DESIGN AND DEVELOPMENT OF AN EFFICIENT CHARGING SYSTEM FOR THE BATTERY OPERATED VEHICLES IN BANGLADESH

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*I hereby declare that this thesis titled "**Design and Development of an Efficient Charging System for the Battery Operated Vehicles in Bangladesh**" is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis. This thesis has also not been submitted for any degree in any university previously.*

MD REZAUL AWAL
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ABSTRACT

In this research work, an inclusive study has been carried out on the effect of Battery operated Electric Three Wheelers locally called ‘Easy-bike’ on the Bangladesh national power grid. Easy-bike has become a widely used para-transport in urban transportation system of Bangladesh. These vehicles were first commercially introduced in 2004. Since then, there has been an increase in large numbers and now the number has raised to 1 million. Their power consumption has been significant and poses impact to the electricity generation and daily load profile which is a matter of concern for the power sector. Effective charging system and management should address the issue. Very few works has been reported in literature on this issue. Because of the large number of this vehicles even a small amount of improvement of the charger efficiency should have a huge impact on power grid. Necessary data was collected and analyzed here for the evaluation of the effect. The results of the analysis verified that, over the course of the last eleven years, after the deployment of the Easy-bike, the electricity generation at peak hours has been significantly shifted. A huge load was consistently observed over night including peak hour. The represented results indicate that this extra consumption is mostly due to the integration of a dominant load like Easy-bike charging. A survey was also carried out for an in-depth analysis of the effects of Easy-bikes. Various important technical facts and problems of Easy-bike battery and its charging system were discussed. Currently the charging procedure is found to be uncontrolled, and no safety measures are taken for overcharging conditions. An efficient microcontroller based charger has been designed to eradicate the problem found in existing charger, to save energy, as well as to reduce charging time to manage load during peak hour. The charger was constructed and tested in the laboratory. The experimental data proved that there are large scopes of energy saving in this modified charging system. A timer controlled charging circuit has also been proposed to reduce load from peak hour. Effective introduction of the designed circuit and the load management would result in a large power and peak demand shaving for Bangladesh power grid.

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LIST OF SYMBOLS & ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
AVR	Auto Voltage Regulator
BERC	Bangladesh Energy Regulatory Commission
BPDB	Bangladesh Power Deve;opement Board
BRTA	Bangladesh Road Transport Authority
CC	Constant Current
CV	Constant Voltage
DC	Direct Current
DOD	Depth of Discharge
DSM	Demand Side Management
DSP	Digital Signal Processor
ETW	Electric Three Wheeler
EV	Electric Vehicle
HEV	Hybrid Electric Vehicles
MATLAB	Matrix Laboratory
PHEV	Plug-in Hybrid Electric Vehicles
SOC	State of Charge
UPS	Uninterrupted Power Supply
VFPCS	Variable Frequency Pulse Charge System

CHAPTER 1

INTRODUCTION

1.1. Introduction

Hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) are being introduced as the new technologies to replace the internal combustion engine vehicles which are major sources of green-house gases leading to global warming [1]. In Bangladesh, around 70% of the cars imported are HEVs since 2017 but the import of PHEVs and BEVs are significantly lower [2]. However, Electric Three Wheelers (ETWs) such as 'Easy-bikes' or motorized rickshaws can be considered as electric vehicles (EVs) since they are battery operated and needs to be connected to the grid for charging. ETWs are increasing in number rapidly with an estimated amount of 1 million Easy Bikes and 240,000 motorized rickshaws present as of 2018 [3]. They are usually charged overnight and require a large amount of electrical power to charge. With the increase in the use of Easy-bikes and mass penetration in the market there has been a rising concern over the impact of charging on the electrical grid of Bangladesh. These electric vehicles are equipped with five 12 V Lead-acid batteries of different sizes depending on the type of the vehicle. These vehicles are connected for charging by the means of power electronic controllers but in an uncontrolled way. No specific measures are taken to ensure whether the vehicles are appropriately charged or not. There has been a significant negative effect on the daily load curve of Bangladesh and the effect is becoming more prominent day by day. There have also been concerns regarding the quality of the charger and the effect on the power quality and the several environmental concerns associated. The Government of Bangladesh has recently published a policy regarding the charging tariff of Easy-bikes but firm policies to control the deployment and usages are yet to be decided [4]. Though the various socio-economic factors and environmental effects have been documented, there has been no reported work on the effect on the grid and the distribution network [5]–[8].

Traditional charging methods either use constant current or constant voltage to charge the battery, or mix these two schemes. However, these methods may suffer from low charge efficiency, over-charge, or long charge time, etc. A well optimized charging process usually requires a complex control circuitry, such as microprocessors, DSP chips or other power electronics controllers [9]. An efficient battery charger requires a charge controller whose main function is to keep the batteries properly charged and safe for the long term and prevent it from deep discharging [10]. Battery can only be charged by a pulse current at a safe value rate determined by the differential voltage. Constant current charging requires maintaining the current at a fixed value throughout the charging process with the advantage that it requires lesser time compared to constant voltage charging which achieved by maintaining the voltage at a fixed value. The combination methods is used to overcome the disadvantages of both methods such that charging starts with constant current and when the emission of gas starts it continues with constant voltage. The voltage of a lead acid battery rises when charged. When a charge current is applied to the battery through a charge controller circuit, the internal resistance of the battery resists the current flow leading to increase in the battery voltage. The voltage rises sharply as the battery begins to gas towards the end of charge. If gassing is left to continue for a long period of time, the battery will overcharge, thereby resulting in accelerated corrosion of the battery electrodes, loss of electrolyte and physical damage of the electrodes. Gassing also called electrolysis is the decomposition of the liquid water into hydrogen and oxygen gasses. In the meantime a huge amount of energy is wasted creating pressure to the power grid. Battery chargers used for charging the batteries of Easy-bike with constant current method in uncontrolled and poses the similar problems mentioned above. A microcontroller based battery charger has been developed to overcame the challenges that automatically cut-off the charging voltage and maintain a float charge using tickle charge method when the battery is fully charged even where the user forgets to manually stop the charging process.

In this research, the impact on Bangladesh national power grid due to energy requirements of an increased number of EVs over the last fifteen years has been analyzed and generation data has been evaluated. The results of the study of the effects of EV deployment on existing power distribution networks have been presented. A field survey at different cities of Bangladesh has been carried out by the authors to investigate the energy usage pattern, problems related to charging in the charging station and problems concerning the existing charger. The analysis of the survey, the results of the study of the effects of EVs on national grid has been taken as input of the research to develop a viable charging system with microcontroller based charging control system and the technique to manage these load with timer control mechanism.

1.2. Present State of Problem

There are around 1 million battery operated electric vehicle (Easy-bike) plying in our country. These electric vehicles are equipped with five batteries of different sizes depending on the type of the vehicle, which needs to be connected to the grid for charging. Lead-acid batteries are used as the energy storage device and over 1.9 million batteries are used all over the country every year [11]. Average power consumption of a battery-operated Easy-bike is about 8 - 11 kWh per day [12]–[14]. Thus it consumes approximately 11 GWh of electricity every day for charging their batteries, which is a huge amount as far as total electric energy is concerned. It is assumed that there has been a significant shift in peak load due to the huge charging power consumption of EV. These vehicles are interfaced to the grid as active loads in an uncontrolled way. No specific measures are taken to ensure the vehicles to be appropriately connected to the electric power grid. Thus, their power consumption has a significant impact on electricity generation and daily load profile which is a matter of concern for the national power grid and the power sector.

The market available chargers are mainly Chinese manufactured and consists of a step down transformer with multiple taps for voltage adjustment. A knob on the front side allows the user to select a charging current by adjusting the turn ratio. These chargers possess various operational hazards, both for the power system and also for the environment. But still they are being continuously used due to economic advantage. The existing system follows the 'Constant Voltage' charging topology. For a particular selection of the knob, the turn ratio becomes constant so the change in supply voltage or the battery voltage changes the charging voltage and current. In the case of Easy-bikes in Bangladesh, the vehicle owners keep the knob at the highest point (15 Amp RMS) and do not change it later. The system does not have any self-control or feedback mechanism; therefore the batteries continue to consume more power even after the charging is completed. The overcharging wastes a lot of energy since after the charge is completed it uses energy from the grid to create gassing [15]. This has a very adverse effect for the electricity sector of Bangladesh. Moreover, the chargers are connected to the grid from 7 pm and continue till 8 am next day for 8 to 12 hours, thus taking valuable energy from the grid during peak hour. This is another concern for the power sector, thus need attention to address the problem.

1.3. Previous Research, Shortcomings and Motivation

1.3.1. Previous research

Many researchers have been reported on EV, Battery charging and renewable energy concerning performance, socio-economic effect etc. Recently a research study has been performed by Mahinur et al. assessing the social, economic and environmental impacts of battery operated auto rickshaw in Khulna city [16]. M. Iqbal et al. at his research tried to show the economic conditions which ultimately influence the income of auto-rickshaw and motor rickshaw drivers [11]. This research paper also focused on the monthly income, profit & investment of both Easy-bike & rickshaw drivers. Similar study has been done by S. Mandal et al. in Rajshahi city [13]. Another study has been performed by Mustafizur et al. aiming at developing a sparedsheet-based techno-economic model to estimate the cost of charging of Easy-bikes using solar energy. The model also calculates the mitigation of green house gas emissions [17].

The lead acid batteries used by electric vehicles have always presented the problem of low efficiency and high loss. In order to promote the popularization and application of electric vehicles, many researchers have put forward the fast charging method of battery. Based on this understanding, the fast charging principle of battery was analyzed by Yuanpeng et al [18]. The depolarization pulse fast charging method and the high current decline fast charging method were also studied, so as to provide reference for the people interested in the topic.

Ben Festus et al inhis work, has developed a microcontroller based lead acid battery charger [10]. The developed charger is an improvement over existing designs as it is equipped with wrong polarity detection, over charge protection, float charge and a digital display. The charging rate is displayed in percentage on the digital display for easy charge status monitoring and display of other related technical information. A Printed Circuit Board was also developed for the device. The battery charger was designed for 12V and 6V lead acid battery types.

Pamela et al. reviewed different charging techniques of lead acid batteries [19]. When designing a charger of a battery, some parameters such as, the State of Charge (SOC), the lifetime of the battery, and the charging time were considered for better performance and efficiency. Optimal charging of stand-alone lead-acid and lithium-ion batteries were studied by Yasha et al. to maximize the charging efficiency [20].

Most recently, a variable frequency pulse charge system (VFPCS) was proposed by Cheng S. Lee et al. to improve the battery-charge response. Unfortunately, it was only suitable for small size of battery such as cellular phone charger. Recently, Multi-state charge algorithm based on the UC 3909 switch mode lead-acid battery charger controller, particularly focused on a large size lead-acid battery has been developed. It is capable of providing a bulk constant current with 1/10 C to charge the battery. The proposed scheme was extended to four series-connected 150AH batteries (48V) charged successfully. The experimental results reveal that two series-connected 150AH batteries (48V) was fully charged using up to 15A within 5 hours. Charging time thus reduced than the traditional methods, and battery temperature remained with no significant change [9].

1.3.2. Shortcomings

Few researches have been reported on social and economic aspect of Easy-bike in certain regions of Bangladesh. Several researches have been carried out on charging system of electric cars/ buses which run on Li-ion battery. Few researches have been performed on small charger mostly for charging mobile phone. The charging system of battery operated Easy-bike with five 12 V lead acid batteries has never been optimized, nor the effect were reported on National Power Grid in Bangladesh. A well optimized charging process usually requires a control circuitry, such as microprocessors or other power electronics controllers. Easy-bike charging system due to its uncontrolled charging and cause wastage of energy to the electrical power grid, need due attention, which has remained unaware for the researcher.

1.3.3. Motivation

Due to the socio-economic reasons use of Easy-bike cannot be eliminated from the society. Rather, it will be increased substantially day by day. It will further increase the load to the power grid, adding huge load during peak hour, thus imposing additional load shedding to the grid. Due attention is required to address the issue. Existing charger is very simple in design, having many disadvantage like, uncontrolled charging current causing wastage of energy and gassing which cause significant pollution to the environment; overcharge causing over heat thus decreases battery life; harmonics and imbalance in phases causes poor power quality, etc. No research has been reported so far to address the issue. Thus, design and development of a smart control circuit for the modification of existing charger and its charging system felt necessary.

1.4. Objective and Thesis Outcome

1.4.1. Objective

- To study the existing battery operated electric vehicles and their charging systems.
- To analyze the effect of the battery operated vehicles on national grid.
- To design and construct an effective charging system and simulate for optimization.
- To analyze the performance of the developed system and compare with the existing system.

- To develop charging management system and mechanism to reduce the impact of the battery operated vehicle on national grid.

1.4.2. Thesis outcome

Successful completion of the work should improve efficiency of the system and reduce the negative effect of battery operated electric vehicle on national grid.

1.5. Thesis Outlines

This thesis comprises of six chapters as follows:

- Chapter 2 highlights on EV scenario in Bangladesh, analyses charging system and charger of battery operated Easy Bike.
- Chapter 3 analyses load curve, load factors, demand side management and effect of battery operated EV on power grid.
- Chapter 4 elaborates on the modelling of the components of a modified charger in MATLAB/SIMULINK, describes design and construction of charger, timer and effective charging system of Easy Bike.
- Chapter 5 illustrates the results obtained from the simulations, along with discussions based on the detailed analysis performed on the implemented models - regarding power consumption, charging time and load side management.
- Finally, Chapter-6 wraps up the work done in this thesis, discussing recommendations and potential suggestions for future works towards better operation and design of Easy Bike charging system.

CHAPTER 2

CHARGING SYSTEM AND CHARGER ANALYSIS OF BATTERY OPERATED EASY BIKE

2.1. Introduction

Easy-bikes were first commercially introduced in 2004 and since then, there has been an increase in large numbers due to their convenience in transportation, concern regarding the availability of energy sources like fuel-gasoline and decarburization of the economy. However, their power consumption has a significant impact on electricity generation and daily load profile which is a matter of concern for the power grid. Most of these vehicles are either locally assembled or bought from china. There has been a revolution in the mass transportation system in Bangladesh where an estimated 250 million people use this transport. In almost all cities they serve as the major intra-city transport. Having significant social impact, it has very important economic aspects as well. It has developed a local automobile industry creating more than 3 million jobs over the years. Since its inception, an estimated amount of 125 billion BDT has been invested in these industries, where a large number of low-income generating people are making a living through these vehicles [13]. The number of vehicle has exceeded 1 million and is increasing day by day. There is a concern from BPDB that the number of Easy-bike plying in the road is unregistered by BRTA due to the lack of policy, though recently some municipalities are giving licenses paving a way into the legalization of these vehicles. Recently, Bangladesh Energy Regulatory Commission (BERC) has imposed 7.70 BDT tariff for charging these vehicles only in garage. But, the full control and regulation of these vehicle in terms of use and charging are yet to be attained by the Government and still under process [4].

2.2. Survey of Easy-bike and Survey Results

In the process of the research on the effect of the deployment of Easy-bikes, a field survey was carried out at different cities of Bangladesh ie. Kishoreganj, Khulna, Patuakhali, Lalmonirhat, and Pabna. Easy-bikes are major intra-city transport system in these cities and have various significant socio-economic impacts. The survey mainly focused on different aspects of the battery, the charger and the charging system. 200 vehicle owners participated in the survey and shared their detailed views. The survey form was formulated in Bengali considering the literacy level of the operators as attached in appendix-A and filled-up by the operators as shown as appendix-B. Most of the vehicles were procured as new vehicles and around one fourth were secondary.

