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Bi Facial Solar Photovoltaic Panel Based E Rickshaw with Prismatic Lithium Ferro Phosphate Battery

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Abstract: **Global warming, air quality depletion, look for higher energy efficiency, crisis of fossil fuel, urban congestion etc, has forced to look for alternate urban mobility solutions and has fast tracked technological development on every aspects. Adaptation and popularity of E rickshaw is an important step to address towards these challenges and found very effective across globe including India. The present E rickshaw predominantly uses lead acid batteries with individual or shared electric charging infrastructure, the need for autonomous and more efficiency is explored in different methods and methodologies like solar charging- both at charging stations and vehicle top, swappable battery infrastructure, improved vehicle and component design, etc.**

In all related available research work and studies, monofacial solar photovoltaic panel is used in vehicle rooftop, while it is unambiguously accepted that bifacial solar panel is having higher efficiency for the same size as compared to monofacial. Similarly lithium ferro phosphate batteries are having better performance, energy and power density, life and reliability in comparison to lead acid batteries. The purpose of this study is to provide an overview and explores possibilities on certain technical parameter & check feasibility of conversion of existing conventional type e rickshaw with lead acid batteries to bifacial solar panel based e rickshaw with lithium ferro phosphate batteries for making it more autonomous.

Keywords- bi facial solar photovoltaic panel, electric rickshaw, e mobility, lithium ferro phosphate batteries, lithium battery, renewable energy, solar photovoltaics.

I. INTRODUCTION

The Word rickshaw originates from Japanese word “jinrikisha” (jin- human, riki – power or force, sha- vehicle) which literally means “human powered vehicle” while e rickshaw is referred as battery powered vehicle.

Transportation accounts for 20% of global energy use and it contributes 25% to 30% of the emissions. With the rapid acceleration of the automobile markets, battery powered electric vehicles (EVs) represent a promising pathway towards improving air-quality, energy security (avoiding oil imports) and economic opportunities. The gradually increasing momentum behind EV adoption, both from Government and Automotive Industry shall ensure that electrification of transport sector will play an important role in mobility going forward nurtured by policy support from Government.

Electric rickshaw has already made great stride towards mobility especially last mile connectivity or into urban mobility. The advantages over ICE based local transportation have several and the acceptance is very high in Indian context with government is working very hard on promoting these new age mobility segment for reducing greenhouse emission, dependencies on fossil fuel, decongestion of roads, reduced noise pollution etc. The advantages are also evident as advancement on the renewable resources in total electricity generation, higher conversion rate of energy to fuel ratio etc.

Electric vehicle technology is not a new entrant, but was tried and developed during 1828-32 by but it isn't until the 1870s or later that electric cars become practical. During 1900s, Compared to the gas- and steam-powered automobiles at the time, electric cars are quiet, easy to drive and didn't emit smelly pollutants quickly becoming popular with urban residents, especially women, which however lost its prominence due to advent of advanced gas engine.

During 1990s electric 3-wheeler are launched in India & got widespread acceptance from all. At present over 1.8 million are plying only in Indian roads using mostly lead acid batteries as energy storage. Several state and central government are providing incentives and encouragements for adaptation of e rickshaw.

Several research in past has indicated various benefits and utilized solar energy (solar photovoltaic) as additional medium to enhance range and thus revenue, reduce

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dependency on grid power, reduce carbon emission etc. and quantified the same.

From merely putting solar panel on top of e rickshaw to putting it at various position with varied and optimal solar module placement angle is identified by analyzing the various configurations like front alone tilt at 16°-degree, rear alone tilt at the 5°-degree and combined front at 16°-degree, and rear at 5°-degree to reduce the aerodynamic drag effect and increase efficiency. [1, 6, 11].

A typical e rickshaw is a low speed, short range(80-130 KMS) three wheeler BLDC motor driven vehicle for passenger or goods transport, using 48V or 60V battery energy storage system with majority using mono block lead acid(4X12V or 5X12V with 100-120Ah) or integrated LiFePO4 (48-64V 80-100Ah) battery. Even battery hybrid system, such as battery- supercapacitor are been investigated for increasing the life of the energy storage system. [2]

It is proved that upto 25-30% energy saving can be achieved using monofacial solar panel apart from various benefits [3]

Apart from low speed e rickshaw, various other vehicles like AGVs, wheelchair, robots integrated with solar photovoltaic are found to be equally beneficial, strengthening the hypothesis of solar panel integrated e rickshaw as an attractive option. [4]

