COST OPTIMIZATION AND COST ANALYSIS OF MEDIUM SCALE EV CHARGIGN STATION USING LINEAR PROGRAMMING

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JULY 2022

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A thesis
submitted as partial fulfilment of the requirement for the degree of

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JULY 2022

CERTIFICATE OF APPROVAL

The thesis entitled as "**Cost optimization and cost analysis of medium scale EV charging station**" submitted by **Md. Omar Faruk** , bearing Matric ID. **ET171027** and **Aly Azfar**, bearing Matric ID. **ET171004** of session **Autumn 2020**, to the Department of Electrical and Electronic Engineering, International Islamic University Chittagong, has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering and approved for the examination held on **22th July, 2022**.

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DECLARATION

It is hereby declared that this work has been done by us and no portion of the work contained in this thesis/project has been submitted elsewhere for the award of any degree or diploma.

Md. Omar Faruk

Md. Aly Azfar

ACKNOWLEDGMENT

All praises and thanks to Allah, the Lord of the world, the Most Beneficent, the Most Merciful for helping us to accomplish this work. For this Prototype development and report preparation, we would like to thank our thesis supervisor Engr. Md. Shahid Ullah, Asst. Professor, EEE, or his massive support and watchful guidance. Without his guidance, it was almost impossible to continue with the thesis work. He was very helpful and ever affectionate to endure the mistakes we had committed in the thesis work and always encouraged us by correcting our wrong proceedings. It was only the endless support offered by him that enabled us to complete this devoted task.

We would also like to thank our parents, faculty members, classmates and seniors for giving us inspiration all the time on completing the thesis. We are extremely blessed for having such kind people among us.

Authors

ABSTRACT

Energy storage system combined with an optimal energy management system can be a reliable solution for minimizing the grid energy costs for fast charging electric vehicle charging station integrated with on-grid photovoltaic system. In this study, the main goal is to optimize grid energy cost by optimizing energy management system for a medium scale electric vehicle charging station in the context of Bangladesh. The suggested solution (charging station with storage and EMS) is simulated in MATLAB, and its performance is evaluated using the Bangladesh energy regulatory framework and power tariff structure. Two different forecasting methods are used for forecasting PV output and grid electricity unitary price following peak, off-peak and super off-peak hours of national grid. The focus of the investigation is on the system's economic performance. Its cost-effectiveness is determined using an optimization technique that produces the best control strategy and necessary infrastructure design. Linear programming optimization technique is used to solve the problem. The energy cost is analysed by four case studies such only load, load with PV, load-PV with Heuristic EMS and finally load-PV with LP EMS. Different cost is found during different case studies. The most important elements for this analysis are charging load and tariff structure. Hence, electric vehicle infrastructure is near future for Bangladesh, charging demand is modelled using an artificial EV load estimator algorithm for 50 kW DC fast chargers. Overall, the results demonstrate that, based on forecasted data and load demand, the system might be a financially feasible cost-cutting alternative during peak-period pricing. On the other hand, demonstrates how input factors have a significant impact on system design and performance. The most essential of them was determined to be the power tariff, PV output and load demand. As a result, a thorough examination of this parameter's impact is carried out.

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LIST OF ABBREVIATIONS

ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
BERC	Bangladesh Energy Regulatory Commission
CCS	Combined Charging System
DSO	Distribution System Operation
DC	Direct Current
ESS	Energy Storage System
EES	Electrical Energy Storage
EMS	Energy Management System
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
GA	Genetic Algorithm
IEA	International Energy Association
ISO	International Organization for Standardization
LP	Linear Programming
MILP	Mix Integer Linear Programming
MINLP	Mix Integer Non-Linear Programming
MG	Micro-Grid
MT	Medium Tension
PV	Photovoltaic
PSO	Particle Swarm Optimization
RH	Rolling Horizon
SAM	System Advisory Model
THD	Total Harmonic Distortion
VRE	Vehicle Renewable Energy

CHAPTER 1
INTRODUCTION

1.1 Introduction

Electric vehicles (EVs) are gradually increasing on the street day by day, such as only electric vehicles and hybrid vehicles that have both fuel and electric power strains. As a result, pressure on the electricity grid is getting higher [1]. Electric vehicles (EVs) play a key role for renewable energy end-use because they allow fossil fuels to be substituted in critical modes of transportation, namely road and rail. In terms of demand, electric vehicle is not only energy efficient than fuel-based combustion engines but also it is more flexible for required energy sources like different kinds of renewable sources. Energy sourcing from various renewable sources might support in the greater integration of VRE. [2]. In terms of supply, various technologies such as vehicle-to-grid (V2G) may transform electric vehicles (EVs) into energy storage devices (ESD). The storage devices would really be capable to store electrical power from the electrical network throughout the low-peak time duration, and again draw down the stored energy back into the system when the energy is required the most. This would increase the grid's overall flexibility and make it more adaptable to changing needs [3].

Breakthroughs in the field of electric vehicles (EVs) were the primary focus of research and development in the year 2020, while initiatives to electrify marine vehicles and airplanes were limited [4]. It is possible to ascribe the rise in the number of electric vehicles (EVs) to favourable legislative conditions (such as tax incentives, stricter emission restrictions, and aid for electric vehicle charging facilities), in addition to the benefits that such vehicles provide [5]. Consumers in the developed countries like European country and USA continue to find the economic benefits shown in figure 1.1, environmental benefits, driving convenience and the novelty of possessing modern technologies make the vehicle attractive [6].

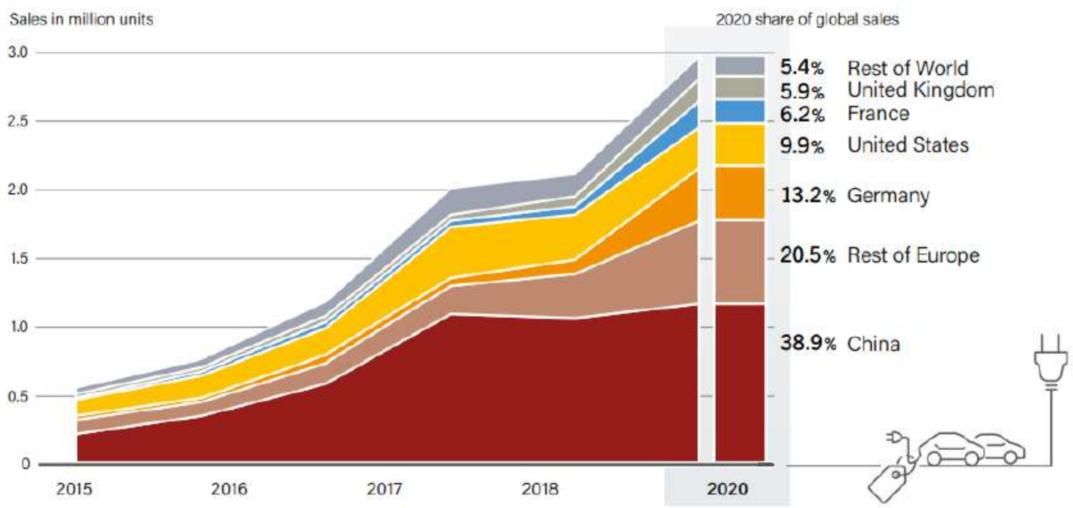

Fig 1.1 Global electric vehicle scenario [6]

According to a new report that was just published by the IEA today, global energy-related carbon dioxide emissions are on track to increase by 1.5 billion tonnes in 2021, which would be the second-largest increase in the history of the phenomenon. This would reverse the majority of the decline that occurred in 2018 because of the pandemic of COVID-19 [7]. A carbon-intensive recovery from the global financial crisis would see the highest yearly increase in emissions since 2021.

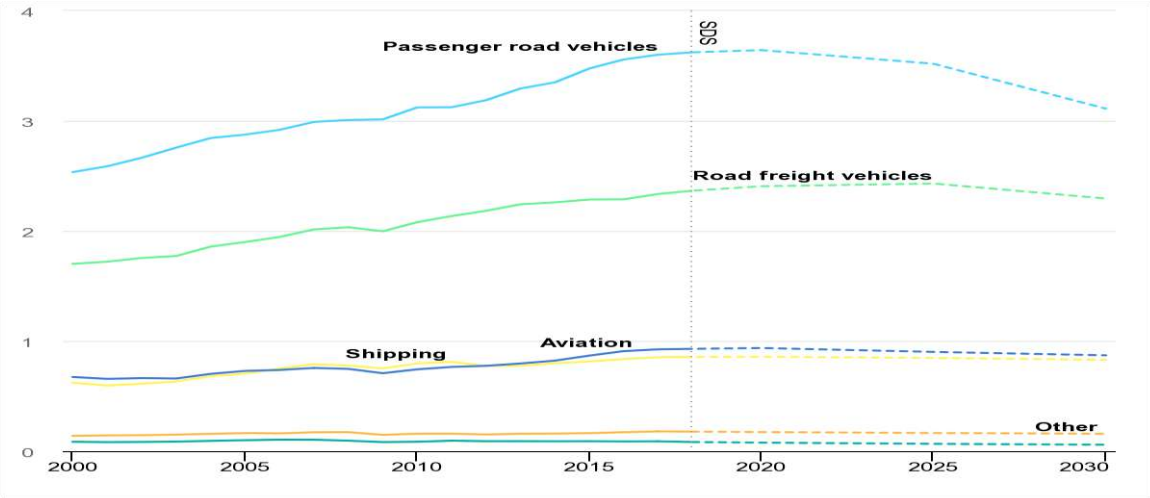

Fig 1.2 Transport sector CO2 emissions 2000-2030 [8]

The transport sector plays a big role in contributing to global carbon emissions. According to the IEA [8], the transport sector needs to contribute to 20 % (showed in figure 1.2) of the total emissions reduction to 2030. The transition to electric vehicles has the potential to cut down on carbon emissions produced by the transportation industry. The development of charging infrastructure has been driven by the growth of the market for electric vehicles (EVs), and this will continue to be the case. The number is bound to increase globally, primarily in developed countries and China, while traditional petrol stations will slowly start to decline. Bangladesh has to follow a similar trend. Bangladesh Energy Regulatory Commission (BERC) has introduced a new tariff under Medium Tension AC (MT-7) under 11 KV specially for EV Charging stations [9].

On the other hand, in Bangladesh maximum electric power plants are coal based [10]. Which means increasing electric vehicles will not reduce the carbon emission significantly and it puts a pressure on the national grid. An energy management system with a hybrid energy source can play a role in minimizing the grid use in case of Bangladesh. Several studies show that massive deployment of EVs will likely affect the power distribution grid if no upgrades on the existing system are performed and no smart charging methodologies are implemented [11]. Effects include voltage instability, increased peak demand, power quality problems, transformer heating and overloading [12]. These issues are even more relevant for quick- and fast charging. Due to their nature, focused on minimizing charging time, they are not compatible with dynamic charging [13], considered instead a viable and successful means of reducing some of the negative effects of home charging.

1.2 Motivation

The proposed thesis work showed a lack of a heuristic approach, encompassing both technical and economic analysis (economic viability) aspects for an EV DC fast charging station storage system. This project aims at covering this gap, further investigating the role that ESSs can play in the integration of fast charging stations into the electric grid, at any location of Bangladesh. The design of the storage system will be conducted, with focus on the economic performance as well as considering the impact on the distribution grid. The study intends to assess the feasibility of the solution and to provide a possible approach to implementing it in other similar applications.

1.3 . Objective and Research Question

- To optimize the cost of medium scale electric vehicle charging station through optimizing energy management system in the context of Bangladesh.
- To implement a Linear Programming optimization technique to efficiently optimize EV charging station and reduce the cost of energy for national grid

Research Questions

- How EMS work in the context of medium scale EV charging station
- How to minimize cost and maximize the profit of an EV charging station

1.4 Thesis outline

The thesis consists of seven chapters. After the introduction, chapter two describe the reader with some background information about current EV charging technology, energy storage, research gap and summary of proposed study. The third chapter focuses on the energy storage system and different kinds of energy storage methods where chapter four has covered the forecasting and estimation. Here, special attention is drawn on the PV forecasting and electricity prices, which are of particular importance to model the economic impact of the analyzed system. The most important part which is artificial EV load estimation is also described elaborately in this chapter. In the fifth chapter, methodology and the modelling process is described in detail. The mathematical formulation of the problem is presented. In the sixth chapter, the main simulation results are shown and briefly commented and an extensive discussion of the results and their implications. Both the economic and grid impact perspective are examined. Finally, the final chapter summarizes the key points of discussion and provides the reader with an overview of the work conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An energy management system (EMS) is a framework for industrial, commercial, and public organizations to control their energy consumption. It assists businesses in identifying possibilities for adopting and enhancing the energy-saving technology, particularly those that do not actually require huge capital investments. The successful implementation of an EMS usually requires specialized knowledge and staff training. According to the International Organization for Standardization (ISO), an energy management system entails formulating and implementing an energy strategy; establishing attainable targets for energy use; designing action plans to achieve these targets; and measuring progress. This could mean putting in place new energy-efficient technology, cutting down on energy waste, or making improvements to existing processes to lower energy costs [14].