Easy-bikes have five 12 V battery connected in series. Four of them are placed beneath the seats of the passengers and one that of the driver. Mainly flooded lead acid batteries are used for these types of vehicles. Other specification of 4 batteries or even 6 batteries are also available with battery capacities of 48V and 72V but five battery vehicles are most commonly used here. In the study, Easy-bikes having the 5 battery configuration of 180 Ah capacities were considered. The motor of the Easy-bikes generally consumes about 1100W having a rated voltage and current of 60V and 22 Amp respectively. The motors are usually brushless DC (BLDC) motors. Table 2.1 represents the specification of the motor considered in this study and the power consumption.

Table 2.1. Electric vehicle motor specifications

Specs	Value
Rated Power (W)	1100
Rated Voltage (V)	60
Rated speed (RPM)	3420
Rated Current (A)	22
No load current (A)	5
Rated torque (NM)	3.9

2.2.1. Battery analysis of Easy-bike

The batteries used in Easy-bikes are flooded lead acid batteries with a Depth of Discharge (DoD) value of around 90-100% and hence has a lower cycle life. Theoretically, lead acid batteries usually have a cycle life of about 200 cycles at this DoD [21]. Most of the batteries have a life is less than 270 cycles, assumed that batteries are charged once every day. The survey shows that majority battery banks had to be replaced within 9 months as shown in fig.2.1.

Five lead acid batteries are used in each vehicle having a capacity of 180 Ah. With a single charge, the Easy-bikes travel a distance of around 120 km in average fully discharging the battery.

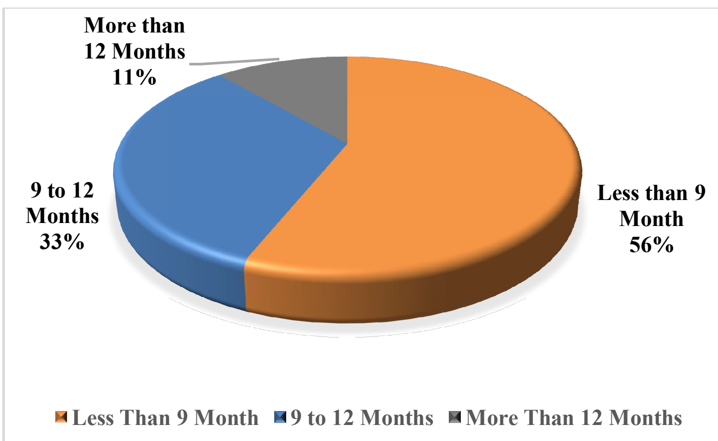


Fig. 2.1. Life of Easy-bike battery

According to the dealers outside Dhaka, some Chinese manufacturer offers warranty. The survey results show that majority of the vehicles have battery warranty in the range of 4 to 8 months as shown in fig. 2.2. About 55% of the sample does not have warranty for their battery bank. Though the dealers offer a warranty, the users also expressed that it is very difficult to get replacement during warranty period. The dealers try to repair the used battery instead of replacing it. Because of the large number of vehicles, there is a huge demand for battery in the market. The cost of five batteries is around BDT 40,000.00 to 60,000.00. There is a value of the old or damaged battery and generally the value of such battery bank ranges from BDT 15,000.00 to 20,000.00 and they can be sold directly to the battery seller.

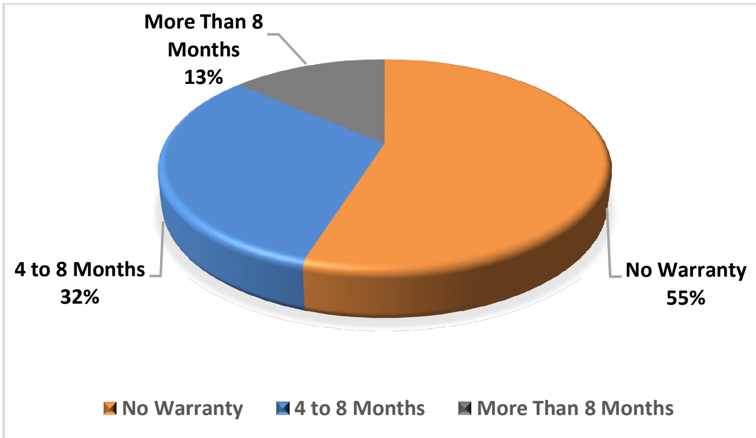


Fig. 2.2. Warranty of Easy-bike battery

The electrolyte is a chemical medium that allows the flow of electrical charge between the cathode and anode of a battery. Flooded lead acid uses DI water as electrolyte and needs regular watering because of loss of water due to overcharging. The survey data shows that the Easy-bike battery needs 5 litter of water in every 7 to 15 days. Most of the user use commercially available electrolyte but some do use normal water, which is harmful for battery and affects the battery life.

2.2.2. Battery charging and charger analysis

Most of the Easy-bikes have the battery charger generally procured with them. Around 39% of the vehicles need to procure the charger separately from the market, according to the survey, which have variable costs depending on the quality of the charger. Chargers consisting of copper transformers are more expensive than those with aluminium transformers. They are usually single phase chargers. According to the survey, around 87% of the Easy-bikes are charged at garages and the rest 13% at home. Factors like the security of vehicles, space, and availability of separate electricity lines for charging influences the charging procedure at garages. The charging cost of the vehicles varies from garage to garage. Most of the user needs to pay BDT 100.00 to 125.00. But the charging rate can be higher than BDT 150.00 as shown in fig.2.3. The cost is not only for charging the vehicles but also for ensuring security. Depending on the quality of the system, the cost of a battery charger varies from BDT 2500 to 5000.

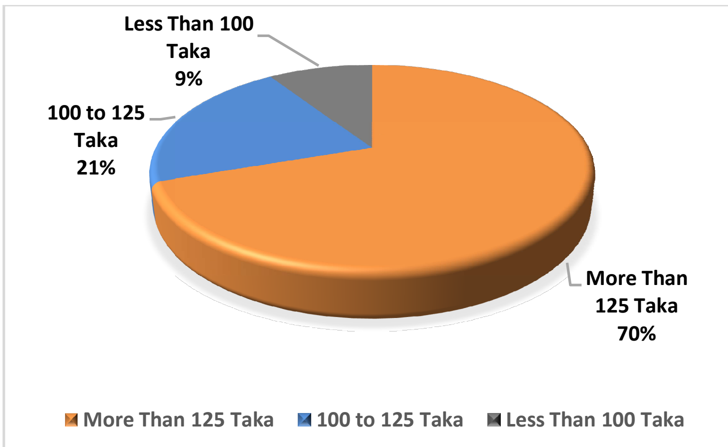


Fig. 2.3. Charging cost of Easy-bikes

The current three-wheeler charger technology is very simple consisting of few power-electronic components. The charger should be most reliable and long-lasting for them. In the field of power electronics simplicity begets reliability. This charger is very simple, though it suffers from few problems like overheating due to overcharging, wastage of energy, environmental hazard etc. One of the major difficulties of this charger is that it takes 8 to 10 hours to charge the battery fully which affects the plug-in and plug-out time.

2.2.3. Existing charging pattern (plug in and plug out time) of Easy-bike

The vehicles are charged overnight, starting to get connected to the grid by 7 pm and all vehicles connected by 11 pm. From 11 pm to 6 am the next morning a high load is observed in recent years due to Easy-bike charging. Most of the vehicles are plugged out from the grid between 6 am to 7 am. Whereas almost all the vehicles are disconnected by 8 am. Fig.2.4 and fig.2.5 shows the plug-in and plug-out time of Easy-bikes respectively.

The charging procedure is actually uncontrolled, the vehicle owners commonly plug-in their vehicles and let it charge at full current throughout the whole night. The vents of the lead acid batteries are also kept open in the procedure to create ventilation for gassing due to overcharging. The survey provided a good exposure on very thoughtful issues regarding Easy-bikes and Easy-bike charging.

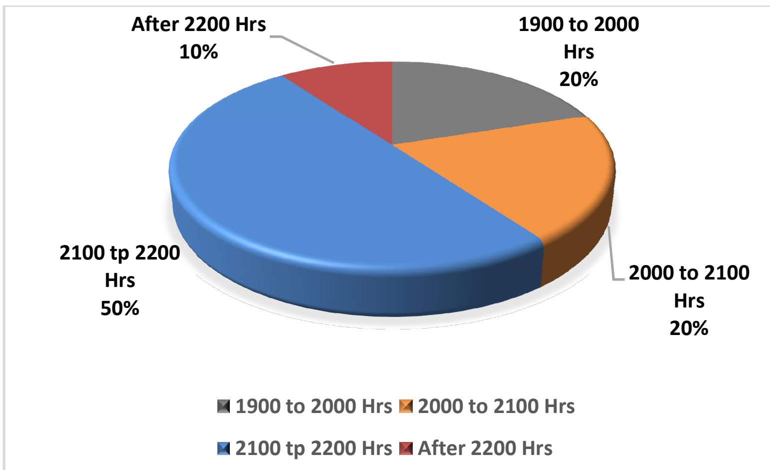


Fig. 2.4. Easy-bike plug-in time

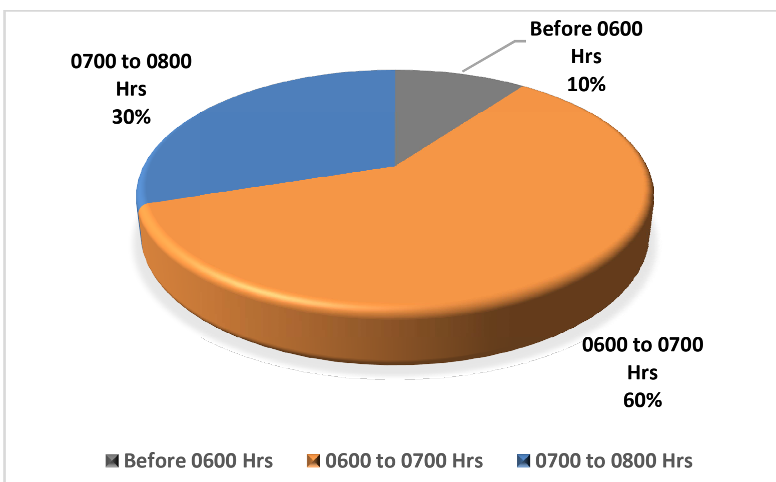


Fig. 2.5. Easy-bike plug-out time

Table 2.2 shows the percentage of vehicles plugged in to and plugged out from the grid for charging purpose.

Table 2.2. Percentages of vehicles plugged in and plugged out from the grid

Status	Time	Vehicles (%)
Plug-in EVs	7 pm to 8 pm	20
	8 pm to 9 pm	20
	9 pm to 10 pm	50
All connected	10 pm to 6 am	100
Plug-out EVs	6 am to 7 am	60
	7 am to 8 am	30
Not connected	8 am to 7 pm	100

2.3. Existing Charger Analysis

The market available chargers are mainly Chinese manufactured and consists of a step down transformer with multiple taps for voltage adjustment. The tapings are made on the high voltage side to reduce cost. A rectifier in the low voltage side converts the voltage to pulsating DC. There is no capacitor in the system so the battery current is also pulsating for these chargers. A knob on the front side allows the user to select a charging current by adjusting turn ratio. Fig.2.6 shows the schematic diagram of existing Easy-bike charger.

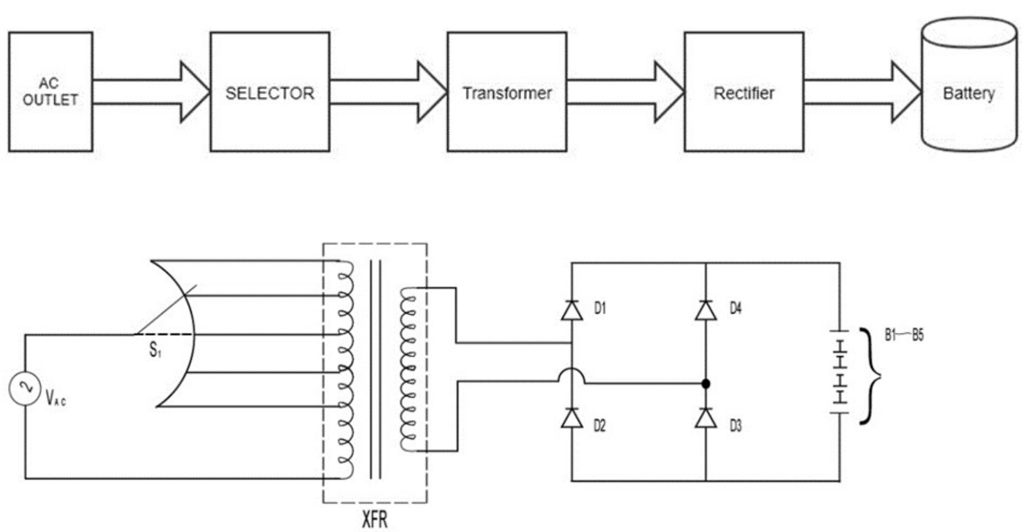


Fig. 2.6 Schematic diagram of existing Easy-bike charger

These chargers possess various operational hazards, both for the power system and for the environment. But still they are being continuously used due to economic advantage. A detailed analysis on the charging problems is discussed in this section.

2.3.1. Uncontrolled charging and waste of energy

The existing system follows the ‘Constant Voltage’ charging topology. For a particular selection of the knob, the turn ratio becomes constant so the change in supply voltage or the battery voltage changes the charging voltage and current. In the case of Easy-bikes in Bangladesh, the vehicle owners keep the knob at the highest point (15 Amp RMS) and do not change it later. The system does not have any self-control or feedback mechanism, therefore the batteries continue to consume more power even after the charging is complete. This excessive energy causes the lead acid solution in the battery to boil and creates gassing. As a result, hydrogen and oxygen gas keeps floating in the charging garage and if the garage is not well ventilated, then there is a serious risk of explosion. The temperature of the plates and the electrolytes are also increased in the process. This is one of the main reasons of the reduction in the cycle life of the batteries. The overcharging wastes lot of energy to create gassing [15]. This has a very adverse economic effect on the power sector of Bangladesh.

2.3.2. Battery cycle life and environmental hazard

The batteries are very adversely affected by overcharging. As mentioned earlier, the cycle life of the batteries are reduced to 270 cycles from 1000 cycles thus causing a battery to be replaced within 9 months. The battery cannot be disposed anywhere since lead is very harmful. Thus the batteries are replaced by the vehicle owners at a lower price but the hazards still remain. These old batteries are mostly recycled by the battery sellers in a process that still possess threat to the environment due to the reformation of lead. Also, the battery water needs to be replaced frequently since they get vaporized due to overcharging. This incurs extra cost for the vehicle owners.

2.3.3. Voltage and phase unbalance

The charger is a single-phase charger and consists of an AC/DC converter. They are connected randomly to the power system while charging. The supply from the utility is balanced three phase power. The single phase charging process creates a mismatch in one or more of the balanced line-to-line voltages of the three-phase system [22]. This voltage and phase unbalance causes larger unbalanced current in the neutral phase creating a huge problem in the local distribution network. Since three-phase power systems are intended to stay balanced, a very small unbalance can damage any equipment connected to the system [23]. The system will incur more heating effects and losses. The unbalanced load causes losses in the distribution transformer and the unit fails even at relatively low load.

