Solar Battery Charging Station with Automated Switching System

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DECLARATION

We do hereby declare that the thesis titled "**Solar Battery Charging Station with Automated Switching System**" is submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the completion of Bachelors of Science in Electrical and Electronics Engineering. We also declare that this is our original work and was not submitted to any other places for the award of any other degree or any other publication.

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ABSTRACT

In today's environmentally conscious climate there is more and more interest being taken in alternative forms of power supply. Bangladesh is witnessing a significant increase in solar energy generation as a part of renewable energy generation as a safety net for the shortage of conventional power sources (coal, oil, gas etc.). Solar energy can be produced and converted to electrical energy via solar panels and then stored in batteries which can then be used for multiple household and commercial purposes. This project deals with the modified design of the pilot project, SBCS or Solar Battery Charging Station. This project is an attempt to assist the urban and rural areas with eco-friendly and cheap electricity supply, decreasing the load on the national grid in the process. The batteries charged in the process can also be used by electricity-driven rickshaws that will be helpful for those rickshaw pullers who are either old or physically handicapped. The implementation of the project includes charging 48-volts battery sets using two 200W solar panels providing discrete amount of power at different times of the day. In addition to that the project also includes an automated switching system by which the station will shift to backup power to charge the batteries if the solar irradiance is too low for the batteries to be charged in a given time constrain. This paper gives a full description of the charging process, both by the solar panels and by national grid.

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CHAPTER 1: INTRODUCTION

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Solar photovoltaic power generation has long been seen as a clean sustainable energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. [1] PV has recently become broader and of a very wider usage in technological world nowadays. Solar photovoltaic is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. More than 100 countries use solar PV. [1]A PV system, in general, consists of a PV array which converts sunlight to DC electricity, a control system that regulates battery charging and operation of the energy storage in the form of batteries and loads. A good, solid and reliable PC charge controller is one of the key components of any PV battery charging system to achieve low cost and many other benefits a user can get from it. Its main function is to regulate the voltage and current from the PV solar panels in a PV system into a rechargeable battery. Another function of the PV charger is to disconnect the array when the battery is fully charged, hence keeping the battery out of any damage due to overcharging. It can also prevent the batteries from damage due to excessive discharging and to protect the life of the batteries in the PV system. [2]

Solar Battery Charging Station (SBCS) was initially conceived worldwide to bring the electricity price within the capacity and ability of the rural people to pay for it. It also aimed the community and small business entrepreneurs by supplying their electricity demands without using the national grid as the source. [3] In the context of Bangladesh, this was highly necessary to be implemented since solar energy can be availed as a backup for electricity generation to enhance the shortage of power which the national grid is unable to provide due to load shedding, frequent maintenance problems of the older power station, lack of gas and coal etc. [4] Moreover our poverty-stricken rural areas face the toughest situations for the electricity crisis. Hence, this project was undertaken to make solar energy popular as one of the most accessible and affordable renewable energy sources among our people. Nowadays more and more people are availing solar energy as their main source of electricity. The compound solar cells can absorb huge amount of energy in a single day and the solar batteries are charged in a very short time period, which is 5-7 hours on average.When compared to charging stations ran by generators that usually take 8 hours on average, it is seen that the difference is not significantly large. [3]However, considering the eco-friendly solar power source and the emission of toxic carbon monoxide from the diesel burning, the solar solution is overall better. [3]Carbon monoxide makes it hard for body parts to get the oxygen they need to run correctly. Exposure to carbon monoxide makes people feel dizzy and tired and gives them headaches. In high concentrations it is fatal. Elderly people with heart disease are hospitalized more often when they are exposed to higher amounts of carbon monoxide.[5] In the solar cells, the electricity is instantaneously converted and then stored in the charging station which is consumed by the batteries. If the users do not need the energy instantaneously, they can keep the batteries in a safe place and use it later since it will be stored for a long period of time.

1.1 BACKGROUND AND MOTIVATION

Bangladesh is a third-world developing country where the crisis of electricity is a major problem around the country. Even though the situation is improving in the divisional cities, the other districts did not hit that much luck in terms of its progress. On the outskirts of the city electricity is mainly provided by "Palli Bidyut" or Rural Electricity System that can supply a very limited amount of electricity. Basically in those areas load shedding covers the most time of the day due to lack of adequate supply of electricity demand. Thus those areas are unable to cover their basic household demands, let alone any industrial activities that require electricity. This project aims to cover up that shortage by building a solar battery charging station in rural areas of Bangladesh. This will enable the rural population to gain access to affordable renewable energy. It also aims to provide eco-friendly, cheap electrical power to them. In addition to that, it can provide power to the batteries of the electricity-driven rickshaws. Rickshaws are the most popular source of transportation in Bangladesh, especiallyDhaka, mainly because of its short-trip suitability, lower road-space occupancy, andmobility in narrow-roads, route-flexibility, door-to-door services and relative cost-effectiveness compared to other public transports.[6]The electrically assisted rickshaws have opened a new sector of automation ofvehicles in Bangladesh and have the potential of making an enormous contribution to the growing economy of this country. More importantly due totheir lesser travelling time and the electrical assistance they have improved lifestyles of the rickshaw pullers through increased earning and reduced stress on health. Being the most common and flexible mode of transport in Bangladesh, rickshaws have created a legacy of their own, such automation of which can lead to a better lifestyle not only for the pullers but the passengers also. The true prospect of these electrically assisted rickshaws is still unexplored due to the ban put on its commercialization because of their energy consumption from the national grid. Our research has shown that these rickshaws can be made independent of the national grid and be made self-sustained through the utilization of the abundant solar energy available in Bangladesh.[6]However, there are some drawbacks of the project. First of all the setup cost might be way too high for almost all the rural families to setup the whole thing in the first place. Then there is the battery transportation hassle and lower energy capacity of the batteries. The battery carrying hassle might also result in the damaging of the batteries if handled improperly, adding to the overall cost again. Moreover, due to lack of education of people in the rural areas they might mishandle the batteries during charging and might discharge off fully while use from which the battery might be unusable.

Despite these drawbacks the project was undertaken being motivated by its success in many parts of the world like Cambodia, [3] Laos, India, and Kenya. It is one of the best alternatives for charging wet-cell batteries used in multipurpose works; starting from household works to providing power to solar vehicles or battery-driven rickshaws.

The design in this project can charge two 48V, 20Ah battery rails (Four 12V batteries connected in series) at a time. These battery rails are intended to be used mainly in battery-driven rickshaws but can also be used in other household purposes.

1.2 DESCRIPTION

Bangladesh is a tropical country where due to its geographical location, the time sunlight is available covers up most of the time in a 24-hour day. Hence our country is a perfect area where solar energy can be captured and be used in multiple purposes. If this project can be implemented commercially and be successful, not only it will bring a revolutionary change in the lifestyle and the economic aspects of our country but also decrease the pressure of electricity demands on the national grid. Solar energy is a solution that can provide power without using national grid and is completely environmentally clean. It also saves money on constructing electrical transmission lines. Also since in almost every national budget the cost per unit of electricity consumed is increasing and hence the need of solar powered electricity is getting more and more necessary since the average population would not be able to cope up with this persisting increase in electricity costs.

When it comes to the sector from which the potential benefit of SBCS is the highest, it is the electricity-driven rickshaws. Rickshaws are the most popular source of transportation in Bangladesh, especiallyDhaka, mainly because of its short-trip suitability, lower road-space occupancy, andmobility in narrow-roads, route-flexibility, door-to-door services and relative cost-effectiveness compared to other public transports.In Dhaka, the average trip-length is of 3.8 km [7] and the number of people travelingtogether is also usually very short, thus, rickshaws become the ideal mode of transport.The statistics indicate that in Dhaka, women and children are using 40% of the loadedrickshaws, or people with goods about 30%, of other users are students. [7] They alsoprovide a beneficial alternative to the higher charge of taxis, auto-rickshaws and othermode of transports. In terms of the GDP of Bangladesh, a contribution of 34% [8] of thetransport sector comes through rickshaws. In Dhaka alone, approximately $300,000 isexchanged between rickshaw-pullers and passengers every day. It is estimated that thereare about 2 million rickshaw pullers in Bangladesh and around 19.6 million people (14%of total population) [9] indirectly relies on rickshaw-pulling business, that is, theirfamilies, manufacturers, garage owners, painters, repair-men. An astonishing fact isrevealed by a research that shows that an average income is decreased by 15% for a jobshift from rickshaw pulling to others. Furthermore, 20% of the population in Dhakadirectly or indirectly relies on rickshaw pulling sector, that adds up to about 2.5 million people. [8] These statistics clearly suggest that enough importance should be given tothis sector and improvements through technological advancements in this matter couldbe vital to the development of the country.

In many parts of Dhaka, roads that can hardly bear three lanes for cars; have rickshaws,private cars and buses clustering and causing traffic jam. There are minor road accidentson a regular basis. Being a slow-speed, muscle driven vehicle; Rickshaws are oftenblamed to be the cause of traffic jams. Additionally, it doesn't provide enough earningsfor the pullers in contrast to the immense physical strain involved with the occupation.In this modern day, the need to renovate the traditional design of rickshaws is evidentsince it could speed up the roads in this country, simultaneously, it could curtail thephysical and financial strain of the rickshaw-pullers. Thus, these fuel-free transportsshould more convincingly be brought under a massive modernization rather thanabolition.

1.3 OBJECTIVES OF THE PROJECT

Electrical energy from the national grid is a non-renewable source which is produced from non-renewable fuels like gas and coal. Hence it cannot be considered as a long-term contributor as both of the fuels are finite in supply and will run out eventually. The incomplete combustion of these fuels is also contributing to pollution to our environment, emitting greenhouse gases, non-biodegradable waste products etc. Moreover, the power crisis in the rural areas is still acute even though situation is improving in the urban areas. Some days earlier the batteries of the electric-rickshaws and other electricity-driven vehicles were charged using electricity from the national grid. Since there are nearly thousands of them, the amount of power required every day is a significant proportion of the daily demand of electricity, therefore worsening the already existing power crisis. As a result the government recently banned the electric-rickshaws to run in the city in a hope to reduce the demand. Hence to eradicate the problem, an alternative, renewable source of energy is highly required right now and solar power is the best option available. The implementation of the SBCS can be one of the best alternatives that can broaden the way of getting rid of this electricity crisis. Some of the ways that can be achieved are:

i) Our charging station can be used to charge batteries including rickshaw battery rails either in rental or monthly payment basis.
ii) Saves valuable human power.
iii) If our project can be implemented in the rural areas, the unemployed people of the village areas can earn money and run families by being employed in the charging stations.
iv) The load on the national grid will decrease significantly.

v) The automated switching system will ensure that excess power from the backup power generation system is not drawn, therefore saves money and lessens the pressure on those sources further.

vi) The project is an eco-friendly one.

