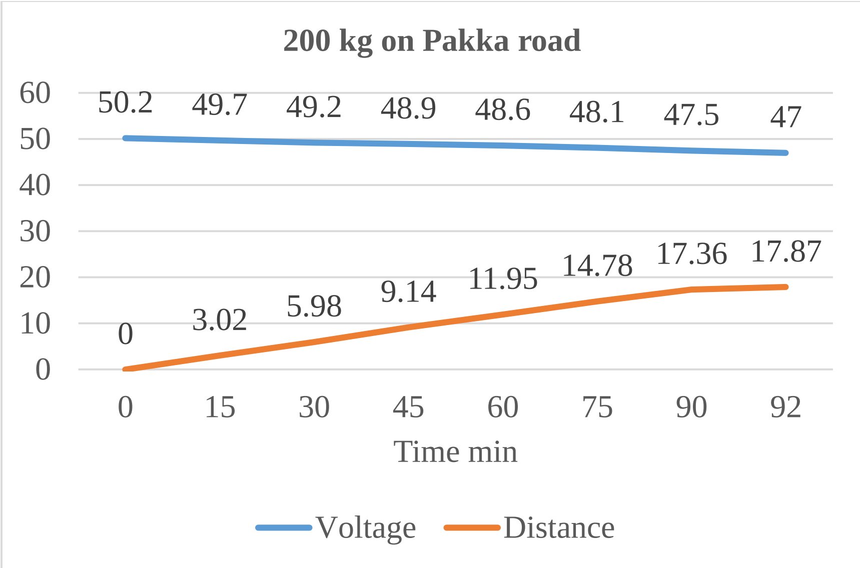
(b)

Fig. 4.5: Effect of applied load 100 kg on both roads

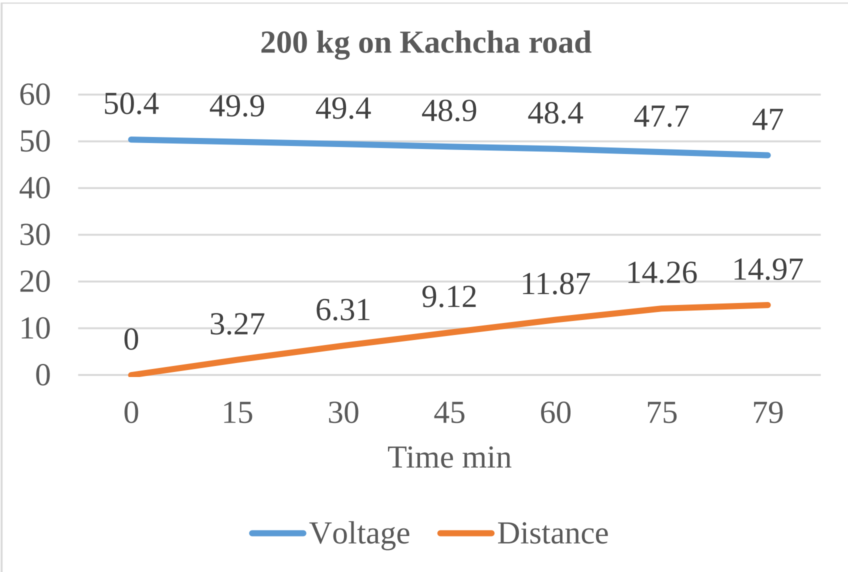
Graphical representation of applied load 100 kg on both road i.e., treatment $A_1B_1$and A_1B_2 is shown in the fig. 4.5. It is shown that the backup time and distance covered is more in treatment A_1B_1. Treatment A_1B_1 it means 100 kg load on pakka road gives more distance cover and backup time is 18.44 km and 96 min respectively. In the treatment A_1B_2 i.e., 100 kg load on kachcha road gives 15.02 km distance cover and backup time is 84 min. In the treatment A_1B_2 backup time and distance cover is less as compare to treatment A_1B_1 because in the kachcha road, resistance is more as compare to the pakka road. Due to that required power is more so it can reduce the backup time and distance cover per charge.

4.6.2 Effect of A_2(200 Kg) Applied Load On Distance Cover and Backup Time for Both Roads (B_1 and B_2)

The effect of 200 kg applied load on the distance covered and backup time per charge of battery on the both roads are shown in the following graphical representation. In the graphical representation the value of voltage drop is also shown.