This user friendly ecologically and economically viable solar auto rickshaw as a sustainable transport for rural urban areas with an increase in utilization of natural power like solar energy having solar radiations in different climatic conditions are researched and found suitable [5,7]

The research has proved with various numerical methodologies, different optimization technique, duration of project of critical path method, and overall result validated by regression analysis that replacing conventional electric vehicle system by the solar energy system will be a feasible solution for the distribution of electric power in the electric vehicle and if meteorological conditions is good and any location are gathers sufficient amount of solar radiation throughout the year than such type of solar powered electric vehicle is the very efficient system at that place and one of the powerful advantages of this system is, it reduce pollution from the environment. [8]

Retrofitting, design and fabrication of the existing diesel auto in to solar power based electric vehicle is also been researched successfully found that a wide scope for retrofitting of the existing three wheelers in to solar powered vehicles is possible without discarding the vehicles in to scrap yard. [9]

Research on very reliable, extended range power supply for electric vehicle with PV panel with battery to overcome the battery oriented vehicle issues like rapid charging and discharging of battery rapidly is been carried out for better acceleration performance, controlled regenerative braking, longer driving range, longer battery life and smaller battery pack to minimize the stresses on battery during acceleration and braking of permanent magnet brushless dc motor. [10]

A novel optimized technique to charge e-rickshaw battery by using single (current) sensor based MPPT of SPV module has been researched where single sensor is used to optimize the charging power of cell/battery. The optimal charging of cell/battery is achieved by choosing correct duty cycle of MOSFET based boost converter. The best possible value of duty cycle is achieved by a new high level optimization technique (GSA). [12]

Numerical and experimental studies on solar powered minibus has indicated that flat solar panel is a better option compared to other geometry from fuel economy point of view which gives low drag coefficient and optimum lift coefficient gives better stability. [13]

Effect of climatic condition for roof mounted solar photovoltaic panel is been experimentally investigated and discovered that the orientation, wind speed, sun hours and the dynamic speed of vehicle are the variables responsible for to and fro of production of electricity and as the wind speed increases the generation by adding extra cooling by dynamic state of vehicle, thus mounting a panel on roof of vehicle holds good option. [14]

Investigation on the variation of EC during various electric vehicle drive modes is done and attempted to find out the areas of improvement for the e-rickshaw is been carried out. [15]

Review on relative merits and demerits of various electrical machines including brushed DC, BLDC, IM, and PMSM, SRM as well as the cost benefits of energy-efficient motors have been carried out in terms of torque and efficiency and it is been established that BLDC is attractive and, to a good extent, a feasible option. [16]

A novel solar fed energy storage system with noval MPPT algorithm tracking is also researched which charges the battery and the super capacitor thus eliminating the need of frequent charging stations and also preventing the fast draining of batteries in electric vehicles and providing an efficient transport technology. [17]

A novel regenerative braking along with sensor less control of the BLDC motor driven solar powered E-rickshaw has been researched where the PWM switching with back-EMF regenerative braking method has delivered a comprehensive performance among other regenerative braking approach available in respect of simplicity of the control, and amount of energy recovered, which can be a potential solution to curb the EV range issues. [18]

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A solar-wind hybrid power system has been designed as grid tied approach for electrification of light weight electric vehicle. [19]

The V/f controlled induction motor drive for electric vehicle application is with a 4kW induction motor drive with Solar PV system is designed and modelled in MATLAB/Simulink under different conditions and the speed, torque of the drive motor is researched in addition to the output of PV string and DC-DC Boost converter. [20]

Electric, hybrid, autonomous vehicles and robots utilizing the solar PV technology are also reviewed which suggests that in a developing country like India, there is a huge demand for green-powered electric vehicles for the transportation sector. Further, integration of renewable PV technology with electric, hybrid and autonomous vehicles would be a green and sustainable step to decarbonize the road transportation sector. Studies of solar powered electric vehicles suggest that a very little effort has been made to implement and design solar powered vehicles by the Indian government [21].

II. BI FACIAL SOLAR PHOTOVOLTAICS SYSTEM

Mono facial solar photovoltaic panels has an opaque backing, bifacial solar photovoltaic panels has a transparent back, usually glass, to allow the photovoltaic cells to benefit from diffused albedo light, thereby increasing energy generation.

To make use of this additional light the photovoltaic cells are manufactured to increase the rear surface absorption, whilst also using a form of selective deposition to allow light between the rear contacts and onto the cell surface. This adds complexity and cost to the manufacturing process.