1.4 OUTLINE OF THE PAPER

The paper portrays the enormous potential of the use of the solar energy by building a Solar Battery Charging Station. Chapter 2 is about the overview of the whole setup in the project where the block diagram, pictures and the implementation of the setup is explained. In Chapter 3 description of the type of batteries that can be charged by the setup is given as well as a brief of the charge controllers and a detailed explanation of the automated switching system we included in the project. All our test results, graphs and analysis are given in chapter 4. In chapter 5 the conclusion and future works are described which also includes our success as well as constrains and bottlenecks of this project in detail.

CHAPTER 2: OVERVIEW OF THE PROJECT AND THE SETUP

2.1 THE CONCEPT

The idea behind implementing the SBCS is to make the electrically assisted rickshaws completely independent of the national grid and green through providing energy for charging their batteries using solar power. Although it is known that energy consumption of these rickshaws can be significantly reduced using the developed torque sensor paddle technology and the PV array support, the energy needed to charge their battery at the end of the day still has to come from the national grid. This not only puts extra load on the already overloaded national grid but also increases environmental pollution and diminishes the fossil fuels used for generatingthis energy. [6]

Theoretically, each electrically assisted rickshaw consumes over 960Wh of energy each day from the national grid to charge itsbattery. The SBCS is designed to harness the ample solar energy incident on Bangladesh in order to charge the batteries of the electrically assisted rickshaws both in urban and rural areas. Aside from the PV array, used to harness solar energy, the station will also facilitate a diesel generator or national grid power for emergencies like cloudy days, where the irradiation is not sufficient to charge the batteries or malfunction of the PV array system. [6]

It is suggested that two sets of batteries are allocated for each rickshaw. One to be handed over at the end of the day, which is expected to be 50% discharged and will be set for charging while the second set of battery would be fully charged by the SBCS already and be ready for service. The concept is shown in the figure below. [6]

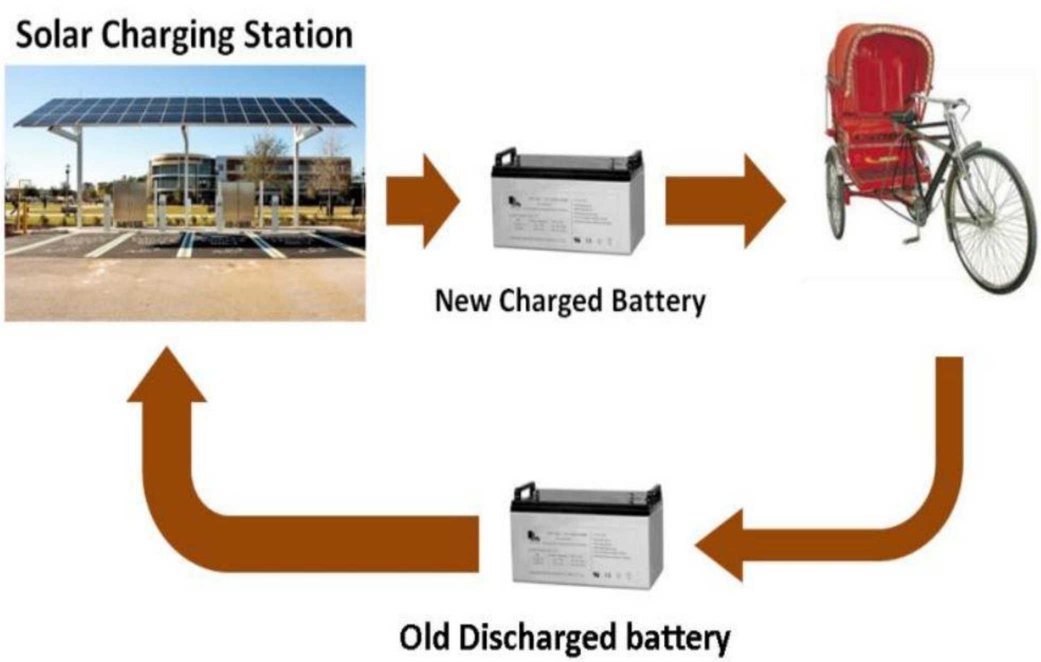

Fig 2.1: The SBCS Concept

2.2 DESCRIPTION OF THE WHOLE SYSTEM

The idea of the whole setup of the project is to charge multiple batteries within a given period of time. When the solar irradiance is not enough to meet the charging time, the system will automatically switch to the backup power which can be a generator or the national grid. The following block diagram gives the overview of the whole system.

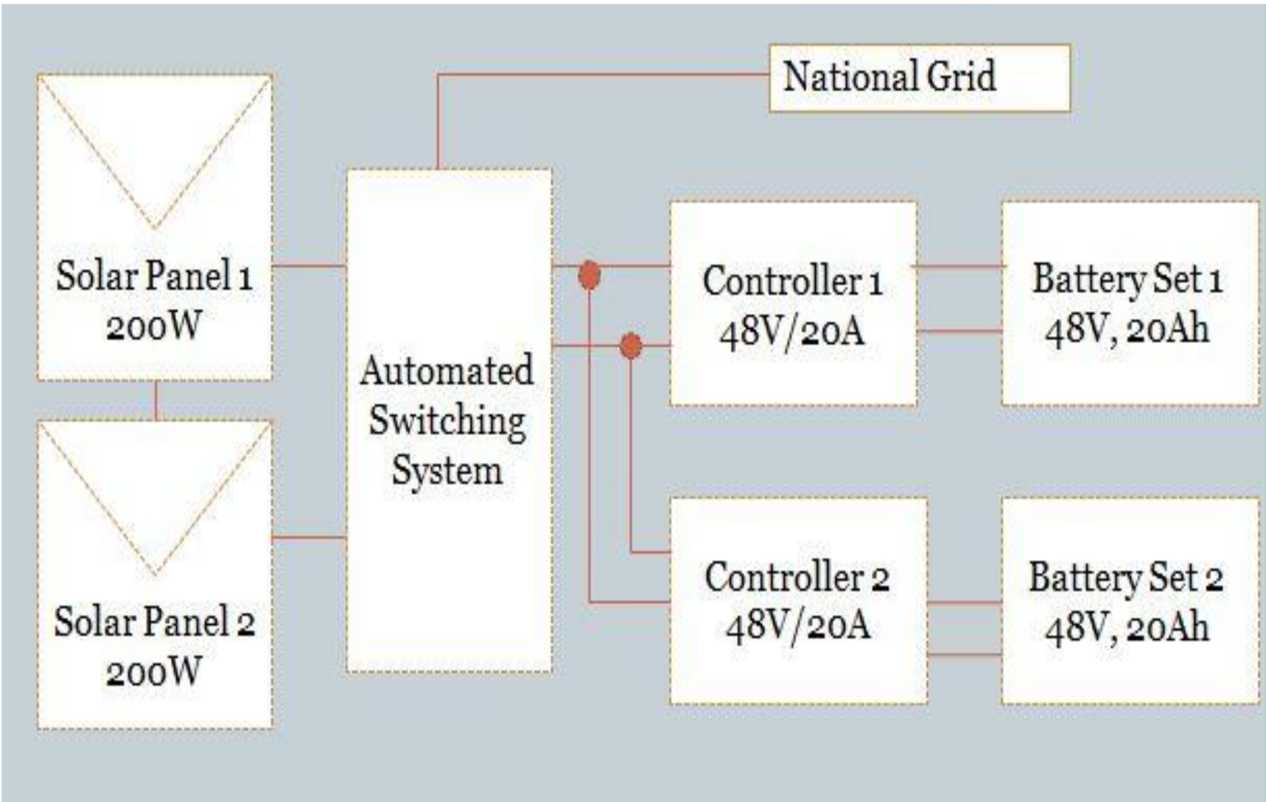

Fig 2.2: Block diagram of the Solar Battery Charging Station

For simplicity of the project, the backup power we used was from the national grid because availing a generator was not economically friendly for us in terms of initial cost as well as operational and maintenance cost.

2.3 HARDWARE IMPLEMENTATION

Solar energy is trapped and converted to electrical energy by solar panels and then it is stored in the batteries which can then be used for multipurpose works. In the hardware implementation project, the following components are used:

i) 2 (Two) PV solar panels of equal power ratings (400W total power)
ii) A mechanical support made of iron bars for the PV panels
iii) 8 (Eight) 12V, 20 Ah lead acid batteries connecting in series combination to make 2 (Two) 48V, 20Ah batteries
iv) Two PV controllers
v) Wire connections

The two solar panels are connected in series with each other which is in turn connected to the automated switching system. Another input of the switching system is taken by the national grid connection. The details of the switching system will be discussed in chapter 3. The output of the switching system is connected to the two PV controllers, where the controllers are connected parallel to each other so that they can charge two battery sets simultaneously. The outputs of the controllers are connected to the two battery banks that are to be charged.

The reason behind choosing two panels of 400Wp power is because we can then charge two battery banks at a time without compromising current distribution. The problem would have occurred if we attempted to use a single 200Wp panel to charge two sets of batteries. There the current would have been divided and it would have taken more time (theoretically twice the expected time) to completely charge the two sets of batteries.

2.4 REASONS BEHIND IMPLEMENTING BACKUP POWER

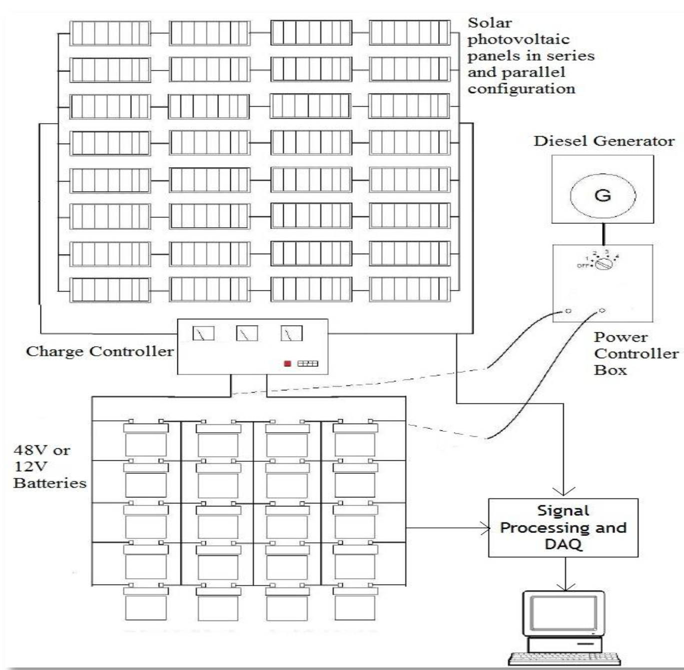

Fig 2.3: The basic concept of the SBCS Implementation [3]

As the SBCS will charge the batteries for the battery rails used in the electricity-driven vehicles, it is very likely that a time constrain will be present there. Many customers will need the batteries to be charged within a fixed time. For example, an electric-rickshaw puller will need his batteries charged within 5 hours. It might be possible if the solar irradiance is high and constant within that 5 hour period. However, weather conditions might change and the solar irradiance might not be enough to charge the batteries within that time. In this case a backup power delivery is required to cover up the loss of electrical power. In addition, the system will also contain an automated switching system that will switch the power source of the battery charging to the backup power without any manual input. There is also a software interface in the system that will monitor the charging status of the batteries as well as the input parameters in real-time.