2.2 Literature review of Energy Management System (EMS)

Several research have been done implementing various forms of optimization approach in order to solve the issues of energy management in a variety of contexts, including smart homes, microgrids of residential areas, electric vehicles, and EV charging stations, etc. For instance, Sukumar et al [15], suggested “a mixed mode MG EMS with power sharing, continuous run, and on/off switching. The power sharing mode considers power trading with the main grid, but the continuous run option requires the fuel cell to stay functioning. A linear programming (LP) optimization approach is used to solve both of these modes”. A mixed integer linear programming (MILP) optimization approach is used to implement the on/off mode., which optimizes MG operation in relation to main grid, fuel cell, and ESS on/off connection status. Communication technologies for MG operation MILP-based optimization model is proposed in [16], to compute energy consumption scheduling in MG EMS. For optimal energy management of residential MG, an operating cost-minimization model is proposed in [17]. It comprises energy trading cost, penalty cost on adjustable load shedding, EVs batteries wearing cost, the range anxiety term for electric vehicles (EVs). Three types of loads are considered: critical, adjustable, and shiftable loads. The range anxiety of EVs is characterized as the fear factor of running out of energy before reaching the destination. Risk level-based three scenarios in range anxiety terms are explored to analyse the trade-off between the operational cost of MG and the average state of charge (SOC) of EVs battery. In [18], Tenfen and Finardi came up with a plan for effective energy management to reduce the operating costs of MG and integrate curtailable and shiftable loads in DR. The objective function contains the O&M costs, start-up and shutdown costs, energy trading costs with the main grid, and load shedding cost. An isolated three-phase imbalanced MG is modelled using a mixed-integer nonlinear energy management system that has been developed here. It reduces the amount of fuel that is used, the expenses associated with starting up and shutting down CGs, and the penalty cost associated with meeting reactive power requirements. Structures are put in place for the mathematical models and ABCD parameters of the CG, ESS, transmission line, and transformer. The second phase of the proposed MINLP model, which is divided into two consecutive stages, includes MILP-based unit commitment models and nonlinear programming-based optimum power flow models. This deterioration solves the problems of disobedience and non-convergence where a mixed-integer nonlinear EMS model for optimal operation have proposed in [19] for an islanded MG considering DR. The developed model incorporates the operating cost of CGs as an objective function. Likewise, droop controlled active and reactive power transmission of AC side CGs and operation of water desalination units are also included as a constraint in the proposed model. In Reference [20], developed a strategic EMS for a grid-connected MG, which was restricted by an operating window for the nominal transformer operation and voltage security. The produced model uses the modified gradient descent solution technique to reduce MG operating cost using forward and backward sweep algorithms and calculates MG's power flow solution. Both of these are accomplished by utilizing the developed model. In Reference, [21] suggested "a contract-based deployment of the energy of parked EVs to minimize the operation cost of an MG by using two-stage stochastic programming." A multi-objective optimization concern for contract pricing of EV aggregators is piloted that models the uncertainty of deriving behaviours of EVs [22].

In reference [23], Strelec and Berka proposed an approximate dynamic programming technique to overcome the curse of dimensionality in the suggested EMS model of a grid-connected MG. Sensorial field weight regression and lookup table are used to compute the approximate value of the cost function. Different scenarios of load demand, wind speed, and ambient temperature are generated to evaluate their uncertainty in the proposed model, which uses economic dispatch and unit commitment operations to optimize the energy scheduling of MG. Like other optimization techniques, the rule-based optimization technique was also used in EMS. In reference [24], presented a rule-based EMS to achieve optimum operation of the MG by operating real-time switching between battery charging and discharging mode, off MPPT mode of PV, and load shedding mode depending on produced load imbalance and state of charge of the battery. Elsie et al. [25] developed, “a multi-objective EMS using Zigbee-based reliable communication infrastructure to do optimal MG operation to minimize operation cost, minimization of GHGs emission cost, and maximize energy trade profit.” A multi-objective economic load dispatching system for a remote MG that takes into account the expense of battery deterioration. Using a genetic algorithm (GA) and a rule-based method, respectively, it can do both day-ahead operations as well as real-time tasks. The real-time operation comprises diesel generator supply, battery supply, and load shedding options in a sequential order to keep load generation balance’s economical model and matrix real coded Genetic Algorithm based smart EMS model was proposed for a grid incorporated Microgrid in [26]. NN model were used for solar power prediction. The ESS economical model optimizes the operation, and maintenance costs and maximize the energy arbitrage revenue. Similarly, in reference [27], Golshannavaz et al. suggested an EMS that was based on a GA in order to improve the generation and reserving schedules of a grid-connected MG. It does this by modelling the unpredictability of wind power and load demand using a technique of scenario development and reduction. The operating cost, the energy purchase cost, the reactive power support cost, the active power reserve cost, the demand-responsive cost, the load shedding cost, and the switching cost of automatically controlled switches cost are all included in the objective function.

This is done in order to improve the technological and economic performance of MG. Radosavljevi et al. [28] proposed an optimal EMS for a grid-connected MG that evaluates uncertainties of RERs, load demand, and electricity price using the point estimate method. The efficiency of PSO in discovering the best solution is revealed to be better than GA, combinatorial PSO, fuzzy self-adaptive PSO, and adaptive modified PSO. In Reference [29], for optimal energy management of a grid-connected MG a differential evolution approach was suggested. The main objectives of the proposed study were optimal operational cost and reduce emission costs of MG. Operational cost of MG comprises bidding cost of DERs, DR incentives, and trading cost of energy with main grid. Yu et al. [30] proposed an optimal EMS for a grid-connected MG, which specifies the energy scheduling of MG with the purpose of its optimal economic operation. Ant colony algorithm is very known optimization technique for optimal EMS. In [31], a two-layer EMS model based on ant colony algorithm for an islanded MGwas suggested for optimal operational cost. It comprises the bidding cost of RERs, battery, CGs, penalty cost on load shedding, and DR incentives in both day-ahead scheduling and 5 min interval real-time scheduling layers. With experimental validation, three cases of normal operation, sudden high requirement of load demand, and plug and playability are studied. Marzband et al. [32] presented, “the gravitational search algorithm-based EMS of a remote MG to minimize MG's operating cost and the penalty cost on undelivered power where three cases of regular operation, sudden high requirement of load demand, and plug and play feature are taken into the concern to assess the efficacy of the proposed method with empirical validation”.

2.3 Research Gap

From the above-mentioned literature, most of the EMS is based on smart homes, residential areas, and home-based EV charging stations. Moreover, most of them only addressed the EMS of microgrid residential areas. But overlooked EMS for any specific EV charging station

2.4 Summary of Present Work

The world is moving fast towards electric vehicles from fuel-based vehicles. As a result, the importance of electric charge station’s requirement increasing day by day. An electric charge station is nothing but a source of electrical energy. Energy can be used from different sources like solar, fuel base power generators or energy storage systems. Today the concept of microgrid also plays a potential role in energy sourcing which has more than one source of energy. But Energy management is very important for load balancing and cost optimization. We are proposing an energy management system (EMS) based on a rolling horizon (RH) strategy and linear programming optimization technique for a grid-connected solar-based Electric vehicle charge station. The optimization technique will take the forecast of gird price (following the peak and off-peak hour), power generated by solar, Energy stored in ESS, SOC of battery, time(24hours), and electric vehicle load as inputs. As output optimization technique will provide battery charging and discharging commands for one day-based constraint we provide.

2.5 Our Contribution

We did great research on energy management systems. We found different work on energy management and optimization like smart home energy optimization, and energy optimization for EV and residential areas using GA where but we didn’t find any work on energy management optimization for a specific electric charge station using linear programming. This is our contribution to work on an electric vehicle charging station energy management optimization using linear programming to minimize cost.

CHAPTER 3
ENERGY STORAGE SYSTEM

3.1 Introduction

Energy storage system is a part and parcel of Energy Management System (EMS) for EV charging station. In this chapter we provided background information about electrical energy storage system and energy storage management system. An overview of the management of storage methods and related technologies will be followed by a general description of possible applications.

3.2 Overview of ESS

Several decades have passed since the application of energy storage. During the 1800s, batteries were developed, and during the early 1900s, the first pumped storage installations were put into operation [33]. More recently, the use of storage has been growing alongside the proliferation of portable gadgets, the electrification of the transportation sector, and the expansion of variable renewable energy sources (mostly wind and solar power), amongst other factors. Since the output of renewable energy sources has been going up recently, the power grid needs to be more flexible. This can be done by balancing supply and demand through energy storage [34]. The use of storage technology has the potential to improve the proportion of variable renewable energy (VRE) in power grids by lowering the amount of curtailment and boosting flexibility. However, because renewable energy sources are irregular, there are significant challenges such as energy generation and load maintenance for the system's stability and reliability. Many practical methods have been sought to satisfy these criteria, including electrical energy storage, or EES, where load shifting is achieved through demand management and grid connectivity, among others. EES identified the most promising and dependable procedures among all possible options [35].

Subsequently, there are many forms of energy storage (and key technologies) include mechanical (pumped storage, flywheels), electrochemical (batteries, including lithium-ion and lead-acid), chemical (hydrogen) and thermal energy storage (molten salt storage and hot water tanks) which are the preferable solution for load maintenance. Depending on the type of technology, storage duration can greatly vary: from less than 10 hours (e.g., some batteries) to seasonal storage (e.g., pumped storage). Battery energy storage systems were among the technologies with the most activity in 2020, as they are easy to deploy and benefit from cost reduction trends [36] which are described below.

3.2.1 Different Kinds Energy Storage System

As previously stated, there are many classifications based on techniques for electrical energy storage devices. Mechanical, Electrical, Electrochemical, Thermal, Chemical, and Thermochemical are some of the typical techniques of classification depending on the kind of energy stored in the system which are given in Table 3.1.

Table 3.1 Various types of Electrical Energy Storage (EES) Methods

SL NO	ESS METHOD	RANGE & DURABILITY	APPLICATION	INTRODUCER	YEAR
1	NAS battery (Natrium Sulfur battery [37]	• A durability rating of 15 years • The charge-discharge cycle is greater than 2250 times • Faster than an AC-DC converter by a factor of five • The optimal amount of capacity needed is 344.79 MVA • he capacity that is rated for use under normal conditions is 86.20 MVA	• Electrical Vehicles	Ford Motor company, USA	1966
2	Super Conducting Magnetic Energy Storage [38]	• An efficiency rate of 99 percent in the storage of energy	• Pumped Hydro system	Evolution by Boom and Peterson ins 1971	1969
3	Grid- Tie BESS (LiFEPO4 – battery energy [39]	• The effective utilization rate is 92.8% • At a switching frequency of 50 Hz, the peak efficiency is equal to 97.8 %	• Fast frequency Regulation • Load following • Extremely high-power factor • Low THD		40-50 years ago,
4	Lithium-sulfur batteries and lithium-air battery [40][41]	• An approximate energy density of 2,000 Wh/kg	• Frequency Regulation • Car Batteries Storage • UPS		40 years ago,
5	VRB flow batteries [42]	• 10,000 charge cycles • Lifetime of 20 years • Energy density is 25 Wh/l	• Frequency Regulation • Car batteries storage	Skyllas-Kazacos and co-workers	Early 1990s
6	Hybrid energy storage system [43]	• HESS comprises of SMES and battery. • Higher power density of SMES	• Wind energy resource • Grid operation		Early 2000s

		• Increased capacity for energy storage in Li-ion batteries • Rapid reaction			
7	Double-layer capacitor or HESS supercapacitors	• Benefits that come with using batteries as well as supercapacitors	• In order to quickly control the voltage on the grid • Grid stability • Electric vehicle		1960s

3.2.2 Energy Storage System of the model.

The mathematical formulation of the model does not limit the simulation to a specific storage technology. However, the proposed design and discussion includes any particular storage method and technology. In this study, an energy storage is designed (showed in figure 3.1) in MATLAB application with some specific parameters which is shown in table 3.2.