(a)



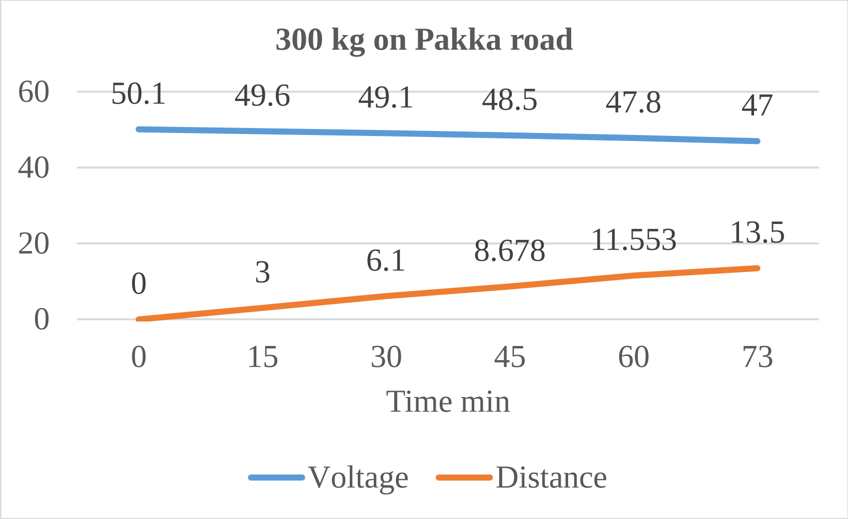
(b)

Fig. 4.6: Effect of applied load 200 kg on both roads

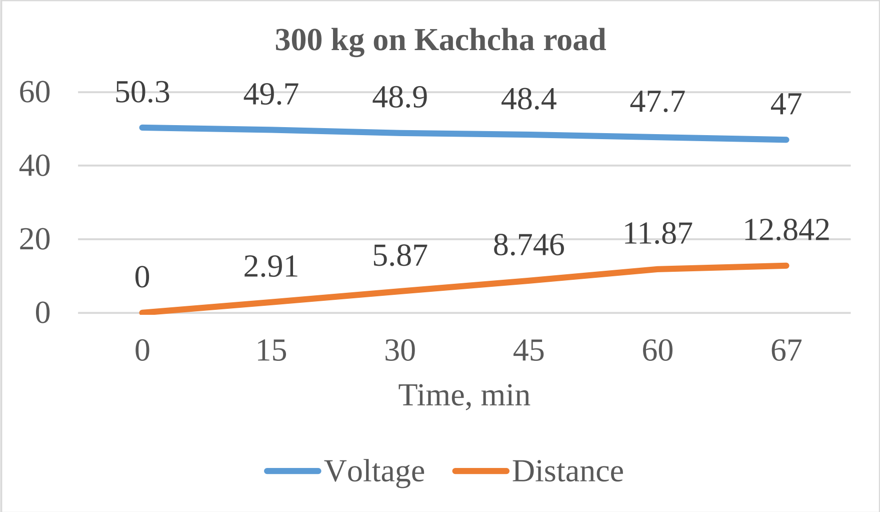
Graphical representation of applied load 200 kg on both road i.e., treatment $A_2B_1$and A_2B_2 is shown in the fig. 4.6. It is shown that the backup time and distance covered is more in treatment A_2B_1. Treatment A_2B_1 it means 200 kg load on pakka road gives more distance covered and backup time is 17.87 km and 92 min respectively. In the treatment A_2B_2 i.e., 200 kg load on kachcha road gives 14.97 km distance covered and backup time is 79 min. In the treatment A_2B_2 backup time and distance covered is less as compare to treatment A_2B_1 because in the kachcha road, resistance is more as compare to the pakka road. Due to that required power is more so it can reduce the backup time and distance covered per charge.

4.6.3 Effect of A_2(300 Kg) Applied Load On Distance Covered and Backup Time for Both Roads (B_1 and B_2)

The effect of 300 kg applied load on the distance covered and backup time per charge of battery on the both roads are shown in the following graphical representation. In the graphical representation the value of voltage drop is also shown.



(a)



(b)

Fig. 4.7: Effect of applied load 300 kg on both roads

Graphical representation of applied load 300 kg on both road i.e., treatment $A_3B_1$and A_3B_2 is shown in the fig. 4.7. It is shown that the backup time and distance covered is more in treatment A_3B_1. Treatment A_3B_1 it means applied load 300 kg on pakka road gives more distance covered and backup time is 13.5 km and 73 min respectively. In the treatment A_3B_2 i.e., 300 kg load on kachcha road gives 12.82 km distance cover and backup time is 67 min. In the treatment A_3B_2 backup time and distance covered is less as compare to treatment A_3B_1 because in the kachcha road, resistance is more as compare to the pakka road. Due to that required power is more so it can reduce the backup time and distance covered per charge.

4.6.4 Interaction Effect of Applied Loads and Roads On the Distance Covered Per Charge

The developed solar powered farm rickshaw was tested on the different applied loads and roads condition. In this evaluation tested the full charged battery covered distance on the different applied loads and roads. The combination of applied load 100 kg on pakka road is giving the highest distance covered of 18.44 km per charge whereas the combination of applied load 300 kg on kachcha road is giving the lowest distance covered per charge of 12.842 km. Table 4.6 shows the distance covered with respect to different applied loads and roads.