2.3.4. Harmonics

Most of the charger use step down transformer to reduce the voltage level and then rectify for charging the battery. The AC to DC conversion injects harmonics in the distribution system and reduces the power factor of the device resulting heating of the charger. Due to low quality power supply charging cost also increases. Many power electronic components like diode gets heated as the conduction becomes asymmetric. The excessive current may also trip overload-protection circuits and also decrease the life of vital components [24].

2.4. Traditional Charging Process

A well optimized charging process usually requires a complex control circuitry, such as microprocessors, DSP chips or other power electronics controllers [9]. Nowadays, the lead-acid battery is widely used in a variety of applications such as electric vehicle, uninterruptible power system (UPS), and emergency power supply, etc. However, some drawbacks, e.g., poor energy density characteristics, long charging time, and short lifetime discourage its further commercial applications. Therefore, the development of optimized algorithm to achieve a rapid charging and prolong the battery lifetime is still an indispensable research issue in industry. Traditional charge methods either use constant current or constant voltage to charge the battery, or mix these two schemes. However, these methods suffer from low charge efficiency, over-charge, or long charge time, etc. Traditional battery charging modes include: 1. Constant Voltage (CV) charge 2. Constant Current (CC) charge 3. Constant Voltage-Constant Current (CV-CC) charge 4. Pulse charge 5. Positive and Negative Pulse charge.

2.4.1. Constant voltage charge mode

The CV mode is the simplest way to charge the battery. Its charging curve is shown in fig.2.7. It can be seen that the charging current decreases gradually when the battery is going toward fully charged status. This method does not push the battery temperature rising significantly, and no over-charge will occur. However, normally it needs a long charging time, and it may be beyond the rated current at the beginning charge stage.

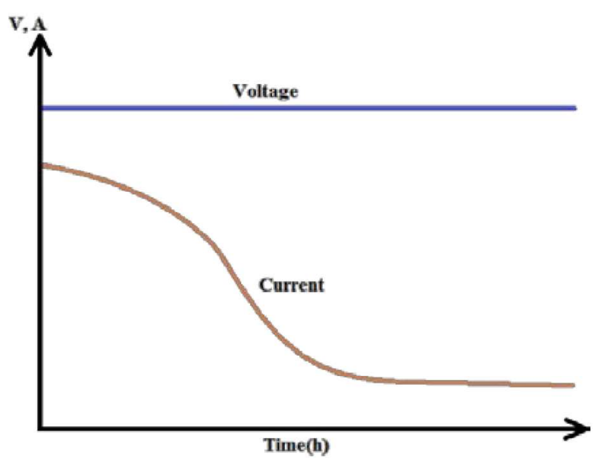


Fig. 2.7. Constant voltage charge mode [9]

2.4.2. Constant current charge mode

The charging curve using CC is shown in fig.2.8. Based on the CC charge, it is feasible that the charging current can be set under the rated current so that it will not be over the rated limit. On the other hand, the charged voltage will depend on the charging current, and the charge time can be easily estimated. However, the drawback is that it may cause over-charge, and the battery temperature may rise up quickly.

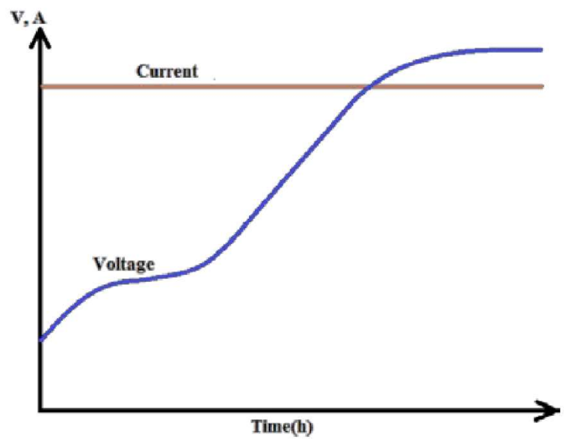


Fig.2.8. Constant current charge mode [9]

2.4.3. Constant voltage - constant current charging mode

The CV-CC charge mode combines both CV and CC charging method. Fig.2.9 indicates its charging curve.

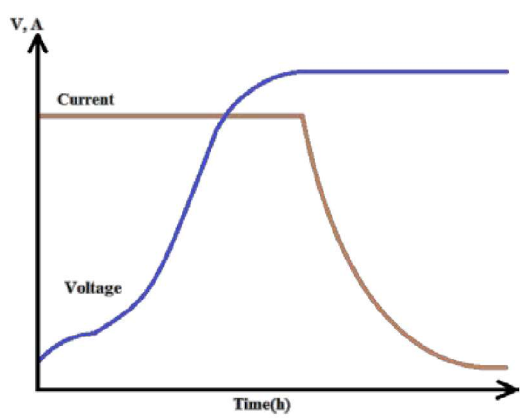


Fig.2.9. Charging curve using CV-CC mode [9]

At the initial charging stage, the constant current is used to charge the battery until the battery voltage reaches over-charged stage or pre-defined voltage. Then, the charging mode will switch to CC one to maintain the battery voltage, avoiding too high voltage. The advantage of this method is that the charging time can be reduced dramatically.

2.4.4. Pulse charge mode

Each charging cycle includes “charge” and “rest” stage. In the “charge” period, the battery is charged. In the “rest” period, the battery is at a rest status where the battery has more time to balance the battery chemical reaction. As a result, the battery voltage will become more stable, and its working life can be prolonged. Another advantage is that the charging time can be decreased using a large current which may be over-rated. Fig.2.10 depicts the profile of pulse charge cycles.

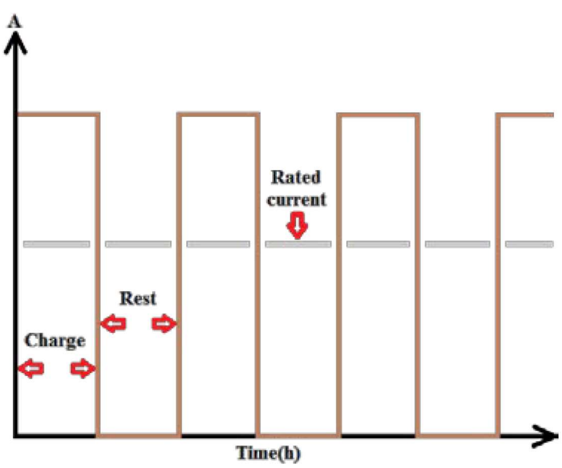


Fig. 2.10. Pulse charge [9]

2.4.5. Positive and negative pulse charge

The concept of applying a short discharge pulse during the charge cycle sometimes referred to as "reflex charging" or "burp charging" started with patents "Rapid charging of batteries" in 1971 by W. Burkett & R. Jackson. Some of the fast charging systems presently available incorporate negative pulse fast charging algorithms that claim to have great benefits to batteries including reduced recharge time, lower temperature rise, full recharge capabilities, as well as shorter equalization times. However, this method may reduce charge efficiency. Fig.2.11 depicts the profile of Positive and Negative Pulse Charge.

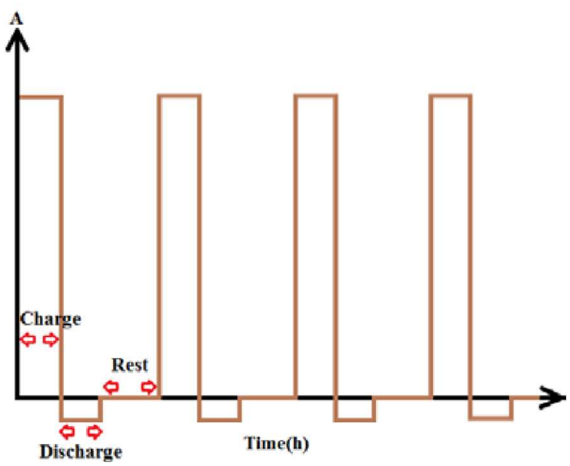


Fig. 2.11. Positive and negative pulse charge [9]

2.5. Summary

In this chapter charging system of Easy-bike has been evaluated. In doing so the survey results on Easy-bike has been evaluated. Problem related to Easy-bike charging system was also taken into consideration for the evaluation. The traditional charging process has been explained in this chapter. In the following chapter grid analysis in respect of EV charging system will be discussed followed by analysis on the effect of Easy-bike charging system in power grid.

CHAPTER 3

GRID ANALYSIS AND EFECT OF BATTERY OPERATED ELECTRIC VEHICLE ON POWER GRID

3.1. Introduction

The utility energy sector in Bangladesh has one national grid with an installed capacity of 18,753 MW (including 2800 MW captive power) as of June 2018. The total energy generation in the fiscal year 2017-2018 was 62,677.91 GWh as of June 2018. About 53% of the total generation are consumed by the domestic (households) sector, 34% by the industrial sector and the rest 13% by others [25]. The increased demand has caused problems in the distribution network and has been the major contributor in load shedding. A major portion of the total generated electricity is consumed by the charging of Easy-bikes everyday in uncontrolled way which is not appropriately accounted for by the authority. The charging load is not specifically consumed by the domestic or industrial sector rather mixed over all sectors since no policy and specific charging infrastructure is developed to control the sector for charging. The vehicles generally charge from utility supplies both legally and illegally. They are commonly charged overnight and take around 10-12 hours consuming an average of 12 units of electricity [26]. An approximate consumptiondue to the the charging of Easy-bike has been calculated interms of total generation and demonstrated in table 3.1. In calculating the consumption, number of Easy-bikes has been considered approx 1 million with average energy consumption 12 kWh per vehicle [3]. The calculated value of around 7% consumption by Easy-bikes is a matter of serious concern. This also raises a matter of debate on establishing firm policies for the control on the consumption of electricity.

Table 3.1. Estimated Easy-bike charging consumption of total energy generation

Details (as of June 2018)	Energy in units (1 unit = 1kWh)
Total Energy Generation in Bangladesh in one year	62677.91×10^6
Total Energy Generation in Bangladesh in one day	171.72×10^6
Number of average units consumed by all Easy-bikes	12×10^6
Percentage of total Easy-bike consumption as of whole generation per day	6.99 %

3.2. Power Grid Analysis

Electricity plays a vital role in the economic growth through sustainable structure as well as poverty eradication and security of any country. Future economic growth crucially depends on the long-term availability of electricity, which is affordable, available and environmentally friendly. In line with this, Bangladesh is moving ahead extensively to create sustainable growth of power sector for overall development of the country economy. Present installed generation capacity in public, private & import sector is 15,953 MW [26], [27]. Electricity demand is increasing whereas the available generation also increases with demand. Up to date, maximum generation achieved is 10,958 MW on May 28, 2018. At present, 90% of the total population has access to electricity and per capita generation has increased to 464 kWh (including captive). The change in the vital parameters of the electrical grid - installed capacity, maximum demand, maximum peak generation and maximum load shedding from 2005 to 2018 have been pictured in fig. 3.1. It is observed that over the last eleven years installed capacity and generation has been increased. At the same time demand has been increased significantly. As such, load shedding has never been reduced.

A clear picture of the current scenario can be denoted from here. The daily load pattern of Bangladesh has a typical pattern giving three different types of variations throughout the year – during summer, winter and the holy month of Ramadan. Besides fluctuations are observed during holidays or certain circumstances like change in weather or natural disasters. Following sections load curve will be analyzed and load factor, load management and demand side management will be further explained.

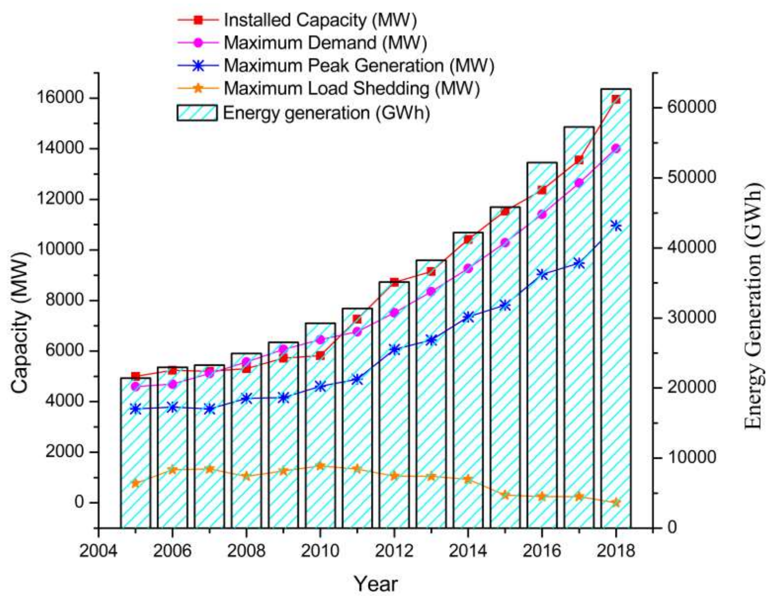


Fig. 3.1. Power and energy generation scenario of electrical grid from 2005 to 2018

3.2.1 Load curve analysis

A load curve is an important aspect in the documentation of power generation and distribution system. The generation (in MW) at every hour can be extracted from the load curve. Important parameters such as average load, maximum demand, size and the number of generating unit and operating schedule can be determined. Besides fluctuations are observed during holidays or certain circumstances like change in weather or natural disasters. According to a study, Easy-bikes were first introduced in 2004 and was fully marketed by 2008. Therefore, the daily load curve for the year 2005 was considered for analysis since there were no significant load added due to electric vehicle charging. The year 2018 is assumed as having a significant number of vehicles. A plot of both the curves is shown in fig.3.2. The load curves are available in Bangladesh Power Development Board (BPDB) website.

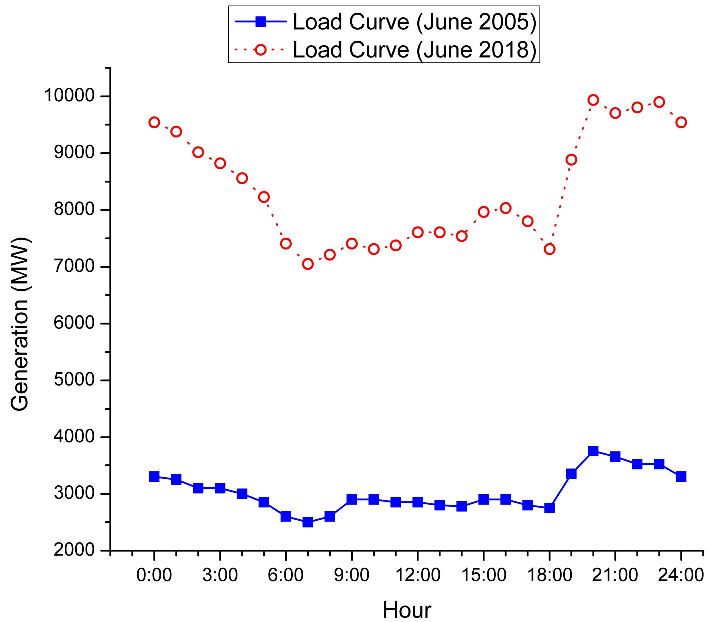


Fig. 3.2. Load curve of a day in June 2005 and June 2018

Fig. 3.3 shows a daily load curve of a day in August 2018. This daily load curve has been plotted for study and analysis where the peak generation load is 10,862 MW.