CHAPTER 3: PV PANELS, BATTERY AND THE CHARGE CONTROLLER

3.1 THE SOLAR PV PANELS

Photovoltaic currently is one of the most-important long-term power sources. This is considered as the most important source of power that can be obtained from the sun as it can convert sunlight to electricity at a high efficiency. Also it can produce this electricity at a very low cost. It is also eco-friendly since it does not emit any greenhouse or pollutant gases. Since a typical photovoltaic cell produces less than 3 watts at approximately 0.5 volt dc, cells must be connected in series-parallel configurations to produce enough power for high-power applications. Cells are configured into module and modules are connected as arrays. Modules may have peak output powers ranging from a few watts, depending upon the intended application, to more than 300 watts. Typical array output power is in the 100-watt-kilowatt range, although megawatt arrays do exist. [10]

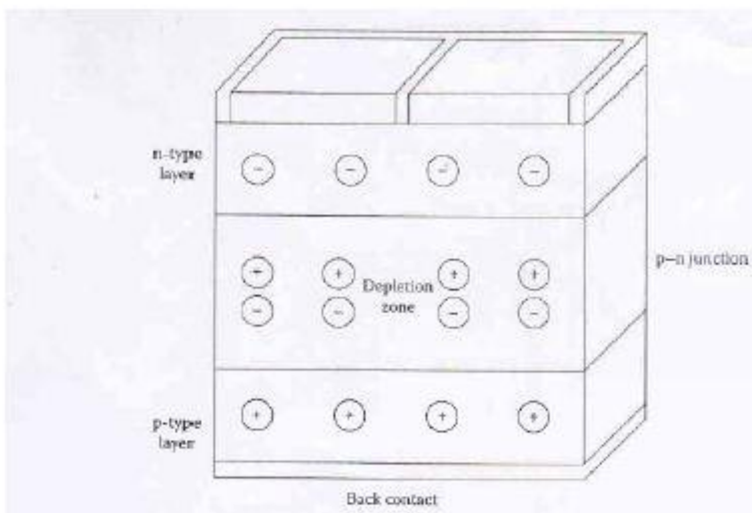

Fig 3.1: p-n junction of a PV cell [10]

Two different types (p-type with an abundance of positively charged holes)and (n-type with an abundance of negatively charged electrons) semiconductors aresandwiched in a solar cell to create a built-in-electric field at the junction or interface.When light ray impinges upon this the energy absorbed from it is used to dislodge electronsthat arrive at the depletion zone while the developed interfacial field or voltage makes theelectrons flow through an external circuit or load connecting two sides of the cell. [10]

A PV or solar cell is the basic building block of a PV (or solar electric) system. An individual PV cell is usually quite small, typically producing about 1 or 2W of power. To boost the power output of PV cells, they have to be connected together to form larger units called modules. The modules, in turn, can be connected to form larger units called arrays, which can be interconnected to produce more power. By connecting the cells or modules in series, the output voltage can be increased. On the other hand, the output current can reach higher values by connecting the cells or modules in parallel.[10]

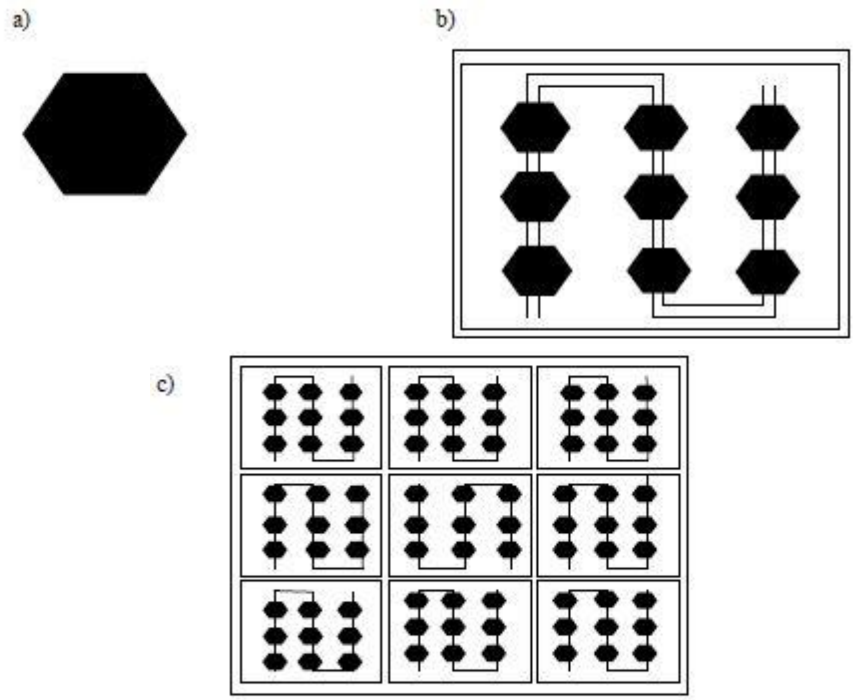

Fig 3.2: a) PV cell, b) PV module,
c) PV array [10]

PV devices can be made from various types of semiconductor materials, deposited or arranged in various structures. The three main types of materials used for solar cells are silicon, polycrystalline thin films, and single crystalline thin film. Solar energy systems are typically classified into two systems: Passive and Active system. Passive systems do not involve panel system or other moving mechanisms to produce energy. Active systems typically involve electrical and mechanical components to capture sunlight and process it into usable forms such as heating, lighting and electricity.[10]

The solar PV panels we will be using in this system includes a 400Wp PV array (panel 1 and panel 2) that can fully charge two 48V,20Ah battery simultaneously from 50% SOC within a day. Two 200Wp PV modules, connected in series, provides power to a 68V DC bus which is then divided and fed in to the two sets of batteries using two 48V, 20A charge controllers. The charge controller is shown in Chapter 3.4. The specifications of the PV modules are:

- Maximum Power: 200 Wp
- Nominal voltage: 34.92V
- Nominal current: 5.70A
- Open circuit voltage: 44.64V

- Short circuit current: 6.2A
- Number of cells: 72
- Weight: 14.5kg
- Dimensions: 1580*808(MM*MM)
- Max system voltage: 600DC
- Power tolerance: +-3%

Fig 3.3: The Solar PV Panels

The PV array in the charging station has been designed to facilitate change in tilt angle in accordance with the changing seasonsthus facilitating higherirradiation power harnessing. From March till August (our last month of the project) the array was tilted at 10° with the ground and at 40° from October till February.

3.2 BATTERY DESCRIPTION

The battery stores the energy produced by the panels that is not immediately required by the load. This stored energy can either be used during the time of low solar irradiance where the current from the panel is not enough to drive the loads, or during night when solar power is unavailable. The common type of batteries used here are ***maintenance-free lead-acid*** batteries. They are 12V, 20Ah sealed, deep cycle lead-acid rechargeable batteries that is popular for use for multiple purpose applications. The batteries use AB plastic shell and valve technology for its protection. It also complies with environmentally friendly requirements. They also usually have long service life-cycle. [11] This type of batteries serves two important purposes in the photovoltaic system: to provide electrical energy generated by the panels whenever the energy is not supplied by the solar panels, and to store excess energy generated but the panels whenever the energy exceeds the load. These batteries does not have the **memory effect**, meaning that there is no need to discharge for the purpose of the recharging the batteries. [11] The batteries in the PV system experience a cyclical process of charging and discharging, depending on the presence, absence or adequacy of sunlight. These cycles of charging and discharging occur whenever the energy produced by the panels does not match the energy required to support the load. If the battery does not store enough energy to meet the demand during the periods without sunlight, the system will be exhausted and will be unavailable for consumption. If however, the system is oversized, that is by adding too many battery units and panels, this will be inefficient and expensive at the same time since there will not be enough loads to consume that energy.

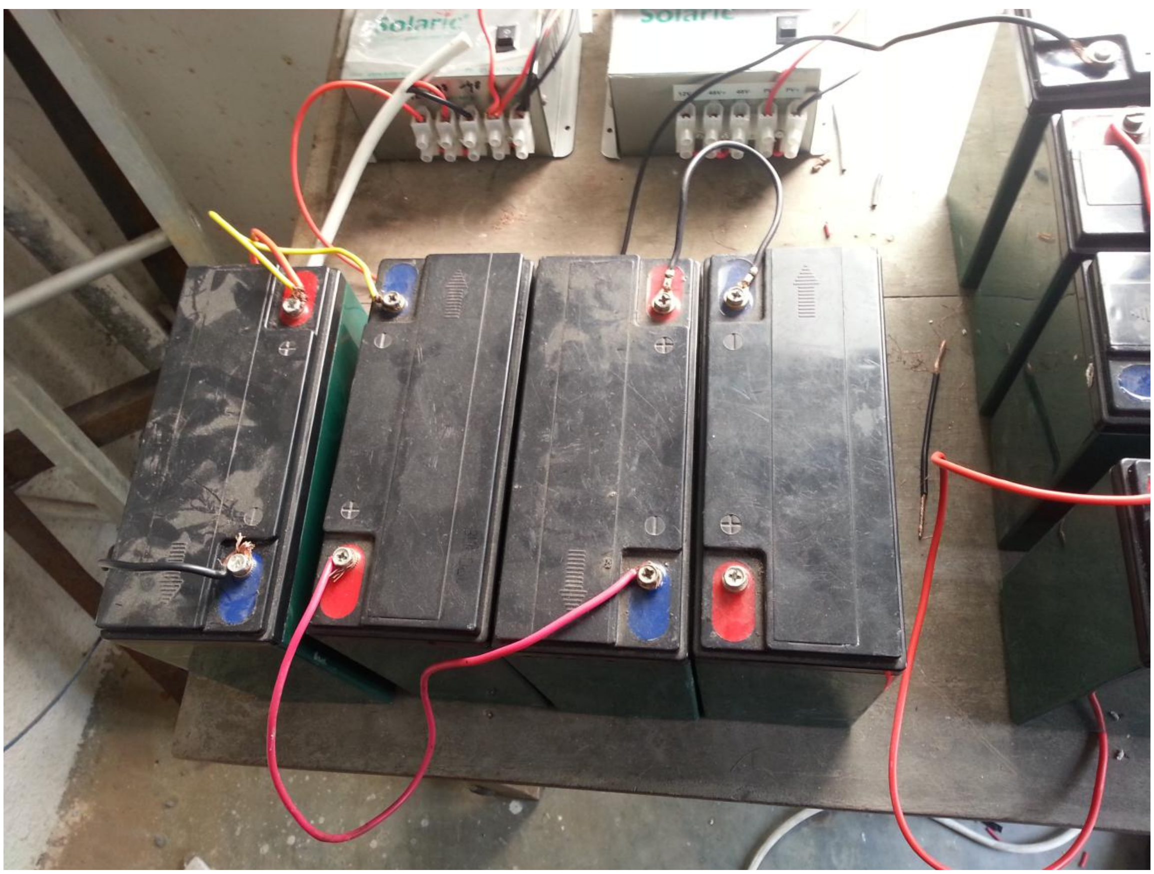

Fig 3.4: The Maintenance-Free Lead-Acid Batteries

3.3 BATTERY STATE OF CHARGE (SoC)

Lead acid batteries are charged in three stages, which are 1). **constant-current charge**, 2). **topping charge** and 3). **float charge**. The *constant-current charge*applies the bulk of the charge and takes up roughly half of the required charge time; the *topping charge* continues at a lower charge current and provides saturation, and the *float charge* compensates for the loss caused by self-discharge. [12]