Table 4.6: The distance covered with respect to different interactions of applied loads and roads

Distance covered		
Load/Road	**Pakka road**	**Kachcha road**
100 kg	18.44	15.02
200 kg	17.87	14.97
300 kg	13.5	12.842

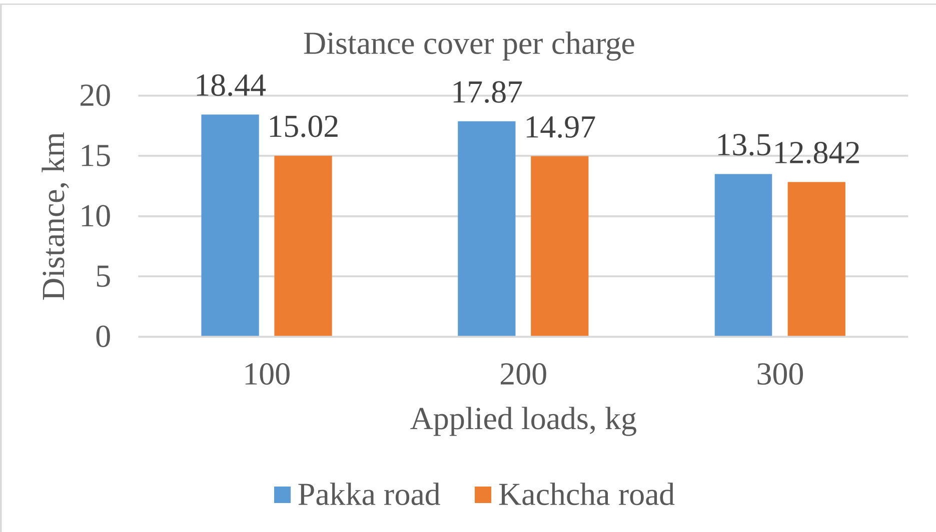


Fig. 4.8: Effect of different applied loads and roads on distance covered per charge

Graphical representation of distance covered at various combinations of applied loads with road is shown in the fig. 4.8. It is shown that the distance covered is found to be highest for treatment 100 kg on pakka road followed by 200 kg pakka, 100 kg kachcha, 200 kg kachcha, 300 kg pakka and 300 kg kachcha roads respectively. The maximum value of distance covered per charge is 18.44 km for interaction of applied load 100 kg on pakka road. The minimum value of distance covered per charge is 12.84 km for interaction of applied load 300 kg on kachcha road.

4.6.5 Interaction Effect of Applied Loads and Roads On the Backup Time of Per Charge

The developed solar powered farm rickshaw was tested on the different applied loads and roads condition. In this evaluation tested the full charged battery backup time on the different applied loads and roads. The combination of applied loads 100 kg on pakka road is giving the highest backup time was 96 min per charge whereas the combination of applied load 300 kg on kachcha road is giving the lowest backup time was 67 min. Table 4.7 shows the battery backup time with respect to different applied loads and roads.

Table 4.7 The battery backup time with respect to different interactions of applied loads and roads

Battery backup time		
Load/Road	**Pakka road**	**Kachcha road**
100 kg	96	84
200 kg	92	79
300 kg	73	67

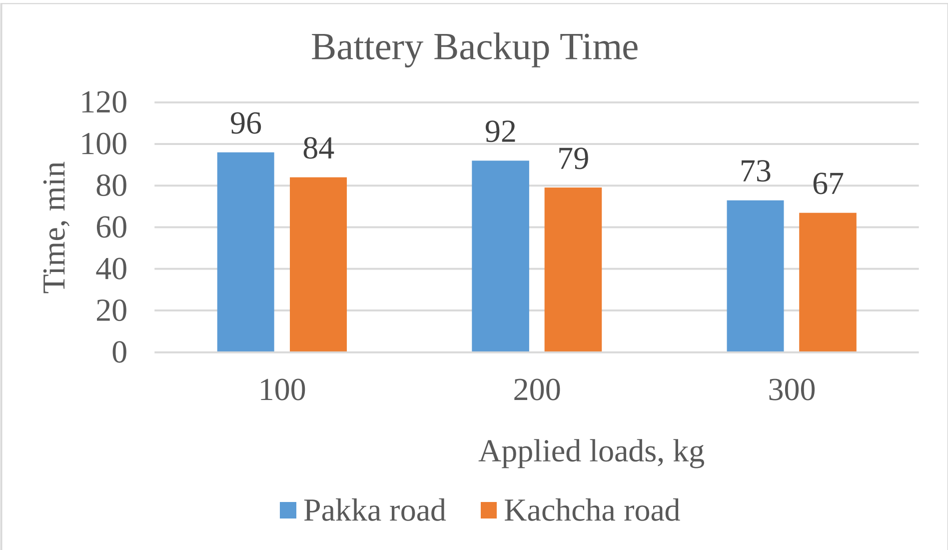


Fig. 4.9: Effect of different applied loads and roads on battery backup time per charge

Graphical representation of battery backup time per charge at various combinations of applied loads with road is shown in the fig. 4.9. It is shown that the battery backup time is found to be highest for treatment 100 kg on pakka road followed by 200 kg pakka, 100 kg kachcha, 200 kg kachcha, 300 kg pakka and 300 kg kachcha respectively. The maximum value of battery backup time per charge is 96 min for interaction of applied load 100 kg on pakka road. The minimum value of battery backup time per charge is 67 min for interaction of applied load 300 kg on kachcha road. The maximum speed of developed solar powered farm rickshaw is 15 km per hr and average speed is 12 to 13 km per hr.