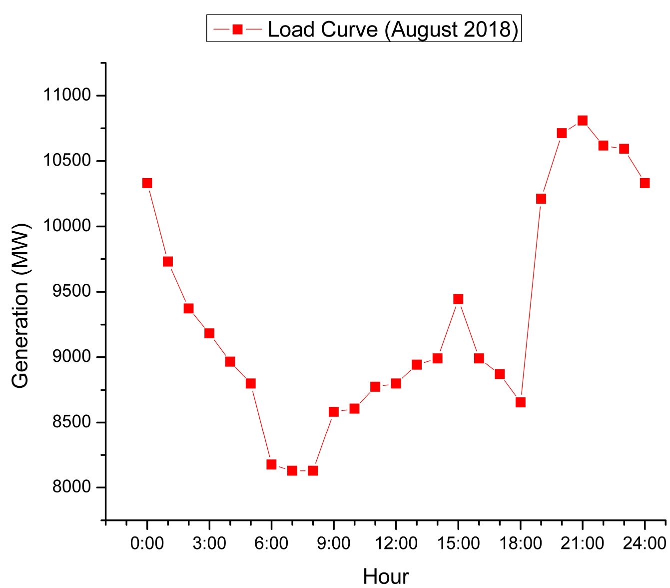


Fig. 3.3. Daily load curve of a day in August 2018

It is observed that the difference between peak and off-peak load is almost 3500 MW, which is very large. If this variation and peak demand is reduced then the overall power scenario will be improved.

3.2.2. Load factor and load management

The demand for electricity in the system varies throughout the day and night. The maximum demand occurs from 5 pm to 11 pm which is termed as 'peak hour' and another part of the time is termed as off-peak hour. The extent of this variation is measured in terms of Load Factor, which is the ratio of average and maximum demand. For economic reasons, it is desirable to have a higher Load Factor, as this would permit better utilization of plant capacity. Moreover, the cost of energy supply during peak hour is higher, to facilitate relatively more utility appliance to put in operation during the peak hour. For these reasons, load management is essential throughout the year for better capacity utilization of power plants and minimum generation cost.

There are some loads in the system which can be avoided or minimized by consumers during peak hour. In order to shift these kinds of loads from peak hour to off-peak hour by introducing some mechanism is termed as load management. From the viewpoint of load management, (i) Two-part tariff is introduced for 3-phase consumers, where peak hour price is much higher than the off-peak hour that motivates consumers to avoid or use less in the peak hour; (ii) Market and Shopping malls are kept close after 8.00 PM; (iii) Holiday staggering is implemented to keep industries, markets & shopping malls close on area basis holiday marked day; (iv) Consumers are encouraged to use energy-efficient bulb, electric appliances, pumps etc; (v) Consumers are encouraged to keep their air-conditioner's temperature at 25 degrees and so on. These measures also minimize load-shedding across the country.

3.2.3. Demand-side management

Demand-side management (DSM) modifies energy use to maximize energy efficiency. DSM tries to get the maximum benefit out of existing energy generation. DSM involves changing energy use habits of consumers and encouraging them for using energy-efficient appliances, equipment etc. at their premises. To keep load shedding at a minimum level, BPDB has taken a number of steps for demand-side management, which are as follows:

- Load Management Committee has been formed in every distribution zone/ circle/ division to monitor the proper load distribution during irrigation. BPDB could shift about 500 MW irrigation load from peak hour to off-peak hour.
- Industries operating in two shifts are being requested not to operate during peak hours. Holiday staggering for industries has been implemented, which contributes about 200 MW load shifting.
- As part of DSM, BPDB is monitoring shop/market closure time at 8 p.m. It is estimated that this measure contributes about 400 MW.
- BPDB has taken motivational programs to enhance awareness of the consumers during peak hours. Consumers are being urged through electronic and print media to be rational and economical in electricity use during peak hour by switching off unnecessary loads like extra lighting, ironing, pumps, air conditioners, welding machines etc. As part of the demand-side management program, BPDB has taken steps to use CFL in BPDB's offices and also trying to motivate consumers to use Energy efficient lamps [26].

Load shifting from peak hour thereby reduces load shedding. Table 3.2 shows total load that have been shifted from peak to off-peak hour by the process of DSM.

Table 3.2. Load shifted by DSM [26]

Item	Irrigation (MW)	Industry (MW)	Shops (MW)	Total Load Shifted (MW)
Load Shifted	500	200	400	1100

There are many reasons for the increase of peak load but an increase of Easy-bikes and motorized rickshaws charging load connected to the grid is one of the main reasons for raising peak load. BPDB may not be aware that approximately 700 MW of load is connected to the grid during peak hour due to the charging of EVs, mostly by Easy-bike. If this load is shifted from peak hour to off-peak hour than peak load will be considerably shaved. These loads in the system during peak hour can be avoided or minimized by the consumers if the demand Side Management is exercised by the authority. In order to shift these kinds of loads from peak hour to off-peak hour appropriate authority can motivate people and make policy. It can also be implemented by introducing technology like timer control mechanism. Timer control can be set into the charger or into the power system in the charging station to control the Easy-bike to be connected to the grid avoiding peak hour and peak load.

3.3. Grid Analysis - Effect of Easy-bike on Power Grid

A statistical method of analysis is undertaken to understand the effect of charging of Easy-bikes in the distribution network. The generation curve from the BPDB website is used for analysis and is considered as the load curve since Bangladesh has no spinning reserve. A load curve is an important aspect in the documentation of power generation and distribution system since it shows the variation of load on the electrical power station with respect to time. In this paper, the daily load profile of a day in June for the year 2005 and 2018 have been explored.

3.3.1. Load curve normalizing method

Though Easy-bikes have been introduced in 2004, the load curve for that year is unavailable. Therefore 2005 load curve is used and this year has been considered to have very few commercially available Easy-bikes. But in 2018, there are about 1 million commercially available Easy-bikes. The load curves of 2005 and 2018 have been normalized with respect to the highest generation of peak value of that particular day. The normalized curves are depicted in fig. 3.4.

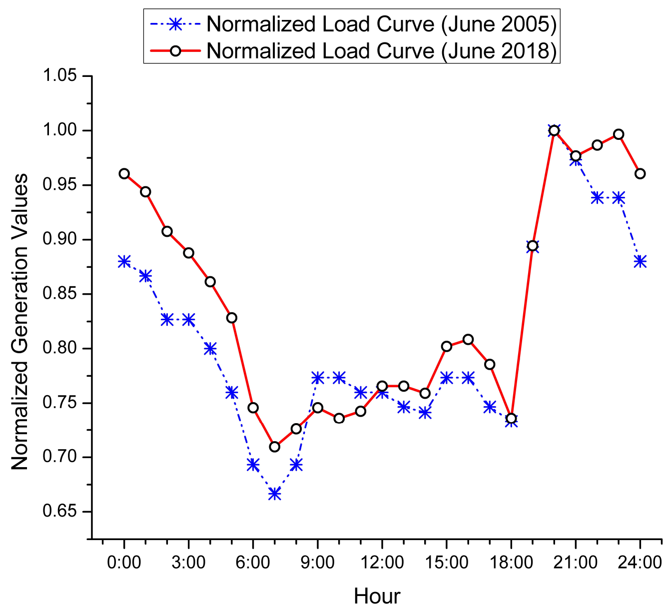


Fig. 3.4. Normalized load curves of 2005 and 2018 for the month of June

From the normalized curves it can be observed that from 6 pm to next day 8 am the load consumption is significantly higher for 2018. These changes have been triggered by many reasons including climate change, increase in load consuming sectors like shopping malls and offices etc. For the time range of 6 pm to 12 am, the two curves showed a mismatch with an overshoot error. Before 2008, shopping malls remained open till 10 pm or more and so in the 2005 load curve there was a high load at that time range. But after 2008, the Government of Bangladesh ordered all shopping malls to remain close after 8 pm to curtail power consumption during these peak hours. This removed the extra power consumption after 8 pm but still a high load is observed at midnight. The presence of this high load indicates the existence of a high power consuming load which maybe Easy-bike charging validating the 7% energy consumption calculation showed previously.

3.3.2. Data mapping method using Easy-bike charging data

Here the methodology of the proposed statistical analytic method is described. The data available at the BPDB website is the generation data. Since Bangladesh has no spinning reserve, the generation curve may be assumed as the load curve.

- Step 1 – Data Acquisition: The daily load profile of a day in June for the year 2005 and 2018 have been taken for analysis.
- Step 2 – Data Mapping: The ratio of the lowest generation of June 2018 and June 2005 has been determined. To map the data of 2005, the ratio is multiplied with the hourly generation data of 2005. AC loads consume most of the generated energy. 2018 has lower AC loads than in 2005. The ratio of the lowest generation value was taken to minimize the error in consumption.
- Step 3 – EV Data Integration: Table 3.3 shows the percentage of vehicles that are connected to the grid with the status of vehicles which is taken from table 2.2.

Table 3.3. Percentage of vehicles connected to the grid

Hour of Connection	Percentage of Vehicle Connected to Grid (%)
06:00 hrs to 07:00 hrs	60
07:00 hrs to 08:00 hrs	30
08:00 hrs to 19:00 hrs	0
19:00 hrs to 20:00 hrs	20
20:00 hrs to 21:00 hrs	40
21:00 hrs to 22:00 hrs	90
22:00 hrs to 06:00 hrs (next day)	100

It is assumed that 70% of the vehicles are active and are charged at the same time overnight. According to the survey report Easy-bikes generally consume around 12 units of electricity [27]. Easy-bike charger takes around 10-12 hours to charge lead-acid battery considering the charging characteristics of the charger. The load percentage of Easy-bikes connected to the grid at those particular time has been added with the mapped data of 2005. With the addition of extra load due to Easy-bike charging with mapped 2005 curve, the new load curve named 'Mapped load curve' is plotted. This new load curve along with the unaltered 2018 load curve is shown in fig. 3.5.

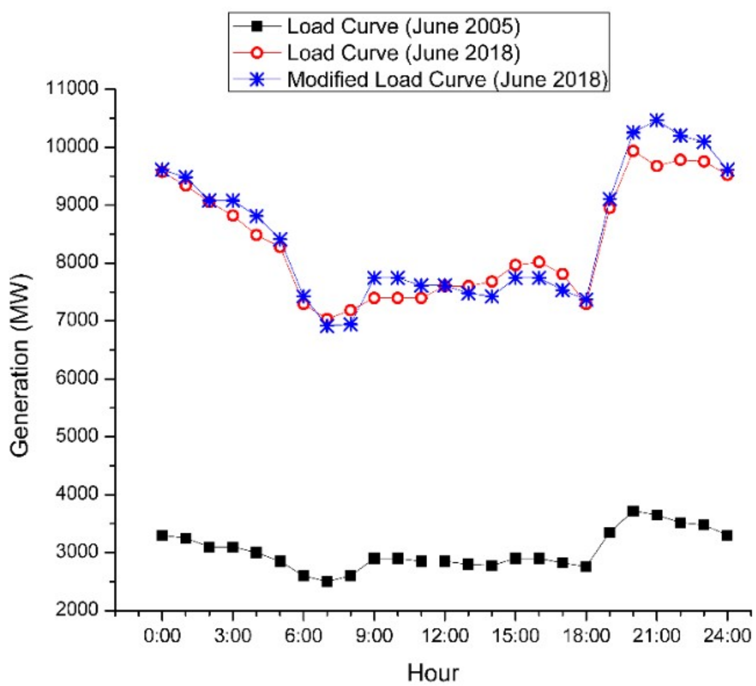


Fig. 3.5. June 2018 load and mapped load of June 2005 including Easy-bike load

It can be seen from fig. 3.5 that the mapped load curve and the original load curve fitted very well together with a maximum error of 9%. The curves corresponded very well from 10 pm to 6 am next day. According to table 3.3, these hours denote the time when all the vehicles were connected to the grid for charging. During the day (from 6 am to 7 pm) when less (30%) or no Easy-bikes were connected for charging, the mapped load showed a little mismatch. These changes might have been triggered by various reasons including climate change, increase in load consuming sectors like shopping malls and offices, load for cooling devices etc.

For the time range of 7 pm to 10 pm, the predicted curve and the original curve showed a mismatch with an overshoot error of around 8%. Before 2008, shopping malls remained open till 10 pm or more. Therefore, there was a high load at that time range in the 2005 load curve. But after 2008, the Government of Bangladesh ordered all shopping malls to remain close after 8 pm to curtail power consumption during these peak hours [27]. This removed the extra power consumption after 8 pm but still, a high load is observed which is due to Easy-bike charging.

3.3.3. Peak load shift

The time at which the peak generation occurred was also analyzed in the last 11 years from 2008 to 2018. Due to unavailability of data and to reduce redundancy data from 2008 was considered. A significant trend was noted in the time at which the highest generation occurred in a day. The trend in the time of highest generation for a specific year is pictured in fig. 3.6. It can be observed that from 2008 to 2018 more peaks of highest generation occurred at 9 pm which was previously at 7 pm or 8 pm. An explanation of the trend lies in the fact that local electric vehicles mostly Easy-bikes are charged and the charging phase generally starts after 6 pm with most of the vehicles connected to the grid by 9 pm, as dictated by the survey. From 2008 to 2018 consumption by other electrical loads have also increased but a shift in the peak generation time may be due to the addition of an extra significant load to the grid – Easy-bike charging. Both fig. 3.5 and fig. 3.6 shows the significant effect that Easy-bikes in Bangladesh has on the daily load curve and peak generation time.

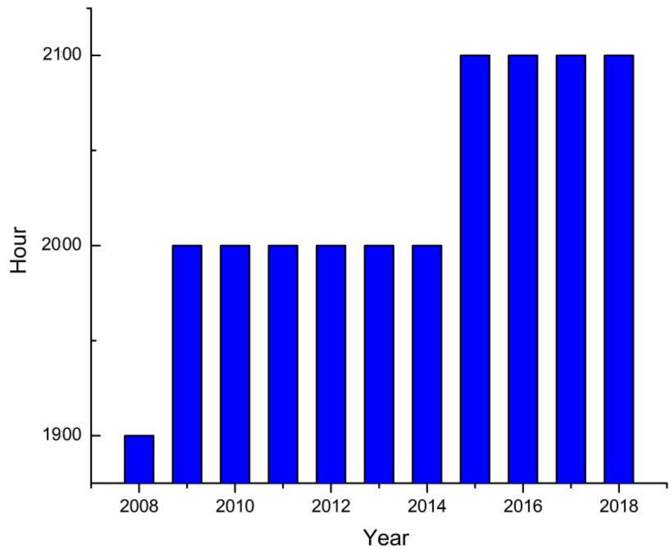


Fig. 3.6. Illustration of the change in peak generation hours over the last eleven years

In the analysis, the charging load of 70% vehicles were used instead of 100% and still, the effect of mapping shows a very strong correspondence to the original curve strongly indicating the presence of a high energy-consuming load which may be Easy-bike charging. Considering these facts and knowing the load requirement of Easy-bike charging the future electricity demand can be predicted with our proposed method.

3.4. Summary

In this chapter power grid analysis was done in respect of EVs, like Easy-bike and battery operated vehicles. The daily load curve for last eleven years was analyzed and effect of Easy-bike was also studied. The change in the peak hour consumption has been identified which gives an indication of the impact of electric vehicles on the electrical grid. In the following chapter design and construction of microcontroller based modified charger will be discussed. Further the timer controlled load control mechanism will be formulated.

CHAPTER 4

DESIGN AND CONSTRUCTION OF MODIFIED CHARGER FOR EASY BIKE

4.1. Introduction

There are few advantages and disadvantages of the existing charger as mentioned in chapter 2. The main feature of this charger is its durability and easy to build with less cost which makes the driver and garage owner comfortable to buy these types of charger. The main disadvantage of this charger as already described in previous chapter; waste of energy, decrease of the battery life, as well as environmental hazard which must be addressed for better efficiency and performance. To solve the problems stated previously, a simple solution has been formulated modifying the existing charger. This modified charger will not only resolve the problems of overcharge, energy wastages, uncontrolled charge etc. but also will perform efficiently with faster charging, which will help load management in the power sector.