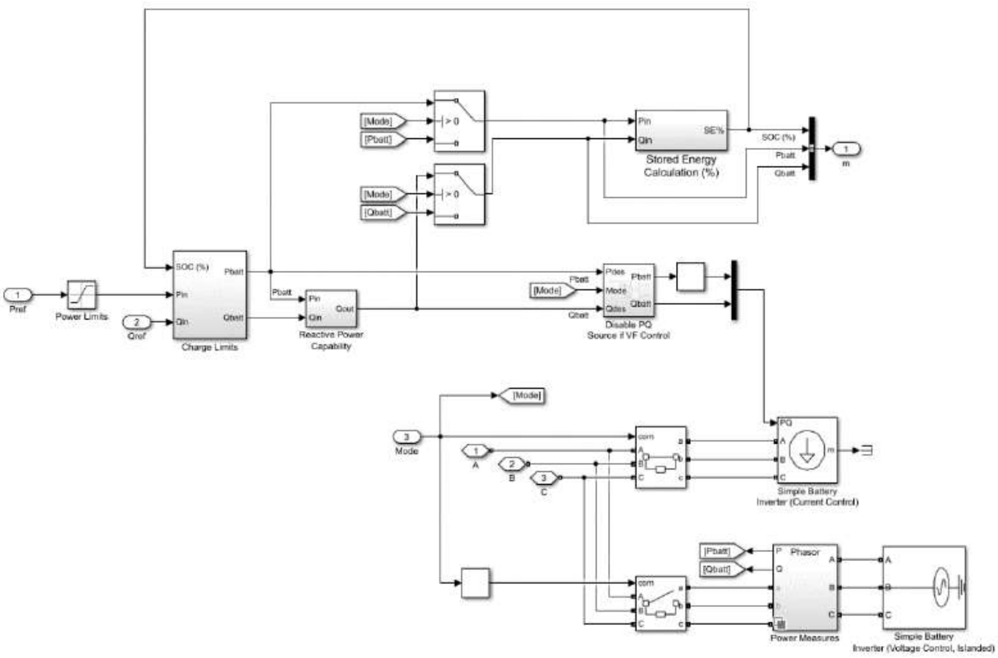

Fig 3.1 ESS model design in MATLAB

Table 3.2 ESS parameters

Parameters	Value
Rated Power	400kw
Capacity	2500 kw
Efficiency	96%
Initial SoC	50%
Lowest SoC	11%
Nominal frequency	50Hz
Line-Line voltage	11kv
Simulation mode	Phasor

CHAPTER 4

FORECASTING AND EV LOAD ESTIMATION

4.1 Introduction

This chapter illustrates the methods for the purpose of irradiation and electricity price forecasting and also shows an artificial algorithmic EV load profile generator for simulating EV load profiles under diverse circumstances.

4.2 Forecasting

Autoregressive integrated moving average (ARIMA) – based forecasted PV output, ARARMA based forecasted electricity price and load demand forecast used as LP based EMS input signal.

4.2.1 PV output forecasting:

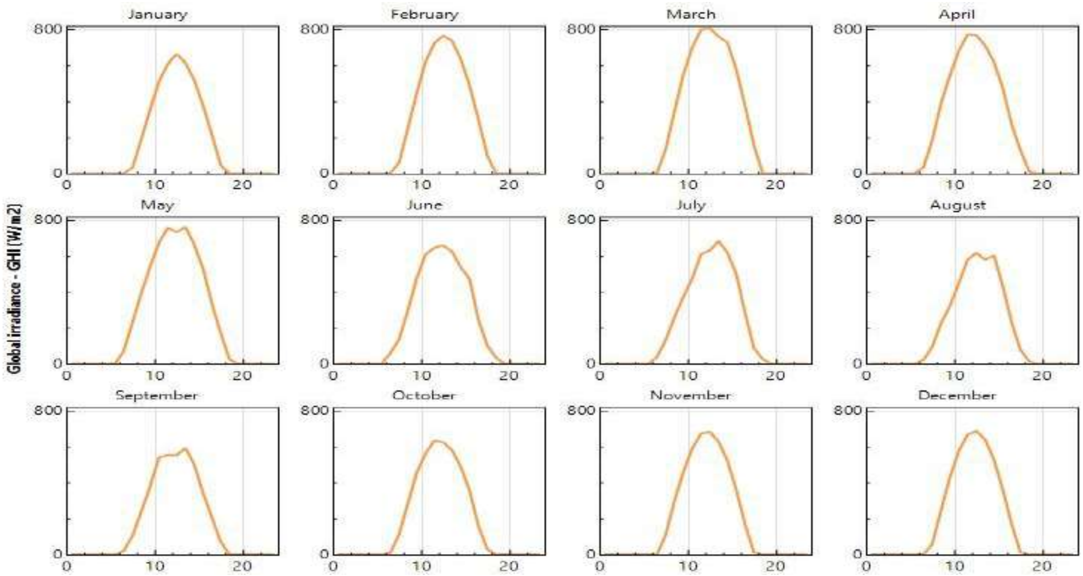

Fig 4.1 Irradiation profile for a year [SAM]

There are two ways to forecast PV output, either using physical model or statistical model. For daily forecasting, a statistical model is the most effective tool. The ARIMA model is the most accurate statistical tool available when the temporal resolution is limited [44]. ARIMA model is considered for 24 hours forecasting, yearly data (showed in figure 4.1) like irradiation, temperature and clear index were allocated from System Advisor Model (SAM) [45]. ARIMA may be broken down into its primary components, which are the autoregressive component of class p (AR (p)) and the moving average component of class q (MA (q)). Differentiation was utilized in order to achieve the goal of making the series stationary in the integrated component of class d (I (d)). The PV output is shown in figure 4.2.

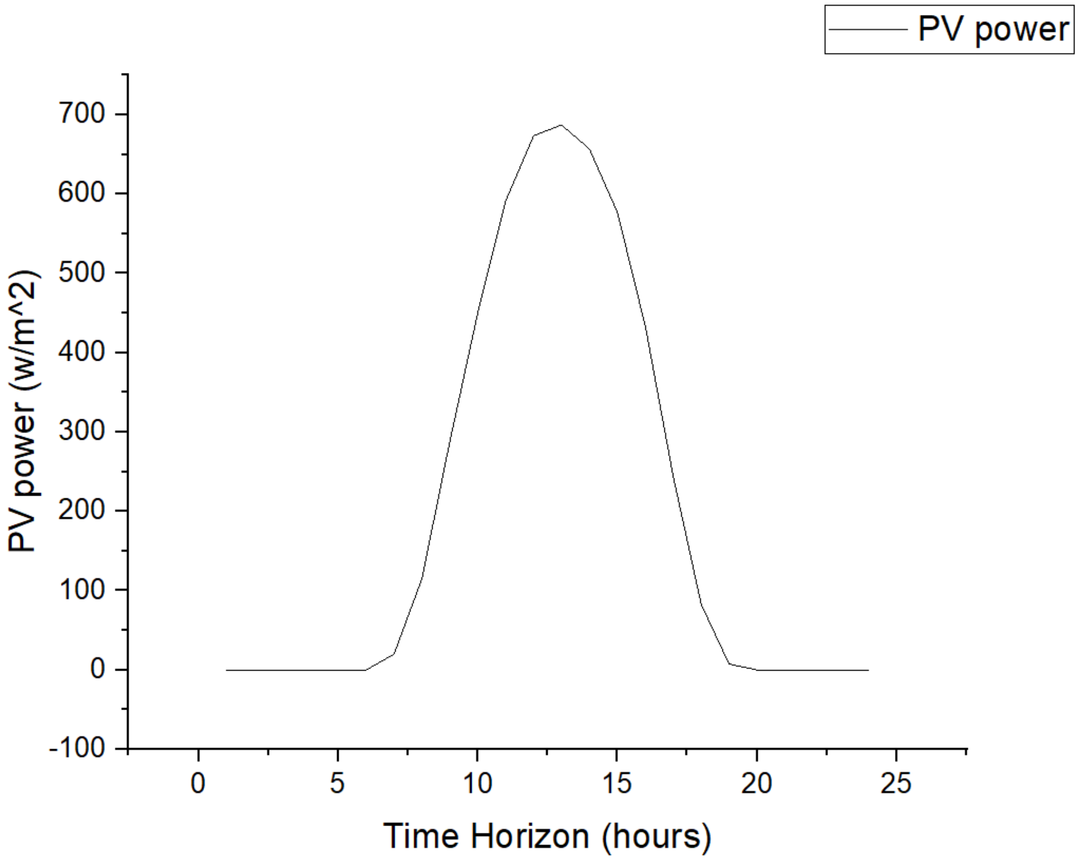

Fig: 4.2 Single day forecasted PV output [45]

4.2.2 Electricity Price Forecasting

For getting day ahead electricity pricing forecast, time series based ARMA model is being used. Both long-capacity and short-capacity forecasts are provided by ARIMA model [46]. This model is used to predict the unitary price of energy based on information from the Dhaka power distribution company in Bangladesh that has been collected over the past year [47]. The price based on peak, off-peak and super off-peak hour shown in figure 4.3.

Fig: 4.3 Day ahead grid electricity forecasted price. [49]

4.3 EV Load Estimation

For the estimation of electric vehicle load profile an artificial stochastic scenario generator is used [53]. The model was implemented in MATLAB software. In this model, the fundamental components of the selected scheme are shown in figure 4.4.

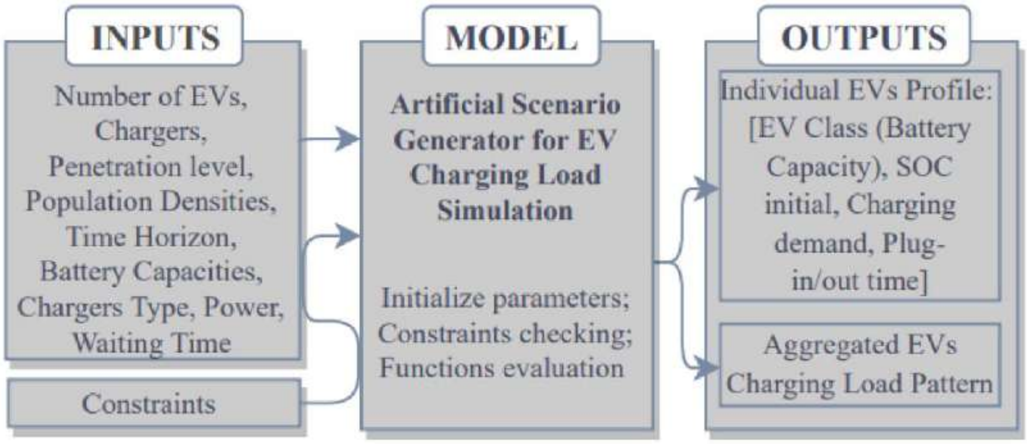

Fig 4.4 The selected scheme's basic structure [53]

However, these profiles are established on the charging behaviour of electric vehicles (EVs) in various sectors of the region. This behaviour was analysed to give a probabilistic framework for describing the stochastic nature of EVs, and it was used to create the profiles. An algorithm has been implemented in order to determine the timetable for the charging of electric vehicles and, as a result, accomplish the load profile in a way that is more accurate. We used three type of cars model’s data for generating day ahead EV charging load profile for 65% penetration level. Here the cars profile.

Table: 4.1 Cars profile.

Model	Battery Capacity(kwh)	Estimated 50kW CCS Charge Time (0-80%)
MG ZS EV [48]	50.30	60 minutes
Tata Nexon [49]	30.20	60 minutes
Tata Tigor [50]	26.00	65 minutes

This equation may be used to determine the number of vehicles ($\boldsymbol{n_{EV}^{i}}$) coming at a given time. [51]

$$\boldsymbol{n_{EV}^{i} = f_d\left(t_1, EV_{t1}^{exp}, t_{slot}^{i}\right) \; where \; lb < n_{EV} < ul} \qquad (1)$$

Where f_d is a probability density function that provides the number of EVs arriving during every 15 minutes of the day.