4.7 COMPARATIVE ANALYSIS OF WITH AND WITHOUT SOLAR POWER FOR BATTERY BACKUP TIME AND DISTANCE COVERED

The result obtained during performance evaluation of developed solar powered farm rickshaw were compared with that, battery connected with solar power and battery disconnected with solar power in terms of distance covered and battery backup time.

Table 4.8: Comparative analysis of battery connected and disconnected with solar power to measure the distance covered and battery backup time

Comparative analysis of solar power connection		
	Distance covered (km)	**Backup time (min)**
Connected	22.453	128
Disconnected	18.44	96

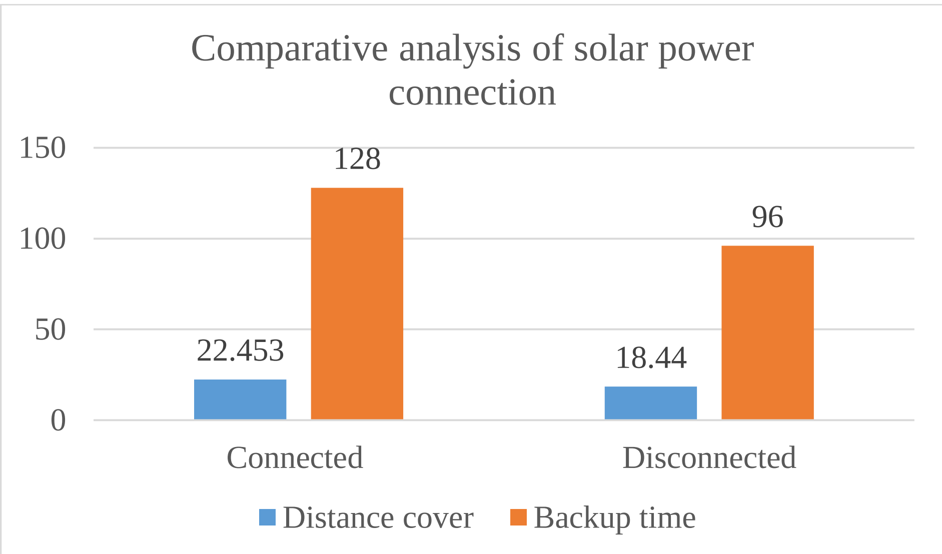


Fig. 4.10: Comparative analysis of solar power connected and disconnected with battery during transport

Graphical representation of solar power connected and disconnected during transport shows effect on distance covered and backup time of battery is shown in the fig. 4.10. It is shown that when battery is connected with the solar powered during transport gives highest value of distance covered and battery backup time is 22.453 km and 128 min respectively. In the disconnected condition distance covered is 18.44 km and battery backup time is 96 min. Battery backup time and distance covered was more in with solar connection as compare to without solar connection was 32 min and 4.01 km respectively. In the travelling condition battery was charge but not as like parking condition. In the travelling condition some resistance is coming such as like tree shadow due to that performance of solar charging during transport reduces.

4.8 ECONOMIC BENEFITS OF SOLAR POWERED FARM RICKSHAW

The operation cost was analysed for the developed solar powered farm rickshaw. Depreciation cost was calculated on the basis of straight-line method. Operational cost for the machine was calculated based on some assumptions. The assumption for cost analysis considered was discussed along with the calculation in Appendix-C. The developed solar powered farm rickshaw was found to be at the cost ₹ 28.96 per hour. The payback period of solar powered farm rickshaw was found 2.01 years. The cost parameter is shown in table 4.9.

Table 4.9: Cost parameters of developed solar powered farm rickshaw

Sr. No.	Parameters	Values
1	Capital cost of solar powered farm rickshaw, ₹	128107
2	Total operating cost, ₹/h	28.96
3	Payback period, year	2.01
4	Benefit cost ratio	7.46

CHAPTER - V

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

Rickshaws are small, three-wheeled vehicles which are used extensively in many Asian countries for transportation of people and goods. Rickshaws run on fossil fuels such as petrol, LPG and CNG. Fossil fuel operated vehicle create a huge problem of environmental pollution. This is due to the use of an inefficient engine, in general a 2 or 4 stroke, with almost no pollution control. In upcoming years, the major problem will be depletion of ozone layer which is caused by release of CFC's from vehicles. Energy crisis is a main issue in all over the world but it is also important to know about the available reserves of conventional energy resources like fossil fuels and uranium. The automobile industry in India is currently rapidly growing with an annual production of over 4.6 million vehicles, with an annual growth rate of 10.5% and vehicle volume is expected to rise greatly in the future. The demand of energy is rapidly increasing day by day comparatively to the discovery and production of fossil fuels. The production is less as compare to demand; therefore, prices of fuel is increasing day by day. To deal with these problems, we need to look at the non-conventional and eco-friendly sources of energy, which is available in inexhaustible form in nature.