During the constant-current charge, the battery charges to 70 percent; the remaining 30 percent is filled with the slower topping charge. The topping charge is essential for the well-being of the battery and can be compared to a little rest after a good meal. If deprived, the battery will eventually lose the ability to accept a full charge and the performance will decrease due to sulphation. The float charge in the third stage maintains the battery at full charge. [12]

The chart on the next page represents the state of charge (SoC) against the open circuit battery voltage:

	STATE OF CHARGE				
	V open circuit	V open circuit	V open circuit	V open circuit	specific gravity
charge	6-V battery	12-V battery	24-V bank	48-V bank	per cell
100%	6.37	12.73	25.46	50.92	1.277
90%	6.31	12.62	25.24	50.48	1.258
80%	6.25	12.50	25.00	50.00	1.238
70%	6.19	12.37	24.74	49.48	1.217
60%	6.12	12.24	24.48	48.96	1.195
50%	6.05	12.10	24.20	48.40	1.172
40%	5.98	11.96	23.92	47.84	1.148
30%	5.91	11.81	23.62	47.24	1.124
20%	5.83	11.66	23.32	46.64	1.098
10%	5.75	11.51	23.02	46.04	1.073

Table 3.1: Chart showing the lead-acid battery SoC against open circuit battery voltage [13]

3.4 CHARGE CONTROLLER DESCRIPTION

Fig 3.5: PWM Charge Controller

The purpose of charge controller is to ensure efficient charging of system battery andalso supplying power to the load. PWM (Pulse Width Modulation) help to regulate the often-inconsistent voltage putout by solar panels in order to protect the system batteries from overcharging. Thecharge controller handles the job of battery charging by constantly checking the currentbattery state and self-adjusting accordingly to send only the right amount of charge tothe battery. [2]

In essence, the charge controller works by adjusting the current from the powersource(solar panels) according to the battery's condition and recharging requirements,which is in contrast to on/off charge controllers which suddenly cut off power transferto minimize battery overcharging. According to the ratings of the battery used only anoptimum of 3A current can pass through the battery. With the help of the chargecontroller the current passed through the battery is kept within an optimum range.ThePWM charge controller does this by checking the state of the battery to determine bothhow long (wide) the pulses should be as well as how fast they should come. [2]

With that information, the charge controller then self-adjusts and sends the appropriatepulse to charge the battery – it varies the length and speed of the pulses sent to thebattery as needed. This is essentially a rapid on and off switch. When the battery isnearly discharged, the pulses may be long and continuous, and as it becomes charged,the pulses become shorter or trickled off.

The ratings of the charge controller:

- 48V
- Max current allowed: 20A

3.5 THE AUTOMATED SWITCHING SYSTEM

The purpose of the automated switching system is to eliminate human efforts and errors while switching from the solar power to backup power and vice versa. It will also ensure that excess current is not drawn from the backup power while there is enough irradiance from the solar panel producing sufficient current to charge the batteries. This will not only saves money and save electricity from the already-overloaded national grid, it also ensures the efficient utilization of the solar resources available to us.

For the construction of the switching circuit, we followed one of the simplest concepts using minimal devices possible so that it can be built with the least cost possible. The following simulation was performed using Proteus 7 Professional.

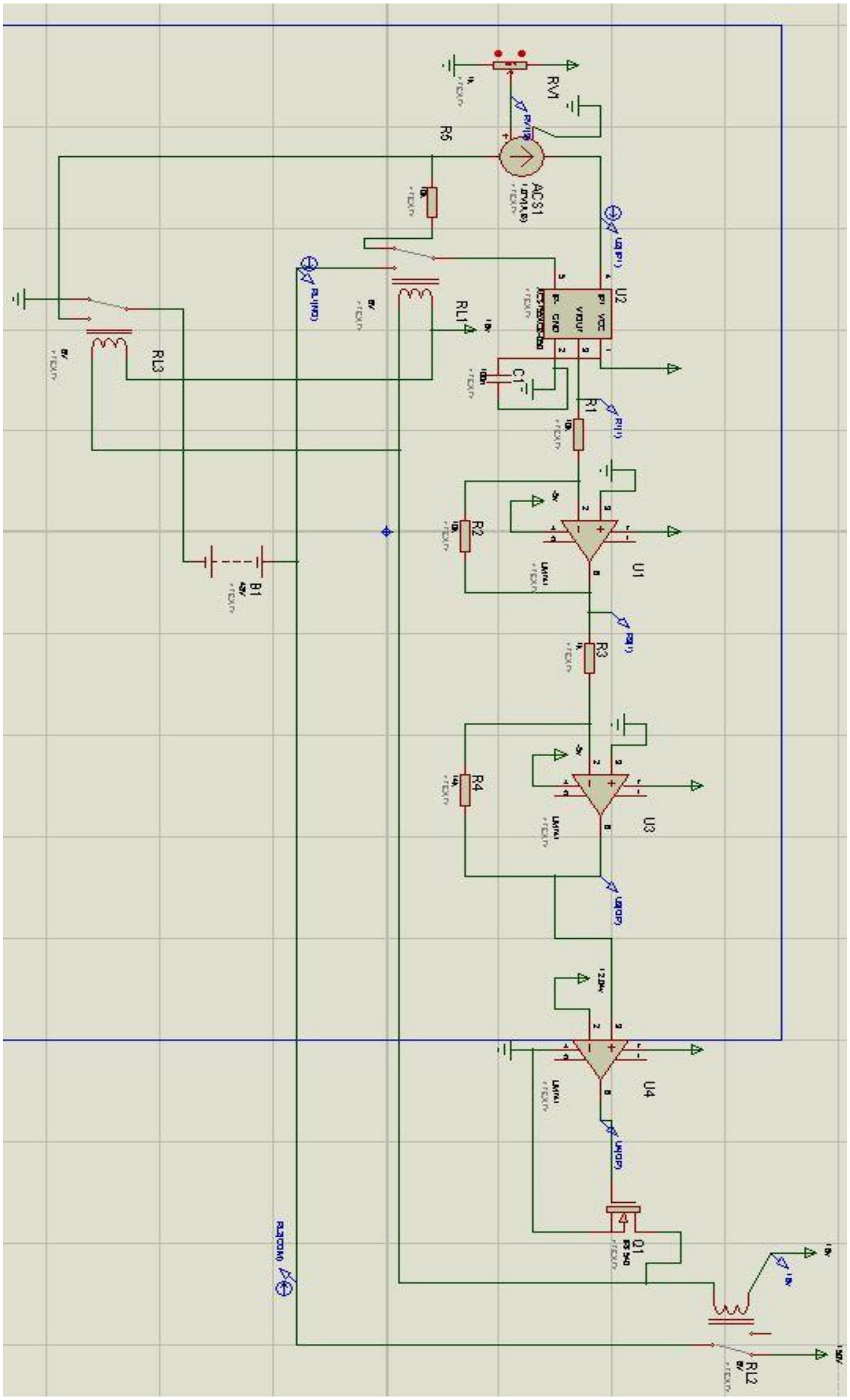

Fig 3.6: Circuit diagram of the Automated Switching System

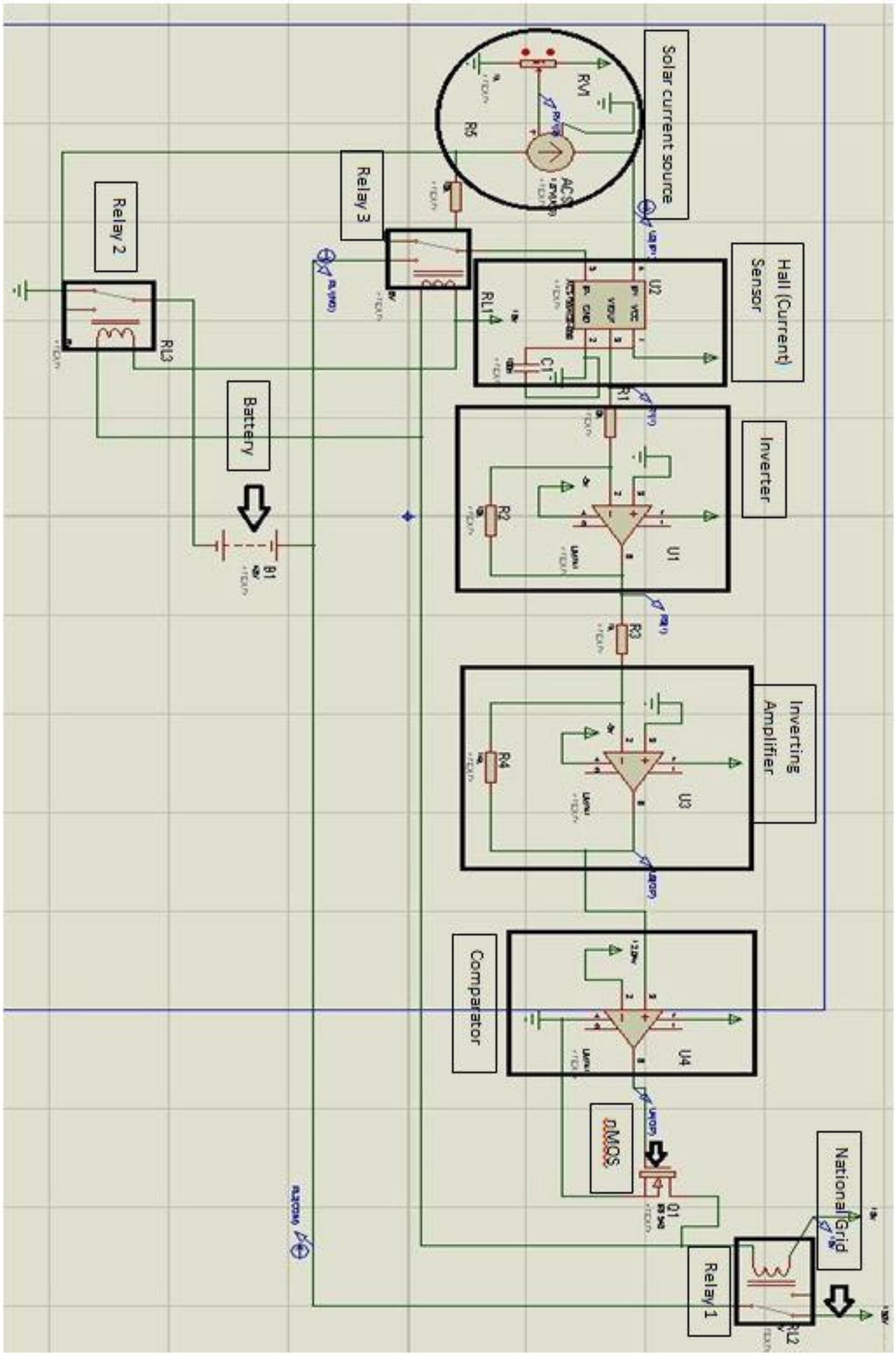

Fig 3.7: Labeled circuit diagram of the Automated Switching System

Components used:

- Hall (current) sensor (ACS755xCB-050) – 1 pc
- Op-Amp (LM741) – 3 pc
- MOSFET (IRF540) – 1 pc
- 6V Relay – 3 pc
- Current source with potentiometer (simulated as solar power)
- Resistors (variable values)
- Capacitor (100nF)

From Fig 3.7, it is seen that the current source, which is simulated as the solar power source, is connected to the current sensor that outputs a voltage corresponding to a preset amount of current value. However, the voltage output is so small that it does not have enough increment steps for proper comparison of voltage in a comparator. Hence this voltage was needed to be amplified. So a scale-and-shift circuit was introduced in the design which consists of two main component sets, an inverter and an inverting amplifier. The amplification ratio of the input and the output voltage is set at 14 (fourteen) for the purpose of setting the optimum set voltage for the negative pin of the comparator. The output voltages at the end of the inverter and the inverting amplifier are calculated by $V_{out}=V_{in}(-R_F/R_I)$ where $R_F/R_I=1$ for the inverter and 14 for the inverting amplifier.

As the output voltage is fed from the scale-and-shift circuit to the comparator, it will compare that voltage with that of the preset voltage given in the negative pin of the comparator. If the input voltage is high, the output of the comparator will be HIGH which will switch ON the nMOS switch and in turn will also switch ON Relay 1 and hence connect the batteries with the national grid. It will also turn Relay 2 and Relay 3 to NORMALLY ON position and hence the battery will be disconnected from the solar power. If the output of the comparator is LOW, it will turn OFF the nMOS switch and in turn will also switch OFF Relay 1 and hence disconnect the batteries from the national grid. It will now turn Relay 2 and Relay 3 to NORMALLY OFF position which will connect the batteries with the current source (solar power).

For our simulation purpose, the comparator negative voltage was set to 2.04V because this was the voltage that was corresponding the current of 2.5A coming from the current source. The positive voltage was compared with this preset voltage for different ranges of current values coming from the current source. The condition for switching the relay switch was set as follows:

- Relay 1, 2 and 3 will be set to NORMALLY ON position when current form the current source, I>=2.5A. In this condition, the batteries will be charged by the solar power ONLY. The scenario is shown in fig 3.8b
- Relay 1, 2 and 3 will be set to NORMALLY OFF position when current form the current source, I<2.5A. In this condition, the batteries will be charged by the national grid ONLY. The scenario is shown in fig 3.8a