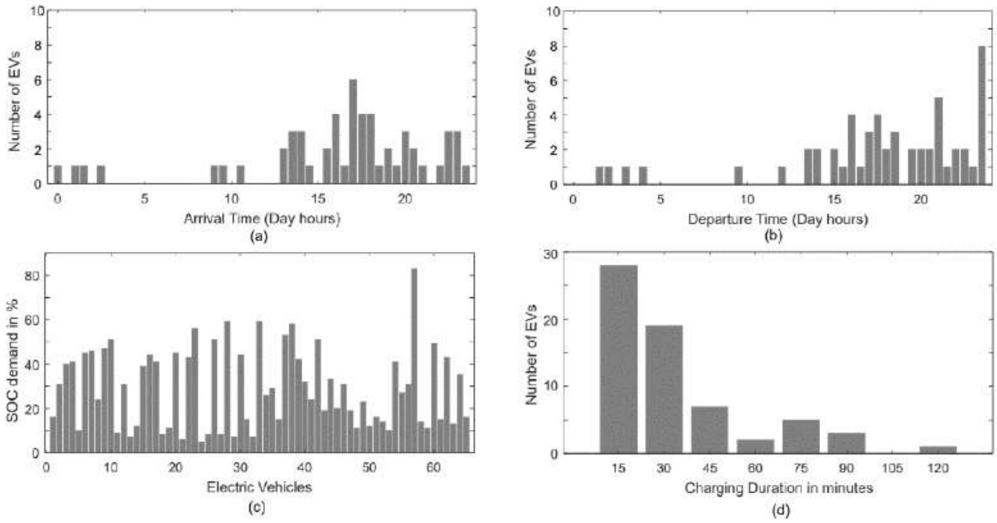

Fig 4.5 Different aspect of generated EV charging profile in MATLAB

In figure 4.5, there are four visual presentation of electric vehicle load under different scenario where in the first graph is showing number of EVs with respect to arrival time where in second graph is presenting the number of EVs with respect to departure time. In third and fourth graphs are showing SOC demand of each EV and charging duration of EVs respectively.

```
%Input Parameters
%Control Parameters for generating EV load profile
Total_EVs=100; % Total number of EVs in circulation in the region
Pen_Level=65; % Penetration level, Number of EVs charging consuming grid power

%For Charging profile in Resedential Sector
%Hrs of the day
TimeIntervals=[0,3,7,11,14,17,19,21,24];
% Number of cars during the above intervals of the day. CAN BE p.u FOR ANY NUMBER OF CARS
CarDist=round([6,0,5,7,17,26,22,17]*Pen_Level*Total_EVs/(100*100));

% 60 means, timeslot size is one second, and 60/15 means 15 mins size of timeslot
timeScale=60;
% Daily charge load profile 24 hours
timeHorizon=24;
%Time slots in the time horizon
timeSlots_t=timeHorizon*timeScale*60;
% in KWh , Battery capacities range
BC=[26,30.2,50.3];

chargingPower=50;%kW Charging Station capacity
chargers_count=10;% total number of charging stations
max_wait=15*60; % maximum waiting time of the EV to wait for its turn to charge

GenerateRandomSchedule_new_ScenerioGenerator(TimeIntervals,CarDist,timeHorizon,timeSlots_t,BC,chargingPower,chargers_count,max_wait);
run('PlotBox_ScenerioGenerator.m');
```

Fig 4.6 MATLAB input parameters for EV load estimation algorithm

All the necessary inputs like total number of EV, penetration level. EV battery capacity array and charging time for EV load estimation is shown in figure 4.6. Meanwhile the total load for single is shown in figure 4.7.

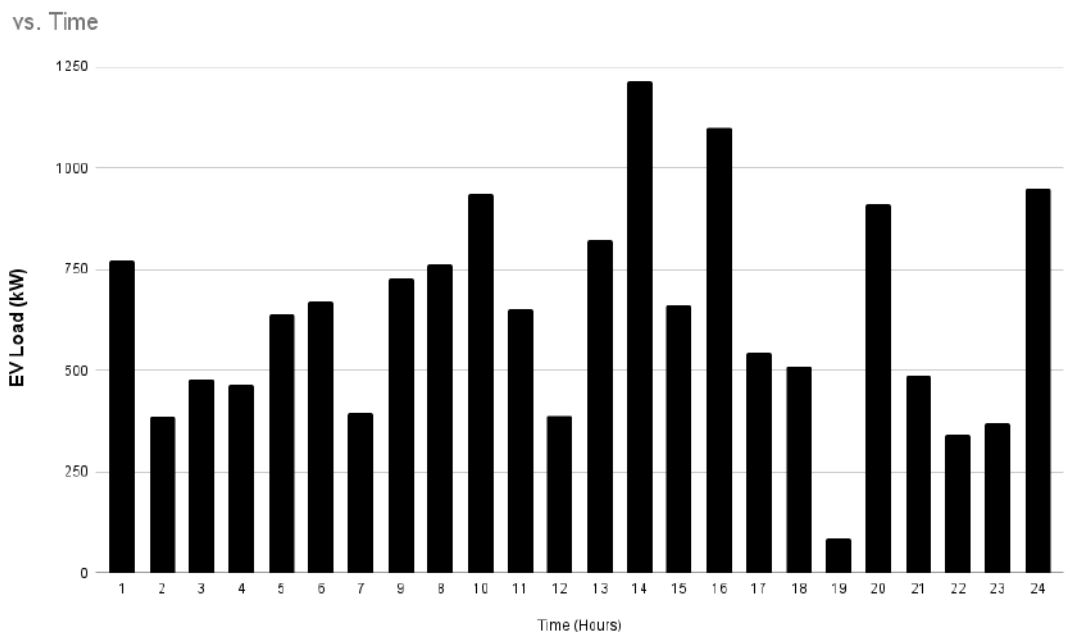

Fig 4.7 Single day EV charging demand [MATLAB]

CHAPTER 5

METHODOLOGY AND SYSTEM MODELING

5.1 Introduction

This chapter illustrates the work flow of the study with block diagram of the proposal, UML diagram proper explanation for better understanding and characterization in the section 3.2 and 3.3 respectively.

5.2 Block Diagram of EV Charging Station

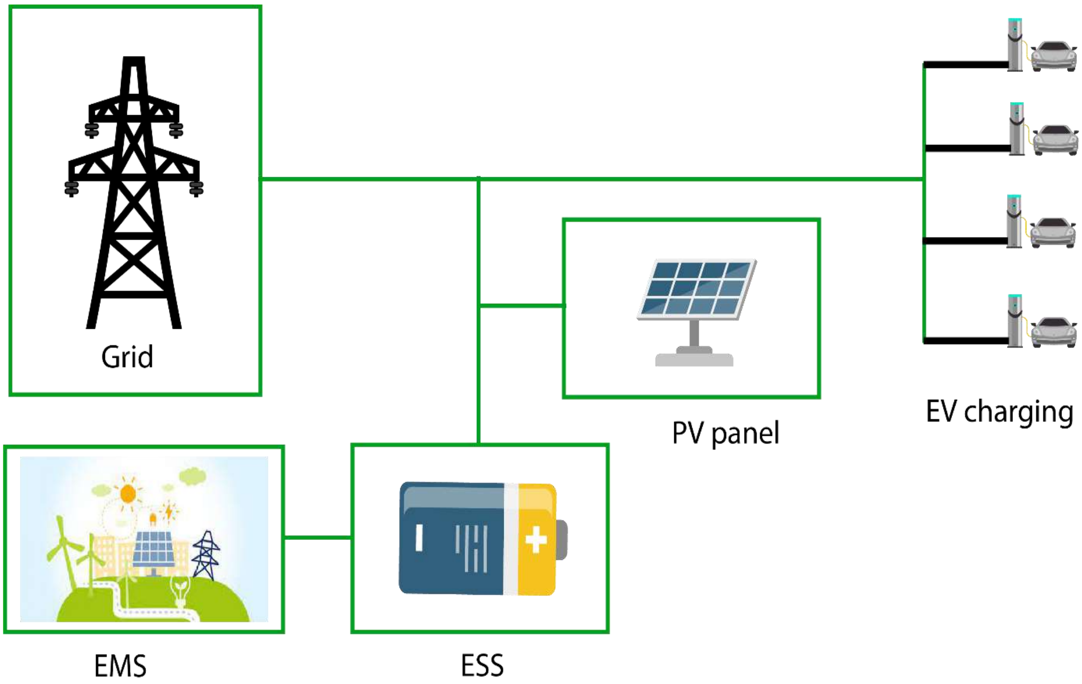

Fig-5.1 Proposed system block diagram

The main aim of the proposed optimal energy management system to minimize the grid energy cost of the EVCS. In this study empirical approach is used. The energy management system of the EVCS fulfils its charging demand with the power supplied from the PV system, grid and ESS (shown in figure 5.1) shows the proposed system with energy sources. To reach the optimal cost, electricity tariff, PV irradiation profile, Energy storage system and EV demand is taken into consideration. The EMS managed the charging and discharging of ESS following peak, off-peak and super off-peak hours of grid and electricity price.

5.3 Methodology

The process of complete study has been broken down into nine major steps which are shown in figure 5.2. In the beginning of the study different kind of electric vehicles profile like battery capacity, charger types, charging duration, car mileage is considered into analysis and has been selected three cars (shown in table: 4.1) for the load estimation using artificial load profile generator algorithm. Since assumed charging station comprise PV as power source, for short-term forecasting the output of PV for single day a modern linear model is used known as ARIMA. The main goal of the study is related with cost, the unitary grid electricity cost data is collected from Bangladesh power electricity tariff report 2020 where Authority of power sector in Bangladesh announced MT-7 category for specifically electric vehicle charging stations. After collecting all necessary data linear programming optimization technique is taken into consideration for optimizing the proposed charging station energy management system for minimizing the grid uses during peak hour which helps to get an optimal solution. Since linear programming is a mathematical process under some constraints, mathematical modelling and objective function is defined as next step after selection of linear programming as optimization technique. For implementation purpose and getting result under different case studies, simulation model of electric vehicle charging station (EVCS) is developed using MATLAB Simulink 2022b. Finally, the model simulates for different case studies and analyse the use of grid energy and cost.

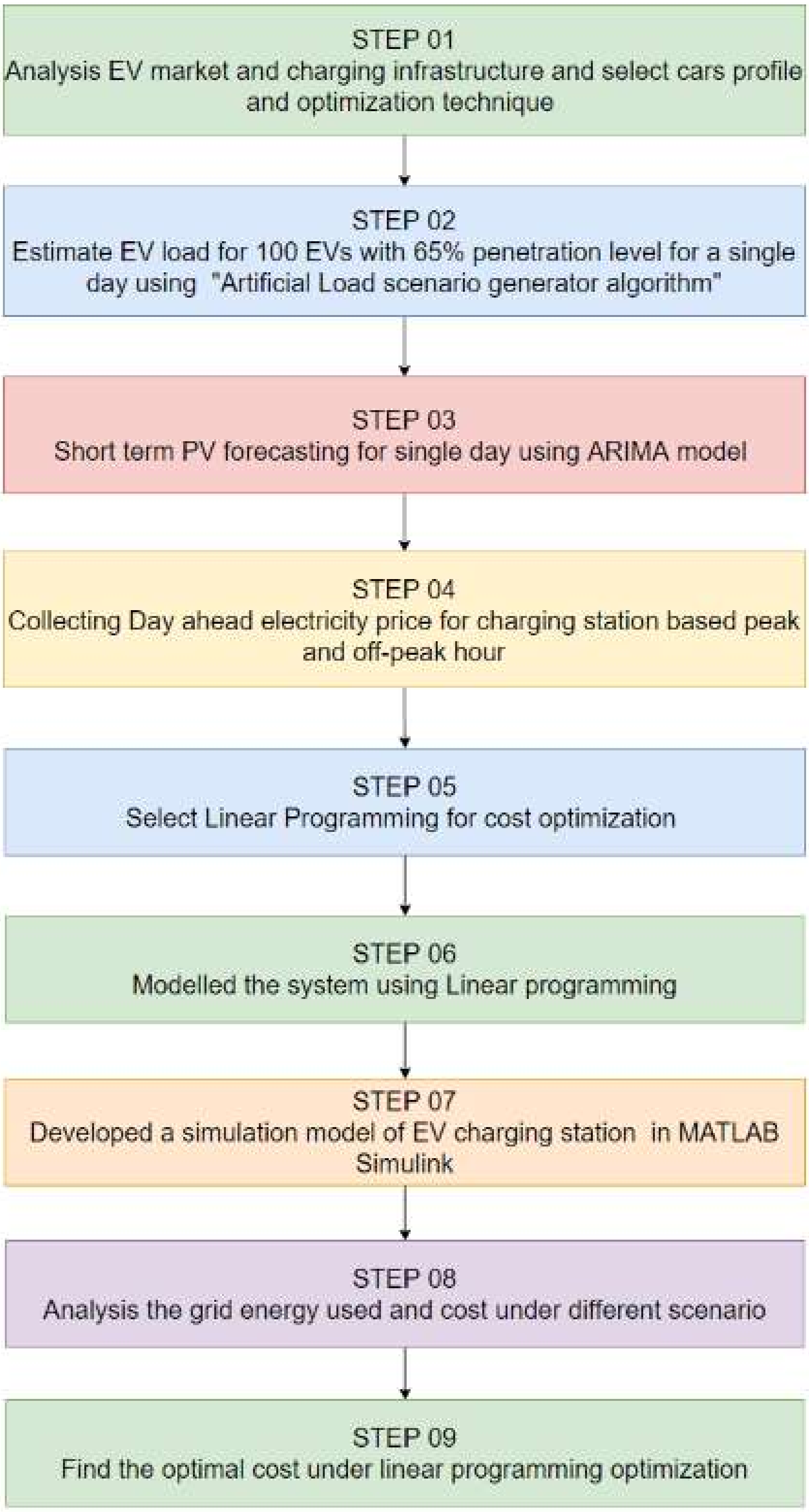

Fig 5.2 Flowchart of Proposed work

In order to get the whole process started, as mentioned before all the data are collected from different source like literature, website, and application (SAM). Data of EV load and PV output generation, as well as grid electricity pricing, were gathered and forecasted using a variety of time series-based models. The main optimization stage followed the pre-processing stage. EVs and ESS were charged first from the grid. Additionally, the grid supplied the energy to the system load which was primarily served by the ESS and PV. During periods of high electricity price or grid peak hour ESS discharged to maximize profit and skipped the peak hour of grid.