Over the last two decades, many experiments had been done to control emission from IC engine. So, this solar powered vehicle may be one of the solutions for the above problems, due to its pollutant free operation. The most significant source of renewable energy is sun. Amazingly the sun is an infinite resource of energy to fulfil all energy requirements forever. Depending on the location, the daily incidence ranges from 4 to 7 kWh/m^2, with the hours of sunshine ranging from 2300 to 3200 per year. Solar powered vehicles which plays a vital role for the upcoming energy crisis. Because of the above facts, we decided to develop solar powered farm rickshaw as research work of master degree program. Our main motive in development of solar powered farm rickshaw was pollution free ride and affordable for different farm works.

Solar powered farm rickshaw was designed and developed. The developed solar powered farm rickshaw is simple in design, comfortable to run on farm road, easy to operate, low in maintenance cost without fossil fuel and pollution free ride. It utilizes the solar energy for power generation effectively and economically. The main components of developed solar powered farm rickshaw are solar panel, MPPT solar charge controller, lithium-ion battery, electronic motor controller and BLDC motor. Here, three polycrystalline solar panels of 150 Watt each were attached on roof of solar powered farm rickshaw, which converts the light energy into electrical energy. Solar panels generate power as well as shadow over the structure. The generated power is transmitted into the lithium-ion battery through MPPT solar charge controller. MPPT solar charge controller act as battery protecting structure. Lithium-ion battery was used in developed solar powered farm rickshaw, which is mainly used in electrical vehicle due to its better performance. Lithium-ion battery provide power to the BLDC motor as per requirement. The power of BLDC motor was calculated considering the maximum total load, maximum operating speed and all the resistances during transport. Here 48 volt 1200 watt BLDC motor is used to drive the solar powered farm rickshaw. The BLDC motor is mainly used in the electrical vehicle due to its better performance as compare to the other DC hub motor.

Keeping all the above aspects, an attempt was made to assess the functional operation and evaluation of the developed solar powered farm rickshaw considering its performance in context with its working. In the performance evaluation of solar powered farm rickshaw was measure solar charging, battery discharge in idle condition, voltage drop and time required per km, backup time and distance covered per charge, comparative analysis with and without solar power during transport and cost of operation. Battery discharge for transport was measured applying three different load on the pakka and kachcha road. Data observed for various parameters by the solar powered farm rickshaw were evaluated after necessary calculations.

Statistical analysis was performed to study the effect of independent parameters and their combined effect on dependent parameters such as voltage drop and time required per km. The results of univariate analysis indicated that the effect of applied loads on voltage drop per km and effect of applied load and roads on time required per km were all significant.

Looking to the results obtained, it can be concluded that the overall performance of the developed solar powered farm rickshaw was found better at an applied load 100 kg and on pakka road during operation with connected solar power. Then the cost economics of machine was calculated to check the economic feasibility for adoption by farmers. Based on the results and evaluation reports the following conclusions were obtained:

5.2 CONCLUSIONS

The following conclusions were drawn from the above conducted study.

1. The required time to charge the solar powered farm rickshaw through solar charging and electrical vehicle charger was 8 hr and 3 hr respectively.
2. In the idle condition battery backup time was 3.35 hr, which more than road transport condition.
3. The effect of applied load A_1 i.e., 100 kg and road B_1 i.e., pakka road on voltage drop and time required per km was found lower 0.15 V and 4.1 min respectively. While the effect of applied load A_3 i.e., 300 kg and road B_2 i.e., kachcha road on voltage drop and time required per km was found higher i.e., 0.25 V and 6.33 min respectively.
4. The backup time and distance covered per charge was found higher in applied load 100 kg on pakka road i.e., A_1B_1 was 96 min and 18.44 km respectively. While lower in applied load 300 kg on kachcha road i.e., A_3B_2 was 67 min and 12.842 km respectively.
5. Comparative analysis of performance of solar powered farm rickshaw with and without solar power during transport in terms of battery backup time and distance covered shows that the values of backup time and distance covered with solar power were 128 min and 22.453 km respectively. Similarly, the values of backup time and distance covered without solar power were 96 min and 18.44 km respectively. Hence, the values of battery backup time and distance covered for with solar operation were 32 min and 4.01 km more than that of without solar operation.
6. The developed solar powered farm rickshaw was useful to carry a load up to 600 kg. The developed machine was helpful to the farmer for transportation of production from farm to the nearest market, milk transportation up to the

dairy, labour transportation. It meant to be helpful for nearest farm work up to 20 km distance.

7. The cost of operation of developed solar powered farm rickshaw was found ₹ 28.96 per hour.
8. The payback period of the developed solar powered farm rickshaw was found 2.01 years.