The first functioning prototype was designed by the Japanese researcher H. Mori in 1966, and the first bifacial PV system was deployed as a part of the Russian space program in the 1970s, but the high costs limited the viability of this technology. As the global PV market developed and manufacturing costs fell during 2010, bifacial solar photovoltaic experienced resurgence as several manufacturers sought to differentiate their products and offer customers with higher performing products.

The majority of bifacial solar photovoltaic panels is currently offered in framed module format, though unframed laminates are also available. Bifacial modules prices have been falling rapidly and the gap between these and conventional monofacial, monocrystalline modules has narrowed, making them an attractive option to developers. Bifacial solar photovoltaic panels are now moving closer to the tipping point of commercial viability, moving from the early adopters to more widespread deployment.

In bi facial solar photovoltaics system both sides of the cells can absorb solar radiation, utilizing the scattered light from the ground and surroundings which also implies a more difficult energy yield forecast due to the extra rear irradiance contribution. The instantaneous bifacial gain at time t, $BG_i(t)$ is defined here as:

$$BG_i(t)=[100\%X(P_{bifacial}(t)/P_{mpbifaical})/(P_{monofacial}(t)/P_{mpmonofacial})]-1$$

Where $P_{bifacial}$ and $P_{monofacial}$ are measured power values and $P_{mpbifaical}$ and $P_{mpmonofacial}$ are front side power ratings measured on a flash tester at STC with the back of the bifacial module covered with an opaque material.

Total energy production of tilted bifacial systems appears to be maximized at the same orientation as for monofacial modules. One exception is E-W bifacial vertical modules, which can outperform optimally oriented monofacial modules, especially with enhanced albedo. [22].

Most likely from e mobility point of view, dynamic partial shading is a reality in application, which makes the research and comparative assessment of three MPPT algorithms, namely the PSO, GA, and P&O for PV systems more relevant and these techniques can be employed to detect the global MPP under any circumstances, especially when the PV generator suffers from partial shading. Under shade, the new method seems to be reasonable to be used for tracking the MPP and a good tradeoff between simplicity, speed, and efficiency.[23]

From solar photovoltaics point of view, Bifacial PV modules and systems deliver more energy than equivalent mono facial modules in the same orientation. The gain is not fully understandable till now into the application of e mobility sector because of several factors as all studies are centered on stationery applications with research and experimentations centered on different surfaces, orientations, reflections, effect of temperature, ground clearances, fixed axis and duel axis tracking, effect of environmental factors etc.

Various literature and work indicates that the subject itself is new and in primary stage with limited options were exercised in implementing solar photovoltaics with more focus on enhancing the range of the vehicle, aerodynamics, component level behavior, integration challenges etc. From solar photovoltaics point of view, various developments are taking place at a higher pace and its applications into e mobility sector are yet to be fully explored.

The introduction of bi facial solar photovoltaics into e rickshaw is fairly a new subject with high possibility, such as availability of over 70% open area, providing ample opportunities to generate much higher energy on the same surface area, where normally solar panels are installed

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(rooftops). Additional areas like side panels are an option to be explored.

All these initial points motivated us to carry out this research and are broadly forming into research objective and are part of the study.

III. LITHIUM ION BATTERIES

Lithium ion batteries for electric vehicle are most suitable because of several advantages like high energy density and long cycle life over other technology batteries but temperature raise in cell as well as battery pack poses several challenges. While low temperature affects the performance, life and reliability but higher or abnormal temperature may cause explosion or fire and raises severe safety concern.[24]

The demand due to e mobility as well as into energy storage segment is expected to fuel lithium ion batteries to over 900 GWh by 2025. A common lithium-ion battery consists of lithium compound-based cathode, carbon-based anode, electrolyte and separator. In general, the cathode materials are coated on an aluminum foil and the anode materials are coated on a copper foil, respectively. The aluminum and copper serve as the current collectors. A piece of porous polymer separator that is immersed in electrolyte and sandwiched between the anode and cathode prevents the shorting of the two electrodes.

From Lithium ion battery family, Lithium Ferro Phosphate (LFP) is preferred choice for e rickshaw because of high life of cells (upto 3000 cycles) with stable electrochemistry. Lithium Ferro Phosphate comes with two different foam factors- Cylindrical & Prismatic. The comparison between Cylindrical & Prismatic cell is given in table- 1.