In the proposed system ESS is connected parallelly with PV. Through a uniform communication protocol, it was thought that the charging station could automatically figure out when an EV arrived, when it left, how much power it had when it started, and how much power it had when it stopped. Complete operation designed and implemented in MATLAB. Complete control flow or information flow and energy flow shown in figure 5.2

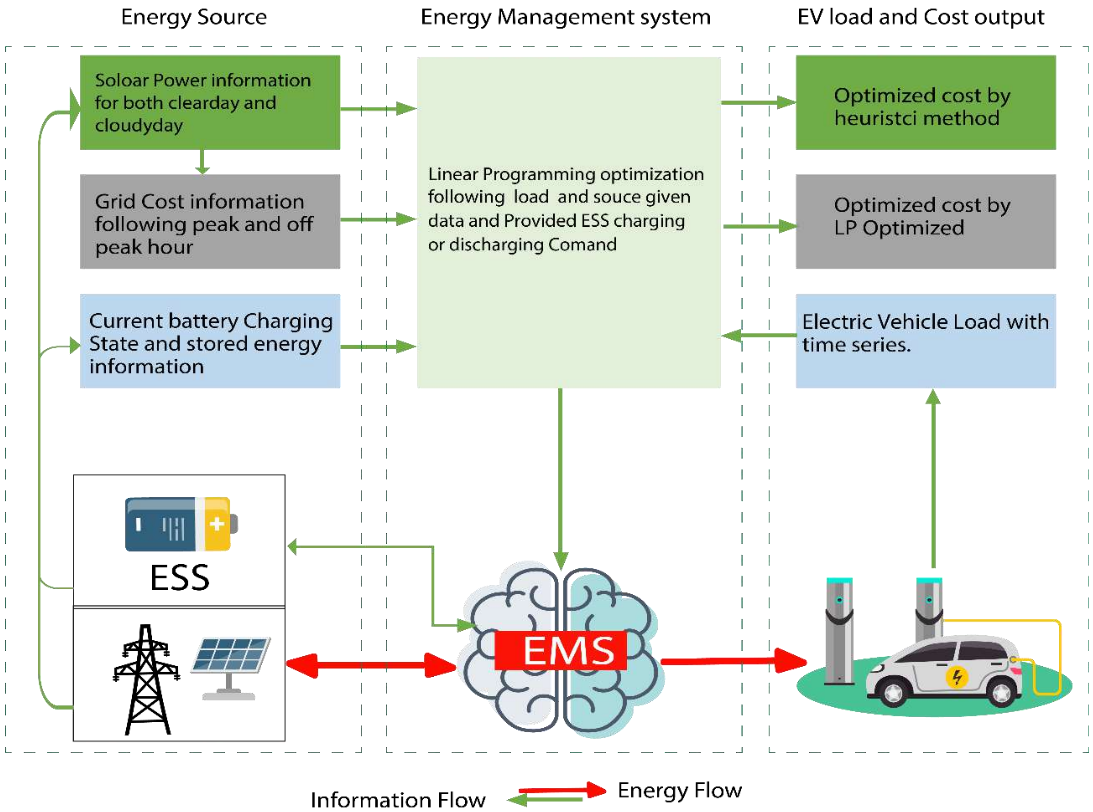

Fig 5.3: Energy and information flow of proposed EMS

5.4 Linear Programming

Linear programming (LP) or Linear Optimization may be defined as the problem of maximizing or minimizing a linear function that is subjected to linear constraints which is shown in figure 5.3. The constraints may be equalities or inequalities. The optimization problems involve the calculation of profit and loss. Linear programming problems are an important class of optimization problems, that helps to find the feasible region and optimize the solution in order to have the highest or lowest value of the function [54].

Linear programming is the method of considering different inequalities relevant to a situation and calculating the best value that is required to be obtained in those conditions. Some of the assumptions taken while working with linear programming are:

- The number of constraints should be expressed in the quantitative terms
- The relationship between the constraints and the objective function should be linear
- The linear function (i.e., objective function) is to be optimized

5.4.1 Components of Linear Programming

The basic components of the LP are as follows:

- Decision Variables
- Constraints
- Data
- Objective Functions

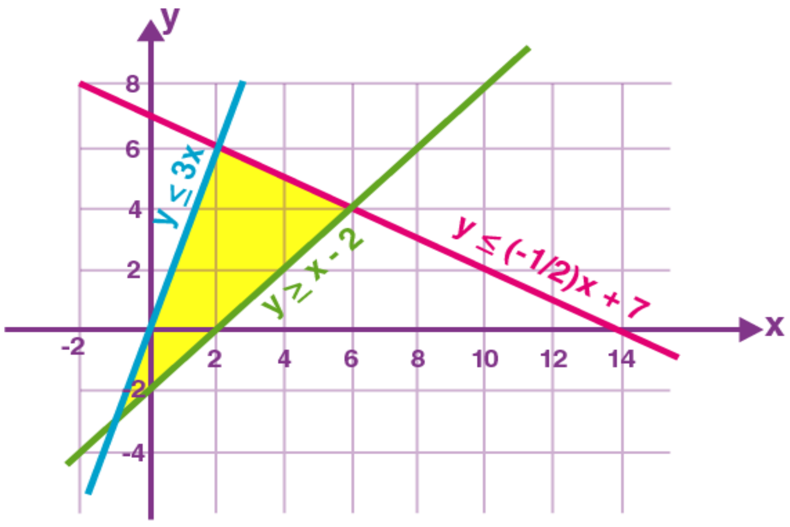

Fig 5.4: Graphical representation of Linear Programming

5.4.2 Characteristics of Linear Programming

The following are the five characteristics of the linear programming problem:

- **Constraints** – The limitations should be expressed in the mathematical form, regarding the resource.
- **Objective Function** – In a problem, the objective function should be specified in a quantitative way.
- **Linearity** – The relationship between two or more variables in the function must be linear. It means that the degree of the variable is one.
- **Finiteness** – There should be finite and infinite input and output numbers. In case, if the function has infinite factors, the optimal solution is not feasible.
- **Non-negativity** – The variable value should be positive or zero. It should not be a negative value.
- **Decision Variables** – The decision variable will decide the output. It gives the ultimate solution of the problem. For any problem, the first step is to identify the decision variables.

5.4.3 Methods to Solve Linear Programming Problems

The linear programming problem can be solved using different methods, such as the graphical method, simplex method, or by using tools such as R, MATLAB solver etc. Here, simplex method is used in our proposed study.

5.4.4 Linear Programming Applications

A real-time example would be considering the limitations of labours and materials and finding the best production levels for maximum profit in particular circumstances. It is part of a vital area of mathematics known as optimization techniques. The applications of LP in some other fields are

- Engineering – It solves design and manufacturing problems as it is helpful for doing shape optimization
- Energy Industry – It provides methods to optimize the electric power system.
- Transportation Optimization – For cost and time efficiency.

5.5 System modelling using linear programming

Linear Programming (LP) is used to represent the suggested EMS optimization with a 24-hour-long horizon (T) with time step (t). Heuristic optimization method is also considered and compared the optimized result with heuristic and no storage result. The associated constrains were presented in the following equations. In Fig 5.3 show how, linear programming used for proposed EMS optimization

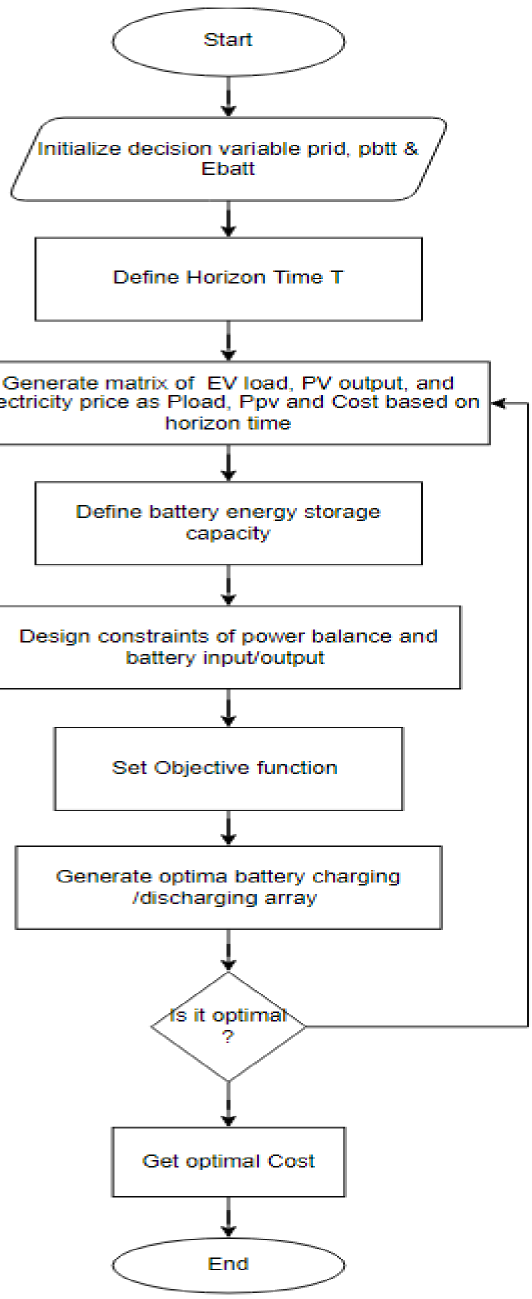

Fig: 5.5 Flowchart of linear programming optimization for proposed EMS optimization

5.5.1 Constraint Design:

In order to obtain the optimal solution for proposed EVCS. Constraints such as equalities and inequalities are taken into account in the optimized model.

5.5.1.1 Energy Storage System

The charging and discharging power of an ESS may be automatically adjusted according to overloaded energy or inadequate energy. Therefore, utilizing an ESS can increase the flexibility of an EMS. The upper and lower bounds of capacity, as well as the highest charging and discharging power, are the operational constraints of ESS, which can be defined in terms of power,

$$E_{ESS}(t) = P_{ESS}(t) * \Delta T \quad (1)$$

where the power of the ESS is denoted by PESS (t). When the ESS is discharged, PESS (t) has a positive value, but when it is charged, it has a negative value. The state of charge, or SOC, of the EVCS at any given moment t can be assessed in terms of its power as,

$$SOC(t) = SOC(t-1) - \phi_{bat} * [P_{ESS}(t) * \Delta t] \quad (2)$$

where ϕ_{bat} is a parameter that relies on the ESS's technology. The global balance of SOC established by this condition.

$$\sum_{t=1}^{T-1} SOC(t+1 - SOC(t) \geq 0) \quad (3)$$

In this way, the SOC at the end of the time horizon is greater or equal to the initial value of SOC, ensuring similar condition for performing the scheduling of the next day.