SUGGESTIONS FOR FUTURE RESEARCH

Much of the research reported in this study was exploratory and has evoked questions that can be answered by more detailed and specialized investigations. This research has great potential to be explored, thus open a wide area of research to conduct.

Based on the experience gained from this research, several suggestions for future research are as follows:

1. Dynamo can be enclosed in a wheel of solar farm rickshaw to increase the backup time of the battery.
2. To reduce the solar charging time can be develop solar charging station or provide one more backup battery.

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APPENDIX – A

DESIGN CONSIDERATION OF SOLAR POWERED FARM RICKSHAW

1. BLDC Motor Power Calculations

The following three methods are used to calculate the power of BLDC motor:

Method:1

1.1 Rolling resistance

The rolling resistance force can be expressed as,

$$\mathbf{F_{ROLLING} = \mu_R \times W}$$

$$= 0.010 \times 600 \times 9.81$$

$$= 58.86 \text{ kg m/s}^2$$

$$= 58.86 \text{ N}$$

1.2 Aerodynamic drag force

The aerodynamic drag force can be expressed as,

$$\mathbf{F_{DRAG} = [(1/2) \times C_d \times A \times \rho \times (V)^2]}$$

$$= [1/2 \times 0.32 \times 1.3 \times 1.2 \times 8.33^2]$$

$$= 17.31 \text{ kg m/s}^2$$

$$\mathbf{= 17.31\ N}$$

1.3 Force of acceleration

The acceleration force can be expressed as,

$$\mathbf{F_{ACCELERATION} = [m \times a]}$$

The maximum velocity/speed to be attained by the rickshaw is 30 kmph or 8.33 m/s in metric units. Acceleration force is calculated as:

$$\text{Acceleration} = (8.33 - 0)/100 = 0.08 \text{ m/s}^2$$

$$\text{Acceleration force} = FA = \text{Mass} \times \text{Acceleration}$$

$$FA = 600 \times 0.08$$

$$\mathbf{FA = 48\ N}$$

1.4 Total tractive force

The total tractive effort has to be the sum total of all the three above forces,

$$FD = F_{ROLLING} + F_{DRAG} + F_{ACCELERATION}$$

$$= [\mu R \times W] + [(1/2) \times cD \times Across \times \rho \times (V)^2] + [m \times a]$$

$$= 58.86 + 17.31 + 48$$

$$= 124.17\ N$$

The power needed to be supplied by the motor in order to provide the current speed and acceleration is therefore being,

$$P = FD \times V$$

$$= 124.17 \times 8.33$$

$$\mathbf{= 1034.33\ watt}$$

Method :2

Selection of BLDC motor was also carried out based on following formula

$$P(Watts) = W \times g \times V \times S$$

$$= 600 \times 9.81 \times 8.33 \times 2/100$$

$$\mathbf{= 980.60\ Watt}$$

Method: 3

$$P\ (Watt) = (Torque \times RPM)/9.55$$

$$Torque = Total\ force\ (F_{ROLLING} + F_{DRAG} + F_{AC}) \times Radius$$

Therefore, taking values of total force acting on solar car from method 1

$$Torque = 124.17 \times 0.24$$

$$= 29.80\ Nm$$

RPM = (Top speed in m/minute) / circumference of wheel

= 500/1.51

= 331.12

P (Watt) = (25.52 × 331.12)/9.55

= 884.83 Watt

Considering the values derived from the above three methods and market availability, 48 volts, 1200 W BLDC motor has been selected to power solar farm rickshaw.

2. Battery Bank Capacity

The battery bank capacity is selected using the following relation;

$$\textbf{Battery Capacity (Ah)} = \frac{\text{(Rated Wattage of BLDC Motor} \times \text{Operating Hours)}}{\text{(Nominal Voltage} \times \text{Maximum Allowable Discharg)}}$$

$$= \frac{1200 \times 1}{48 \times 0.80}$$

= 31.25 Ah

Considering the values derived from the above method and market availability, 48 V 30 Ah lithium ion battery has been selected to power the solar powered farm rickshaw.

2.1 Calculations for battery backup time

$$\text{Battery discharging current} = \frac{\text{Power (watt)}}{\text{Battery voltage (volt)}}$$

$$= \frac{1200}{48}$$

Battery discharging current = 25 A

Then,

$$\text{Battery backup time} = \frac{\text{Battery capacity}}{\text{Battery discharging current}}$$

$$= \frac{30}{25}$$

Battery backup time = 1.2 hr.

3. Photovoltaic (PV) Panel Sizing

$$\text{Total PV panels energy needed} = \frac{\text{Total power consumption}}{\text{efficiency of all the auxiliary unit}}$$

Assume,

Efficiency of solar charge controller (ESC) = 95%

Efficiency of battery (Eb) = 80%

Efficiency of BLDC motor controller (Emc) = 95%

$$\text{Size of the panel} = \frac{\text{Total power required for motor}}{(\text{Esc x Eb x Emc})} \quad \text{(Gupta, 2016)}$$

$$= \frac{1200}{(0.95 \text{ x } 0.80 \text{ x } 0.95)}$$

= 1662.04 W

Here the size of panel is much larger which is difficult to attach in the rickshaw also, cost of the system would be higher.