4.2. Design of Modified Charging System

In this design the selector block is replaced by the control circuit. Control system always sense battery and AC outlet and takes the feedback of input voltage, output voltage and charge current. The control system is inbuilt with the Lead acid battery management system with overcharge control mechanism. This is a simple microcontroller base control circuit where TRIAC is used as switch for tapping the transformer to control the current. This solution is much cheaper and easy to modify the existing charger. Fig. 4.1 shows schematic diagram of modified Easy-bike charger.

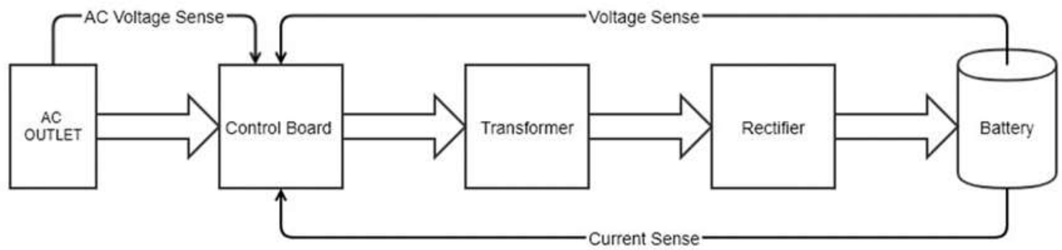


Fig. 4.1. Schematic diagram of modified Easy-bike charger

4.2.1 Flowchart (Algorithm)

After the whole system is turned on, it is subjected to the charging current and the charging voltage. In the first state, the state of charge of the battery is detected. If the battery is not fully charged, it starts charging. The system in this state checks the charging current to ensure it stays in a predetermined limit and also to switch the transformer taps to increase or decrease the current. If the charging current is below the lower limit, the switch number in the hardware is increased to different switch which has a higher voltage tap connected to it. If the current is below the upper limit, the current switch is changed to switch will lower voltage value tap of the transformer. In this way the current is controlled and the battery is charged with constant current. Also in state one, the battery voltage is always being monitored and compared to a predetermned value. Fig. 4.2 shows the flowchart of modified Easy-bike charger control operation.

If the battery voltage increases, indicating a fully charged state, charging stops and a timer is turned on. The timer value is also compared with a predefined value, since after a specific time the charging would again continue but for a very short time now. This is the trickle charging state and the charging time here is the trickle charge time. This tickle charge continues till the time charger is disconnected. By following this algorithm, developed system controls charging of the battery.

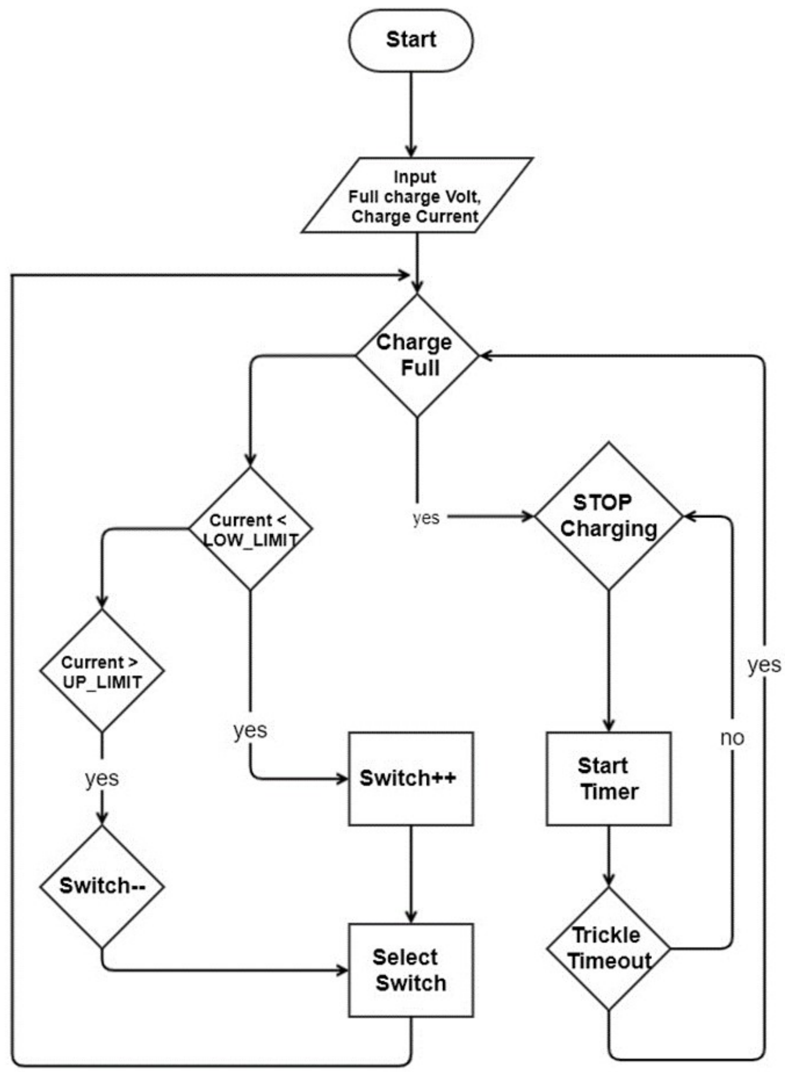


Fig. 4.2. Flowchart of modified Easy-bike charger control operation

4.2.2. Simulation analysis

Before the whole system is implemented in hardware, the design of the modified charger has been simulated using MATLAB SIMULINK. The system was simulated in various blocks to mimic the total system in hardware. The blocks are powergui, controller and switches, transformer, rectifier, battery charging and measurement. Fig. 4.3 shows the entire simulation arrangement. The operation of deferent blocks of SIMULINK has been explained in the subsequent paragraphs.

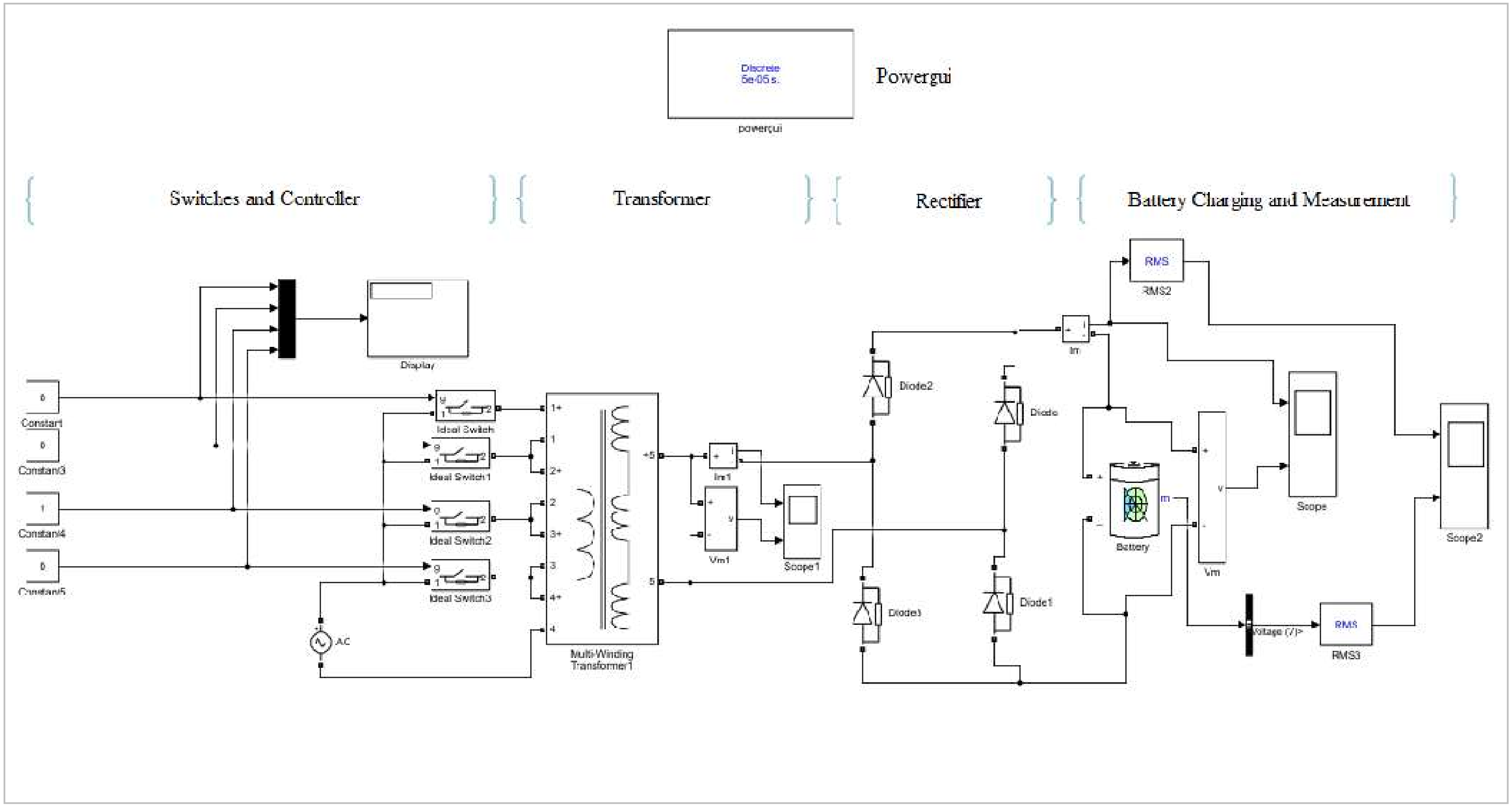


Fig. 4.3. Simulation blocks

System model can be derived from the ideal transformer equation,

$$\frac{V_p}{V_S} = \frac{N_p}{N_s} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.1)$$

Here, V_p , V_s are primary voltage and secondary voltage respectively and N_p, N_s are primary and secondary turns respectively. In this system primary turns ratio is changed to control the output voltage which controls the output current. So, the output voltage equation for the system is,

$$V_s(t) = \frac{N_s}{N_p(x)} V_p(t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (4.2)$$

As the input turns of the transformer is variable and the output tape turns is kept fixed. Moreover, input voltage is dependent on number of turns of input turns. So, the input voltage with respect to input turns ratio can be derived,

$$V_p \propto N_p \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.3)$$

$$V_p(t) = K_p N_p(x) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.4)$$

So, the final equation for the system becomes,

$$V_s(t) = \frac{N_s}{N_p} V_p(t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (4.5)$$

$$V_s(t) = \frac{N_S}{N_p(x)} K_p N_p(x) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (4.6)$$

$$V_s(t) = N_s K_p \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (4.7)$$

Here, $K_p = \frac{V_p}{N_p}$ is constant. The unit of $K_p\ is\ Volt/turn$. Here, in this simulation four discrete turns produces four different voltages.

4.2.2.1. Power-gui

The power-gui block opens a graphical user interface (GUI) that displays steady-state values of measured current and voltages as well as all state variables (inductor currents and capacitor voltages). The power-gui block allows to modify the initial states in order to start the simulation from any initial conditions. The block also opens tools for steady-state and simulation results analysis and for advanced parameter design. It allows to choose one of the following methods to solve a circuit:

- Continuous, which uses a variable-step solver from SIMULINK.
- Discrete electrical system for a solution at fixed time steps.
- Phasor solution.

Here discrete power-gui block has been used, since the solution at fixed time steps was necessary.

4.2.2.2. Switches and controller block

In the simulation four individual switches are used with four taps of the transformer. The battery is charged with the constant current technology. In the design, the charging current is kept at a range between 12 Amperes to 15 Amperes. If the charging current drops below 12 Amperes, due to the battery voltage, the switches at the input of the transformer changes to a higher voltage tap to increase the current. Again, if the charging current goes above 15 Amperes the switches at the input of the transformer changes to a lower voltage tap to decrease the current. Switch 1 is connected to a highest voltage tap (tap 4) and switch 4 to the lowest voltage tap (tap 1). The controller is a closed loop system with feedback. It generates the signal for the switches to determine which one will be on and which one will be off. The controller takes the output voltage and current as feedback and runs on two logics – (1) The whole charging system would operate if the battery voltage is below 78 volts and (2) Charging current is kept at a range between 12 Amperes to 15 Amperes. However due to the SIMULINK software constraints, the controller could not be added as a separate block, hence the signals to the switches were manually given and the system was simulated to check for the desired outcomes.

4.2.2.3. Transformer block

A 1 kW toroidal transformer was used with five taps at input (four with the four switches and 1 common) and a single tap at output. Each tap at input varies by 10 volts with the highest tap starting at 220V in this simulation. In this case, the multi-winding transformer block was used from simscape library. The simulation output from the transformer at switch 1 (tap 4) is shown in fig. 4.4. Tap 1 is the highest voltage tap and tap 4 to the lowest voltage tap. Switch 1 is connected to a highest voltage tap (tap 4) and switch 4 to the lowest voltage tap (tap 1).

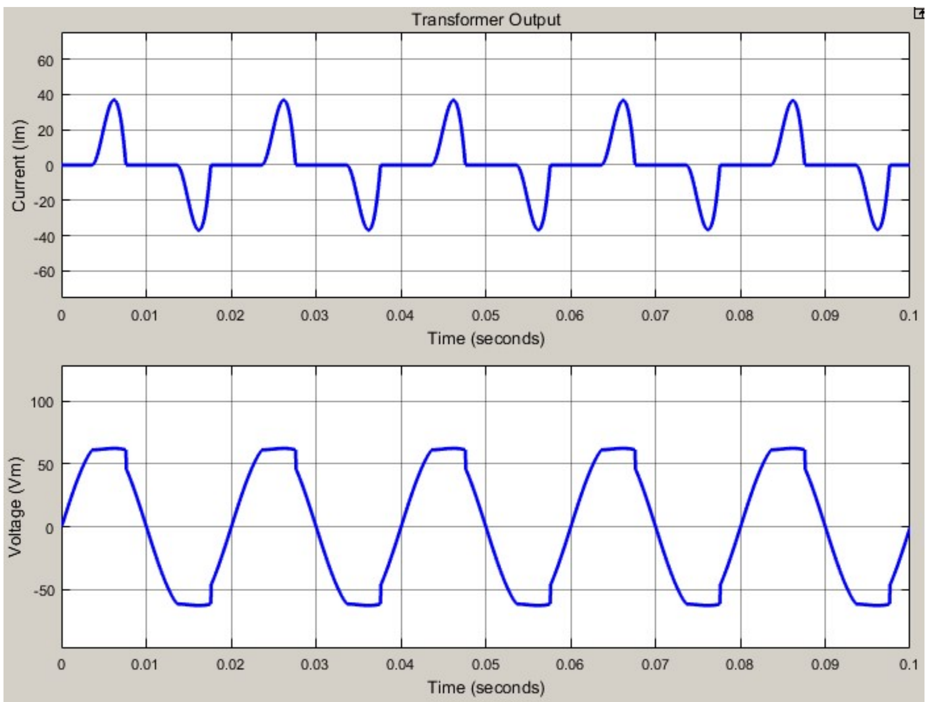


Fig. 4.4. The simulation output from the transformer at switch 1 (tap 4)

4.2.2.4. Rectifier block

A full bridge rectifier is used to rectify the AC output from the transformer to make it DC. This DC voltage is used to charge the battery. Four diodes are arranged in full bridge rectification topology. The simulation output from the rectifier is shown in fig. 4.5.