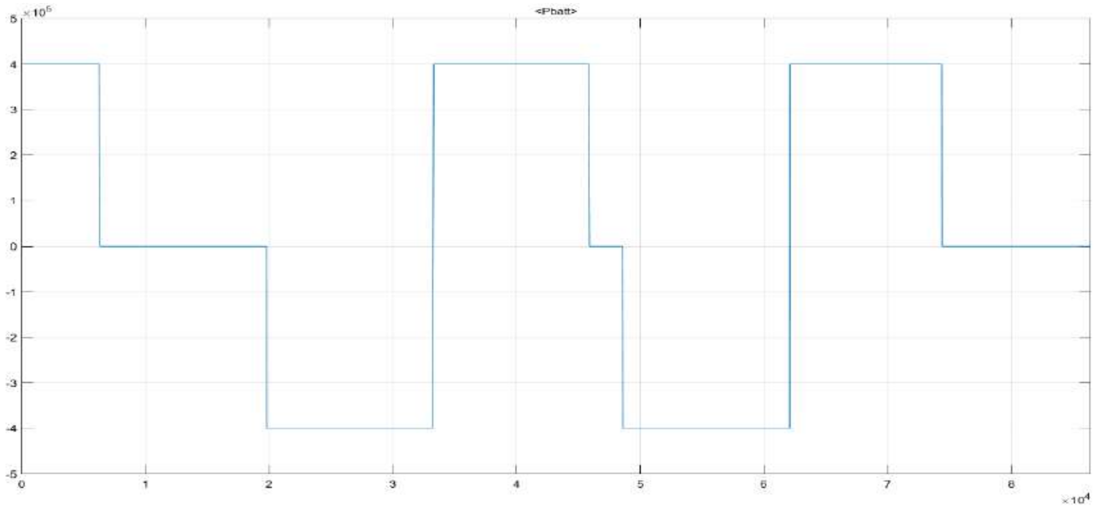

Fig: 5.6 ESS battery power profile [MATLAB]

The power capacity of ESS is about 400kw which is shown in figure 5.5 on the other hand the state of charging of EV charging station’s storage system is shown in figure 5.6

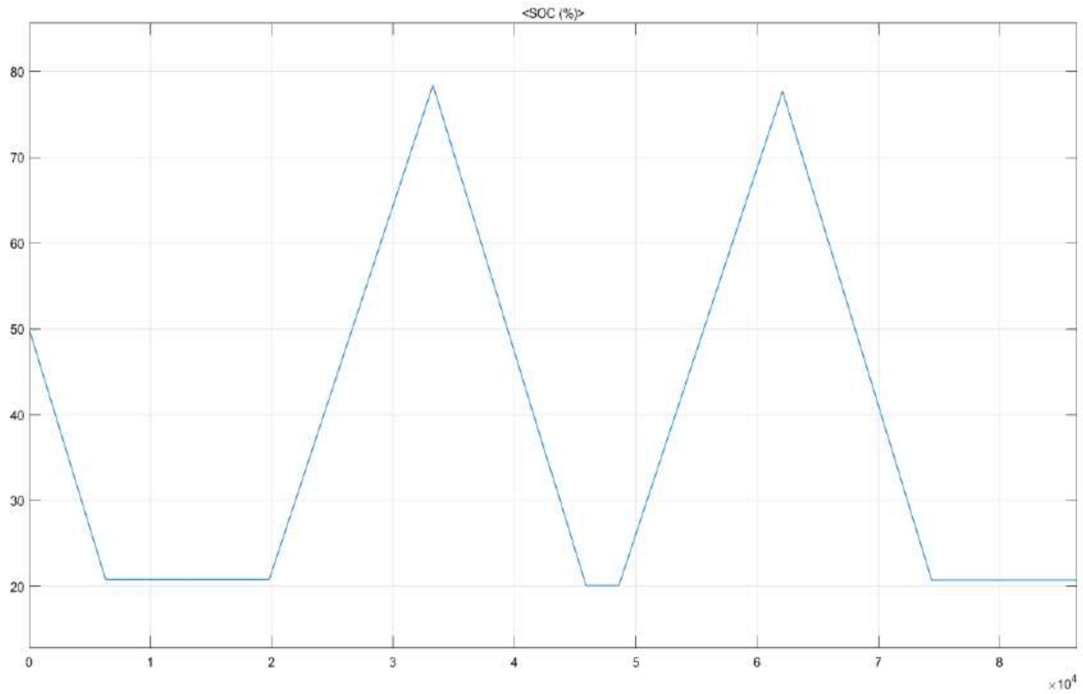

Fig: 5.7 ESS SOC (%) profile [MATLAB]

5.5.1.2 Energy Balance

The power grid must guarantee the balance between consumption and production system.

$$\sum_{t=1}^{T} E_{grid}(t) + \sum_{t=1}^{T} E_{PV}(t) + \sum_{t=1}^{T} E_{ESS}(t) = \sum_{t=1}^{T} E_{Load}(t) + E_{Losses}(t) \tag{4}$$

Where, $E_{grid}(t)$ is the Energy from grid and $E_{PV}(t)$ is the energy from solar photovoltaic cell which are only two sources used in the proposed EVCS.

5.5.1.3 Energy Sources

Hence the proposed EVCS is grid connected, so there are two energy sources. One from grid and another one is solar.

In terms of power, the grid's energy may be described as

$$E_{grid}(t) = P_{grid}(t) * \Delta(t) \tag{5}$$

On the other hand, day ahead solar energy source is forecasted using ARIMA method and the energy of PV can be defined in terms of power as

$$E_{PV}(t) = P_{PV}(t) * \Delta(t) \tag{6}$$

5.5.1.4 EV Charging Demand:

The Electric vehicle load energy which is discussed in previous chapter was artificially estimated using an algorithm is considered as load for this EVCS which is known as E_{Load}. The power required to meet the load energy requirements of electric vehicles may be described as,

$$E_{Load}(t) = P_{Load}(t) * \Delta(t) \tag{7}$$

On the other hand, for the purpose of simplicity the lost energy is considered as constant for the EVCS and which is defined in the system parameters.

$$E_{Losses} = P_{Losses} * T \tag{8}$$

5.5.2 Objective function:

Operational costs have been defined to be minimized, which is to say, the cost of absorbing energy from a power grid, defined as,

$$TotalCost = minf(cost) = \sum_{t=1}^{T} E_{grid}(t) * C_{grid}(t) \tag{9}$$

Here, TotalCost is the variable which has to be minimized. E_{grid} is the energy of the dispatchable generators and C_{grid} is the unitary cost associated to the generator.

The formulation of the objective function can be considered for several kinds of sources. Here, the power absorbed from the utility grid is considered as a dispatchable generator $P_{grid}(t)$, and the associated operating cost, $C_{grid}\ (t)$ as a parameter that changes in terms of the time. By establishing an extra variable with a negative value of operating cost, which may be the future work for the EVCS system, the ability to sell energy to the main grid can be incorporated into the goal function. This will allow the system to be more profitable.

CHAPTER 6

SIMULATION AND RESULT

6.1 Introduction

This chapter focuses on the simulations. The simulation is run base on the electricity price, PV forecasting and EV load estimation which was illustrated in the previous chapter 4 and 5. The simulation is designed into 4 case studies (Table: 6.1) for no storage, heuristic and linear programming method. All the case studies are present for the different method and sources fees.

6.2 System Design Layout

Simulation model is developed using MATLAB Simulink for getting cost result under different case studies where the model is shown in figure 6.1. The simulation run for 24 hours where 5 minutes is the simulation time step.

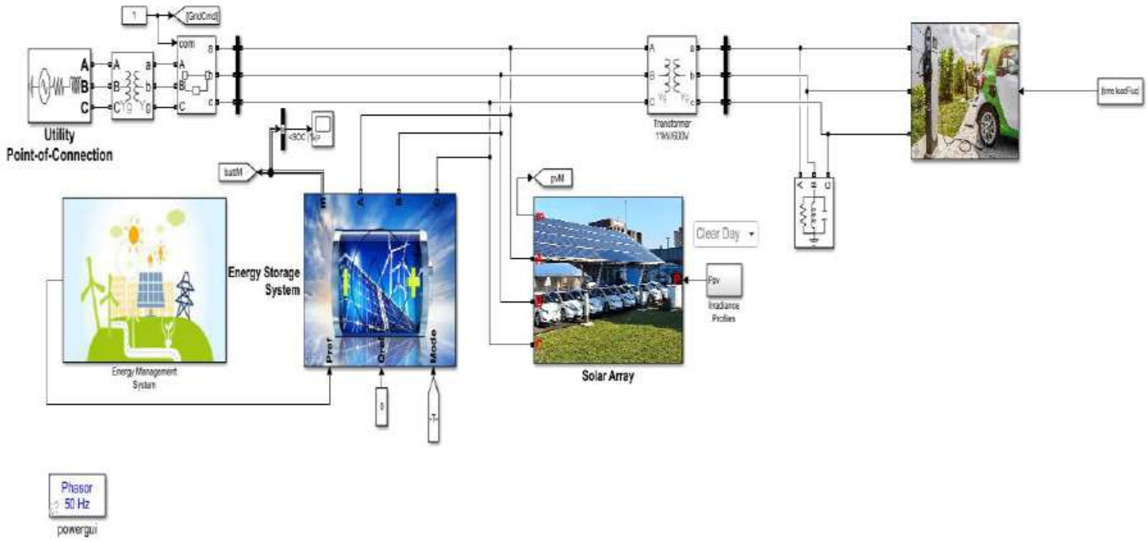

Fig 6.1 System design layout [MATLAB}

6.3 Simulation Parameters

The following table 6.1 summarizes the input parameters which were kept constant in all simulations, with corresponding value.

Table 6.1 Simulation parameters.

Parameter	Value	Comment
Line-Line Voltage	11kv	Line-line voltage of the utility grid
System frequency	50Hz	Under the frequency system run
Rated Power	400 kw	In order to implement ESS in the system
Rated Capacity	2500 kwh	The energy storage capacity of system ESS
Efficiency	96%	ESS efficiency considered for the system simulation
Initial SoC	50%	Initial SoC considered for the ESS.
Horizon	24 hours	The simulation is run for 24 hours where 300s was the step size of the simulation
Nominal Voltage	600v	Nominal voltage for EV variable load. Charging voltage
Nominal Power	20 mw	Nominal power of transformer(11kv/600v)
Panel Area	2500 m^2	Solar panel area is considered for PQ model

6.4 Case Studies Design

Four different case studies are presented and given in Table 6.1 with a simulation time horizon of 24 hours.

Table 6.2: Considered case studies for single day.

Case No	Case Name
Case 01	Only Grid and Load
Case 02	Grid, PV and Load
Case 03	Loads, PV, battery and EMS with Heuristic
Case 04	Loads, PV, battery and EMS with Linear Programming

6.4.1: Case 01- Only Grid and Load

On average, the 100 electric cars consumed 17126 kwh (figure:6.2) of electricity per day with 65% penetration level and different SOC demand. The lowest SOC demand was about 5% and the highest 85% where minimum charging time was about 4 minutes and maximum time about 38 minutes. The electric cars battery capacity was 20.6 kwh to 50.30 kwh

The maximum load in the distribution grid without PV and ESS was about 1.2 MW per hour showed in figure 4.6. If the maximum load exceeds the limit of distribution line it might be a safety issue. Also, there is chance of frequency instability because no load balance strategy. In this base case, the total cost of energy consumed from grid is about $1246 per day (shown in figure 6.3) which about $0.45 million per year.

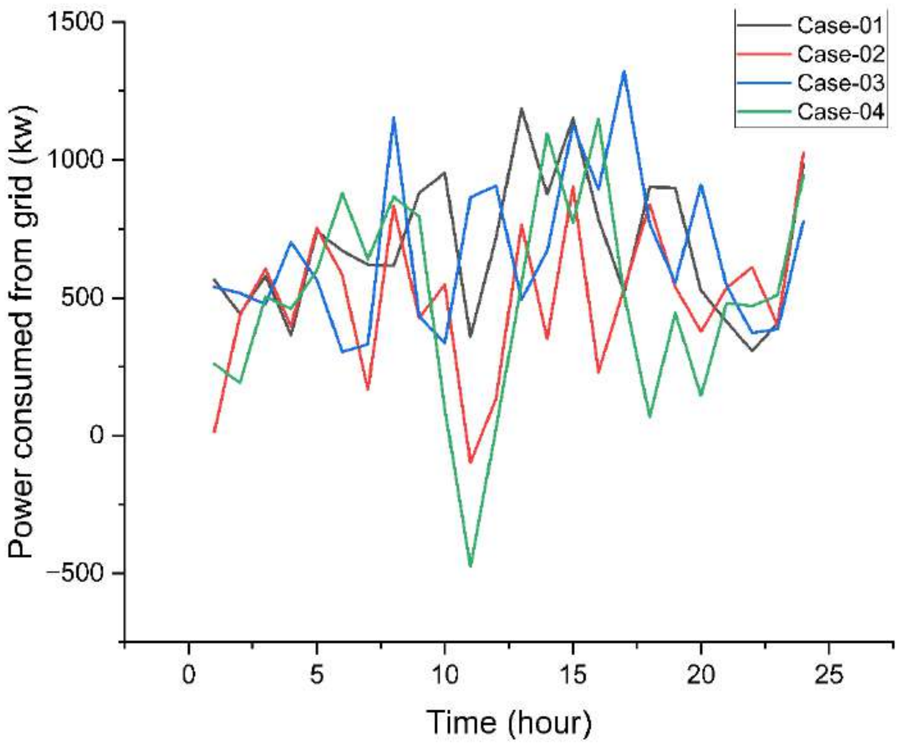

Fig 6.2: Different scenario of power consumption from the grid for case1, case2 and case3 respectively.