Alternate method:

Selection of solar module and array

$$\text{Array Load} = \frac{\text{Battery charging requirement (Wh/day)} \times \text{Depth of Discharge}}{\text{Battery efficiency} \times \text{charge regulator efficiency}}$$

$$= \frac{1440 \text{ (Wh/day)} \times 0.80}{0.80 \times 0.90}$$

= 1600 Wh/day

$$\text{Array size} = \frac{\text{Array load}}{\text{Annual average Insolation(kWh/m2 /day)} \times \text{mismatch factor}}$$

$$= \frac{1600}{5 \text{ (kWh/m2 /day)} \times 0.85}$$

= 376.47 W

$$\text{No. of solar panels} = \frac{\text{Array size}}{\text{solar panel size}}$$

$$= \frac{376.47}{150}$$

= 2.50 i.e. 3

Here 150 W three polycrystalline solar panels are used to power the solar farm rickshaw.

3.1 Charging time of battery by solar photovoltaic module

$$\text{Charging time} = \frac{\text{Ampere required for battery}}{\text{ampere delivered by solar photovoltaic module}}$$

$$= \frac{30}{6.08}$$

= 4.93 hr

Charging time for battery by solar modules is 4 hr 55 min.

APPENDIX - B

PERFORMANCE PARAMETERS OF DEVELOPED SOLAR POWERED FARM RICKSHAW

1. Solar charging

Table B-1 Observed values of solar radiation and voltage change with respect to time for the solar charging of solar powered farm rickshaw.

Sr. No.	**Time (hr)**	**Solar radiation (w/m^2)**	**Voltage(V)**
1	9.5	302.5934	47
2	10.5	492.6964	47.7
3	11.5	472.1375	48.3
4	12.5	378.4562	48.6
5	13.5	499.0594	49
6	14.5	540.3514	49.3
7	15.5	503.5668	49.7
8	16.5	488.8927	49.9
9	17.5	345.5871	50.1

2. Battery discharge in idle condition

Table B-2 Observed values of solar radiation and voltage change with respect to time for the solar charging of solar powered farm rickshaw.

Sr. No.	**Time (min)**	**Voltage (V)**
1	0	50.2
2	15	49.8
3	30	49.7
4	45	49.6
5	60	49.6
6	75	49.5
7	90	49.4
8	105	49.2
9	120	49.1
10	135	49
11	150	49
12	165	48.9
13	180	48.7
14	195	48.4
15	201	47

3. Voltage drop per km

Table B-3 Observed values of voltage drop per km for different treatments and replications

Treatment	Replications				Mean
	R_1	R_2	R_3	R_4	
$T_1(A_1B_1)$	0.1	0.1	0.2	0.2	**0.15**
$T_2(A_1B_2)$	0.2	0.1	0.1	0.2	**0.15**
$T_3(A_2B_1)$	0.2	0.1	0.3	0.2	**0.2**
$T_4(A_2B_2)$	0.2	0.2	0.3	0.2	**0.23**
$T_5(A_3B_1)$	0.2	0.3	0.2	0.3	**0.25**
$T_6(A_3B_2)$	0.3	0.2	0.2	0.3	**0.25**

4. Time required per km

Table B-4 Observed values of time required per km for different treatments and replications

Treatment	Replications				Mean
	1	2	3	4	
$T_1(A_1B_1)$	4.05	4.08	4.1	4.18	4.1
$T_2(A_1B_2)$	6.2	6.3	6.14	5.52	6.04
$T_3(A_2B_1)$	4.34	4.41	4.48	4.3	4.38
$T_4(A_2B_2)$	6.01	6.03	6.1	6.15	6.07
$T_5(A_3B_1)$	4.42	4.44	4.56	4.4	4.46
$T_6(A_3B_2)$	6.32	6.28	6.45	6.28	6.33

5. Backup time and distance covered with and without solar during transport

Table B-5 Observed values of backup time and distance covered with and without solar during transport

Sr. No.	Time (min)	Distance covered	
		With solar	Without solar
1	0	0	0
2	15	3.12	3.05
3	30	6.19	5.97
4	45	8.98	9.14
5	60	12.17	12
6	75	14.78	15.24
7	90	17.85	17.89
8	96	18.3	18.44
9	105	19.45	
10	120	21.38	
11	128	22.453	

APPENDIX-C

CALCULATIONS FOR COST ECONOMICS

1. Initial cost of machine

The initial cost of solar powered farm rickshaw was calculated on the basis of cost of materials used for fabrication and the labour cost during fabrication.