Description	**Cylindrical & Prismatic cell**	
	Cylindrical	***Prismatic***
Production capacity	Cylindrical cells can be produced much faster and simple design.	More complex design, assembly time, labor, and material.
Energy density	Low energy density.	High energy density.
Cell count per battery pack	Several as normal capacity starts from 5/6 Ah.	Limited as normal capacity starts from 20 Ah- over 200 Ah.
Electrical connections	High electrical connecions.	Low electrical connections.
Cost of assembly plant	High.	Low.
Working on High-pressure environments	Moderate.	High.
Cost of welding	Low.	High.

However due to easy configuration and high energy density with Prismatic cell, it is widely used for e rickshaw.

Due to modular shape, various configurations with Prismatic cell is possible with popular models are with 48/51.2/60.8/64/74V system with various capacities like 80/86/100/160/172/200Ah etc.

All lithium ion batteries are made with battery management system- an integral part due to safety concerns.

IV. MOTIVATION

Several researchers had studied various aspects and concept of electric rickshaw from design point of view, its applications, reducing carbon footprints, reducing urban traffic congestion, job creation, reducing grid dependencies etc. Several researchers had also studied various aspects and concept of integration of solar photovoltaic panels on electric rickshaw.

From technical point of view, it is unanimously agreed that the energy required to drive electric rickshaw is more than the energy delivery by solar photovoltaic panels on any given day, making it grid dependent to certain extent, which itself is significant enough to make solar integrated electric rickshaw as commercially nonstarter.

The ways of reducing grid dependencies had made us motivated to overcome the problems of low energy generation along with variable and environment dependent solar irradiance and design an alternative method of obtaining the energy to run the electric rickshaw from the grid supply by way of using bi facial solar panel into best possibly ways and available spaces to generate maximum energy with least dependency on grid power.

V. OBJECTIVES

Several The overall objective of this research study is to framework a pathway to utilize an existing prospect, such as e rickshaws, as energy storage options for integrating renewable energy sources in a self-sustainable manner.

To assess appropriate technology and practices that can be materialized to find a scientific approach for creating an interconnection among technologies, e mobility, and solar energy to address certain integration related problems.

To assess suitability of the identified method through a theoretically study that can address the general objective and address the problems discussed in the background section.

This research is focused on theoretically examines the concept of making and designing an electric three wheeler which can be free from grid charging in normal sunny days by using bifacial solar photovoltaic panels and its arrangement under certain conditions and assumptions. The concept and design is further checked under various solar irradiance and various loading conditions.

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VI. ENERGY MODELS

E_{ij}= 2.77*10^{-4}*[m_{ij}.g.(f.cosφ + sinφ) + 0.038(ρ.C_z.A.v_{ij}^2)+ (m_{ij}+m_f)(dv/dt)]d_{ij}

Whereas,

E_{ij} = Mechanical energy required at the wheels to drive on a distance d_{ij} [kWh]
m_{ij} = Total vehicle mass [kg], considered as 500KGs
m_f = Fictive mass of rolling inertia [kg], considered as 20KGs
g = Gravitational acceleration [m/s2], considered as 9.81 m/s^2
f = Vehicle coefficient of rolling resistance [−], considered as 34.335
φ = Road gradient angle [°], considered as 3°
ρ = Air density [kg/m3], considered as 1.225 kg/m3
C_z = Drag coefficient of the vehicle [−], calculated as 0.665
A = Vehicle equivalent cross section [m2], considered as 1.75 SQM
v_{ij} = Vehicle speed between the point i and the point j [km/h], considered as 6.94M/S
d_{ij} = Distance driven from point i to point j [km], considered as 59.023 km.

E-Rickshaw being an open vehicle, the cavity inside forms a low-pressure region which redirects the external flow to pass through it and mix with the turbulent regime as a result of which the coefficient of drag is obtained higher. Aerodynamic drag increments with the square of speed; in this way it turns out to be critically significant at higher velocity. Due to the formation of the high-pressure region on the front end and low-pressure pocket on the back end creating a pressure difference. This formation of a pressure gradient plays a significant role in producing the drag. Pressure drag is dependent on the frontal area hence more the cross area more is the pressure drag. Secondly, the formation of a boundary layer on the roof of the vehicle tends to create a velocity profile in which flow velocity is zero at the surface and accelerates at a free stream which negligibly affects the drag coefficient overall.[25]

C_z= Drag force/(0.5*ρv2*cross sectional area)
Where,
Drag force= 3.50 KGs= 3.50*9.81= 34.335 N
Density = 1.225kg/m^3
Flow Velocity = 6.94 m/s
Cross Sectional Area = 1.75 m^2
So, C_z= 0.665

Power Consumption for Electric Vehicle:
Let, the weight of the vehicle (with passengers) = 500 kg
Peak velocity of vehicle = 25 KM/h= 6.94 M/s
The total theoretical power needed to run the vehicle at peak velocity, w.r.t. it's mass.
Total theoretical power = Total weight*g*Peak speed* gradient of velocity = 500*9.81*6.94*0.03= 1021 W

Here, the BLDC motor considered is of following technical parameters.