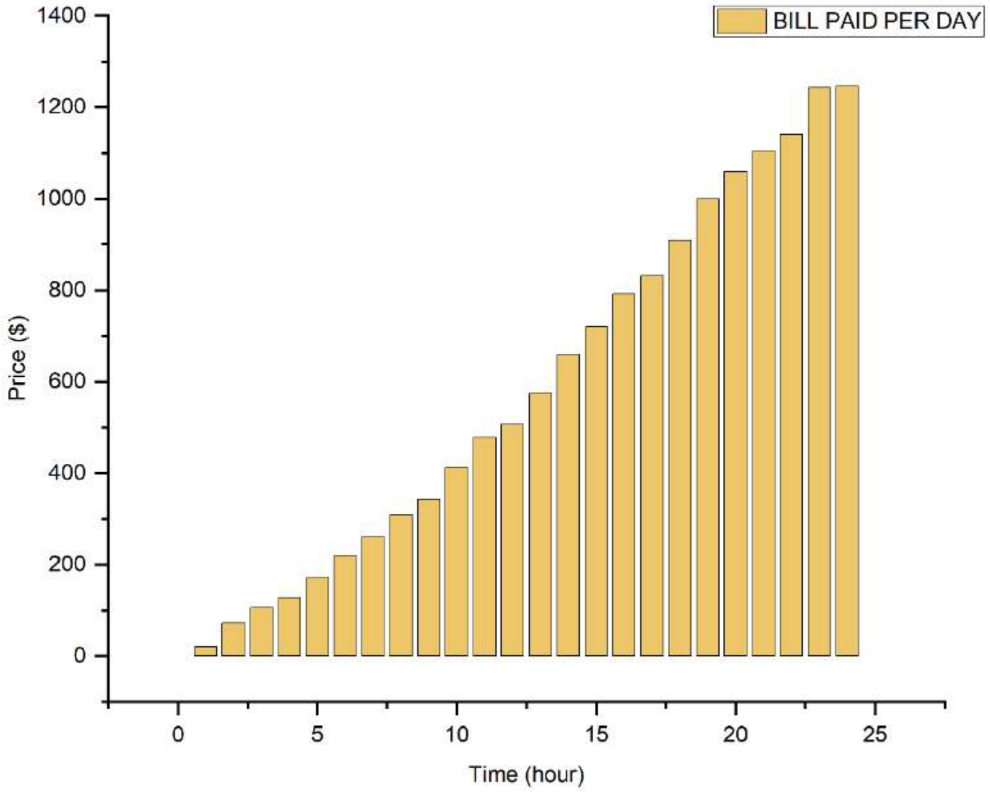

Fig: 6.3 Total grid energy cost under based case 1 after adding PV to EVCS.

6.4.2 Case Study 02 - Grid, PV and Load

In this case, PV is added in the distribution grid as another source which generate about 500kw power for a single day showed in figure 6.4. As we know Bangladesh is a developing country, about 97% electricity produced using fossil fuel which is cause for emitting greenhouse gases mainly Carbon dioxide. According [53], Bangladesh has been emitting about 23-million-ton greenhouse gasses for generating 43TWh electricity which is very high. Contribution renewable energy can help to reduce the emitting of greenhouse gas specially carbon.

As a result, power consumption from the national grid use is decreased which is shown in figure 6.1. After adding PV to the electric vehicle charging station, it decreased the pressure from grid as well as cost. The total energy used from the grid is about 12155 kwh which lower that case 01 which is environment friendly.

The total energy cost for grid is about $911(shown in figure 6.4) for charging electric vehicles for a single day showed in figure 6.4 which $335 lower than based case and the reduction is about 36.7%. Annually it will reduce about $127800 after using PV in the charging station for charging electric vehicles.

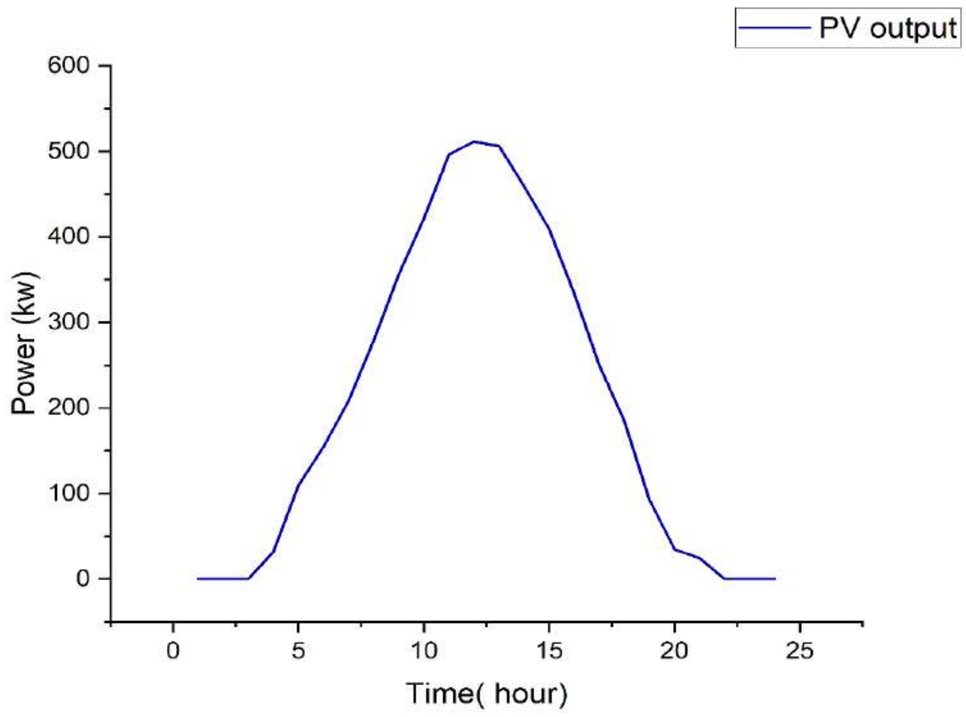

Fig 6.4: Power generation from PV for a single day

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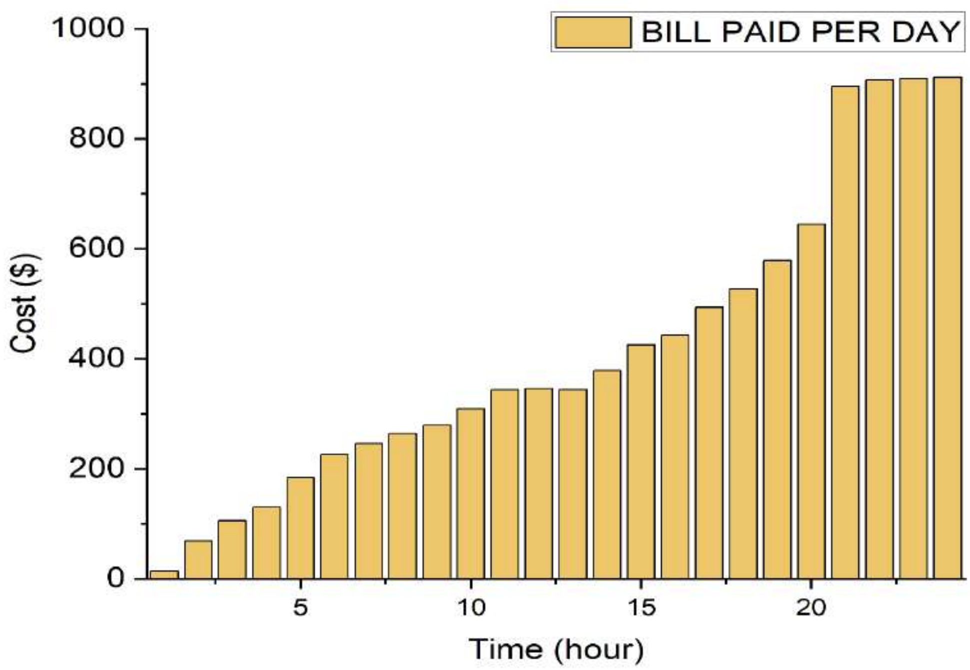

Fig 6.5: Total grid energy cost under case2 after adding PV to EVCS.

6.4.3 Case study 03- Loads, PV, battery and EMS with Heuristic

Energy management system with heuristic optimization method is used with PV, ESS and estimated load in this case study. The simulation is run under the all parameters in Table 6.1. In this case study heuristic method is considered where the heuristic method is designed using MATLAB State flow. The result of charging is irregular with respect to price which is shown in figure 6.6.

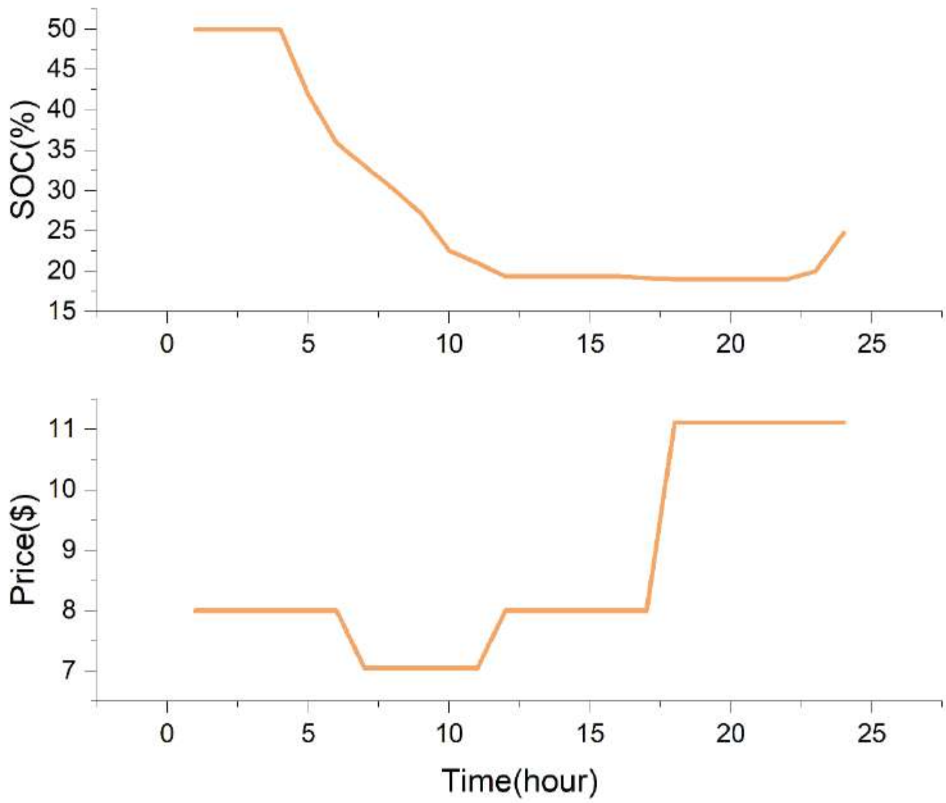

Fig 6.6: Battery Charging/discharging scenario with respect to grid price during peak and off-peak hour

In this case study battery is discharging initially from 50% to 20% during off-peak and supper off-peak hour. At end of the peak hour battery started to charging.

After single day simulation the total energy used from grid is about 11773.9 kwh. 11773.9 kwh and the cost of energy is about $899.6 (showed in figure 6.7) which is 1.26% and 38.5% less than case2 and case1 respectively.

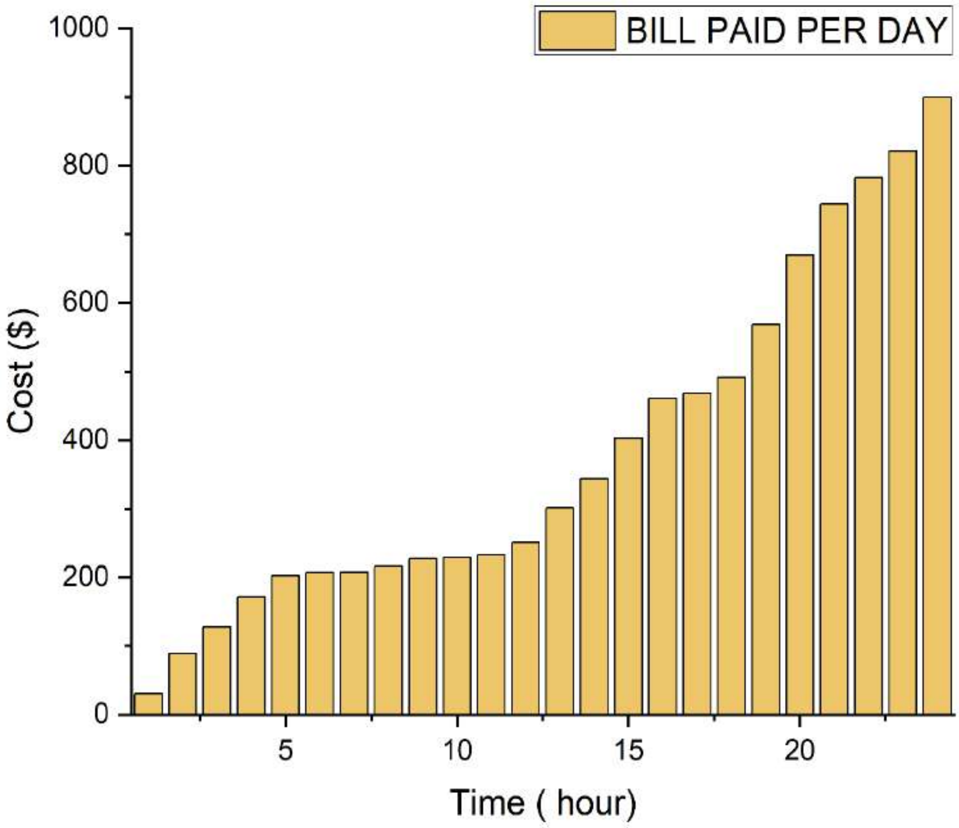

Fig 6.7 Total energy cost under case 3 after implement heuristic method

6.4.4 Case study 04- Loads, PV, battery and EMS with Linear Programming

In this case, an energy management system is added with an energy storage system where the energy management system is optimized with linear programming. Energy system takes the dataset of load, short term PV forecast, nation grid electricity price of peak, off-peak and supper-off-peak hour and current state of energy storage system. Energy management system provide a command to energy storage system for charging and discharging after evaluating power generation and consumption as well as following grid price according to peak hours. The optimized energy storage charging and discharging array is shown in figure 6.8.