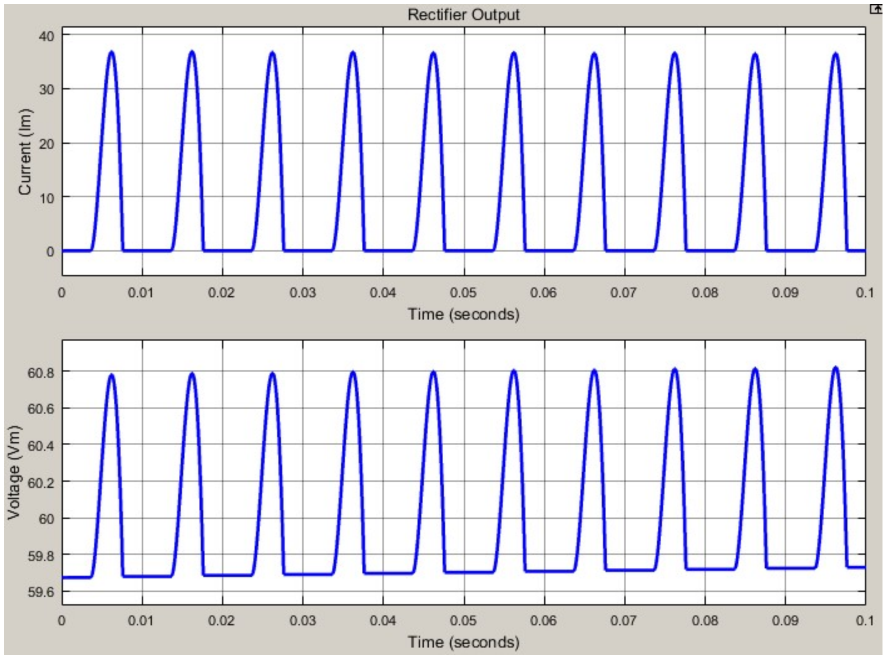


Fig. 4.5. The simulation output from the rectifier

4.2.2.5. Battery charging and measurement block

The DC output from the rectifier has been used to charge the battery. Fig. 4.6 shows the RMS values of the voltage and current waveform for switch 1 (tap 4).

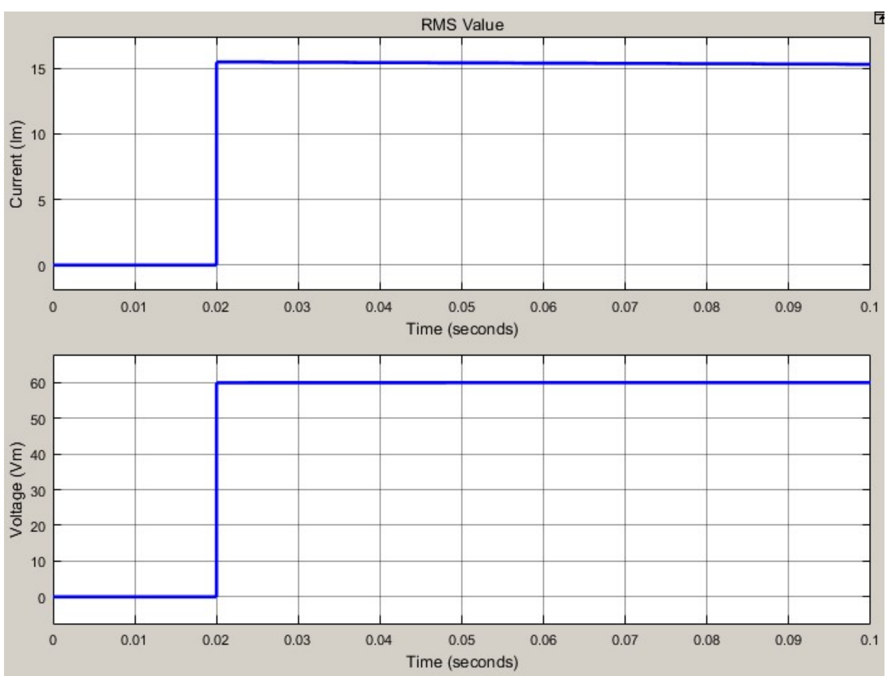


Fig. 4.6. RMS values of the voltage and current waveform for switch 1 (tap 4)

For simulation a battery block was used to mimic the real life battery. The main parameters selected for the battery in simulation is 60V and 20Ah capacity. Scopes were used to see the waveform for the battery voltage and the charging current. According to the simulation, charging was done only at the peak of the voltage curve and the voltage was pulsating in nature. Therefore the value of both the voltage and the current was obtained by using RMS blocks to measure a steady state value.

4.2.3. Hardware design and construction of modified charger

After necessary analysis in SIMULINK hardware design could be finalized and construction of modified charger was made. Fig. 4.7 shows design of modified charger.

4.2.3.1. Controller unit

In control unit, atmega328P microcontroller has been used which is a microchip AVR 8-bit microcontroller. Few features of this microcontroller are stated as below:

- Up to 20 MIPS Throughput at 20MHz
- 2KB of internal RAM and 32KB of Internal Flash Memory
- Two 8-bit timer counter and one 16-bit timer counter
- 6 Channel ADC
- Power Consumption-Active Mode: 0.2mA–Power-down Mode: 0.1µA–Power-save Mode: 0.75µA (Including 32kHz RTC)

The atmega328 has internal 8MHz RC oscillator which is less precise oscillator. For this an external oscillator of 16 MHz. was added to the controller unit. This oscillator generates pulse which drives the whole microcontroller. The microcontroller needs ADC reference voltage for converting the analog sample into digital value. In this design, 5V as ADC reference input has been used. ADC reference input pin is AVCC. An LC filtering is needed for noise free reference voltage.

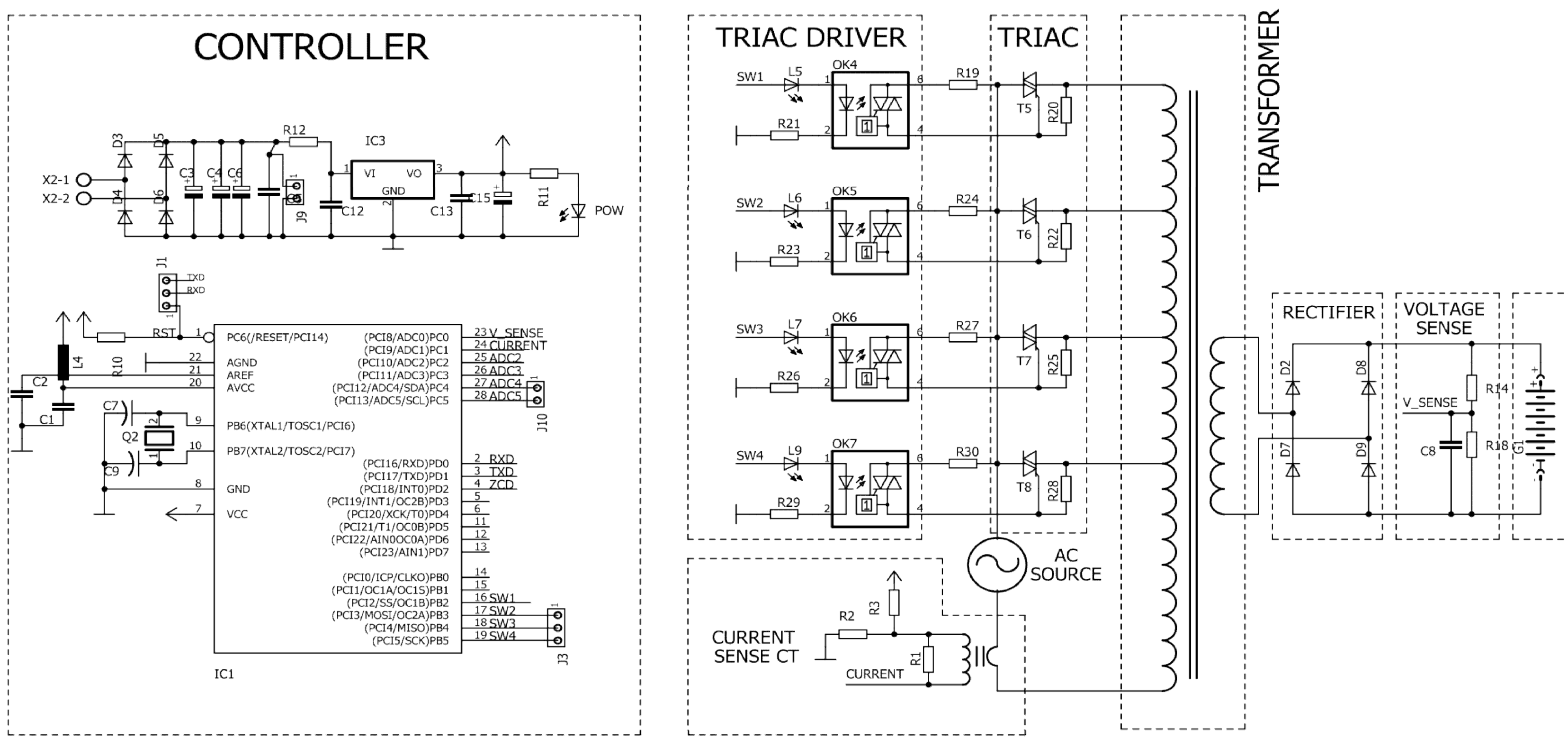


Fig. 4.7. Circuit diagram of modified charger

4.2.3.2. Control unit power-up

Control unit is power up by a step down transformer. So the step down transformer generates 12Vp-p AC. A bridge rectifier is required to convert the AC into DC. After Bridge Rectification Polar Capacitor filters out AC ripple from the power signal. Then 5V DC voltage is regulated to power-up microcontroller. Fig. 4.8 shows the circuit diagram of Control Unit for Power-up.

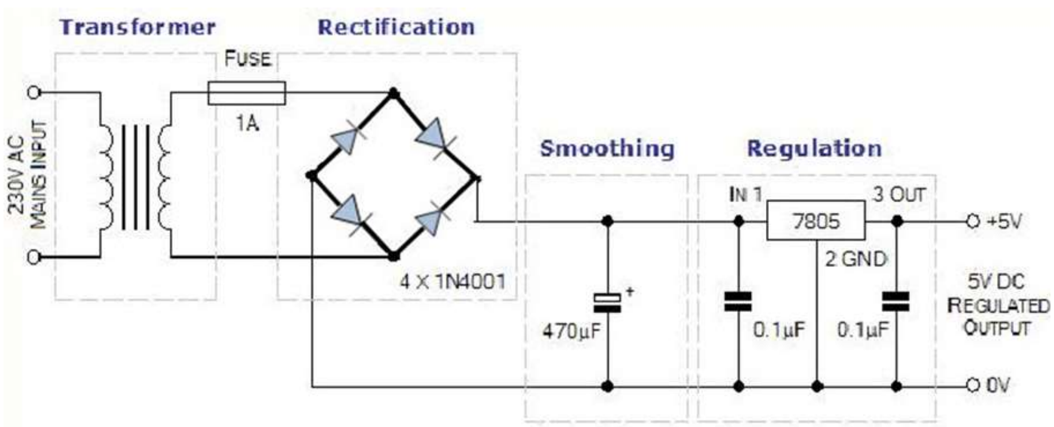


Fig. 4.8. Circuit diagram of control unit for power-up

4.2.3.3. TRIAC unit and TRIAC driver

This unit is used instead of manual selector switch. TRIAC is bi-directional switch for alternating current (AC).

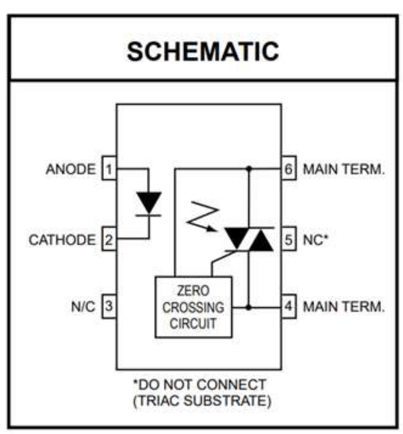


Fig. 4.9. Schematic diagram of TRIAC unit and driver

BTA41 TRIAC has been used in the design. To drive the TRIAC directly using microcontroller signal and also provide isolation between microcontroller isolated TRIAC drivers is mandatory. In the application, TRIAC output opto-coupler has been used as TRIAC driver. Fig. 4.9 shows the schematic diagram of TRIAC unit and driver. The developed system was tested in the laboratory. Thus it gave a time frame for any bug in the system to be corrected.

4.3. Timer Circuit for Load Control

The timer circuit can be incorporated into the Easy-bike charging system to manage load by limiting the charging connection pattern. In such case Easy-bike drivers after completion of their duty can plug in the vehicle in their respective garage as usual and get back to their home. Timer control system will decide charging start time. Considering the off-peak hour and suggested charging connection pattern, start time of timer circuit can be maintained. There will be a restriction imposed to charge the vehicle between 5 pm to 10 pm. Driver will be allowed to charge the vehicles any time from 10 pm till 5 pm next day.

4.3.1 Timer control mechanism

The timer-circuit can be incorporated in three ways, (i) Central system with one timer-circuit at the charging station, (ii) Central system with one timer-circuit at the charging station and individual relay coil at the charger (iii) Staggered system with individual timer to the charger. There are advantages and disadvantages of all the three systems. If the system is centrally controlled all the vehicle will be charged simultaneously creating huge imbalance in load. To minimize this, individual relay coil may be introduced to the chargers (Option 2). In this case control is dependent on charging station as well as individual charger. If the timer circuit is set to individual charger (Option 3) with random generation number then the load can be staggered and controlling will be easier. It will be programmed to add all the vehicles to the charger within 15 to 30 minutes from start time to facilitate generating random number and connect the vehicle in staggered time. Fig. 4.10 shows the timer control mechanism for staggered connection. Timer control mechanism consists of timer, relay, Control Unit for Power-up and microcontroller. Since the timer mechanism will be incorporated in the modified charger control circuit, so control unit for power-up and microcontroller can be the same.

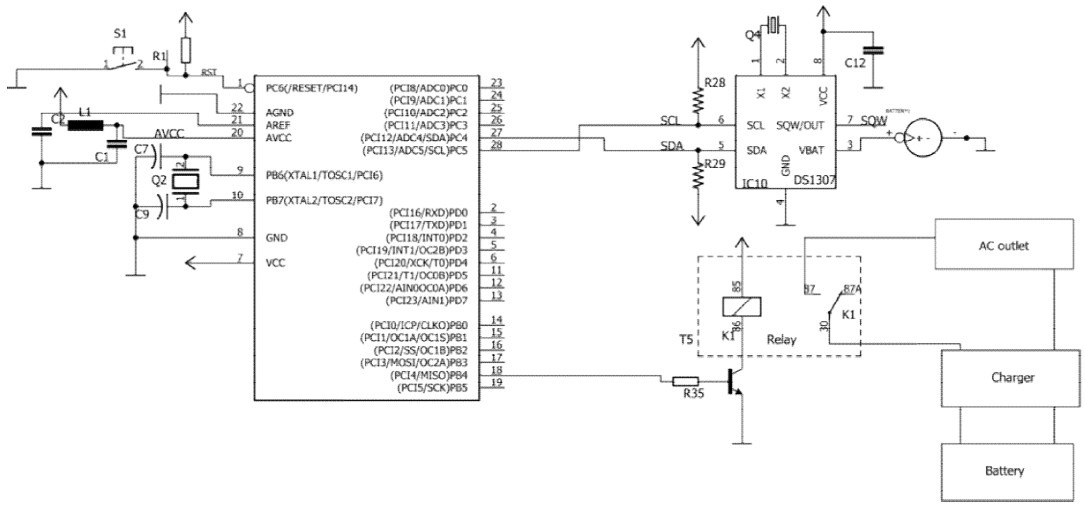


Fig. 4.10. Timer control mechanism for charging control

4.3.2. Flowchart (Algorithm)

Fig. 4.11 shows the algorithm for the timer mechanism for staggered connection. There will be a restriction imposed to charge the vehicle between 5 pm to 10 pm. Driver will be allowed to charge the vehicles any time from 10 pm till 5 pm next day. Timer clock after configuration will continuously check time. If the time is in between 10 pm to 5 pm next day it will generate random number for individual charger time slot. Then relay contact will be closed for the charger to get started. If the time is in between 5 pm to 10 pm the relay contact will remain open so the battery cannot be charged.