Sr. No.	Components	Price
1.	Solar Panels	14637
2.	MPPT solar charge controller	7900
3.	Lithium-ion battery	29300
4.	BLDC motor unit	19970
5.	AC charger	3300
6.	Fabrication cost	53000
Total Cost		**128107**

Following assumptions were made for cost estimation of solar powered farm rickshaw.

1. Expected life of farm rickshaw = 15 years
2. Expected life of lithium-ion battery = 8 years
3. Working hour(H) = 700 h/year, when working hour is 2 h/day
4. Salvage value (S) = 10 per cent of initial cost
5. Rate of interest = 10 per cent per annum
6. Repair and maintenance = 3 per cent of initial cost

2. Cost economics of rickshaw

Fixed cost

A. Depreciation (D)

It is the cost of value of machine with passage of time

$$D = \frac{C - S}{L \times H}$$

$$D = \frac{87607 - 8760.7}{15 \times 700}$$

D = ₹ 7.50 / h

B. Interest

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

$$I = \frac{87607 + 8760.7}{2} \times \frac{0.10}{700}$$

I = ₹ 6.88 / h

Fixed cost of rickshaw = ₹ **(**7.50 + 6.88)/ h = ₹ 14.38 / h

Variable cost

C. Repair and maintenance

$$RM = \frac{\text{Initial cost}}{\text{life } H} \times P$$

$$= \frac{C \times P}{H}$$

$$= \frac{87607 \times 0.03}{700}$$

= ₹ 3.75 /h

D. Operating cost of rickshaw

Operating cost of rickshaw = Fixed cost + variable cost

= ₹ 14.38 /h + ₹ 3.75 /h

Operating cost of rickshaw = ₹ 18.13 /h.

3. Cost economics of lithium-ion battery

Fixed cost

A. Depreciation (D)

It is the cost of value of battery with passage of time

$$D = \frac{C - S}{L \times H}$$

$$D = \frac{40500 - 4050}{8 \times 700}$$

D = ₹ 6.50 / h

B. Interest

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

$I = \frac{40500 + 4050}{2} \times \frac{0.10}{700}$

I = ₹ 3.18 / h

Fixed cost of battery = ₹ (6.50 + 3.18)/ h = ₹ 9.68 / h

Variable cost

C. Repair and maintenance

$RM = \frac{\text{Initial cost}}{\text{life H}} \times P$

$= \frac{C \times P}{H}$

$= \frac{40500 \times 0.02}{700}$

= ₹ 1.15 /h

D. Operating cost of battery

Operating cost of battery = Fixed cost + variable cost

= ₹ 9.68 /h + ₹ 1.15 /h

Operating cost of battery = ₹ 10.83 /h.

Therefore, the total operating cost of solar powered farm rickshaw is,

= Operating cost of rickshaw + Operating cost of battery

= 18.13 + 10.83

= 28.96 / h

4. Payback period

Initial cost of machine, ₹= 128107

Custom hiring charge, ₹/km = 8 / km

The normal speed of solar powered farm rickshaw is 15 km/ hr

Therefore, hiring charges/ h = 8 × 15

CHC = ₹ 120 /h

Average net annual benefit = ₹ (CHC - TOC) × Annual utility

= (120 – 28.96) × 700

Average net annual benefit = ₹ 63728

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benifit}}$$

$$= \frac{128107}{63728}$$

Payback period = 2.01 years

5. Benefit: Cost ratio

$$\text{B: C ratio} = \frac{\text{Total benefit}}{\text{Total cost of investment}}$$

Total benefit = Average net annual benefit (₹) × Life of machine (L) in year

= 63728 × 15

= ₹ 955920

Total cost of investment, = ₹ 128107

$$\text{B: C ratio} = \frac{955920}{128107}$$

B:C ratio = 7.46

6. Breakeven point

$$BEP = \frac{\text{TFC}}{\text{CHC} - \text{TOC}}$$

$$= \frac{24.06}{120 - 28.96}$$

BEP = 0.26

Compliance Report

Thesis Evaluation

1.	Name of the candidate: **Mr. Lanjekar Pranay Rajendra** Registration No. : **2050219010**	
2.	Degree: **M.Tech. (Agril. Engg.)** with specialization in **Renewable Energy Engineering**	
3.	Title of thesis: **DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW**	
Detail report		
Sr. No.	**Comments of examiner**	**Action taken**
	Comments given by Dr. N. L. Panwar, Associate Professor, Dept. of Renewable Energy Engg., College of Tech. and Engg., Maharana Pratap University of Agriculture and Technology, Udaipur	
1.	Marks on respective pages and may be get corrected before submission	Corrected as suggested by the examiner.

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CERTIFICATE - II

Date: 12/10/2021

This is to certify that the thesis entitled **“DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED FARM RICKSHAW"** submitted by **Mr. LANJEKAR PRANAY RAJENDRA (Reg. No. 2050219010)** to Junagadh Agricultural University, Junagadh in partial fulfilment of the requirements for award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in the subject of **RENEWABLE ENERGY ENGINEERING** after recommendation by the external examiners were defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, forward with recommendation.

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