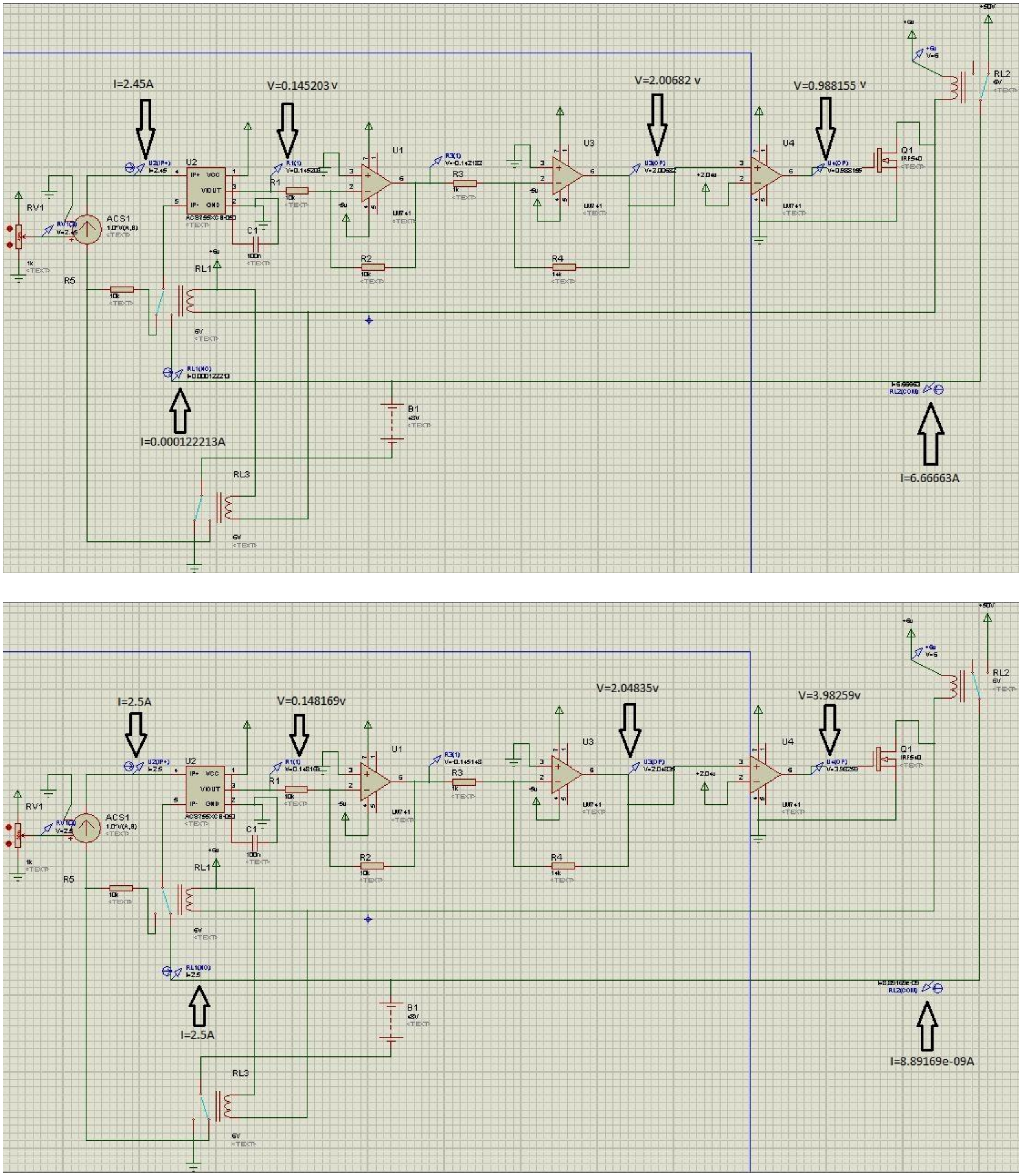

Fig 3.8: The switching mechanism when connected to

a) national grid, b) solar panels

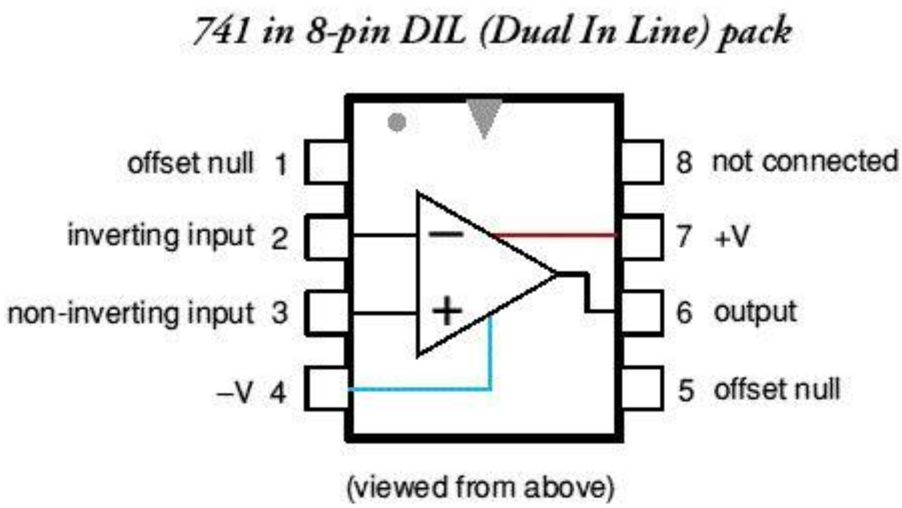

Fig 3.9: PIN diagram of LM741 Op-Amp

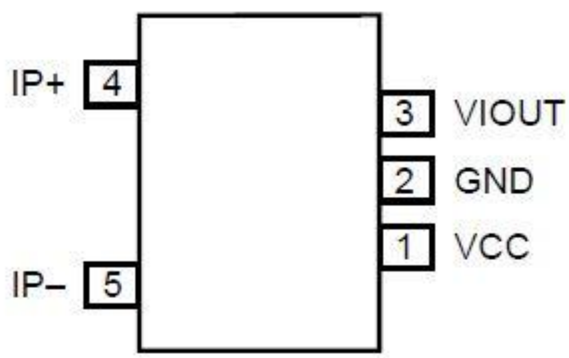

Fig 3.10: PIN diagram of ACS755xCB-050 Hall sensor

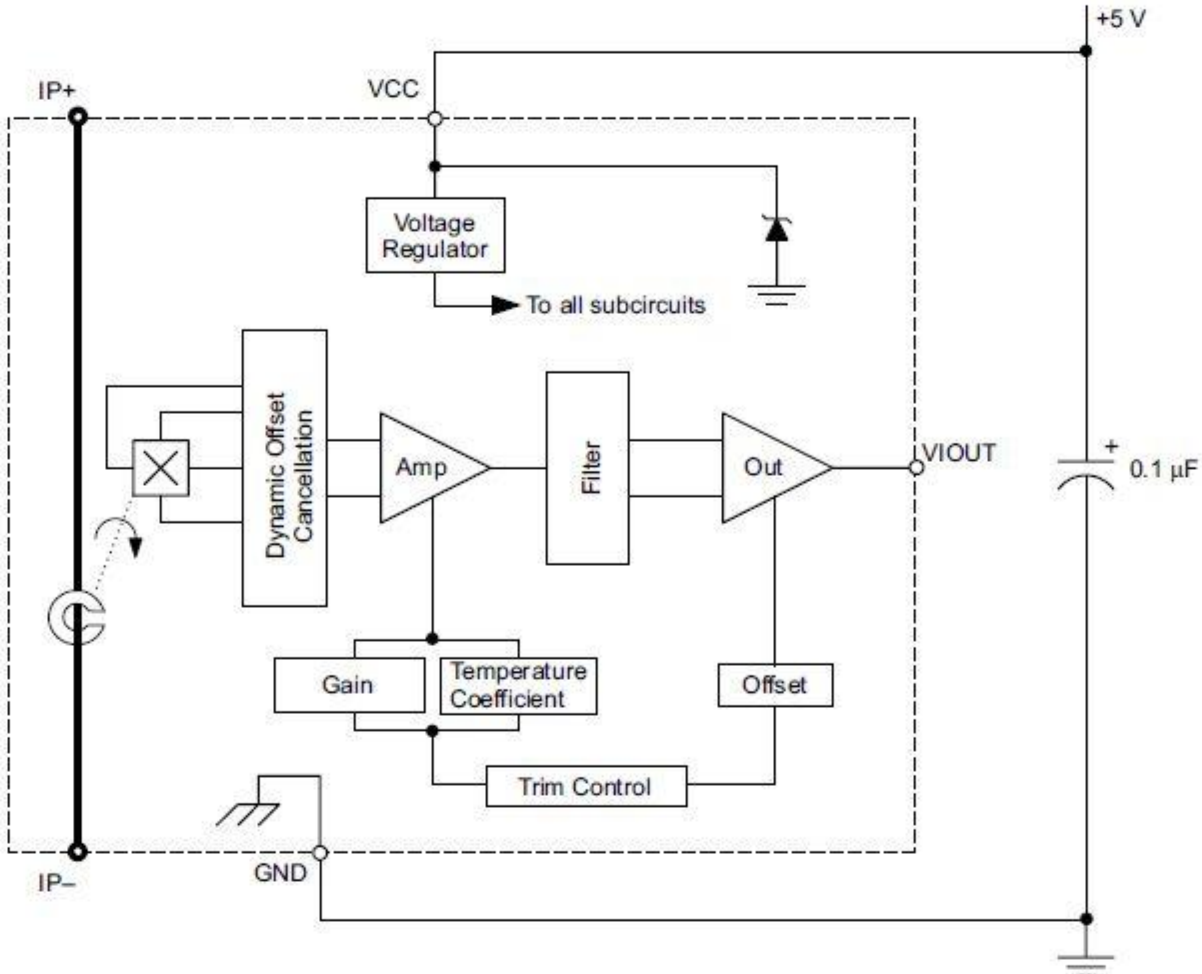

Fig 3.11: Internal circuit diagram of the ACS755xCB-050 Hall sensor

CHAPTER 4: TEST RESULTS AND ANALYSIS

For the purpose of our field tests, we used the tilt factor charts of SWERA-Bangladesh [14] so that the tile angle of the solar panel can be varied to obtain maximum irradiance possible. For that during the Winter season (October to February) the tilt angle was 40° whereas during the Summer season (March to September) the tilt angle was 10°. To determine how much advantage can be gained by changing the tilt angle, the following charts were used:

Hour angle	±7.5		±22.5		±37.5		±52.5		±67.5		±82.5		±97.5	
Month \Tilt	23°	10° & 40°	23°	10° & 40°	23°	10° & 40°	23°	10° & 40°	23°	10° & 40°	23°	10° & 40°	23°	10° & 40°
Jan	1.14	1.17	1.15	1.17	1.16	1.19	1.17	1.21	1.20	1.26	1.37	1.54		
Feb	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.17	1.21	1.29		
Mar	1.05	1.04	1.05	1.04	1.05	1.03	1.04	1.03	1.02	1.02	1.00	1.01		
Apr	0.99	1.01	0.99	1.01	0.98	1.01	0.97	1.00	0.95	0.99	0.93	0.98	0.95	0.99
May	0.96	1.00	0.96	1.00	0.95	0.99	0.93	0.98	0.91	0.97	0.89	0.96	0.97	1.00
Jun	0.95	0.99	0.95	0.99	0.94	0.99	0.92	0.98	0.90	0.97	0.88	0.96	0.78	1.92
Jul	0.95	0.99	0.95	0.99	0.94	0.99	0.92	0.98	0.89	0.97	0.86	0.95	0.76	0.91
Aug	0.97	1.00	0.97	1.00	0.96	1.0	0.95	0.99	0.93	0.98	0.89	0.97	0.82	0.93
Sep	1.00	1.01	1.00	1.01	1.00	1.01	0.99	1.01	0.98	1.00	0.96	0.99	0.70	0.88
Oct	1.06	1.04	1.07	1.04	1.08	1.06	1.08	1.07	1.08	1.07	1.13	1.16		
Nov	1.17	1.20	1.17	1.20	1.19	1.24	1.22	1.28	1.27	1.38	1.62	1.93		
Dec	1.19	1.26	1.21	1.26	1.23	1.29	1.26	1.36	1.36	1.52	1.53	1.79		

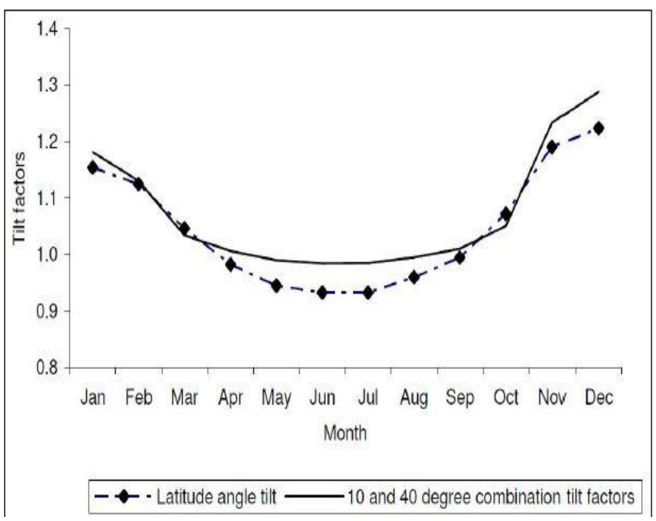

Fig 4.1: Comparison of tilt factors for tilt angle 10° and 40° angle combinations

Fig 4.2: Short circuit current and irradiance for tilt angles a) 10°, b) 23° and c) 40°

From the figure it can be verified that a higher tilt angle leads tobetter output of the PV array as the sun is at a lesser elevation in the winter. It can beseen that the incident irradiation on the PV module more than doubles for the 40° tilt anglein contrast of that for the 10° tilt angle. It can also be seen that the short circuit current(short circuit current of a PV module is directly proportional to the incident irradiationon the PV module) of the PV module increases by about 1.2A for the 40° tilt angle.Similarly for the other months (e.g. Summer season), 10° tilt angle yields better result than 40° due to thehigher tilt factors.

Testing and Analysis

In this section, a description and comparison is given between our obtained results in two different seasons of the year; summer and rainy season. For summer we conducted the test in the month of June and for winter season it was conducted at the end of February. The test was conducted to see how much two 48V battery banks can be charged using our prototype on a single day.

Fig 4.3: Readings taken from the field

Time	Voltage			Current			Amp-Hour	
	Panel	Battery Set 1	Battery Set 2	Panel	Battery Set 1	Battery Set 2	Battery Set 1	Battery Set 2
OC		48.8	48.6					
0	50.2	50.0	50.1	2.48	0.67	1.81		
15	51.3	50.4	50.9	2.75	0.56	2.19		
30	51.9	50.7	50.9	2.40	0.73	1.67		
45	51.8	51.1	51.2	3.48	1.12	2.36		
60	53.0	51.2	51.4	3.69	1.27	2.42	0.870	2.090
75	53.3	51.3	51.6	3.77	1.42	2.35		
90	51.5	51.1	51.0	1.34	0.49	0.85		
105	52.4	51.4	52.4	4.26	1.75	2.51		
120	52.4	51.4	52.0	3.90	1.63	2.27	2.182	4.170
135	52.6	52.1	52.5	2.04	0.83	1.21		
150	52.5	51.7	52.6	3.60	1.58	2.02		
165	52.6	51.7	52.4	3.35	1.58	1.77		
180	52.3	51.6	52.1	1.72	0.74	0.98	3.454	5.820
195	53.4	52.2	52.8	3.09	1.35	1.74		
210	53.4	52.0	52.6	2.79	1.20	1.59		
225	53.4	52.2	52.7	2.43	1.05	1.38		
240	53.4	52.3	53.1	2.36	1.03	1.33	4.528	7.224
255	53.5	52.6	53.0	2.13	0.96	1.17		
270	53.5	52.6	53.1	2.13	0.88	1.25		
285	53.3	53.0	53.6	2.67	1.16	1.51		
300	54.0	52.4	53.3	2.53	1.09	1.44	5.552	8.564
315	53.8	52.4	53.4	2.09	0.99	1.1		
330	53.4	52.6	52.9	1.21	0.56	0.65		
345	53.5	52.5	53.0	1.40	0.65	0.75		
360	53.5	52.5	52.8	1.00	0.46	0.54	6.302	9.460
375	53.9	52.7	53.0	1.19	0.58	0.61		
390	53.9	52.7	53.3	1.50	0.70	0.8		
405	53.6	52.7	53.2	1.05	0.48	0.57		
420	53.0	52.7	52.7	0.96	0.43	0.53	6.832	10.070
435	53.9	52.8	53.0	1.00	0.43	0.57		
450	53.0	52.6	53.2	0.72	0.31	0.41		
465	53.5	52.7	52.9	0.75	0.31	0.44	7.110	10.436
OC (after 15 mins)		51.4	51.6					