Rated power(W)-	1500
Rated Torque(N-M)-	6.125
Peak torque(N-M)-	18.000
Operating voltage(V)-	48
Rated Current(A)-	35
Peak Current(A)-	80
Rated RPM-	3000

Maximum Current Flow =p/v =1500/48 = 31.25 A
Total theoretical power required per day = Current flow*Voltage*Running time per day*1.1= 31.25*48*5*1.1= 8.25 kWh/Day.
For actual running condition, GPS data of the vehicle of same motor configuration is taken –
Total distance run in a day- 59023 M.
The total charging carried out in the battery via electrical charger (CC-CV, 58.4V, 20A) is as per figure- 1.
Similarly discharging is been carried out with 20A constant current discharging and the graph is as per figure- 2.
On experimentation with the same battery fitted in an e rickshaw on 25th March 2021 moving around west Delhi with geographical coordinates (28.55, 77.41). The data is taken from Lithion make smart BMS with data logging system.
A total 79823 vehicle operation data points from BMS-Data-logger is been considered & actual discharge voltage on constant load graph is plotted as figure- 3. Similarly, actual discharge current on constant load graph is plotted as figure- 4 & the distance travelled by the vehicle is as per figure- 5.
From actual experimentation, the average battery energy consumption/KM- 58.98W/KM and the time taken to travel this distance is 5 hours.

For PV design consideration, the following bifacial solar panel is considered with 30% B_fG -

Brand(Adani ELAN Series)	ASB-7-355
Dimension (L*H)	1998X1010 cm^2
Weight	31.1 kg
Max. Power (p.max.)	446 Wp
Open Circuit Voltage (V_{oc})	46.40 (v)
Short Circuit Current (I_{sc})	9.74 (A)
Max. Power Point of Voltage (V_{mpp})	38.1 (V)
Max. Power Point of Current (I_{mpp})	10.90 (A)

The annual average DNI(4.318) & GHI(5.209) for Delhi(LONG,N,7,2- 77.15, LAT,N,7,2- 28.75) & its monthly average DNI & GHI is provided as per figure- 6.

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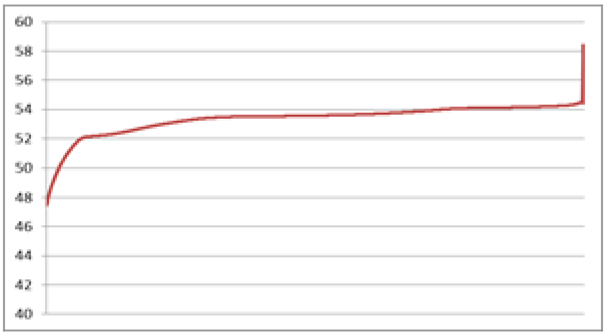

Figure-1(Charging voltage at CC, 19.995A, CV)

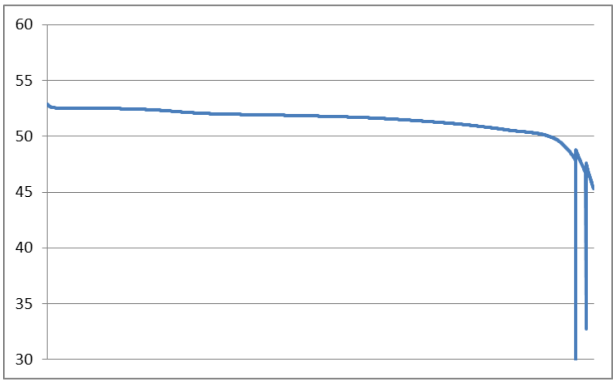

Figure- 2(Discharge voltage at constant current, 19.995A)