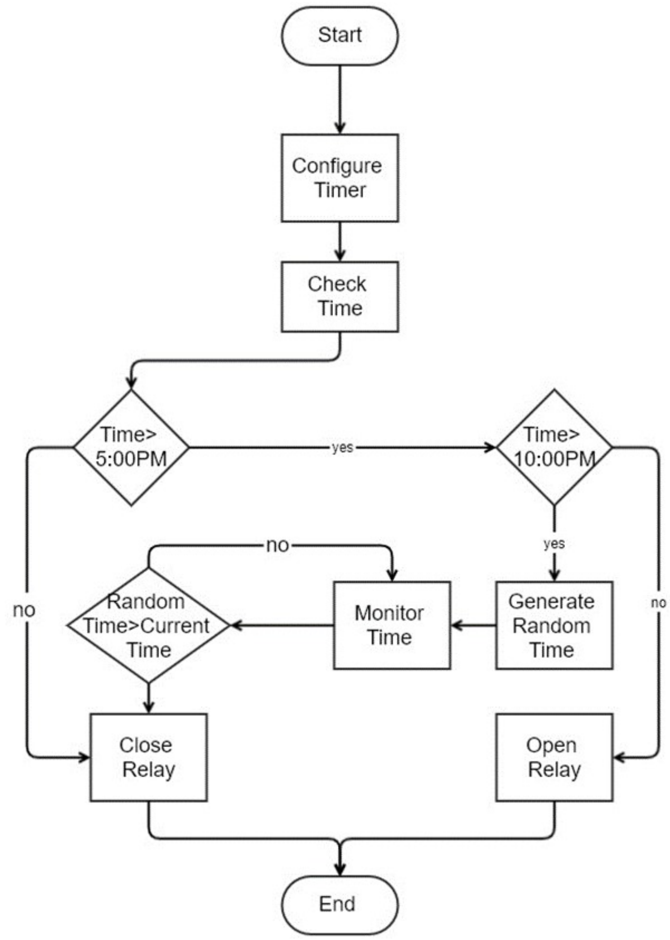


Fig. 4.11. Algorithmfor timer control mechanism

Modified battery charger combined with the timer control circuit makes the system more prudent. Here the microcontroller has been used for both the system. Once the timer control circuit is used with the existing charger due to the long charging time of 10 to 12 hours it shifts the charging time even at 10 am next morning and the load is added during off peak hour next day. In case of timer control circuit combined with the modified charger due to the fast charging the plug-out time remains the same even if the plug-in time shifted to 10 or 11 pm. This is the advantages of modified charger combining with the timer circuit. In this case the peak load is significantly reduced as well as reduces energy consumption. Fig. 4.12. Combines circuit diagram of modified charger with timer control circuit.

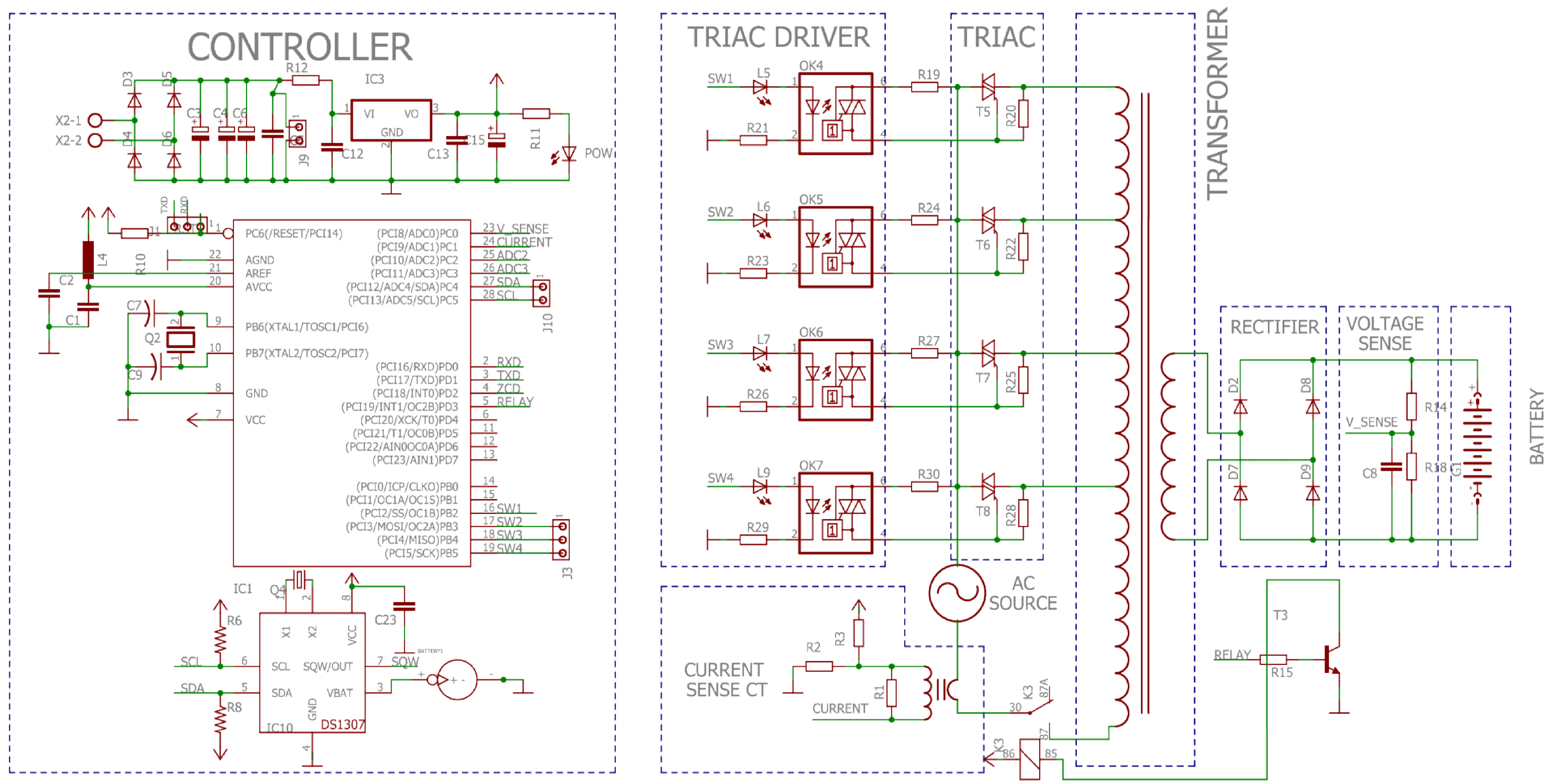


Fig. 4.12. Combined circuit diagram of modified charger including timer circuit

4.4. Summary

In this chapter the design and construction of modified battery charger has been formulated. The design was simulated and verified. The timer control system and circuit design was further developed and integrated with the modified charging system. In the next chapter the constructed modified charger after necessary test will be evaluated and test result will be analysed. With the timer control mechanism so developed will be verified for load management of the charging system.

CHAPTER 5

TEST RESULTS ANALYSIS AND DISCUSSIONS

5.1. Introduction

The developed system was tested in the laboratory for a week. Two vehicles with similar battery condition were selected for the study. One of them was charged by the modified charger and other with the conventional charger. Since there was a need of the continuous measurement of the electrical parameters during the charging of the vehicle, a commercially available data-logging system was used with both the chargers. The data-logger measures and stores electrical parameters such as voltage, current, power, power factor and efficiency. The data for seven days were analyzed. In the continuous time domain energy can be calculated from the following equation.

$$E = \int_{t1}^{2} P(t)dt \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (5.1)$$

Where, $P(t)$ is the power function in continuous time domain. For the purpose of calculating sample power data using a data acquisition system after a certain interval, discrete equation for energy measurement is required. Discrete equation for Energy measurement can be written,

$$E = \sum_{i=1}^{i=N} P_i \Delta t \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (5.2)$$

$$E = (P_1 + P_2 + P_3 + \cdots P_N)\,\Delta t \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5.3)$$

Here, Δt is the data sample time interval.

Now, the energy for both existing and modified charger was calculated using the above mentioned equation.

5.2. Lab Test Result

The modified charger is designed to follow the lead acid battery charging cycle. It charges the battery with a constant current of around 12-15 amp. When the voltage becomes 80V, it stops charging and waits for 10 minutes. Then it switched on again to top up the losses and switched off when the voltage reached 80V. It continues to provide tickle charge for every 10 minutes as long as the charger is connected to the battery. The conventional charger charges the battery in constant voltage mode so its current goes down as the battery voltage increase. The charger continues to inject currents to the battery even when the battery voltage saturates. Table 5.1 shows a comparative results of two charger for 7 days. The modified charger needs 7 to 9 hours to charge the battery. The conventional charger continues to charge the battery as long as the system with the battery is connected to the power supply.

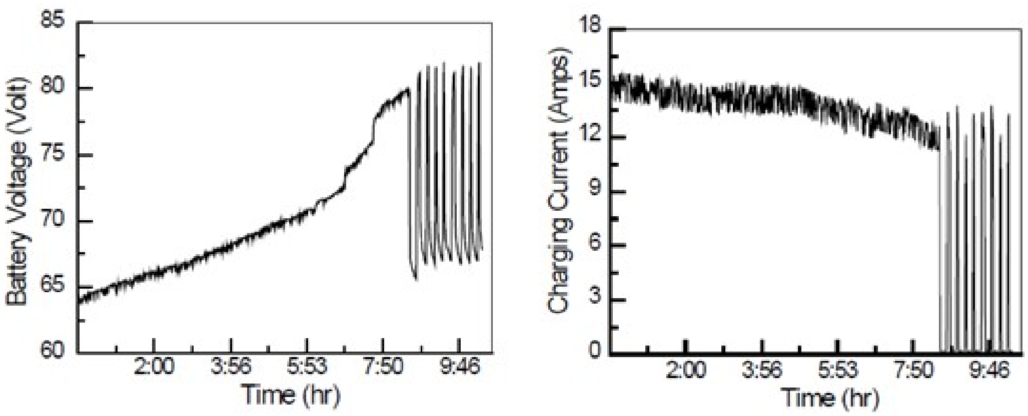
Table 5.1. Comparative results of existing and modified charger

Event	**Charger**	**Day -1**	**Day -2**	**Day -3**	**Day -4**	**Day -5**	**Day -6**	**Day -7**
Charging Time (hrs)	Con	12.20	12.51	12.26	11.14	11.01	12.44	12.22
	Mod	8.30	8.01	8.31	8.28	9.11	6.58	7.33
Energy Consumed (kWh)	Con	13.59	13.88	13.75	13.77	13.51	13.71	13.80
	Mod	11.18	10.02	11.05	11.15	11.35	9.48	9.45

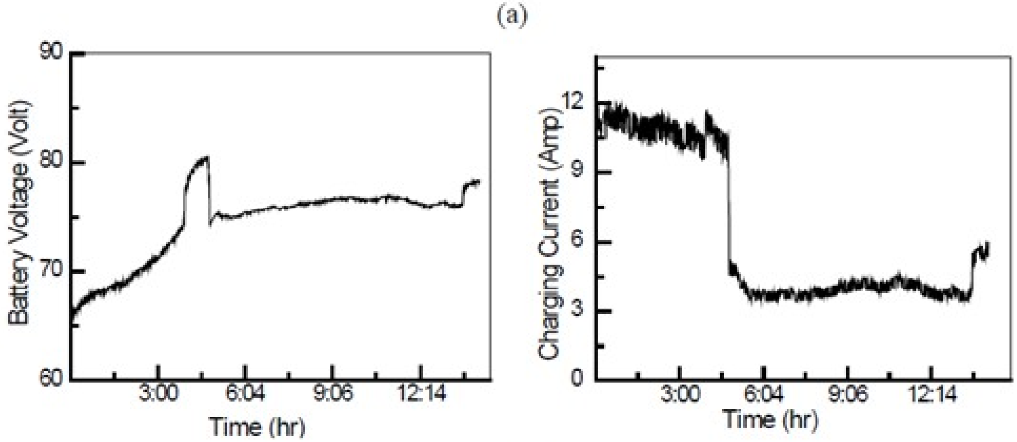
Note: Con and Mod stand for conventional and modified charger, respectively.

5.3. Lab Test Analysis

From the test result it is observed that the time taken by modified charger to fully charge the battery is much lower than the conventional charger. The energy consumed by the system with the modified charger is also lower than the system charged with the conventional charger. Fig. 5.1 and fig. 5.2 shows the charging pattern of the two chargers for Day 1 and 7 respectively. In the graphics of modified charger it is observed that the charging voltage rises gradually till it reaches to 80 V and then tickles with respect to tickle charging. Similarly current remain constant in between 12 to 15 amp till the voltage reaches to the desire voltage and then tickle with respect to time. In case of conventional charger current falls abruptly after certain time and both current and voltage is not stable. In case of modified charger as the process is not continuous, the amount of gassing reduces considerably. The loss in the system is also small. In case of conventional charger since charging continues even after full charge, so it causes excessive gassing and increase in battery temperature. In case of modified charger the quality of voltage and current waveform much smoother than the existing charger waveform.