Table 4.1: Charging Profile for Summer season

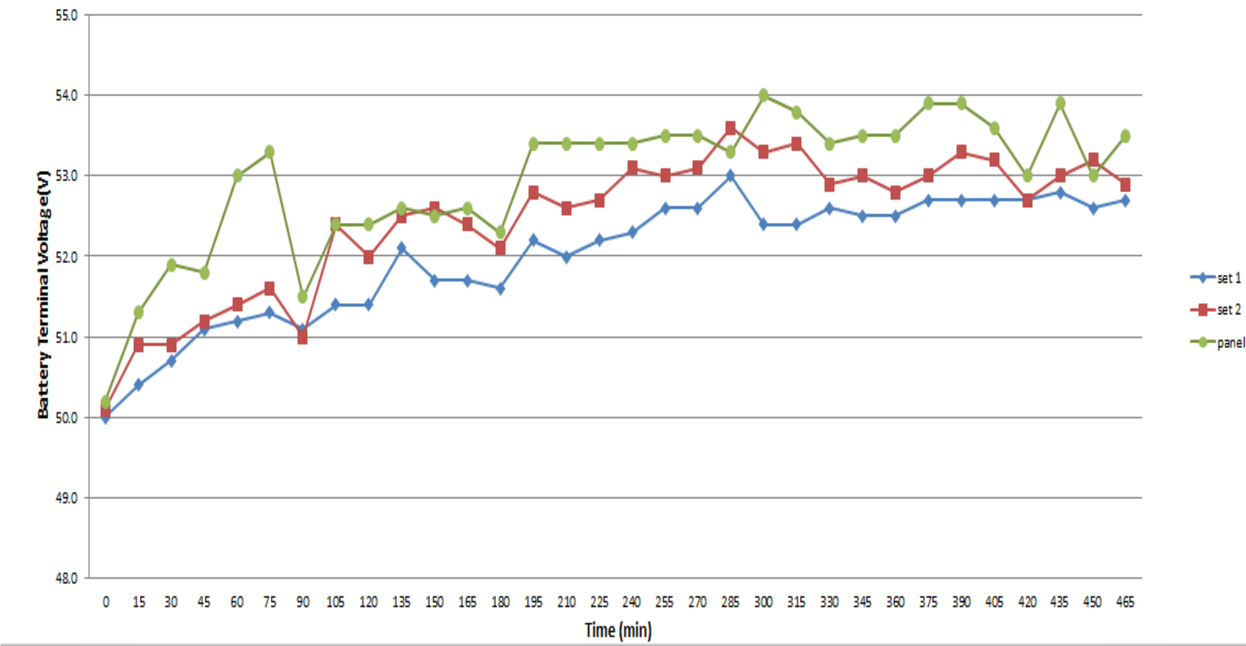

Fig 4.4: Voltage vs. Time Graph for the Summer Charging Profile

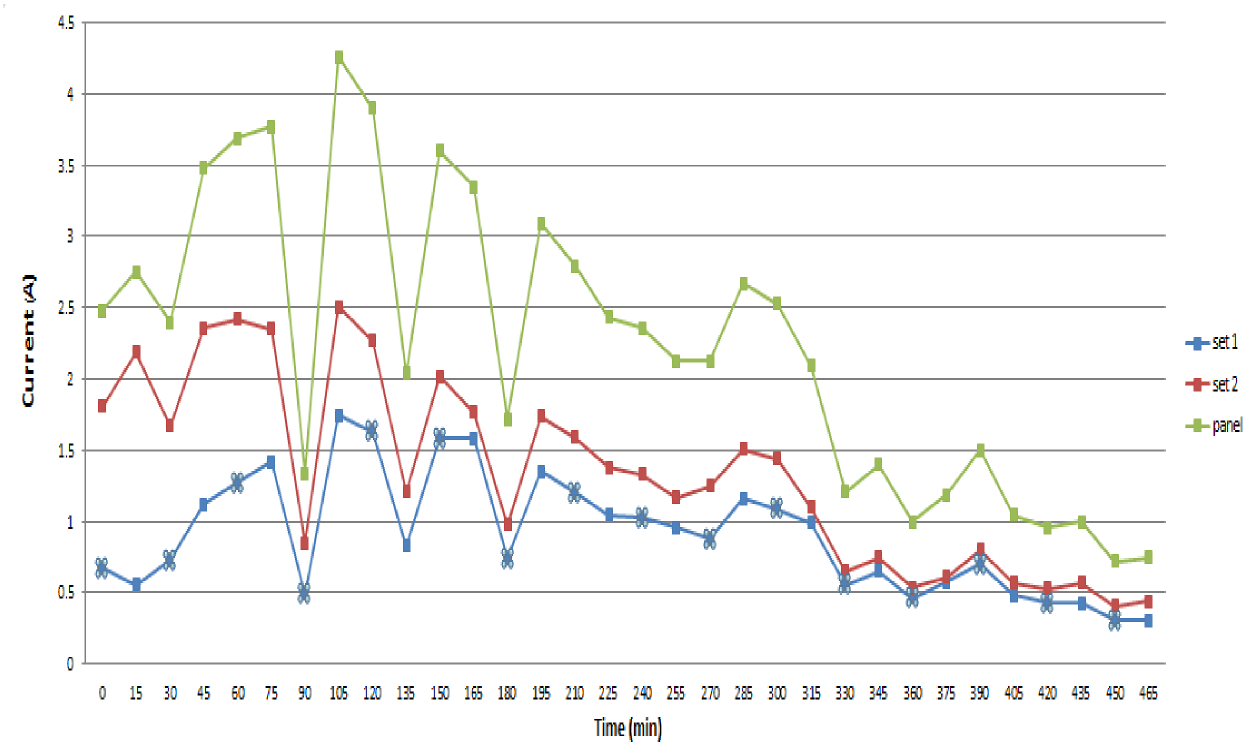

Fig 4.5: Current vs. Time Graph for the Summer Charging Profile

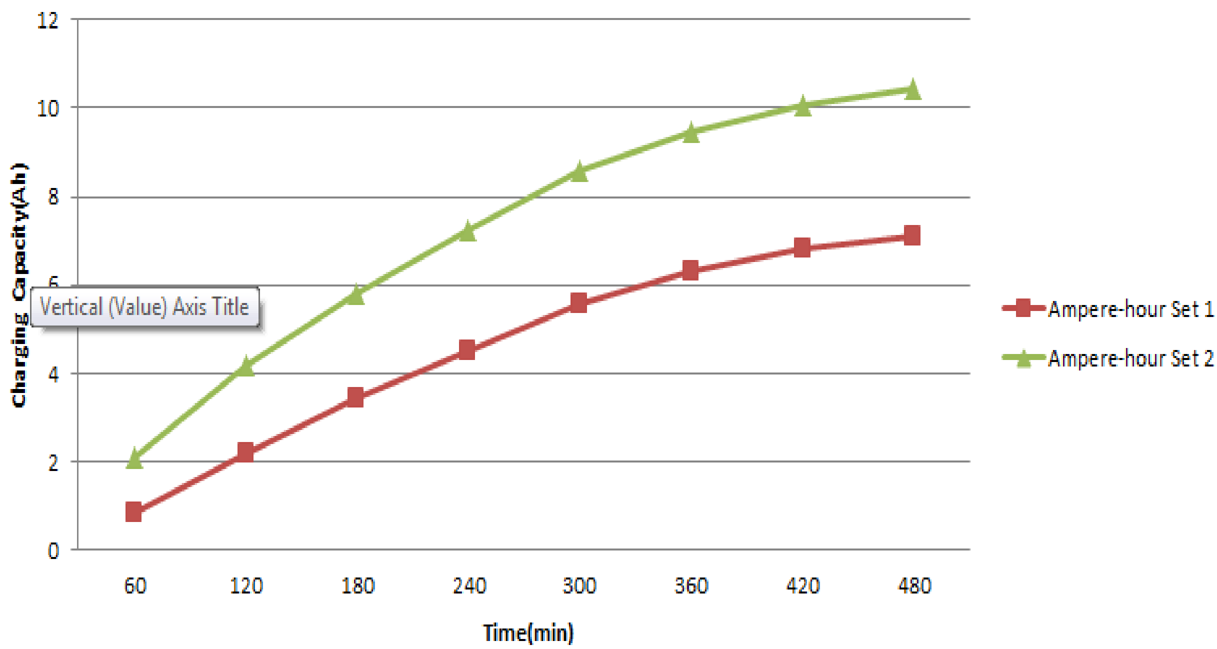

Fig 4.6: Ampere-Hour vs. Time Scatter-Plot for the Summer Charging Profile

The charging was started at 9:30 AM. As seen in fig 4.5, it is seen that as time increases up to 11:30 AM the current from the panels gradually increase and the peak current was found to be 90 minutes from the starting time that was 4.26A, which is at 11 AM. After that the current gradually decreases and goes to less than 1A 420 minutes after the test started, which is at 3:30 PM. As time progresses, the battery gets charged gradually which is shown in fig 4.4 by the gradual increase in battery voltage for both set of batteries. It is also seen that the rate of voltage increase drops after 300 minutes from the start of the test, which is consistent with the lesser current drawn from the solar panel as seen in the previous graph in fig 4.5. The battery charge status is shown in figure 4.6 which shows that the battery set 2 is getting more charged than battery set 1, which is consistent with current being drawn more by set 2.

	VOLTAGE			CURRENT			Ampere Hours (Ah)	
Time	Panel Voltage (V)	Battery Set 1(V)	Battery Set 2(V)	Panel Current(A)	Battery Set 1(A)	Battery Set 2(A)	Set 1	Set 2
OC	65.5	48.2	47.8					
0	51.6	49.1	48.8	3.89	2.23	1.66		
15	52.5	49.7	49.6	4.03	1.68	2.35		
30	53.1	49.8	50.2	3.99	1.54	2.45		
45	53.2	50.2	50.4	3.95	1.85	2.1		
60	53.2	50.3	50.6	3.77	1.84	1.93	1.825	2.14
75	53.4	50.3	50.7	3.53	1.5	2.03		
90	53.6	50.3	51	3.59	1.39	2.2		
105	51.4	50.3	50.6	3.19	1.71	1.48		
120	53.7	50.5	51.2	3.77	1.47	2.3	3.44	4.05
135	51.7	50.5	50.4	2.39	1.38	1.01		
150	54.4	50.6	51.6	3.55	1.31	2.24		
165	53.6	50.6	51.4	2.82	1.51	1.31		
180	52.6	50.8	51	2.42	1.27	1.15	4.86	5.77
195	52.9	50.9	51	2.49	1.28	1.21		
210	53.3	51	51.4	2.35	1.29	1.06		
225	52.9	51.1	51.2	2	1.21	0.79		
240	52.7	51.2	51.2	1.83	1.14	0.69	6.12	6.82
255	52.3	51.1	51.1	1.34	0.89	0.45		
270	52.1	51.1	51.1	1.13	0.76	0.37		
285	51.9	50.9	51	0.84	0.59	0.25	6.97	7.26