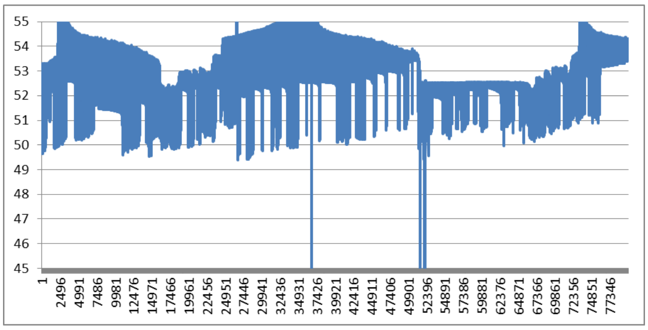

Figure- 3(Discharge voltage graph at different operation point)

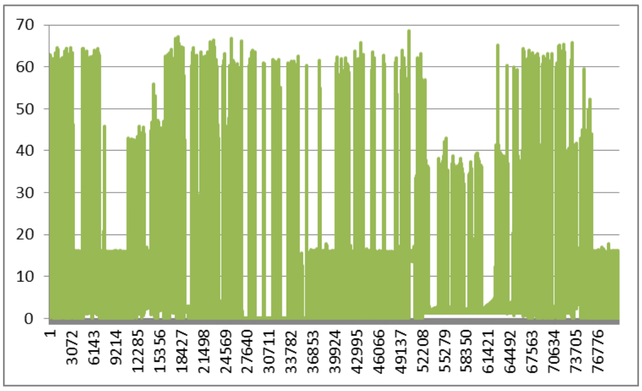

Figure- 4(Discharge current at different operation point)

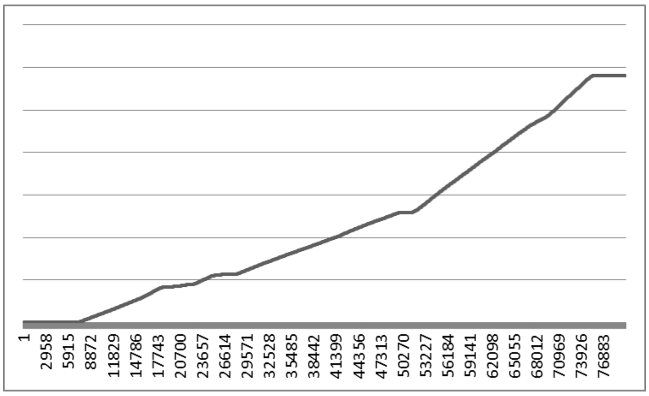

Figure- 5(Distance covered by vehicle during trial)

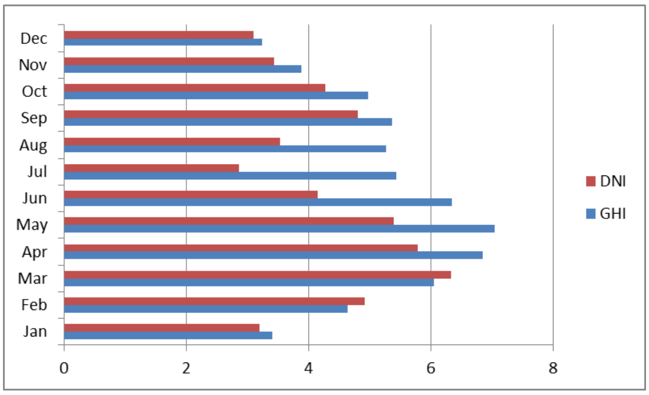

Figure- 6(Monthly DNI & GHI at 28.55, 77.41)

RESULT & DISCUSSION

The possibilities of incorporating bi facial solar in e rickshaw is very high if solar irradiations are good and lithium ion batteries are used as energy storage.

The nominal generation of a single bi facial solar panel shall be around 2-2.5kW, which is much higher than normal solar panel of corresponding size or capacity. The experimental run with full load for upto 56 KMs, indicate that the energy consumption is almost similar to the theoretical solar generation on normal sunny day. This additional generation is substantial to increase the daily frequency of charging to extend charging period and thus saving.

VI. FUTURE WORK

The present work has only explored the possibilities of adding solar panel to e rickshaw. There are several aspects, which are not explored in this present work and without which the possibilities of bifacial solar panel based e rickshaw with lithium ion batteries cannot be firmed up. On the technical side, detailed designing of fitment of bifacial solar panel on e rickshaw to be explored, designing of charge controller, inverter/ converter & its compatibility with existing system etc. Techno- commercial comparative analysis is also to be carried out for economical feasibility. Incorporation of multiple bifacial solar in e rickshaw is also a subject of interest. Multiple cell chemistry along with

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different foam factor of lithium ion batteries is also to be explored.

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