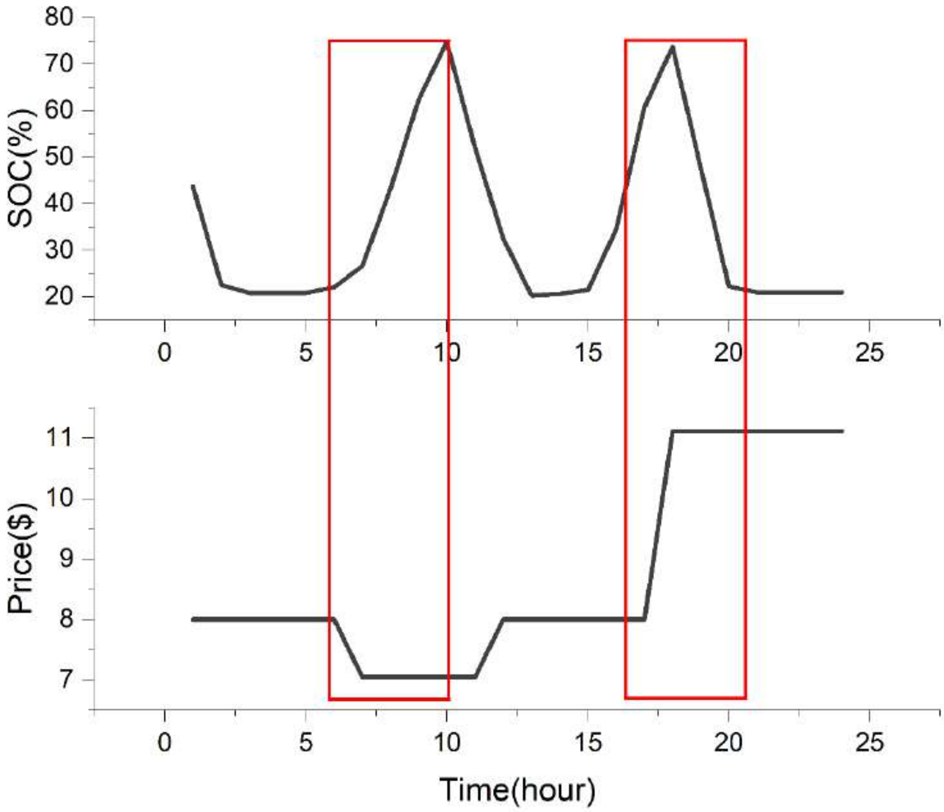

Fig 6.8: Optimize battery charging and discharging command from EMS following grid peak and off-peak price.

In this case study we noticed in figure 6.1 that the grid consumption during peak load is significantly decrease because of optimized discharging of battery during peak load and PV. As result the proposed electric vehicle charging consumed low energy from grid and reduced a decent amount of cost.

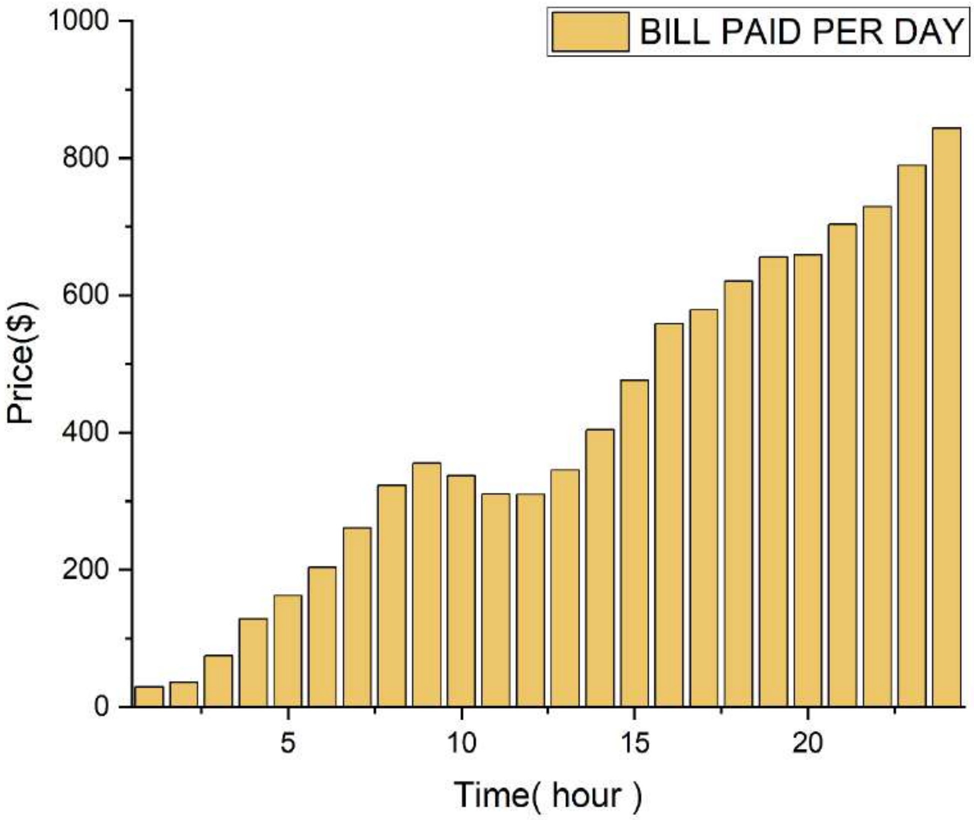

Fig 6.9 Total grid energy cost under case3 after implement EMS

The total energy used from the grid is about 11690 kwh and bill paid about $843 for a single day shown in figure 6.9. In the base case which was about $1245 per day which is 47.7% higher than this case. On the other hand, it reduces 8 percent cost than case2.

6.5 Result Analysis

The aforementioned scrutiny demonstrates the total power demand and costs analysis under four scenarios and 65% EVs penetration during a day. The scrutiny aims to minimize the cost, as well as energy optimization in the context of medium-scale EV-charging station scenarios. This study considers fast charging to illustrate the impact of different power levels of EVs charging. In terms of case 1 sharp peak is introduced in the charging station power demand, while fast charging is employed even when the maximum number of EVs are connected. Per-hour electricity demand rose prominently by 1.2 MW and the average demand per day is about 0.8 MW, as well as the total cost of energy consumed from the grid, is about $1246 per day. Moreover, in the context of case

2, charging station average energy consumed from the grid per day is about 0.6MW, which is substantially lower than case 1 and the overall cost mitigate by 36.7%. In addition, an energy management system with heuristic optimization method has been used in case 3, as a result, the total energy used from the grid takes the edge off and the average consumption is about 0.48MW per day. The daily cost of energy is about $899.6 which is 1.26% and 38.5% less than case2 and case1 respectively. Furthermore, in case 4 an energy management system is added with an energy storage system where the energy management system is optimized with linear programming. After using the linear programming method for optimization, the system would show significant results and the total cost is $843 for a single day, which is lower than the other three cases respectively. The cost under different cases is shown in figure 6.10.

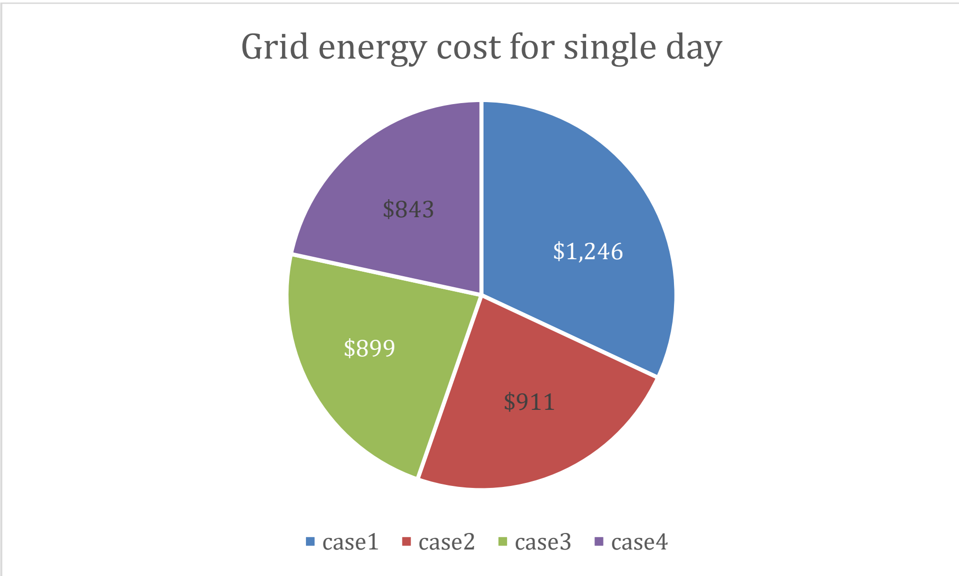

Fig 6.10: Different cost of energy for case1, case2 , case3, case4

CHAPTER 7
CONCLUSION

7.1 Introduction

This chapter concludes the thesis project, providing the reader with an overview of the work conducted and the results' interpretation. The key findings described in the previous charters are briefly discussed and fit into a broader perspective. Some comments on future possible developments, based on proposed regulations, are also provided.

7.2 Conclusions

In this study, an optimization technique is proposed to minimize the energy cost of an EVCS using linear programming. To obtain the result the proposed technique gave an output of battery scheduling for charging and discharging following peak, off-peak and super off-peak hours. PV output forecasting, electricity price forecasting and electric vehicle load estimation are also considered into account for getting optimal result for the proposed EVCS. Electric vehicle load estimation is generated artificially for the lack of real EVCS data in Bangladesh. To make the model more realistic the system result is compared with heuristic method and no storage mode. The system is designed in three case studies where first one for basic that mean without storage system and second and third case design for heuristic method and linear programming respectively. The cost under heuristic method has found 74752.3tk, on the contrary cost has decreased by 7.43% after applying linear programming optimization which is 70032.3tk. However, in this study linear programming is more effective than heuristic method.

7.3 Limitations

In the thesis work some limitations were found. First, the limited purpose of MATLAB Simulink is to model practical electric vehicle charging station's circumstances, since the situation in the real world has a lot of implications for the EVCS. Second, In Bangladesh still electric vehicle is not launched except some electric bikes and rickshaws. As a result, there not real EV charging station data found for electric vehicle load calculation. However, to meet the limitation some algorithm and technique have been used for generating data.

7.4 Future Work

In future, artificial intelligence can be used for getting more optimal cost for electric vehicle charging station. Since Electric vehicle charging station is the next future of transport sector real time load data can be used for getting more accurate result.

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APPENDIX

Nomenclature

Indices	Defination
T	Horizon time 24 hours
t	Step time 300s
Variables	**Defination**
n_{EV}^{i}	Number ofe EVs
Lb	Lower bound
Ub	Upper bound
E_{ESS}	Energy of ESS in kwh
P_{ESS}	Power of ESS in kw
SoC	State of charge in percentage
E_{grid}	Energy of grid in kwh
P_{grid}	Power of grid in kw
E_{PV}	Solar energy in kwh
E_{Load}	Load energy in kwh
P_{Losses}	Power losses in kw
P_{Load}	Total load power in kw
$TotalCost$	Total cost of grid energy
C_{grid}	Unitary pirce value of gird per kwh