(a)



(b)

Fig. 5.1. Charging voltage and current for day 1 (a) Mod charger (b) Con charger

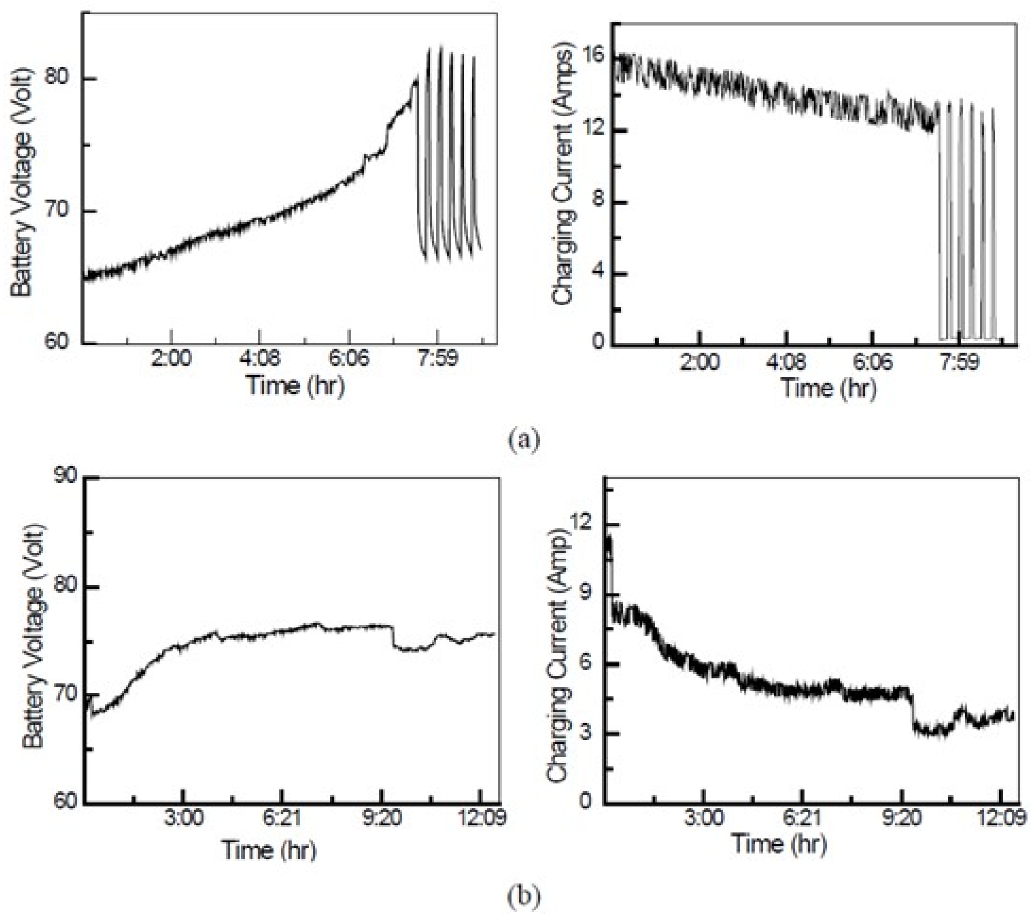


Fig. 5.2. Charging voltage and current for day 7 (a) Mod charger (b) Con charger.

5.3.1. Data analysis

From table 5.1 the average energy consumed by modified and conventional charger can be readily found. Table 5.2 shows average savings of energy and time by modified charger. Again from table 3.1 it is estimated that the average units consumed by 1 Million Easy Bikes is 12 x 10^6 Unit. From table 5.2 it can be easily found that total 3.2 x10^6 Unit energy can be saved if the entire Easy-bikes are charged by the modified charger.

The percentage energy saved with the modified charger will be 26.67%, which is very substantial amount and will reduce the negative effect of power grid. As such, the overall effect of power grid will be reduced by 1.87%, which is also a substantial amount.

Table 5.2. Average energy and time savings by modified charger

Event	Charger	Average Result	Average savings by Mod Charger
Charging Time (hrs)	Conventional	11.97	3.98 hrs
	Modified	7.99	
Energy Consumed (kWh)	Conventional	13.72	3.20 kWh
	Modified	10.53	

5.3.2. Cost benefit analysis

The average cost of the charger as found from the survey report is BDT 3,750.00. For the modification the cost involvement is BDT 600.00 (Details are attached as Annex to this paper), which is 16 % of the charger cost. The tariff rate as fixed by DPDC for the charging of EV is BDT 7.70 per Unit already mentioned in previous chapter can be utilized for cost analysis. As already found out total energy saved per Easy-bike is 3.2 Unit if charged by a modified charger. As such, total money saved per Easy-bike per year could be easily calculated would be BDT 8,993.60, which is much higher than the charger modification cost. Details of cost benefit analysis are shown in table 5.3 and table 5.4.

Table 5.3. Increased cost of modified charger

Average Cost of Existing Charger (BDT)	Modification Cost (BDT	Percentage of Cost Increased (%)
3,750.00	600.00	16

The modification cost would be 6.67 % of saved amount, as such overall savings will be BDT 8,393.60 per modified charger per year and the effect on power grid will be substantially reduced. As the energy can be saved by using modified charger, individual driver will also be benefited due to the reduction in charging cost, as the charging time and unit consumption per vehicle is reduced.

Table 5.4. Overall savings of modified charger

Energy Saved per Day per Mod Charger (Unit)	Tariff Rate (BDT)	Cost Saved per Year per Mod Charger (BDT)	Overall Saved per Year per Mod Charger (BDT)
3.2	7.7	8,993.60	8,393.00

5.3.3. Load management by timer control mechanism

The electrical grid of Bangladesh needs to adapt to address the effect of electric vehicles. According to the analysis of the pattern of connection, if all the EVs are connected to the grid after 10 pm a significant reduction in peak load can be ensured. It is expected that 70% of the total Easy-bike is connected to the grid and with average consumption of 1 KW by one Easy-bike highest 700 MW load can be shifted from peak hour to off-peak hour in this process. By controlling the charging system using timer control mschsnism, as described in previous chapter, substatial amount of load can be shifted from peak hour to off-peak hour.

Most of the the drivers plying vehicles in urban area and complete their trips by 6 to 7 pm. Thus vehicles are connected to the grid for charging as soon as they return to the garage. Thus EV charging connection to the power grid in peak hour may be restricted technologically by timer mechanism. Table 5.5 shows suggested percentage of vehicle that may be connected to the grid to eradicate the problem. In this process it is assumed that 90% vehicles will be plugged in by 10:30 pm from 10 pm. Since charging time of modified charger to charge the battery fully is almost 8 hours and the habit of most of the driver is expected plug out vehicles will be 6 am. Rest of the vehicle may be plugged out by 8 am. There are some Easy-bike drivers who may come for charging or topping up even during day time between 8 am to 5 pm, thus provision to be kept to connect during off-peak hour till 5 pm.

Table 5.5. Suggested percentages of vehicles plugged in and plugged out from grid

Status	Time	Percentage of Vehicles (%)
Plug-in EVs	10 pm to 10:30 pm	90
	10:30 pm to 11 pm	10
All connected	11 pm to 6 am	100
Plug-out EVs	6 am to 7 am	60
	7 am to 8 am	30
	8 am to 5 pm	10
Not connected	5 pm to 10 pm	100

Table 5.6 shows percentage and amount of load that can be shifted as per suggested plug in and plug out time from peak hour to off-peak hour using timer control mechanism.

Table 5.6. Load management using timer control mechanism

Time	Surveyed Load (%)	Suggested Load (%)	Shifted Load (%)	Shifted Load (MW)
Load shifted between 7 to 8 pm	20	-	20	140
Load shifted between 8 to 9 pm	40	-	40	280
Load shifted between 9 to 10 pm	90	-	90	630
Load balanced between 10 to 11 pm	100	100	-	-
Load balanced between 6 to 7 am	40	40	-	-
Load balanced between 7 to 8 am	10	10	-	-
Load balanced between 8 am to 5 pm	10	10	-	-

The analysis shows that the peak load has been shifted significantly from peak hour to off-peak hour. Fig. 5.3 shows the graphical representation of load reduced from peak hour using timer circuit. It can be observed from the graph that the maximum load has been reduced by 630 MW in the time range between 9 pm to 10 pm due to the shifting of the charging load which is very significant and reduce the effect of East-bike charging load of power grid.

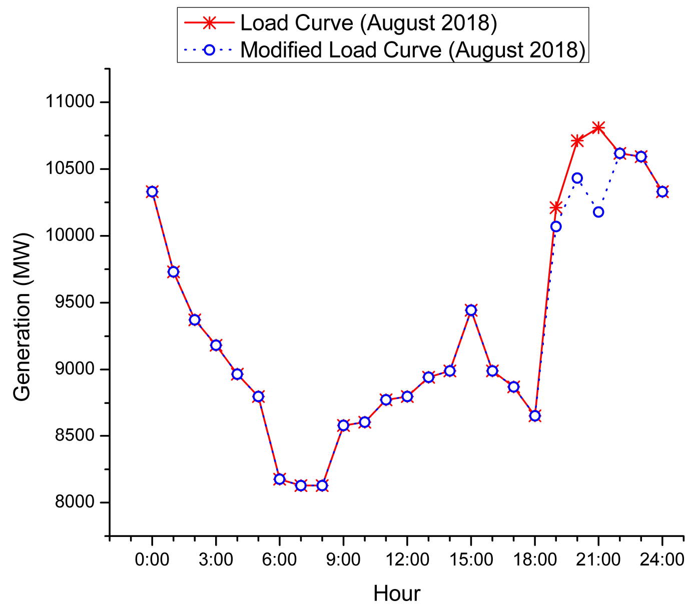


Fig. 5.3. Load reduced from peak hour using timer circuit

5.3.4. Other results

Other results found out from modified charger are as follows:

- Controlled Charging Current has been achieved in this charging system.
- Overcharging problem could be eradicated.
- Gassing due to overcharging could be eliminated.
- Water refill requirement of battery could be decreased.
- Battery life would be increased due to the elimination of overheating problems.

5.4. Summary

In this chapter the results of the lab test for modified and existing conventional has been analyzed. The energy consumed by the modified charger has been compared with the existing charger and found much more efficient. A timer control mechanism was further evaluated to manage load for shaving it from peak hour. In the following chapter the research findings will be discussed. Furthermore, suggestion will be proposed for future study and smooth management of EV operation.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1. Conclusions

In this research work, an inclusive study has been carried out on the effect of Easy-bike on the Bangladesh national power grid. In the process, important characteristics were analyzed for specific trends and data for the research on the effect of Easy-bike charging system. The results of the analysis verified that, over the course of the last eleven years, after the deployment of the Easy-bike, the peak generation hour has been shifted from 7 pm to 9 pm. A huge load was consistently observed at night from 7 pm to 8 am the next day. The represented results indicate that this extra consumption is due to the integration of a dominant load like EV charging, which is approximately 700 MW and effects peak hours. A survey was also carried out for an in-depth analysis of the effects of Easy-bikes. Various important technical facts and problems has been found out, especially on Easy-bike battery and charging system. Currently the charging procedure is uncontrolled, and no safety measures are taken for overcharging conditions. An efficient microcontroller based charger has been developed to eradicate the problem found in existing charger. It will save energy, reduce charging time and reduce load during peak hour. A timer controlled charging circuit has also been developed to reduce load from peak hour.

6.2. Research Findings

A research work has been carried out on design and development of charging system of battery operated electric vehicle. The research findings are appended bolow:

- Survey results show that the current charging process is uncontrolled, and no safety measures are taken for overcharging conditions.
- The results of the analysis of power grid verified that over the course of last eleven years, a huge load is consistently observed at night from 7 pm to 8 am the next day and the peak generation hour at peak hours has been shifted from 7 pm to 9 pm.
- The represented results indicate that this extra consumption is due to the integration of a dominant load like EV charging which is approximately 700 MW every day, mostly, during peak hours.
- A microcontroller based charger control circuit has been designed and developed which can works with safety in overcharging conditions.
- The performance of the developed charger has been tested and found efficient in terms of energy, time and cost saving in comparison with the existing charger.
- A substantial amount of load can be reduced from peak hour if the developed timer control mechanism is implemented.

6.3. Future Work

Easy-bike charging system and its effect on national power grid is a vast topic. There are lot many scope for both researchers and Government to study and make the system more controlled and efficient. Few suggestions for the scope of future work are appended as follows:

- A circuit may be developed to improve the power factor of charging system.
- A circuit may be developed to reduce harmonics and phase unbalance problem of charging system.
- Transformer core loss can be reduced by efficient design and material selection.

- Alternate battery technology (secondary Li ion) can be explored for Easy-bikes.
- Solar charging of Easy-bike can be integrated to the system.
- Further study may be made on charging management system and suggest efficient charging mechanism.

6.4. Summary

The power grid of Bangladesh needs to adapt itself to acclimatize the effect of Easy-bike charging. Integration of EVs, like Easy-bikes, to the electrical grid is a very important concern and it requires profound research on their effects. It is found that there has been a significant shift in peak load due to the huge charging power consumption of EV. Therefore, it is high time that the Government of Bangladesh give proper attention to this serious issue and control the time of charging to prevent the distribution congestion and loss of power. Developement ofefficient and cost effective charger and controlled charging procedure may help to solve this serious issue.

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APPENDIX A

<u>ইজি বাইক সার্ভে ফর্ম</u>

১। গাড়ীর বডি নম্বর ঃ

২। গাড়ী প্রস্তুত কারকের নাম ঃ

৩। কেনার সাল ঃ নতুন/পুরাতন

৪। সর্বশেষ ব্যাটারী বদলানোর তারিখ ঃ

৫। ব্যাটারী বদলানোর খরচ ঃ

৬। ব্যাটারী প্রস্তুত কারকের নাম ঃ

৭। ব্যাটারী সাধারনত কতদিন চলে ঃ ব্যাটরী সংখ্যা/ভোল্টঃ

৮। ব্যাটারীর গ্যারান্টি আছে কিনা ঃ________________থাকলে কতদিন ঃ______

৯। ব্যাটারী চার্জারের দাম ঃ _________________ কোথা থেকে কেনা ঃ স্থানীয় বাজার/ঢাকা

১০। ব্যাটারীর চার্জ কোথায় করা হয় ঃ বাড়ি/গ্যারেজ প্রতিদিন চার্জের খরচ ঃ

১১। এক চার্জ এ (সারা রাত চার্জে) আনুমানিক কত কিলোমিটার চলে ঃ

১২। ব্যাটারীর পানি কতদিন পরপর লাগে ঃ

১৩। ব্যাটারীর পানি হিসাবে কি ব্যবহার করা হয় ঃ

১৪। চার্জে বসানোর সময় ঃ______________এবং খুলে নেয়ার সময় ঃ_____________

মন্তব্য (যদি থাকে) ঃ

স্থান ঃ

তারিখ ঃ

____

স্বাক্ষর

APPENDIX B

ইজি বাইক সার্ভে ফর্ম

১। গাড়ীর বডি নম্বর ঃ

২। গাড়ী প্রস্তুত কারকের নাম ঃ সবেল বোরাক

৩। কেনার সাল ঃ ২০১৫ ইং নতুন/পুরাতন

৪। সর্বশেষ ব্যাটারী বদলানোর তারিখ ঃ ১২/১০/২০১৮

৫। ব্যাটারী বদলানোর খরচ ঃ ৫৪০০০

৬। ব্যাটারী প্রস্তুত কারকের নাম ঃ Power +

৭। ব্যাটারী সাধারনত কতদিন চলে ঃ ১৫মাস ব্যাটরী সংখ্যা/ভোল্টঃ ৫ পিচ ১২

৮। ব্যাটারীর গ্যারান্টি আছে কিনা ঃ না থাকলে কতদিন ঃ X

৯। ব্যাটারীর চার্জারের দাম ঃ ৪০০০ কোথা থেকে কেনা ঃ স্থানীয় বাজার/ঢাকা

১০। ব্যাটারীর চার্জ কোথায় করা হয় ঃ বাড়ি/গ্যারেজ প্রতিদিন চার্জের খরচ ঃ ১৬০

১১। এক চার্জ এ (সারা রাত চার্জে) আনুমানিক কত কিলোমিটার চলে ঃ ১৫০ কি মি.

১২। ব্যাটারীর পানি কতদিন পরপর লাগে ঃ ১৫ দিন

১৩। ব্যাটারীর পানি হিসাবে কি ব্যবহার করা হয় ঃ বৃষ্টির পানি না কেনা পানি

১৪। চার্জে বসানোর সময় সন্ধ্যা ৭টা এবং খুলে নেয়ার সময় সকাল ৮টা

মন্তব্য (যদি থাকে) ঃ

স্থান ঃ মিরপুর

তারিখ ঃ ০৫/০৫/২০১৭

সিরাজ

স্বাক্ষর