Table 4.2: Charging Profile for Winter season

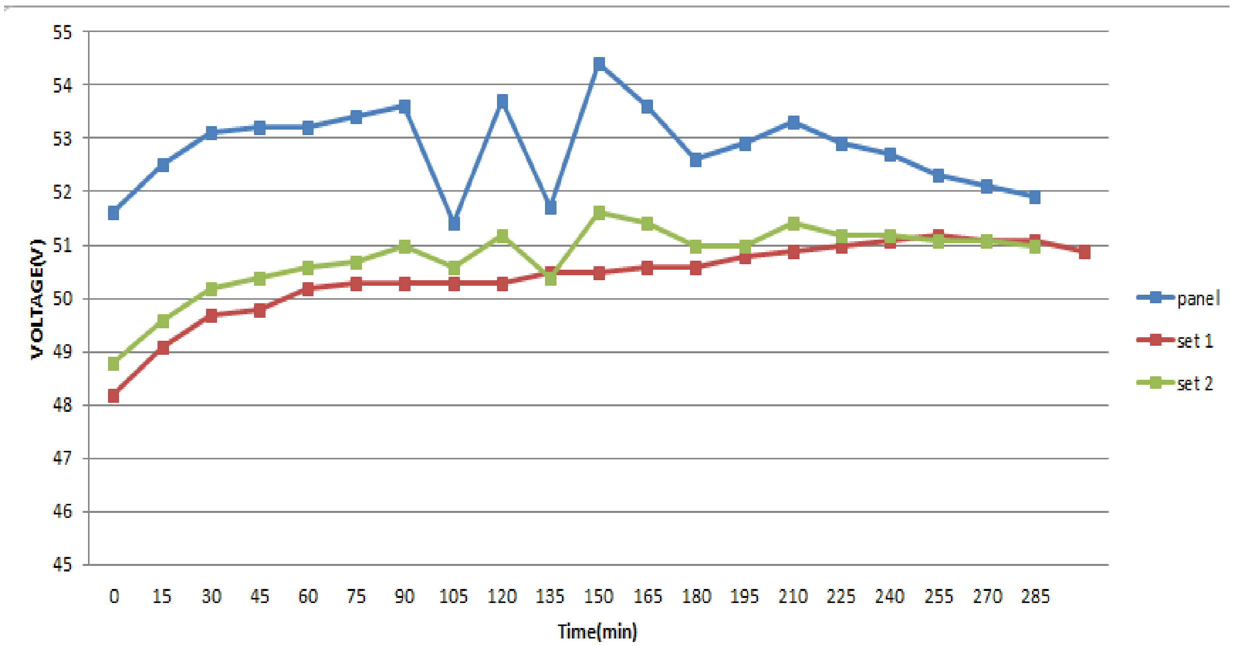

Fig 4.7: Voltage vs. Time Graph for the Winter season Charging Profile

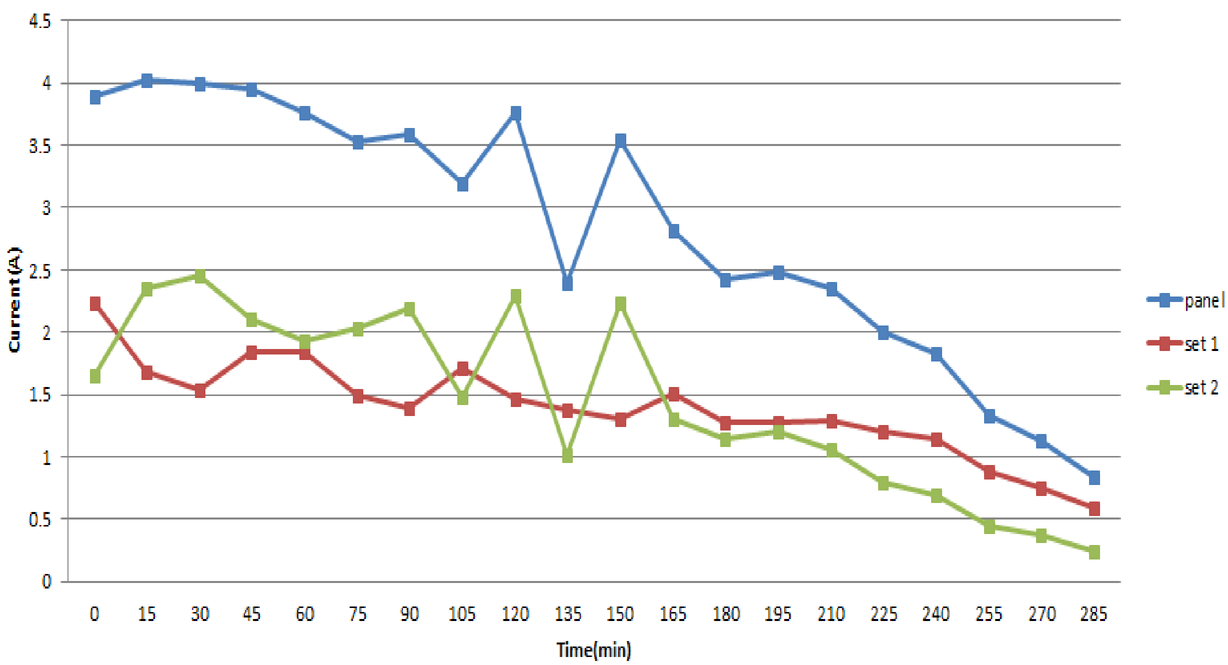

Fig 4.8: Current vs. Time Graph for the Winter season Charging Profile

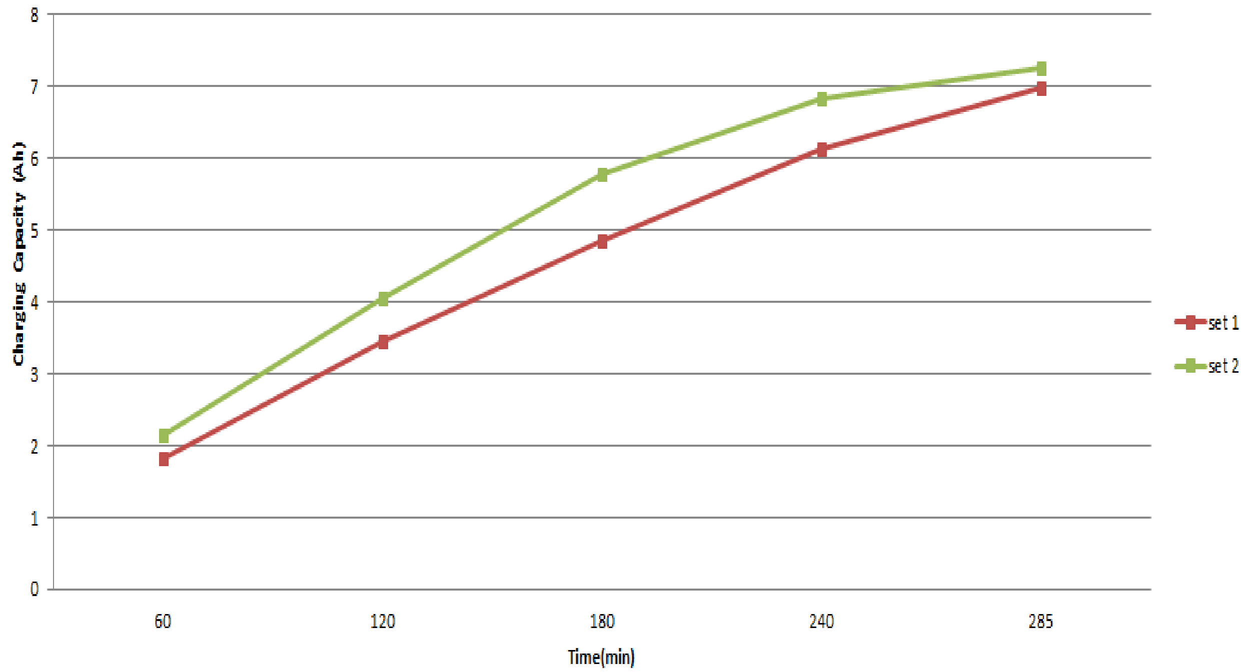

Fig 4.9: Ampere-Hour vs. Time Scatter-Plot for the Winter season Charging Profile

The charging was started at 11:00 AM. As seen in fig 4.8, it is seen that as time increases up to 1:30 PM, that is 150 minutes from the starting time, the current from the panels remains more or less equal and the peak current was found to be 30 minutes from the starting time, which is at 11:30 AM. After 1:30 PM the current gradually decreases for the last 135 minutes and goes to less than 1A which is at 3:45 PM. During the whole charging process the battery set 2 draws a little bit more current than battery set 1. As time progresses, the battery gets charged gradually which is shown in fig 4.7 by the gradual increase in battery voltage for both set of batteries. The battery charge status is shown in figure 4.9 which shows that the battery set 2 getting a little bit more charged than battery set 1, which is consistent with current being drawn more by set 2.

CHAPTER 5: CONCLUSION AND FUTURE WORKS

5.1 CONCLUSION AND SUCCESS OF THE PROJECT

Dhaka is one of the densely populated cities in the world and hence the availability of land within the heart of the city will be very scarce. Hence for the purpose of building the SBCS in a large scale, the outskirts of Dhaka city is the perfect place, for example, Keraniganj, Gazipur, Savar etc. In this scenario, a rickshaw operator would go to local service stations, where hisdischarged batteries would be swapped with fully chargedbatteries. The fully charged batteries would be brought from anoff-site recharging station, which will be built in the city outskirts, to the service stations inside the city, as shown in Fig. 5.1. [15] For the rural areas, since the availability of land is not a major problem, this chain transport system is not required.

Fig 5.1: Possible infrastructure of SBCS

By conducting some tests and analysis on the results obtained from the station we used for the project, we came to some significant beneficial findings. From our result data it is found that it is possible to save (7.13+10.45) x 48 = 803.84Wh or 0.80kWh of electricity from the national grid every time the battery banks are charged. It is possible to save more if it is implemented in a larger scale. For example, charging 20000 battery banks would take approx. 10MW of electricity from the national grid, approx. 1% of the total electricity demand in Dhaka city.[4] Hence it can be deduced clearly that if this project is implemented in a larger scale, this will prove to be a huge contributor of the savings of electricity in major cities like Dhaka and as a result, will improve the load-shedding conditions more.

In addition to that, the Automated Switching System makes sure that the human involvement in the process of switching between solar power and national grid power for charging batteries in SBCS is eliminated, which might involve human errors and higher labour costs overall. It also saves valuable human time involved in the system because of manual inspection and replaces it with automation, which will result in a more efficient system and the saved human time to some other useful stage of works related to the SBCS.

5.2 FUTURE WORKS

Fig 5.2: A Normal Tri-Wheeler Van

Fig 5.3: Tri-Wheeler Van with PV support

Fig 5.4: Battery and Motor of the Tri-Wheeler Van

Based on the success of the project results of SBCS with Automated Switching System, a pilot project is planned as shown in the figures above and the previous page. Fig 5.2 shows a normal tri-wheeler van that is mainly used as a transport to carry school children to and from their schools. However, if their design is modified a little bit to accommodate normal passengers; they can be a very good alternative to rickshaws and can replace them effectively. Since it is widely regarded that conventional rickshaws are one of the main reasons of the traffic jam issue in Dhaka city and all the other metropolitan cities, the replacement can potentially have a huge improvement on the traffic jam situation. The possibility of replacing rickshaws is aided by the fact that it can have the route flexibility of the rickshaws. It also makes the transport fares cheaper since it can carry more passengers at once compared to conventional rickshaws. With the development of the technologies getting faster, the rickshaws will be easier to pull, which will be highly helpful for old or disabled rickshaw pullers.

Fig 5.5: “Ambulance” van used in remote parts of the village

In the rural areas, the tri-wheelers shown in Fig 5.5 are used as ambulances because the roads are not wide and good enough for a conventional ambulance to run on these roads. Since they are muscle-pulled vehicles, this might be a problem to patients who might need medical attention fast. However if these vehicles can be made electricity-driven, not only the service be faster, it will also lessen the efforts of the driver.

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